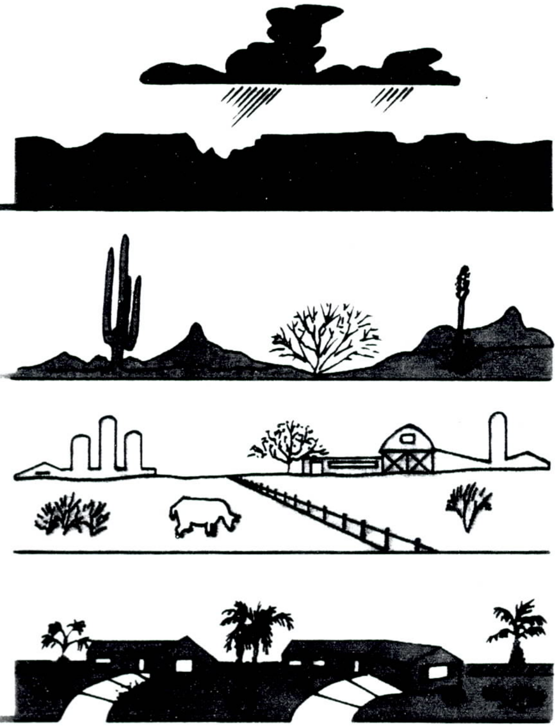

FLOOD CONTROL
DISTRICT OF
MARICOPA COUNTY

Nonpoint Source Water Quality Control:

Biological Treatment of Stormwater & Runoff From A Vehicle Maintenance Yard

NONPOINT SOURCE WATER QUALITY CONTROL: Biological Treatment of Stormwater Runoff from a Vehicle Maintenance Yard

by

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An EPA 319(h) Demonstration Project
Final Report

A Cooperative Effort By:

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&
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ABSTRACT: A submerged-flow vegetated treatment system was constructed in the fall of 1992 to serve as dry well head protection from contaminated runoff exiting a vehicle maintenance yard. The treatment cell was separated and one side was planted with *Typha latifolia* (cattail) and the second side served as a non-vegetated control. Since construction, the system has been undergoing a "seasoning" period in which vegetation has matured and a microbial population was established. Monitoring was conducted to assess the efficiency of "oil and grease" removal, and to confirm the presence of hydrocarbon degrading microorganisms. Results from the first eleven (11) months of operation indicate the system is efficiently removing "oil and grease" from the runoff. Average removal/retention efficiencies range from 15.5% for the non-vegetated control side to 86.94% for the vegetated side of the system. Monitoring of physical parameters suggest that the vegetated side of the treatment cell has higher microbial activity. Respirometry and plating experiments corroborate these findings. The vegetation appears to facilitate the removal of hydrocarbons by adsorption followed by subsequent biodegradation. The existence of microbial populations even after extended periods of drought indicates that sorbed hydrocarbons support microbial growth during extended periods without stormwater input. Maintenance requirements appear to be minimal. The use of a submerged-flow vegetative treatment system for dry-well head protection appears to be effective for petroleum-type hydrocarbon removal.

A non-vegetated treatment system consisting of a series of Graded Biological Filters was also constructed. Results suggest that this system was not well-suited for use as dry-well head protection in the arid Southwest and the system was abandoned after three months of operation.

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INTRODUCTION

To improve the quality of stormwater runoff emanating from a vehicle maintenance yard, and to provide well-head protection for dry wells, two treatment systems were constructed. These systems consisted of a series of Graded Biological Filters (GBF) designed to protect the Western dry-well and a Submerged-Flow Vegetated Treatment System (SVTS) to protect the Eastern dry-well. Each system was subject to variable strength petroleum contaminated runoff, temperature extremes, and extended periods without rain. In addition, both the GBF and SVTS systems had to be practical as well as economical to construct, and require very little in the way of operation and maintenance activities.

Design, monitoring and analysis was performed to achieve three goals. Both the GBF and SVTS systems were designed to provide suitable environments for the microbial degradation of both aliphatic and aromatic petroleum hydrocarbons. Monitoring was done primarily to: 1) Determine the "oil and grease" capture / removal efficiency of each system, and 2) Confirm the presence of petroleum degrading microorganisms. Finally, monitoring results were reviewed in order to form an opinion regarding the efficacy of using a GBF system as dry-well head protection and in the case of the SVTS, to assess the impact vegetation had on improving the quality of petroleum contaminated urban stormwater runoff.

The GBF complex was completed in September 1992, and active monitoring was conducted from 12/92 through 2/93. Water samples obtained from the GBF were analyzed for "oil and grease", pH, and conductivity. During this time several problems were encountered which caused sampling to be discontinued. As a result, the primary focus of this report will concern the development, operation and monitoring of the SVTS.

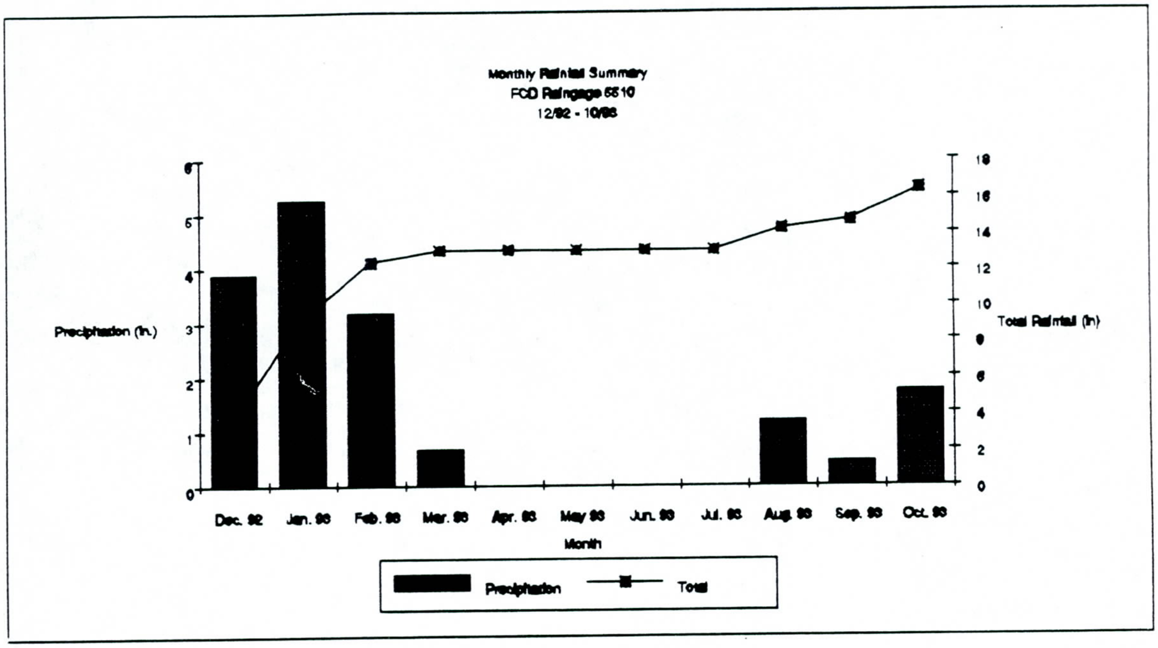

FIG. 1. Rainfall history at 319(h) study site.

Construction of the SVTS was completed in November 1992, and the results presented in this paper represent the first 11 months of operation. During these 11 months, the system underwent a seasoning period in which the vegetation matured and a microbial population was established. Sampling of the system was conducted to collect both water and soil samples. Water samples were analyzed primarily for the "oil and grease" content, but additional parameters, such as pH and conductivity were also measured to gain insight into biological activity occurring within the system. Soil samples were collected and analyzed for "oil and grease", and used in tests to confirm the presence of hydrocarbon degrading organisms.

Sampling activities were conducted both during and between runoff producing storm events. The first event sampled occurred on December 3, 1992, which marked the beginning of one of the wettest winters recorded in the Phoenix area. Approximately 12.4" of rain was recorded at the study site from December, 1992 through March, 1993 (Fig. 1). This was followed by a period of dry weather that lasted until a relatively dry monsoon season started in the first week of August, 1993. In all, wet weather sampling was conducted during storm events which occurred during the winter of 1992/1993 and the monsoon of 1993. Dry weather sampling was conducted between the wet seasons from March 1993 through July 1993, and again during the 1993 post-monsoon period.

Constructed wetlands have been used to successfully treat a variety of wastewaters. Representatives include domestic wastewater, acid mine drainage, paper pulp mill effluents, and urban stormwater runoff (Hammer and Bastian 1989). This study focused upon using a constructed wetland for treatment of urban stormwater runoff. The next section is intended to give some background information regarding general urban stormwater runoff quality. Management of runoff quantity and quality using dry wells will also be briefly discussed. Finally, background information regarding wetland components and how they interact to serve as a biofiltration system for removal of organic compounds, nutrients, and metals is presented.

Following the background section, the remainder of this paper will concern the design, construction, and analysis of the first years operation of the SVTS system. Materials and methods used to site, design, and construct the SVTS will be described. Sampling methods, analytical procedures, and protocols will also be described and discussed. Finally, results obtained during thé first eleven (11) months of operation will be presented and discussed.

Background

Stormwater Quality

Along with the passage of the Clean Water Act amendments in 1987 came the National Pollutant Discharge Elimination System Stormwater permitting requirements. These requirements have focused the attention of industrial experts, as well as, State and Local government planners and engineers on the problem of stormwater quality and its impact upon receiving waters. To date compliance with these regulations has cost municipalities much time and money, and caused an increased awareness regarding both the quantity and quality of urban stormwater runoff to develop. In the past, stormwater management concerned itself with quantity controls and focused primarily on conveying the stormwater as rapidly and as safely as possible away from urbanized and agriculturally developed areas (U.S. EPA 1983). Now it is time to consider the impact urbanization has had upon not only the quantity, but the quality of stormwater runoff.

Urbanization has diminished the amount of pervious area thereby reducing infiltration, and increasing the likelihood of contaminants contacting stormwater runoff. As a result, stormwater runoff volume has increased while the quality has decreased from these areas. Urban stormwater runoff has become a major source of nonpoint source pollution as it washes off contaminants deposited from urban activities (Pond 1993). Depending on the materials stored or used and their proximity to rainfall, urban stormwater runoff can have varying concentrations of heavy metals, nutrients, organic compounds, pesticides, and herbicides.

The first national concerted effort to characterize the quality of urban stormwater runoff was conducted in the late 1970's by the U.S. Environmental Protection Agency (EPA) over a period of five (5) years. It was called the Nationwide Urban Runoff Program (NURP). The NURP study built upon previous work and was designed to overcome inconsistencies and omissions in the current stormwater quality database so that stormwater quality management would be based upon fact rather than conjecture. Individual projects were conducted at the local level, but were coordinated and reviewed by a centralized guidance team. The final report was completed in 1983 and it concluded that there was a need to manage both stormwater quantity and quality to protect both surface and subsurface receiving waters.

The Arizona Department of Environmental Quality (ADEQ) came to this conclusion as well. The 1988 Nonpoint Source Assessment Report noted a significant impact by nonpoint source pollution, including urban runoff to surface waters in Arizona, specifically the Middle Gila River Basin. This basin is situated in the south central portion of the state and includes the Phoenix metropolitan area. Of the 811.9 km of waterways monitored, 593.2 km only partially supported their intended use, while 218.7 km showed nonsupport of their intended use (ADEQ, 1988). It was also noted that the Salt and Middle Gila rivers downstream of the Phoenix metropolitan area have been the most affected by nonpoint source pollution in the State.

Groundwater impacts from nonpoint source pollution have also occurred and urbanization appears to be a major contributor within the Phoenix Active Management Area (ADEQ 1988). The major contaminant groups present include volatile organic compounds (VOC's), benzene, toluene, ethylbenzene, xylene (BTEX), heavy metals, and pesticides. In 1978 a Maricopa Association of Governments (MAG) study reported that the major groundwater impacts were attributed to urban, industrial, and agricultural activities within the

Phoenix Metropolitan area (Schmidt 1985). Hydrologic modifications were also noted. As far as the urban contribution, leaky underground storage tanks, septic tank leachate and stormwater runoff were cited as significant contributors to the degradation of receiving waters (ADEQ 1988).

Past and present studies regarding the quality of urban stormwater suggest that this runoff can contain pollutants which may exhibit either chronic or acute toxicity in organisms residing in both the aquatic and terrestrial environments. Inorganic metals such as Pb, Zn, Cu, Cr, and As were detected in greater than 50% of all NURP studies (U.S. EPA 1983). Although these are all naturally occurring metals, studies indicate that a substantial amount of the heavy metals occurring in urban stormwater runoff are anthropogenic in origin. For example, 50% of the estimated nonpoint source load of Cu to the Lower South San Francisco Bay from Santa Clara Valley was associated with brake-pad wear (*Santa Clara Valley* 1992).

Metals are not the only pollutants now associated with urban stormwater runoff. Organic compounds such as the Base Neutral Acid compounds fluoranthene and pyrene were detected in runoff from a parking lot in Tucson, Arizona (Wilson et al. 1989). Preliminary results from an ongoing study conducted by the Flood Control District of Maricopa County (FCDMC) and The United States Geologic Survey (USGS) indicate the presence of these and several other organic compounds in urban stormwater runoff including Bis(2-Ethyl Hexyl)Phthalate, naphthalene, phenol, and toluene (FCDMC 1993). In 1988, stormwater runoff from paved areas surrounding three industrial and one commercial site revealed the presence of 22 organic compounds including polycyclic aromatic hydrocarbons (PAH's), some of which are suspected carcinogens (Kafura et al. 1988).

Pesticides are also present at detectable quantities in urban stormwater runoff. Diazinon and Dachal were reported in stormwater runoff entering a dry well in Phoenix (Schmidt 1985). The City of Mesa, Arizona reported the presence of DDE in runoff samples obtained in 1993 from both an industrial and a residential site (*Mesa* 1993). DDT and its degratory product DDE seem to be omnipresent in the Phoenix metropolitan area. DDT was detected by the FCDMC/USGS study in runoff from a heavy industrial site in 1992. DDE tended to be more ubiquitous and was reported in runoff from industrial, commercial and residential landuse areas throughout urbanized Maricopa County (FCDMC 1993).

Other common pollutants found in urban runoff can be grouped into broad categories. Bacteria are one such group, and they are usually monitored as total coliforms, fecal coliform, and fecal streptococci. Excessively high concentrations of these constituents have been found in stormwater runoff from both the Phoenix and Tucson metropolitan areas (ADEQ 1988). FCD/USGS data as well as that collected by Resnick, DeCook and Phillips (1983) substantiate this trend.

Another common group is the suspended sediment (Total Suspended Solids, TSS) load carried by urban stormwater runoff. Suspended sediment is very important in regards to urban stormwater runoff quality. It has been shown that hydrocarbons, surfactants, and heavy metals adsorb to dust particles and are eventually washed into urban stormwater conveyances during storm events (Asplund et al. 1980). Lead and petroleum hydrocarbons show especially high affinities for the surfaces of small suspended soil particles. Strong correlation coefficients exist between heavy metals such as Pb and particle size. For example, it has been shown with a 95% confidence interval that Pb is strongly associated with particles less than 63 μm in size, as are Cu and Zn (Elrick and Horowitz 1987).

One of the most interesting of the groups of compounds found in urban stormwater is the "oil and grease" fraction. "Oil and Grease" is defined as that fraction soluble in trichlorotrifluoroethane (*Standard Methods* 1989). Apart from the common oils, motor oil, lubricating oil, fuel oils, etc., the "oil and grease" fraction in stormwater may represent a whole host of organic, inorganic, and other hydrophobic compounds. It has been implied that the "oil and grease" fraction acts to sequester these constituents somewhat like activated carbon does in the removal of organic compounds (Wilson et al. 1989).

In general, a myriad of pollutants exist in urban stormwater runoff. Organic compounds from industrial, transportation, and residential activities are all present at least on a transient basis. Heavy metals such Cu, Pb, and Zn appear very often, as do bacteria and suspended solids. Petroleum hydrocarbons, prevalent in almost every commercial, industrial, and transportation activity exhibit the same preponderance in urban stormwater runoff. This has been substantiated by both private and federally sponsored research.

Stormwater Management Options

In the past, large-scale stormwater management options practiced in urbanized Maricopa County have mainly focused upon the quantity aspects of urban stormwater runoff. Large conveyance structures have been constructed which route stormwater to surface waters with little regard to water quality. Some of the more striking include the Indian Bend Wash which routes urban stormwater from Phoenix, Paradise Valley, and Scottsdale to the Salt River, the Arizona Canal Diversion Channel which takes runoff from North and Central Phoenix and delivers it to the Lower Gila River via Skunk Creek, New River, Agua Fria and the Salt rivers, and the East Maricopa Floodway which receives drainage from the eastern portion of Maricopa County, including Mesa and Chandler, and routes it to the Middle Gila River. These structures function very well in directing flood waters away from populated areas and have reduced the loss of life and property in Maricopa County due to flooding. They do not, however, significantly impact the quality of the water they convey.

On a smaller scale, however, many municipalities require stormwater management options that result in treatment of both the quantity and quality of stormwater. Recently, these practices have been termed Best Management Practices or BMP's. Stormwater BMP's take the shape of educational, regulatory, and structural stormwater controls. The best form of stormwater quality management lies in educating the public and industry to keep potential pollutants out of contact with stormwater runoff. This amounts to good housekeeping, and is probably the easiest control to implement. Regulatory controls are already being practiced, and on the local level have taken the form of stormwater ordinances and on-site detention requirements. Basic structural BMP's include detention and retention facilities such as catchment basins, sedimentation ponds, and infiltration/filtration basins (Pond 1993). These controls all function on the same basic premise. Retain the runoff and regulate the volume in an attempt to increase the hydraulic retention time within a given control structure and allow pollutant laden particles to settle out of suspension (Birch et al. 1992). Many times however, it is not feasible or desirable to allow for long retention times, such as when standing water poses a hazard to children or allows mosquito populations to soar. When this is a concern, the water must be conveyed rapidly even though this will adversely affect the pollutant removal capability of a given control due to suspended particles not having sufficient time to settle.

One of the most prevalent structural stormwater management options in Maricopa County is on-site detention associated with dry wells. This practice maintains stormwater runoff on-site, or within a given subdivision and allows for the passive injection of stormwater into the vadose zone. A basic dry well configuration consists of a sedimentation chamber filled with "pea-gravel" through which a slotted injection pipe passes into the vadose zone. Dry wells typically end within the vadose zone and are not hydraulically connected to the aquifer. However, as the well matures, a saturated transmission zone may form which may facilitate surface runoff introduction into the aquifer itself (Wilson et al. 1989).

Management of stormwater quantity can be readily achieved using this methodology, but questions regarding the impact stormwater quality has on the receiving-waters (i.e., groundwater) are raised. Nutrients, pesticides, herbicides, heavy metals, and polynuclear aromatic hydrocarbons (PAH's) are all likely constituents of urban stormwater runoff that if introduced to the groundwater could pose a threat to drinking water supplies.

Based upon the contaminants noted in urban stormwater runoff and the way in which dry wells work, it would appear that this type of stormwater management would contribute to groundwater contamination. Several local studies have addressed this issue, and some surprising results were obtained. Kenneth Schmidt (1985) examined the quality aspects of a dry well situated within a commercial parking lot in Phoenix, Arizona. It was found that none of the pollutants detected in the runoff appeared in groundwater samples, and that the stormwater runoff actually improved the groundwater quality down gradient of the dry well.

In another study, injection tests were conducted on an experimental dry well in Tucson, Arizona by University of Arizona researchers. In this test, five (5) injections of simulated urban runoff were made into the dry-well and the attenuation of the contaminants were observed. The test showed significant, but incomplete attenuation of the pollutants as they migrated laterally within the vadose material and mixed with native groundwater (Wilson, et al. 1989).

L.G. Wilson and others (1989) recently conducted a comprehensive dry well survey and sampling study to assess the potential of dry-wells to contribute to groundwater contamination in the Tucson metropolitan area. This study indicated that the dry well pollution potential is very site specific. The pollution potential is dictated by the landuse drained by the dry well, the wells age, and the type of maintenance conducted at the site. Wilson's study also indicated that contaminants hard to detect in the stormwater runoff entering the well became concentrated within the dry well sediments. The compounds most concentrated were PAH's and phenolic compounds, while ethylbenzene, toluene, and xylene were accumulated to a lesser degree. Wilson (1989) proposed that the major mechanism for removal of these compounds from the well sediments was volatilization, and to a lesser degree biodegradation.

Wetlands in General

More and more stormwater managers are considering the use of either natural or constructed wetlands to treat stormwater runoff. In the case of natural wetlands, this issue has posed the question, how can wetlands be used to treat stormwater runoff without being damaged? EPA guidance suggests at a minimum, stormwater should receive some pre-treatment to remove the settlable solids, regulate the flow, and to remove toxic constituents before introduction into the wetland (Nichols 1992). Constructed wetlands could be managed in a different manner in that pretreatment may be incorporated directly into the system.

Wetlands, both natural and constructed, are dynamic systems whose individual components work in concert to remove or attenuate a variety of pollutants commonly found in urban stormwater runoff. Most constructed and natural wetland systems are comprised of five components: 1) a mixture of substrates each having different hydraulic conductivities, 2) vegetation adapted to frequent inundation and capable of surviving in anaerobic substrates, 3) either free-surface or submerged water flow, 4) both invertebrates and vertebrates, and 5) both aerobic and anaerobic microbial populations (Hammer and Bastian 1989).

Wetland Substrates

Wetland substrates are generally made up from a mixture of soil (silt and clay), sand, and gravel. Their obvious function is to provide structural support for the vegetation, however, from a treatment standpoint they provide a large surface area for adsorption of organics, complexing of anions and cations, straining of particulate matter, and as a surface for microbial attachment (Hammer and Bastian 1989). Wetland soils can be comprised of entisols (new soils such as those from volcanic activity), highly weathered oxisols, and or organic histols (Faulkner and Richards 1989). Wetland soils are also regions of variable reduction-oxidation potential. Because of this, they are typically a major system for processing nutrients and other materials often found in urban runoff.

The reactivity of a given soil is usually dependant upon the surface area and charge of the particles. Clay-sized particles and the organic content aid in charge development (Bohn et al. 1985). The charge associated with a soil, often measured as the cation exchange capacity (CEC), promotes the removal of several wastewater constituents via ion exchange. Nitrate, sulfate and phosphate are three such anions that can be removed. Wetland soils may also remove pollutants via adsorption and complexation. Adsorption occurs primarily by ligand exchange while complexation usually refers to metals binding with organic matter present in aquatic sediments (Faulkner and Richardson 1989).

Most wetlands contain anaerobic zones because after inundation, microbial activity and chemical oxidation rapidly utilize the available oxygen. This provides an environment conducive to the transformation of nutrients (Leibowitz et al. 1991). As an example, facultative bacteria exist in the anaerobic substrates that reduce nitrate and nitrite to nitrous oxide and N_2 gas in the denitrification process. Davido and Conway (1989) studied the Iselin, Pennsylvania Marsh/Pond/Meadow wetland system and found it to be an effective system for removing nitrogen from wastewater.

Wetland soils also provide for metals retention. This is achieved via adsorption, precipitation and complexation with organic matter in sediments (Weider 1988). It has been shown that in reduced soils, metal removal is most effectively achieved via metal-sulfide formation (Engler and Patrick 1975). Some metals capable of complexing with sulfide include iron, zinc, copper, and mercury. Lead and other metals commonly found as surface coatings on small soil particles associated with the particulate phase of stormwater are also retained in wetland systems. This efficiency is usually related to how well suspended solids are removed.

Organic compounds, such as petroleum hydrocarbons, can also be removed from stormwater runoff by wetland systems. The process most likely begins with adsorption of the hydrocarbon onto the surface of soil particles and vegetation. The captured (adsorbed) hydrocarbons can then be volatilized or metabolized by bacteria and fungi if environmental conditions such as sufficient oxygen and nutrients are present (Portier and Palmer 1989).

Wetland Vegetation

Wetland vegetation includes woody plants, emergent, submerged and floating aquatic plants. Woody plants occur in bogs, swamps and estuarine environments. Bald cypress (*Taxodiium distichum*) and pond cypress (*Taxodiium distichum* var *nutans*) are woody plants typical of the southeastern United States freshwater forested swamps (Mitsch and Gosselink 1993). These systems have been cited as being nutrient sinks and have been investigated for the effects of wastewater additions (Mitsch and Gosselink 1993). However, since most wetland systems dominated by woody species are natural in origin, their use as water treatment systems is discouraged because they are easily mismanaged. An example is the mismanagement of a natural forested wetlands in Washington State used to treat stormwater runoff. Frequent and persistent inundation, as well as fluctuating water levels, have resulted in the loss of almost 1.2 ha of habitat at that site (Nichols 1992).

Herbaceous, or non-woody plants are more commonly associated with constructed wetlands, especially those designed for water treatment. Emergent, submerged, and floating aquatic macrophytes have all been tested for use in wetlands for wastewater treatment (Guntenspergen et al. 1989). The most promising from a water quality standpoint appear to be emergent and floating aquatic species. Submerged aquatic plants are slow in growth and don't tolerate high nutrient, low light conditions which makes their application as a treatment system difficult (Guntenspergen et al. 1989). The choice of vegetation is dictated by the type of wetland constructed and what pollutants are targeted for removal. Floating aquatic plants are desirable for nutrient removal because of their ability to remove nutrients directly from the water column. In addition, floating aquatic plants tend to have high growth rates and large standing crops which allows for greater rates of nutrient uptake (Reddy and DeBusk 1985). Rooted emergent vegetation is more suited for particle removal and can be used to treat flows with high suspended solids concentrations such as those typical of stormwater runoff.

From a water quality enhancement standpoint, wetland vegetation serves several important purposes. First, emergent vegetation can act to slow flood waters upon entering the system reducing erosion and causing suspended sediments to fall out of suspension. Second, within the water column, stems and leaves provide a surface area for periphyton attachment and growth. Third, most aquatic plants have a mechanism with which to transport oxygen and other gases to the rhizomes and out into surrounding anaerobic soils creating an aerobic zone which facilitates aerobic microbial degradation of pollutants. Finally, wetland vegetation is capable of nutrient removal, hydrocarbon retention and metal uptake on their own (Pond 1993).

Vegetation that reduces the velocity of runoff into a wetland treatment system can greatly enhance the pollutant removal efficiency of the system. Aquatic species such as the cattail (*Typha latifolia)* are known to grow rapidly and in dense stands. These stands act to slow water flow and trap pollutant laden particles. Pond (1993) found that soils associated with *Typha latifolia* had the highest concentrations of total petroleum hydrocarbons (TPH), lead and zinc when compared to other plant species considered in his work.

Periphyton, both free-swimming and attached to the surface of submerged aquatic vegetation also demonstrate the removal of pollutants such as nutrients, metals and certain hydrocarbons from stormwater runoff and other wastewaters (Pond 1993). Representative periphytic communities consist of single celled and filamentous green algal forms, diatoms, and protozoans. Vymazal (1989) studied the efficiency of periphyton communities for nutrient elimination, and found they can be an effective means of removing nitrogen and phosphorous from aquatic environments. These organisms are ubiquitous in the aquatic environment, but this study did not assess their contribution to the removal of hydrocarbons by the SVTS.

The most important feature of aquatic plants in terms of hydrocarbon degradation for this study would appear to be the capability to oxygenate the surrounding anaerobic soils. The ability to transport oxygen and other gases to the aquatic substrate is well documented and aided in plant selection for the SVTS. Gases enter and exit plant leaves and stems through minute openings called stoma. Once inside, gas transport occurs through pressure differentials or via passive diffusion. Gas transport in floating leaved aquatic plants, as well as alder (*Alnus glutinosa*) is accomplished by pressure gradients set up by thermoosmotic gasflow (Grosse 1989). In essence, thermoosmotic gasflow occurs when pressure rises within the arenchymal tissue, (small cells containing gas), of a leaf because it is warmer than the ambient air. This temperature differential causes an increase in pressure, which in some cases is great enough to establish airflow throughout the plant tissue, which is especially important to deep water species (Grosse 1989). Diffusion alone however, can satisfy the oxygen demand of the roots for plants occurring in shallow regions, or that have short leaf to root morphology such as the reed *Phragmites australis* (Armstrong and Armstrong 1988). Gases then diffuse out of the plant tissue to the surrounding environment. Diffusion from the rhizomes creates an aerobic zone (rhizoshpere) in the surrounding soils which facilitates microbial oxidation reactions that modify nutrients, metals and organic compounds (Gersberg et al. 1986). This adaptation to living in reduced saturated soils may also protect the plants themselves by oxidizing phytotoxins such as Fe^{2+} hydroxide (Grosse 1989).

The extent to which aquatic plants diffuse oxygen to the surrounding wetland soils can be measured as radial oxygen loss (ROL). A study conducted by Michaud and Richardson (1989) investigated the ability of five (5) wetland plant species to diffuse O_2 into the benthic soils. The emergent perennial macrophytes cattail, burreed, spikerush, woolgrass, and rush were compared. Researchers found that the cattail (*Typha latifolia)* had the highest rate of radial oxygen loss on a per unit biomass basis. This study also revealed that ROL varies with different aquatic species which implies that vegetation selection could influence the amount of oxygen in the sediments.

The influence aquatic vegetation has on pollutant removal in wetlands is not restricted to microorganisms or oxidation of metals associated with the rhizosphere. Aquatic plants themselves are capable of cycling nutrients, complexing metals and even the absorption of petroleum hydrocarbons. Cycling of the nutrients nitrogen and phosphorous is well known, and the plants utilize these nutrients for their own metabolic activities and storage. Nutrients are however cycled, and as such, for true nutrient removal the plants must be harvested (Mitchell 1974).

Metal uptake and assimilation has also been documented for aquatic plants where it occurs in root, stem and leaf tissues. Lead and zinc uptake by *Typha latifolia* was investigated by Zhang et al. (1990). His work revealed that *Typha latifolia* responded to increasing zinc and lead concentrations by assimilating some of the highest levels documented, 1800 ppm and 976 ppm respectively in root tissue. Earlier work by Grill et al. (1985) identified heavy metal complexing peptides, called phytochelatins. The peptides were isolated from higher vascular plants and represent the major metal binding activities within the plant cells and allow metals to be sequestered within the plant tissue. Complete removal of metals from aquatic environment by this mechanism, can only be accomplished by harvesting the aquatic plants.

Bioaccumulation of petroleum hydrocarbons in aquatic plants has been documented, but references are rare. Work by Kathe Seidel (1976) appears to be some of the first regarding TPH uptake and utilization by plants. She found that phenol can be stored and utilized by *Scirpus lacustris* for amino acid production both when phenol was injected and when *Scirpus lacustris* was cultured in solutions of 10 to 100 mg phenol/l.

Some very recent work conducted by Pond (1993) indicated that certain aquatic macrophytes exposed to hydrocarbon contamination can retain these compounds in their tissues. Individual sampling events revealed that all plants studied accumulated TPH levels in the root tissue with *Typha latifolia* exhibiting the highest mean concentration of 4433 ppm. Some of the highest levels of TPH found in aquatic plant tissues were recorded in coastal rush (*Juncus roemerianus*); 9000 ppm in the shoot tissue (Lytle and Lytle 1987).

Wetland vegetation is an integral part of the pollutant removal capability of these systems. For constructed wetlands, the type of pollutants targeted for removal should indicate the types of vegetation to use. This study focused upon the removal/remediation of petroleum hydrocarbons. As demonstrated by the literature review just presented, *Typha latifolia* appeared well suited for this type of pollutant removal, and was chosen for introduction into the SVTS.

Wetland Microbiology

Wetland plants and soils support a diverse population of bacteria, fungi, and actinomycetes. These organisms represent the first step in the food chain and are responsible for obtaining energy from numerous man-made compounds entering the system. Energy is obtained during their metabolic activities which take the form of fermentation, aerobic respiration, and anaerobic respiration.

Pollutant removal by microorganisms is merely their attempt at satisfying their own nutritional requirements. Microbes can be classified into three major groups by what energy source they use. Chemoorganotrophs utilize organic compounds, photoautotrophs use energy from the sun (UV radiation), and chemolithotrophs oxidize inorganic compounds (Portier and Palmer 1989). The SVTS was designed to remove petroleum hydrocarbons which is most effectively accomplished by aerobic chemoorganotrophic bacteria. Metabolism of petroleum hydrocarbons by bacteria has been well documented, as early as 1928 researchers had shown soil bacteria capable of metabolizing certain hydrocarbons (Portier and Palmer 1989). The primary attack on both straight chain (aliphatic) and ringed (aromatic) hydrocarbons requires oxygen, thus the need for vegetative ROL is paramount in wetland systems. It is interesting that only a few bacteria are capable of surviving on C_1 compounds, while a whole host of bacteria capable of utilizing 10-18 carbon compounds are quite prevalent (Gottschalk 1986). Some common genera include: *Pseudomonas, Acinetobacter, Mycobacterium, Nocardia, and Corynebacterium.*

Both the vegetation and the microbial population it harbors work together to remove hydrocarbon pollutants from wetland systems. Not only does *Typha latifolia* absorb petroleum hydrocarbons and sequester heavy metals, but the extensive rhizosphere has been shown to support a diverse microbial population capable of oxidizing petroleum products (Morozov and Torpischeva 1973). The impact soil microbes have upon petroleum contamination may be seen by reduced TPH levels in aerobic soils surrounding the root structures of aquatic vegetation. Petroleum oxidizing microbes were found to contribute to significantly low TPH levels in soils surrounding *Iris pseudacorus* in a study by Pond (1993).

Free Surface and Submerged Flow

Wetlands used for wastewater or stormwater treatment are typically designed so that either a free water surface is present or only subsurface flow exists. A free water surface implies that a water column exists above the substrate, while a subsurface system is one in which water flow is through a porous medium (Tchobanoglous and Burton 1991). In a constructed free surface wetland, the water column depth is dictated by the vegetation, whereas in a subsurface wetland, rhizomal depth may dictate the depth of the saturated soil column. The system developed for this 319(h) project was designed as a subsurface flow wetland.

Wetlands as Habitat

Natural wetlands serve as habitat for many vertebrate and invertebrate animals, and more than 20% of the plant and animal species on the federal endangered or threatened species list rely upon wetlands for habitat (Reily and Wojnar 1992). Constructed wetlands offer the chance to establish such habitat in a managed setting. Even small constructed wetlands like the one described in this paper provide habitat. A cursory inventory of the subject 319(h) wetland revealed the presence of mollusks, insects, amphibians, and birds.

MATERIALS AND METHODS

Study-Site

Four (4) vehicle maintenance yards were visited and each was examined for possible installation of the treatment systems. Criteria used in selecting a treatment site included what materials were stored or used at the site, what activities typically occurred, were existing dry-wells in place, and was the site hydraulically isolated. The Maricopa County North Valley Vehicle Maintenance Yard at 16821 N. Dysart Rd. in Surprise, Arizona satisfied most of these criteria and was chosen for this study. Fig. 2 shows a schematic of this vehicle maintenance yard.

As is typical of most VMY's, the fuel bays are almost constantly in use. Both unleaded gasoline and diesel fuel are dispensed into light duty trucks and heavy duty road maintenance vehicles. Maintenance is performed on the vehicles, such as oil and transmission fluid changes inside covered garages. Vehicle washing is also a maintenance activity occurring at the site. An automatic car-wash is located on the western side of the Operations Building and has a grit chamber for treatment prior to discharge to a sanitary sewer. Asphalt paving equipment is also washed at the site, but this occurs on a concrete wash pad adjacent to the automatic carwash. Water from the concrete wash pad is supposed to enter the grit chamber, but at times this surcharges and water enters the west end of the detention basin.

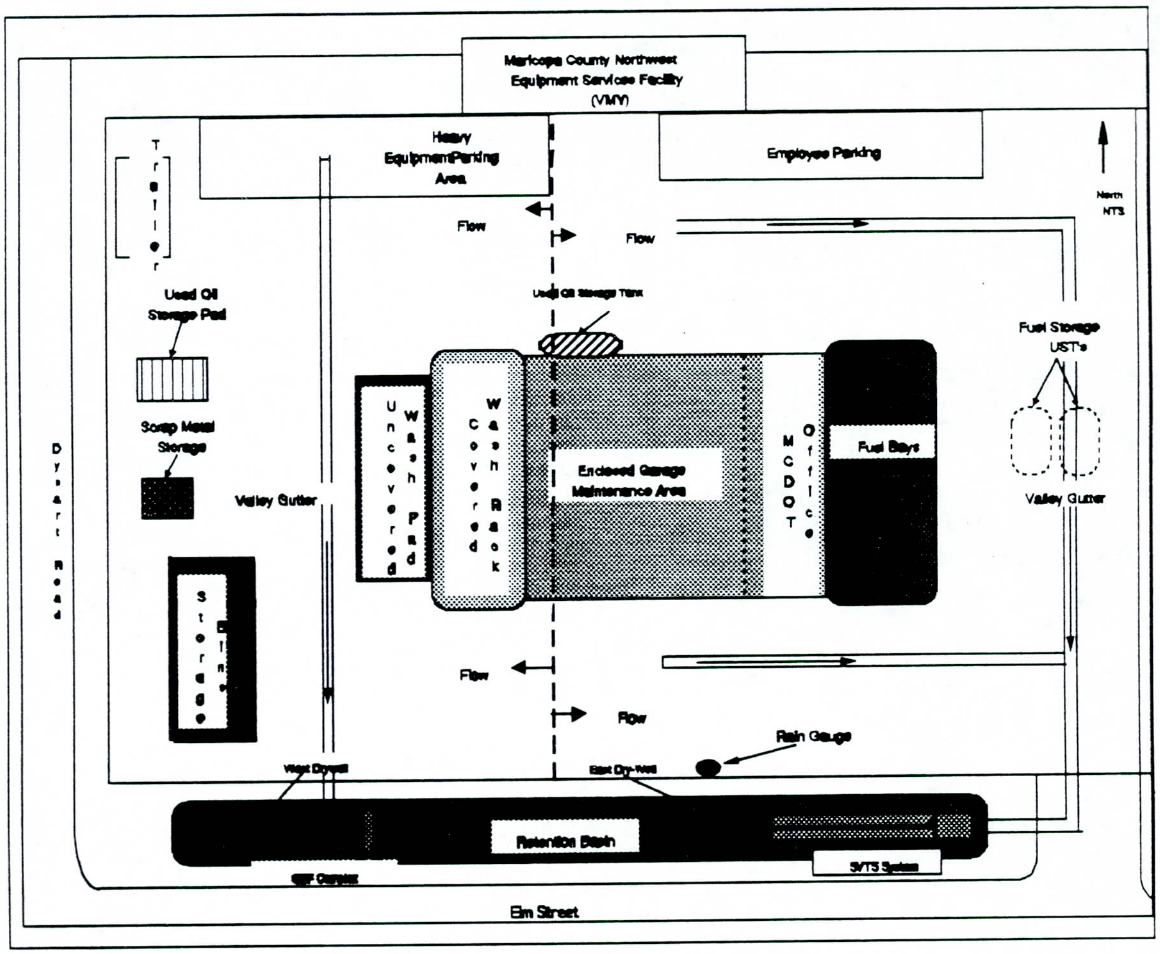

FIG. 2. North Valley Vehicle Maintenance Yard schematic.

Since this yard is charged with vehicle maintenance, as well as road construction and asphalt paving, materials needed to accomplish these tasks are generally stored on-site. Table 1 reviews a list of commonly stored materials and their respective storage quantities.

TABLE 1. Commonly stored materials and potential stormwater pollutants.

Motor Oil	1500 L
Grease	200 L
Unleaded Gasoline	44,000 L
Diesel Fuel	44,000 L
Misc. Solvents	200 L
Transmission and Hydraulic Fluid	400 L

The VMY occupies a 0.8 ha. (1.94 acres) area, of which almost 95% contributes runoff. On-site detention is provided by a 590 m^3 (20,835 ft^3) detention basin. The basin is located on the southern perimeter of the yard and WACO Drilling of Phoenix installed two dry wells in 1988, one at the east end and one at the west end of the basin. These wells have 7.6 m (25 ft) deep settling chambers with a gravel drainage field. Perforated injection pipe is used to introduce stormwater into the vadose zone. The top of the injection pipe has a screened inlet to prevent large debris from entering and ultimately clogging the inlet. Prior to this study, stormwater runoff entered these wells untreated.

Vadose zone soils at the site have been classified by the U.S. Soil Conservation Service as Laveen Loam. Laveen Loam formations are characterized by deep, well-drained soils which occur on old alluvial fans and valley plains typical of the area surrounding the site. Depth to groundwater is between 91.4 m (300 ft) and (183 m) (600 ft) below ground surface (bgs) according to the Arizona Department of Water Resources Phoenix Active Management Area Map of 1987 (ADWR 1988). This depth was corroborated by three Town of El Mirage, Arizona water production wells located within 5 miles of the site which had water levels that ranged from 128 m to 134 m (420 to 440 ft.) bgs as measured in May 1992.

Runoff is directed to the detention basin via a valley-gutter system that effectively splits the flows and allows each dry well to accept approximately one-half of the total runoff volume generated. For a two-year, six-hour design storm, each dry well would be expected to process approximately 113,000 L (30,000 gal). The dry wells appeared to be effectively drained, however on at least one occasion it was noted that the western well backed up. This could be due to clogging of the gravel layer, especially since this well receives a higher particulate load. Modifications made to the basin to accommodate the GBF system may also have contributed to this problem.

Flows entering the respective dry wells are very different in pollutant loading. The western dry-well receives runoff from material storage areas and wash-bays. Materials stored in this area include aggregate piles for roadway repair and cold-mix asphalt piles. Weekly wash activities are also conducted in this portion of the basin and consist of washing heavy construction equipment and asphalt laying vehicles, as well as light-duty trucks and passenger vehicles. These activities produce runoff laden with suspended sediments and on occasion, high strength petroleum contaminants.

The dry well located at the east end of the basin receives runoff from the fuel bays and the maintenance garages. General vehicle maintenance activities occur in covered garages, and negligible stormwater contamination originates there. Runoff from the fuel bays contains petroleum hydrocarbons, and appears to be a contributor to contaminated stormwater entering the eastern portion of the basin.

Modifications

In conducting this study, several modifications were made to the VMY. The SVTS treatment system was constructed in the east end of the detention basin and the GBF complex in the west end. A telemetered rain-gauge was installed to monitor rainfall, and asphalt berms were placed to capture runoff exiting the property.

The SVTS was constructed in the east end of the basin to serve as dry well head protection by treating contaminated runoff originating primarily from the fuel bays and to a lesser degree, service garage areas. The GBF was constructed in the west end of the basin to treat runoff from the vehicle parking area, wash bays, and material storage bins. These bins housed among other things, cold-mix asphalt from which runoff often contained high concentrations of high molecular weight asphaltenes. The rain-gauge was installed so that an accurate rainfall history for the site could be developed, as well as to serve as an early warning system to allow for rapid response by the sampling team. The gauge is now part of the Flood Control District's early warning system and has been assigned FCD gauge I.D. No. 5510. Early on in this project it was noted that a significant portion of runoff was bypassing the SVTS. Maintenance crews at the yard placed cold-mix asphalt berms along the eastern border of the parking area which essentially eliminated that problem.

GBF Construction

The GBF is a system of five aggregate dikes configured to filter storm and wash water emanating from the vehicle storage, material storage, and wash areas of the yard. Each dike was based on a 5.1 m arc length and required approximately 0.75 m^3 of core material and an additional 0.2 m^3 of cover material. Refer to Table 2. for a complete listing of the materials used to construct individual dikes. To discourage infiltration, dikes were placed upon a 30 mil Dynaloy pond liner furnished by Palco Linings, Inc., Stanton, California.

Table 2. GBF Core Materials.

Filter No.	Core Material	Cover
1	3" to 4.5" dia. Fractured Clean Local Aggregate	None
2	1" to 1.5" dia. Fractured Clean Local Aggregate	0.5' to 0.75" dia. Gravel
3	2.5" to 3.5" dia. Volcanic Cinder	0.5' to 0.75" dia. Gravel
4	2.5" to 3.5" dia. Volcanic Cinder w/ PAC	0.5' to 0.75" dia. Gravel
5	1" to 1.5 " dia. Fractured River Rock & Imbiber Core	0.5' to 0.75" dia. Gravel

Individual dikes were constructed in-place by positioning approximately 0.75 m^3 of core material onto a pre-cut 1.0" mesh chicken wire rectangle (6' wide x 18' long). The wire was molded around the core material and fastened with metal clips to maintain integrity. Clean local aggregate was applied to cover each filter except No. 1. Figure 3 provides a schematic of the GBF system.

Dikes one and two were constructed with large aggregate to serve as filters for larger debris such as leaves and paper waste. Dike three was placed using volcanic cinders so as to provide more surface area for sorption of organics and attachment of microbes. Dike four again used volcanic cinders, but was coated with powdered activated carbon (PAC) to further increase the surface area for attachment and sorption. Finally, dike number five was designed as a fail-safe by installing a polymer core (Imbiber Beads, manufactured under license from the Dow Chemical Co.). This core should have allowed for the capture of virtually all non-polar organic compounds present in the runoff.

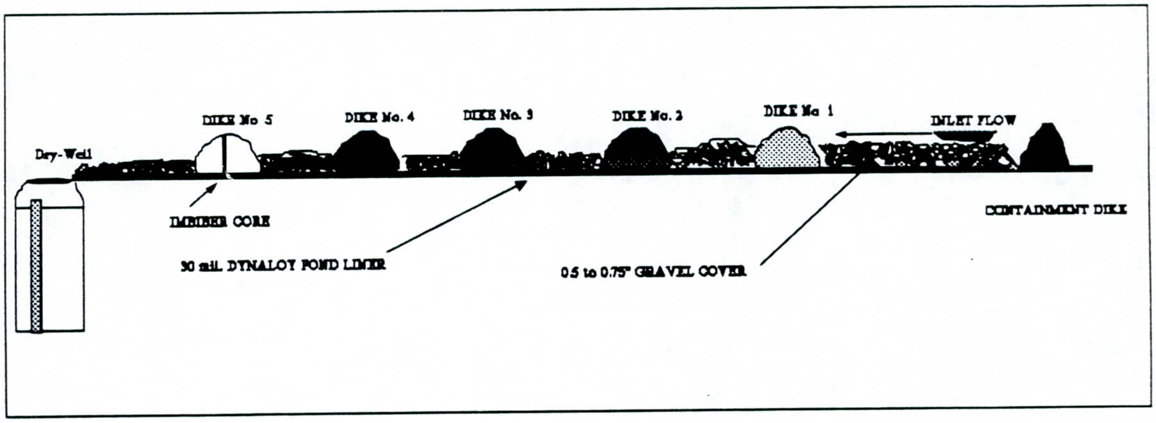

FIG. 3. Profile of GBF Complex located in the west end of detention basin.

Along with dike placement, two other modifications were necessary. First, irrigation water is provided to the GBF system by means of a single articulating sprinkler. This was installed to combat desiccation of the filters during times of drought. The second modification involved placement of a containment dike at the upstream end. Site visitations during storm events indicated that a significant portion of the flow once thought to enter the western dry-well was in fact flowing to the east, forming a ponding area in the middle of the basin. The containment dike worked too well and the western dry-well has since been overwhelmed on several occasions.

SVTS Design and Construction

The submerged-flow vegetated treatment system used for this study has four principal components: 1) Settling basin, 2) Flow equalizer, 3) Treatment zone, and 4) Outlets. Figure 4 provides a schematic showing the plan-view of the SVTS system.

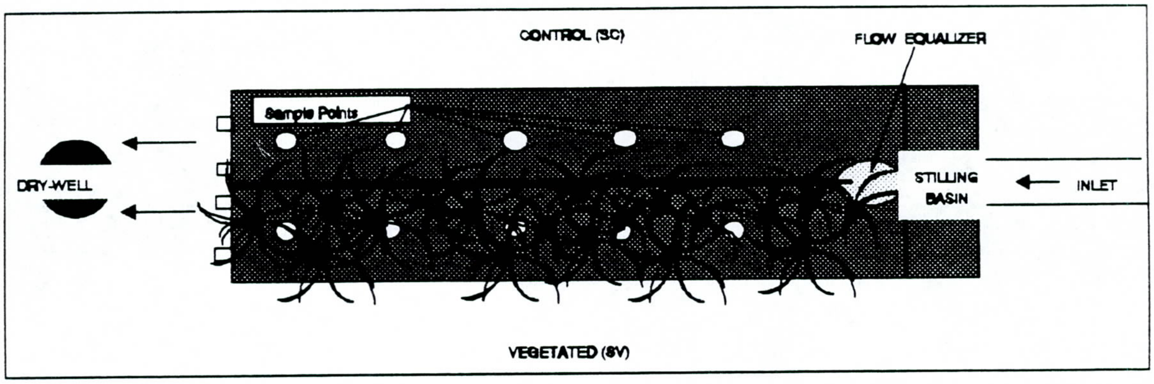

FIG. 4. Plan-view of submerged-flow vegetated treatment system located in the east end of the detention basin.

Economy and familiarity of construction dictated that concrete serve as the structural component for the SVTS. Fifteen centimeter (6.0") walls rest on a 10 cm (4.0") minimally reinforced at-grade slab to form the treatment cell and settling chamber. The settling chamber is isolated from treatment cell and flow equalizer by a separator wall which is also 15 cm thick. All walls use No. 4 vertical steel bars spaced 41 cm (16.0") center on center and two rows of horizontal steel for reinforcement. Hydraulic connection between the settling chamber and the flow separator was achieved by boring 2.5 cm (1.0") diameter holes through the 15 cm separation wall. In a similar manner, the flow equalizer was perforated so as to allow equal volumes of stormwater to enter both the vegetated (SV) and non-vegetated control (SC) portions of the treatment cell. Flow exits the system via four 15 cm (6.0") PVC conduits placed within the downstream wall at the time of the concrete pour. Two of the conduits, one on each side (SV and SC), are equipped with PVC valves and 90° upsweep pipes to allow water level adjustments, while two are capped.

Stilling Basin

The stilling basin has a surface area of 2.32 m^2 (25 ft^2) and a volume of 1.8 m^3 (62.5 ft^3). Within the basin, irrigation piping enters the system to maintain a constant water depth in times of drought. Runoff velocity and energy are dissipated within this basin which allows for some suspended sediment removal. Hydraulic connection between the stilling basin and the rest of the system is achieved through submerged holes.

This portion of the system has a free water surface and hence some operation problems could have been encountered. Free water surfaces are attractive to pests such as mosquitos and to inquisitive children. Although neither have caused a significant problem during this study, similar treatment systems should probably incorporate a covering of some type.

Flow Equalizer

Flows were effectively split between the SV side and the SC side of the treatment cell by using a PVC barrel cut into quarters. One quarter of the barrel was perforated so that water would enter the treatment cell from the bottom. This allowed the equalizer to act as an oil skimmer. In addition, a ball-float valve was housed within the flow equalizer to supply irrigation water and to maintain a saturated zone within the system.

Treatment Cell

The SVTS treatment cell was 10.7 m (35 ft) long, 1.5 m (5 ft) wide, and had a depth of 0.9 m (3 ft). It was separated longitudinally by means of a plywood wall covered with a Palco 30-mil oil resistant PVC liner. The separator provided the study with a means of comparing the SV side to the non-vegetated SC side. This configuration provided an overall empty volume of approximately 14.8 m^3 (525 ft^3). When the filter media was added, the volume was reduced to an active treatment volume of 10.5 m^3 (370 ft^3). The design slope was 1%. Using these dimensions, Darcy's Law produced a theoretical hydraulic retention time (HRT) of 3.3 minutes.

Outlet Works

Each side of the treatment compartment is served by two 15 cm (6.0") PVC conduits and valves. One valve on each side was fitted with 90° PVC sweeps. The sweeps are allowed to swivel and allow the amount of standing water within the system to be adjusted from a minimum depth of 10.0 cm (4.0") to approximately 21.5 cm (8.5").

Sample Ports

Sample ports were installed at the time of substrate placement and cattail planting. They were configured along the flow path and spaced approximately 1.8 m (6.0') center on center. The ports were fabricated out of 15 cm (6.0") perforate PVC pipe. In all, ten (10) sample ports were installed, five (5) on each side. Samples taken from these ports are labeled SV-1 through SV-5, and SC-1 through SC-5.

Irrigation System

To avoid undue stress to the vegetation during extended dry periods, irrigation water is provided to the system by means of a ball-float valve. This is an adjustable valve located within the flow equalizer, and is another means of varying the depth of standing water within the system. The water source is the municipal system of El Mirage, Arizona. El Mirage uses groundwater exclusively, and disinfection using chlorine is neither required nor practiced.

Soil/Gravel Matrix

Substrate used for the SVTS was obtained locally. Figure 5 shows the typical material placement within the treatment cell of the clean washed aggregate, wetland-type soil, and clean silica sand used as substrate for the SVTS.

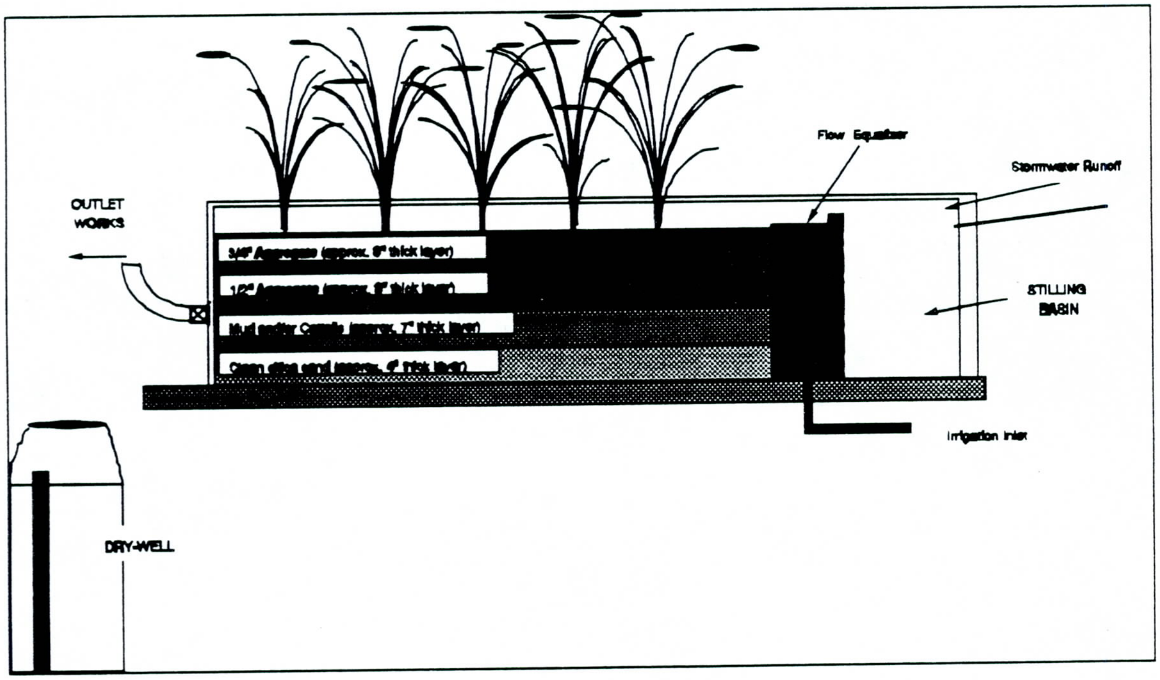

FIG. 5. SVTS treatment cell substrate.

The soil gravel matrix employed consisted of two size classes of clean fractured aggregate. The top layer is 20 cm (8") thick with an average diameter of 2 cm (3/4"). This overlays another 20 cm thick layer of 1.3 cm (1/2") diameter rock. These relatively coarse layers serve three primary functions; 1) to strain out large debris and prevent clogging of the finer material layers below, 2) to provide structural support for vegetative growth, and 3) to provide surface area for adsorption of pollutants and establishment of microorganisms.

Below the coarse aggregate layers, a 20 cm (8.0") thick lens of soil was placed for vegetation establishment. This material was excavated at the same time and location as was the vegetation. The material is alluvial in nature and was obtained from the bed of the East Maricopa Floodway in Eastern Maricopa County.

The bottom 10 cm (4") of the treatment cell was filled with clean silica sand. With the less permeable "mud" strata above, it was thought that capillary rise and evaporation would be minimized by providing the irrigation water with a hydraulically attractive horizontal pathway. In this way, evaporation losses may be reduced to only those associated with transport through the plant tissue (evapotranspiration).

Vegetation

The constructed wetland used for this study was designed as a submerged-flow system. Emergent vegetation was required because the system would never be fully submerged. The system would be subject to high temperatures and long periods without rainfall. Petroleum hydrocarbons were targeted for removal by the system and hence, the vegetation chosen would need demonstrated ability to survive in their presence.

Typha latifolia (Cattail) was chosen as the vegetation for this system because native stands of Typha latifolia were readily available and as the literature suggests, can tolerate reasonably high levels of petroleum contamination and still be effective at pollutant removal. The cattails were obtained from an area of the East Maricopa Floodway subject to inundation by agricultural tail-water. The use of native stands provided the system with vegetation already acclimated to the temperature extremes expected at the study site. Pollutants (petroleum hydrocarbons) targeted for removal in this study, have been successfully assimilated into the tissue by *Typha latifolia* and, its associated microbial population have been shown capable of metabolizing them.

Source Water

There are two primary sources of water. Stormwater is the predominant source as this is what the system was designed to accept. Irrigation water was provided as noted above, and on occasion, wash-water from maintenance activities is also introduced into the system.

Vertebrates and Invertebrates

Although not a design parameter, the insects, snails and birds play a role in the operation and maintenance (O&M) of a SVTS system. Vertebrates represented at this site included only birds. Negative impacts as a result of these animals could include increased nutrient loading, specifically nitrogen and introduction of undesirable algal species or bacteria.

Of the invertebrates expected, mosquitoes are of most concern. Maricopa County requires that standing water cannot persist for more than 12 days. This was another reason for designing the system for submerged flow.

Microbial Population

Microbes capable of using both aliphatic and aromatic hydrocarbon compounds as nutrient sources are present in natural environments (Gottschalk 1986). Research demonstrated microbial degradation of PAH's as early as 1947 (Hammer and Bastian 1989). Interestingly, only a few bacterial species are capable of surviving on hydrocarbon compounds of eight (8) or fewer carbons, while the use of long-chain hydrocarbons as a nutrient source is widespread (Gottschalk 1986). For the purpose of this study, the SVTS system was not inoculated and used only naturally occurring microbes that were either present in the mud associated with the cattails, or have been deposited via natural pathways (i.e., atmospheric deposition, stormwater, and birds). Had it been necessary, inoculate from activated sludge could have been used.

Operational Theory

Vegetated treatment systems are dynamic systems whose performance is subject to pollutant loading, water and nutrient availability, predatory pressures, and climatic conditions. These systems require a "seasoning period" in which the vegetation matures and a healthy microbial population develops. Figure 6 summarizes the general treatment strategy, one of physical removal of pollutants, vegetation establishment, microbial support, and eventual bioremediation of the hydrocarbons.

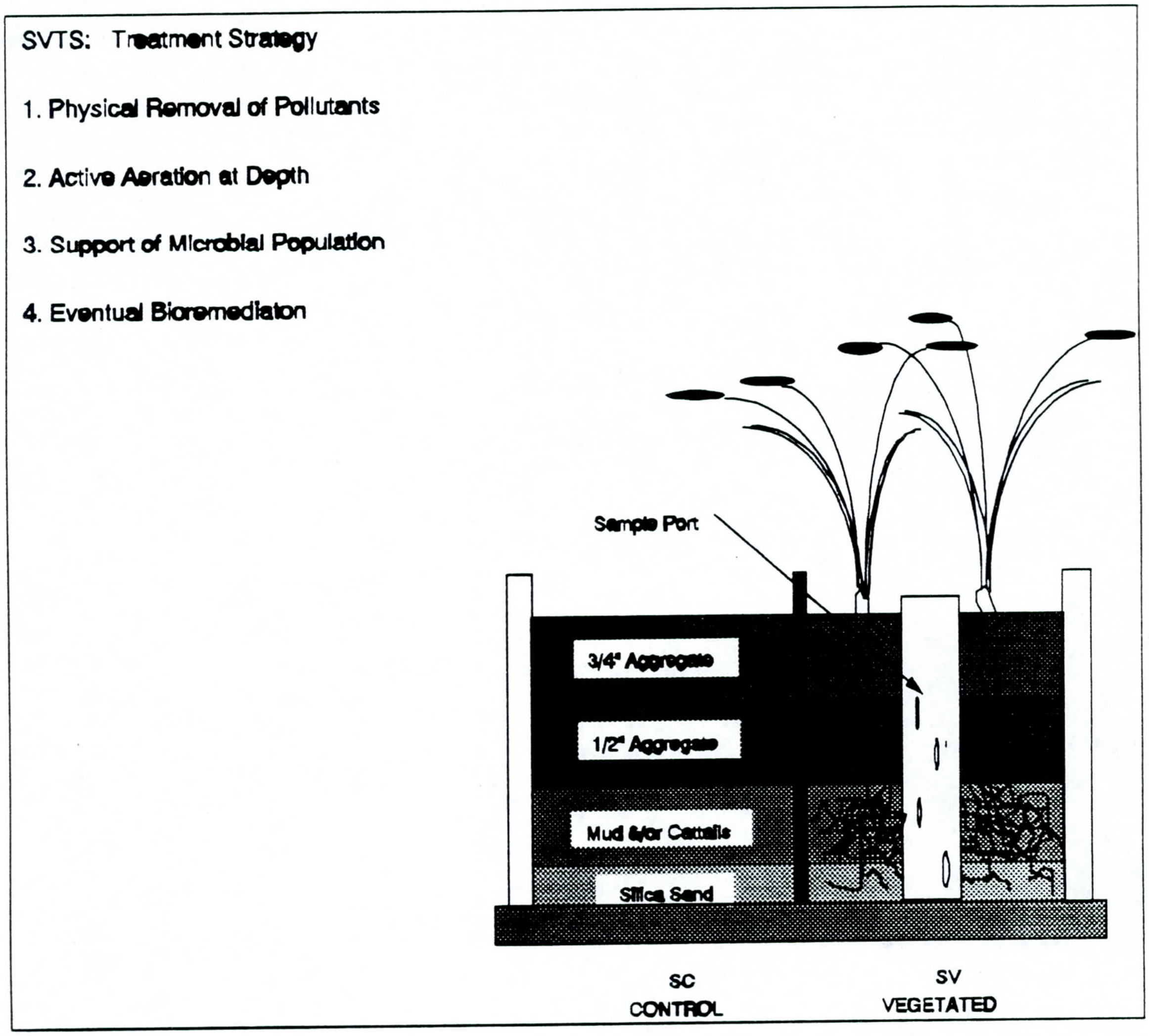

FIG. 6. SVTS treatment strategy.

During the "seasoning period" which can be 12 months or more, the SVTS is capable of removing hydrocarbons from stormwater. Removal at this stage probably refers to a buildup of contaminants within the soil/gravel matrix and assimilation into plant tissue, not microbial degradation. Hydrocarbon removal is primarily due to physical mechanisms such as, settling, straining, and adsorption. Volatilization and photochemical oxidation processes are the most likely remediation pathway during this period.

As the system continued to mature, root development created an aerobic zone within the water column and the soil/gravel matrix. This aerobic zone or "rhizosphere" provided the environment necessary for microbial development and subsequent metabolism of the hydrocarbons.

When the system reaches maturity, it is expected that four primary environmental fate and transport mechanisms will work together to reduce the amount of hydrocarbons present in the effluent. Volatilization and the photochemical oxidation of hydrocarbon compounds should occur in the upper strata of the treatment zone. Settling and adsorption of petroleum contaminated particles at depth will provide the carbon substrate for microbial metabolism and, will also provide substrate storage for periods without rainfall. Finally, root growth and plant metabolism will provide oxygen necessary to sustain a healthy microbial population necessary for the degradation of the physically captured hydrocarbon compounds.

Sampling and Analysis (GBF)

Water and soil samples were collected upstream and downstream of each of the dikes. Six storm events were sampled and analyzed for "oil and grease", pH, and conductivity, while soil samples were obtained on two occasions and used to assess the microbial activity associated with this system. Method 413.2 was used for all "oil and grease" analyses which were performed by Western Technologies, Inc., Phoenix, Arizona. Measurements of pH and conductivity were made in the field using a HACH One pH meter (Model No. 44200) and a HACH Conductivity/TDS meter (Model No. 44600).

Results (GBF)

Results from the "oil and grease" analysis indicates very little retention/removal by the GBF complex. Detectable quantities of "oil and grease" was present in all samples analyzed, and Figure 7 provides the reader with a summary of the average concentrations.

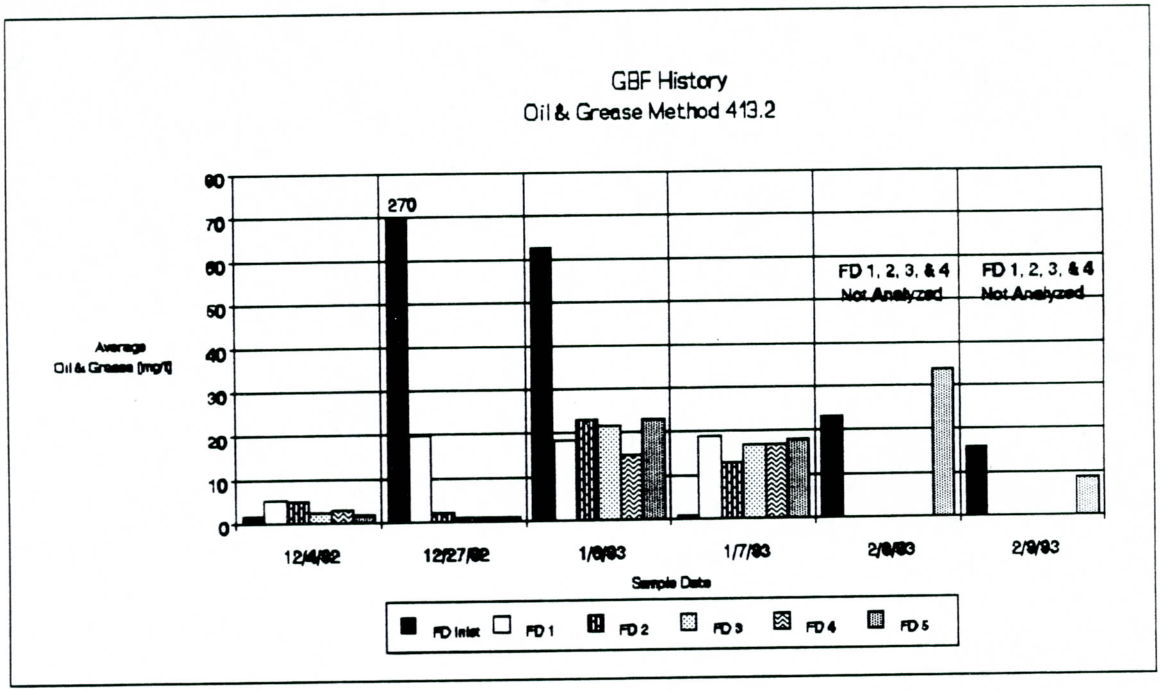

FIG. 7. Average "oil and grease" concentrations from the GBF complex for the sample period 12/92 through 2/93.

"Oil and Grease" in the runoff during storm events appears to distribute evenly throughout the system, and removal if any, is a function of adsorption to the surface of the filter media. Short-circuiting of the polymer core-material in Dike No. 5 could explain the presence of "oil and grease" downstream of this dike, but an even more likely cause was the surcharging of the western dry-well. The first witnessed surcharge occurred during the 2/8/93 storm event and it can be assumed that previous events had caused similar overflows.

Results from pH and conductivity monitoring indicated that the GBF had little effect on these parameters. Inlet pH ranged from 8.75 to 10.53 units while corresponding measurements downstream of Dike No. 5 ranged from 8.73 to 10.12 units. Conductivity measurements revealed little change from inlet to downstream of Dike No. 5. The last measurements taken (2/8/93) showed 457 mS/cm at the inlet and 492 mS/cm downstream of Dike No. 5.

Contamination caused by surcharging and the lack of a seasoning period in which a fixed bacterial film becomes established on the filter media invalidates these data from a quantitative aspect. Because of these problems it was decided to focus the remainder of the 319(h) resources to the monitoring and analysis of the SVTS. The remainder of this paper will now detail those results.

Sampling and Analysis (SVTS)

Sampling of the SVTS was conducted to satisfy several goals. First and foremost, sampling was used to assess the overall "oil and grease" removal efficiency of the SVTS, and to compare the effect vegetation has upon it. Second, it was used to assess the "oil and grease" retention, again comparing the vegetated side to the control side. Finally, sampling was conducted to assess microbial activity and confirm the presence of hydrocarbon degrading microorganisms.

Sampling efforts focused upon the "oil and grease" component of stormwater. "Oil and Grease" concentrations in the incoming, and effluent streams were used as an indicator of the hydrocarbon removal efficiency of the system. When using "oil and grease" as an indicator, it is essential to bear in mind that it is a nonspecific analytical method. "Oil and Grease" is defined as any compound recovered as a substance soluble in trichlorotrifluoroethane or other solvents (*Standard Methods* 1989). In some cases, the "oil and grease" concentration can be due to chlorophyll, certain organic dyes, or even sulfur compounds. Although their are uncertainties associated with this analytical method, for the purpose of this study it was adequate since the major source of organic carbon should clearly be petroleum hydrocarbons.

Two methods were employed in this study for the analysis of "oil and grease": 1) EPA Method 413.2 used by Westech Laboratories Inc., Tempe, Arizona, and 2) Hach Procedure 410, "Oil in Water" used by field workers. Samples analyzed by both of these procedures were obtained using "grab-sample" methods. Both analytical methods employ a similar procedure in which a sample is subjected to a dissolution within a solvent (trichlorotrifluoroethane (413.2) or 1,1,1-trichloroethane (410)), followed by spectrophotometric analysis. For the contract laboratory work, samples were collected in amber glass bottles, pre-preserved with sulfuric acid and chilled to 4° C for transport. Necessary chain-of-custody procedures were adhered to. Samples analyzed with the Hach field method were collected in clean amber glass bottles and evaluated immediately on-site.

In addition to the "oil and grease" component, chemical and physical parameters potentially useful in assessing biological activity were also monitored, these are listed in Table 3. Table 3 also indicates which analytical method was used including measurements made in the field.

TABLE 3. Water quality parameters monitored.

Parameter	Method
pH	Field
Conductivity	Field
Dissolved Oxygen	Field
Total Petroleum Hydrocarbons	Modified 8015
Volatile Organic Compounds	8260
Semi-Volatile Compounds	GC/MS
Oil and Grease	413.2
Oil in Water	Hach 410

Wet and dry weather sampling was conducted at the SVTS from December 3, 1992 through September 1993. Event sampling was conducted for storms occurring on 12/3/92, 12/28/92, 2/28/93, 8/6/93, and 9/10/93. Sampling during those storm events entailed collecting grab samples at the inlet, outlets, and at each "sample port". Stormwater collection continued at approximately one (1) hour intervals for the duration of each event. During the 12/3 and 12/28 storm events, the SVTS was operated in a "batch" mode. That is, the outlets were closed and stormwater was allowed to accumulate within the treatment compartment. The mode of operation was changed to "flow-through" for the 2/28/93 and all subsequent storm events by installing the 90° PVC sweeps and leaving the outlet valves fully open.

Dry weather sampling for "oil and grease", in which the samples were sent to the contract laboratory for analysis, was conducted on 2/1/93, 2/4/93, and 2/7/93. Oil in water analysis (Hach) from samples collected during dry-weather sampling was conducted during the months of March, April, May, June, July, August, and September 1993. The frequency of sampling was approximately two-times a month, and the analysis was conducted in the field using a Hach model DR/2000 direct reading spectrophotometer.

Field measurements of pH, conductivity, temperature and dissolved oxygen (D.O.) were conducted for each sampled storm event, and during most of the dry-weather visits to the site. The majority of the pH and temperature measurements were obtained using a Hach One pH meter, model No. 44200. Calibration using two laboratory supplied buffers was done before each sampling endeavor. Conductivity measurements were initially made using a Hach Conductivity/TDS meter, model No. 44600. Dissolved Oxygen measurements were made with a Horiba Water Quality Checker U-10. Initial sampling efforts with this meter also substantiated pH and conductivity trends established with the previous meters so it was used in this capacity for the remainder of the study.

Sediment Sampling

Sediment samples were taken to assess pollutant buildup and microbial activity. Sampling took place during dry-weather on 7/16/93, 8/24/93 and 10/15/93. The first samples represent the system after a three-month dry period, while the second was taken two-weeks after the first monsoon storm, and the third was post-monsoon.

Sediment samples were obtained using a stainless steel soil probe. After collection, the soil was placed in 375 ml sediment jars and transported to either the contract laboratory, or the Environmental Engineering Laboratory at Arizona State University. Once at the contract laboratory, soil samples were analyzed for "oil and grease", TPH, VOC's and semi-volatile organic compounds. Samples taken to Arizona State University were used in respirometry and plating experiments.

Microbial Assessment

Sediment and liquid samples were used to assess the activity of microorganisms present in the SVTS. Respirometry was used to compare relative microbial activity of the SV portion of the system with respect to the non-vegetated (SC) control side. Plating experiments were used to confirm the presence of petroleum degrading bacteria.

Respirometry apparatus used in the study consisted of 250 ml glass jars, fitted with a stopper through which a glass tube with septum was passed (Figure 8). These jars were filled with approximately 65 ml of soil, aggregate, and water obtained from the SVTS. A full set of respirometry bottles included control and spiked samples from each sample port. The control consisted of soil and water, whereas the spiked sample had 0.01 grams of toluene, naphthalene or phenanthrene added. Head-space volumes were measured, while CO_2 production and O_2 consumption were monitored with a Gow-Mac 500 Gas Chromatograph.

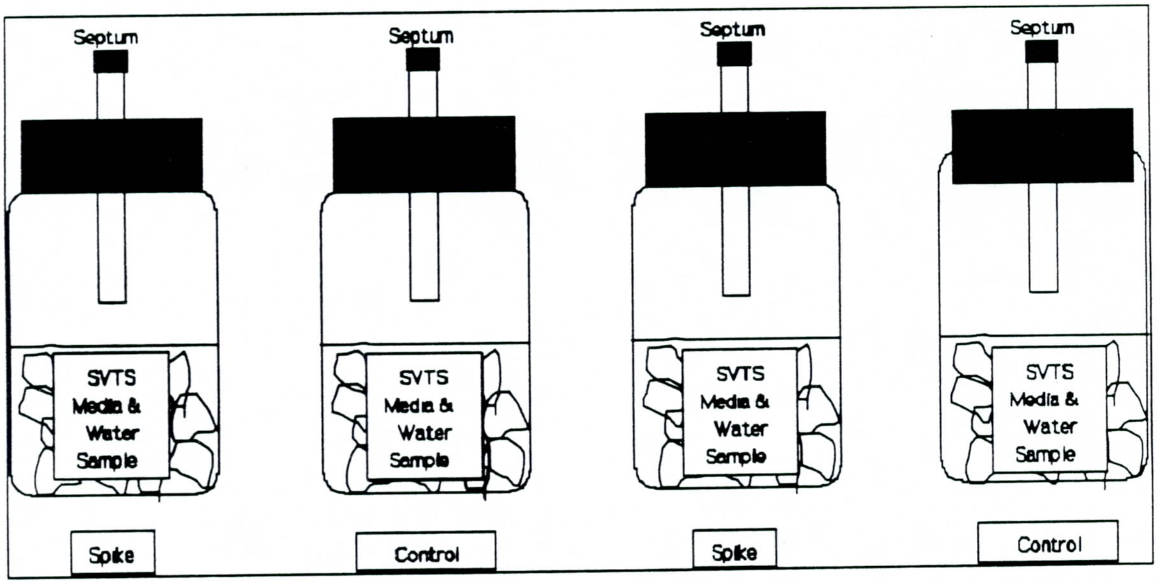

FIG. 8. Respirometry apparatus.

As a visual confirmation of the presence of petroleum degrading microorganisms, a plating technique developed by Kiyohara and others (1981) was used. This technique calls for growing bacteria on a mineral salt agar plate, and then spraying the surface with a 10% (wt/vol.) ethereal solution of hydrocarbon. If petroleum hydrocarbon degraders are present, clear rings within the hydrocarbon crystal coating surrounding the degrading colonies will appear. This study used a modification of this method. Instead of a mineral agar, a standard plate count agar (peptone, yeast, dextrose, and agar) was used. The hydrocarbons naphthalene and phenanthrene, were then applied by means of a syringe with the tip bent to allow a spray to be emitted.

RESULTS (SVTS)

Overview

Sampling efforts to date were geared towards three goals: 1) to assess the "oil and grease" removal/capture efficiency, 2) to determine if microbial activity is more prevalent within the SV side of the system, and 3) to confirm the presence of hydrocarbon degrading organisms. Regarding the first goal, analytical results from both the contract laboratory and Hach field measurements will be presented which indicate oil and grease retention. Conductivity, pH, and dissolved oxygen measurements are then presented to show trends associated with microbial activity. Finally, results from respirometry studies and plating experiments are presented which confirm the presence of hydrocarbon degrading bacteria.

Oil and Grease (413.2)

EPA 413.2 (IR) is the method employed by Westech Laboratories Tempe, Arizona to analyze for "oil and grease". This method consists of extracting a sample with trichlorotrifluoroethane and subjecting the extraction to infrared spectrophotometry. A sample detection limit of as little as 0.2 mg/l is possible. As with all methods used to determine the "oil and grease" content, interference from any compound soluble in the solvent can occur. It is also possible that some of the heavier weight hydrocarbon residuals may not solubilize in the solvent and thus cause an erroneous reading (*Standard Methods*, 1989). Water samples collected during the storm events of 12/3/92, 12/28/92, 2/8/93, and 8/6/93 were analyzed by this method and the average "oil and grease" concentrations are shown in Table 4. The results depicted are from samples obtained during collection of stormwater from the inlet and outlets (both SV and SC) of the treatment system.

Except for the inlet samples of 12/3/92, "oil and grease" was not detected in incoming or effluent waters from December 1992 through the middle of January 1993. It is thought that during this time, sites available for adsorption within the gravel matrix and on the surface of vegetation were vacant and the 'oil and grease" compounds were being sequestered. The absence of "oil and grease" in runoff from the VMY probably occurred because of the 7.58 inches of rain recorded at the site during this period which gave little time for pollutant buildup to occur.

TABLE 4. "Oil and Grease" average values from event sampling, as analyzed by Westech Laboratories Tempe, Arizona.

Event Date	No. of Samples	Average Oil and Grease Concentration (mg/l)		
		INLET	SV-OUT	SC-OUT
12/3/92	3	2.33	< 1.0	< 1.0
12/28/92	1	< 1.0	< 1.0	< 1.0
2/8/93	2	155.5	17.5	275.0
8/6/93	3	5.50	6.0	<5.0

During the 12/28/92 event, it was discovered that a significant portion of runoff supposed to enter the SVTS was running off the property. Cold-mix asphalt curbs were installed on 1/14/93 to correct the problem. Over the next two weeks the site received another 1.53 inches of rain which apparently washed some of the asphalt constituents into the SVTS. The combination of stormwater runoff containing hydrocarbons from the fuel bays and leachate from the new asphalt apparently loaded the SVTS with petroleum hydrocarbons. The next sampled event, 2/8/93 revealed "oil and grease" concentrations in the runoff to vary from 280 to 31 mg/l. Effluent concentrations from the vegetated side ranged from 14 to 21 mg/l while effluent from the control side ranged from 270 to 280 mg/l (Fig. 9).

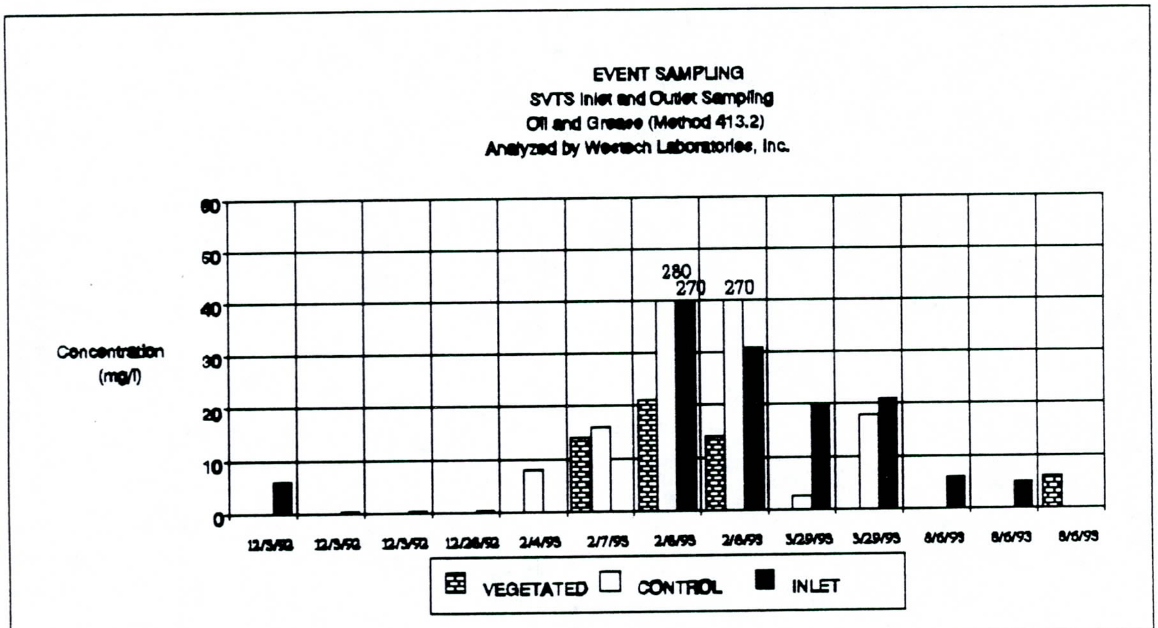

FIG. 9. History of "oil and grease" analysis from storm event sampling.

A graphical history depicting the results of the event sampling for "oil and grease" is provided in Figure 9. These data reflect the incoming and effluent values obtained during each sampled event. Multiple samples were collected during each event, and these data show the high variability associated with each storm.

Using the average of all contract lab "oil and grease" results and the rational equation, SVTS removal/retention efficiencies were calculated. A mass balance approach was used and the overall results ranged from 86.94% removal in the vegetated SV effluent to 15.50% in the control SC effluent. If one takes a look at a single event such as 2/8/93, the difference is even more pronounced. During this event, the removal/retention efficiency of the SV side ranged from 54.84% to 92.5%. The SC side efficiency ranged from 0% to -100%. The negative percent efficiencies associated with the control side of the system indicate that "oil and grease" accumulates, and then is "washed-out" at higher concentrations than what is entering in the incoming stormwater. The overall removal/retention efficiency, as well as the variability can be seen in Figure 10.

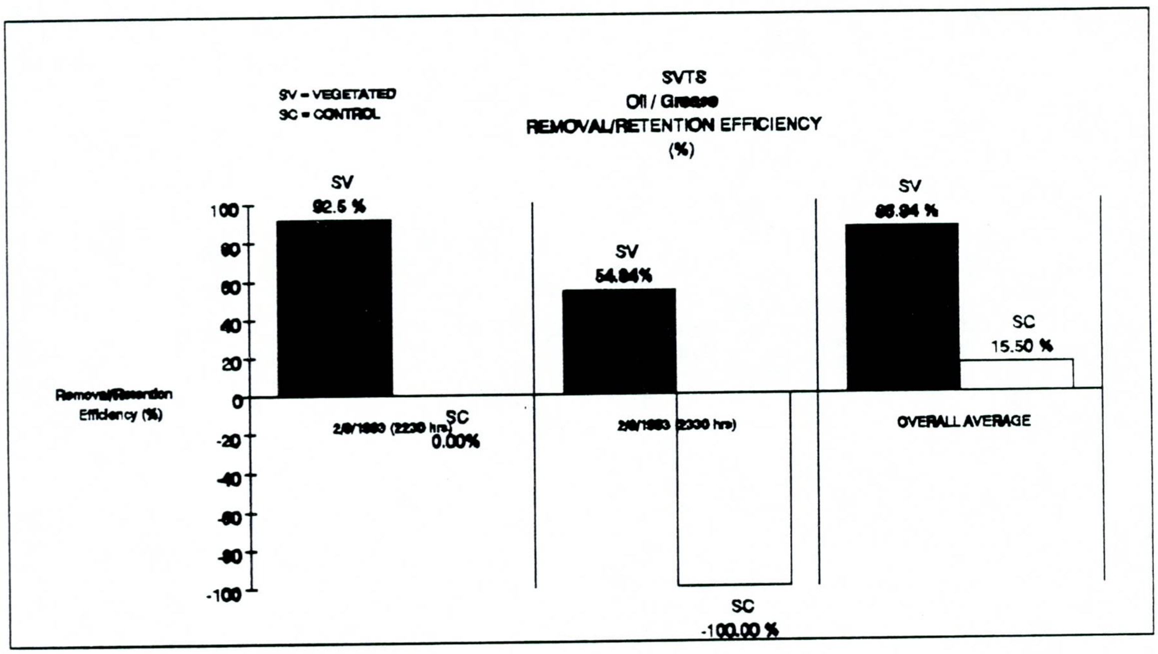

FIG. 10. Overall "oil and grease" removal/retention efficiency for SVTS and the variability found in 2/8/93 storm event.

Oil in Water (Hach Field Method 410)

Although 0.67 inches of rain fell during the month of March, the intensity and duration of individual events was insufficient to produce an outflow from the SVTS. To compensate for the lack of rainfall data, it was decided to obtain samples from the inlet and outlets to determine the duration "oil and grease" would appear from the SVTS when no "new" stormwater was entering. Removal/Retention of "oil and grease" was assessed during this dry period by field screening for "oil in water" using Hach Method 410. Figure 11 provides the results from samples obtained after the last runoff producing rainfall event in 2/93 up to the first event of the monsoon season which occurred on 8/6/93.

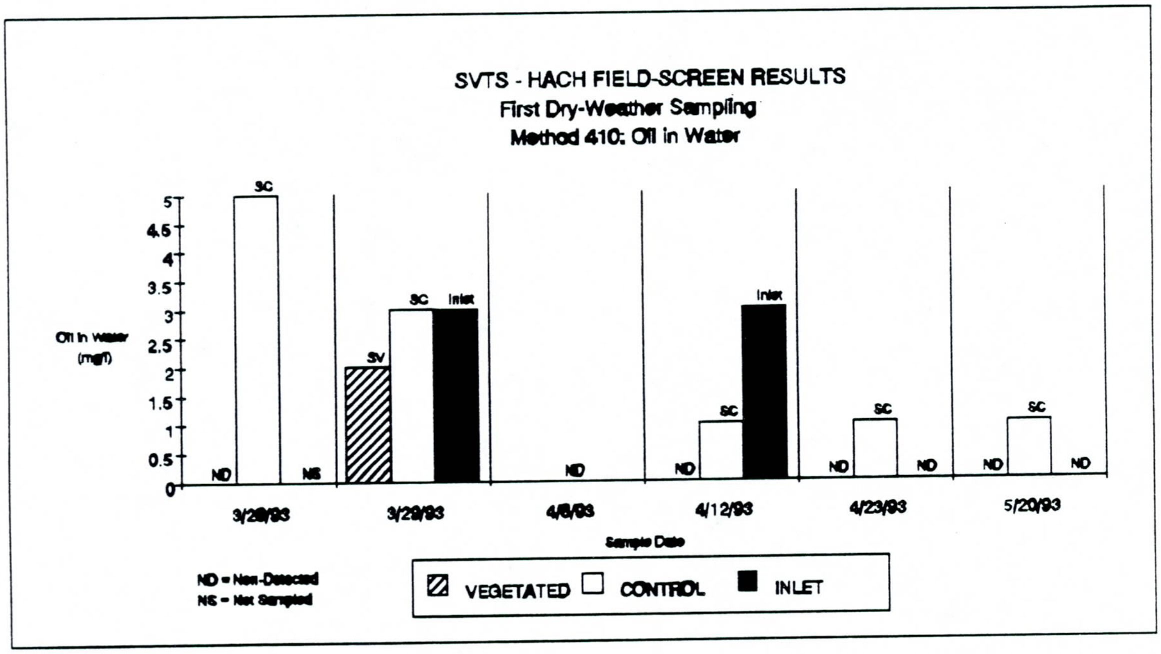

FIG. 11. Results of first dry weather sampling effort for flow from equalizer and both SV and SC outlets.

According to these results, "oil in water" did not appear in effluent from the SV side of the system after March 29, 1993. This is in contrast to both inlet (flow equalizer) water and SC side effluent stream. The inlet water had traces (3 mg/l) of "oil and grease" up to and including 4/12/93. After that time no "oil and grease" has been detected in the inlet. The SC effluent still showed 1.0 mg/l of "oil and grease" at the last sampling effort which occurred on May 20, 1993.

Similar dry weather sampling and analysis was conducted during the post-monsoon season. Figure 12 shows that the trend established during the first dry-weather sampling was continued. An exception occurred on 8/27/93 when analysis of the effluent from the vegetated side produced an "oil in water" concentration of 64 mg/l. This was likely due to impurities in the 1,1,1-Trichloroethane solvent and, or interference from other naturally occurring compounds such as chlorophyll.

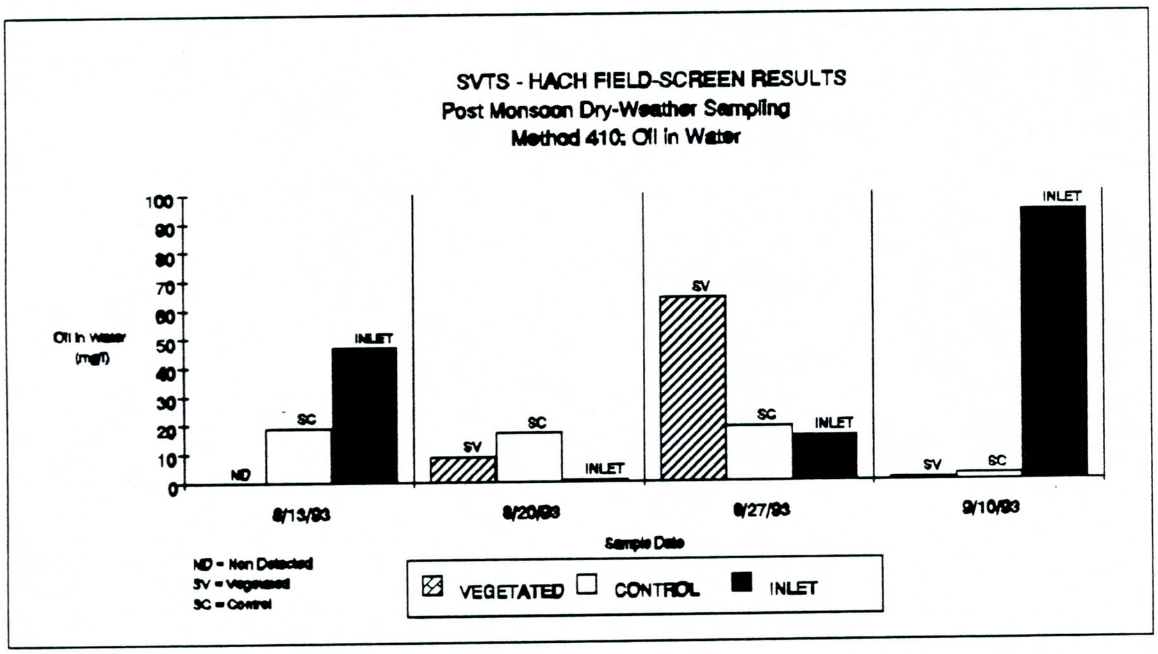

FIG. 12. Post monsoon results for HACH method 410, oil in water.

To further assess the "oil and grease" retention capability of the system, soil samples were obtained from around each sample port on both the SV and SC sides of the treatment cell. Samples were collected on 7/16/93 and submitted to the contract laboratory for the analysis of "oil and grease", TPH, VOC's and Semi-VOC's. The results show that within the SV portion of the treatment cell "oil and grease" is being retained in contrast to the SC portion in which "oil and grease" levels were non-detectable. Neither side revealed a build-up of lighter weight petroleum hydrocarbons (TPH) or VOC's. A semi-volatile compound was detected, Di-n-Butyl Phthalate, on both SV and SC sides. It is thought that this compound is leaching from the plastic barrel of the flow equalizer. Table 5 presents these data.

TABLE 5. Results of soil sample analysis from 7/16/93.

Sample Location	Oil and Grease (mg/kg)	Di-n-Butyl Phthalate (ug/l)	TPH (mg/kg)
SV-1	80.0	1800.0	<20.0
SV-2	<5.0	Not Analyzed	Not Analyzed
SV-3	40.0	Not Analyzed	Not Analyzed
SV-4	<5.0	Not Analyzed	Not Analyzed
SV-5	<5.0	<200.0	<20.0
SC-1	<5.0	1900.0	<20.0
SC-2	<5.0	Not Analyzed	Not Analyzed
SC-3	<5.0	Not Analyzed	Not Analyzed
SC-4	<5.0	Not Analyzed	Not Analyzed
SC-5	<5.0	2400.0	<20.0

Physical Parameters (pH, Conductivity and D.O.)

Trends in the pH and conductivity is one means to indicate whether microbial metabolism is more pronounced in the SV or SC side of the SVTS. It may be that a drop in pH is due to CO_2 production as a result of microbial respiration. High conductivity measurements could also imply increased biological activity within the SV portion of the treatment cell.

From the onset of active sampling, the conductivity of water in the SV portion of the system has been higher than both the inlet water and that of the SC side. Figure 13, shows this trend for 1/93 through 6/93. This has continued as sampling results depicted in Table 6 attest. In general, pH of the runoff is on the alkaline side (average = 8.67), but after passing through the SV side of the system it drops. On average, pH values of the SV effluent were approximately 7.8 pH units. In contrast, SC effluent pH averaged over 8.0 pH units.

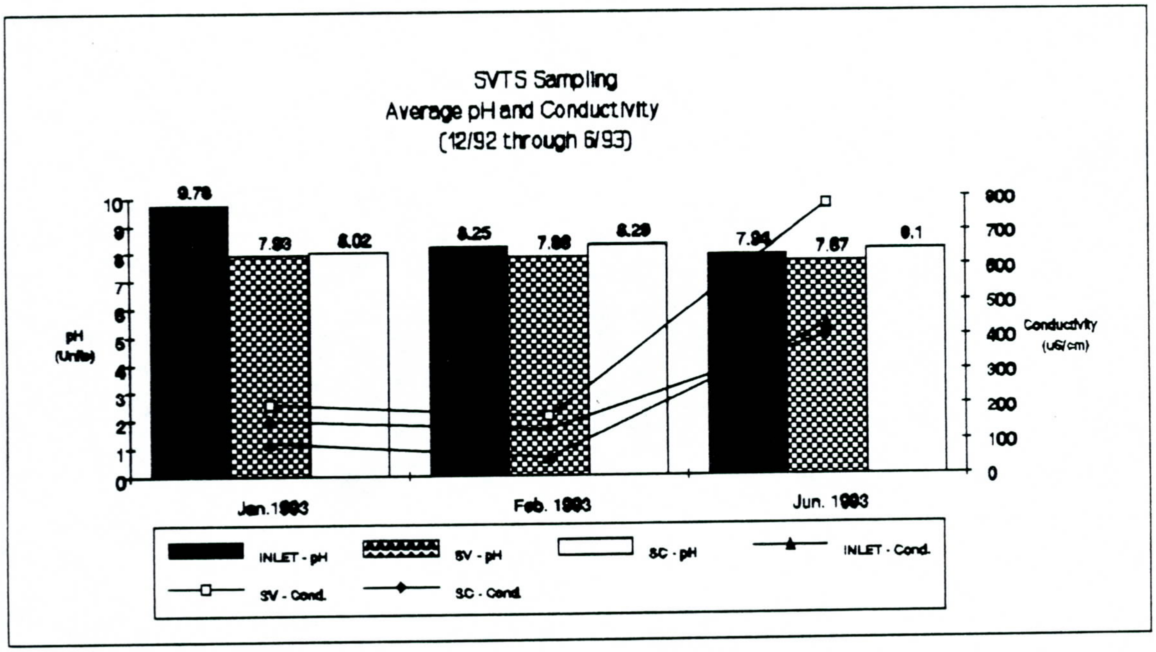

FIG. 13. Results of pH and conductivity measurements from 1/93 through 6/93.

Dissolved oxygen results have not been as expected. It was hoped to demonstrate that the *T. latifolia* would increase the D.O concentration within the water column and soil/gravel matrix of the SV portion of the system. As seen in Table 7, a decrease in D.O. concentrations is noted in both the SV and SC sides. Decrease in dissolved oxygen concentrations occurred from SV-1 to SV-5, while D.O. concentrations did not vary as much from SC-1 to SC-5. It is theorized that the decrease in D.O. on the vegetated side is due to microbial respiration. This would explain the decrease in D.O. of the SV side when compared to that of the SC side, especially since respirometry and plating experiments indicate higher microbial activity within the SV side of the system. This would also indicate that more organic compounds are retained and aerobically biodegraded on the SV side.

TABLE 6. History of average pH and conductivity measurements from 12/92 through 6/93.

Date	Sample Port	pH (units)	Conductivity (mS/cm)
Jan. 1993	Inlet	9.78	0.096
	SV-Outlet	7.93	0.206
	SC-Outlet	8.02	0.158
Feb. 1993	Inlet	8.25	0.051
	SV-Outlet	7.86	0.169
	SC-Outlet	8.29	0.132
Jun. 1993	Inlet	7.94	0.430
	SV-Outlet	7.67	0.780
	SC-Outlet	8.10	0.400

TABLE 7. Average dissolved oxygen concentrations within the SVTS ports SV-1, SV-5, SC-1, and SC-5.

Measurement Date	SV - 1 (mg/l)	SV - 5 (mg/l)	SC - 1 (mg/l)	SC - 5 (mg/l)
1/14/93	2.80	0.80	2.80	2.35
2/1/93	5.10	2.80	3.05	5.00
2/4/93	2.80	2.20	2.20	4.20
2/7/93	1.50	2.20	1.55	3.50
6/21/93	5.30	1.60	3.80	3.00
7/6/93	2.27	0.96	3.21	2.74
8/2/93	3.12	1.64	3.00	3.35
8/13/93	2.23	0.88	2.03	2.30
8/20/93	4.23	1.44	2.17	1.97

Respirometry Results

Two respirometry experiments were conducted and in all cases, both control and spiked samples indicated microbial activity (i.e., carbon dioxide production and oxygen consumption). This was true for samples obtained from both the SV and SC sides of the treatment cell. The results indicate that more microbial activity occurs in the SV portion of the system. This is shown in Table 8 and Table 9, as the percent increase in carbon dioxide production of the vegetative side over the SC side. Table 7 contains the results from samples obtained on 7/16/93, almost three months since rainfall had occurred at the site, while Table 8 presents results from samples obtained two weeks after the first monsoon event. Very little difference in results from samples obtained on different sampling dates can be discerned, indicating that drought conditions did not significantly impact microbial activity.

TABLE 8. % increase in carbon dioxide production of the Vegetated side over the Control side of the SVTS from samples obtained on 7/16/93.

Spike	% Increase in Carbon Dioxide Production SV1/SC1	% Increase in Carbon Dioxide Production SV5/SC5
Toluene	16.72	67.65
Naphthalene	16.70	20.21
Phenanthrene	31.76	43.12

TABLE 9. % increase in carbon dioxide production of the Vegetated side over the Control side of the SVTS from samples obtained on 8/20/93.

Spike	% Increase in Carbon Dioxide Production SV1/SC1	% Increase in Carbon Dioxide Production SV3/SC3
Toluene	25.68	31.20
Naphthalene	15.70	45.64
Phenanthrene	48.54	61.93

Plating Results

Plating techniques were used to provide a visual confirmation of the presence of petroleum degrading microorganisms. Two experiments were conducted, each using filtered 5.0 ml. samples obtained from a slurry of sediment and water taken from each sampling port. In all, twenty plates were prepared and tested with both naphthalene and phenanthrene, each one exhibited degradation of the hydrocarbons. Although the method used in this study was not designed to actually determine the microbial population, an attempt was made to count colony forming units (CFU). Results of this endeavor are provided in Table 10.

TABLE 10. 96 hr. plate count summary of hydrocarbon degrading colony forming units from filtered 5.0 ml samples obtained after the 1993 monsoon.

Sample I.D.	Count (cfu)
SV-2	69
SV-4	>300
SC-2	19
SC-4	5

DISCUSSION

Monitoring of the GBF system was abandoned after approximately three (3) months because of surcharging of the dry-well, lack of microbial development, and problems with obtaining "representative samples". Surcharging could be corrected by providing an equalization area to control the volume and rate of stormwater entering the system.

To further improve this system, the equalization area could be vegetated. As the SVTS results show, vegetation definitely enhanced the capture and eventual biotransformation of the "oil and grease" fraction present in stormwater runoff. In this system, the vegetation may increase removal efficiency of the rock filters by: 1) Providing increased surface area for adsorption thereby reducing the impact of high strength discharges, and 2) Providing bacterial "seed" developed in the rhizoshpere(s) of the vegetated portion and subsequently washed into the gravel filters during runoff producing events. The "seed" would help to establish and then add to any fixed biological-film on the filter media. It should be kept in mind that the data collected were inconclusive, and that future performance of a GBF complex in this capacity is speculative.

Although beyond the scope of this demonstration project, visual evidence of the detention of petroleum compounds by the GBF was noted. This evidence was in the form of staining which occurred in the impound area upstream of Dike No. 1, and can be attributed to mechanical capture of the hydrocarbons via adsorption. This staining was due to runoff from a storage area housing asphalt paving trucks and sealer equipment. Discolored sediment did not appear on the downstream side of Dike No.1. Storage of asphalt in this manner has since been discontinued at this site and staining was no longer present at the time this report was written.

The remainder of this study focused on the development of a submerged-flow vegetated treatment system capable of attenuating hydrocarbon contaminants in runoff from a vehicle maintenance yard. After almost one year of use, the system has demonstrated "oil and grease" removal/retention and proven itself capable of providing an environment conducive to the microbial degradation of petroleum hydrocarbons. The contribution of vegetation to overall pollutant removal and microbial establishment has been noted but the exact mechanism has not been quantified. The system has thus far exhibited low maintenance requirements, and the vegetation has survived the first summer. This paper dealt with the first year, or "seasoning period" of the system, and preliminary results were presented. The results focused upon the removal/retention of "oil and grease" within the system, and if any microbial activity was taking place.

A review of the "oil and grease" analyses indicates that a significant fraction of this contaminant is being removed by the SVTS from the stormwater runoff. The real question is what is happening to this component of the stormwater? In the case of the SC side, it would appear that the "oil and grease" fraction is slowed but not removed by the soil/gravel matrix. It could be that the SC matrix retains "oil and grease" up to some saturation concentration, after which, the "oil and grease" components are "washed-out", usually at higher concentrations than appear in stormwater runoff. That would account for the large pulses of "oil and grease" observed in the effluent after the placement of the asphalt berms. Quite the opposite can be said about the vegetated side of the system.

Data indicated that once "oil and grease" enter the SV side, the majority of it remains within the system. This was demonstrated by the positive removal efficiencies as shown by the contract laboratory analysis and the HACH field measurements. Further evidence to support the build-up of "oil and grease" in the SV side comes from the sediment sampling in which oil and grease were detected in association with the sediments. Although "oil and grease" build-up was documented, the actual fate is questionable.

If the residence time within the system is sufficient, several possible fates await the "oil and grease" sequestered within the soil/gravel/rhizome matrix. Over time, the lighter molecular weight components will probably volatilize. Some authors suggest that this is the primary removal mechanism for volatile and semi-volatile compounds found in dry-wells (Wilson, 1989). Other likely fates include some type of aerobic microbial decomposition, and assimilation of the hydrocarbons into plant tissues themselves. Results from monitoring and the respirometry and plating experiments suggest that the former fate is a definite possibility, while assimilation into plant biomass can only be speculated upon, since no plant tissue analysis was conducted.

Results of the field measurements show that the SV side of the treatment system tends to lower the pH of stormwater. This phenomena may indicate microbial metabolism, especially when one considers the approximate two-fold increase in conductivity. The rationale being that aerobic respiration tends to produce CO_2 which would eventually form carbonic acid and hence, decrease the pH. The decrease in pH implies an increase in $[H^+]$ and or HCO_3^-, which will increase the conductivity. The degree to which the pH lowered and conductivity rose did fluctuate, especially after storm events. Both during and immediately following a storm event, the pH and conductivity on both sides of the system would match that of the incoming runoff. Over time, water in the SC portion would begin to match pH and conductivity levels exhibited in the equalizer. Measurements taken from the SV portion of the system show that some time was need for measurements to stabilize. Typically, it took a period of about six (6) to ten (10) days before pH and conductivity to decrease and increase, respectively. The time lag could imply that biological mechanisms were at work to bring these levels back to equilibrium after being "shocked" by an influx of stormwater from an event.

Evidence to further support the assumption that the SV side of the treatment system fostered more biological activity than the control side (SC) was found in the respirometry and plating experiments. Increased CO_2 production in the SV samples over that of the SC samples indicate a greater microbial population. Since this activity was recorded in both spiked samples (hydrocarbon added) and controls (no additional hydrocarbon) it can also be said that the SV portion supported more petroleum degrading microbes. The existence of petroleum hydrocarbon degrading microbes was further confirmed by the plate tests. Respirometry tests did not show as dramatic a difference between the SV and SC sides in activity as did the plate counts. This could be attributed to greater adsorption phenomena associated with sediments from the SV side that limit bioavailability of the hydrocarbons.

The impact vegetation has had upon the removal efficiency of the system is positive, but not completely quantified. As the literature suggests, plant biomass can provide wetland systems with a place of attachment for microbes, aerate anaerobic soils, and assimilate a variety of common stormwater pollutants (Pond 1993). Increased microbial activity due to the presence of the *Typha latifolia* was demonstrated by the respirometry and plating experiments. The soil samples did reveal higher microbial activity and populations residing within the SV side. One may assume that this could have been due to the radial oxygen loss of the *Typha latifolia* providing an aerobic rhizosphere and thus a suitable environment for petroleum hydrocarbon degraders. Whether or not significant quantities of petroleum hydrocarbons were actually assimilated into plant tissue cannot be stated with assurance. Literature, however, does suggest that some of the highest recorded levels of TPH found in root structures were obtained from stands of *Typha latifolia* (Pond 1993).

Overall, the SVTS has demonstrated removal/retention of "oil and grease", and done so with very little maintenance. To date the City of El Mirage, Arizona water-use records indicate only 5,000 gallons of water has been used by the system. This includes the time of initial filling in 12/92 and during drawdown and subsequent re-filling during the summer for sampling purposes. Finally, fertilizer, in a ratio of 10:15:10 of nitrogen(600 mg as N), phosphorous (6.4 mg as P_2O_5), and potassium (600 mg as K_2O) , was applied in a single dose of 60 ml because the vegetation looked distressed. No other maintenance activities have been conducted on the SVTS.

CONCLUSIONS

Although it is still early in the life of the system, the goals of this project were realized. A submerged-flow vegetated treatment system was constructed at a vehicle maintenance yard to serve as well-head protection for a dry well from stormwater runoff generated on-site. The treatment cell of the system was constructed so that the any water quality impacts due to the *Typha latifolia* planted in the SV side of the cell could be compared to that of the control, or non-vegetated (SC) side.

The goals of this study were to: 1) Provide an environment suitable for the growth of petroleum degrading microorganisms, 2) Confirm their presence, and 3) Determine the "oil and grease" capture/removal efficiency of the system. Respirometry and plating experiments revealed the presence of hydrocarbon degrading microbes. Respirometry experiments showed higher CO_2 production and implied microbial degradation of hydrocarbons. Plating experiments visually confirmed the presence of hydrocarbon degrading bacteria. Both tests conclude that the vegetated side (SV) supported higher numbers of microbes and captured "oil and grease" better than the non-vegetated (SC) side used as the control. This correlates well with the "oil and grease" analysis, in which the vegetated side demonstrated a much higher overall removal efficiency than that of the non-vegetated control.

This report only comments on the first 11 months of operation, and as such, the results should be looked at as preliminary. Future analysis should be completed before the system is called a success. For instance, plant tissues should be analyzed to see if "oil and grease" uptake is occurring, and to determine if any metals are being sequestered within the tissue. The fate of the "oil and grease" is still an unknown. It can be speculated that both the vegetation, and its associated microbial population are indeed utilizing the petroleum hydrocarbons, but that has not been proven inconclusively. To do so, a much more rigorous sampling methodology must be devised, one that includes the capability of performing a good mass balance upon the "oil and grease" fraction. This will require obtaining flow-weighted composite samples from the inlet and both outlets for the duration of a storm event(s).

Submerged-Flow vegetated treatment systems such as the one constructed for this project are capable of attenuating petroleum hydrocarbons found in urban stormwater runoff. The use of an SVTS as dry well head protection has been investigated and found to be suitable for petroleum compounds. In the future, systems such as these will probably find use in this capacity at both public and privately owned vehicle maintenance yards and service stations.

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