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Pilot Scale Design and Demonstration of a Filter System for Adsorption of Oil and Grease in Urban Runoff

A thesis submitted in partial satisfaction of the requirements for the degree Master of Science in Civil Engineering

by

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ABSTRACT OF THE THESIS

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Master of Science in Civil Engineering
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Professor Michael K. Stenstrom, Chair

A pilot scale study of an oil sorbent filter system for the adsorption of oil and grease from urban runoff was conducted. Particular attention was paid to the design and construction of the filter and to the performance of the sorbent media in different field conditions. The filter system was tested at a multi-use commercial facility and a high-use parking lot, both of which were in Anaheim, CA. Hydraulic performance, pollutant removal, and overall feasibility were examined in three separate filter runs. The filter performed comparably to other catch basin treatment devices in removal of oil and grease but achieved a higher removal of suspended solids. Oil and grease removal ranged from 5 to 38%, and suspended solids removal ranged from 22 to 92%. Filter flow characteristics were adversely affected by the accumulation of fine particles on top

of the filter bed. Filter run times were less than 2 hours at flow rates between 1 and 3 GPM per $ft.^2$, and filter by-pass occurred in each run. Further pilot testing must be conducted to improve the hydraulic performance of the filter and the adsorption of oil and grease.

1.0 Introduction

1.1 Goals

Pollution associated with stormwater runoff and industrial washwater is under increasing scrutiny by regulatory agencies and environmental protection groups throughout the United States. Specifically, the concentration of oil and grease in runoff from industrial sites and urban areas frequently exceeds the level determined as "safe" by the USEPA (Coburn, 1994). A number of source control and treatment methods for oil and grease control have been tested, but few technologies have been identified that are effective and have widespread applicability. The goal of this study was to conduct a pilot test of the performance of oil adsorbent media that was previously evaluated in the laboratory by Lau and Stenstrom (1995). The capacity of polypropylene adsorbent media to adsorb oils from water in ideal conditions is well known, thus particular attention was paid to the design and construction of the filter in order to best use the adsorptive capacity of the media in the field. An equally important focus was placed on making observations that would help identify appropriate applications of the technology.

1.2 Approach

The study consisted of four major components:

1. Extensive literature review to assess the need for new technology and engineered systems to control oil and grease contamination in runoff.

2. Construction of a portable filtration unit to enable pilot testing of the adsorbent media in a pressurized filter column.
3. Testing of the filtration system at various sites to gather quantitative and qualitative data on the performance of the filter media in field conditions.
4. Preliminary evaluation of how and where the adsorbent media filtration system could be applied.

Although adsorption of oil and grease was the major target mechanism in this study, some conventional filtration of particulate matter by the polypropylene media was also anticipated and carefully examined in each of the pilot tests. In fact, the combined potential for removal of oil and grease and fine particles and the implementation of pressurized flow were the key distinguishing factors between this system and other catch basin treatment devices. One of the major obstacles to removing non-point source pollutants from urban runoff is the diffuse nature of the sources of pollution and the degree of variability in the size, shape, and orientation of the catch basins used to collect the runoff. As a result, a great deal of attention was paid to the development of a treatment technology and engineered system that would address the complexity of retrofitting existing drainage basins and achieve efficient removal of oil and grease and particulate matter from a variety of sources.

2.0 Background

2.1 Oil and Grease- Sources and Impact

The term "Oil and Grease" encompasses a number of different compounds and refers specifically to a standard laboratory test method that quantifies the mass of material in a water sample that is solvent-extractable (*Standard Methods*, 1992). Included in this parameter are hydrocarbons, lubricating oils, and greases common in food preparation activities. This class of compounds is present in runoff water as a result of a wide array of societal activities and natural processes, including the following major sources (Stenstrom et al, 1982; Pitt et al, 1995):

- dumping of used motor oil
- emissions of engines in normal operation
- spills during transportation of bulk quantities of oil
- drippings from vehicles and industrial equipment
- erosion of paved surfaces
- waste from restaurant facilities

Although oil spills are dramatic events and often generate substantial news media coverage around the world, spills are not the largest source of oil and grease pollution. In 1982, marine transportation was the largest source of petroleum hydrocarbons to the oceans at greater than 2 metric tons annually (Stenstrom et al, 1982). At the same time, it was estimated that urban runoff introduced between 0.1 and

0.5 metric tons of hydrocarbons annually into the oceans, compared to 0.1 to 0.4 metric tons annually from oil spills (Stenstrom et al, 1982). Due to improved technology and regulation of point sources and increased urbanization in coastal areas such as Southern California, the volume and relative contribution of oil and grease from urban runoff has increased since 1982 and generated concern over the potential impacts on aquatic life and human health (Surfrider Foundation, 1994).

The U.S. Environmental Protection Agency (USEPA) estimated in 1994 that over 180 million gallons of used motor oil is poured into U.S. storm drains every year by "do-it-yourself" auto mechanics, which is 16 times greater than the amount of oil released in the Exxon Valdez spill in Alaska (Coburn, 1994). In the Los Angeles Basin, it was reported that approximately 15 million gallons of oil is discharged into Santa Monica Bay each year, the volume equivalent of one Exxon Valdez spill (Surfrider Foundation, 1995). While the concentrations of oil in runoff are generally at least two orders of magnitude lower than those generated by an oil spill, seasonal rainfall and routine dry weather discharges create a continuous, long term source of oil to the ocean. Furthermore, stormwater outfalls are often located in the vicinity of beaches and thus present a risk of acute human health effects and long term toxicity to aquatic life (Stenstrom et al, 1982; Surfrider Foundation, 1994). It will be important to continue the evaluation of potential toxicological risks associated with the long history of discharge of waste oils and greases to the ocean in order to guide the development of control technologies for urban runoff pollution.

2.2 Current Pollution Prevention and Treatment Efforts

In order to address the risks associated with urban runoff pollution, a great deal of work has been done in recent years to develop management and infrastructure tools to enable environmental professionals and industrial managers to reduce the amount of pollution discharged to storm drains. These tools are commonly called "Best Management Practices (BMP's)" and consist of new operating procedures for facilities and improved infrastructure components that minimize or eliminate pollutants in industrial effluent and urban runoff. Operating procedures are often the most robust improvements a facility or community can make because they require people to change their ways and to become educated about the impact of their activities on community resources such as rivers and estuaries. Achieving these management changes can be difficult and sometimes costly, but the change often extends to additional operations not originally targeted by the BMP because people apply what they have learned to all of their activities. An example of a source control BMP that requires broad spectrum changes within a community is the control of land use and development to maximize pervious land area and vegetated land, which can provide opportunity for biological degradation of pollutants prior to discharge to oceans and lakes (Stenstrom et al, 1982). This style of land management allows a greater percentage of runoff water to infiltrate into the ground, where the water is subject to filtration effects in the soil and biodegradation by naturally-occurring bacteria.

Infrastructure improvements do not carry the same potential for cultural change, but they are often easier to implement and more permanent than operational BMP's. Because the pollutants in urban runoff are typically from non-point sources, treatment technologies have focused on small urban catchments that are known to collect highly polluted runoff. Installation of treatment devices at these locations is typically designed to reduce pollutant loads at the 'hot spots' and does not guarantee the consistently high level of pollution control often achieved in the control of point sources. Some common infrastructure BMP's used to control oil and grease and particulate matter in runoff include the following (CA Stormwater Quality Task Force, 1993; Uribe & Associates, 1994):

- Detention Ponds: allow for settling of particles and dense material; require large amounts of space
- Catch Basin and Inlet Devices: subject of current testing; potential for >75% removal of coarse solids and oil and grease
- Infiltration ponds: depend on highly permeable soil; can be highly effective at removing insoluble constituents; require considerable space
- Porous Pavement: similar considerations to infiltration ponds; space conservative, but subject to installation and maintenance problems in certain applications
- Oil/Solids Clarifiers: moderate removal of oils and solids in new designs; high cost of installation and maintenance relative to other options
- Sand Filters: good removal of solids; subject to frequent maintenance routines due to clogging; moderate removal of oil and grease

- Street Cleaning: difficult to determine effectiveness; potential to remove some coarse solids before discharge to drainage system

2.3 Catch Basin Inserts

Due to the perceived cost of retrofitting extensive storm drain systems, treatment devices that can be installed in individual catch basins, close to the source of pollution, may be a cost-effective means of controlling certain runoff pollutants (Pitt et al, 1994). Consequently, a detailed review of current technologies designed to treat urban runoff is both relevant and necessary for this study.

At least 8 manufacturers currently offer dedicated catch basin insert devices for the removal of solids and oil and grease (W&H Pacific 1992; Pitt et al, 1994; CBIC, 1995) The inserts are typically basket or tray-type devices designed to be suspended from the drain grate or attached to the side walls of a catch basin. In addition, researchers at the University of Alabama at Birmingham are developing a multi-chambered tank that includes a modified catch basin and is designed to remove substantial quantities of solids, oils, and other putative stormwater toxicants (Robertson et al, 1994). Problems typically associated with catch basin inserts include the following (Pitt et al, 1994; CBIC, 1995):

- Frequent clogging due to coarse material and debris
- Poor removal of fine particles, which often carry other pollutants
- Insufficient hydraulic capacity to handle stormwater flows

- Inconsistent sorption of oil and grease
- Difficult maintenance procedures

The ability of catch basins to remove pollutants varies from 0 to 98%, depending on the observed flow rate, suspended solids load, and length of use (CBIC, 1995; Pitt et al, 1994). The Catch Basin Insert Committee (CBIC), located in Washington State, recently tested three commercially available inserts and found that none reduced the total suspended solids (TSS) concentration by more than 20 mg/L in bench scale tests, and the devices often produced no removal of TSS in the field (CBIC, 1995). The main factors contributing to the poor removal of fine particles were frequent washout of the solids at moderate to high flows, frequent short-circuiting and by-passing of flow, and the build-up of a crust on the surface of the filter media (Pitt et al, 1994; CBIC, 1995).

Oil and grease removal in catch basin inserts also varied in recent studies between 0 and 90%, with performance consistently dropping off during use (Pitt et al, 1994; CBIC, 1995). The higher removal percentages reported by the CBIC were typically seen in bench tests with new media; percentage removal was consistently lower in the field experiments. Specifically, oil and grease removal in the field was always less than 30% and dropped off quickly at or above 2 inches of cumulative rainfall in the CBIC study (1995). The decrease in removal after 2 inches of rainfall was attributed to the build-up of a layer of sediment on top of the filter media, which prevented penetration of subsequent pollutants into the filter bed (CBIC, 1995). Further confounding the performance of catch basin inserts was the effect of flow. Certain catch basins were designed for high flow, and some devices were designed to dissipate the energy of incoming water and maintain a substantial hydraulic retention time in the filter (Pitt et al, 1994, CBIC, 1995). In general, the devices that were able to create a low velocity zone where the flow was in contact with the filter media demonstrated better removal of oil and grease due to the increased opportunity for adsorption (CBIC, 1995).

Recent improvements in the hydraulic performance and ease of maintenance of catch basin inserts have resulted in greater usability and reliability. However, it is important to note that the inserts are best suited to catch basins that drain relatively small areas and are easily accessed for maintenance (CBIC, 1995). Catch basin inserts may have a negative impact on drains in areas that are subject to high peak flows because the insert can become an obstacle to flow (CBIC, 1995). Major advantages of the current devices are the ease of maintenance and the increased ability to remove oil and grease. Maintenance is less costly and cumbersome because the inserts are lightweight and can be lifted out of the catch basin by one or two individuals for cleaning (CBIC, 1995). This process is favorable to the use of eductor trucks, which are used to vacuum sediment out of traditional catch basin sumps. Older catch basins also do not remove oil and grease, thus any removal by current designs is a substantial improvement. The most significant remaining obstacles to the use of catch basin inserts are the specificity of the devices according to flow, the dimensions of the targeted basin, and the need to protect the oil-adsorbing media from sediment build-up (CBIC, 1995). The degree to which each catch basin retrofit requires a custom insert device inhibits the widespread use of the technology for non-point source pollution prevention, especially in the private sector. Diagrams of a number of commercially-available catch basin inserts can be found in Appendix A.

2.4 Adsorbent Media

A number of oil and grease adsorbent media were evaluated for use in stormwater treatment by Lau and Stenstrom (1995b) in bench scale tests. In those tests, performance of different media varied considerably, but greater than 50% removal was demonstrated with all sorbents (Lau and Stenstrom, 1995b). As a result, Lau and Stenstrom (1995b) concluded that installation of an oil sorbent system in catch basins is a feasible means of removing oil and grease in urban runoff. Schematic diagrams of the processes used in those bench scale tests are reproduced in Figures 2.1 and 2.2.

Figure 2.1 Schematic Diagram of Bench Scale Micro-Column Study (Lau and Stenstrom, 1995b)

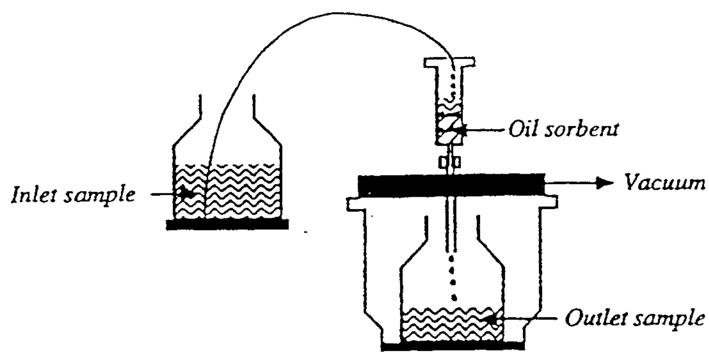
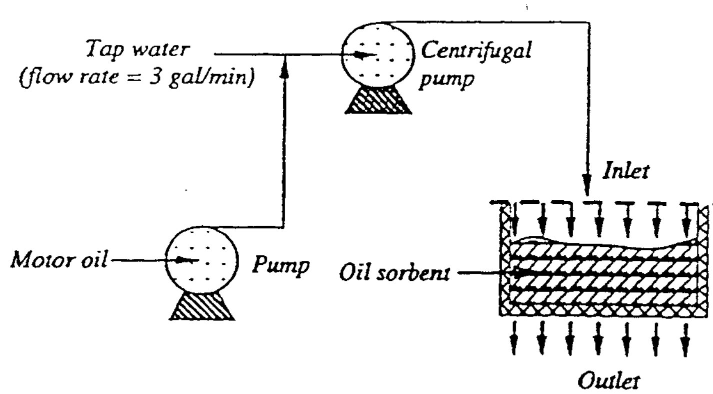


Figure 2.2 Schematic Diagram of Bench Scale Continuous Flow Study (Lau and Stenstrom, 1995b)



2.5 Other Devices

Catch basin inserts are just one category of treatment systems for removal of solids and oil and grease from runoff. There are two additional types of technologies that should be noted in the context of adsorbent media treatment devices. The first of these units is a "Compost Storm Water Treatment System", developed by W&H Pacific Inc. in Oregon. The Compost system uses readily available, high quality compost material as adsorbent media in large tanks placed at a storm drain outfall to take advantage of the high capacity of the humic compounds to adsorb metals, oils, and organic matter (W&H Pacific, 1992). The second technology is a "Multi-Chambered Stormwater Treatment Train" developed by the Department of Civil and Environmental Engineering at the University of Alabama at Birmingham. Included in the Multi-Chambered Treatment Train (MCTT) is a modified catch basin connected to a two-chambered tank, which is separated into an enhanced settling chamber and a mixed-media filter (Robertson et al, 1994).

The Compost system achieved promising removal rates in initial testing, averaging 95% removal of suspended solids and 87% removal of petroleum hydrocarbons (W&H Pacific, 1992). In addition, many of the constituents that are adsorbed or settled out in the compost bed, like oil and grease, are subsequently biodegraded by naturally-occurring microorganisms (W&H Pacific, 1992). The data on oil and grease removal was obscured by the sampling technique and low influent concentrations (average of 4 mg/L), but observations suggested that substantial removal occurred (W&H Pacific, 1992). The Compost system has the advantages of requiring less space than conventional detention ponds and making use of readily available compost material. Two potential obstacles to the use of an outfall-based compost system are the requirement for a parcel of land at crucial points in the storm drain system for siting of the compost bed and the risk of pollutant leaching into the groundwater. In the 1992 report, W&H Pacific stated their interest in developing smaller, drop-in modules to fit next to existing catch basins. A diagram of the compost system can be found in Appendix B.

The Multi-Chambered Treatment Train (MCTT) developed by Robertson, et al (1994) combines several conventional treatment methods into an integrated system that is installed below grade in place of a conventional catch basin. Runoff water passes over a flash aerator and into a grit chamber to remove large particles and volatile compounds; the water then flows into a second chamber where inclined tube settlers remove smaller particles and fine bubble diffusers and adsorbent media pads remove oil and grease (Robertson et al, 1994). In the final tank, water passes through a mixed-media filter, which includes, sand, peat, and filter fabric (Robertson et al, 1994). Results of pilot testing of this system showed substantial (70-100%) reductions in observed toxicity and suspended solids reductions (20-60%) (Robertson et al, 1994). Toxicity analysis was conducted using the Microtox™ test, which measures only the relative toxic effect of water samples on a bacteria culture. The filter chamber was responsible for the bulk of the toxicity reduction but also increased the suspended solids concentration over that of the effluent from the first settling chamber (Robertson et al, 1994). Specific oil and grease removal was not reported. Overall, the MCTT demonstrated the capability to reduce a broad range of pollutants and associated toxicity, but the removal rates and overall unit performance were greatly dependent on the influent flow rate (Robertson et al, 1994). The dependence on flow rates generally limits the use of the device to smaller drainage areas due to the correlation between the size of the chambers and the peak flows to be treated. A diagram of the MCTT system can be found in Appendix C.

3.0 Project Description

3.1 Filter Design and Construction

Design of the filtration system was based on the bench scale work performed by Lau and Stenstrom (1995) and a number of criteria developed to address the expected conditions for field implementation. The filter was designed with overall dimensions that enabled transportation of the unit by van or pickup truck. Also, the system was designed to pump runoff water from catch basins and manhole sumps in order to allow flexibility in the locations where the filter could be run. The process flow of the system consists of a centrifugal pump, basket strainer, globe valve, 6-inch diameter filter column, differential pressure gage, and flow meter. The process and instrumentation diagram is shown in Figure 3.1. The unit was constructed with PVC piping and fittings and was mounted on a steel frame with wheels for maximum portability. A schematic drawing and photographs of the unit are shown in Figures 3.2 - 3.5.

Construction of the filter was performed by the author, and the process yielded a number of design and construction challenges. Early versions of the system used ball valves for all flow control, a large duplex basket strainer, and pipe caps on both ends of the filter columns. Later versions evolved to include globe valves for better flow control, a smaller, more practical basket strainer, and flange connections at the tops of the filter columns to enable easy access during media clean-out. Unions were also inserted before and after each filter column to allow partial disassembly of the unit when necessary. Clear PVC pipe was chosen for the filter columns and crucial process piping in order to facilitate visual inspection of the filter performance. The detailed specifications and dimensions of the final version of the filter are shown in Table 3.1 and Table 3.2 respectively.

Ideally, the design of the filter flow rate and bed depth would be determined from the isotherms developed in the bench scale tests. Because of the enormous variability in source water obtained in runoff sampling and the desire for flexibility in the range of applications, the final dimensions and operating parameters were instead designed to accommodate a reasonable range of catch basin flows and scaled for pilot testing.

Figure 3.1 Process and Instrumentation Diagram

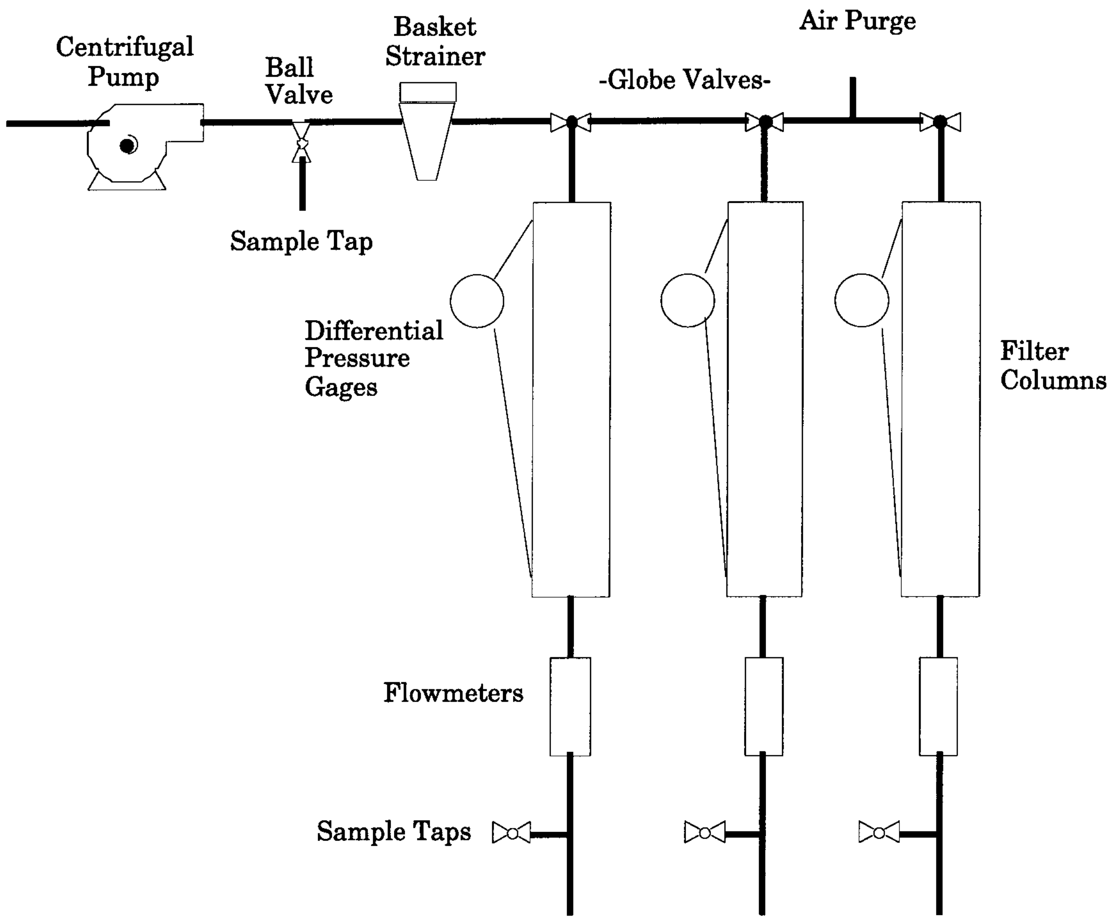


Figure 3.2 Schematic Diagram of Filter System

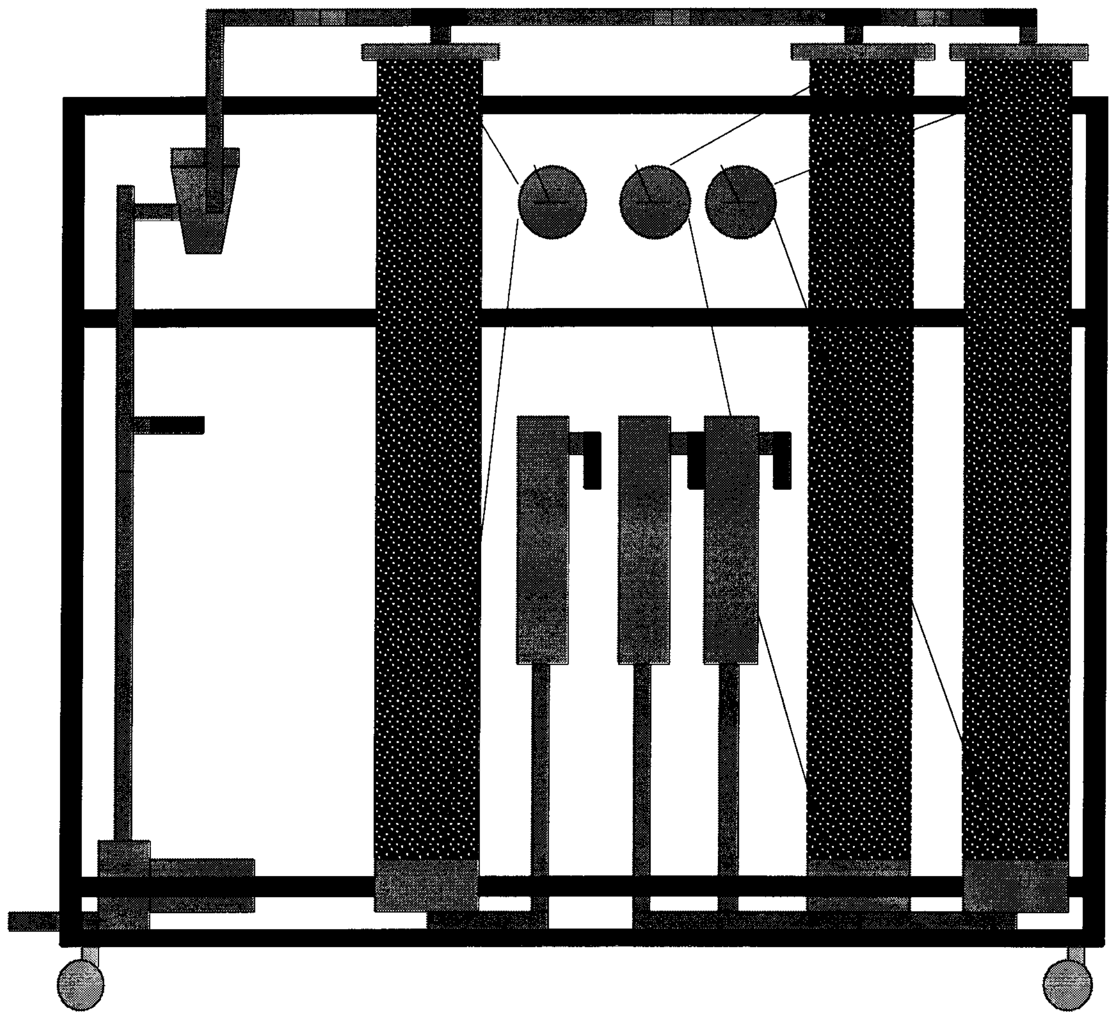


Figure 3.3 Photograph of Filter, Front View. Note: The third column is obscured from view from this angle. The picture was taken shortly after Filter Run 3, and the used media from that run can be seen in the column on the right side of the picture. The white patch visible in the used media is indicative of an area where filter by-pass did not occur, and the black patches are areas of by-pass.

Figure 3.4 Photograph of Filter, Rear View. <u>Note</u>: Only two of the three columns are visible in this picture, which was taken shortly after Filter Run 3. The column on the left hand side of the photograph was used in Filter Run 2. The filter by-pass is visible along the back side of the column, and the progression of the pollutant front in the bulk media is visible along the front of the column.

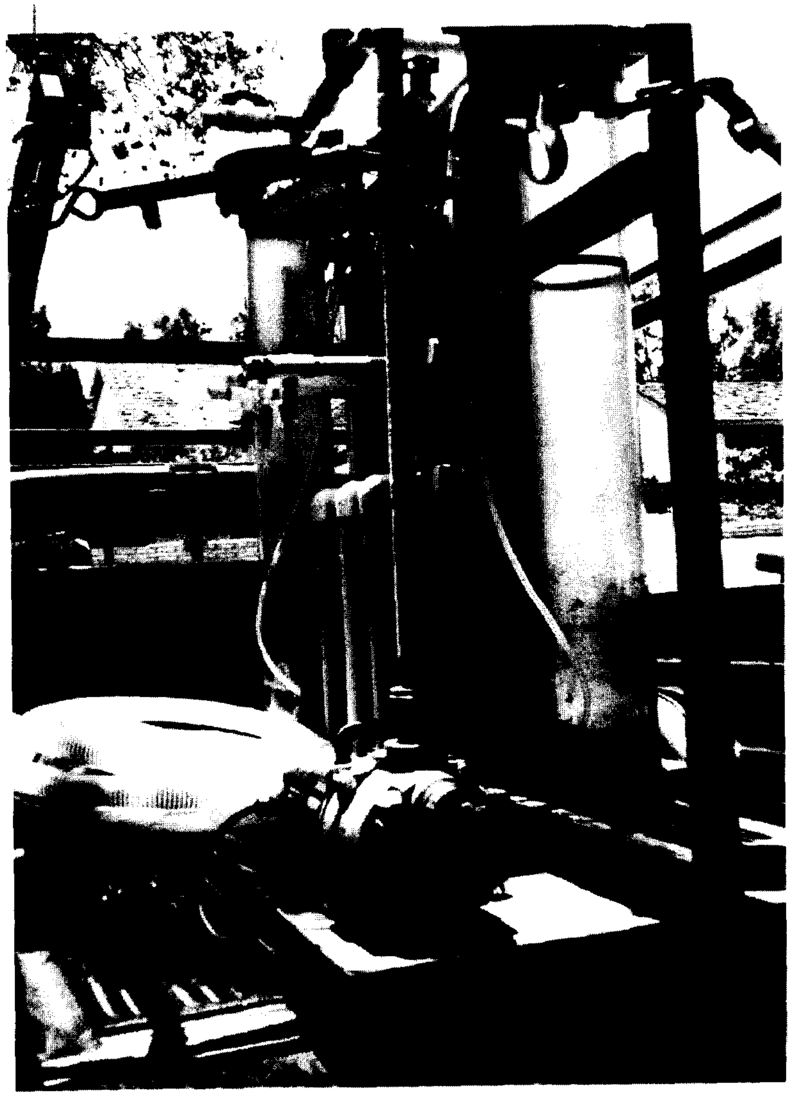


Figure 3.5 Photograph of Filter, in Transport. Note: The filter was constructed to fit easily in a standard pickup truck or van.

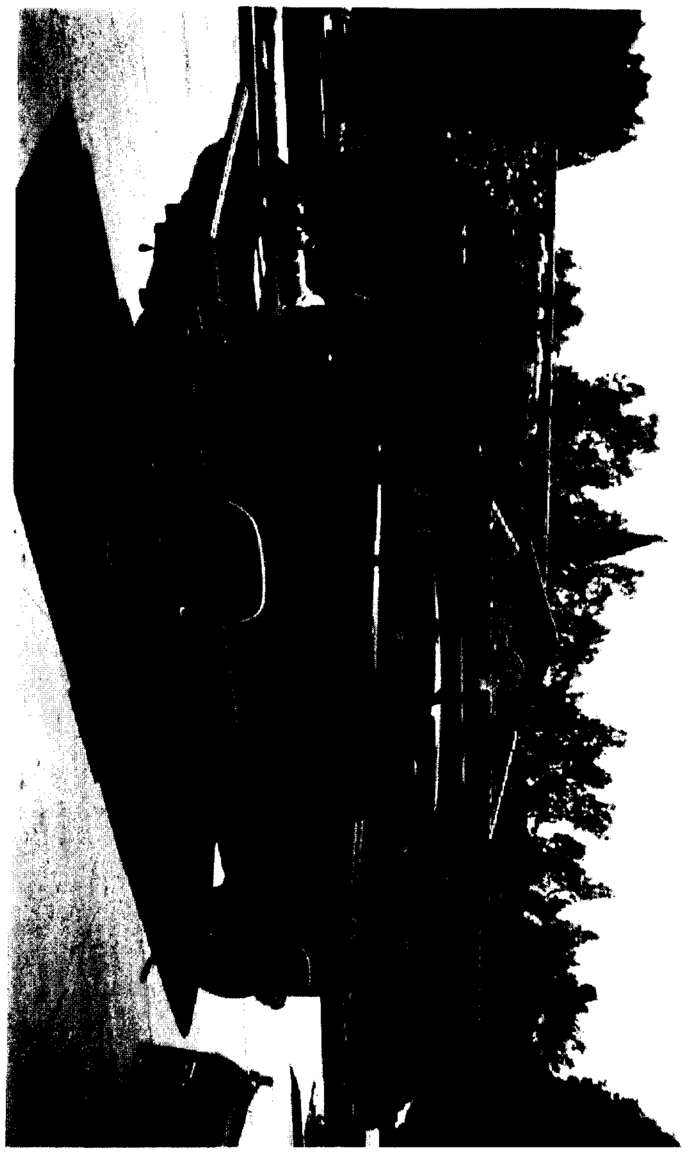


Table 3.1. Filter System Specifications

Unit	Description
Pump	Teel Model 2P004, 3/4 hp; centrifugal pump; self-priming
Process Piping	1" Schedule 40 PVC
Basket Strainer	Hayward, single basket; 1/36" diameter mesh basket - modified to 1/8" diameter mesh; 1" SOC connection
Globe Valves	PVC Globe valves, 1" SOC connection
Ball Valves	PVC Ball valves, 1" SOC connection
Labcock Valves	Asahi labcock valves, 1/4"
Differential Pressure Gages	Dwyer Magnahelic differential pressure gages; 0-10 psi
Flowmeters	Dwyer Visi-Float flowmeters; 0-20 GPM
Pipe Unions	PVC unions; Buna O-ring; 1" SOC connection

Table 3.2. Filter System Dimensions

Unit	Dimensions
Entire System, length	5 feet
Entire System, width	3 feet
Entire System, height	5 feet, 1 inch
Filter Column, diameter	6 inches
Filter column, length	4 feet
Filter bed depth, typical	6 inches
Effective surface area of filter media	0.196 ft^2

3.2 Adsorbent Media

As reported by Lau and Stenstrom (1995b), a number of oil adsorbent media products are available for various oil spill cleanup activities. At least three of these products have also been tested in runoff adsorption environments. For initial testing in this study, 3M® Type 210 particulate adsorbent media was chosen for its apparent advantages as a flow-through media. Many of the other commercially available media were woven into fibrous pads, which could impede flow in a packed column apparatus. The Type 210 media was packed by hand into the columns to a bed depth of approximately 6 inches in each test. Packing was accomplished by dropping 18 to 24 inches of media into the column, placing a stainless steel screen on top of the media, and pressing down on the screen to the maximum extent practicable by hand. New media was installed for each test, and an attempt was made to dissect and inspect the spent media following each filter run in order to determine the hydraulic and adsorptive performance of the filter. Photographs of the dissected media can be found in the Results chapter in Figures 4.4 and 4.5.

3.3 Site Description

The filter system was tested at two different industrial sites in Anaheim, CA during the months of April and May 1996. The first site selected for pilot testing was a multi-use commercial facility characterized by restaurant facilities, retail shops, and light industrial activity. This site was used for the events referred to in this study as "Filter Run 1" and "Filter Run 3". The filter was placed near a catch basin located along a maintenance road that served the various restaurants and shops located in the immediate area. The catch basin collected runoff water from a paved surface that received large amounts of vehicle and pedestrian traffic on a daily basis. The tributary area also contained several "back alleys" that served the restaurants and shops. All of the paved surfaces were washed down on a nightly basis by custodial crews, using high-flow hoses. The runoff water from this site was observed to be relatively high in solids, organics and oil and grease. This site was chosen because it was representative of a site which could be a source for oil and grease contamination in both wet weather and dry weather storm drain flows (CA Stormwater Quality Task Force, 1993). Power for the filter pump was available at the site, and the runoff water was pumped from the catch basin using flexible nylon hose. The effluent water was discharged to an adjacent road, which occasionally resulted in return flow of the filtered water into the catch basin.

The second site selected for pilot testing was a high-use, commercial parking lot. This was the site used for the event referred to as "Filter Run 2" in this study. The filter was setup near a conventional catch basin at the hydraulic point of concentration of the parking lot; A surface area of approximately 10,000 square feet directly surrounding the catch basin was washed during the test using a high-flow hose and Anaheim tap water. The high-flow hose generated approximately 20 GPM of water. It was recognized that the washdown of the parking lot surface generated runoff water of different quality than that generated during storm events. For the purposes of this study, it was determined that any differences between the two source waters would not be crucial to the results of the tests. Power for the pump was provided by a gas generator. The runoff water was pumped into the filter from a small pool created directly in front of the catch basin using sand bags. All effluent water from the filter column was drained to a point downstream of the catch basin via clear vinyl tubing.

3.4 Filter Runs

The filter was run in the field on three separate occasions, following an initial test run of the system using clean water to identify any operational problems. The first complete filter run ("Filter Run 1") was conducted at the mixed-use commercial site described in section 4.3. Approximately one hour was required for setup, including unloading of the filter system from the truck. Testing began at 2:05 AM, which roughly corresponded to the initiation of the washdown routine at the site. Water was pumped through only one of the three columns, and the depth of the filter media in the column was 8 inches initially, allowing for some compression of the bed during testing. The filter was run at a flow rate between 1 and 2 gallons per minute (GPM).

Filter run 2 was conducted one week after Filter Run 1 at the parking lot facility described in section 4.3. Approximately 1 hour was required for setup. Testing began at 10:15 PM, which ensured that the area of the parking lot used in the test was clear of all vehicles. Water was pumped through one column, which was packed with 6 and 1/4 inches of media. The media was packed tightly in this test to minimize compression of the bed following initiation of the filter run. The goal of minimizing filter bed compression was developed in response to the observation in Filter Run 1 that particulates tended to by-pass the media during the first several minutes of operation, when bed flux was at a maximum. The filter was run at approximately 2 GPM for the duration of the testing.

Filter Run 3 was conducted one day after Filter Run 2 at the multi-use commercial site that was also used in Filter Run 1 and described in section 4.3. Approximately 30 minutes was required for setup due to increased familiarity with the site. Testing began at 1:30 AM, which corresponded to the initiation of the washdown routine in the area. Water was pumped through one column, which was packed with 5 1/2" of adsorbent media. The media was again packed tightly to minimize any filter bed compression. The filter was run at approximately 1 GPM for the duration of the event. A new, braided nylon suction hose was used in this run to achieve more reliable influent flow into the pump.

The duration of the filter run in each case was determined by observation of the head loss through the filter and the condition of the adsorbent media. It was anticipated that the run would be terminated when either the head loss increased to the point of reduced flow or the media became saturated with pollutants. The actual determining factors for run time that were used in each case are discussed explicitly in the Results chapter.

3.5 Analytical Methods

All oil and grease analyses were performed using a solid phase extraction method developed by Lau and Stenstrom (1995a). The analyses for oil and grease and the additional water quality parameters were performed by Sim-Lin Lau in the laboratory at the University of California, Los Angeles. In addition to oil and grease, a number of samples were also analyzed for the following parameters:

- Total Suspended Solids (TSS)
- Volatile Suspended Solids (VSS)
- Conductivity
- Turbidity
- pH

Grab samples were collected from the filter system immediately following the pump discharge and just before the connection to the drainage hose. Oil and grease and water quality samples were collected in I-Chem Boston Round amber 1L bottles and refrigerated at 4 degrees Celsius within 2 hours after collection. Although the influent and effluent samples were collected within in 2 minutes of each other, it was difficult to guarantee that the effluent samples represented the same "package of water" that was sampled before contact with the filter media. This issue of inherent variability is discussed in more detail in the Results and Discussion chapters of the study.

4.0 Experimental Results

4.1 Filter Performance

The following section covers the filter hydraulic performance and observations made during field implementation. The flow rate was controlled by a combination of the globe valves and height of the discharge hose below the filter unit. There was a lag of several seconds in flow rate adjustment when opening and closing the globe valves due to the lack of a back pressure valve on the effluent hose. Once an equilibrium was established, the flow rate remained constant, varying no more than 0.1 GPM above or below the reported value. The system was easily staged near different catch basins with little disturbance to surrounding traffic. The only major staging requirements were a nearby power source and a relatively flat space measuring at least 8 feet by 5 feet.

The clear PVC pipe enabled observation of the filter media condition and pollutant collection during operation, and was instrumental in determining the actual duration of the filter run. Filter run time was 2 hours or less in each of the runs due to sediment build-up in the filter column and erosion of the filter bed. Measurement of the head loss in the filter was inhibited by the use of the Magnahelic™ gages. The Magnahelic gage was designed for air and gas operation and was not well-suited to this application. The more appropriate Capsuhelic™ gages were not available within the time frame of this study. As a result, condensation inside the pressure gages in filter runs 2 and 3 and prevented precise determination of head loss during those events.

Filter Run 1

The first filter run was conducted at the multi-use commercial site and was exactly 2 hours in duration. The initial flow rate was 1.5 GPM, and the initial differential pressure was 1.0 psi. Within 15 minutes, the influent flow formed a channel along 50% of the side of the filter column, appearing to by-pass the adsorbent media. This observation was determined by the dark color of the media along the side of the filter bed, covering approximate 50% of the circumference of the column. The depth of penetration of the dark pollutant front was observed to be less than 1 inch in those areas not subject to flow along the side wall. After 45 minutes, the penetration of the pollutant front was 3 inches, and the extent of filter by-pass appeared to be unchanged. A pink color was observed in the influent intermittently throughout the filter run. A significant portion of the color was removed in the filter media, as apparent by the coloring of the media and the reduction of observed color in the effluent. The run was terminated at 2 hours because the influent flow was increasingly channeling along the side wall and by-passing the filter bed. Immediately before termination, the differential pressure was 4.3 psi and the flow rate was 0.75 GPM. Complete operating data for this filter run can be found in Table 4.1.

Filter Run 2

The second filter run was conducted at the parking lot site and was 1 hour and 50 minutes in duration. The initial operating differential pressure was 0.6 psi, and the initial flow rate was 2.0 GPM. Behavior of the differential pressure gage was erratic because the flow rate and back pressure in the effluent hose was altered frequently during operation to experiment with media performance. The flow rate was maintained at approximately 2.0 GPM throughout the run but exceeded 5 GPM several times during adjustment. By-pass of particulates along the side wall of the filter column was observed within 10 minutes of operation, and the by-pass channel extended to approximately 1/3 the circumference of the column. Penetration of the dark pollutant front in the remaining portion of the column was 1 inch after 10 minutes of operation. The circumference of the by-pass channel remained constant through 1 hour and 30 minutes of operation. The penetration of the pollutant front was 2.5 inches at the 1 1/2 hour mark. At 1 hour and 45 minutes, an increasing percentage of the influent flow appeared to be by-passing the filter bed along the side wall. The filter run was terminated at 1 hour and 50 minutes based on the determination that the increased filter by-pass was preventing adequate contact between the influent and the adsorbent media. Behavior of the differential pressure gage was inconsistent, but the trend of decreasing head loss late in the run was consistent with the increasing degree of by-pass. Complete operating data for this filter run can be found in Table 4.2.

Filter Run 3

The third filter run was conducted at the multi-use commercial site and was 2 hours in duration. The initial operating differential pressure was 0.8 psi, and the initial flow rate was 1.0 GPM. The flow rate was maintained at 1 GPM throughout the entire run. Influent water appeared to be extremely turbid throughout this test, and a thin layer of sediment formed on top of the media within the first several minutes of operation. The formation of a by-pass channel along the side wall was similar to that in Filter Run

1, and the by-pass covered approximately 30% of the column circumference. The penetration of the pollutant front exclusive of the bypass was only 3/4 inch after 30 minutes. Shortly after 1 hour of operation, the pressure gage was obscured by condensation, and penetration of the pollutant front was 1.5 inches. The filter run was terminated at 2 hours due to the observation of an apparently impermeable crust of sediment on top of the media and no apparent change in the penetration of the pollutant front. It was concluded that the sediment crust forced a majority of the influent flow to by-pass the filter bed. Complete operating data for this filter run can be found in Table 4.3.

The filter media was dissected following each filter run. In each case, particles were collected throughout the entire diameter and depth of media, and it was estimated that no more than 20% of the filter bed retained its original white color in any of the runs. During operation of the filter, water was observed dripping out of the media evenly across the bed at the bottom of the filter in addition to the water that was flowing down the side of the column, by-passing the media. The precise fraction of flow passing through the media relative to that channeling along the side wall was not determined in the field, but it was estimated that, during normal operation, less than 50% of the water was able to by-pass the filter bed. Once the particulate matter had formed a crust on top of the filter, the fraction of water by-passing the media increased to as much as 90 - 100%. A complete tabulation of the operating data for each filter run can be found in Tables 4.1 -4.3.

Table 4.1 Filter Run 1 Operating Data

Time	ΔPressure [psi]	Flow Rate [GPM]	Comments
0:00	1.0	1.5	sampled in/out
0:15	1.8	1.0	dark color by-passed media at side of column, 50% coverage
0:30	2.0	1.5	
0:35	2.4	1.0	dark front penetrated 2" through media
0:40	2.5	1.0	
0:45	2.5	1.25	dark front penetrated 3" through media
0:50	2.8	1.0	by-passing of media along side wall 50% of circumference.
0:55	3.0	1.0	purged air
1:00	3.4	1.0	sampled in/out
1:05	3.8	1.25	
1:08	3.9	1.0	keeping constant water height of 5" above media
1:15	3.9	1.0	
1:20	3.9	1.0	purged air
1:30	3.95	1.0	
1:35	3.9	0.75	observed pink color in water
1:40	4.0	0.75	
1:42	4.05	0.5	
1:43	4.1	0.5	black front penetrated 4" through media
1:45	4.2	0.5	7" water above media
1:48	4.3	0.5	
1:51	--	0.75	lost pressure- kink in hose
1:56	--	0.75	
2:00	--	--	stopped test

Table 4.2 Filter Run 2 Operating Data

Time	ΔPressure [psi]	Flow Rate [GPM]	Comments
0:00	0.6	2.0	by-pass along side wall (30%) w/i 5 min.
0:10	1.3	1.5	dark front penetrated 1" though media
0:15	1.7	1.0	
0:30	5.1	2.5	freed-up intake hose to allow greater inflow
0:45	5.0	1.5	dark front penetrated 2" through media
1:00	3.2	2.0	returned to initial operating intake
1:15	3.2	2.0	
1:30	3.1	2.25	dark front penetrated 2.5" through media
1:45	2.8	2.5	flow appears to have cut a path through media and is not achieving good contact
1:50	2.2	2.0	terminated filter run

Table 4.3 Filter Run 3 Operating Data

Time	ΔPressure [psi]	Flow Rate [GPM]	Comments
0:00	0.8	1.0	sampled; sediment crust formed
0:15	1.1	1.0	pink color influent; by-pass media, 30%
0:30	1.0	1.0	dark front penetrated 0.75" through media
0:45	1.0	0.75	dark front penetrated 1.25" through media
1:00	1.0	1.0	dark front penetrated 1.5" through media
1:15	--	1.0	pressure gage wet- invalid data
1:30	--	1.0	dark front penetrated 1.5" through media
1:45	--	1.0	
2:00	--	1.0	terminated filter run, excessive by-pass

4.2 Removal of Pollutants

Percent removal achieved by the filter was calculated by the following equation:

$$\frac{(C_I - C_E)}{C_I} = \% \text{ Removal}$$

C_I = influent concentration
C_E = effluent concentration

Removal of oil and grease ranged from 5 to 38%, and 60% of the sample sets showed removal rates between 13 and 23%. In one set of samples, the effluent concentration of oil and grease was 16% higher than the influent concentration. TSS removal was not consistent but equaled or exceeded 90% in 3 out of 7 sample sets. In two of the TSS sample sets, the effluent concentration was almost 200% higher than the influent concentration. The calculation of negative removal rates was consistent with similar runoff filtration studies and is considered in the Discussion chapter.

A significant build-up of fine particulate matter was observed in the filter media after each run. Only minor changes in turbidity and conductivity were achieved by the filter media, and there was consistently little or no change in pH in all cases. It was acknowledged during each filter run that it was difficult to time the influent and effluent sample collection precisely in order to sample the same "package" of water in each case. This problem was amplified by the significant amount of mixing that occurred in the water column, which was maintained at 8 - 12 inches above the filter bed. A tabulation of the water quality results can be found in Tables 4.4 - 4.6 and in Figures 4.1 - 4.3.

Table 4.4 Results of Filter Run 1

Time	Influent [mg/L]	Effluent [mg/L]	Removal [mg/L]	% Removal [%]
		Oil & Grease		
0:00	166.83	155.78	11.05	6.62%
1:00	4.08	2.53	1.55	37.99%
2:00	6.66	5.39	1.27	19.07%
		TSS		
0:30	121.00	10.75	110.25	91.12%
2:00	35.13	20.50	14.63	41.65%
		VSS		
0:30	83.20	10.25	72.95	87.68%
2:00	32.75	20.00	12.75	38.93%
		Conductivity		
	[μmho/cm]	[μmho/cm]	[μmho/cm]	
0:30	735.00	812.00	-77.00	
2:00	870.00	901.00	-31.00	
		Turbidity		
	[NTU]	[NTU]	[NTU]	
0:30	41	10	31	75.61%
2:00	31	17	14	45.16%
		pH		
0:30	7.2	7.3	-0.1	
2:00	7.1	7.3	-0.2	

Table 4.5 Results of Filter Run 2

Time	Influent [mg/L]	Effluent [mg/L]	Removal [mg/L]	% Removal [%]
		Oil & Grease		
0:00	7.11	6.79	0.32	4.50%
0:45	8.35	7.04	1.31	15.69%
1:30	5.89	4.52	1.37	23.26%
		TSS		
0:00	2.50	6.90	-4.40	-176.00%
0:45	9.86	0.74	9.12	92.49%
		VSS		
0:00	0.16	1.47	-1.31	-818.75%
0:45	1.66	0.22	1.44	86.75%
		Conductivity		
	[μmho/cm]	[μmho/cm]	[μmho/cm]	
0:00	1023.00	952.00	71.00	
0:45	1019.00	1030.00	-11.00	
		Turbidity		
	[NTU]	[NTU]	[NTU]	
0:00	3.25	6.13	-2.88	-88.46%
0:45	3.35	0.65	2.71	80.75%
		pH		
0:00	7.60	7.80	-0.20	
0:45	7.80	7.85	-0.05	

Table 4.6 Results of Filter Run 3

Time	Influent [mg/L]	Effluent [mg/L]	Removal [mg/L]	% Removal [%]
		Oil & Grease		
0:00	6.16	5.34	0.82	13.31%
0:30	4.34	5.05	-0.71	-16.36%
1:00	6.49	5.41	1.08	16.64%
2:00	6.06	4.92	1.14	18.81%
		TSS		
0:00	183.75	142.50	41.25	22.45%
0:30	245.75	25.00	220.75	89.83%
2:00	45.83	128.00	-82.17	-179.29%
		VSS		
0:00	129.00	105.25	23.75	18.41%
0:30	146.25	24.43	121.82	83.30%
2:00	38.17	94.80	-56.63	-148.36%
		Conductivity		
	[μmho/cm]	[μmho/cm]	[μmho/cm]	
0:00	1015.00	987.00	28.00	
0:30	923.00	969.00	-46.00	
2:00	1036.00	1066.00	-30.00	
		Turbidity		
	[NTU]	[NTU]	[NTU]	
0:00	36	54	-18	-50.00%
0:30	71	17	54	76.06%
2:00	19	42	-23	-121.05%
		pH		
0:00	6.60	6.75	-0.15	
0:30	7.10	6.85	0.25	
2:00	6.70	6.75	-0.05	

Figure 4.1 Percent Removal of Oil and Grease

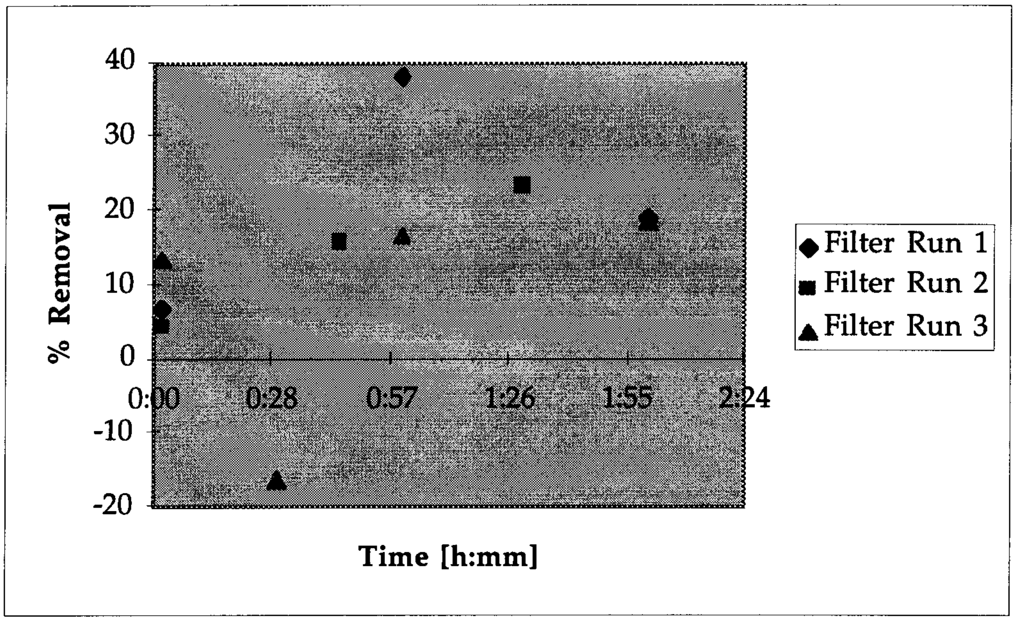


Figure 4.2 Percent Removal of TSS. Note: The negative values on this chart were divided by 10 in order to clearly display all data points on one graph.

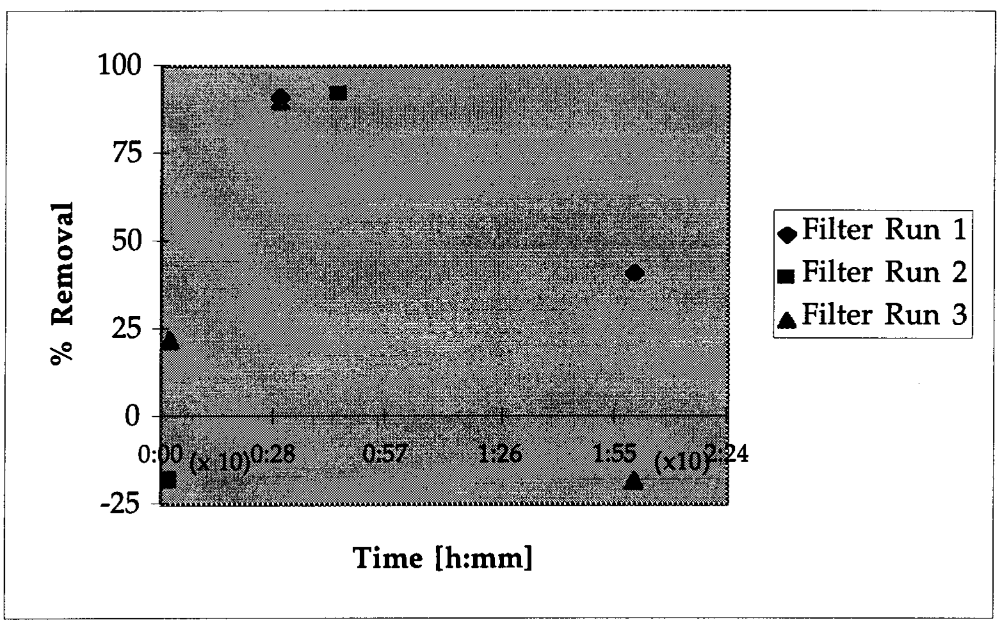
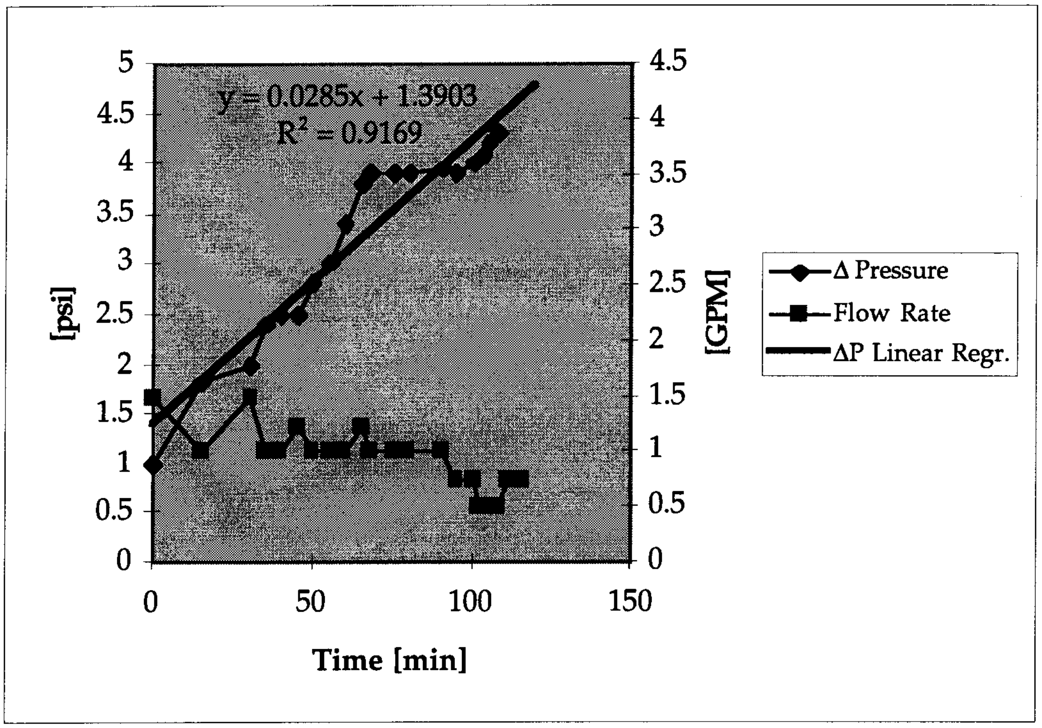


Figure 4.3 Differential Pressure and Flow Rate in Filter Run 1



4.3 Field Observations

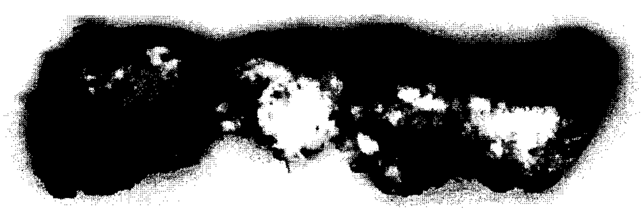
One of the most consistent and important observations that was made in each filter run was the formation of a sediment crust on top of the adsorbent media during operation. The sediment layer formed quickly, usually within 10 to 15 minutes, and appeared to become increasingly impermeable over time. In at least two of the three filter runs, the sediment crust caused substantial by-pass of the flow through the adsorbent media and subsequent termination of the run. Likewise, the filter system did not appear to reach terminal head loss in any of the filter runs. The ability of the flow to by-pass the media appeared to prevent the head loss in the filter column from accumulating to critical levels.

Although the flow rate was not intentionally varied by a significant amount during the filter runs, the system was operated at greater than 5 GPM several times, which corresponded to greater than 25.5 GPM per $ft.^2$, as calculated for the 6 inch diameter column. The higher flow rate did not appear to have any adverse impact on the filter bed. A pink color was observed in the influent water intermittently during filter runs 1 and 3. The source of the color was not identified, but it was speculated that the color was likely indicative of the presence of food waste from the restaurant facilities in the area. The adsorbent media retained a significant amount of the pink color, and the color was accordingly less apparent in the effluent water. In fact, the pink color served as an excellent marker of flow through the media. Upon dissecting the media after operation, the pink color was found evenly distributed throughout the filter bed.

Photographs showing the condition of the adsorbent media after operation and the sediment crust described above can be found in Figures 4.4 and 4.5. Note the sharp edge of the crust and build-up of particles on the side of the media where by-pass occurred.

Figure 4.4 Photograph of Filter Media After Operation. Note: Particles were adsorbed and/or collected throughout the filter media. This piece of media measured approximately 5" by 3" and was cut from the middle of the bed following Filter Run 1.

Figure 4.5 Photograph of Sediment Crust and Pollutant Front in Filter Media. Note: This piece of adsorbent media was cut from the top of the filter bed following Filter Run 3 and measured approximately 3" by 1". The piece was cut such that the material on the left edge was flush with the side wall of the column during operation and the material on the right side of the picture was located in the middle of the column. The dense nature of the sediment crust is visible on top of the media, and the effect of by-pass along the side wall is visible on the side of the media. Penetration of the pollutant front was clearly less substantial in this portion of the media due to the dense sediment crust. Similar cross-sections observed following Filter Runs 1 and 2 showed deeper penetration of the pollutant front and a relatively homogeneous gray color throughout the filter bed (as seen in Figure 4.4).



5.0 Discussion

5.1 Feasibility and Effectiveness

The oil and grease removal achieved in this study did not meet expectations, but the removal rates were quite similar to the those obtained using the catch basin inserts described in the Background chapter. The filter was able to remove greater than 13% of the influent oil and grease in 7 of the 10 sets of samples, with a maximum removal of 38%. The Catch Basin Insert Committee in King County, WA reported less than 30% removal of oil and grease in every field test as part of their evaluation of current commercial catch basin inserts (CBIC, 1995) In addition, the formation of an impermeable sediment crust on the filter media described in this study was also a key inhibitor of filtration in the King County Study. Finally, the lower removal percentages achieved in this pilot test over that of the bench scale results obtained by Lau and Stenstrom (1995) were paralleled in the King County study by lower removals in field compared to their bench tests.

The process of design, construction, and operation of the adsorbent media filter did yield a number of real and potential advantages over traditional catch basin insert designs. One improvement over current technologies was the use of pressurized flow to force runoff water and the associated pollutants through adsorbent media at a high rate. This technique was most likely responsible for the filtration of fine particles throughout the entire filter bed. In fact, the widespread collection of particles and accompanying build-up of sediment on top of the adsorbent media resulted in high TSS removal in 4 of the 7 sample sets. Unfortunately, the sediment crust also limited the penetration of oil and grease and other pollutants into the filter bed. Another improvement was in the flexibility in the application of the filter system. The catch basin grate in the parking lot location was not removable by hand due to a series of pavement layers and poor maintenance, and the depth of the basin was estimated to be over 12 feet. These factors would have made installation of a catch basin insert labor-intensive, costly, and unsafe. The filter system tested in this study was staged at the parking lot location safely and without modification.

One factor that greatly affected the accuracy of the pollutant removal sampling was the degree of mixing that occurred in the filter column and the accompanying inconsistency in hydraulic retention times. Because 8 to 12 inches of water was maintained above the filter bed during operation of the filter, influent water did not travel through the system as a "package" in a plug flow type fashion. Consequently, it was difficult to determine an approximate hydraulic retention time and an appropriate time between collection of the influent and effluent samples. Flow by-pass of the filter bed also may have caused washout of the sediment that was trapped above the media, causing erroneously high concentrations of solids and oil and grease in the effluent. This phenomenon was observed to cause negative removal rates in other studies of catch basin devices (Robertson et al, 1994 and CBIC, 1995). Due to the relatively small size of the filter column in this study and low flow rates used in the filter runs, it was possible that even a small fraction of flow by-pass could have made a large impact on the effluent concentration.

The capacity of the adsorbent media and ultimate filter run time in the field were not discovered in the course of the study because terminal head loss was not achieved. Due to the hydraulics of the column, increasing head loss across the filter caused greater by-pass of the media instead of the anticipated flow resistance. As a result, the filter run time was determined by clogging of the media by fine particles and was significantly less than desired. However, the even flow through the media exclusive of the by-pass zone indicated that the media could produce long filter run times if the hydraulics of the system were improved to control flow by-pass. In addition, the ability of the current filter system to handle high flows, in excess of 6 GPM per ft^2, indicated that the media could conduct the relatively high flows which are commonly encountered in the first flush runoff.

5.2 Applications

For the purpose of speculation, it was estimated that a filtration device designed for use in parking lots and commercial facilities should be capable of treating flow rates approximately equal to the peak flow from a 1-year return frequency storm event over a 10,000 ft^2 drainage area, which was estimated at 0.5 inch per hour. This set of criteria was chosen as reasonably representative of the maximum runoff rates recorded annually in the Southern California basin and not suggested as a precise statistical event. The flow rate generated by a storm of this magnitude over the suggested drainage area would be approximately 50 GPM.

The maximum flow rate achieved in this study was 25.5 GPM per ft^2 , using a filter column with a 6 inch diameter and surface area of 0.196 ft^2 . Thus, in order to treat a peak flow of 50 GPM, a filter surface area of 2 ft^2 would be required. This number was calculated by dividing the peak flow by the maximum filter flow rate. As a result, the total required filter surface area would be approximately 10 times greater than the surface area provided by one of the 6 inch diameter columns used in this pilot study. That discrepancy could be covered by using three 12 inch diameter columns in the construction of the full scale version of the filter.

Based on the head loss observed in Filter Run 1 (approximately 3 feet over the static head), a safe estimate for the minimum head requirement would be 6 feet. A majority of the catch basin dimensions observed during the course of this pilot study were greater than 6 feet above the underlying storm drain lines, with freeway catch basins consistently exceeding 8 feet. Consequently, a system designed to handle peak flows under the above conditions and head requirements could be placed adjacent to existing catch basin sites but not inside of the basin due to the required surface area of the filter. However, if the system was designed to treat only mean rainfall intensities, the design flow rate would drop below 10 GPM and would require a total filter surface area of only 0.39 ft^2 . Such a system could be installed in many existing catch basins in Southern California.

Overall, a pressurized adsorbent media filter could prove to be a viable solution for catch basins that have high concentrations of oil and grease and relatively low suspended solids loads. With improved hydraulics to control filter by-pass at higher solids concentrations, the adsorbent filter could also be applied in areas where removal of fine particles is required. Any such application would represent a substantial improvement over current technology because current catch basin inserts are known to be ineffective at removing smaller particles. Highway catch basins may be an ideal location for the adsorbent media filtration technology due to the fact that highways are often constructed several feet above the typical elevation of surrounding developments and typically drain smaller surface areas. As a result, the highway drain inlets may provide a substantial head above the underlying storm drain network, allowing energy-conservative filtration. Additional considerations for application of the technology are discussed in section 7.0.

6.0 Conclusions

The results obtained from the design, construction, and operation of the pilot scale adsorbent media filter indicate that a number of hydraulic problems related to filtering oil and grease must be resolved before the system can be designed for a range of flow rates and types of runoff. The filter achieved pollutant removal levels comparable to or better than current catch basin insert devices. However, oil and grease removal was modest, and a portion of the flow by-passed the media entirely by creating a small channel along the side wall of the filter column. The filter demonstrated the potential to remove significantly greater percentages of fine particulate matter than achieved by most other runoff treatment devices, particularly catch basin inserts. The ability of the pressurized filter column to direct flow through the adsorbent media at flow rates in excess of 6 GPM per ft^2 was demonstrated and provides the basis for a great deal of future work. Using the information gained by constructing this initial pilot scale filter system, a redesigned unit will be constructed in order to improve the hydraulics of the filter column and enable precise determination of design flow rates and filter run times.

7.0 Recommendations for Future Work

Additional pilot scale testing of the filter is needed to determine the ultimate capacity for removal of oil and grease and particulate matter. Ultimately, the system must be tested using runoff water from a wide array of locations at a range of different flow rates. It is recommended that future work on the adsorbent media filter focus on the control of flow by-pass along the side wall of the filter column. In particular, the new design should account for the accumulation of high loads of fine particulate matter. Possible redesigns include an upflow filter, which would dissipate the energy of the influent water and allow better penetration of particulates into the media. Another possible redesign would involve a deeper filter bed to increase the resistance to flow along the side wall of the filter column.

The consistency of the field observations obtained in this study and those reported in studies of catch basin inserts and settling tanks suggests there is a major challenge in the management of solids in the process of adsorption of oil and grease in urban runoff. However, the pilot scale adsorbent media filter tested in this study demonstrated a clear potential for performance improvements over catch basin inserts and other current best available technologies (BAT's). As a result, this study sets the stage for a period of redesign and a second period data collection in the field.

8.0 Appendix

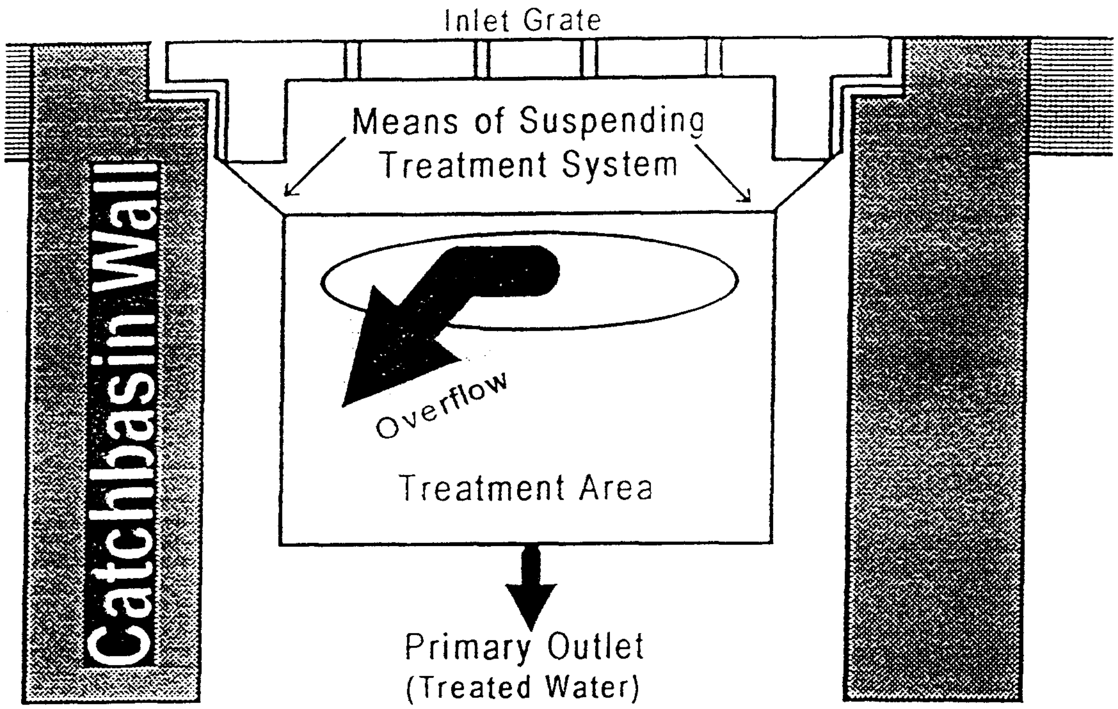
Appendix A. Samples of Current Catch Basin Insert Designs

Appendix B. Design of Compost Storm Water Treatment System

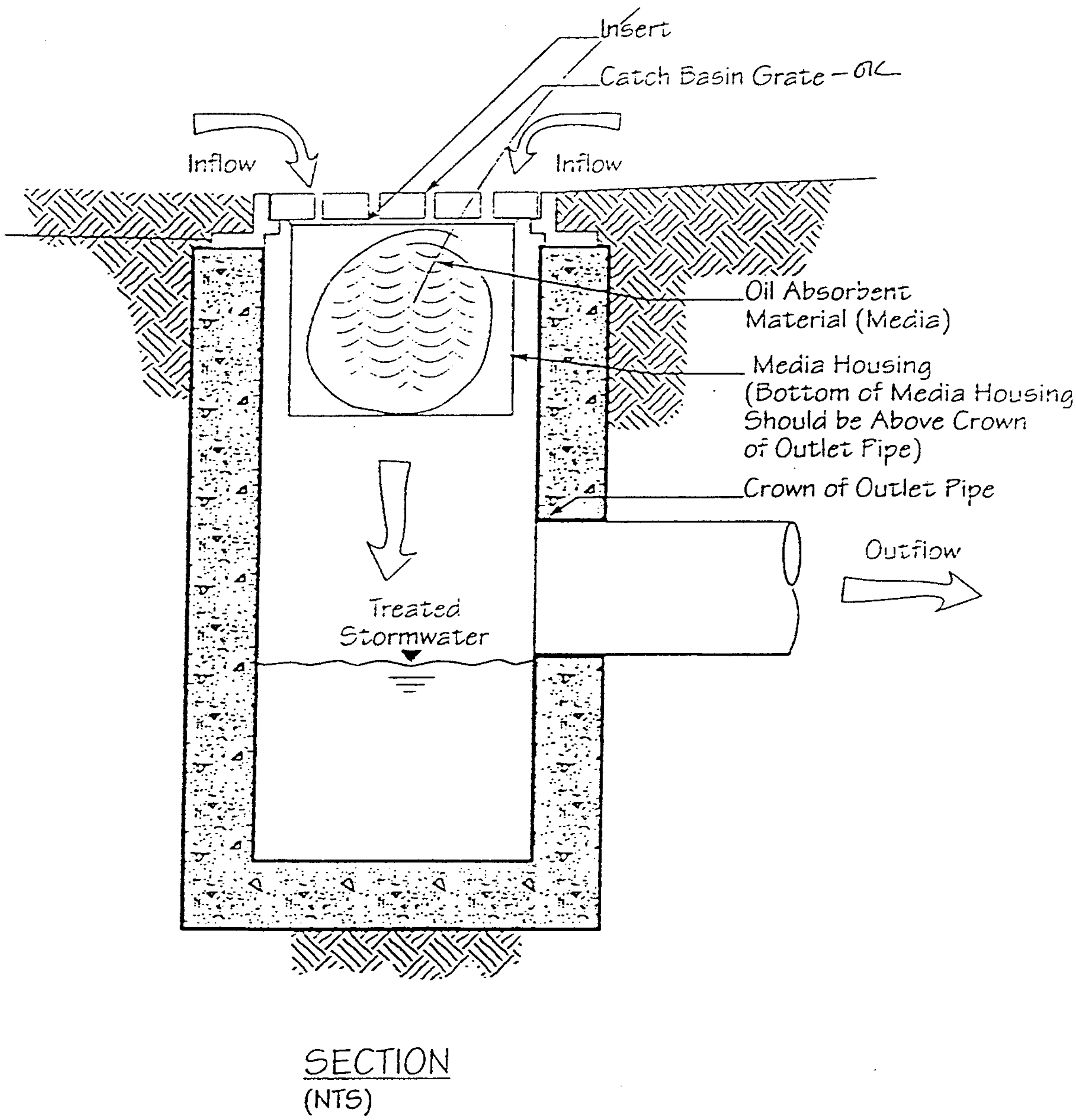
Appendix C. Design of Multi-Chambered Stormwater Treatment Train

Appendix D. Adsorbent Media Product Information

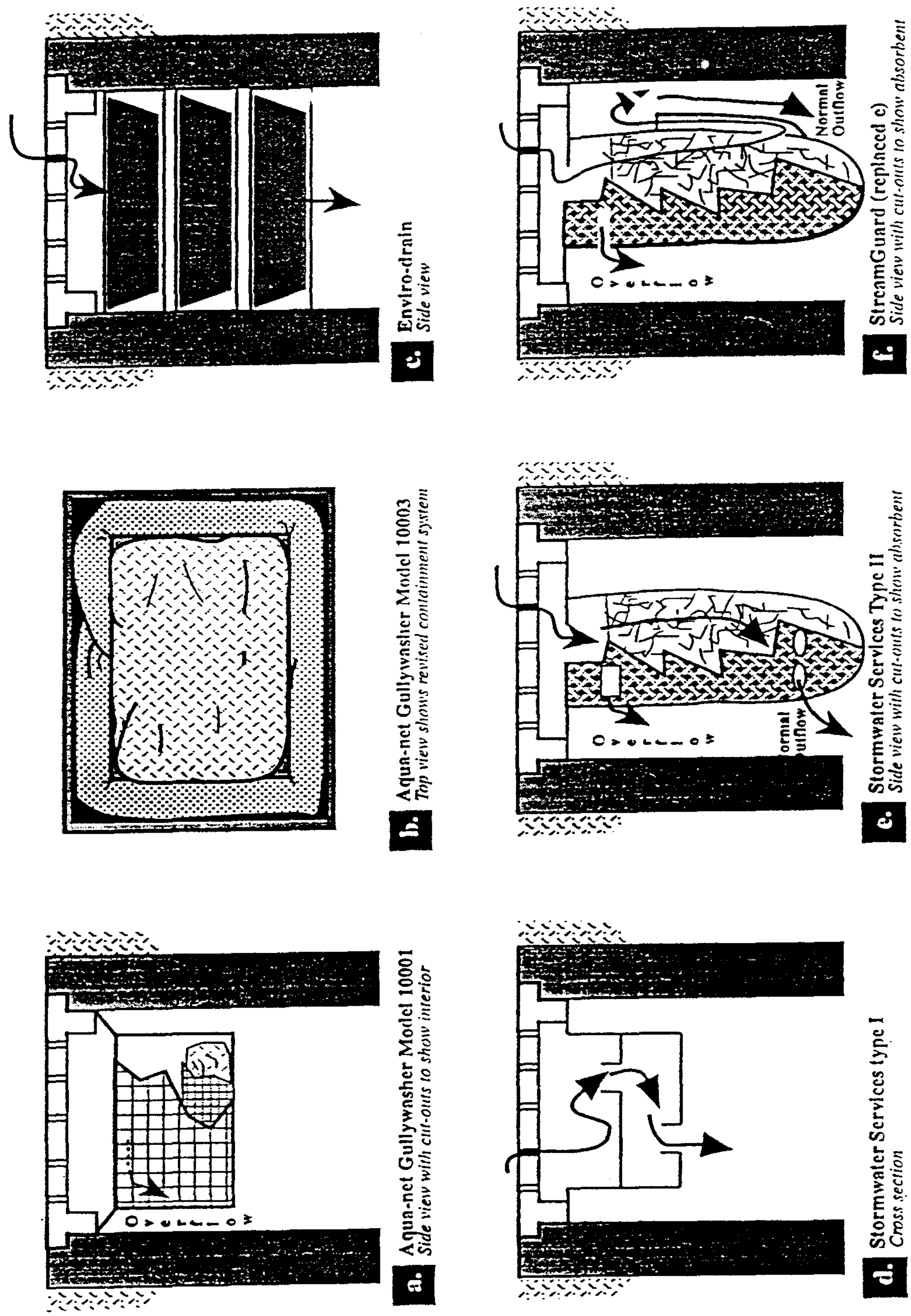
Appendix A. Samples of Current Catch Basin Insert Designs (CBIC, 1995)



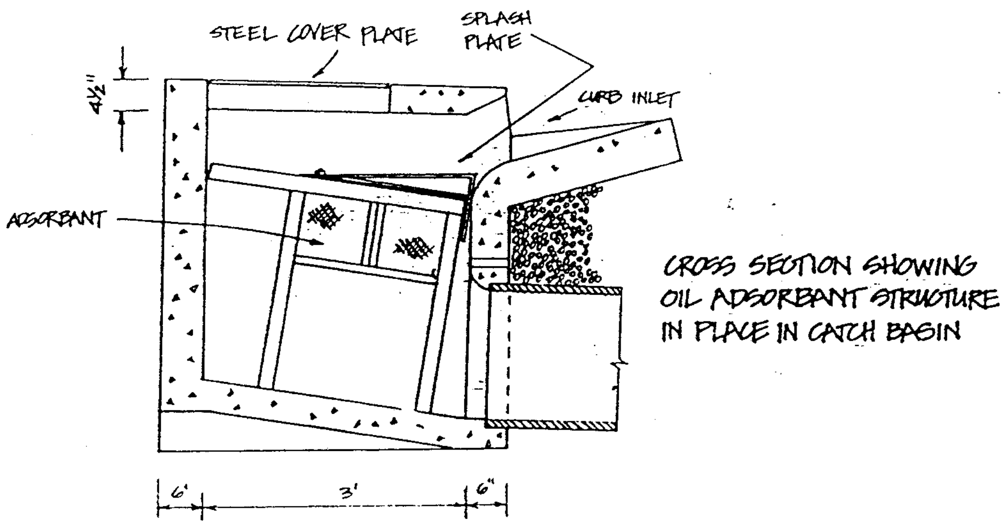
Appendix A, continued. (CBIC, 1995)

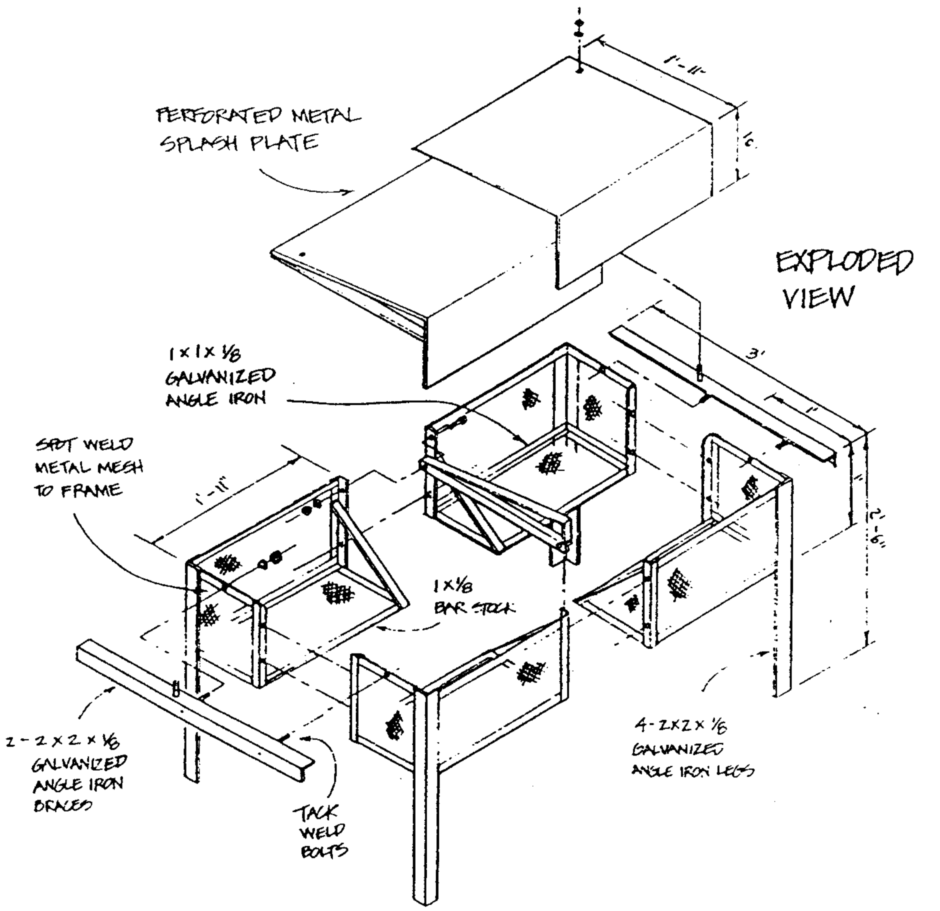


Appendix A, continued. (CBIC, 1995)

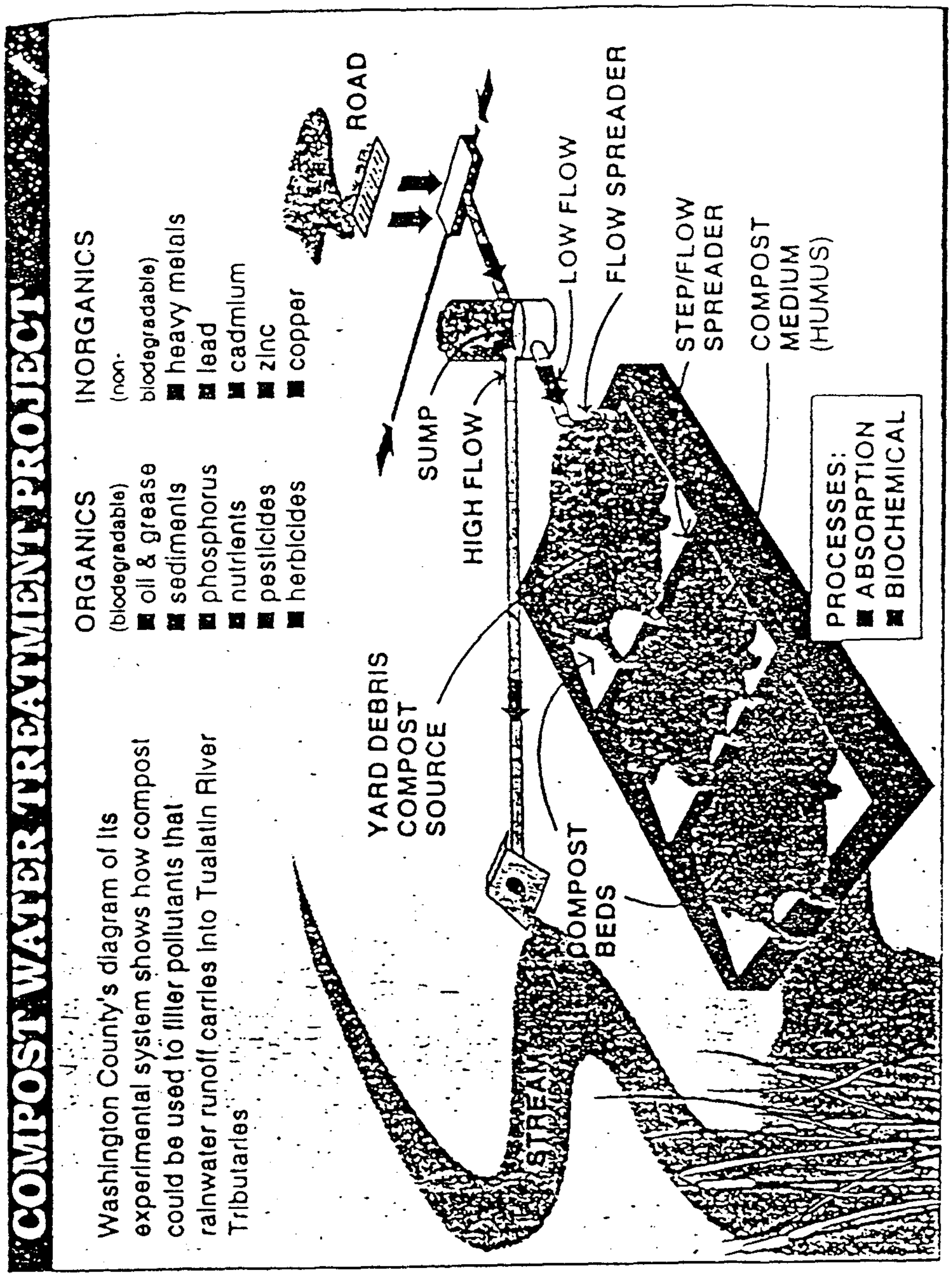


Appendix A, continued. (Silverman, 1982)

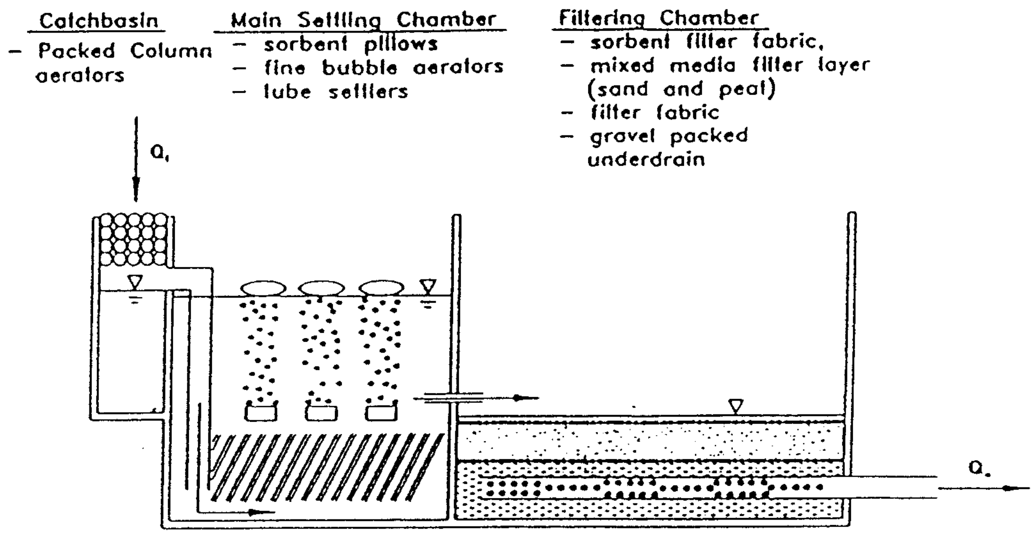




Appendix B. Design of Compost Storm Water Treatment System (W&H Pacific, 1992)



Appendix C. Design of Multi-Chambered Stormwater Treatment Train (Robertson et al, 1994)



T-210 Particulate

Particulate is most useful when combined with a wire fence as a barrier to filter out oils and other hazardous liquids in flowing water. It can be used for manual placement or for mechanical blowing in open areas on large spills.

Product	Size	Packaging
Particulate T-210	25 lbs./Bag 35 Gals./Bag	1 Bag/Bale

9.0 References

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