Contractor's Report to the Board

CIWMB Used Oil Demonstration Grant

Laboratory Evaluation of Four Storm Drain Inlet Filters for Oil Removal

July 2005

Produced under contract by:

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Acknowledgments

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William Kerlin, under the oversight of Dr. Susan Crawford (Chemistry Department, CSUS) performed most of the chemical analysis using the EPA 1664 method. California Laboratory Services (CLS) performed all analyses not performed at CSUS. The study team appreciates the advice of other experts, especially Dr. Pat Kinney of Kinetics Inc. and Dr. Michael Barrett of the University of Texas, Austin. Coordination on testing parameters and filter selection was provided by the project investigators of the other two grant recipients: Eric Strecker of GeoSyntec and Alex Waite of the City of La Mirada.

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Executive Summary

Vehicular motor oil from leaking vehicles, illegal disposal, and accidental spills are often carried to natural water bodies via stormwater flows. To remove oil from contaminated stormwater, a number of different storm drain inlet filters have been developed. Unfortunately, knowledge of their effectiveness in removing oil under common field conditions is often lacking or is based almost solely on manufacturers' tests. The goal of this project was to provide an independent third-party evaluation of several representative devices under a common protocol. Four full-scale filters were tested: the Drain Pac™, FloGard+Plus™, Ultra Urban™, and Hydro-Cartridge™. The Drain Pac™ filter is essentially a polypropylene fabric bag hanging beneath a frame. The FloGard+Plus™ is also a bag but with pouches of adsorbent material placed around the bottom perimeter. The Ultra Urban™ insert is a box with a bed of adsorptive media built into the bottom and two sides. The Hydro-Cartridge™ insert is also a box, with an internal baffle system that acts like a settling basin. It also contains a bag of adsorbent material that floats on the surface of the water in the box. Each filter was tested under three loading scenarios: (1) a spike dose to simulate an illegal discharge of oil to a storm drain, (2) a continuous dose in oil-free water to test the adsorptive capacities of the filters, and (3) a continuous dose plus sediment to more realistically simulate stormwater.

To perform the necessary experiments, a test facility was constructed at California State University, Sacramento. Testing protocols were developed for water flows and volumes, dosing, and sampling. Water flow rates of 57 to 132 L/min (15 to 35 gpm) were chosen based on typical Sacramento and Los Angeles rainfall intensities falling on the area normally serviced by a single storm drain. In the continuous flow experiment, a water volume equivalent to an annual rainfall volume was applied in a series of daily runs to simulate individual storms and drying periods between storms. Daily composite samples were collected by hand. EPA Method 1664 was used to analyze oil and grease concentrations.

In the spike dose experiment, each filter was dosed by pouring 4 liters of used motor oil directly into the device to simulate an illegal dumping after an oil change. The 4 liters of oil was followed by flushing with water at a flow rate of 95 L/min until oil concentrations approached the reporting limit of 5 mg/L. Initial oil capture, calculated by subtracting the amount of free oil that dripped out of the filter within 24 hours from the amount added, ranged from 8 to 56 percent for the Drain Pac™, FloGard+Plus™, and Ultra Urban filters. After flushing with water, the final retention efficiencies ranged from 5 to 56 percent. The Hydro-Cartridge™ insert initially captured the entire 4 liters. Subsequent water flows, however, flushed out all but 25 percent of the oil.

In the continuous dose experiment, an annual volume of clean water dosed with 15 mg/L of oil was passed through the filters in 20 daily runs. The oil removal efficiency of the Ultra Urban™ and FloGard+Plus™ filters averaged 61 and 25 percent respectively. The mean removal rates for the Drain Pac™ and Hydro-Cartridge™ filters were not statistically different from zero. Generally speaking, the efficiency of free oil removal appeared to be related to the amount of media that contacted the flow of water. Flow rate variation between 57 L/min and 132 L/min had little or no effect on oil removal. No substantial reduction in performance with cumulative volume treated was observed, suggesting that the adsorptive capacities of the filters were not depleted in a year's worth of runoff. Thus, media replacement more frequently than once per year is not warranted. Differences among the different kinds of adsorptive media could not be distinguished from the data collected.

To create more realistic stormwater conditions, a continuous flow plus sediment experiment was performed. In this experiment, a finely ground silica simulated particles found in stormwater. Oil was mixed directly with the dry sediment to encourage attachment to the particles and then injected into the influent as a slurry. Approximately 25 percent of the oil was metered into the influent as free product. Target concentrations were 15 mg/L of oil and 100 mg/L total suspended solids (TSS). Because this experiment was added to the scope during the project, there was time to run only about 70 percent of an annual volume through the filters. Adding the sediment caused a statistically significant change in the removal efficiencies of three filters. The Ultra Urban™ oil removal efficiency dropped from 61 percent without sediment to 16 percent with sediment. The Drain Pac™ and Hydro-Cartridge™ efficiencies rose from zero to about 30 percent each. The FloGard+Plus™ efficiency rose from 25 to 35 percent but that wasn't statistically different. Experimental difficulties left considerable uncertainty in the measurements of sediment removal, however, so correlations between sediment removal and oil removal were not possible. Nevertheless, oil removal appeared to be dependent both on sediment capture and free oil removal efficiencies. Recognition of this dual treatment need may lead to new ideas for applications and design.

To attempt to remove any dissolved materials from a complex matrix like stormwater in a device that fits into a storm drain and operates without power or operator attention for a year at a time is a daunting task. Given the difficulty of this task, the fact that these devices were even partially successful is commendable. Based on the results of this project, however, drain inlet filters offer aquatic ecosystems only limited protection from used oil pollution.

Introduction

Problem Statement

Despite the fact that over 80 million gallons of used oil are recycled annually in California, 20 million gallons remain unaccounted for each year(1). While it is true that engines burn some of this unaccounted-for oil, significant amounts are thought to leak from vehicles and are carried into storm sewer systems, and subsequently, to the state's waters by storm water flows. Vehicular motor oil comes from leaking vehicles, illegal disposal, and accidental spills. Nationally, measurements of oil and grease in stormwater runoff average 24 mg/L of oil and grease with a median concentration of 4 mg/L. Concentrations as high as 11,000 mg/L have been reported. (2) The large range of oil concentrations in stormwater is suspected to be the result of two loading scenarios. Extremely high, but very rare, concentrations are suspected to result from accidental spills on paved areas during car maintenance or by the direct, illegal disposal of used motor oil into drain inlets. These high concentrations can cause acute toxic effects in aquatic organisms. Lower, more common concentrations are likely the result of gradual build-up on paved surfaces from leaking vehicles. Measurements on California highways show the presence of about 4 mg/L of oil and grease in runoff where average annual daily traffic (AADT) volumes are greater than 30,000(3). These concentrations are suspected to cause chronic, undesirable effects on aquatic life, since crude oil is toxic to some aquatic life at levels as low as 0.3 mg/L(4). In response to this suspected environmental issue, the California Integrated Water Management Board (CIWMB) awarded the California State University, Sacramento, Office of Water Programs a grant to evaluate commercial storm drain inlet filters for removal of oil and grease from storm run-off.

Objectives and Research Questions

Though illegal disposal and accidental spills into drain inlets can be reduced through public education and enforcement of waste laws, they cannot be completely eliminated. Similarly, there will probably always be some fugitive oil on the roadway from leaking cars. Consequently, pollution prevention measures installed in the storm drain system are desirable. One such measure is the placement of filters in storm drain inlets to capture and retain oil and grease. A variety of such devices have been developed and marketed. Unfortunately, knowledge of their effectiveness in removing oil and grease under common field conditions is often lacking or is based almost solely on tests by the manufacturers themselves. Even when manufacturers' tests are completely honest, it can be difficult to compare the performance of different devices because of different experimental conditions. There is a need for independent third-party evaluations of these devices under a standard protocol. To date, the Environmental Protection Agency (EPA) Technology Verification Program has evaluated only the Hydro-Kleen™ drain inlet filter, but mean and median influent oil and grease concentrations were 62 and 65 mg/L respectively(5). These are higher than what is typically seen in stormwater. The first objective of this study was to compare relative performance of four types of drain inlet filters in a controlled and repeatable environment for two used oil loading scenarios. For one of the two loading scenarios, the second objective was to measure performance changes over time to determine the optimum schedule for media replacement due to limitations in absorptive capacity. Specific research questions are answered regarding the two oil loading scenarios.

There are four research questions addressed by the three experiments in the study. The first is to determine the abilities of the filters to capture and retain spike doses of used motor oil that result from spill scenarios. This question is addressed by the spike dose experiment. The second question is to determine the abilities of the filters to remove continuous doses of used motor oil that are more common in stormwater runoff. The third question is to determine the optimal filter replacement. The second and third questions are addressed by the continuous dose experiment. During the continuous dose experiment it became more obvious that significant differences in performance may result from the presence of sediment in the water. This lead to the addition of a fourth research question, which is to determine the change in oil removal with the presence of sediment compared to the experiment without sediment. This question is addressed by the continuous dose plus sediment experiment. In each experiment, an effort was made to test the filters in a controlled and repeatable environment so that comparisons of performance among the filters could be made.

The four drain inlet filters tested were: FloGard+Plus™, Hydro-Cartridge™, Ultra Urban™, and Drain Pac™.

Concurrent Research

This project is one of three Used Oil Demonstration Grants to evaluate the used oil capture and retention properties of drain inlet filters. The other grant recipients, GeoSyntec and the City of La Mirada, are performing their evaluations under field (i.e. uncontrolled) conditions. GeoSyntec is also performing evaluations under laboratory (i.e. controlled) conditions. Several aspects of the experiments in this project were designed in coordination with the other grant recipients to facilitate comparison of data and provide additional insights into the performance and potential of these devices.

Report Organization

The report is organized into the following sections: Experimental Procedures and Facilities, Spike Dose Experiment, Continuous Dose Experiment of Free Oil, Continuous Dose Experiment of Oil Plus Sediment Experiment, Discussion, and Conclusion.

Experimental Procedures and Facilities

This section describes the physical components, test parameters and analytical methods for the three experiments. Set-up and operations unique to each experiment scenario are discussed in the section corresponding to that experiment. Physical parameters discussed here are volume, flow rate, and oil concentrations. Analytical methods discussed here are oil and grease, total suspended solids (TSS), and total petroleum hydrocarbons (TPH).

Experiment Scenarios

Three oil loading scenarios were used in this project. The spike dose loading scenario was designed to test how well the filters retain large amounts of used oil added in a catastrophic manner. In the spike dose experiment, 4 liters of used oil were poured directly into each filter, simulating a roadway spill or illegal disposal by someone servicing a vehicle. To simulate oil passing through the filters as part of stormwater flows, two continuous dose scenarios were used. In the continuous dose experiment, oil was injected into clean water which was then passed through the filters. In the continuous dose plus sediment experiment, oil was first mixed with a dry simulated sediment. The oil-contaminated sediment was then mixed with water and the resulting slurry was injected into clean water and was then passed through the filters. Some oil was directly injected into the water flow to the filters as well. Details on the experimental methods are presented in later sections.

Drain Inlet Filter Selection

Filter selection was based on information from CIWMB staff, coordination with other grantees, consideration of filter types, and available performance information. Consideration was also given to filters that are commonly used and to select different types of filters.

Filter types can vary by both physical design and by the type of media they use. Based on Caltrans' experience with filters(6), tray-type filters were avoided because of problems with insufficient hydraulic capacity and clogging from vegetation. The remaining types of filters were baffle boxes, baskets, fabrics, media filters, and screens. Some filters are a combination of these types.

Coordination with Other Grantees and CIWMB Input

CIWMB staff recommended the Hydro-Cartridge by Advanced Aquatic Products as one of the four filters to be tested. The staff reported that this particular filter may gain popularity as a spill control BMP for used motor oil. They wanted the product tested before allowing cities to use other grant money to install these devices (Dana Stokes, email communication, 11/5/2003).

CIWMB staff also encouraged choosing filters that would be tested in the field by the other grantees. Testing inserts that were concurrently being tested in the field was desirable because of the limitations of laboratory testing. Testing similar filters would allow comparison of the laboratory results to the results of the field/lab hybrid studies to be conducted by GeoSyntec and to the field studies to be conducted by the City of La Mirada.

The four inserts selected for evaluation by GeoSyntec are the Drain Pac™ by Drainworks, the Curb Inlet Basket™ by Suntree, the FloGard+Plus™ by Kristar, and the Hydro-Kleen™ by Hydrocompliance(7). The City of La Mirada selected the Drain Pac™, the Triton™ by Rebel Environmental, and the Ultra Urban™ Filter by AbTech (Waite, Alex, personal communication, October, 2003). Summary information on these filters is presented in Table 1.

Hydro-Kleen was not selected because it is functionally similar to the Hydro-Cartridge. The Curb Inlet Basket was not selected because oil removal was less than that reported for other filters(8). The Triton™ filter did not have oil removal results and the design seemed more likely to clog. The remaining three filters, Drain Pac™, Ultra Urban™ and the FloGard+Plus™, have demonstrated oil removal in past studies. Each seems to have allowances for high flow bypass. Each filter is of a different type, and each uses a different type of media as shown in Table 1. Based on this information the four filters selected for this study are FloGard+Plus™, Hydro-Cartridge™, Ultra Urban™, and Drain Pac™. Table 2 lists the filters studied by each grantee.

Table 1. Information for Filters Selected for Testing by The Other Grantees.

Technology Brand Name	Manufacturer	Removal Data Source	Oil Removal Efficiency, (%)	Media Type
Curb-Inlet Basket	Suntree Technologies, Inc.	www.suntreetech.com	Only sediment removal reported	Rubberizer™ Polymer
Drain Pac™	Pactec, Inc.	Navy Environmental Leadership Program, UCLA	17%-95% (NELP); 51%-81% (UCLA)	polypropylene

Technology Brand Name	Manufacturer	Removal Data Source	Oil Removal Efficiency, (%)	Media Type
FloGard+Plus™	KriStar Enterprises, Inc.	KriStar Inc. (independent labs), UCLA (High Capacity catch basin)	Fossil Rock™ absorbs 99% of diesel and motor oi1, 54% O&G (KriStar); 69-90% oil and grease (UCLA) at 15 gpm	Amorphous Alumina Silicate
HydroKleen	Hydro Compliance Management, Inc.	HCM: www.stormwater-products.com	83%-95% (BTEX)	Activated Carbon
Triton	Revel Environmental Manufacturing	Not available	Not available	Polypropylene fabric
Ultra Urban Filter	AbTech Industries	Abtech, UCLA, Astro Environmental	83% O&G (AbTech), 80% O&G (UCLA), 85% O&G (Astro Environmental)	Smart Sponge® Polymer mixture

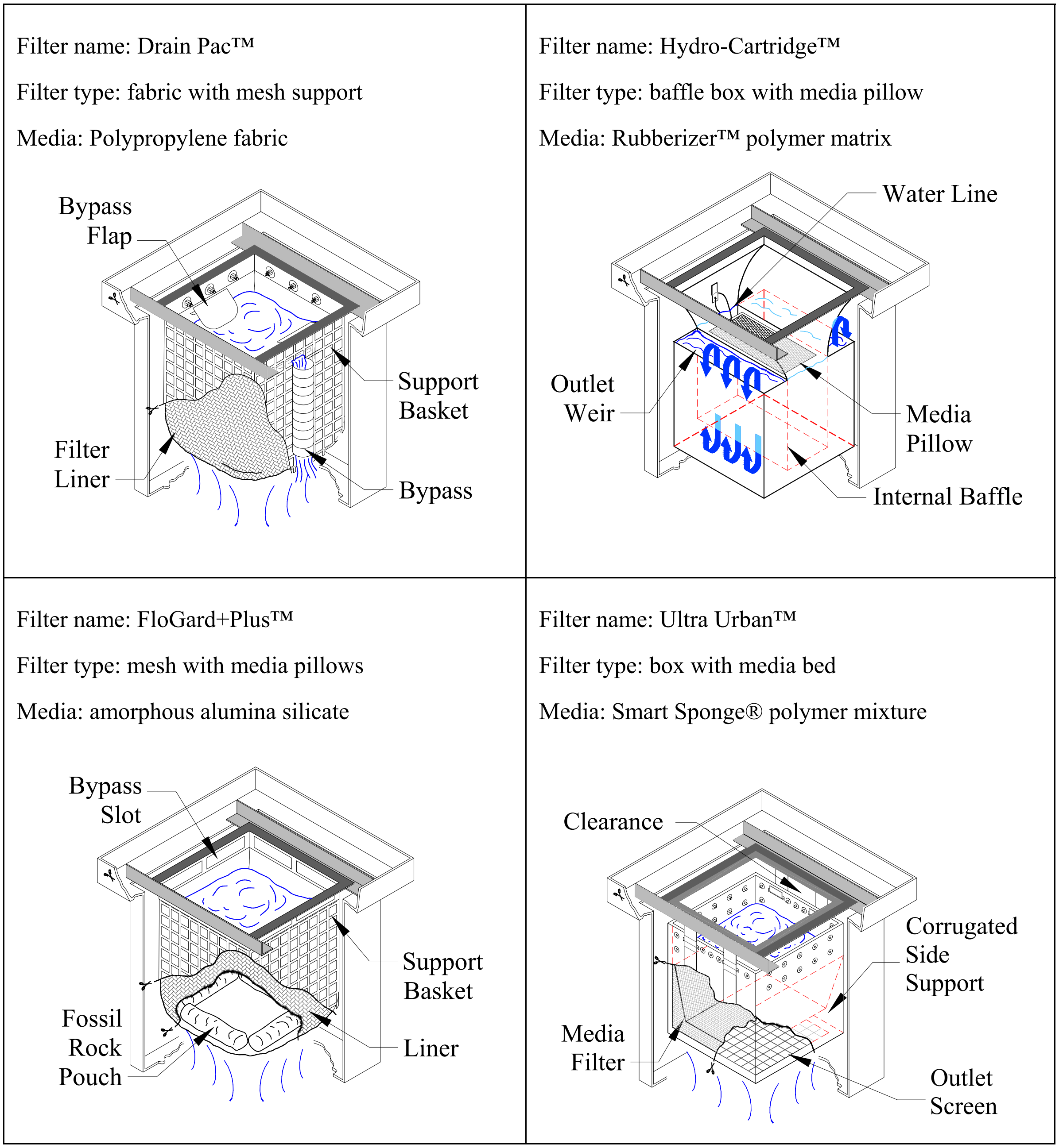
Table 2. CIWMB Used Oil Grant Recipients and the Products Tested.

Office of Water Programs	GeoSyntec	City of La Mirada
lab study	*combined lab/field study*	*field study*
Hydro-Cartridge™		
Drain Pac™	Drain Pac™	Drain Pac™
Ultra Urban™		Ultra Urban™
FloGard+Plus™	FloGard+Plus™	

Description of Selected Filters

The filters selected for testing in this project were the Drain Pac™, FloGard+Plus™, Hydro-Cartridge™, and Ultra Urban™ filter filters. All filters were sized to fit into an opening 600 mm by 600 mm. Filter schematics and characteristics are presented in Figure 1.

The 600 mm x 600 mm (2 ft by 2 ft) inlet dimension was selected from among the common drain inlet sizes presented in Chapter 4 of the Federal Highway Administration (FHWA) Urban Drainage Design Manual(9). Manufacturers of the selected filters confirmed that this is a common size inlet and that filter products are readily available. Area calculations are based on this inlet size.



Filter name: Drain Pac™

Filter type: fabric with mesh support

Media: Polypropylene fabric

Filter name: Hydro-Cartridge™

Filter type: baffle box with media pillow

Media: Rubberizer™ polymer matrix

Filter name: FloGard+Plus™

Filter type: mesh with media pillows

Media: amorphous alumina silicate

Filter name: Ultra Urban™

Filter type: box with media bed

Media: Smart Sponge® polymer mixture

Figure 1. Schematics of the Drain Inlet Filters Tested.

General Set-up Description

A test facility was constructed on the campus of California State University, Sacramento (CSUS). Irrigation water was used as the feed water. It contained no detectable suspended solids and its dissolved solids were around 200 mg/L. The 38 mm (1.5 in) supply line was equipped with a check valve, flow meter and totalizer, gate valve, injection ports, and a manifold that distributed flow to the four filters. As shown in Figure 2, the influent water flowed as two sheets through two slotted pipes placed on opposite sides of each filter to simulate drainage into a drop inlet located in a street gutter. As the influent water flowed through an individual filter, the effluent collected in the bottom of a tank that was attached to a 100 mm (4 in) effluent pipe. As shown, the 12 mm (0.5 in) sample port penetrated the wall of the 100 mm pipe and ended in an upturned elbow. Before reaching the sample port the effluent flow was consolidated into the 4-inch pipe and appeared well-mixed at this point, so samples were considered representative.

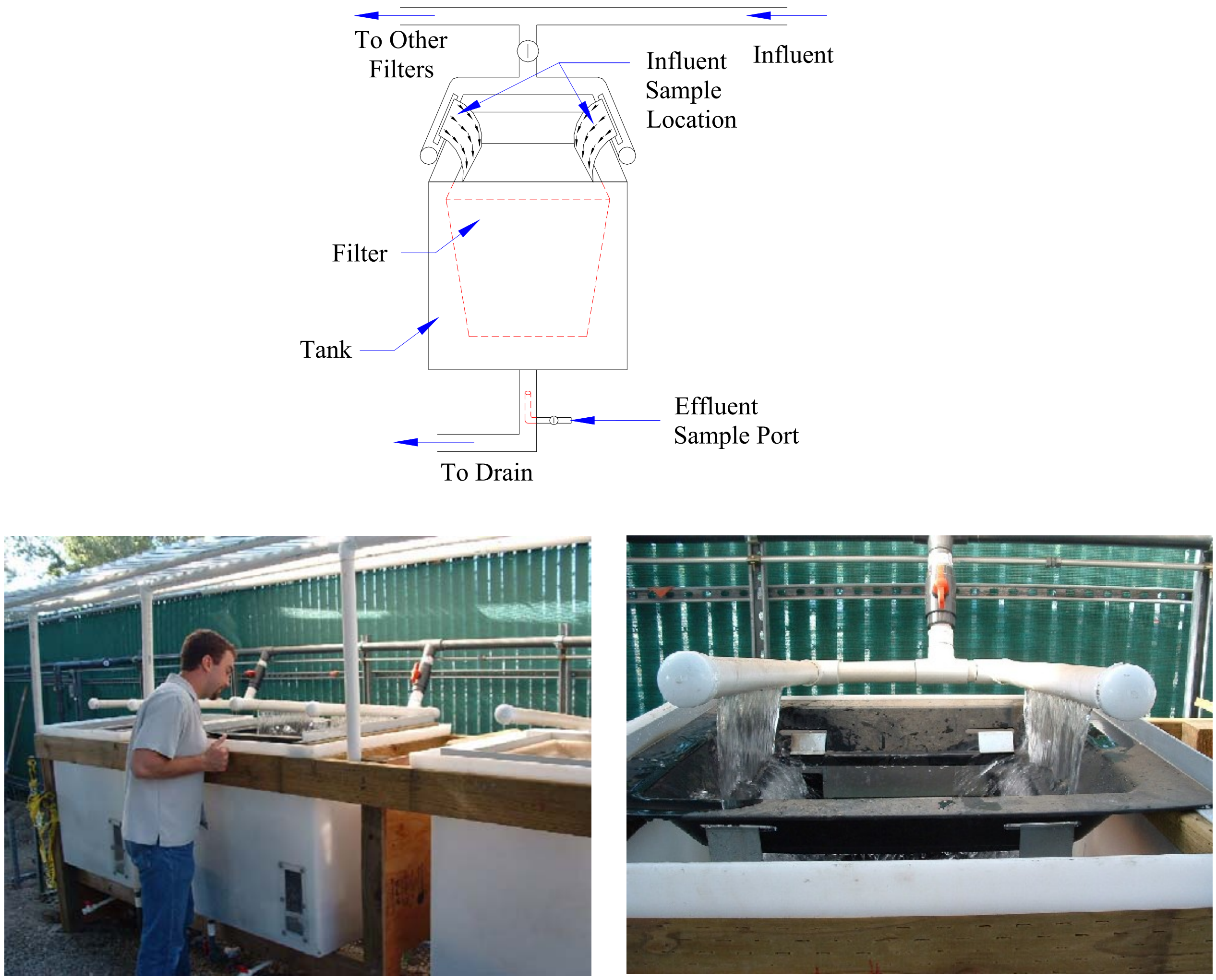


Figure 2. General Schematic of Filter Test Stand, Test Facility Test Stand, and an Influent Profile.

Test Parameters

General test parameters include drainage area selection, total volume, flow rate, oil concentration, and sediment concentration.

Drainage Area Selection

A theoretical drainage area served by the filters must be chosen as the basis for calculating volume and flow for the experiments. The drainage area chosen was about 0.1 hectare (0.25 acre) based on Caltrans installations(10) and on FHWA sizing guidance(11).

Total Volume

The experimental goal was to pass a year's worth of runoff through each filter. The selection of volume was based on the highest annual average total rainfall among three major urban areas of California. The selected rainfall depth was 51 cm (20 inches) which, when applied to the 0.1 ha drainage area, resulted in a volume of 454,000 liters (120,000 gallons). The annual volume was applied over 20 days simulating 20 rainfall events. Consequently, each continuous dose test run used 23,000 L (6,000 gal) of water. Because of time constraints, the continuous dose plus sediment experiment consisted of only 15 runs, each with 23,000 L. The filters were allowed to dry several days to a week between test runs, simulating the time between storms in field conditions.

Each of the three experiment scenarios used a different total volume of water. For the spike dose scenario, water was applied as needed until the level of oil being flushed was reduced to near the analytical method reporting limit (~5 mg/L). This was accomplished with only 16,000 liters (4,100 gallons) for each filter. For the continuous dose scenario, a volume of water was chosen that would be approximately equal to the annual amount of water that typically flows through the selected drain inlet size. An annual volume was used because an objective of the study is to measure oil adsorbing capacity throughout a maintenance/replacement cycle which, for reasons of convenience and logistics (replacement in summer), was chosen as one year. To estimate this amount, a drainage area and an annual rainfall depth was selected. Because of time constraints, only 70 percent of the annual volume could be used in the continuous dose plus sediment experiment.

Flow Rate

Initially, a convenient flow rate was selected based on the time in a workday available to run 23,000 liters (6,000 gallons) through a filter. A flow of 95 L/min (25 gpm) accomplishes this in four hours. This allows ample time for set-up, running the test, clean-up, and sending the samples to the lab within an 8-hour workday. This flow rate was used to back-calculate the intensity that would result in this flow rate for the 0.1 ha drainage area using the Rational Method:

$Q = C\ I\ A$

where,

Q = Flow Rate (volume/time),

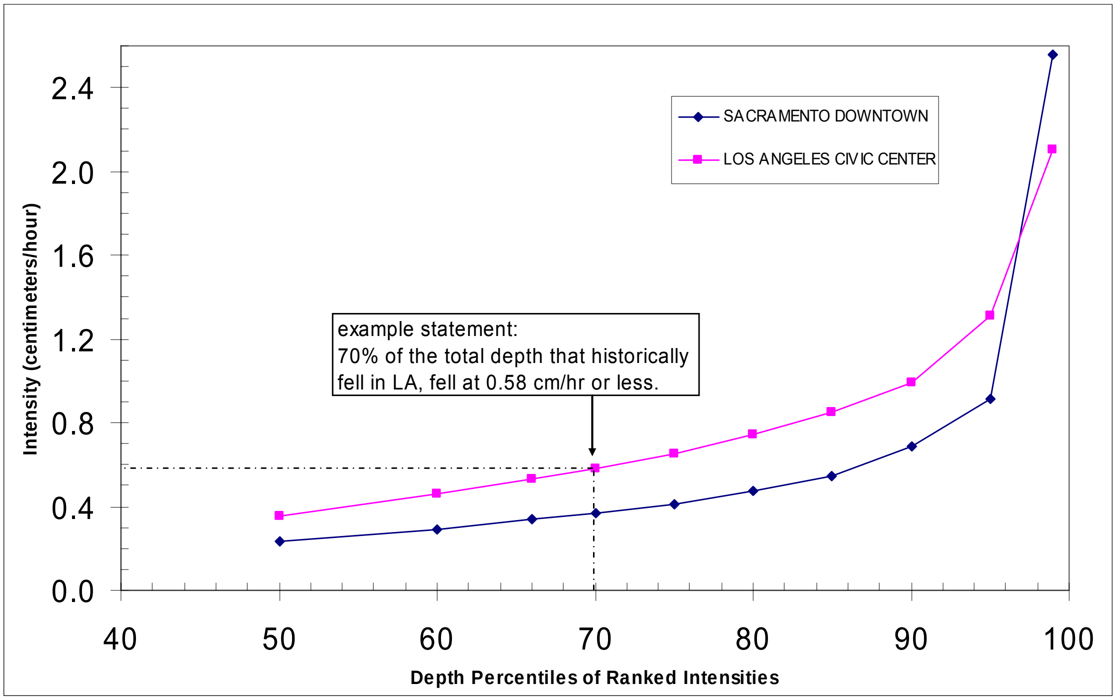
C = Runoff Coefficient = 0.95 (Note: 0.95 may be high for smaller size storms since depression storage has a greater impact on small flows than on the flood flows from which these runoff coefficients are typically developed.),

I = Rainfall Intensity (volume per unit area/time), and

A = Drainage Area = 0.1 ha (0.25 acre).

Using the Rational Method, an area of 0.10 ha (0.25 acres), and a flow of 95 L/min (25 gpm), the resulting intensity is 0.58 cm/hr (0.23 inches/hr). Figure 3 presents hourly intensity percentiles for 63 years of data from Sacramento and 51 years of data from Los Angeles based on total rainfall depth. As shown, 70% of the rainfall depth in Los Angeles fell at an average hourly intensity less than or equal to 0.58 cm/hr (0.23 in/hr). These ranges demonstrate that testing at a flow of 95 L/min (25 gpm) is a reasonable representation of typical California flows for a 0.1 ha (0.25 acre) drainage area. To determine the impact of flow on performance, two other flow rates were selected, 57 L/min and 132 L/min. Intensities were calculated for these flow rates as well. A comparison of selected flow rates and intensities is presented in Table 3.

In the experiments, rainfall intensities up to approximately the 50th percentile are represented by a flow of 57 L/min (15 gpm). The intensities between approximately the 70th and 85th percentile intensity are represented by a flow rate of 95 L/min (25 gpm). The 82nd to 95th percentile is represented by a flow rate of 132 L/min (35 gpm). Considering both example locations, the flow rates used in this study represent a wide range of intensities from 50 percent to 95 percent.



example statement:
70% of the total depth that historically fell in LA, fell at 0.58 cm/hr or less.

Figure 3. Rainfall Intensities Ranked by Total Annual Rainfall Depth for Sacramento and Los Angeles .

Table 3. Flow Rates Corresponding to Intensity Percentiles.

Flow Rate		Intensity		Percent of water that occurs at or below the flow rate and intensity Sacramento	Percent of water that occurs at or below the flow rate and intensity Los Angeles
gpm	L/min	in/hr	cm/hr		
15	57	0.13	0.33	62%	50%
25	95	0.23	0.58	85%	70%
35	132	0.31	0.79	95%	82%

Continuous Dose Oil Concentration

The continuous dose concentration scenario is meant to model typical stormwater runoff from municipal areas. The influent water was spiked with used motor oil. The oil flow introduced in the influent flow was calibrated to the flow of water so the resulting concentration was around 15 mg/L.

Figure 4 presents the oil concentration percentiles from data reported for the National Pollutant Discharge Elimination System (NPDES) stormwater monitoring. The data set consists of analyses of 1,834 samples from over 200 cities, collected in an effort by the University of Alabama to characterize the quality of stormwater runoff(12). Analysis of the data set showed a median concentration of 2.0 mg/L, an 85th percentile concentration of 10 mg/L, and an average concentration of 23.1 mg/L (detection limits were substituted for non-detected values).

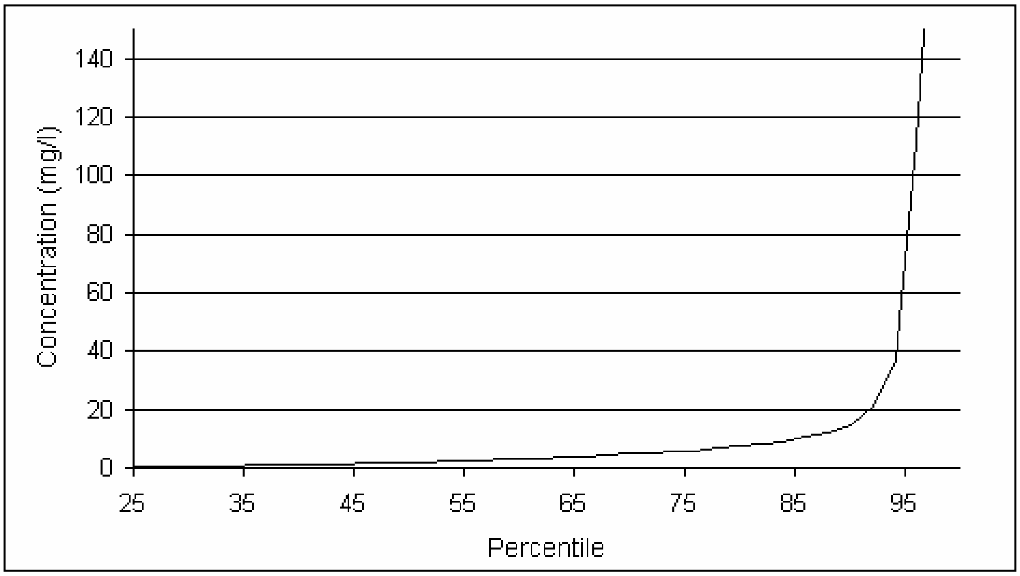


Figure 4. Percentile Ranking of Oil and Grease Concentrations From NPDES Stormwater Monitoring Data for Oil[13].

The goal of this study is to test a typical concentration but still be able to quantify performance. The expected detection limit for oil is 5 mg/L. The high end of expected removal efficiencies is around 70 percent. Avoiding an effluent that drops below the detection limit requires a theoretical concentration of 16.7 mg/L. Based on these estimates, the oil pump was calibrated for 15 mg/L. The exact dose was verified in the field by analysis of water samples. This concentration is a trade off between what is typically found in stormwater and what was practical for conducting the study.

Sediment Concentration

For the continuous dose plus sediment experiment, a target Total Suspended Solids (TSS) concentration of 100 mg/L was used. The sediment used was a ground silica with 99 percent of the particles smaller than 0.106 mm. In practice, the particle size distribution was likely skewed larger because of agglomeration when oil was pre-mixed with dry sediment.

Spike Dose

Direct dose loading is meant to model an illegal dumping scenario. In the case of illegal disposal of used motor oil, it could be expected that the oil dumped would be the amount drained from a vehicle engine – approximately 4 liters (1.06 gal). To mimic this situation, four liters of used motor oil was directly poured into each drain inlet filter without any external flow of water. A drip pan below the filter collected whatever oil immediately exited the filter over the 24-hour period following the oil application. The short-term efficiency of the filter was calculated from a mass balance on the oil. In a field situation, a drain inlet filter could be exposed to a number of rainfall events before the drain inlet filter is replaced. To simulate this, clean water was passed through the filters after the initial application at 95 L/min (25 gpm). The sampling schedule was adjusted, to reflect the expectation that oil concentrations change rapidly as oil is washed out of the filter.

Pump Calibration

The pump used was a positive displacement pump with a ceramic cylinder and piston. The pump had a variable stroke rate and variable volume deliverability per stroke.

Calibration of Metering Pump for Oil Concentrations

Initially, oil dosed into the system sticks to the inside of the pipes, tanks, and valves reducing the concentration of oil in the water. Secondly, Method 1664 does not capture 100 percent of the mass of oil dosed. To address these issues the system was dosed with free oil and water until oil analyses of the influent and effluent were similar. The metering pump was calibrated so that the influent values were near the target dose for two of the four filter test stands. Location 1 is the first test stand in the row of stands that influent water reaches. Location 4 is the last test stand. Locations 1 and 4 were used to calibrate because they represent the shortest and longest distances, respectively, that influent water must travel. Both extremes were considered to verify that additional oil losses were not occurring due to the longer pipe distances. The metering pump was calibrated in two steps. First, oil was pumped from the metering pump into a beaker for a set period of time. This allowed for the metering pump to be adjusted to approximately dose at 15 mg/L oil into a flow of 25 gpm. The second step consisted of oil analysis of the influent water/oil mixture at the sampling port. The metering pump stroke rate was increased until the oil analysis at the influent location was reported near 15 mg/L. The results from this calibration are in Table 4 and Figure 5.

Table 4. Feed Pump Calibration Data for 95 L/min.

Stroke Rate	Concentration (mg/L)	Date	Location
692	9.3	5/26/2004	1
800	11.5	5/26/2004	1
900	13.9	5/26/2004	1
900	14.9	5/26/2004	1
900	14.1	5/27/2004	4
900	14.6	5/27/2004	4
900	14.3	5/27/2004	4
900	14	5/27/2004	4
925	14.5	6/3/2004	4
925	15.9	6/3/2004	4
950	15.9	6/1/2004	1
950	13.7	6/4/2004	1
950	14.2	6/4/2004	1
950	13.8	6/4/2004	1
950	14.1	6/4/2004	1
950	14.6	6/3/2004	4
950	14.8	6/3/2004	4
950	14.9	6/3/2004	4
950	14.7	6/3/2004	4
950	14.9	5/27/2004	4
950	16	5/27/2004	4
999	17.1	6/1/2004	1

For other flows, (57 & 132 L/min) the pump setting (stroke rate and stroke volume) were adjusted in proportion to the change in flows (95 to 57 L/min and 95 to 132 L/min).

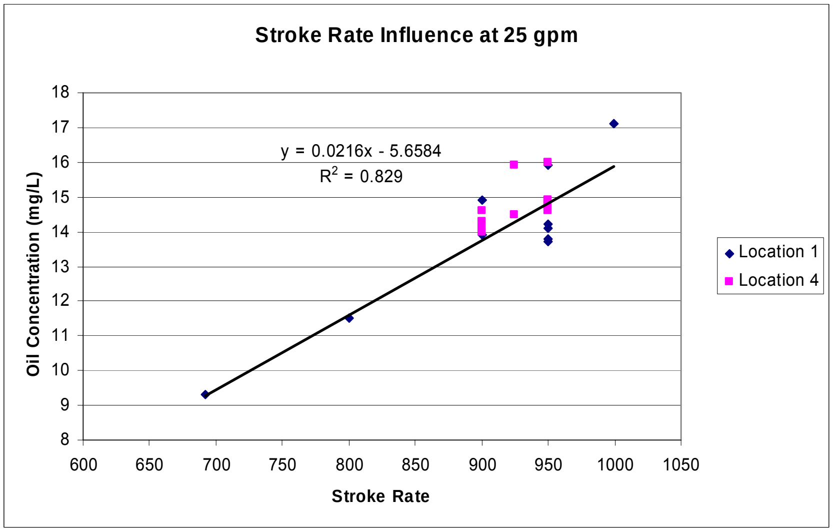


Figure 5. Relationship Between Feed Pump Stroke Rate and Measured Dose.

Sampling Method

For the continuous dose scenarios, influent samples were taken as water fell from the slotted pipes immediately above the filters. Influent samples were only taken for the continuous dose experiments. Effluent samples were taken from the effluent sample port after opening the port to allow stagnant water to flush from the pipe. In the spike dose experiment, this procedure was modified (see later discussion).

For the continuous dose experiment, influent samples were composited every 22,000 liters by filling half of the sample container at 11,000 liters and filling the remaining half of the container at 22,000 liters. For the continuous dose plus sediment, both influent and effluent grab samples were taken every 11,000 liters.

Samples for oil analysis were preserved using 3 to 4 ml of hydrochloric acid (HCl, 12.5 molar). The analysis of the water samples for oil was performed by the Chemistry Department at CSUS using modifications to EPA Method 1664. The reporting limit for this procedure was established at 5 mg/L. In the event of a problem with the primary sample, a duplicate of each sample was taken throughout the study. The sample was refrigerated until analysis of the primary samples met quality assurance and quality control protocols. All samples were stored in a refrigerator between 0^o and 10^o Celsius until analyzed.

Comparing Effluent Sample Locations

There are two possible locations to collect effluent samples: (1) at the sample port after the water flow consolidated in the 100 mm (4 in) drain pipe and (2) in the flow directly below the filter (see Figure 6). Table 5 shows the results of 12 samples taken from the sample port and directly below the filter. Figure 7 illustrates the variability in samples taken from the two locations. It appears that the samples collected from the sampling port better represent oil concentrations of the entire flow. This is because no change in concentration was expected between subsequent effluent samples because oil dose and flow rate into the filters was held constant. The samples taken from the port were more consistent than samples taken directly below the filter. The samples collected directly below the filter showed more fluctuation. This could be because the effluent flow from the filters covers a larger area and collecting a sample that is representative of the entire flow is more difficult. Also, the oil may not have been evenly distributed throughout the effluent flow. In the Hydro-Cartridge^{TM} discrete oil droplets were observed exiting over the weir of the filter. This may not have been true for other filters. Collecting a sample from a confined flow resulted in a more consistent result than a sample taken directly below the filter.

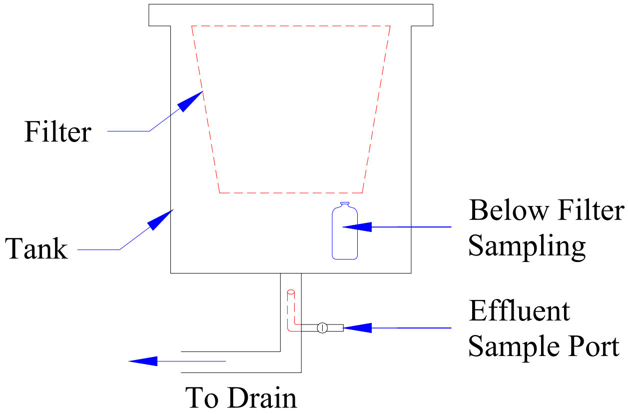


Figure 6. Schematic of Effluent Sampling Points.

Table 5. Comparison of Results Between Samples Collected From a Confined Flow to Samples Collected From an Unconfined Flow.

Filter		Sample Port (mg/L)	Sampling Below Filter (mg/L)	Percent Difference	Date	Flow Rate (gpm)	Theoretical Concentration (mg/L)
Hydro-Cartridge™	Effluent	15.5	14.9	4%	7/7/2004	15	15
Hydro-Cartridge™	Effluent	18.5	22.3	-19%	7/20/2004	15	15
Hydro-Cartridge™	Effluent	18.9	24.5	-26%	7/27/2004	15	15
Hydro-Cartridge™	Effluent	16	29.4	-59%	8/3/2004	15	15
Drain Pac™	Effluent	17.9	28.1	-44%	7/15/2004	15	15
Drain Pac™	Effluent	20.1*	17.2	16%	7/29/2004	15	15

*The primary sample had a value of 33.1 mg/L which is almost three standard deviations (3x4 mg/L=12 mg/L) away from the mean (18 mg/L) of all 15 effluent samples for Drain Pac™ at 15 gpm and 15 mg/L. The duplicate samples value of 20.1 mg/L was used instead.

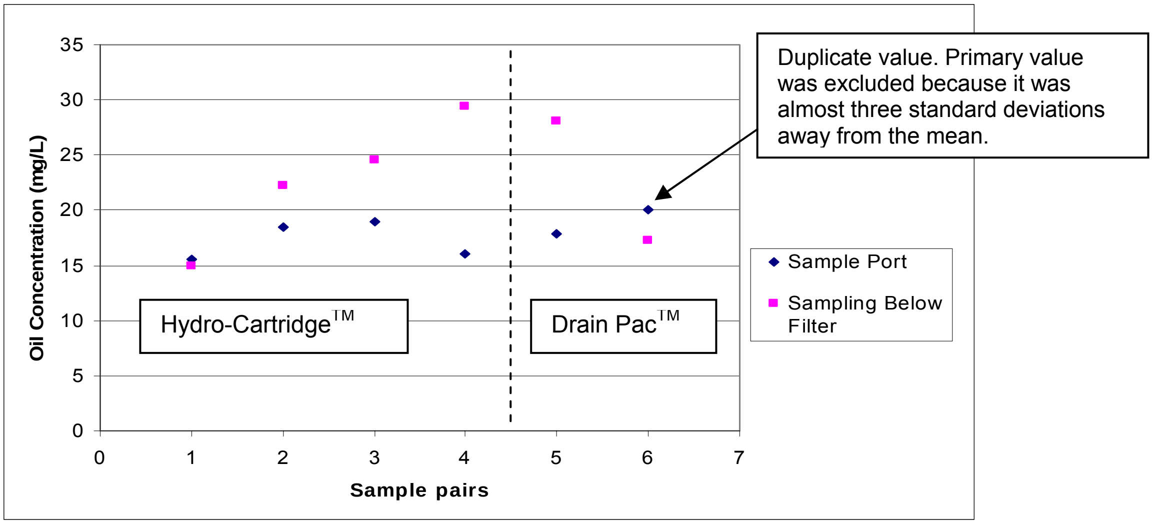


Figure 7. Comparison of the Results from Samples Collected from the Sample Port and Samples Collected Directly From the Filter.

Analysis Methods

The primary water quality analyses used in the study were Total Suspended Solids (TSS), Oil and Grease, and Total Recoverable Petroleum Hydrocarbons (TRPH). This section describes the tests and adjustments that were made to the analysis methods.

Total Suspended Solids (TSS, Standard Method 2540D)

Standard Methods 2540 D(14) was followed, except that the sample was mixed by shaking the bottle thoroughly instead of using a magnetic stirrer. This eliminated the problem of inconsistent mixing of heavier-than-water particles due to the vortex caused by the stirrer. The particles were small enough to stay in suspension until an aliquot could be drawn with a pipette. To assure a representative extraction of the sample, a large mouth 100-ml pipette was used to extract the test aliquot. The data used to develop the method is discussed below.

An acceptable percent recovery is 80 percent to 120 percent. Percent recovery was tested using diatomaceous earth and de-ionized water. Diatomaceous earth was selected because it has a particle size that is retained by the filter prescribed by the test method.

Nine samples were drawn from a single solution of 200 mg/L that was prepared by taking 200 mg of solids and adding water to a volume of 1000 ml. The results of the analysis are shown in Table 6. The percent recovery for several samples were out of range. This was likely because the samples were taken from the same solution which may have experienced imperfect mixing.

Table 6. Replicate TSS Analyses of a 200 mg/L Diatomaceous Earth Standard.

Sample ID #	Initial filter mass (grams)	Final filter mass (grams)	Difference (grams)	Volume (ml)	Concentration (mg/L)	Percent recovery
D	1.0558	1.0719	0.0161	98.5	163.4	**81.7%**
E	1.0588	1.075	0.0162	99.5	162.8	**81.4%**
F	1.0578	1.0733	0.0155	98.7	157.0	**78.5%**
G	1.0565	1.0732	0.0167	100.5	166.1	**83.0%**
H	1.0576	1.0732	0.0156	100.0	156.0	**78.0%**
I	1.0604	1.0776	0.0172	100.0	172.0	**86.0%**
J	1.0546	1.0705	0.0159	99.8	159.3	**79.6%**
K	1.0554	1.0727	0.0173	98.1	176.3	**88.1%**
L	1.0511	1.0698	0.0187	99.1	188.7	**94.3%**

The method was adjusted to improve accuracy. Individual prepared solutions were prepared for each sample point. The results are in Table 7. Percent recovery was within 80 to 120 percent, demonstrating acceptable accuracy of the TSS method.

Table 7. TSS Analyses for Different 100 mg/L Diatomaceous Earth Standards.

Sample ID #	Initial sediment mass (grams)	Initial filter mass (grams)	Final filter mass (grams)	Difference (grams)	Volume (ml)	Concentration (mg/L)	Percent recovery
1	0.1004	1.0652	1.0745	0.0093	100	93	**93%**
2	0.1005	1.0629	1.0728	0.0099	100	99	**99%**
3	0.1003	1.0653	1.0752	0.0099	100	99	**99%**
4	0.1004	1.0677	1.0777	0.0100	100	100	**100%**
5	0.1001	1.066	1.0754	0.0094	100	94	**94%**
6	0.1003	1.0644	1.0744	0.0100	100	100	**100%**
7	0.1003	1.0617	1.0714	0.0097	100	97	**97%**
8	0.1004	1.0699	1.0799	0.0100	100	100	**100%**

Oil and Grease (EPA Method 1664)

EPA Method 1664(15), was followed to analyze motor oil with two modifications. First, to save time, flash evaporation was used instead of distillation. Second, to increase yield, a 20-minute extraction time was used instead of 15 minutes.

A standard spike mixture in acetone was created using 200 ± 2 mg of stearic acid and 200 ± 2 mg of hexadecane in a 100-ml volumetric flask. Samples were prepared by placing 950 ml to 1000 ml of deionized water and 1 ml of standard spike into a 1 liter amber bottle to produce a concentration of 4 mg/L. Samples were shaken vigorously for 2 minutes by hand. The sample was then acidified to a pH of 2 or less and then shaken vigorously again for 1 minute by hand.

Extraction of the sample was performed by pouring the contents of the bottle into a 2-liter separatory funnel. To the bottle, 30 ml of n-hexane was added and shaken to remove all organic material, then poured into the separatory funnel for extraction. The separatory funnel was shaken for no less than 2 minutes and then allowed to equilibrate for no less than 20 minutes.

The aqueous layer is drained off the bottom and kept for second extraction in the original sample bottle. The organic layer was filtered through 10 g of dry sodium sulfate (prior rinse with 20 ml of n-hexane) into a clean and tarred 100-ml round bottom flask containing 3 glass balls. The organic layer was then put on a rotor-evaporator to remove the n-hexane. Extraction of the aqueous layer was repeated two more times following the same procedure. The round bottom flask containing the oil/grease residue was weighed for sample recovery.

While the bulk of the Method 1664 analysis was conducted at California State University, Sacramento (CSUS) a small portion was contracted out to California Laboratory Services (CLS).

Total Petroleum Hydrocarbon (EPA Method 8015M)

EPA Method 8015(16), as modified to detect motor oil, was used to detect the occurrence of oil concentrations below the reporting limit of Method 1664 (i.e. 5 mg/L). Method 8015 analysis was conducted by CLS.

Spike Dose Experiment

The spike dose experiment is used to compare the ability of the filters to capture illegal or accidental oil spills and to retain the oil during subsequent flushing with clean water. This section presents the study method and results of the experiment.

Method for Spike Dose Experiment

To simulate illegal disposal of used motor oil following an oil change, the filters were tested by individually dosing each filter with 4 liters of oil poured directly into clean filters.
Figure 8 shows how oil was typically poured into a filter.

Figure 8. Application of Spike Dose of Four Liters.

Set-up and Operation Unique to this Experiment

A drip pan installed beneath each filter collected oil that passed through the filter for the first 24 hours after the oil was added. The difference between the oil applied and the oil collected in the pan was the initial mass retained by the filter. After the drip pan was removed, oil-free water was flushed through the filters at 95 L/min (25 gpm).

Sampling and Analysis

After the start of flushing, a geometric sampling schedule was used so that more samples were taken early in the flushing to better characterize the period when the concentration of oil leaving the filter changes rapidly. To capture the first flush concentration, the first sample bottles were placed directly under the filters before water was applied. The bottles were placed in the flat-bottomed tank that supported the filters. Subsequent samples were collected from the effluent sample ports. Flushing was continued until only a light sheen of oil appeared in the sample bottles, which usually corresponded to concentrations that were near the reporting limit.

Observations

The following observations were made during and after the spike dose experiment of each filter.

FloGard+Plus™

The oil adsorbing media in the FloGard+Plus™ filter (see Figure 9) is located only on the bottom of the filter, so an effort was made to pour directly into the center of the media to avoid splashing oil along the sides of the filter where there is only mesh fabric. As the oil was poured into the filter, it pooled up and spread out over the media. The media became discolored with a dark reddish brown sheen where it came into contact with the oil. Within a few seconds the oil began draining through the media filter, even while oil was still being poured into the top. After the oil addition was stopped, the FloGard+Plus™ filter drained oil steadily for several minutes into its collection pan. The oil drained mainly from the center of the filter media. Within an hour, only an occasional drop of oil fell from the media filter. The filter media was still discolored with a dark reddish brown color but with less of a sheen. After four days, a total of 2.88 liters of oil collected in the drip pan beneath the filter, meaning the filter initially retained 1.12 liters. At that point water flushing was started. During initial flushing with oil free water, the water running out of the filter was dark in color. Within five minutes the effluent water ran clear.

New Filter

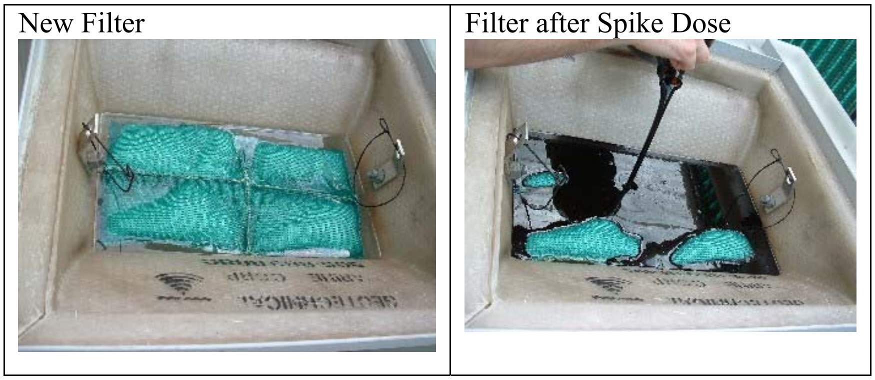
Filter after Spike Dose

Spike Dose Dripping

Figure 9. Photographs of FloGard+Plus™ During the Spike Dose Experiment.

Hydro-Cartridge™

Four liters of used motor oil were poured directly onto the media pillow floating in the Hydro-Cartridge™ filter (see Figure 10), displacing the column of water over the weir. The oil collected on and around the pillow floating on the column of water held by the Hydro-Cartridge™. After an hour, the media pillow became discolored with a reddish brown color, and there was still a considerable amount of oil pooled around the pillow. There was no noticeable oil or oil sheen in the Hydro-Cartridge™ effluent area. During the initial flushing, the media pillow on the top of the water column, which previously had been reddish brown, faded to light brown.



New Filter

Filter after Spike Dose

Figure 10. Photographs of Hydro-Cartridge™ During the Spike Dose Experiment.

Ultra Urban™

Four liters of used motor oil were poured directly onto the floor of the Ultra Urban™ filter (see Figure 11). Oil formed a small pool and then spread over the bottom of the media filter. The Ultra Urban™ media became discolored with a dark reddish brown sheen wherever the oil came into contact with the media. Nearly the entire four liters of oil was poured into the Ultra Urban™ filter before any oil began to drain out of the media filter. The oil drained from several spots around the center of the filter media. Within an hour there was no noticeable oil draining from the filter. The media had a medium reddish brown color with very little visible sheen where the media had been in contact with the oil. A total of 1.75 liters of oil collected in the drip pan beneath the filter, meaning the filter initially retained 2.75 liters. Four days passed before flushing with water began. During initial flushing, there was no noticeable oil in the effluent sample .

New Filter

Filter after Spike Dose

Spike Dose Dripping

Figure 11. Photographs of Ultra Urban™ During the Spike Dose Experiment.

Drain Pac™

Four liters of used motor oil were poured directly onto the bottom of the Drain Pac™ filter (see Figure 12). Oil pooled some but passed through the filter readily with little apparent retention. The oil coated and discolored the fabric with a dark brownish black color before passing through it. The filter fabric impeded the flow of oil just enough to allow the bottom to fill slightly with oil and form a bowl shape from which the oil drained. Within an hour, the oil draining from the media filter was minimal. After four days, a total of 3.68 liters of oil collected in the drip pan beneath the filter, meaning the filter initially retained 0.32 liters. At this point water flushing began. During initial flushing there was no noticeable oil in the effluent sample.

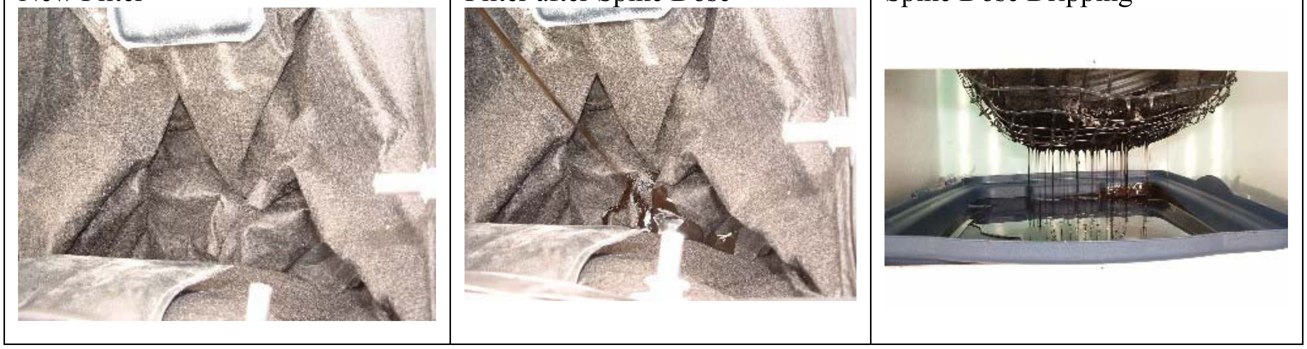

New Filter | Filter after Spike Dose | Spike Dose Dripping

Figure 12. Photographs of Drain Pac™ During the Spike Dose Experiment.

Monitoring Results

The initial efficiency and final efficiency after flushing are shown in Table 8. Initial efficiency was calculated by dividing the oil retained by the filter prior to flushing by the amount applied (4 liters). The final capture efficiency after flushing was calculated by adding the oil flushed to the amount initially dripped from the filter. The oil flushed was calculated by multiplying the concentrations in the effluent samples by the volume of water (i.e. the area under the concentration versus volume curve). This analysis is presented in Appendix A. Clean water was flushed through all four drain inlet filters at a flow rate of 95 L/min (~25 gpm). The initial oil concentrations during the first 20 liters of flushing ranged from 15 mg/L for the Ultra Urban™ filter to 12,000 mg/L for the Hydro-Cartridge™.

Table 8. Initial and Final Oil Retention Efficiencies for Spike Dose Experiment.

Filter name	Initial efficiency[a], %	Final efficiency[a], %
FloGard+Plus™	28	27
Hydro-Cartridge™	100	25
Ultra Urban™	56	56
Drain Pac™	8	5

a. Efficiency calculations in Appendix A.

Changes in the percent of oil retained by each filter as a function of flushing volume are shown in Figure 13. There was a lot of variation in the concentrations measured at the start of the flush. Some of the variation is attributable to difficulties in collecting samples at precise times. Uneven flushing from the filters themselves may be another contributing factor. For clarity, the individual data points have been omitted from Figure 13. Curves were fit to the geometric data series so that concentrations could be estimated at even intervals.

Except for the Hydro-Cartridge™, only limited flushing of the initial mass of oil retained was observed. The FloGard+Plus™ filter had an initial capture efficiency of 28 percent and an estimated final capture efficiency of about 27 percent indicating some flushing of captured oil. The Ultra Urban™ filter had an initial capture efficiency of 56 percent and an estimated final capture efficiency of about 55 percent. The Drain Pac™ filter had an initial capture efficiency of 8 percent and an estimated final capture efficiency of about 4 percent. In contrast, the Hydro-Cartridge™ filter had an initial capture efficiency of 100 percent because the oil collected on the surface of the standing water column within the inner duct (see Figure 13). As water was applied, the oil was washed out, as shown in Figure 13 and Figure 14. The final capture efficiency was estimated at 25 percent.

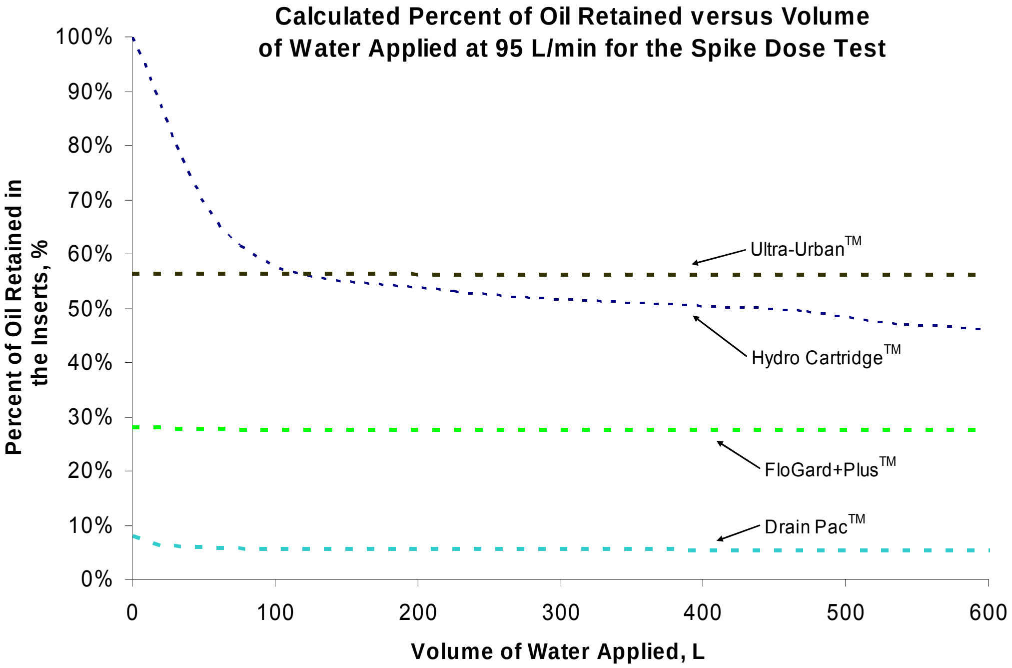


Figure 13. Calculated Percent of Oil Retained Versus Volume of Water Applied at 95 L/min for the Spike Dose Test.

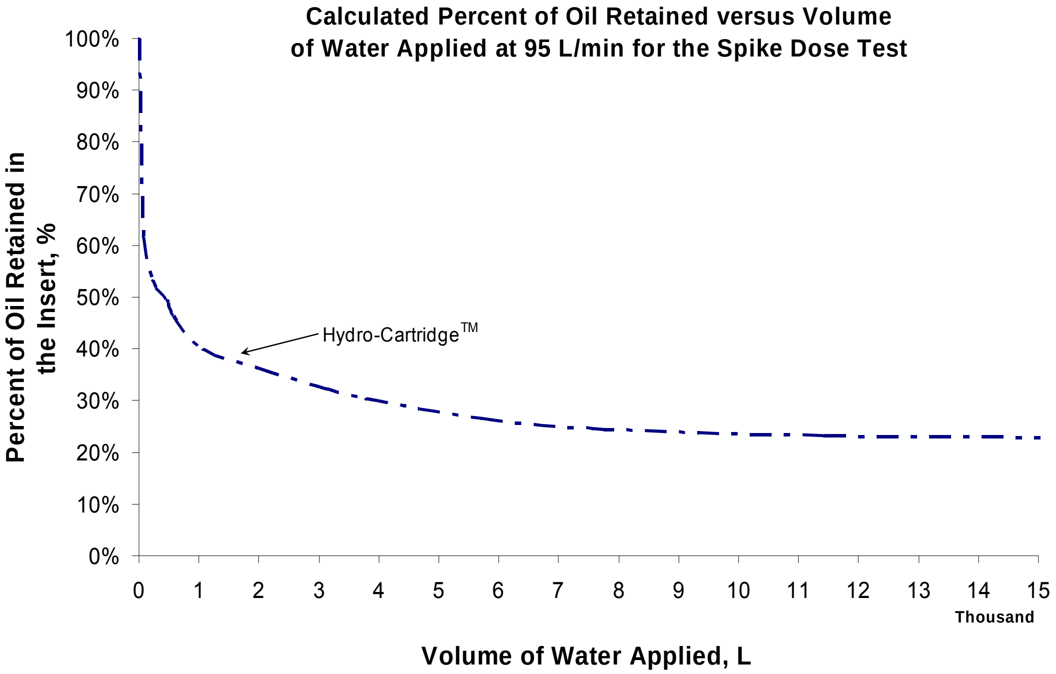


Figure 14. Calculated Percent of Oil Retained Versus Volume of Water Applied at 95 L/min for the Hydro-Cartridge™ Spike Dose Test.

Continuous Dose Experiment

The continuous dose experiment was designed to compare the capacity of the filters to adsorb oil from stormwater. The experiment simulated up to one year of runoff with oil dosed at a level of 15 mg/L. Using free oil (no sediment) was assumed to reach the adsorptive capacity sooner than if sediment were present because some oil would stick to the sediment. Consequently, for the purpose of estimating life of the filter media, this experiment is conservative.

Method

The filters were tested by individually dosing each filter with irrigation water into which used motor oil was continuously introduced by a metering pump (see Figure 15). As described previously, a concentration of 15 mg/L was selected as a target. It was desired to test the filters under the equivalent of a full year's load. At a target oil concentration of 15 mg/L, the target load over the total volume of water applied for the continuous dose experiment, 454,000 liters, was 7.7 liters of oil.

Set-up and Operation Unique to this Experiment

A static mixer, oil metering pump, and an oil reservoir were added to the general set-up as illustrated in Figure 15.

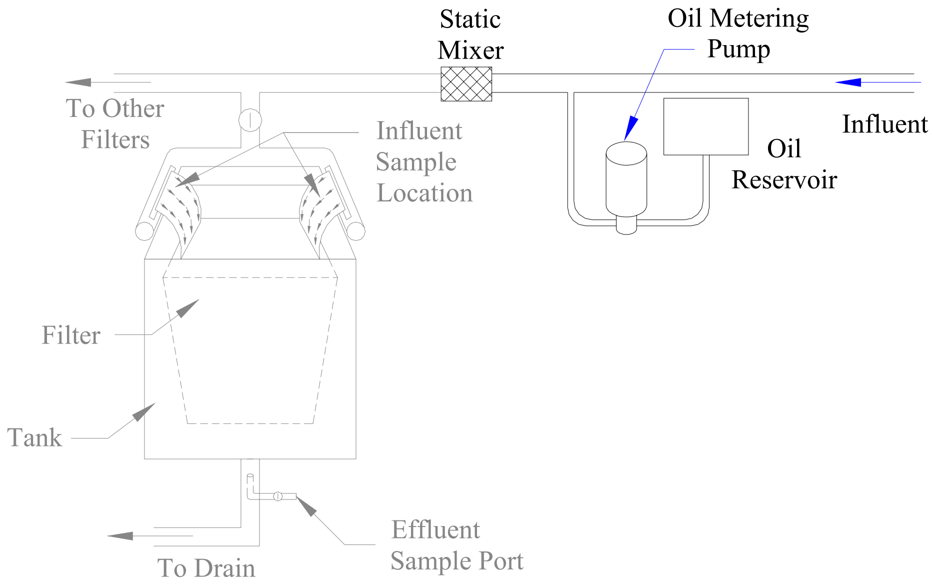


Figure 15. Schematic of Set-Up for the Continuous Dose Experiment.

Sampling and Analysis

To simulate dry periods between storm events, the water applications were scheduled so that each filter would get an equal amount of drying time between test runs. This dry period was two days at test flows of 95 L/min and 132 L/min (25 gpm and 35 gpm) and one week for test flows of 57 L/min (15 gpm). Samples were collected from flows entering and leaving the filters.

Influent and effluent flows were each characterized by daily composite samples. Each 1,000-ml composite sample consisted of two manually collected aliquots. One 500-ml aliquot was collected at approximately 11,000 liters (3,000 gallons). A second 500-ml aliquot taken at approximately 23,000 liters (6000 gallons) was collected in the same bottle. Samples were collected in 1,000 ml amber glass bottles with Teflon caps.

Bottles were labeled with the following information:

- Date and time (composite samples had two times)
- Type (primary, duplicate, triplicate, trip blank)
- Initials of sample taker
- Filter name (i.e. FloGard+Plus^{TM}, Hydro-Cartridge^{TM}, Ultra Urban^{TM}, Drain Pac^{TM})

For the first ten weeks of each run, a duplicate sample was analyzed along with the primary sample. This was done to verify the precision of the sampling and analysis procedures. In case of a problem with either the primary or duplicate sample, a third sample was collected and stored. This triplicate was only analyzed if there were substantial differences between the primary and duplicate samples. Triplicates were taken for the first 10 runs of each filter (weeks 1-10). Duplicates were taken for the second 10 runs of each filter (weeks 11-20). In this period the duplicate was only analyzed if there was a problem analyzing the primary sample.

One additional sample was taken each week to serve as a field blank. A field blank is a sample of water from the site before being dosed with oil. The field blank indicated if contamination of the sample has occurred.

Observations

Pictures of each filter before and after the continuous dose experiment are shown in Figure 16. Over the period of the experiment the filters became more increasingly discolored. Hydro-Cartridge^{TM} had the only significant other observation. Oil droplets were seen escaping over the effluent weir.

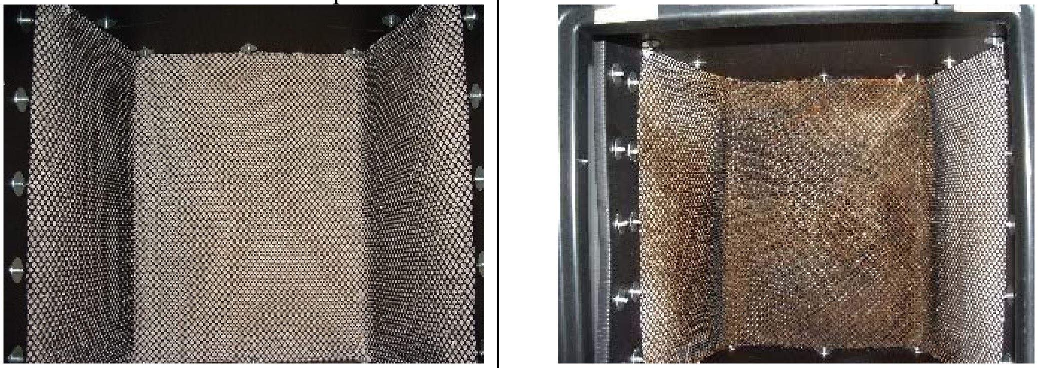
FloGard+Plus^{TM} before continuous dose experiment	FloGard+Plus^{TM} after continuous dose experiment
	

Hydro-Cartridge™ before continuous dose experiment

Hydro-Cartridge™ after continuous dose experiment

Ultra Urban™ before continuous dose experiment

Ultra Urban™ after continuous dose experiment



Drain Pac™ before continuous dose experiment

Drain Pac™ after continuous dose experiment

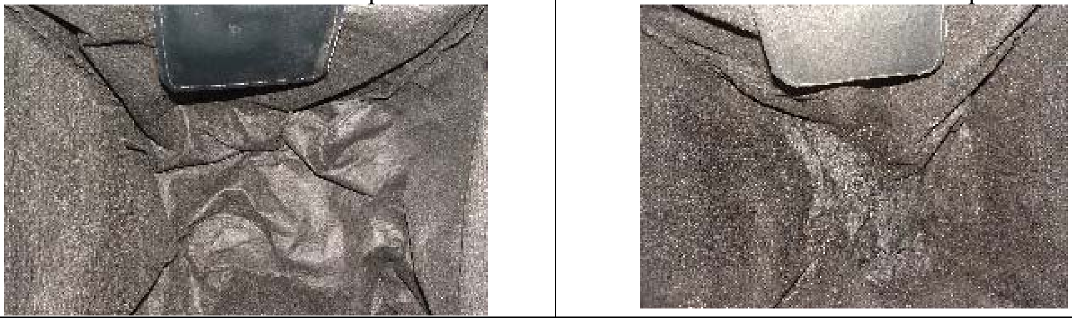


Figure 16. Photographs of Color Changes in Filters in the Continuous Dose Experiment.

Monitoring Results

Continuous Dose Experiment

The results from the continuous dose experiment are plotted in Figure 17 and Figure 18. In each plot, the influent concentration from each daily composite sample is plotted against the corresponding effluent value. The solid diagonal line denotes where influent concentrations equal effluent concentrations. So data points that fall on or around that line represent cases where no removal occurred. Where removal did occur, the data points fall below the line.

As can be seen in Figure 17, for the Hydro-Cartridge™ and Drain Pac™ units, effluent concentrations were less than influent concentrations on some days and greater on others.

Individual data points above the line don't necessarily represent export of oil; more likely they represent imprecision in the sampling and analysis protocols. The important feature to notice is that the data are arrayed around the "no treatment" line. In contrast, the data from the FloGard+Plus^{TM} and Ultra Urban^{TM} filters lie consistently below the line, indicating oil removal (see Figure 18).

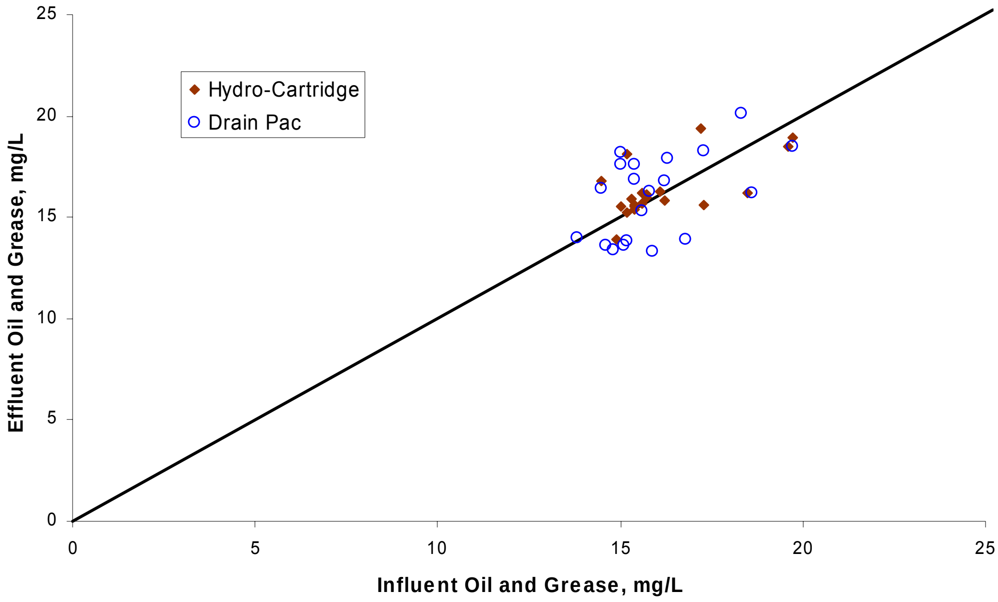


Figure 17. Influent Oil and Grease for Hydro-Cartridge^{TM} and Drain Pac^{TM}.

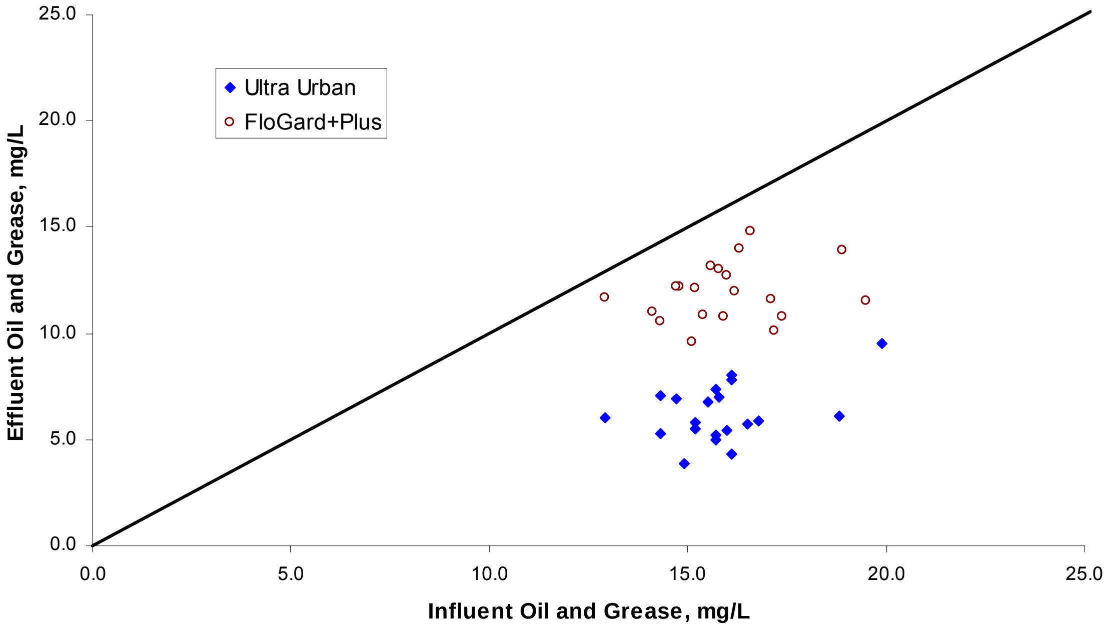


Figure 18. Influent Oil and Grease for Ultra Urban^{TM} and FloGard+Plus^{TM}.

This conclusion is further supported by statistical analysis of the data. For each run, the percent of oil removed was calculated from:

$$\text{Percent removed} = \left(1 - \frac{Ceff}{C\,\text{inf}}\right) * 100$$

where C_{eff} is the effluent concentration and C_{inf} is the influent concentration. The removal percentages were found to be normally distributed, and on this basis the confidence intervals for the means were calculated. Confidence intervals and means expressed as percentages are shown in Table 9; the detailed calculations are shown in Appendix A. When the confidence interval straddles zero, as it does for the Hydro-Cartridge™ and Drain Pac™ filters, the mean percentage removal is not significantly different from zero. Thus, based on the data collected for these two filters, oil removal was not statistically demonstrated. For the Ultra Urban™ and FloGard+Plus™ filters, oil removal is supported by the statistical analysis.

Table 9. Oil Removal (%) for the Continuous Dose Experiment.

Filter	Mean (%)	95% Confidence Interval
Hydro-Cartridge™	-1.3(a)	-4.9 to 2.3
Drain Pac™	-1.0(a)	-6.3 to 4.4
Ultra Urban™	61	57 to 64
FloGard+Plus™	25	20 to 29

(a) Based on the confidence interval, this value indicates a lack of statistically demonstrable treatment, not negative removal.

Generally speaking, the efficiency of oil removal appeared to be related to the amount of media that contacts the flow of water. The Ultra Urban™ filter, which consistently produced the lowest effluent concentrations, contained the most media, and all of the inflow was directed through it. The next most efficient filter, the FloGard+Plus™, contained the second largest amount of media, and most of the water was forced through it, especially at lower flows. The Hydro-Cartridge™ filter contained bags of media that floated on the inner column of water, presumably to adsorb the film of oil expected to accumulate there. In practice, stormwater appeared to flow down along the inner walls of the filter and did not contact the media significantly. In fact, the stormwater was observed to flow down fast enough to entrain small droplets of floating oil which would then pass underneath the baffles and escape the filter entirely. This may explain why spikes were occasionally observed in the effluent data for Hydro-Cartridge™. In the Drain Pac™ unit, the filter liner acts as the adsorptive media, but it is very thin compared to the media beds in the FloGard+Plus™ and Ultra Urban™ filters.

To check for variations in performance as a function of volume treated or flow rate, the ratios of C_{eff}/C_{inf} for the daily samples were plotted against the volume of water passed through the various filters. These graphs are shown in Figure 19 and Figure 20. C_{eff}/C_{inf} equaling 1.0 signifies no oil removal. As can be seen in Figure 19, the Hydro-Cartridge™ and Drain Pac™ results plotted close to the “no treatment” line. No trends were apparent. In Figure 20, the results for the Ultra Urban™ and FloGard+Plus™ filters are shown. Increasing the flow rate appears to have reduced the removal efficiency of the Ultra Urban™ filter somewhat. A similar phenomenon may have occurred in the FloGard+Plus™ filter, but the trend, if it exists, is not very clear in the figure. What is interesting to note is that for both Ultra Urban™ and FloGard+Plus™ filters, treatment performance did not degrade over time. If the adsorptive capacity of the filter media was approaching saturation, C_{eff}/C_{inf} would be expected to increase as more water was passed through the filters. The fact that this was not seen suggests that these filters contain sufficient adsorptive material to handle a year's worth of runoff at this oil concentration.

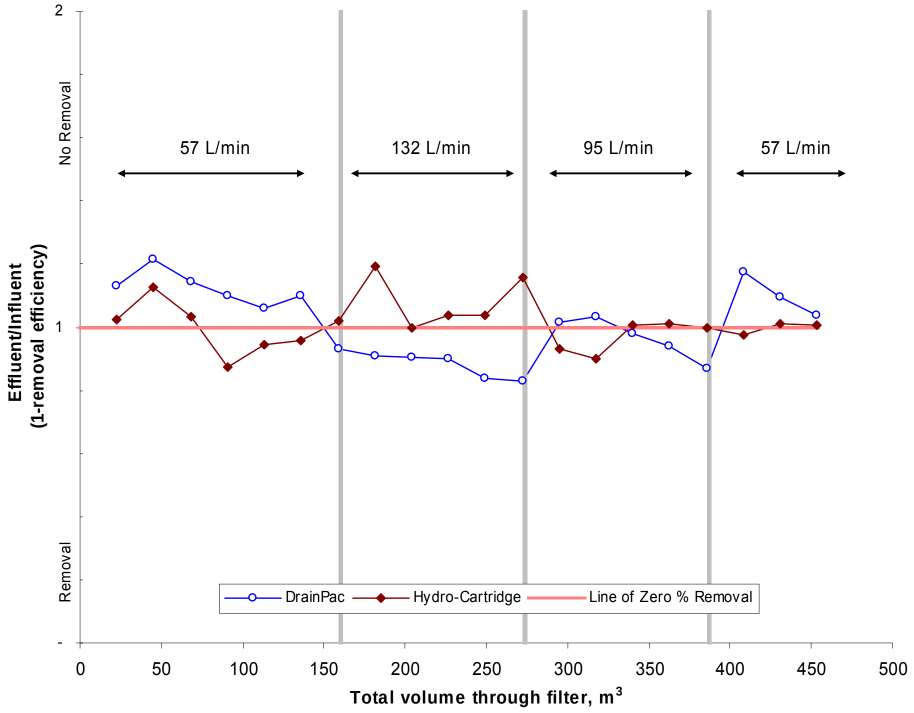


Figure 19. C_{eff}/C_{inf} as a Function of Cumulative Volume through Drain Pac^{TM} and Hydro-Cartridge^{TM} Filters.

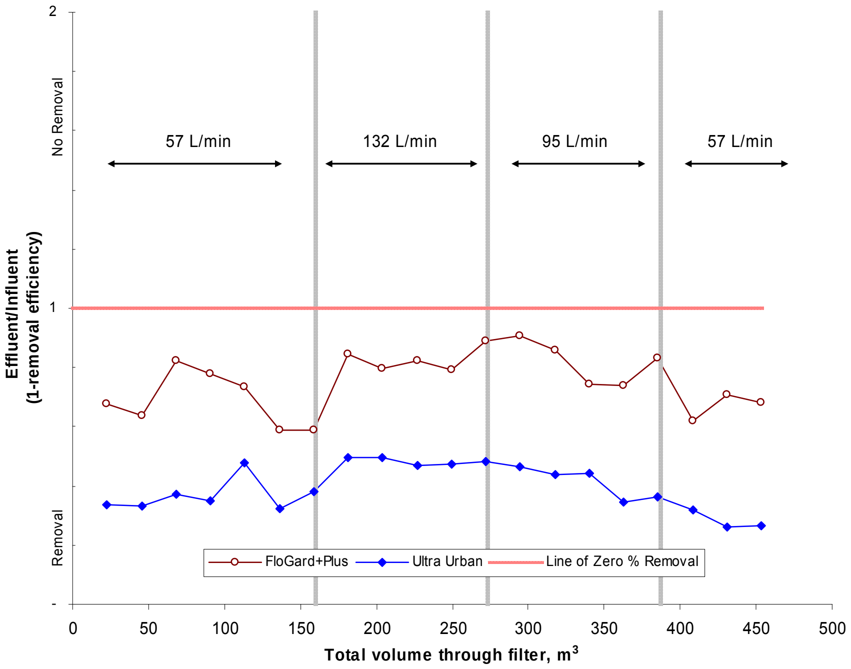


Figure 20. C_{eff}/C_{inf} as a Function of Cumulative Volume through FloGard+Plus^{TM} and Ultra Urban^{TM} Filters.

Clean Water Flush Test

At the conclusion of the continuous dose experiment, a clean water flush (CWF) test was performed. This test indicates how well the filters retain previously captured oil. This is important because stormwater oil concentrations vary from storm to storm. If flushing is substantial, oil captured during storms with high oil concentrations could be released during subsequent storms with low oil concentrations.

Method for Flushing Experiment

Oil-free water was run through each filter at 95 L/min. Effluent samples were collected on a geometric time series schedule at 5, 10, 20, 40, 80, and 160 minutes. A different method of analysis (Method 8015) had to be used because the reporting limit of Method 1664 is only 5 mg/L. The results are not directly comparable to the 1664 test.

Observations

Oil could not be observed in the effluent flow during the experiment so observations are limited to the effluent samples. Hydro-Cartridge™ and Drain Pac™ had noticeable sheens of water on the first few samples. In comparison, FloGard+Plus™ and Ultra Urban™ seemed cleaner. All filters, after the first five samples had very little to no noticeable sheen.

Monitoring Results

The results are displayed in Figure 21. Drain Pac™ and Hydro-Cartridge™ appeared to flush out more oil compared to the other two filters. This result is consistent with their poor performance over the long term. It appears that whatever small amount of oil captured in a storm escapes in subsequent flows. The flush concentration for the FloGard+Plus™ was initially around one fifth the concentration for the Hydro-Cartridge™ and Drain Pac™ but quickly fill to very low values. This might have been some oil adhering to the liner rather than having adsorbed to the media. The smallest flush came from the Ultra Urban™ filter, which had the largest amount of adsorptive media.

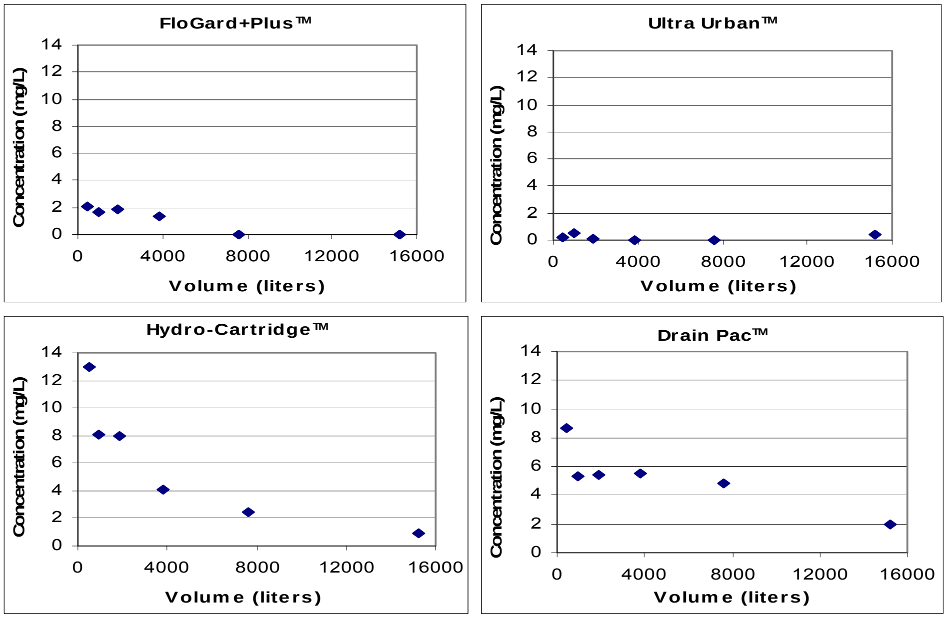


Figure 21. Graphs of Effluent Concentrations in the Clean Water Flush Test Using Method 8015.

Continuous Dose Plus Sediment Experiment

Oil mixed with sediment-free water may not be a good model of stormwater runoff. In field conditions where sediment is present, a substantial fraction of the stormwater oil may be adsorbed to sediment particles. Accordingly, the oil removal efficiency of a drain inlet filter will be significantly influenced by its ability to remove sediment. The continuous dose plus sediment experiment is designed to determine if adding sediment changes the removal results observed in the previous experiment without sediment. This experiment is thought to be more typical of real stormwater than the free-oil scenarios, but also harder to simulate in a reproducible procedure.

This experiment was not in the original proposal. It was added later to address issues that became more obvious during the previous experiment without sediment. Due to time constraints, setup and procedures were developed quickly and adjustments were made throughout the experiment.

Method

The sediment chosen was a manufactured fine silica material (Sil-Co-Sil 106). This was chosen because other laboratory experimenters had used it in this context, and it was becoming an industry standard (Michael Barrett, personal communication, 11/25/03). The silica was mixed with oil using a kitchen mixer in the laboratory and then added to water to make a slurry. The slurry was pumped into the feed water flow at rates sufficient to achieve the desired concentrations. As described later, a metering pump was also used to inject free oil.

Set-up and Operation Unique to this Experiment

A mixing tank, electric mixer, peristaltic pump, and circulation pump were added to the general set-up as illustrated in Figure 22. The slurry was contained in a 132-liter circular tank with a conical bottom. Mixing was provided by a ¾-hp motor that turned two 7.6-cm (3-inch) blades on a 1.3-cm (1/2-inch) shaft. A peristaltic pump took slurry from a point near the bottom of the tank and fed it into the filter influent line. To accommodate changes in the influent flow rate due to different tests (57 to 132 L/min or 15 to 35 gpm) and the because the peristaltic pump dosing rate was a constant 200 mL/min, the volumes and concentrations of solids in the slurry were varied so that the influent concentration was always 100 mg/L. Before testing began, solids were observed to accumulate on the bottom of the tank. A compressed air bubbler system was installed to re-suspend this material. Although this was partially successful, the aeration system was eventually replaced by the circulation pumping system shown in Figure 22. At that time, the port used to take the slurry from the tank to the filter influent line was moved to the discharge pipe of the circulation pump (see Figure 22). As discussed later, these changes are suspected to have caused problems for calculating solids removal by both mass balance and concentration methods.

The initial target concentrations were 5 mg/L oil and 100 mg/L sediment. Samples were initially analyzed for oil content both by Method 1664 and Method 8015. Because the effluent concentrations were expected to be below the reporting limit for Method 1664. However, data generated by Method 8015 appeared to be biased slightly low. Although this bias was well within the normal quality control acceptance limits of the method, it was decided that Method 1664 yielded data that was more consistent with the continuous dose experiment. The influent concentration was raised so that Method 1664 could be used for all samples. Consequently, the target oil concentration was raised to 15 mg/L after 68,000 L (18,000 gal) had passed each filter. At the same time, the air compressor was replaced by the circulation pump shown in Figure 22 to more thoroughly mix the slurry. With this change, the sampling port was moved from the bottom of the tank to the discharge side of the circulation pump.

It was soon apparent from analyzing influent samples that the goal of 15 mg/L oil was not being reached due to losses, inefficient sampling of influent, and limitations in percent recovery when sediment is present. Mixing more oil into the sediment was tried, but the mixture became tar-like and could not be mixed into the slurry tank. So to add the additional oil, free oil was metered into the feed line through a metering pump. This pump was installed when the total volume applied to each filter had reached 91,000 liters (24,000 gallons). At a cumulative volume of 113,000 L (30,000 gal), the metering pump was replaced with a smaller unit, but the oil injection was not changed.

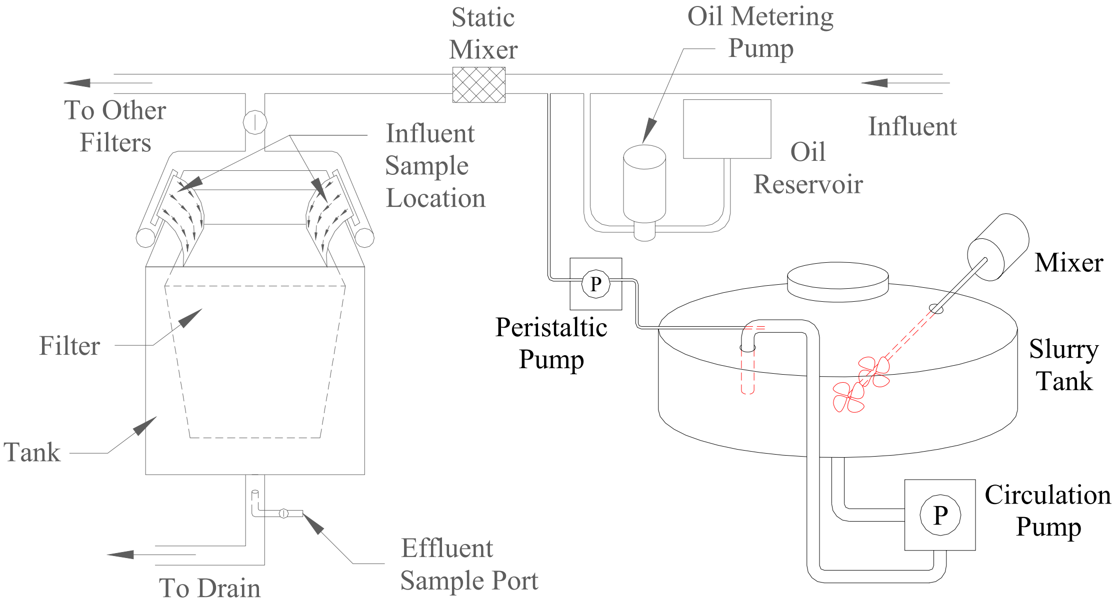


Figure 22. Schematic of Set-Up for the Continuous Dose Plus Sediment Experiment.

Sampling and Analysis

The sampling procedure was similar to that used in the continuous dose experiment with a few exceptions. Only 15 daily runs, for a total of 340,000 liters (90,000 gallons) were passed through the filters (compared to 454,000 liters for the continuous dose experiment). Triplicates where not collected since the confidence in the analysis method was previously established. For the first two runs, TSS samples were taken every 11,000 liters (3,000 gallons). Due to laboratory constraints, the frequency of TSS sampling was halved, and samples were collected every 23,000 liters (6000 gallons) for the remainder of the experiment.

At a cumulative volume of 193,000 liters (51,000 gallons) through each drain inlet filter, the sampling schedule was changed. The time for taking the first daily sample changed from the midpoint of the run (11,000 liters) (3,000 gals) to the beginning (approximately 190 to 380 liters after start up) (50 to 100 gallons). The second daily sampling time was moved from the end of the run (23,000 liters) (6,000 gallons) to the midpoint (11,000 liters) (3,000 gallons). This was done to capture higher concentrations of oil that were suspected to be occurring at the beginning of each run. This variation in concentration with time for each run was suspected to be caused by the circulating pump drawing more sediment at the beginning of the run than later.

To verify consistent doses of sediment from run to run, a single sample was taken at the same time as the last oil sample of that run. At the same time, an effluent sediment sample was taken to estimate sediment removal at that time. At the end of the test, a mass balance on the sediment was performed to confirm results. The mass balance was calculated by estimating the mass of TSS delivered to the filters using the influent TSS concentrations multiplied by water volume. The mass in the units was estimated by weighing the filters after weeks of drying. The sediment was removed and the filters weighed again. The material removed was also dried in an oven overnight and weighed to confirm the results. In the case of the Ultra Urban™ filter, the difference in mass between the used filter and a new filter was used because it was not practical to separate the sediment that was caught within the media.

Observations

During the continuous dose plus sediment experiment, sediment gradually built up on the inner mesh lining of the FloGard+Plus^{TM} filter (see Figure 23), the sediment binded the holes in the mesh and caused the water level to rise in the filter. However, the filter did not bypass. Sediment was visually present in the water samples collected.

Before

After

Figure 23. Photographs of FloGard+Plus^{TM} During the Continuous Dose Plus Sediment Experiment.

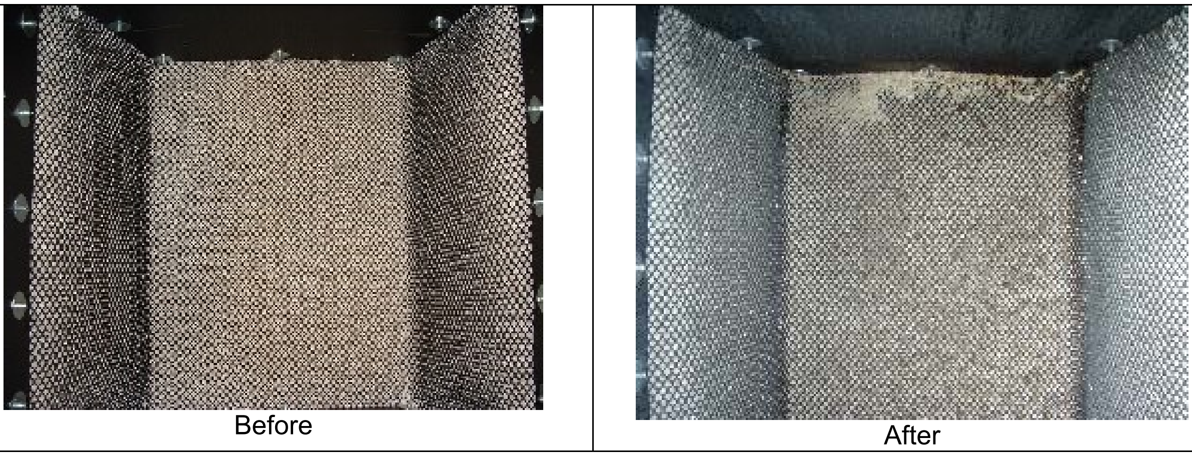
In the Hydro-Cartridge^{TM} filter a small amount of sediment built up on the surface of the floating media pad (see Figure 24). As with the other filters sediment was observed in the effluent samples. At the end of the experiment the floating media pillow was removed and sediment was observed in the media pillow. There was a slight discoloration to the media pillow indicating low oil removal efficiency.

Before

After

Figure 24. Photographs of Hydro-Cartridge^{TM} During the Continuous Dose Plus Sediment Experiment.

The Ultra Urban^{TM} filter (see Figure 25) had a slight build up of sediment sludge on the bottom on the filter, and the media had a slight discolor by the end of the experiment..



Before

After

Figure 25. Photographs of Ultra Urban^{TM} During the Continuous Dose Plus Sediment Experiment.

The Drain Pac^{TM} filter (see Figure 26) lining clogged up during the first test run, and bypass occurred a few hours into the first run. Bypass continued at the start-up of each additional run.

Before

After

Figure 26. Photographs of Drain Pac^{TM} During the Continuous Dose Plus Sediment Experiment.

Monitoring Results

The research question for this experiment was this: Are the oil removal performances of these filters different when oil is added to clean water compared to water containing sediment? The simple answer appears to be "yes." Removal percentages were calculated for all the daily samples as in the continuous dose experiment. Again, the data sets were found to be normally distributed, and confidence intervals for the means were calculated. The results are shown in Table 10. Detailed calculations are shown in Appendix A. In this case, all of the filters showed positive removal percentages that were statistically different from zero.

Table 10. Oil Removal (%) for the Continuous Dose Plus Sediment Experiment.

Filter	Mean (%)	95% Confidence Interval (%)
Hydro-Cartridge	32	18 to 45
Drain Pac	30	18 to 43
Ultra Urban	16	5.0 to 28
FloGard+Plus	35	22 to 48

A graphical comparison of the results from the two experiments (Table 9 and Table 10) is shown in Figure 27. In the figure, 95 percent confidence limits are plotted as vertical lines, and mean values are shown as diamonds. For each filter, the results from the continuous dose experiment ("free oil") are plotted next to the results from the continuous dose plus sediment experiment ("w/ sediment"). Mean oil removal percentages for the Hydro-Cartridge^{TM}, Drain Pac^{TM}, and FloGard+Plus^{TM} filters increased when sediment was present in the water. In contrast, the mean oil removal percentage for the Ultra Urban^{TM} filter dropped. Equally important, the 95 percent confidence limits for the Hydro-Cartridge^{TM}, Drain Pac^{TM}, and Ultra Urban^{TM} results do not overlap, meaning the differences between the means are statistically significant. Though the mean removal percentage for the FloGard+Plus^{TM} increased when sediment was present, the difference cannot be said to be statistically significant.

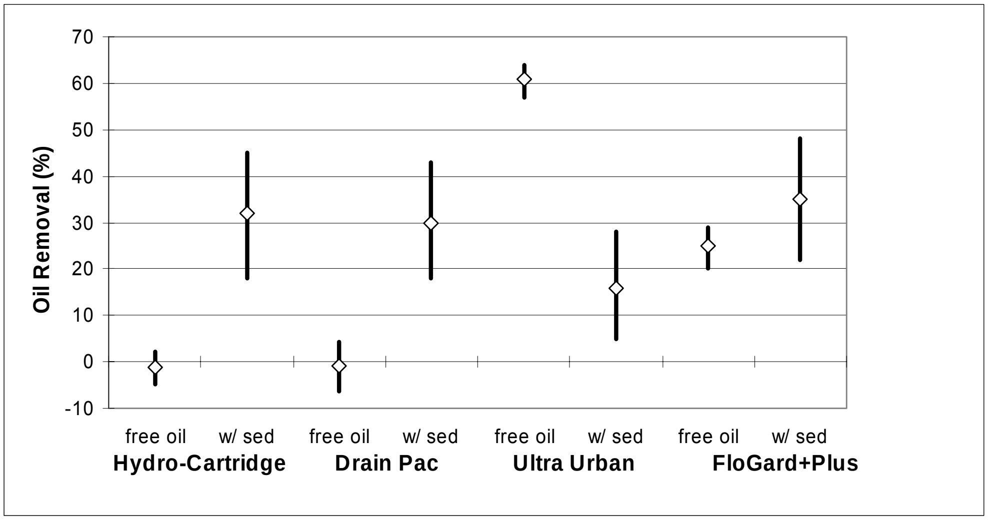


Figure 27. Comparison of Mean Oil Removal Rates and Confidence Intervals for the Continuous Dose and Continuous Dose Plus Sediment Experiments.

Explaining why filter performance changes is complicated by the complex and generally unknown partitioning of oil between the liquid and solid phases, as well as the sediment removal characteristics of the different filters. The results from the continuous dose plus sediment experiment are plotted in Figure 28 and Figure 29. As before, the measured influent concentration from each daily composite sample is plotted against the corresponding effluent value. The solid diagonal line denotes “no treatment”. As described previously, enough oil to produce 15 mg/L in the influent was pre-mixed with the dry sediment. In addition, about 5 mg/L of free oil was directly injected into the inflow. Although the actual phase partitioning of the oil in the influent is not known, assuming that about 5 mg/L is dissolved is useful in trying to interpret the graphs in Figure 28 and Figure 29. Influent oil concentrations vary from about 5 mg/L to over 45 mg/L. Concentrations higher than about 20 mg/L represent samples with relatively high TSS concentrations. In these cases, the oil associated with the particles constitutes the majority of the measured oil concentration. At the other end of the scale, in samples with low influent concentrations, a substantial fraction of the oil is dissolved due to the 5 mg/L of injected free oil.

To fully interpret Figure 28 and Figure 29, the sediment capture efficiencies of the various filters are needed. Reported in Table 11 are sediment capture efficiencies calculated by two methods. The mass balance method was described earlier in this section. The TSS method is simply the average removal based on the TSS concentrations of influent and effluent samples. The discrepancies between the two sets of results are addressed in the Discussion section later in this report. The mass balance results are considered to be more accurate. Based on the mass balance results, the Hydro-Cartridge^{TM} and Drain Pac^{TM} filters were the most effective at capturing solids and the Ultra Urban^{TM} filter was the least effective. Sediment settled and accumulated in the Hydro-Cartridge^{TM} central chamber. The filter liner of the Drain Pac^{TM} was a relatively effective screen, acting like a geotextile. Because its liner is more porous, the FloGard+Plus^{TM} was not as effective as the Drain Pac^{TM}. Finally, the large pore sizes in the Ultra Urban^{TM} media beds let small particles through relatively readily.

Table 11. Sediment Removal (%)

Filter	Removal based on mass balance[a]	Removal based on TSS data
FloGard+Plus™	24%	-5%
Hydro-Cartridge™	36%	5%
Drain Pac™	39%	19%
Ultra Urban™	11%	1%

(a)Influent mass estimated from influent TSS measurements and the volume of water applied to each filter.

With this information, some explanations for the filter behaviors exhibited in Figure 28 can be attempted. At high influent concentrations, where most of the oil is in the solid phase, the Hydro-Cartridge™ is fairly effective because of its ability to remove the particles. At low concentrations, though, where a substantial fraction of the oil is dissolved, Hydro-Cartridge™ performance falls off dramatically because it is not effective at removing free oil as demonstrated in the continuous dose experiment. Drain Pac™ performance is similar to that of Hydro-Cartridge™ and for the same reasons. At high concentrations, where most of the oil is in the solid phase, the Ultra Urban™ filter is not very effective because it doesn't remove small particles efficiently. Based on its effectiveness at removing free oil in the continuous dose experiment, the Ultra Urban™ filter might be expected to be more efficient at the low influent concentrations than what is shown in Figure 29. Here, the escape of oil-bearing particles may be hurting overall removal efficiency. Finally, the FloGard+Plus™ filter is moderately effective at high influent concentrations because it captures sediment and also at low concentrations because it contains a reasonable amount of adsorptive media. Nevertheless, it must be emphasized that these explanations are speculative. Additional testing and the collection of additional types of data, such as particle size distributions and measurements of oil partitioning, are needed to confirm these ideas.

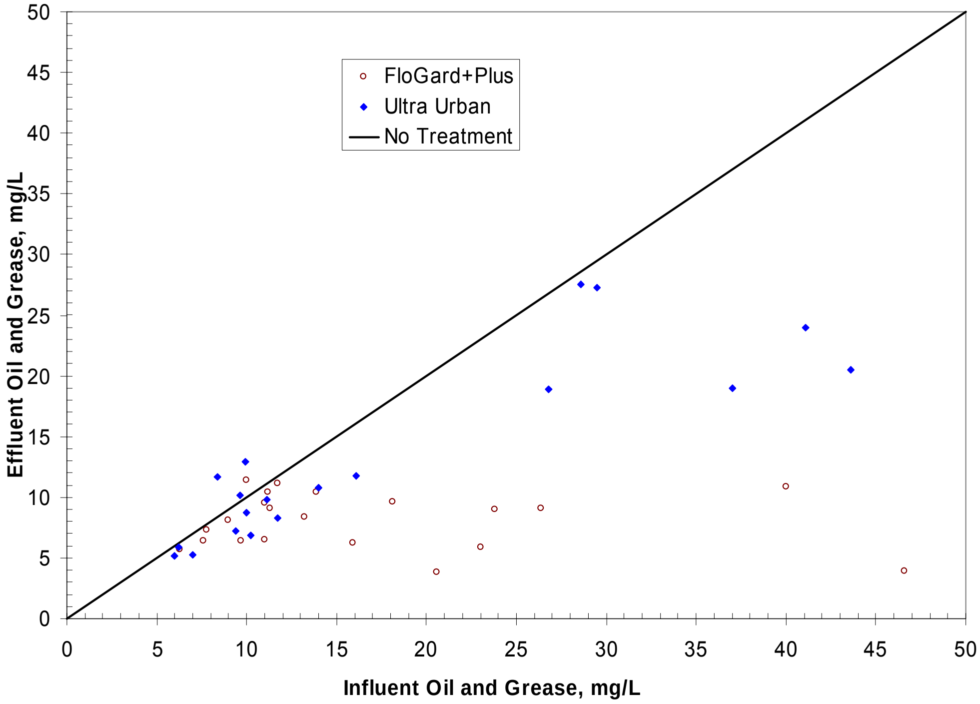


Figure 28. Influent Oil and Grease for FloGard+Plus™ and Ultra Urban™ (with Sediment).

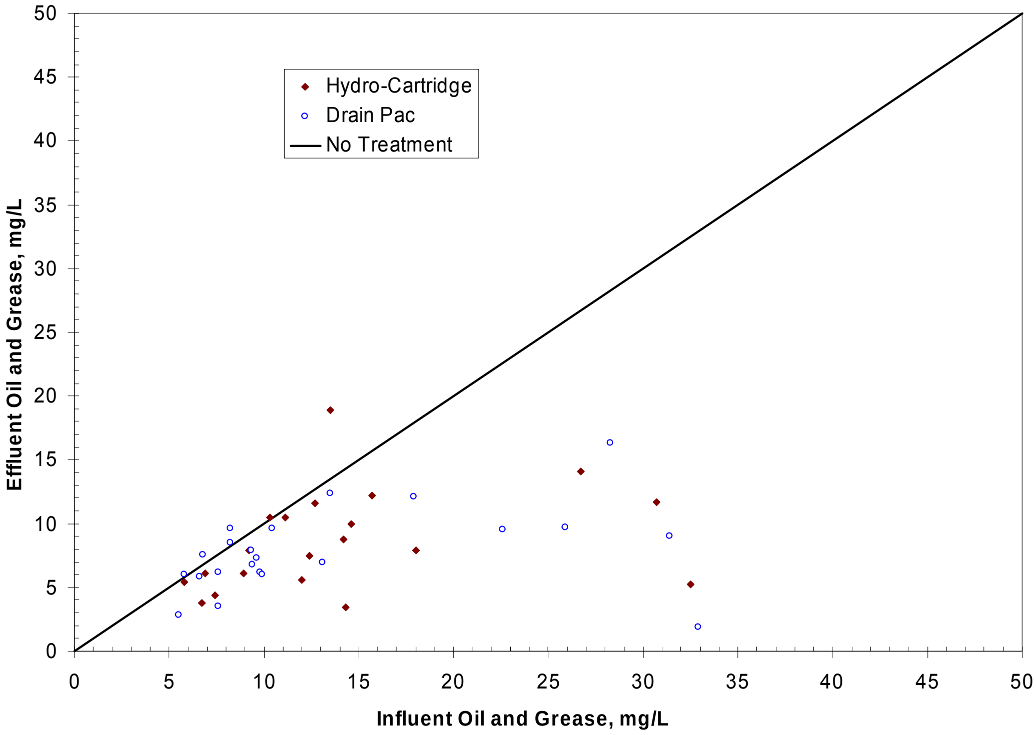


Figure 29. Influent Oil and Grease for Hydro-Cartridge™ and Drain Pac™ (with Sediment).

Discussion

The discussion of the project results will be divided into three areas: test procedures, role of adsorptive media, and sediment-related effects.

Test Procedures

The creation of standard test procedures was mostly successful. One problem that remains unresolved is the differences between the sediment capture estimated from TSS measurements and that estimated by the mass balance method. This difference is suspected to be caused by problems with equipment and sampling procedures.

Because of inadequate mixing, the dosing system may have may have delivered higher solids concentrations at the beginning of each run, prior to the TSS sample taken at the end (Runs 1 to 9) or midpoint (Runs 10 to 15). As described earlier, a circulation pump was used to assist the paddle mixer in mixing the slurry. The pump take-off was at the bottom of the slurry tank, as shown in Figure 30. The take-off for the peristaltic pump dosing the filter influent was on the circulation pump discharge piping. Larger and heavier particles are thought to have settled to the bottom of the tank at the beginning of each run, which would have increased the initial sediment concentration being dosed to the filters. These large particles dosed at the beginning of each run were effectively removed by the drain inlet filters. These are the solids that were measured in the mass balance. When the TSS water samples were collected either midway or at the end of each run, the majority of the particles in the flow were small and not easily removed by the filters. This is why little apparent removal was observed from the TSS data. Unfortunately, TSS samples were never collected at the beginning of a run, so this conjecture cannot be directly verified. Indirect evidence comes from oil data which showed higher concentrations at the beginning of runs than at midpoints or ends. Because oil is attached to particles, higher oil concentrations suggest higher numbers of particles.

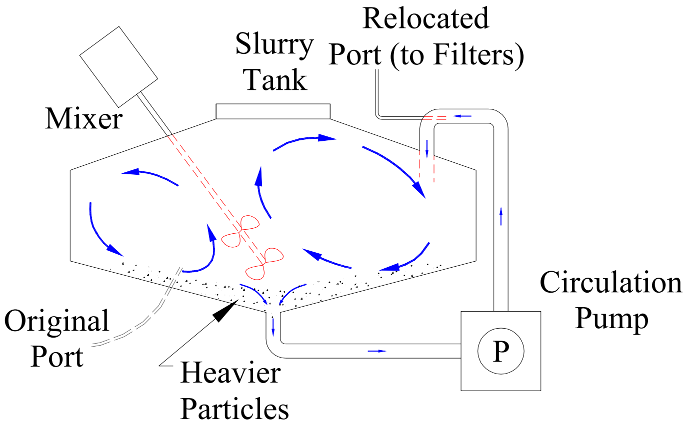


Figure 30. Slurry Tank for Continuous Dose Plus Sediment Experiment.

While the TSS sampling methodology underestimated removal efficiencies, the mass balance methodology may have overestimated them. There are uncertainties in the measured masses of the oil/sediment mixtures taken from the filters at the end of the experiment. After air drying, oily coatings on the porous silica particles probably trapped some water within. Oven drying was started but had to be stopped when adsorbed oil started to volatilize (as evidenced by odors in the lab). Consequently, the mass of material removed by the filters contains an unknown fraction of water and oil. A partial correction was made by assuming that the oil/solids ratio was the same as that in the original mixture and subtracting the mass of oil. Whether or not this assumption is correct, the water content of the mixture was still unknown. It should be noted that the uncertainties in the TSS measurements also affect the mass balance methodology. In determining the percentage removed in the mass balance, the influent sediment mass was calculated from the TSS measurements and the applied volumes of water.

Role of Adsorptive Media

Clearly, adsorptive media is an essential component of the oil removal process in these devices. In the continuous dose experiment, the success of the various filters at removing free oil was generally directly proportional to the amount of media contacting the simulated stormwater. The Ultra Urban^{TM} filter contained the most media and achieved the highest removal rate (61 percent removal). The Hydro-Cartridge^{TM} and Drain Pac^{TM} filters contained no media and achieved essentially no oil removal. The FloGard+Plus^{TM}, which contained some media, but less than the Ultra Urban^{TM}, performed accordingly (25 percent removal). Similar performances were observed in the spike dose test, with the Ultra Urban^{TM} filter showing better long term retention than the FloGard+Plus^{TM} filter, which retained more oil than the Drain Pac^{TM} filter. In the short term, the Hydro-Cartridge^{TM} filter retained virtually the entire spike dose. As a spill control device, this design worked better than the others. Once water started to flow, however, most of the captured oil was washed out. In contrast, oil that was adsorbed onto media in the various filters did not readily wash off. This was apparent in both the spike dose experiment and the clean water flush test at the end of the continuous dose experiment. The data collected in this experiment do not allow a judgment on the relative merits of the different adsorptive media used in the various filters.

Sediment-Related Effects

The presence of sediment greatly changes the treatment dynamics in these devices. Filters which showed no removal of free oil (Hydro-Cartridge^{TM} and Drain Pac^{TM}) removed almost one third of the applied oil in the presence of sediment. Another filter which was fairly successful at removing free oil (Ultra Urban^{TM}) was only one quarter as efficient when sediment was added to the inflow. When most of the oil is attached to suspended particles, oil removal efficiencies generally tracked with mass balance estimates of sediment capture. A close correlation wasn't observed in this project, however, for two reasons. First, experimental difficulties introduced uncertainty into the sediment capture efficiency data. Second, and more importantly, the simulated stormwater contained an unknown mixture of particle-bound and free oil. So successful treatment depended on both the ability to capture and retain particles plus the ability to adsorb free oil. Maximizing oil removal, then, requires maximizing both removal processes. For instance, a Hydro-Cartridge^{TM} insert placed in series with an Ultra Urban^{TM} filter would likely remove more oil than either alone. Such an arrangement, however, would not fit into a typical storm drain.

Finally, it must be noted that the removal efficiencies measured in this project may not, in fact are likely not, the values that would be observed in a field installation. One confounding factor is the highly variable composition of real stormwater. Fugitive oil is not uniformly distributed in the environment. So while one storm drain may receive a relatively high oil concentration because of a leaking car upstream, another drain nearby may receive almost no oil. Similarly, the numbers, sizes, and compositions of particles in stormwater depend on several site-specific factors such as local land use, rainfall intensity, and the time since the last storm. Particle surface area (determines by size and number) and composition affect how much oil binds to the solid phase. A legitimate question to ask is how well the Sil-Co-Sil 106 emulates real stormwater particles. Because the continuous dose plus sediment experiment was added to the project well into the contract period, there wasn't time evaluate this issue. This would be a good subject for future research. Nevertheless, the experiments performed here used flows, operating schedules, and oil and sediment concentrations that are close enough to reality that the results can be considered typical.

Conclusion

To attempt to remove any dissolved materials from a complex matrix like stormwater in a device that fits into a storm drain and operates without power or operator attention for a year at a time is a daunting task. So it shouldn’t be surprising that the drain inlet filters tested in this project were less than 100 percent successful. Oil removals measured in these experiments ranged from 0 to 61 percent in sediment-free water and 16 to 35 percent in simulated stormwater with sediment. Likewise, the filters were only partially successful at retaining a simulated illegal oil discharge. Oil retention rates varied from 5 to 56 percent of a 4-liter spike dose. The Hydro-Cartridge^{TM} device initially retained the entire spike dose, but subsequent water flows flushed out three quarters of the captured oil. Given the difficulty of this treatment task, the fact that these devices were even partially successful is commendable. Based on the results of this project, however, drain inlet filters offer aquatic ecosystems only limited protection from used oil pollution.

Abbreviations and Acronyms

AADT - average annual daily traffic

CIWMB - California Integrated Waste Management Board

CLS - California Laboratory Services

CSUS - California State University, Sacramento

CWF - Clean Water Flush

DIF - drain inlet filter

EPA - Environmental Protection Agency

FHWA - Federal Highway Association

g - gram

gpm - gallons per minute

HCL - hydrochloric acid

in - inch

L/min - liters per minute

m - meter

mg/L - milligram per liter

ml - milliliter

OWP - Office of Water Programs

TPH - Total Petroleum Hydrocarbon

TSS - Total suspended solids

Glossary of Terms

adsorption: the accumulation of a dissolved or suspended substance onto the surface of a solid adsorbent.

agglomerated: the combination of particles to form a larger particle.

aliquot: a single portion: as in the individual parts that make up a composite sample.

composite sample: a sample made of more than one aliquot taken at different times during a test run.

concentration: the mass of a constituent per a given volume of water.

effluent: flow of water exiting the filters.

free oil: Oil not attached to solids.

influent: entering; going into (the filter).

media: material that removes pollutants by either physical or chemical properties (filter).

stormwater: intermittent runoff caused exclusively by precipitation.

synthetic: created; not naturally observed.

Appendix A: Calculations

This appendix contains the calculations for the three experiments. The calculations are for spike dose efficiencies and the continuous dose efficiencies for both the free oil experiment and the oil plus sediment experiment. Statistical calculations are also presented.

Spike Dose Calculations

This section presents two techniques used to calculate the oil flushed by each filter for the spike dose scenario. The results using each method are presented for each filter in later sections. The techniques, numerical and graphical, are described below.

The numerical technique uses the actual data points to calculate the mass of oil flushed by calculating the mass flushed between each data point. Concentration is assumed to be constant between data points. The first data point is the concentration from time zero through the collection of that data point and half way to the next data point (Figure 31). The second data point represents the concentration between the first and second sample, and so on until the final data point. The mass flushed is calculated by multiplying concentration by the interval of time and flow rate between samples. The results of the numerical technique are shown in Table 12, Table 14, Table 16, and Table 18.

A graphical technique uses a hand drawn curve through effluent concentration values. Hand drawn curves were used because best fit polynomials and exponential curves did not match the data set well. The area under the spike dose flush curve represents the total mass flushed through a filter. The graphical technique uses the curve to extrapolate between actual data points. The curve is divided into sections based on the shape of the curve. For each section a concentration is selected from the curve. The point on the curve was selected so that the underestimated portion of the section was approximately equal to the overestimated portion of the section (Figure 31). Points are then used to calculate the mass of oil flushed by using the equation $M=C*Q*\Delta t$ (mass $_{\text{flushed}}$) = (concentration $_{\text{from curve}}$)*(volume $_{\text{flushed}}$) for each segment of the curve. The results of the graphical technique are shown in Figure 32, Figure 33, Figure 34, Figure 35, Table 13, Table 15, Table 17 and, Table 19.

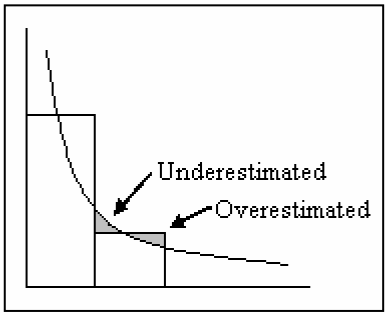


Figure 31. Representation of Overestimating and Underestimating.

The two techniques of calculating the amount of oil flushed result in similar numbers, as shown in the following sections.

FloGard+Plus™

For the numerical technique without using extrapolation, 4 data points were used. Table 12 shows the volumes at which the samples were taken, the results of the analyses, and the calculation of the mass flushed based on these data points. The percent of mass retained decreased from 28 to 27 percent according to the numerical method (Table 12).

Table 12. Spike Dose Retention by Numerical Technique for FloGard+Plus™

Volume at time of sample (Liters)	Sample concentrations (mg/L)	Interval (Liters)	Interval load (grams)	Drip+ flushed (grams)	Mass retained (grams)	Percent Retained
0	0		0.00	2534	985	28%
95	90.30	0-284	25.65	2560	959	27%
473	2.20	285-709	0.94	2560	959	27%
945	1.50	710-1418	1.06	2562	957	27%
1890	0.90	1419-2363	0.85	2562	957	27%

For the graphical technique, the data points shown in Table 13 were used for the hand-drawn curve that approximates the change in concentration during flushing (Figure 32). The first three intervals were selected to minimize over and under estimating based on the hand-drawn curve. The remaining intervals were the same as ones used in the numerical technique. The percent of mass retained decreased from 28 to 27 percent according to the graphical method (Table 13). As shown in Table 13, the percent of oil retained calculated by this method is the same as that calculated by the numerical method.

Table 13. Spike Dose Retention by Graphical Technique for FloGard+Plus™

Volume at time of sample (Liters)	Sample concentrations (mg/L)	Interval (Liters)	Graphical method curve fit concentration (mg/L)		Interval load (grams)	Drip+ flushed (grams)	Mass retained (grams)	Percent Retained
0	0		0		0.00	2534	985	28%
95	90.30	0-200	90.3		18.06	2552	967	27%
260		201-320	10	*	1.20	2553	966	27%
473	2.20	321-709	2.2		0.86	2554	965	27%
945	1.50	710-1418	1.50		1.06	2555	964	27%
1890	0.90	1419-2363	0.90		0.85	2556	963	27%

*-denotes a concentration extrapolated using the curve in Figure 30.

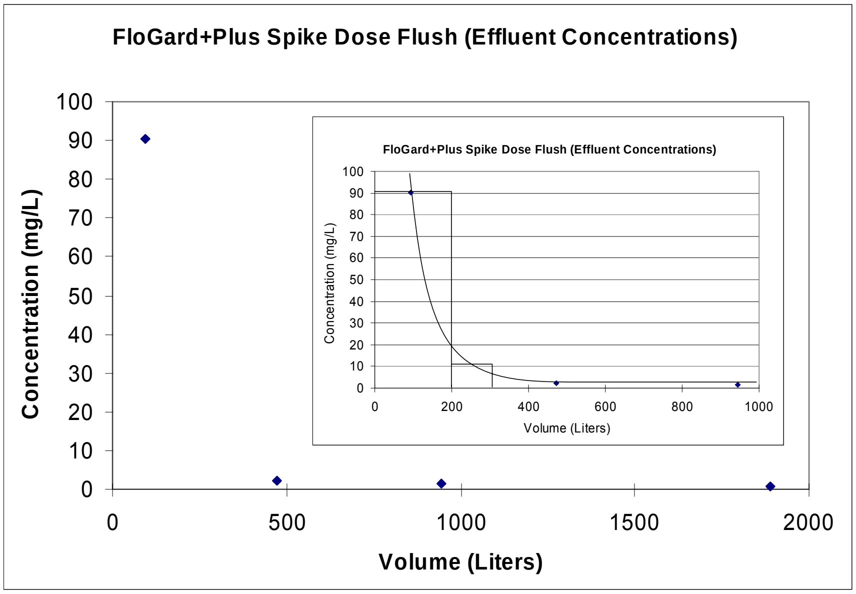


Figure 32. FloGard+Plus^{TM} Spike Dose Flush Results.

Hydro-Cartridge^{TM}

For the numerical technique without using extrapolation, 13 data points were used. Table 14 shows the volumes at which the samples were taken, the results of the analyses, and the calculation of the mass flushed based on these data points. The percent of mass retained decreased from 100 to 19 percent according to the numerical method (Table 14).

Table 14. Spike Dose Retention by Numerical Technique for Hydro-Cartridge^{TM}

Volume at time of sample (Liters)	Sample concentrations (mg/L)	Interval (Liters)	Interval load (grams)	Drip+ flushed (grams)	Mass retained (grams)	Percent Retained
0	0		0.00	0.00	3520	100%
19	12029.90	0-57	685.70	685	2834	80%
95	11100.50	58-142	944.10	1629	1890	53%
189	1357.20	143-331	256.51	1886	1633	46%
473	632.80	332-507	111.23	1997	1522	43%
541	290.10	508-805	86.63	2084	1435	40%
1070	354.30	806-1514	251.11	2335	1184	33%
1958	134.00	1515-2019	67.62	2402	1117	31%
2079	136.20	2020-2930	124.08	2526	993	28%
3780	59.80	2931-3827	53.69	2580	939	26%
3875	70.20	3828-5717	132.68	2713	806	22%
7560	25.50	5718-7605	48.15	2761	758	21%
7651	12.80	7606-11574	50.80	2812	707	20%
15498	2.40	11575-19422	18.83	2831	688	19%

For the graphical technique, the data points shown in Table 15 were used for the hand-drawn curve that approximates the change in concentration during flushing (Figure 33). The first three intervals were selected to minimize over and under estimating based on the hand drawn curve. The remaining intervals were the same as ones used in the numerical technique. Using this method, the estimate of mass retained (25% in Table 15) was somewhat higher than the estimate resulting from the numerical method.

Table 15. Spike Dose Retention by Graphical Technique for Hydro-Cartridge™

Volume at time of sample (Liters)	Sample concentrations (mg/L)	Interval (Liters)	Graphical method curve fit concentration (mg/L)		Interval load (grams)	Drip+ flushed (grams)	Mass retained (grams)	Percent Retained
0	0		0		0.00	0	3520	100%
19	12029.90							
75		0-150	9000	*	1350.00	1350	2170	61%
95	11100.50							
189	1357.20							
225		151-300	2000	*	300.00	1650	1870	53%
473	632.80	301-507			130.69	1780	1739	49%
541	290.10	508-805			86.63	1867	1652	46%
1070	354.30	806-1514			251.11	2118	1401	39%
1958	134.00	1515-2019			67.62	2186	1333	37%
2079	136.20	2020-2930			124.08	2310	1209	34%
3780	59.80	2931-3827			53.69	2363	1156	32%
3875	70.20	3828-5717			132.68	2496	1023	29%
7560	25.50	5718-7605			48.15	2544	975	27%
7651	12.80	7606-11574			50.80	2595	924	26%
15498	2.40	11575-19422			18.83	2614	905	25%

*- denotes a concentration extrapolated using the curve in Figure 31.

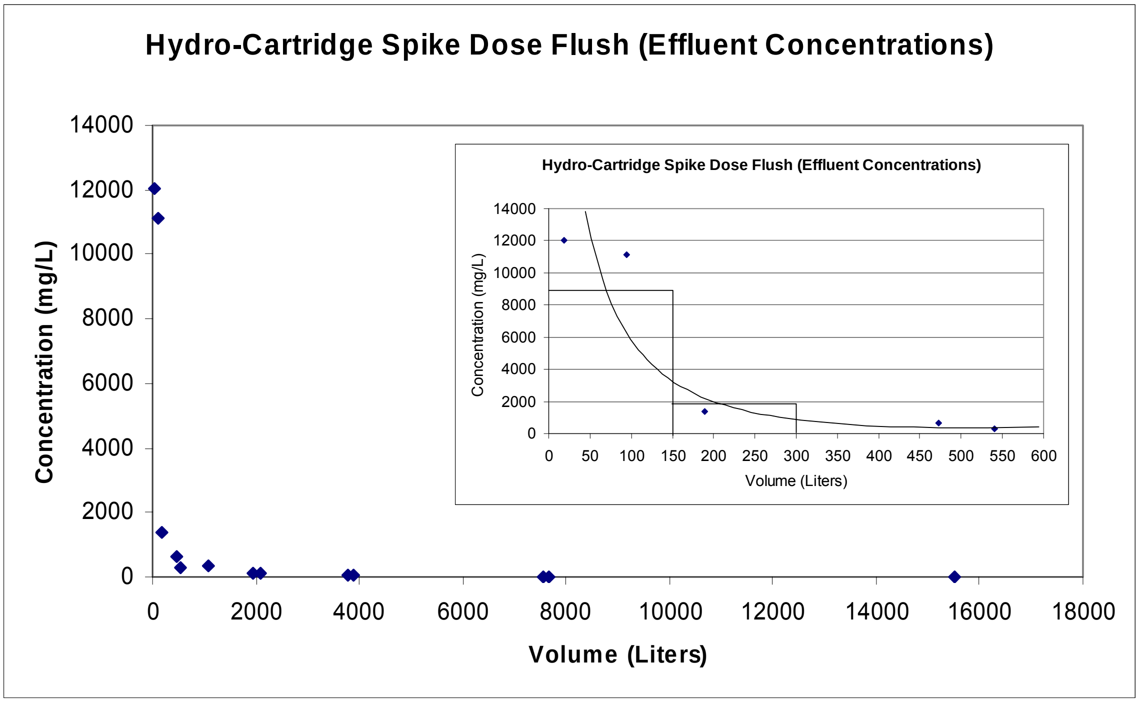


Figure 33. Hydro-Cartridge™ Spike Dose Flush Results.

Ultra Urban^{TM}

For the numerical technique without using extrapolation, 5 data points were used. Table 16 shows the volumes at which the samples were taken, the results of the analyses, and the calculation of the mass flushed based on these data points. The percent of mass retained decreased from 56 to 55 percent according to the numerical method (Table 16).

Table 16. Spike Dose Retention by Numerical Technique for Ultra Urban^{TM}

Volume at time of sample (Liters)	Sample concentrations (mg/L)	Interval (Liters)	Interval load (grams)	Drip+ flushed (grams)	Mass retained (grams)	Percent Retained
0	0		0.00	1540	1980	56%
95	15.30	0-161	2.46	1542	1977	56%
227	6.80	162-446	1.94	1544	1975	56%
665	7.70	447-684	1.83	1546	1973	56%
703	6.20	685-919	1.45	1547	1972	56%
1134	4.70	920-1350	2.03	1549	1970	55%

For the graphical technique, the data points shown in Table 17 were used for the hand-drawn curve that approximates the change in concentration during flushing (Figure 34). The first three intervals were selected to minimize over and under estimating based on the hand drawn curve. The remaining intervals were the same as ones used in the numerical technique. As shown in Table 17, the percent of oil retained calculated by this method is the same as that calculated by the numerical method.

Table 17. Spike Dose Retention by Graphical Technique for Ultra Urban^{TM}

Volume at time of sample (Liters)	Sample concentrations (mg/L)	Interval (Liters)	Graphical method curve fit concentration (mg/L)		Interval load (grams)	Drip+ flushed (grams)	Mass retained (grams)	Percent Retained
0	0		0.00		0.00	1540	1980	56%
95	15.30	0-200	15.30		3.06	1543	1976	56%
227	6.80							
300		201-400	9.00	*	1.80	1544	1975	56%
500		401-600	7.00	*	1.40	1546	1971	56%
665	7.70							
703	6.20							
900		601-1200	6.20	*	3.72	1549	1967	55%
1134	4.70							

*- denotes a concentration extrapolated using the curve in Figure 32.

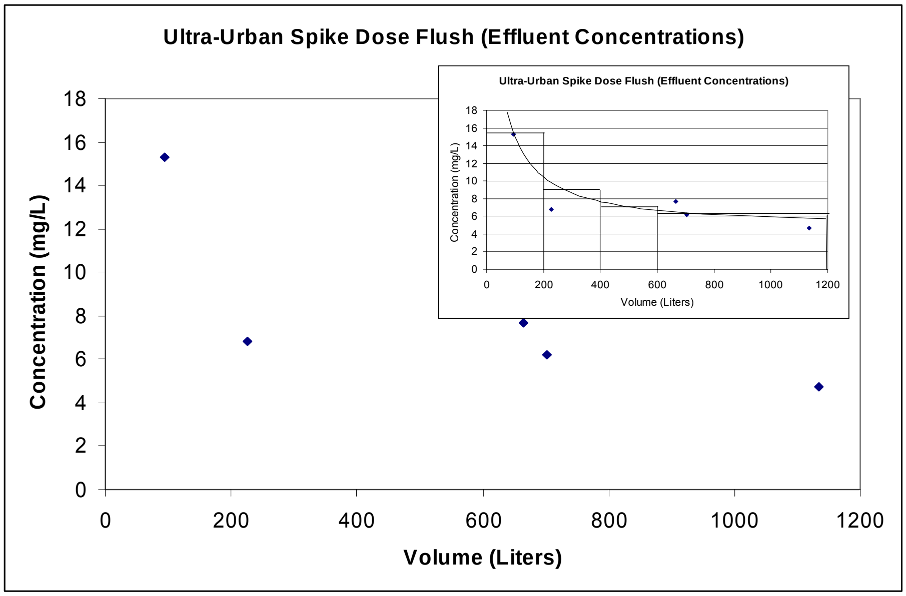


Figure 34. Ultra Urban™ Spike Dose Flush Results

Drain Pac™

For the numerical technique without using extrapolation, 7 data points were used. Table 18 shows the volumes at which the samples were taken, the results of the analyses, and the calculation of the mass flushed based on these data points. The percent of mass retained decreased from 8 to 4 percent according to the numerical method (Table 18).

Table 18. Spike Dose Retention by Numerical Technique for Drain Pac™

Volume at time of sample (Liters)	Sample concentrations (mg/L)	Interval (Liters)	Interval load (grams)	Drip+ flushed (grams)	Mass retained (grams)	Percent Retained
0	0		0	3238	282	8%
19	1610.80	0-57	91.81	3330	190	5%
95	50.10	58-198	7.10	3337	183	5%
302	28.40	199-387	5.36	3342	177	5%
473	17.50	388-765	6.61	3349	171	4%
1058	9.70	766-1087	3.11	3352	167	4%
1115	11.10	1088-1503	4.61	3357	163	4%
1890	6.60	1504-2277	5.11	3362	158	4%

For the graphical technique, the data points shown in Table 19 were used for the hand-drawn curve that approximates the change in concentration during flushing (Figure 35). The first three intervals were selected to minimize over and under estimating based on the hand drawn curve. The remaining intervals were the same as ones used in the numerical technique. As shown in Table 19, the percent of oil retained calculated by this method is the same as that calculated by the numerical method.

Table 19. Spike Dose Retention by Graphical Technique for Drain Pac™

Volume at time of sample (Liters)	Sample concentrations (mg/L)	Interval (Liters)	Graphical method curve fit concentration (mg/L)		Interval load (grams)	Drip+ flushed (grams)	Mass retained (grams)	Percent Retained
0	0		0		0	3238	282	8%
19	1610.80	0-40	1610.8		64.43	3302	217	6%
60		41-80	400	*	16	3318	201	5%
95	50.10	81-198	50.1		5.93	3324	195	5%
302	28.40	199-387	28.40		5.36	3330	190	5%
473	17.50	388-765	17.50		6.61	3336	183	5%
1058	9.70	766-1087	9.70		3.11	3339	180	5%
1115	11.10	1088-1503	11.10		4.61	3344	175	4%
1890	6.60	1504-2277	6.60		5.11	3349	170	4%

*- denotes a concentration extrapolated using the curve in Figure 33.

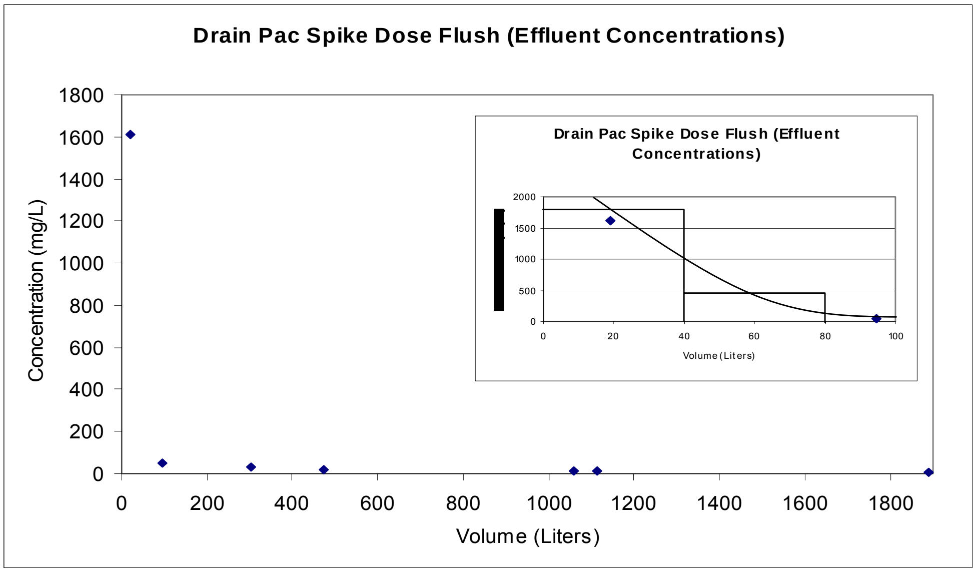


Figure 35. Drain Pac^{TM} Spike Dose Flush Results.

Comparison of Methods

The two calculation methods yield the same results except for the case of Hydro-Cartridge^{TM} in which the difference was 6 percentage points (25% for the graphical technique versus 19% for the numerical technique).

Continuous Dose Calculations

This section presents efficiency calculations for both continuous dose experiments. Efficiency calculations are presented for oil and sediment removal. Removal for each pair of influent and effluent data is expressed as a ratio of effluent over influent concentration. Removal efficiency is one minus this ratio as shown in the following equation:

$$\text{Percent removed} = \left(1 - \frac{Ceff}{C\,\text{inf}}\right) * 100$$

where:

C_{eff} is the effluent concentration and
C_{inf} is the influent concentration.

Continuous Dose

The oil concentrations from the continuous dose of free oil data is presented in Table 20 and Table 21. The average removal efficiency is shown on the bottom Table 20 and Table 21.

Table 20. Oil and Grease Efficiency Calculations for the Continuous Dose Experiments for FloGard+Plus^{TM} and Hydro-Cartridge^{TM}

		FloGard+Plus^{TM}			Hydro-Cartridge^{TM}		
run #	**Volume , m^3**	**influent**	**effluent**	**removal**	**influent**	**effluent**	**removal**
1	23	17.1	11.6	**32%**	15.7	16.1	**-3%**
2	45	15.1	9.6	**36%**	17.2	19.4	**-13%**
3	68	14.8	12.2	**18%**	15.0	15.5	**-3%**
4	91	14.1	11.0	**22%**	18.5	16.2	**12%**
5	113	18.9	13.9	**26%**	19.6	18.5	**6%**
6	136	17.2	10.1	**41%**	19.7	18.9	**4%**
7	159	19.5	11.5	**41%**	15.7	16.0	**-2%**
8	181	15.6	13.2	**15%**	15.2	18.1	**-19%**
9	204	15.2	12.1	**20%**	15.2	15.2	**0%**
10	227	15.8	13.0	**18%**	15.3	15.9	**-4%**
11	249	16.0	12.7	**21%**	15.6	16.2	**-4%**
12	272	16.6	14.8	**11%**	14.5	16.8	**-16%**
13	295	12.9	11.7	**9%**	14.9	13.9	**7%**
14	318	16.3	14.0	**14%**	17.3	15.6	**10%**
15	340	14.3	10.6	**26%**	15.6	15.7	**-1%**
16	363	16.2	12.0	**26%**	15.4	15.6	**-1%**
17	386	14.7	12.2	**17%**	15.4	15.4	**0%**
18	408	17.4	10.8	**38%**	16.2	15.8	**2%**
19	431	15.4	10.9	**29%**	16.1	16.3	**-1%**
20	454	15.9	10.8	**32%**	15.4	15.5	**-1%**
				25%			**-1%**

Table 21. Oil and Grease Efficiency Calculations for the Continuous Dose Experiments for Ultra Urban™ and Drain Pac™

		Ultra Urban™			Drain Pac™		
run #	**Volume, m^3**	**influent**	**effluent**	**removal**	**influent**	**effluent**	**removal**
1	23	16.0	5.4	**66%**	14.5	16.4	**-13%**
2	45	15.7	5.2	**67%**	15.0	18.2	**-21%**
3	68	14.3	5.3	**63%**	15.4	17.6	**-14%**
4	91	16.8	5.9	**65%**	16.3	17.9	**-10%**
5	113	19.9	9.5	**52%**	17.3	18.3	**-6%**
6	136	18.8	6.1	**68%**	18.3	20.1	**-10%**
7	159	15.2	5.8	**62%**	14.6	13.6	**7%**
8	181	16.1	8.0	**50%**	15.2	13.8	**9%**
9	204	14.3	7.1	**50%**	14.8	13.4	**9%**
10	227	14.7	6.9	**53%**	15.1	13.6	**10%**
11	249	15.7	7.4	**53%**	15.9	13.3	**16%**
12	272	16.1	7.8	**52%**	16.8	13.9	**17%**
13	295	12.9	6.0	**53%**	13.8	14.0	**-1%**
14	318	15.5	6.8	**56%**	15.8	16.3	**-3%**
15	340	15.8	7.0	**56%**	15.6	15.3	**2%**
16	363	16.5	5.7	**65%**	19.7	18.5	**6%**
17	386	15.2	5.5	**64%**	18.6	16.2	**13%**
18	408	15.7	5.0	**68%**	15.0	17.6	**-17%**
19	431	14.9	3.9	**74%**	15.4	16.9	**-10%**
20	454	16.1	4.3	**73%**	16.2	16.8	**-4%**
				61%			-1%

Statistical Analysis

For each run, the percent of oil removed was calculated from:

$$\text{Percent removed} = \left(1 - \frac{Ceff}{C\,\mathrm{inf}}\right) * 100$$

where C_{eff} is the effluent concentration and C_{inf} is the influent concentration. The Shapiro-Wilk test was then applied to the data to test the null hypothesis that the data are samples randomly drawn from a normally distributed population(17). Based on the test results, the null hypothesis was accepted in all cases, meaning the removal data were normally distributed. Then mean values and their 95% confidence intervals based on the t-distribution were calculated. Printouts from the spreadsheets written for these calculations are shown in Tables 23 to 26.

Table 22. Statistic Calculations for Normality (Shapiro-Wilk) and Confidence Limits for the Continuous Dose Experiment for Hydro-Cartridge™.

Hydro-Cartridge							
Ordered data	**Reverse ordered data**	**Difference**	**a values**	**bi**			
-19%	12%	0.315114	0.4734	0.149175		**n**	**20**
-16%	10%	0.256887	0.3211	0.082486		stdev	0.077837
-13%	7%	0.195021	0.2565	0.050023		sum bi	0.326934
-4%	6%	0.095338	0.2085	0.019878			
-4%	4%	0.079071	0.1686	0.013331		W	0.928529
-3%	2%	0.058025	0.1334	0.00774		W0.05	0.905
-3%	0%	0.025478	0.1013	0.002581		W0.01	0.868
-2%	0%	0.019108	0.0711	0.001359		Result:	Normal
-1%	-1%	0.006577	0.0422	0.000278			
-1%	-1%	0.005929	0.014	8.3E-05		Mean	-0.01
-1%	-1%						
-1%	-1%			Confidence interval based on t distribution			
0%	-2%					$t_{0.05,19}$	2.09
0%	-3%						
2%	-3%				-0.04938	$< u_x <$	0.023371
4%	-4%				Is zero in the interval?		Yes
6%	-4%						
7%	-13%						
10%	-16%						
12%	-19%						

Table 23. Statistic Calculations for Normality (Shapiro-Wilk) and Confidence Limits for the Continuous Dose Experiment for FloGard+Plus^{TM}.

FloGard+Plus							
Ordered data	Reverse ordered data	Difference	a values	bi			
9%	41%	0.319767	0.4734	0.151378		**n**	**20**
11%	41%	0.301823	0.3211	0.096915		stdev	0.097863
14%	38%	0.238206	0.2565	0.0611		sum bi	0.416907
15%	36%	0.210392	0.2085	0.043867			
17%	32%	0.151569	0.1686	0.025555		W	0.955189
18%	32%	0.145079	0.1334	0.019354		W0.05	0.905
18%	29%	0.114993	0.1013	0.011649		W0.01	0.868
20%	26%	0.060603	0.0711	0.004309		Result:	Normal
21%	26%	0.053009	0.0422	0.002237			
22%	26%	0.038883	0.014	0.000544		Mean	0.25
26%	22%						
26%	21%			Confidence interval based on t distribution			
26%	20%					$t_{0.05,19}$	2.09
29%	18%						
32%	18%				0.200923	$< u_x <$	0.292393
32%	17%				Is zero in the interval?		No
36%	15%						
38%	14%						
41%	11%						
41%	9%						

Table 24. Statistic Calculations for Normality (Shapiro-Wilk) and Confidence Limits for the Continuous Dose Experiment for Ultra Urban^{TM}.

Ultra Urban							
Ordered data	**Reverse ordered data**	**Difference**	**a values**	**bi**			
50%	74%	0.235149	0.4734	0.11132		**n**	**20**
50%	73%	0.229423	0.3211	0.073668		stdev	0.077645
52%	68%	0.166001	0.2565	0.042579		sum bi	0.322719
52%	68%	0.152919	0.2085	0.031884			
53%	67%	0.140127	0.1686	0.023625		W	0.909215
53%	66%	0.131888	0.1334	0.017594		W0.05	0.905
53%	65%	0.119662	0.1013	0.012122		W0.01	0.868
56%	65%	0.091847	0.0711	0.00653		Result:	Normal
56%	64%	0.076868	0.0422	0.003244			
62%	63%	0.01095	0.014	0.000153		Mean	0.61
63%	62%						
64%	56%			Confidence interval based on t distribution			
65%	56%					$t_{0.05,19}$	2.09
65%	53%						
66%	53%				0.569013	$< u_x <$	0.641586
67%	53%				Is zero in the interval?		No
68%	52%						
68%	52%						
73%	50%						
74%	50%						

Table 25. Statistic Calculations for Normality (Shapiro-Wilk) and Confidence Limits for the Continuous Dose Experiment for Drain Pac^{TM}.

Drain Pac							
Ordered data	**Reverse ordered data**	**Difference**	**a values**	**bi**			
-21%	17%	0.385952	0.4734	0.18271		**n**	**20**
-17%	16%	0.336855	0.3211	0.108164		stdev	0.115895
-14%	13%	0.271889	0.2565	0.06974		sum bi	0.494421
-13%	10%	0.230372	0.2085	0.048033			
-10%	9%	0.192955	0.1686	0.032532		W	0.957884
-10%	9%	0.190265	0.1334	0.025381		W0.05	0.905
-10%	7%	0.165896	0.1013	0.016805		W0.01	0.868
-6%	6%	0.118717	0.0711	0.008441		Result:	Normal
-4%	2%	0.056268	0.0422	0.002375			
-3%	-1%	0.017153	0.014	0.00024		Mean	-0.01
-1%	-3%						
2%	-4%			Confidence interval based on t distribution			
6%	-6%					$t_{0.05,19}$	2.09
7%	-10%						
9%	-10%				-0.06394	$< u_x <$	0.044381
9%	-10%				Is zero in the interval?		Yes
10%	-13%						
13%	-14%						
16%	-17%						
17%	-21%						

Continuous Dose Plus Sediment

Table 26, Table 27, and Table 28 illustrate two methods to calculate the mass balance of sediment captured by each filter. One method consists of physically weighing any sediment captured by each filter, while the other method adds the results from the TSS analysis for each filter. Table 26 shows results to the physical method in which the sediment was removed from each filter and weighed and Table 28 show the results for the TSS analysis and the total theoretical value of the mass of sediment captured.

Table 26. Sediment Mass Balance.

	Weighted Sediment & Oil (kg)	Estimated Oil (kg)	Estimated Sediment Removed (kg)	Weighted Average TSS (kg)	Total Applied TSS (kg)	Mass Balance % Removal (Actual TSS In)
FloGard+Plus ™	8.20	1.07	7.13	85.5	29.42	24%
Hydro-Cartridge™	11.84	1.54	10.30	83.3	28.67	36%
Ultra Urban™	3.52	0.46	3.06	82.3	28.29	11%
Drain Pac™	12.90	1.68	11.22	84.4	29.02	39%

Table 27. Oil and Grease Efficiency Calculations for Continuous Dose Plus Sediment Experiment for FloGard+Plus^{TM} and Hydro-Cartridge^{TM}

		FloGard+Plus^{TM}			Hydro-Cartridge^{TM}		
Run #	**Volume, m^3**	**Influent**	**Effluent**	**Removal**	**Influent**	**Effluent**	**Removal**
1	11.34	ND	ND	**ND**	ND	ND	**ND**
1	22.68	ND	ND	**ND**	ND	ND	**ND**
2	34.02	6.1	5.9	**3%**	ND	ND	**ND**
2	45.36	ND	ND	**ND**	ND	ND	**ND**
3	56.7	ND	ND	**ND**	ND	ND	**ND**
3	68.04	ND	ND	**ND**	ND	ND	**ND**
4	79.38	ND	ND	**ND**	5.5	ND	**ND**
4	90.72	ND	ND	**ND**	ND	ND	**ND**
5	102.06	7.8	7.3	**6%**	5.8	5.4	**7%**
5	113.4	6.3	5.7	**10%**	5.9	ND	**ND**
6	124.74	11	9.5	**14%**	6.7	3.8	**43%**
6	136.08	11	6.5	**41%**	7.4	4.4	**41%**
7	147.42	13.9	10.4	**25%**	18	7.9	**56%**
7	158.76	9.7	6.4	**34%**	14.2	8.8	**38%**
8	170.1	10	11.4	**-14%**	12.4	7.5	**40%**
8	181.44	20.6	3.8	**82%**	14.3	3.4	**76%**
9	192.78	11.7	11.1	**5%**	8.9	6.1	**31%**
9	204.12	2.9	8.1	**-179%**	12	5.6	**53%**
10	215.46	26.4	9.1	**66%**	32.5	5.2	**84%**
10	226.8	11.2	10.4	**7%**	6.9	6.1	**12%**
11	238.896	46.6	3.9	**92%**	2.3	2.3	**0%**
11	250.236	23	5.9	**74%**	10.3	10.5	**-2%**
12	262.332	40	10.9	**73%**	15.7	12.2	**22%**
12	273.672	13.2	8.4	**36%**	13.5	18.9	**-40%**
13	285.768	15.9	6.2	**61%**	30.7	11.7	**62%**
13	297.108	7.6	6.4	**16%**	11.1	10.5	**5%**
14	309.204	18.1	9.6	**47%**	26.7	14.1	**47%**
14	320.544	11.3	9.1	**19%**	12.7	11.6	**9%**
15	332.64	23.8	9	**62%**	14.6	10	**32%**
15	343.98	9	8.1	**10%**	9.2	7.9	**14%**
				26%			**30%**

Table 28. Oil and Grease Efficiency Calculations for Continuous Dose Plus Sediment Experiment for Ultra Urban^{TM} and Drain Pac^{TM}

		Ultra Urban^{TM}			Drain Pac^{TM}		
Run #	**Volume, m^3**	**Influent**	**Effluent**	**Removal**	**Influent**	**Effluent**	**Removal**
1	11.34	ND	ND	**ND**	ND	ND	**ND**
1	22.68	ND	ND	**ND**	ND	ND	**ND**
2	34.02	ND	ND	**ND**	ND	ND	**ND**
2	45.36	ND	ND	**ND**	ND	ND	**ND**
3	56.7	ND	ND	**ND**	ND	ND	**ND**
3	68.04	ND	ND	**ND**	ND	ND	**ND**
4	79.38	ND	ND	**ND**	ND	ND	**ND**
4	90.72	6.2	ND	**ND**	ND	ND	**ND**
5	102.06	ND	ND	**ND**	7.6	6.2	**18%**
5	113.4	6	5.2	**13%**	6.6	5.8	**12%**
6	124.74	7	5.3	**24%**	9.8	6.2	**37%**
6	136.08	9.4	7.2	**23%**	13.1	7	**47%**
7	147.42	6.2	5.9	**5%**	7.6	3.5	**54%**
7	158.76	11.1	9.8	**12%**	5.5	2.8	**49%**
8	170.1	10.2	6.9	**32%**	9.9	6	**39%**
8	181.44	11.7	8.3	**29%**	8.2	8.5	**-4%**
9	192.78	16.1	11.8	**27%**	9.4	6.8	**28%**
9	204.12	10	8.7	**13%**	5.8	6	**-3%**
10	215.46	4.5	6.1	**-36%**	32.9	1.9	**94%**
10	226.8	41.1	24	**42%**	9.6	7.3	**24%**
11	238.896	37	19	**49%**	28.3	16.3	**42%**
11	250.236	9.6	10.2	**-6%**	10.4	9.6	**8%**
12	262.332	28.6	27.5	**4%**	25.9	9.7	**63%**
12	273.672	26.8	18.9	**29%**	13.5	12.4	**8%**
13	285.768	43.6	20.5	**53%**	31.4	9	**71%**
13	297.108	9.9	12.9	**-30%**	8.2	9.6	**-17%**
14	309.204	29.5	27.3	**7%**	22.6	9.5	**58%**
14	320.544	8.4	11.7	**-39%**	17.9	12.1	**32%**
15	332.64	4.1	3.5	**15%**	9.3	7.9	**15%**
15	343.98	14	10.8	**23%**	6.8	7.6	**-12%**
				14%			**30%**

Statistical Analysis

The Shapiro-Wilk statistical analysis described previously was repeated for the continuous dose plus sediment data. Printouts from the spreadsheets written for these calculations are shown in Table 29 through Table 32.

Table 29. Statistic Calculations for Normality (Shapiro-Wilk) and Confidence Limits for the Continuous Dose Plus Sediment Experiment for Hydro-Cartridge^{TM}.

Hydro-Cartridge		Oil plus sediment experiment					
Ordered data	**Reverse ordered data**	**Difference**	**a values**	**bi**			
-40%	84%	1.24	0.4734	0.587016		**n**	**20**
-2%	76%	0.781655	0.3211	0.250989		stdev	0.291612689
5%	62%	0.564838	0.2565	0.144881		sum bi	1.25512044
7%	56%	0.492146	0.2085	0.102612			
9%	53%	0.446719	0.1686	0.075317		W	0.974999443
12%	47%	0.355968	0.1334	0.047486		W0.05	0.905
14%	43%	0.291531	0.1013	0.029532		W0.01	0.868
22%	41%	0.182475	0.0711	0.012974		Result:	Normal
31%	40%	0.080555	0.0422	0.003399			
32%	38%	0.065213	0.014	0.000913		Mean	0.32
38%	32%						
40%	31%			Confidence interval based on t distribution			
41%	22%					$t_{0.05,19}$	2.09
43%	14%						
47%	12%				0.17878009	$< u_x <$	0.451343594
53%	9%				Is zero in the interval?		No
56%	7%						
62%	5%						
76%	-2%						
84%	-40%						

Table 30. Statistic Calculations for Normality (Shapiro-Wilk) and Confidence Limits for the Continuous Dose Plus Sediment Experiment for Ultra Urban^{TM}.

Ultra Urban		Oil plus sediment experiment					
Ordered data	Reverse ordered data	Difference	a values	bi			
-39%	53%	0.922674	0.4808	0.443621		n	19
-30%	49%	0.789517	0.3232	0.255172		stdev	0.236497557
-6%	42%	0.478558	0.2561	0.122559		sum bi	0.971871394
4%	32%	0.285068	0.2059	0.058695			
5%	29%	0.246389	0.1641	0.040432		W	0.938192111
7%	29%	0.216022	0.1271	0.027456		W0.05	0.901
12%	27%	0.149964	0.0932	0.013977		W0.01	0.863
13%	24%	0.112857	0.0612	0.006907		Result:	Normal
13%	23%	0.100709	0.0303	0.003051			
23%	23%	0	0	0		Mean	0.16
23%	13%						
24%	13%				Confidence interval based on t distribution		
27%	12%					$t_{0.05,19}$	2.086
29%	7%						
29%	5%				0.04983749	$< u_x <$	0.276194612
32%	4%				Is zero in the interval?		No
42%	-6%						
49%	-30%						
53%	-39%						

Table 31. Statistic Calculations for Normality (Shapiro-Wilk) and Confidence Limits for the Continuous Dose Plus Sediment Experiment for Drain Pac^{TM}.

Drain Pac		Oil plus sediment experiment					
Ordered data	**Reverse ordered data**	**Difference**	**a values**	**bi**			
-17%	94%	1.112981	0.459	0.510858		**n**	**22**
-12%	71%	0.831023	0.3156	0.262271		stdev	0.285240417
-4%	63%	0.662068	0.2571	0.170218		sum bi	1.296756173
-3%	58%	0.614129	0.2131	0.130871			
8%	54%	0.462551	0.1764	0.081594		W	0.984181571
8%	49%	0.409428	0.1443	0.05908		W0.05	0.911
12%	47%	0.344437	0.115	0.03961		W0.01	0.878
15%	42%	0.273491	0.0878	0.024012		Result:	Normal
18%	39%	0.209729	0.0618	0.012961			
24%	37%	0.127764	0.0368	0.004702		Mean	0.30
28%	32%	0.047427	0.0122	0.000579			
32%	28%				Confidence interval based on t distribution		
37%	24%					$t_{0.05,19}$	2.08
39%	18%						
42%	15%				0.17519979	$< u_x <$	0.428183785
47%	12%				Is zero in the interval?		No
49%	8%						
54%	8%						
58%	-3%						
63%	-4%						
71%	-12%						
94%	-17%						

Table 32. Statistic Calculations for Normality (Shapiro-Wilk) and Confidence Limits for the Continuous Dose Plus Sediment Experiment for FloGard+Plus^{TM}

FloGard+Plus		Oil plus sediment experiment					
Ordered data	Reverse ordered data	Difference	a values	bi			
-14%	92%	1.056309	0.459	0.484846		**n**	**22**
3%	82%	0.782747	0.3156	0.247035		stdev	0.302417819
5%	74%	0.692196	0.2571	0.177964		sum bi	1.340936092
6%	73%	0.663397	0.2131	0.14137			
7%	66%	0.583874	0.1764	0.102995		W	0.936229047
10%	62%	0.526611	0.1443	0.07599		W0.05	0.911
10%	61%	0.510063	0.115	0.058657		W0.01	0.878
14%	47%	0.33325	0.0878	0.029259		Result:	Normal
16%	41%	0.251196	0.0618	0.015524			
19%	36%	0.168946	0.0368	0.006217		Mean	0.35
25%	34%	0.088408	0.0122	0.001079			
34%	25%				Confidence interval based on t distribution		
36%	19%					$t_{0.05,19}$	2.08
41%	16%						
47%	14%				0.21535273	$< u_x <$	0.483571629
61%	10%				Is zero in the interval?		No
62%	10%						
66%	7%						
73%	6%						
74%	5%						
82%	3%						
92%	-14%						

Table 33. TSS Efficiency Calculations for Continuous Dose Plus Sediment Experiment for FloGard+Plus™ and Hydro-Cartridge™

FloGard+Plus™		
TSS Influent (mg/L)	TSS Effluent (mg/L)	Effluent / Influent TSS
42	70	-67%
63	67	-6%
140	140	0%
130	140	-8%
96	94	2%
91	94	-3%
53	45	15%
51	39	24%
28	28	0%
32	32	0%
94	102	-9%
95	109	-15%
96	104	-8%
95	109	-15%
96	106	-10%
90	104	-16%
88	95	-8%
101	89	12%
91	84	8%
	Average:	**-5%**

Hydro-Cartridge™		
TSS Influent (mg/L)	TSS Effluent (mg/L)	Effluent / Influent TSS
26	23	12%
26	24	8%
110	97	12%
110	95	14%
75	68	9%
74	79	-7%
63	57	10%
52	59	-13%
24	27	-13%
14	17	-21%
99	90	9%
85	57	33%
106	101	5%
92	88	4%
95	87	8%
95	88	7%
93	85	9%
122	123	-1%
97	88	9%
	Average:	**5%**

Table 34. TSS Efficiency Calculations for Continuous Dose Plus Sediment Experiment for Ultra Urban™ and Drain Pac™

Ultra Urban™		
TSS Influent (mg/L)	**TSS Effluent (mg/L)**	**Effluent / Influent TSS**
51	34	33%
41	47	-15%
62	62	0%
60	57	5%
82	62	24%
82	69	16%
95	78	18%
68	69	-1%
31	30	3%
39	36	8%
90	90	0%
92	88	4%
101	100	1%
95	95	0%
96	100	-4%
107	199	-86%
95	92	3%
63	62	2%
	Average	**1%**

Drain Pac™		
TSS Influent (mg/L)	**TSS Effluent (mg/L)**	**Effluent / Influent TSS**
100	75	25%
84	66	21%
76	58	24%
81	63	22%
75	55	27%
77	61	21%
51	45	12%
51	22	57%
40	30	25%
34	27	21%
95	84	12%
95	105	-11%
91	87.5	4%
91	71	22%
90	67.9	25%
89.9	69.6	23%
97	63	35%
101	101	0%
98	93	5%
	Average	**19%**

Appendix B: Hydraulic Test

The overall effectiveness of an inlet filter partially depends on maintaining hydraulic capacity through the mechanism of the filter that provides treatment. Studies by Caltrans indicate that maintaining hydraulic capacity of drain inlet filters may be a primary factor in achieving acceptable performance[18]. It would be ideal to maintain this capacity throughout the desired maintenance interval. This experiment tested the ability of each filter to treat typical stormwater quality design flows as potentially clogging vegetation was introduced.

After completion of the continuous dose scenario, the hydraulic capacity of each filter was tested by gradually introducing leaves into the filters at the maximum flow rate of the test facility (170 L/min). Figure 36 (top left corner) shows the leaves. The leaves were introduced up to the annual litter load determined in Caltrans studies in the Los Angeles Basin. These studies found that the average annual litter load is around 0.35 m^3/ha-yr (5 ft^3/acre-yr) but varies considerably[19]. Vegetation in the drainage area seemed to be a major cause of this variation. For this reason, 0.6 m^3/hectare per year is often used by Caltrans to estimate load. Corresponding to the hypothetical drainage area of 0.1 hectare (0.25 acres assumed in this study), 0.072 m^3 (2.5 ft^3) of liter, or 72 liters, was added. The vegetation was added in increments of approximately 8 liters. After each increment was added, the flow was increased up to the maximum possible flow of 170 L/min. Each filter took 72 liters of vegetation and passed a flow 170 L/min without bypass as illustrated in Figure 36. An important limitation to this test is that the leaves were not decomposed. It is probable that decomposing leaves would cause more clogging. Evidence for this is the observed clogging of the Drain Pac™ and FloGard+Plus™ filters during the continuous dose with sediment experiment. In this case, very small particles lined the filter liner and caused back-up. In the case of Drain Pac™, the sediment caused bypass to occur throughout the experiment.

Litter (leaves and small twigs) 	Preparing to add litter to each filter. 
FloGard+Plus^{TM} at 170 L/m, did not bypass. 	FloGard+Plus^{TM} at 170 L/m, did not bypass. 

Hydro-Cartridge™ at 170 L/m, minor by pass was observed. 	Hydro-Cartridge™ at 170 L/m. 
Ultra Urban™ at 170L/m, did not bypass 	

Figure 36. Photographs of Various Filters During the Hydraulic Test.

Appendix C: Raw Data

Appendix C contains the raw data collected in the experiments. Except where noted in the report, only concentrations from primary samples were used in the calculations. Primary data not used in the calculations are included here. These data include influent oil and grease concentrations (Method 1664) that were below the reporting limit of 5 mg/L. These data points were excluded from removal rate calculations because small changes in the magnitude of these uncertain numbers had a disproportionately large effect on the efficiency calculation. In total, only four data points were excluded for this reason. Effluent concentrations below the reporting limit have been retained.

Filter 1 – FloGard+Plus™
Filter 2 – Hydro-Cartridge™
Filter 3 – Ultra Urban™
Filter 4 – Drain Pac™

Target oil (5, 15 or 0) (mg/L)	Flow Rate (15, 25 or 35 gpm)	Date	Sample Location (influent or effluent)	Sample Volume During Run	Total V, m^3	Filter (1, 2, 3 or 4)	Primary, duplicate or triplicate	1664	8015M	TSS	TDS	turbidity	test
15	15	6/21/04	influent	6000	23	1	primary	17.1					continuous dose
15	15	6/21/04	influent	6000	23	1	duplicate	17.4					continuous dose
15	15	6/21/04	effluent	6000	23	1	primary	11.6					continuous dose
15	15	6/21/04	effluent	6000	23	1	duplicate	12					continuous dose
15	15	6/22/04	influent	6000	23	2	primary	15.7					continuous dose
15	15	6/22/04	influent	6000	23	2	duplicate	15.2					continuous dose
15	15	6/22/04	effluent	6000	23	2	primary	16.1					continuous dose
15	15	6/22/04	effluent	6000	23	2	duplicate	15					continuous dose
15	15	6/23/04	influent	6000	23	3	primary	16					continuous dose
15	15	6/23/04	influent	6000	23	3	duplicate	16.5					continuous dose
15	15	6/23/04	effluent	6000	23	3	primary	5.4					continuous dose
15	15	6/23/04	effluent	6000	23	3	duplicate	5.3					continuous dose
15	15	6/24/04	influent	6000	23	4	primary	14.5					continuous dose
15	15	6/24/04	influent	6000	23	4	duplicate	15.5					continuous dose
15	15	6/24/04	effluent	6000	23	4	primary	16.4					continuous dose
15	15	6/24/04	effluent	6000	23	4	duplicate	15.3					continuous dose
15	15	6/28/04	influent	12000	45	1	primary	15.1					continuous dose
15	15	6/28/04	influent	12000	45	1	duplicate	16.1					continuous dose
15	15	6/28/04	effluent	12000	45	1	primary	9.6					continuous dose
15	15	6/28/04	effluent	12000	45	1	duplicate	11.2					continuous dose
15	15	6/29/04	influent	12000	45	2	primary	17.2					continuous dose
15	15	6/29/04	influent	12000	45	2	duplicate	13.5					continuous dose

Target oil (5, 15 or 0) (mg/L)	Flow Rate (15, 25 or 35 gpm)	Date	Sample Location (influent or effluent)	Sample Volume During Run	Total V, m^3	Filter (1, 2, 3 or 4)	Primary, duplicate or triplicate	1664	8015M	TSS	TDS	turbidity	test
15	15	6/29/04	influent	12000	45	2	triplicate	15					continuous dose
15	15	6/29/04	effluent	12000	45	2	primary	19.4					continuous dose
15	15	6/29/04	effluent	12000	45	2	duplicate	18.7					continuous dose
15	15	7/1/04	influent	12000	45	3	primary	15.7					continuous dose
15	15	7/1/04	influent	12000	45	3	duplicate	15.5					continuous dose
15	15	7/1/04	effluent	12000	45	3	primary	5.2					continuous dose
15	15	7/1/04	effluent	12000	45	3	duplicate	4.4					continuous dose
15	15	7/2/04	influent	12000	45	4	primary	15					continuous dose
15	15	7/2/04	influent	12000	45	4	duplicate	15.5					continuous dose
15	15	7/2/04	effluent	12000	45	4	primary	18.2					continuous dose
15	15	7/2/04	effluent	12000	45	4	duplicate	18.2					continuous dose
15	15	7/6/04	influent	18000	68	1	primary	14.8					continuous dose
15	15	7/6/04	influent	18000	68	1	duplicate	14.4					continuous dose
15	15	7/6/04	effluent	18000	68	1	primary	12.2					continuous dose
15	15	7/6/04	effluent	18000	68	1	duplicate	12.7					continuous dose
15	15	7/7/04	influent	18000	68	2	primary	15					continuous dose
15	15	7/7/04	influent	18000	68	2	duplicate	14					continuous dose
15	15	7/7/04	effluent	18000	68	2	primary	15.5					continuous dose
15	15	7/7/04	effluent	18000	68	2	duplicate	14.1					continuous dose
15	15	7/7/04	effluent	18000	68	2	Triplicate	14.9					continuous dose
15	15	7/8/04	influent	18000	68	3	primary	14.3					continuous dose
15	15	7/8/04	influent	18000	68	3	duplicate	14.3					continuous dose
15	15	7/8/04	effluent	18000	68	3	primary	5.1					continuous dose
15	15	7/8/04	effluent	18000	68	3	duplicate	5.7					continuous dose
15	15	7/9/04	influent	18000	68	4	primary	15.4					continuous dose
15	15	7/9/04	influent	18000	68	4	duplicate	14.9					continuous dose
15	15	7/9/04	effluent	18000	68	4	primary	17.6					continuous dose
15	15	7/9/04	effluent	18000	68	4	duplicate	15.2					continuous dose
15	15	7/9/04	effluent	18000	68	4	triplicate	17.8					continuous dose
15	15	7/12/04	influent	24000	91	1	primary	14.1					continuous dose
15	15	7/12/04	influent	24000	91	1	duplicate	15.7					continuous dose

Target oil (5, 15 or 0) (mg/L)	Flow Rate (15, 25 or 35 gpm)	Date	Sample Location (influent or effluent)	Sample Volume During Run	Total V, m^3	Filter (1, 2, 3 or 4)	Primary, duplicate or triplicate	1664	8015M	TSS	TDS	turbidity	test
15	15	7/12/04	effluent	24000	91	1	primary	11					continuous dose
15	15	7/12/04	effluent	24000	91	1	duplicate	12.1					continuous dose
15	15	7/13/04	influent	24000	91	2	primary	18.5					continuous dose
15	15	7/13/04	influent	24000	91	2	duplicate	19.7					continuous dose
15	15	7/13/04	effluent	24000	91	2	primary	16.2					continuous dose
15	15	7/13/04	effluent	24000	91	2	duplicate	17.3					continuous dose
15	15	7/14/04	influent	24000	91	3	primary	16.8					continuous dose
15	15	7/14/04	influent	24000	91	3	duplicate	18.8					continuous dose
15	15	7/14/04	influent	24000	91	3	triplicate	17					continuous dose
15	15	7/14/04	effluent	24000	91	3	primary	5.9					continuous dose
15	15	7/14/04	effluent	24000	91	3	duplicate	6					continuous dose
15	15	7/15/04	influent	24000	91	4	primary	16.3					continuous dose
15	15	7/15/04	influent	24000	91	4	duplicate	17.6					continuous dose
15	15	7/15/04	effluent	24000	91	4	primary	17.9					continuous dose
15	15	7/15/04	effluent	24000	91	4	duplicate	17.8					continuous dose
15	15	7/19/04	influent	30000	113	1	primary	18.9					continuous dose
15	15	7/19/04	influent	30000	113	1	duplicate	17.9					continuous dose
15	15	7/19/04	effluent	30000	113	1	primary	13.9					continuous dose
15	15	7/19/04	effluent	30000	113	1	duplicate	13.2					continuous dose
15	15	7/20/04	influent	30000	113	2	primary	19.6					continuous dose
15	15	7/20/04	influent	30000	113	2	duplicate	16.1					continuous dose
15	15	7/20/04	effluent	30000	113	2	primary	18.5					continuous dose
15	15	7/20/04	effluent	30000	113	2	duplicate	18.7					continuous dose
15	15	7/21/04	influent	30000	113	3	primary	19.9					continuous dose
15	15	7/21/04	influent	30000	113	3	duplicate	19					continuous dose
15	15	7/21/04	effluent	30000	113	3	primary	9.5					continuous dose
15	15	7/21/04	effluent	30000	113	3	duplicate	9.4					continuous dose
15	15	7/22/04	influent	30000	113	4	primary	17.3					continuous dose
15	15	7/22/04	influent	30000	113	4	duplicate	19.3					continuous dose
15	15	7/22/04	effluent	30000	113	4	primary	18.3					continuous dose
15	15	7/22/04	effluent	30000	113	4	duplicate	18.6					continuous dose

Target oil (5, 15 or 0) (mg/L)	Flow Rate (15, 25 or 35 gpm)	Date	Sample Location (influent or effluent)	Sample Volume During Run	Total V, m^3	Filter (1, 2, 3 or 4)	Primary, duplicate or triplicate	1664	8015M	TSS	TDS	turbidity	test
15	15	7/26/04	influent	36000	136	1	primary	17.2					continuous dose
15	15	7/26/04	influent	36000	136	1	duplicate	18.4					continuous dose
15	15	7/26/04	effluent	36000	136	1	primary	10.1					continuous dose
15	15	7/26/04	effluent	36000	136	1	duplicate	11.5					continuous dose
15	15	7/27/04	influent	36000	136	2	primary	19.7					continuous dose
15	15	7/27/04	influent	36000	136	2	duplicate	16					continuous dose
15	15	7/27/04	effluent	36000	136	2	primary	18.9					continuous dose
15	15	7/27/04	effluent	36000	136	2	duplicate	24.5					continuous dose
15	15	7/28/04	influent	36000	136	3	primary	18.8					continuous dose
15	15	7/28/04	influent	36000	136	3	duplicate	18.4					continuous dose
15	15	7/28/04	effluent	36000	136	3	primary	6.1					continuous dose
15	15	7/28/04	effluent	36000	136	3	duplicate	6.5					continuous dose
15	15	7/29/04	influent	36000	136	4	primary	18.3					continuous dose
15	15	7/29/04	influent	36000	136	4	duplicate	17.9					continuous dose
15	15	7/29/04	effluent	36000	136	4	primary	17.2					continuous dose
15	15	7/29/04	effluent	36000	136	4	duplicate	20.1					continuous dose
15	15	8/2/04	influent	42000	159	1	primary	19.5					continuous dose
15	15	8/2/04	influent	42000	159	1	duplicate	17.4					continuous dose
15	15	8/2/04	effluent	42000	159	1	primary	11.5					continuous dose
15	15	8/2/04	effluent	42000	159	1	duplicate	10.7					continuous dose
15	15	8/3/04	influent	42000	159	2	primary	15.7					continuous dose
15	15	8/3/04	influent	42000	159	2	duplicate	16.7					continuous dose
15	15	8/3/04	effluent	42000	159	2	primary	16					continuous dose
15	15	8/3/04	effluent	42000	159	2	duplicate	18.8					continuous dose
15	15	8/4/04	influent	42000	159	3	primary	15.2					continuous dose
15	15	8/4/04	influent	42000	159	3	duplicate	14.8					continuous dose
15	15	8/4/04	effluent	42000	159	3	primary	5.8					continuous dose
15	15	8/4/04	effluent	42000	159	3	duplicate	6.9					continuous dose
15	15	8/5/04	influent	42000	159	4	primary	14.6					continuous dose
15	15	8/5/04	influent	42000	159	4	duplicate	14.8					continuous dose
15	15	8/5/04	effluent	42000	159	4	primary	13.6					continuous dose

Target oil (5, 15 or 0) (mg/L)	Flow Rate (15, 25 or 35 gpm)	Date	Sample Location (influent or effluent)	Sample Volume During Run	Total V, m^3	Filter (1, 2, 3 or 4)	Primary, duplicate or triplicate	1664	8015M	TSS	TDS	turbidity	test
15	15	8/5/04	effluent	42000	159	4	duplicate	17.6					continuous dose
15	35	8/9/04	influent	48000	181	1	primary	15.6					continuous dose
15	35	8/9/04	effluent	48000	181	1	primary	13.2					continuous dose
15	35	8/9/04	influent	48000	181	2	primary	15.2					continuous dose
15	35	8/9/04	effluent	48000	181	2	primary	18.1					continuous dose
15	35	8/10/04	influent	48000	181	3	primary	16.1					continuous dose
15	35	8/10/04	effluent	48000	181	3	primary	8					continuous dose
15	35	8/10/04	influent	48000	181	4	primary	15.2					continuous dose
15	35	8/10/04	effluent	48000	181	4	primary	13.8					continuous dose
15	35	8/11/04	influent	54000	204	1	primary	15.2					continuous dose
15	35	8/11/04	effluent	54000	204	1	primary	12.1					continuous dose
15	35	8/11/04	influent	54000	204	2	primary	15.2					continuous dose
15	35	8/11/04	effluent	54000	204	2	primary	15.2					continuous dose
15	35	8/12/04	influent	54000	204	3	primary	14.3					continuous dose
15	35	8/12/04	effluent	54000	204	3	primary	7.1					continuous dose
15	35	8/12/04	influent	54000	204	4	primary	14.8					continuous dose
15	35	8/12/04	effluent	54000	204	4	primary	13.4					continuous dose
15	35	8/16/04	influent	60000	227	1	primary	15.8					continuous dose
15	35	8/16/04	effluent	60000	227	1	primary	13					continuous dose
15	35	8/16/04	influent	60000	227	2	primary	15.3					continuous dose
15	35	8/16/04	effluent	60000	227	2	primary	15.9					continuous dose
15	35	8/17/04	influent	60000	227	3	primary	14.7					continuous dose
15	35	8/17/04	effluent	60000	227	3	primary	6.9					continuous dose
15	35	8/17/04	influent	60000	227	4	primary	15.1					continuous dose
15	35	8/17/04	effluent	60000	227	4	primary	13.6					continuous dose
15	35	8/18/04	influent	66000	249	1	primary	16					continuous dose
15	35	8/18/04	effluent	66000	249	1	primary	12.7					continuous dose
15	35	8/18/04	influent	66000	249	2	primary	15.6					continuous dose
15	35	8/18/04	effluent	66000	249	2	primary	16.2					continuous dose
15	35	8/19/04	influent	66000	249	3	primary	15.7					continuous dose
15	35	8/19/04	effluent	66000	249	3	primary	7.4					continuous dose

Target oil (5, 15 or 0) (mg/L)	Flow Rate (15, 25 or 35 gpm)	Date	Sample Location (influent or effluent)	Sample Volume During Run	Total V, m^3	Filter (1, 2, 3 or 4)	Primary, duplicate or triplicate	1664	8015M	TSS	TDS	turbidity	test
15	35	8/19/04	influent	66000	249	4	primary	15.9					continuous dose
15	35	8/19/04	effluent	66000	249	4	primary	13.3					continuous dose
15	35	8/23/04	influent	72000	272	1	primary	16.6					continuous dose
15	35	8/23/04	effluent	72000	272	1	primary	14.8					continuous dose
15	35	8/23/04	influent	72000	272	2	primary	14.5					continuous dose
15	35	8/23/04	effluent	72000	272	2	primary	16.8					continuous dose
15	35	8/24/04	influent	72000	272	3	primary	16.1					continuous dose
15	35	8/24/04	effluent	72000	272	3	primary	7.8					continuous dose
15	35	8/24/04	influent	72000	272	4	primary	16.8					continuous dose
15	35	8/24/04	effluent	72000	272	4	primary	13.9					continuous dose
15	25	8/25/04	influent	78000	295	1	primary	12.9					continuous dose
15	25	8/25/04	effluent	78000	295	1	primary	11.7					continuous dose
15	25	8/25/04	influent	78000	295	2	primary	14.9					continuous dose
15	25	8/25/04	effluent	78000	295	2	primary	13.9					continuous dose
15	25	8/26/04	influent	78000	295	3	primary	12.9					continuous dose
15	25	8/26/04	effluent	78000	295	3	primary	6					continuous dose
15	25	8/26/04	influent	78000	295	4	primary	13.8					continuous dose
15	25	8/26/04	effluent	78000	295	4	primary	14					continuous dose
15	25	8/30/04	influent	84000	318	1	primary	16.3					continuous dose
15	25	8/30/04	effluent	84000	318	1	primary	14					continuous dose
15	25	8/30/04	influent	84000	318	2	primary	17.3					continuous dose
15	25	8/30/04	effluent	84000	318	2	primary	15.6					continuous dose
15	25	8/31/04	influent	84000	318	3	primary	15.5					continuous dose
15	25	8/31/04	effluent	84000	318	3	primary	6.8					continuous dose
15	25	8/31/04	influent	84000	318	4	primary	15.8					continuous dose
15	25	8/31/04	effluent	84000	318	4	primary	16.3					continuous dose
15	25	9/1/04	influent	90000	340	1	primary	14.3					continuous dose
15	25	9/1/04	effluent	90000	340	1	primary	10.6					continuous dose
15	25	9/1/04	influent	90000	340	2	primary	15.6					continuous dose
15	25	9/1/04	effluent	90000	340	2	primary	15.7					continuous dose
15	25	9/2/04	influent	90000	340	3	primary	15.8					continuous dose

Target oil (5, 15 or 0) (mg/L)	Flow Rate (15, 25 or 35 gpm)	Date	Sample Location (influent or effluent)	Sample Volume During Run	Total V, m^3	Filter (1, 2, 3 or 4)	Primary, duplicate or triplicate	1664	8015M	TSS	TDS	turbidity	test
15	25	9/2/04	effluent	90000	340	3	primary	7					continuous dose
15	25	9/2/04	influent	90000	340	4	primary	15.6					continuous dose
15	25	9/2/04	effluent	90000	340	4	primary	15.3					continuous dose
15	25	9/6/04	influent	96000	363	1	primary	16.2					continuous dose
15	25	9/6/04	effluent	96000	363	1	primary	12					continuous dose
15	25	9/6/04	influent	96000	363	2	primary	15.4					continuous dose
15	25	9/6/04	effluent	96000	363	2	primary	15.6					continuous dose
15	25	9/7/04	influent	96000	363	3	primary	16.5					continuous dose
15	25	9/7/04	effluent	96000	363	3	primary	5.7					continuous dose
15	25	9/7/04	influent	96000	363	4	primary	19.7					continuous dose
15	25	9/7/04	effluent	96000	363	4	primary	18.5					continuous dose
15	25	9/8/04	influent	102000	386	1	primary	14.7					continuous dose
15	25	9/8/04	effluent	102000	386	1	primary	12.2					continuous dose
15	25	9/8/04	influent	102000	386	2	primary	15.4					continuous dose
15	25	9/8/04	effluent	102000	386	2	primary	15.4					continuous dose
15	25	9/9/04	influent	102000	386	3	primary	15.2					continuous dose
15	25	9/9/04	effluent	102000	386	3	primary	5.5					continuous dose
15	25	9/9/04	influent	102000	386	4	primary	18.6					continuous dose
15	25	9/9/04	effluent	102000	386	4	primary	16.2					continuous dose
15	15	9/13/04	influent	108000	408	1	primary	17.4					continuous dose
15	15	9/13/04	effluent	108000	408	1	primary	10.8					continuous dose
15	15	9/14/04	influent	108000	408	2	primary	16.2					continuous dose
15	15	9/14/04	effluent	108000	408	2	primary	15.8					continuous dose
15	15	9/15/04	influent	108000	408	3	primary	15.7					continuous dose
15	15	9/15/04	effluent	108000	408	3	primary	5					continuous dose
15	15	9/16/04	influent	108000	408	4	primary	15					continuous dose
15	15	9/16/04	effluent	108000	408	4	primary	17.6					continuous dose
15	15	10/5/04	influent	114000	431	1	primary	15.4					continuous dose
15	15	10/5/04	effluent	114000	431	1	primary	10.9					continuous dose
15	15	10/6/04	influent	114000	431	2	primary	16.1					continuous dose
15	15	10/6/04	effluent	114000	431	2	primary	16.3					continuous dose

Target oil (5, 15 or 0) (mg/L)	Flow Rate (15, 25 or 35 gpm)	Date	Sample Location (influent or effluent)	Sample Volume During Run	Total V, m^3	Filter (1, 2, 3 or 4)	Primary, duplicate or triplicate	1664	8015M	TSS	TDS	turbidity	test
15	15	10/7/04	influent	114000	431	3	primary	14.9					continuous dose
15	15	10/7/04	effluent	114000	431	3	primary	3.9					continuous dose
15	15	10/8/04	influent	114000	431	4	primary	15.4					continuous dose
15	15	10/8/04	effluent	114000	431	4	primary	16.9					continuous dose
15	15	10/11/04	influent	120000	454	1	primary	15.9					continuous dose
15	15	10/11/04	effluent	120000	454	1	primary	10.8					continuous dose
15	15	10/12/04	influent	120000	454	2	primary	15.4					continuous dose
15	15	10/12/04	effluent	120000	454	2	primary	15.5					continuous dose
15	15	10/13/04	influent	120000	454	3	primary	16.1					continuous dose
15	15	10/13/04	effluent	120000	454	3	primary	4.3					continuous dose
15	15	10/14/04	influent	120000	454	4	primary	16.2					continuous dose
15	15	10/14/04	effluent	120000	454	4	primary	16.8					continuous dose
0	25	10/18/04	influent	125	0	1	primary		ND				post continuous clean water flush
0	25	10/18/04	effluent	125	0.5	1	primary		2.1				post continuous clean water flush
0	25	10/18/04	influent	125	0	2	primary		ND				post continuous clean water flush
0	25	10/18/04	effluent	125	0	2	primary		13				post continuous clean water flush
0	25	10/18/04	influent	250	1	1	primary		ND				post continuous clean water flush
0	25	10/18/04	effluent	250	1	1	primary		1.7				post continuous clean water flush
0	25	10/18/04	influent	250	1	2	primary		ND				post continuous clean water flush
0	25	10/18/04	effluent	250	1	2	primary		8.1				post continuous clean water flush
0	25	10/18/04	influent	500	2	1	primary		ND				post continuous clean water flush
0	25	10/18/04	effluent	500	2	1	primary		1.9				post continuous clean water flush
0	25	10/18/04	influent	500	2	2	primary		ND				post continuous clean water flush
0	25	10/18/04	effluent	500	2	2	primary		8				post continuous clean water flush
0	25	10/18/04	influent	1000	4	1	primary		ND				post continuous clean water flush

Target oil (5, 15 or 0) (mg/L)	Flow Rate (15, 25 or 35 gpm)	Date	Sample Location (influent or effluent)	Sample Volume During Run	Total V, m^3	Filter (1, 2, 3 or 4)	Primary, duplicate or triplicate	1664	8015M	TSS	TDS	turbidity	test
0	25	10/18/04	effluent	1000	4	1	primary		1.3				post continuous clean water flush
0	25	10/18/04	influent	1000	4	2	primary		ND				post continuous clean water flush
0	25	10/18/04	effluent	1000	4	2	primary		4.1				post continuous clean water flush
0	25	10/18/04	influent	2000	8	1	primary		ND				post continuous clean water flush
0	25	10/18/04	effluent	2000	8	1	primary		ND				post continuous clean water flush
0	25	10/18/04	influent	2000	8	2	primary		ND				post continuous clean water flush
0	25	10/18/04	effluent	2000	8	2	primary		2.9				post continuous clean water flush
0	25	10/18/04	influent	4000	15	1	primary		ND				post continuous clean water flush
0	25	10/18/04	effluent	4000	15	1	primary		ND				post continuous clean water flush
0	25	10/18/04	effluent	4000	15	1	duplicate		ND				post continuous clean water flush
0	25	10/18/04	influent	4000	15	2	primary		ND				post continuous clean water flush
0	25	10/18/04	effluent	4000	15	2	primary		0.91				post continuous clean water flush
0	25	10/18/04	effluent	4000	15	2	duplicate		1.2				post continuous clean water flush
0	25	10/19/04	influent	125	0	3	primary		ND				post continuous clean water flush
0	25	10/19/04	effluent	125	0	3	primary		0.71				post continuous clean water flush
0	25	10/19/04	influent	125	0	4	primary		ND				post continuous clean water flush
0	25	10/19/04	effluent	125	0	4	primary		8.7				post continuous clean water flush
0	25	10/19/04	influent	250	1	3	primary		ND				post continuous clean water flush
0	25	10/19/04	effluent	250	1	3	primary		0.56				post continuous clean water flush
0	25	10/19/04	influent	250	1	4	primary		ND				post continuous clean water flush
0	25	10/19/04	effluent	250	1	4	primary		5.3				post continuous clean water flush

Target oil (5, 15 or 0) (mg/L)	Flow Rate (15, 25 or 35 gpm)	Date	Sample Location (influent or effluent)	Sample Volume During Run	Total V, m^3	Filter (1, 2, 3 or 4)	Primary, duplicate or triplicate	1664	8015M	TSS	TDS	turbidity	test
0	25	10/19/04	influent	500	2	3	primary		ND				post continuous clean water flush
0	25	10/19/04	effluent	500	2	3	primary		0.15				post continuous clean water flush
0	25	10/19/04	influent	500	2	4	primary		ND				post continuous clean water flush
0	25	10/19/04	effluent	500	2	4	primary		5.4				post continuous clean water flush
0	25	10/19/04	influent	1000	4	3	primary		ND				post continuous clean water flush
0	25	10/19/04	effluent	1000	4	3	primary		ND				post continuous clean water flush
0	25	10/19/04	influent	1000	4	4	primary		ND				post continuous clean water flush
0	25	10/19/04	effluent	1000	4	4	primary		5.5				post continuous clean water flush
0	25	10/19/04	influent	2000	8	3	primary		ND				post continuous clean water flush
0	25	10/19/04	effluent	2000	8	3	primary		ND				post continuous clean water flush
0	25	10/19/04	influent	2000	8	4	primary		ND				post continuous clean water flush
0	25	10/19/04	effluent	2000	8	4	primary		4.8				post continuous clean water flush
0	25	10/19/04	influent	4000	15	3	primary		ND				post continuous clean water flush
0	25	10/19/04	effluent	4000	15	3	primary		ND				post continuous clean water flush
0	25	10/19/04	effluent	4000	15	3	duplicate		ND				post continuous clean water flush
0	25	10/19/04	influent	4000	15	4	primary		ND				post continuous clean water flush
0	25	10/19/04	effluent	4000	15	4	primary		2				post continuous clean water flush
0	25	10/19/04	effluent	4000	15	4	duplicate		2.9				post continuous clean water flush
0	25	10/25/04	effluent	25	0	1	primary	90.3					spike dose
0	25	10/25/04	effluent	25	0	2	primary	12029.9					spike dose
0	25	10/25/04	effluent	50	0	2	primary	11100.5					spike dose
0	25	10/25/04	effluent	125	0	1	primary	2.2	←ND				spike dose
0	25	10/25/04	effluent	125	0	2	primary	1357.2					spike dose

Target oil (5, 15 or 0) (mg/L)	Flow Rate (15, 25 or 35 gpm)	Date	Sample Location (influent or effluent)	Sample Volume During Run	Total V, m^3	Filter (1, 2, 3 or 4)	Primary, duplicate or triplicate	1664	8015M	TSS	TDS	turbidity	test
0	25	10/25/04	effluent	143	1	2	primary	632.8					spike dose
0	25	10/25/04	effluent	250	1	1	primary	1.5	←ND				spike dose
0	25	10/25/04	effluent	253	1	2	primary	290.1					spike dose
0	25	10/25/04	effluent	283	1	2	primary	354.3					spike dose
0	25	10/25/04	effluent	500	2	1	primary	0.9	←ND				spike dose
0	25	10/25/04	effluent	518	2	2	primary	134					spike dose
0	25	10/25/04	effluent	550	2	2	primary	136.2					spike dose
0	25	10/25/04	effluent	1000	4	2	primary	59.8					spike dose
0	25	10/25/04	effluent	1025	4	2	primary	70.2					spike dose
0	25	10/25/04	effluent	2000	8	2	primary	25.5					spike dose
0	25	10/25/04	effluent	2024	8	2	primary	12.8					spike dose
0	25	10/25/04	effluent	4100	15	2	primary	2.4	←ND				spike dose
0	25	10/25/04	effluent	6015	23	1	primary		0.18				spike dose
0	25	10/25/04	effluent	12055	46	1	primary		0.05				spike dose
0	25	10/25/04	effluent	13355	50	2	primary		2.7				spike dose
0	25	10/26/04	effluent	5	0	4	primary	1610.8					spike dose
0	25	10/26/04	effluent	25	0	3	primary	15.3					spike dose
0	25	10/26/04	effluent	25	0	4	primary	50.1					spike dose
0	25	10/26/04	effluent	60	0	3	primary	6.8					spike dose
0	25	10/26/04	effluent	80	0	4	primary	28.4					spike dose
0	25	10/26/04	effluent	125	0	4	primary	17.5					spike dose
0	25	10/26/04	effluent	125	0	4	primary		0.13				spike dose
0	25	10/26/04	effluent	176	1	3	primary	7.7					spike dose
0	25	10/26/04	effluent	186	1	3	primary	6.2					spike dose
0	25	10/26/04	effluent	280	1	4	primary	9.7					spike dose
0	25	10/26/04	effluent	295	1	4	primary	11.1					spike dose
0	25	10/26/04	effluent	300	1	3	primary	4.7	←ND				spike dose
0	25	10/26/04	effluent	500	2	4	primary	6.6					spike dose
0	25	10/26/04	effluent	5990	23	3	primary		0.7				spike dose
0	25	10/26/04	effluent	6020	23	4	primary		0.85				spike dose
0	25	10/26/04	effluent	12030	45	3	primary		0.23				spike dose

Target oil (5, 15 or 0) (mg/L)	Flow Rate (15, 25 or 35 gpm)	Date	Sample Location (influent or effluent)	Sample Volume During Run	Total V, m^3	Filter (1, 2, 3 or 4)	Primary, duplicate or triplicate	1664	8015M	TSS	TDS	turbidity	test
0	25	10/26/04	effluent	12030	45	4	primary		ND				spike dose
5	35	1/6/05	effluent	1000	4	1	primary						plus sediment
5	35	1/6/05	influent	1000	4	1	primary	ND	0.63				plus sediment
5	35	1/6/05	effluent	1000	4	2	primary						plus sediment
5	35	1/6/05	influent	1000	4	2	primary		0.23				plus sediment
5	35	1/6/05	effluent	2000	8	1	primary						plus sediment
5	35	1/6/05	influent	2000	8	1	primary	ND	0.63				plus sediment
5	35	1/6/05	effluent	2000	8	2	primary						plus sediment
5	35	1/6/05	influent	2000	8	2	primary		0.22				plus sediment
5	35	1/6/05	effluent	3000	11	1	primary	ND	0.37	70	280	22.8	plus sediment
5	35	1/6/05	influent	3000	11	1	primary	6.1	0.54	42	300	22.1	plus sediment
5	35	1/6/05	effluent	3000	11	2	primary	ND	0.26	23	390	11.8	plus sediment
5	35	1/6/05	influent	3000	11	2	primary	ND	0.16	26	390	8.68	plus sediment
5	35	1/6/05	effluent	4000	15	1	primary						plus sediment
5	35	1/6/05	influent	4000	15	1	primary	ND	0.48				plus sediment
5	35	1/6/05	effluent	4000	15	2	primary						plus sediment
5	35	1/6/05	influent	4000	15	2	primary		0.18				plus sediment
5	35	1/6/05	effluent	5000	19	1	primary						plus sediment
5	35	1/6/05	influent	5000	19	1	primary	ND	0.47				plus sediment
5	35	1/6/05	effluent	5000	19	2	primary						plus sediment
5	35	1/6/05	influent	5000	19	2	primary		0.19				plus sediment
5	35	1/6/05	effluent	6000	23	1	primary	ND	0.55	67	290	23	plus sediment
5	35	1/6/05	influent	6000	23	1	primary	ND	0.49	63	280	24.3	plus sediment
5	35	1/6/05	effluent	6000	23	2	primary	ND	0.21	24	300	11.3	plus sediment
5	35	1/6/05	influent	6000	23	2	primary	ND	0.21	26	240	10.4	plus sediment
5	35	1/7/05	effluent	1000	4	3	primary						plus sediment
5	35	1/7/05	influent	1000	4	3	primary		0.074				plus sediment
5	35	1/7/05	effluent	1000	4	4	primary						plus sediment
5	35	1/7/05	influent	1000	4	4	primary		0.65				plus sediment
5	35	1/7/05	effluent	2000	8	3	primary						plus sediment
5	35	1/7/05	influent	2000	8	3	primary		0.15				plus sediment

Target oil (5, 15 or 0) (mg/L)	Flow Rate (15, 25 or 35 gpm)	Date	Sample Location (influent or effluent)	Sample Volume During Run	Total V, m^3	Filter (1, 2, 3 or 4)	Primary, duplicate or triplicate	1664	8015M	TSS	TDS	turbidity	test
5	35	1/7/05	effluent	2000	8	4	primary						plus sediment
5	35	1/7/05	influent	2000	8	4	primary		0.69				plus sediment
5	35	1/7/05	effluent	3000	11	3	primary	ND	0.23	34	280	21.6	plus sediment
5	35	1/7/05	influent	3000	11	3	primary	ND	0.36	51	240	22	plus sediment
5	35	1/7/05	effluent	3000	11	4	primary	ND	0.45	75	240	27.4	plus sediment
5	35	1/7/05	influent	3000	11	4	primary	ND	0.5	100	240	28.1	plus sediment
5	35	1/7/05	effluent	4000	15	3	primary						plus sediment
5	35	1/7/05	influent	4000	15	3	primary		0.25				plus sediment
5	35	1/7/05	effluent	4000	15	4	primary						plus sediment
5	35	1/7/05	influent	4000	15	4	primary		0.44				plus sediment
5	35	1/7/05	effluent	5000	19	3	primary						plus sediment
5	35	1/7/05	influent	5000	19	3	primary		0.28				plus sediment
5	35	1/7/05	effluent	5000	19	4	primary						plus sediment
5	35	1/7/05	influent	5000	19	4	primary		0.48				plus sediment
5	35	1/7/05	effluent	6000	23	3	primary	ND	0.32	47	230	22.8	plus sediment
5	35	1/7/05	influent	6000	23	3	primary	ND	0.29	41	260	24.1	plus sediment
5	35	1/7/05	effluent	6000	23	4	primary	ND	0.52	66	250	29.7	plus sediment
5	35	1/7/05	influent	6000	23	4	primary	ND	0.65	84	250	27.9	plus sediment
5	25	1/10/05	effluent	9000	34	1	primary	5.9	0.84	140	250		plus sediment
5	25	1/10/05	influent	9000	34	1	primary	ND	0.75	140	260		plus sediment
5	25	1/10/05	effluent	9000	34	2	primary	ND	0.97	97	240		plus sediment
5	25	1/10/05	influent	9000	34	2	primary	ND	0.88	110	260		plus sediment
5	25	1/10/05	effluent	12000	45	1	primary	ND	0.71	140	270		plus sediment
5	25	1/10/05	influent	12000	45	1	primary	ND	1	130	260		plus sediment
5	25	1/10/05	effluent	12000	45	2	primary	ND	0.94	95	250		plus sediment
5	25	1/10/05	influent	12000	45	2	primary	ND	1	110	240		plus sediment
5	25	1/11/05	effluent	9000	34	3	primary	ND	0.47	62	290		plus sediment
5	25	1/11/05	influent	9000	34	3	primary	ND	0.52	62	220		plus sediment
5	25	1/11/05	effluent	9000	34	4	primary	ND	0.45	58	240		plus sediment
5	25	1/11/05	influent	9000	34	4	primary	ND	0.45	76	250		plus sediment
5	25	1/11/05	effluent	12000	45	3	primary	ND	0.37	57	270		plus sediment

Target oil (5, 15 or 0) (mg/L)	Flow Rate (15, 25 or 35 gpm)	Date	Sample Location (influent or effluent)	Sample Volume During Run	Total V, m^3	Filter (1, 2, 3 or 4)	Primary, duplicate or triplicate	1664	8015M	TSS	TDS	turbidity	test
5	25	1/11/05	influent	12000	45	3	primary	ND	0.31	60	270		plus sediment
5	25	1/11/05	effluent	12000	45	4	primary	ND	0.38	63	240		plus sediment
5	25	1/11/05	influent	12000	45	4	primary	ND	0.48	81	240		plus sediment
5	15	1/12/05	effluent	15000	57	1	primary	ND	0.43	94	240		plus sediment
5	15	1/12/05	influent	15000	57	1	primary	ND	0.32	96	250		plus sediment
5	15	1/12/05	effluent	18000	68	1	primary	ND	0.55	94	250		plus sediment
5	15	1/12/05	influent	18000	68	1	primary	ND	0.32	91	280		plus sediment
5	15	1/13/05	effluent	15000	57	2	primary	ND	0.32	68	260		plus sediment
5	15	1/13/05	influent	15000	57	2	primary	ND	0.28	75	240		plus sediment
5	15	1/13/05	effluent	18000	68	2	primary	ND	0.34	79	260		plus sediment
5	15	1/13/05	influent	18000	68	2	primary	ND	0.38	74	250		plus sediment
5	15	1/14/05	effluent	15000	57	3	primary	ND	0.26	62	260		plus sediment
5	15	1/14/05	influent	15000	57	3	primary	ND	0.12	82	260		plus sediment
5	15	1/14/05	effluent	18000	68	3	primary	ND	0.47	69	260		plus sediment
5	15	1/14/05	influent	18000	68	3	primary	ND	0.39	82	240		plus sediment
5	15	1/15/05	effluent	15000	57	4	primary	ND	1.6	55	160		plus sediment
5	15	1/15/05	influent	15000	57	4	primary	ND	0.3	75	160		plus sediment
5	15	1/15/05	effluent	18000	68	4	primary	ND	0.79	61	170		plus sediment
5	15	1/15/05	influent	18000	68	4	primary	ND	0.32	77	170		plus sediment
15	35	1/18/05	effluent	21000	79	1	primary	ND	1	45	170		plus sediment
15	35	1/18/05	influent	21000	79	1	primary	ND	0.89	53	170		plus sediment
15	35	1/18/05	effluent	21000	79	2	primary	ND	0.77	57	180		plus sediment
15	35	1/18/05	influent	21000	79	2	primary	5.5	0.65	63	180		plus sediment
15	35	1/18/05	effluent	24000	91	1	primary	ND	0.89	39	170		plus sediment
15	35	1/18/05	influent	24000	91	1	primary	ND	0.85	51	170		plus sediment
15	35	1/18/05	effluent	24000	91	2	primary	ND	0.86	59	180		plus sediment
15	35	1/18/05	influent	24000	91	2	primary	ND	0.65	52	180		plus sediment
15	35	1/19/05	effluent	21000	79	3	primary	1.2	1.2	78	180		plus sediment
15	35	1/19/05	influent	21000	79	3	primary	6.2	0.97	95	180		plus sediment
15	35	1/19/05	effluent	21000	79	4	primary	ND	1.1	45	170		plus sediment
15	35	1/19/05	influent	21000	79	4	primary	ND	1.1	51	170		plus sediment

Target oil (5, 15 or 0) (mg/L)	Flow Rate (15, 25 or 35 gpm)	Date	Sample Location (influent or effluent)	Sample Volume During Run	Total V, m^3	Filter (1, 2, 3 or 4)	Primary, duplicate or triplicate	1664	8015M	TSS	TDS	turbidity	test
15	35	1/19/05	effluent	24000	91	3	primary	ND	2.1	69	180		plus sediment
15	35	1/19/05	influent	24000	91	3	primary	ND	1.6	68	160		plus sediment
15	35	1/19/05	effluent	24000	91	4	primary	ND	1.5	22	180		plus sediment
15	35	1/19/05	influent	24000	91	4	primary	ND	0.95	51	180		plus sediment
15	25	1/20/05	effluent	27000	102	1	primary	7.3	4.1	28	180		plus sediment
15	25	1/20/05	influent	27000	102	1	primary	7.8	4.2	28	180		plus sediment
15	25	1/20/05	effluent	27000	102	2	primary	5.4	4.7	27	180		plus sediment
15	25	1/20/05	influent	27000	102	2	primary	5.8	3.9	24	180		plus sediment
15	25	1/20/05	effluent	30000	113	1	primary	5.7	4.1	32	180		plus sediment
15	25	1/20/05	influent	30000	113	1	primary	6.3	4.2	32	170		plus sediment
15	25	1/20/05	effluent	30000	113	2	primary	ND	5.1	17	180		plus sediment
15	25	1/20/05	influent	30000	113	2	primary	5.9	4.7	14	180		plus sediment
15	25	1/21/05	effluent	27000	102	3	primary	5.2	3.2	30	180		plus sediment
15	25	1/21/05	influent	27000	102	3	primary	6	3.7	31	180		plus sediment
15	25	1/21/05	effluent	27000	102	4	primary	6.2	3.6	30	180		plus sediment
15	25	1/21/05	influent	27000	102	4	primary	7.6	3.4	40	180		plus sediment
15	25	1/21/05	effluent	30000	113	3	primary	5.3	3.6	36	180		plus sediment
15	25	1/21/05	influent	30000	113	3	primary	7	4	39	180		plus sediment
15	25	1/21/05	effluent	30000	113	4	primary	5.8	3.3	27	180		plus sediment
15	25	1/21/05	influent	30000	113	4	primary	6.6	3.5	34	190		plus sediment
15	25	1/25/05	effluent	33000	125	1	primary	9.5					plus sediment
15	25	1/25/05	influent	33000	125	1	primary	11					plus sediment
15	25	1/25/05	effluent	33000	125	2	primary	3.8					plus sediment
15	25	1/25/05	influent	33000	125	2	primary	6.7					plus sediment
15	25	1/25/05	effluent	36000	136	1	primary	6.5		102			plus sediment
15	25	1/25/05	influent	36000	136	1	primary	11		94			plus sediment
15	25	1/25/05	effluent	36000	136	2	primary	4.4		90			plus sediment
15	25	1/25/05	influent	36000	136	2	primary	7.4		99			plus sediment
15	25	1/26/05	effluent	33000	125	3	primary	7.2					plus sediment
15	25	1/26/05	influent	33000	125	3	primary	9.4					plus sediment
15	25	1/26/05	effluent	33000	125	4	primary	6.2					plus sediment

Target oil (5, 15 or 0) (mg/L)	Flow Rate (15, 25 or 35 gpm)	Date	Sample Location (influent or effluent)	Sample Volume During Run	Total V, m^3	Filter (1, 2, 3 or 4)	Primary, duplicate or triplicate	1664	8015M	TSS	TDS	turbidity	test
15	25	1/26/05	influent	33000	125	4	primary	9.8					plus sediment
15	25	1/26/05	effluent	36000	136	3	primary	5.9		90			plus sediment
15	25	1/26/05	influent	36000	136	3	primary	6.2		90			plus sediment
15	25	1/26/05	effluent	36000	136	4	primary	7		84			plus sediment
15	25	1/26/05	influent	36000	136	4	primary	13.1		95			plus sediment
15	15	1/27/05	effluent	39000	147	1	primary	10.4					plus sediment
15	15	1/27/05	influent	39000	147	1	primary	13.9					plus sediment
15	15	1/27/05	effluent	39000	147	2	primary	7.9					plus sediment
15	15	1/27/05	influent	39000	147	2	primary	18					plus sediment
15	15	1/27/05	effluent	42000	159	1	primary	6.4		109			plus sediment
15	15	1/27/05	influent	42000	159	1	primary	9.7		95			plus sediment
15	15	1/27/05	effluent	42000	159	2	primary	8.8		57			plus sediment
15	15	1/27/05	influent	42000	159	2	primary	14.2		85			plus sediment
15	15	1/28/05	effluent	39000	147	3	primary	9.8					plus sediment
15	15	1/28/05	influent	39000	147	3	primary	11.1					plus sediment
15	15	1/28/05	effluent	39000	147	4	primary	3.5					plus sediment
15	15	1/28/05	influent	39000	147	4	primary	7.6					plus sediment
15	15	1/28/05	effluent	42000	159	3	primary	6.9		88			plus sediment
15	15	1/28/05	influent	42000	159	3	primary	10.2		92			plus sediment
15	15	1/28/05	effluent	42000	159	4	primary	2.8		105			plus sediment
15	15	1/28/05	influent	42000	159	4	primary	5.5		95			plus sediment
15	15	1/31/05	effluent	45000	170	1	primary	11.4					plus sediment
15	15	1/31/05	influent	45000	170	1	primary	10					plus sediment
15	15	1/31/05	effluent	48000	181	1	primary	3.8		104			plus sediment
15	15	1/31/05	influent	48000	181	1	primary	20.6		96			plus sediment
15	15	2/1/05	effluent	45000	170	2	primary	7.5					plus sediment
15	15	2/1/05	influent	45000	170	2	primary	12.4					plus sediment
15	15	2/1/05	effluent	48000	181	2	primary	3.4		101			plus sediment
15	15	2/1/05	influent	48000	181	2	primary	14.3		106			plus sediment
15	15	2/2/05	effluent	45000	170	3	primary	8.3					plus sediment
15	15	2/2/05	influent	45000	170	3	primary	11.7					plus sediment

Target oil (5, 15 or 0) (mg/L)	Flow Rate (15, 25 or 35 gpm)	Date	Sample Location (influent or effluent)	Sample Volume During Run	Total V, m^3	Filter (1, 2, 3 or 4)	Primary, duplicate or triplicate	1664	8015M	TSS	TDS	turbidity	test
15	15	2/2/05	effluent	48000	181	3	primary	11.8		100			plus sediment
15	15	2/2/05	influent	48000	181	3	primary	16.1		101			plus sediment
15	15	2/4/05	effluent	45000	170	4	primary	6					plus sediment
15	15	2/4/05	influent	45000	170	4	primary	9.9					plus sediment
15	15	2/4/05	effluent	48000	181	4	primary	8.5		87.5			plus sediment
15	15	2/4/05	influent	48000	181	4	primary	8.2		91			plus sediment
15	15	2/7/05	effluent	51000	193	1	primary	11.1					plus sediment
15	15	2/7/05	influent	51000	193	1	primary	11.7					plus sediment
15	15	2/7/05	effluent	54000	204	1	primary	8.1		109			plus sediment
15	15	2/7/05	influent	54000	204	1	primary	2.9		95			plus sediment
15	15	2/8/05	effluent	51000	193	2	primary	6.1					plus sediment
15	15	2/8/05	influent	51000	193	2	primary	8.9					plus sediment
15	15	2/8/05	effluent	54000	204	2	primary	5.6		88			plus sediment
15	15	2/8/05	influent	54000	204	2	primary	12		92			plus sediment
15	15	2/9/05	effluent	51000	193	3	primary	8.7					plus sediment
15	15	2/9/05	influent	51000	193	3	primary	10					plus sediment
15	15	2/9/05	effluent	54000	204	3	primary	6.1		95			plus sediment
15	15	2/9/05	influent	54000	204	3	primary	4.5		95			plus sediment
15	15	2/11/05	effluent	51000	193	4	primary	6.8					plus sediment
15	15	2/11/05	influent	51000	193	4	primary	9.4					plus sediment
15	15	2/11/05	effluent	54000	204	4	primary	6		71			plus sediment
15	15	2/11/05	influent	54000	204	4	primary	5.8		91			plus sediment
15	15	2/14/05	effluent	57000	215	1	primary	9.1					plus sediment
15	15	2/14/05	influent	57000	215	1	primary	26.4					plus sediment
15	15	2/14/05	effluent	60000	227	1	primary	10.4		106			plus sediment
15	15	2/14/05	influent	60000	227	1	primary	11.2		96			plus sediment
15	15	2/15/05	effluent	57000	215	2	primary	5.2					plus sediment
15	15	2/15/05	influent	57000	215	2	primary	32.5					plus sediment
15	15	2/15/05	effluent	60000	227	2	primary	6.1		87			plus sediment
15	15	2/15/05	influent	60000	227	2	primary	6.9		95			plus sediment
15	15	2/16/05	effluent	57000	215	3	primary	24					plus sediment

Target oil (5, 15 or 0) (mg/L)	Flow Rate (15, 25 or 35 gpm)	Date	Sample Location (influent or effluent)	Sample Volume During Run	Total V, m^3	Filter (1, 2, 3 or 4)	Primary, duplicate or triplicate	1664	8015M	TSS	TDS	turbidity	test
15	15	2/16/05	influent	57000	215	3	primary	41.1		100			plus sediment
15	15	2/18/05	effluent	57000	215	4	primary	1.9					plus sediment
15	15	2/18/05	influent	57000	215	4	primary	32.9					plus sediment
15	15	2/18/05	effluent	60000	227	4	primary	7.3		67.9			plus sediment
15	15	2/18/05	influent	60000	227	4	primary	9.6		90			plus sediment
15	15	2/21/05	effluent	63000	238	1	primary	3.9					plus sediment
15	15	2/21/05	influent	63000	238	1	primary	46.6					plus sediment
15	15	2/21/05	effluent	66000	249	1	primary	5.9		104			plus sediment
15	15	2/21/05	influent	66000	249	1	primary	23		90			plus sediment
15	15	2/22/05	effluent	63000	238	2	primary	2.3					plus sediment
15	15	2/22/05	influent	63000	238	2	primary	2.3					plus sediment
15	15	2/22/05	effluent	66000	249	2	primary	10.5		88			plus sediment
15	15	2/22/05	influent	66000	249	2	primary	10.3		95			plus sediment
15	15	2/23/05	effluent	63000	238	3	primary	19					plus sediment
15	15	2/23/05	influent	63000	238	3	primary	37					plus sediment
15	15	2/23/05	effluent	66000	249	3	primary	10.2		100			plus sediment
15	15	2/23/05	influent	69000	249	3	primary	9.6		96			plus sediment
15	15	2/25/05	effluent	63000	238	4	primary	16.3					plus sediment
15	15	2/25/05	influent	63000	238	4	primary	28.3					plus sediment
15	15	2/25/05	effluent	66000	249	4	primary	9.6		69.6			plus sediment
15	15	2/25/05	influent	66000	249	4	primary	10.4		89.9			plus sediment
15	25	2/25/05	effluent	69000	261	1	primary	10.9					plus sediment
15	25	2/25/05	influent	69000	261	1	primary	40					plus sediment
15	25	2/25/05	effluent	72000	272	1	primary	8.4					plus sediment
15	25	2/25/05	influent	72000	272	1	primary	13.2					plus sediment
15	25	2/28/05	effluent	69000	261	2	primary	12.2					plus sediment
15	25	2/28/05	influent	69000	261	2	primary	15.7					plus sediment
15	25	2/28/05	effluent	72000	272	2	primary	18.9					plus sediment
15	25	2/28/05	influent	72000	272	2	primary	13.5					plus sediment
15	25	3/1/05	effluent	75000	284	3	primary	27.5					plus sediment
15	25	3/1/05	influent	78000	295	3	primary	28.6					plus sediment

Target oil (5, 15 or 0) (mg/L)	Flow Rate (15, 25 or 35 gpm)	Date	Sample Location (influent or effluent)	Sample Volume During Run	Total V, m^3	Filter (1, 2, 3 or 4)	Primary, duplicate or triplicate	1664	8015M	TSS	TDS	turbidity	test
15	25	3/1/05	effluent	69000	261	4	primary	9.7					plus sediment
15	25	3/1/05	influent	69000	261	4	primary	25.9					plus sediment
15	25	3/1/05	effluent	72000	272	3	primary	18.9					plus sediment
15	25	3/1/05	influent	75000	284	3	primary	26.8					plus sediment
15	25	3/1/05	effluent	72000	272	4	primary	12.4					plus sediment
15	25	3/1/05	influent	72000	272	4	primary	13.5					plus sediment
15	25	3/2/05	effluent	75000	284	1	primary	6.2					plus sediment
15	25	3/2/05	influent	75000	284	1	primary	15.9					plus sediment
15	25	3/2/05	effluent	75000	284	2	primary	11.7					plus sediment
15	25	3/2/05	influent	75000	284	2	primary	30.7					plus sediment
15	25	3/2/05	effluent	78000	295	1	primary	6.4		95			plus sediment
15	25	3/2/05	influent	78000	295	1	primary	7.6		88			plus sediment
15	25	3/2/05	effluent	78000	295	2	primary	10.5		85			plus sediment
15	25	3/2/05	influent	78000	295	2	primary	11.1		93			plus sediment
15	25	3/4/05	effluent	81000	306	3	primary	20.5					plus sediment
15	25	3/4/05	influent	84000	318	3	primary	43.6					plus sediment
15	25	3/4/05	effluent	75000	284	4	primary	9					plus sediment
15	25	3/4/05	influent	75000	284	4	primary	31.4					plus sediment
15	25	3/4/05	effluent	78000	295	3	primary	12.9		199			plus sediment
15	25	3/4/05	influent	81000	306	3	primary	9.9		107			plus sediment
15	25	3/4/05	effluent	78000	295	4	primary	9.6		63			plus sediment
15	25	3/4/05	influent	78000	295	4	primary	8.2		97			plus sediment
15	35	3/7/05	effluent	81000	306	1	primary	9.6					plus sediment
15	35	3/7/05	influent	81000	306	1	primary	18.1					plus sediment
15	35	3/7/05	effluent	81000	306	2	primary	14.1					plus sediment
15	35	3/7/05	influent	81000	306	2	primary	26.7					plus sediment
15	35	3/7/05	effluent	84000	318	1	primary	9.1		89			plus sediment
15	35	3/7/05	influent	84000	318	1	primary	11.3		101			plus sediment
15	35	3/7/05	effluent	84000	318	2	primary	11.6		123			plus sediment
15	35	3/7/05	influent	84000	318	2	primary	12.7		122			plus sediment
15	35	3/9/05	effluent	87000	329	3	primary	27.3					plus sediment

Target oil (5, 15 or 0) (mg/L)	Flow Rate (15, 25 or 35 gpm)	Date	Sample Location (influent or effluent)	Sample Volume During Run	Total V, m^3	Filter (1, 2, 3 or 4)	Primary, duplicate or triplicate	1664	8015M	TSS	TDS	turbidity	test
15	35	3/9/05	influent	90000	340	3	primary	29.5					plus sediment
15	35	3/9/05	effluent	81000	306	4	primary	9.5					plus sediment
15	35	3/9/05	influent	81000	306	4	primary	22.6					plus sediment
15	35	3/9/05	effluent	84000	318	3	primary	11.7		92			plus sediment
15	35	3/9/05	influent	87000	329	3	primary	8.4		95			plus sediment
15	35	3/9/05	effluent	84000	318	4	primary	12.1		101			plus sediment
15	35	3/9/05	influent	84000	318	4	primary	17.9		101			plus sediment
15	35	3/11/05	effluent	87000	329	1	primary	9					plus sediment
15	35	3/11/05	influent	87000	329	1	primary	23.8					plus sediment
15	35	3/11/05	effluent	87000	329	2	primary	10					plus sediment
15	35	3/11/05	influent	87000	329	2	primary	14.6					plus sediment
15	35	3/11/05	effluent	90000	340	1	primary	8.1		84			plus sediment
15	35	3/11/05	influent	90000	340	1	primary	9		91			plus sediment
15	35	3/11/05	effluent	90000	340	2	primary	7.9		88			plus sediment
15	35	3/11/05	influent	90000	340	2	primary	9.2		97			plus sediment
15	35	3/14/05	effluent	93000	352	3	primary	3.5					plus sediment
15	35	3/14/05	influent	96000	363	3	primary	4.1					plus sediment
15	35	3/14/05	effluent	87000	329	4	primary	7.9					plus sediment
15	35	3/14/05	influent	87000	329	4	primary	9.3					plus sediment
15	35	3/14/05	effluent	90000	340	3	primary	10.8		62			plus sediment
15	35	3/14/05	influent	93000	352	3	primary	14		63			plus sediment
15	35	3/14/05	effluent	90000	340	4	primary	7.6		93			plus sediment
15	35	3/14/05	influent	90000	340	4	primary	6.8		98			plus sediment

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