Oil and Water Don't Mix: The Application of Oil-Water Separation Technologies in Stormwater Quality Management

By

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FOREWORD

This report is a product of Metro's technology transfer program. The purpose of the program is to assemble and disseminate technical information which has utility to those in the region dealing with stormwater quality issues.

Other reports from this program include:

- o Kulzer, L. 1990. Water Pollution Control Aspects of Aquatic Plants: Implications for Stormwater Quality Management.
- o Kulzer, L. 1989. Considerations for the Use of Wet Ponds for Water Quality Enhancements.
- o Horner, R. 1988. Biofiltration Systems for Storm Runoff Water Quality Control.
- o Kulzer, L. 1988. Considerations for Using Geotextiles in Silt Fence Applications.
- o Galvin, D., and R. Moore. 1982. Toxicants in Urban Runoff.

Questions or comments about this report on oil-water separators should be directed to the author (684-1258) or Dave Galvin (~~684-1216~~). Requests for copies of this or the other reports noted above should be made to:
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We trust that you will find this technology transfer information both interesting and useful. All comments and suggestions are welcome.

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SUMMARY

Background

In recent years, stormwater has been recognized as a major source of pollution to the Pacific Northwest region's rivers, lakes and sound. As it rains and the water hits the ground, stormwater runoff carries pollutants along with it. A common and often noticeable pollutant is oil; its rainbow sheen created as it flows along the streets and curb is nearly ubiquitous. As a result, attempts to control the oil from entering the water bodies has focussed upon passive mechanisms which take advantage of the fact that oil is more buoyant than water and floats to the top. It is the purpose of this study to understand how successful these mechanisms are in practice by summarizing available information on the subject of oil-water separation as applied to stormwater quality management. It presents what is known about the levels of oil found in stormwater, what existing and pending regulations say about allowable levels, what systems are used or available for controlling oil, what is known about their effectiveness, and other related issues, data gaps and ideas pertinent to the subject.

Oil in Stormwater

Several studies have found that oil concentration levels in stormwater runoff generally fall between 1 and 40 milligrams per liter (mg/L) or parts per million (ppm). These concentration levels are dependent upon the land use from which the stormwater comes. Typical oil and grease levels in stormwater runoff are around 5 ppm for residential areas, 5 to 15 ppm for higher density or commercial areas and up to 40 for concentrated traffic areas such as freeways or trucking firms.

Oil-polluted stormwater, although not acutely lethal to aquatic organisms, can have severe chronic effects upon them once entering the aquatic system. Concentration levels as low as 10 to 100 micrograms per liter (ug/L) have been shown to adversely

affect aquatic organisms by altering processes such as feeding or reproduction.

Local use of oil-water separators

Several local jurisdictions currently require or recommend use of oil-water separators for specific development activity and land use. However, most jurisdictions do not address oil and grease criteria directly but normally use the permit process to assess the need for water quality treatment technology on a design by design basis. The Department of Ecology has released a draft version of the "Stormwater Management Manual for the Puget Sound Basin" which specifies oil-water separators for most jurisdictions. As a result of the current trend toward application of this technology for stormwater runoff treatment, knowledge of the applicability of the various treatment technologies has become necessary.

Current guidelines for non-point sources of stormwater runoff have been set by the state as 10 mg/L average daily concentrations with maximum concentrations not to exceed 15 mg/L.

Oil-Water Separation Methods

A variety of separation methods are used for removing oil from water in applications. The range of systems includes passive treatment systems requiring no external energy source, enhanced oil-water separators which require some sort of external energy source and biofiltration. This study focuses on passive oil-water separation systems. These system are most practical for stormwater treatment where access to maintenance and power sources are not readily available.

Gravity Treatment Methods

There are primarily three types of gravity or passive oil-water separators used for stormwater treatment: **spill control,**

American Petroleum Institute (API or baffle type) and coalescing plate separators (CPS).

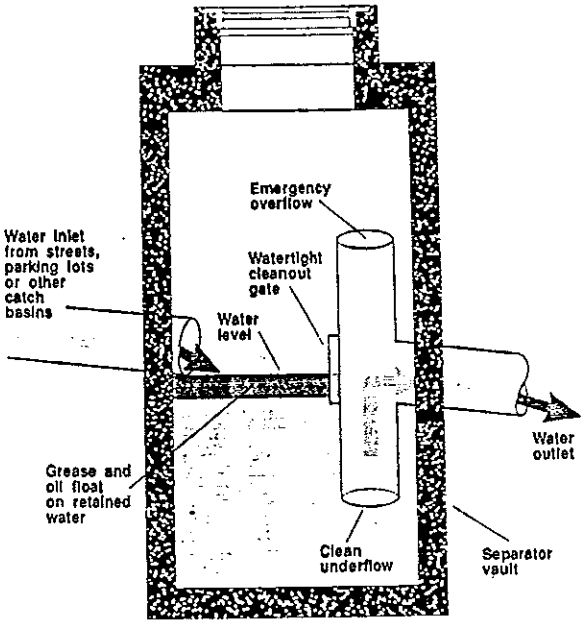
Spill control separators are sometimes more generally called catch basins. They are composed of a cylindrical chamber where sediment and oil and grease are allowed to settle out. The water exits through an outflow orifice at the bottom of the t-shaped configuration (Figure i).

According to local sources, these devices are not particularly effective for oil-water separation. Oil which remains on the surface of the water can be emulsified with the water and carried out with the discharge by the turbulence of new stormwater entering the separator. If oil is allowed to remain in the separator for a long period, the oil level may drop below the orifice level. A following inflow of stormwater may flush the oil through the outflow. They do appear to work in spill situations, if the oil is removed before a subsequent storm event.

API (American Petroleum Institute) or baffle separators are composed of three chambers separated by baffles (Figure ii). The baffle between the first and second chambers limits turbulence; the baffle at the bottom traps sediment; and the one between the second and third chamber restricts oil from flowing into the final chamber. The oil-water separation which occurs is mainly dependent upon the time the water is detained in the separation (center) chamber (sometimes called detention time) and the oil droplet size. API type separators have been determined to be most effective in industrial applications where the oil droplet size is 150 microns and the water residence time should be 30 to 45 minutes.

Coalescing plate separators include a coalescing plate medium or pack which takes advantage of the fact that the distance the droplet must travel is directly related to separation efficiency; the more surface area that the oil-water separator offers, the more oil and grease can be separated as compared to the same size API separator. The coalescing plate medium provides more surface

Figure I. Spill Control Separator



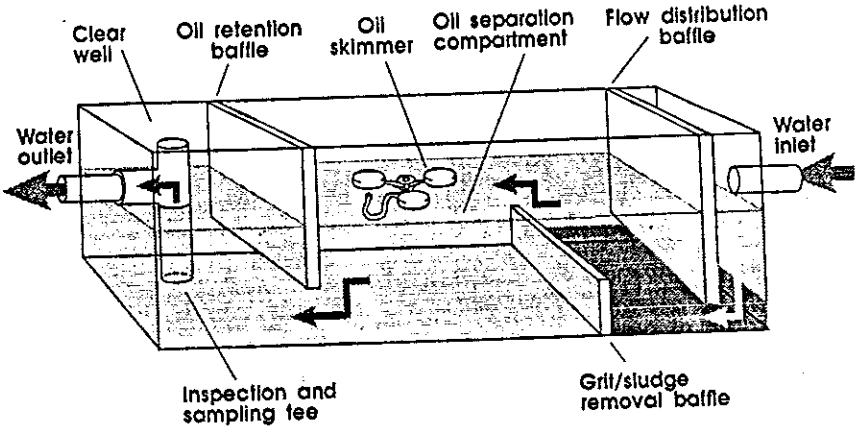


Figure II. API Separator

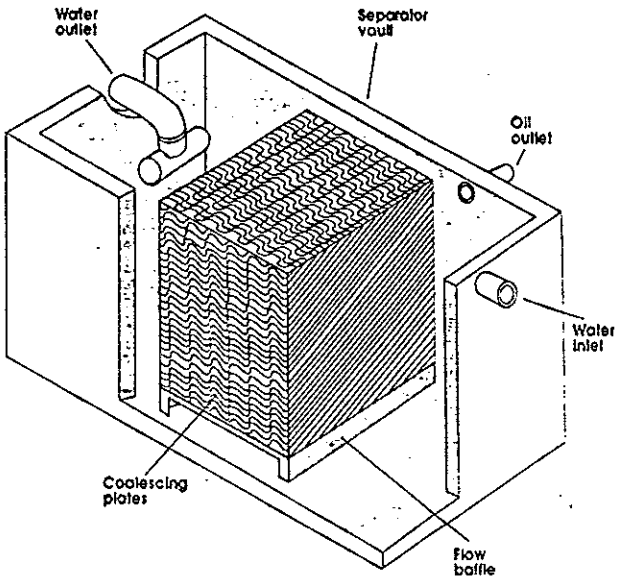


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Figure III. Coalescing Plate Separator

area, thereby reducing the distance the droplets must travel and improving separation efficiency (Figure iii). The plates are normally made of oil attracting material (e.g. polypropylene) which enhances oil removal efficiency. CPS separators have been found to be effective for oil droplet sizes of 60 microns or larger in industrial applications. These devices, as for all separators, must be cleaned at regular intervals to maintain performance.

Recommendations

The following general guidelines for oil-water separation design, implementation, maintenance, alternative controls and research are proposed. The recommendations are based upon local experience with existing applications and analysis of current design methodology. Although these recommendations are based upon the best available evidence, their applications may not be universal in application.

1. Design.

* Generally, the 6 month, 24-hour storm should be used as the initial storm size parameter. Stormwater quality should focus upon smaller, frequent storm events. Design storm size has direct cost ramifications; the larger the storm size selected for design, the greater capacity the treatment method. Therefore, the trade-off between costs of the treatment method and the percentage of stormwater treated should be considered when determining design storm size.

* Coalescing plate separators should be used in places where relatively high oil and grease concentrations are expected: service stations; free-way storm drains; heavy equipment repair; large heavily utilized parking lots; and petroleum related industries.

* API and CPS type separators should be designed with a turn-down elbow inside the first chamber at the inflow pipe and a sample-T at the outflow pipe.

* A floating or rope oil skimming device which removes oil from the oil collection chamber of the separator and drains to a waste-oil tank offers a combination of practicality, low cost and effectiveness for collection of accumulated oil from the separator vault.

* A flow-control structure should be used to divert the first flush caused by large storms into the separator.

* Design consideration must be given to the relative location of both the water table and the outflow from the separator to the receiving water body at the installation site.

2. Implementation Strategy

* Locations which present the possibility of oil emulsification such as car washes and industries which utilize detergents should be identified. The runoff from these sites should be prevented from entering the storm drains.

* It would be beneficial to monitor the characteristics of the application site in advance of system design to better define the runoff pollutant concentration profile.

3. Maintenance

* Most water quality specialists in the region believe that maintenance practices highly affect the performance of oil-water separators. Without adequate maintenance practices, oil-water separator systems may be more damaging to the environment than no pollution controls at all.

* API and CPS type separators should be monitored regularly and accumulated oil removed based upon this monitoring to assure compliance with the 10 mg/L state guideline.

* Maintenance required for spill control separators is much more frequent and difficult to administer as they must be cleaned out after each spill before the next storm flushes the accumulated oil out.

4. Source Control

* The most effective and least costly method of pollution control is to prevent the pollutants from entering the environment in the first place. Source control requires tracing of the pollutant back to where it may have originated. One way to facilitate tracing is by monitoring to identify where unusually high pollutant levels are evident.

* In the cases where age has allowed adequate pollution control to be bypassed, refurbishment programs should be initiated to eliminate these common sources of pollutants.

* Leaking automobile crankcase oil could be reduced by use of leak prevention technology or through mandatory automobile inspection.

* Used motor oil dumped down the storm drain contributes to the pollution problem. This activity may be reduced by implementing public awareness programs.

* Businesses should be encouraged or required to educate their employees regarding pollutant sources and proper waste management practices.

5. Other Considerations

* In addition to the technical aspects of design methodology, less tangible effects must also be considered, namely the practicality of installation, accessibility for maintenance and the congruence of the design with the surroundings.

6. Research

Although the above recommendations have been proposed based on analysis of the available scientific evidence, further investigation is needed to further refine our understanding of oil-water separator effectiveness; therefore, the following list of applied research is proposed:

- **Effectiveness of SC, API and CPS separators as applied in the Northwest environment by measuring influent versus effluent concentrations of oil and grease;**

- Oil and grease droplet distribution as found in stormwater runoff for all land uses;
- Characteristics of oil in stormwater especially as it pertains to the first flush effect and design storm size;
- Environmental effects of oil and grease as it is found in stormwater runoff;
- The effect of maintenance practices upon oil-water separator performance;
- Effectiveness of alternative methods such as biofiltration, porous pavement and microbial digestion;
- Effectiveness of oil-water separator technologies at removing other contaminants found in the stormwater runoff;
- Investigation of new cost effective technologies.

BACKGROUND

Introduction

It rains often in the Seattle metropolitan area and all that water has to go somewhere. It has been estimated that some 12 billion gallons of stormwater flow to local water bodies within King County each year (Metro, 1988). Stormwater management has traditionally focused on control of this volume of runoff water to prevent flooding and property damage.

However, as rainwater hits the ground and moves towards the rivers, lakes and sound, it washes contaminants off road surfaces and carries them into the region's water bodies. In recent years, stormwater runoff has been recognized as a potentially significant source of water pollution. As other sources come under increased regulation and control, stormwater is gaining attention as a generally under-controlled avenue for contaminants to enter our waters.

Among the contaminants of concern found in urban stormwater, **oil** is often visible. The rainbow sheen on stormwater flowing along the curb is nearly ubiquitous. At continuous, low levels, stormwater is the major avenue for oil to get into local waters and sediments. In addition, drainage systems are often vehicles for waste dumping; stormwater can convey large concentrations of oil from spills or dumping directly to local lakes, streams and bays.

How can this contaminant be dealt with? Attempts to control oil in stormwater have tried to capitalize on the principle that oil is more buoyant than water and can be separated simply by letting gravity work or assisting gravity in coalescing the oil out of water and then skimming it off the top. Various passive mechanisms have been used in an attempt to do this. How successful they are in field conditions is a major question. As scrutiny of drainage systems for water quality protection intensifies, additional attention is being focussed on oil and ways to minimize its concentration in the stormwater being discharged into the environment.

This report summarizes available information on the subject of oil-water separation as applied to stormwater quality management. It presents what is known about the levels of oil found in stormwater, what existing and pending regulations say about allowable levels, what systems are used or available for controlling oil, what is known about their effectiveness, and a host of related issues, data gaps and ideas pertinent to the subject.

Oil in Stormwater

What oil is, how it's measured

Oil is a petroleum-based organic substance (actually a complex group of substances). The most general measure of oil in environmental samples is called "oil and grease" or sometimes, "fats, oils and grease", which is based on an extraction from the water sample of essentially all the carbon-based (organic) compounds. This gross measure of total carbon compounds includes petroleum oils, foods and natural oils such as those found in leaves. Yet it has been the standard measure of oil levels in the environment for years. Measurements of total hydrocarbons, polar and non-polar (petroleum) hydrocarbons, and other classes of organic matter are typically subsets of "oil and grease."

How much oil is in stormwater?

Several studies have been conducted which attempt to profile the quantities of oil in stormwater runoff. General levels fall between 1 and 40 milligrams per liter (mg/L) or parts per million (ppm). In a 1984 study in the San Francisco Bay area, oil and grease concentrations in urban stormwater were determined for different land use types (Stenstrom et al., 1984). This study found average oil and grease concentrations in stormwater to range from 4 mg/L in residential areas to 15 mg/L in commercial parking lots. Farris et al. (1974) found oil and grease concentrations ranging from 1 to 16 ppm in residential and commercial runoff samples collected in Seattle. Freeway runoff

samples in Seattle (Dalseg and Farris, 1970; Farris et al., 1973) found higher concentrations of oil and grease: means of 44, 27 and 40 ppm, respectively. The City of Seattle Drainage and Wastewater Utility has taken samples from 14 different storm drain locations from 1986 through 1988 and found multiple and single family residential concentration levels ranging from 2 to 5 ppm and commercial and industrial land use runoff oil and grease concentrations ranging from 2 to 15 ppm. (A single sample of I-5 runoff indicated a level of 12 ppm.) In summary, typical oil and grease levels in stormwater runoff are around 5 ppm for residential areas, 5 to 15 ppm for higher density or commercial areas and up to 40 for concentrated traffic areas such as freeways or trucking firms.

Where does the oil come from?

Studies have attempted to determine the sources of oil and grease in stormwater runoff. A University of Washington study (Zawlocki,1981) that included samples from I-5 and SR-520 determined the major source of organic compounds in runoff is petroleum products: lubrication oils, fuels, and combustion emissions. Latimer (1984) concluded that 71 to 81% of runoff petroleum originates from the "black stripe" which is dripped onto the center of each travel lane: vehicle lubricating oil. Other studies (Wakeham, 1977; Zurcher et al., 1978; Hoffman et al., 1982, 1983; Hunter et al., 1979; and Eganhouse and Kaplan, 1981) have confirmed this conclusion. Any casual observation of parking lots or driveways confirms that most vehicles drip oil.

In addition to the continuous wash-off of oil from road and parking surfaces, oil gets into stormwater from direct dumping of used crankcase oil into storm drains and ditches. In King County annual used oil volume by citizen "do-it-yourselfers" is estimated to be more than one million gallons. Only about 15 percent of this oil is recycled; more than one-third of the people surveyed admit to dumping the used oil directly into a storm drain, ditch or onto the ground (Galvin and Moore, 1982; Ridgley and Galvin, 1982). Incidents of dumping oil as well as

other wastes into storm drains represent 35 percent of all the calls reported to the Interagency Water Quality Trouble Call System and 40 percent of Bellevue's water quality emergency calls.

Environmental Effects of Oil

Oil and grease entering the aquatic environment have various effects. High concentrations of oil due to spills, purposeful or otherwise, can kill many aquatic organisms. (The recent oil spill in Prince William Sound, Alaska, is morbid testimony to this fact.) However the U.S. EPA in the Quality Criteria for Water Manual (1986) states that for the most sensitive marine organisms, marine larvae, much lower oil concentrations, as low as 0.1 mg/L, can be lethal.

Oil and grease contamination in stormwater normally does not present catastrophic effects on aquatic life. Oil in stormwater runoff is more likely to chronically affect aquatic organisms by altering processes such as feeding or reproduction. These long-term effects on organisms have been shown to occur from petroleum product concentrations as low as 10 to 100 micrograms per liter (ug/L), a fraction of the state's 10 ppm guideline for oil and grease concentration in stormwater runoff (U.S. EPA, 1986). A study by Jacobson and Boylan (1973) showed that even lower concentrations of petroleum pollutants, 1 ug/l, can adversely affect marine organisms.

Although it is intuitive that hydrocarbons, metals and other pollutants can affect aquatic life, it is surprising that little investigation has been conducted which definitively determines the environmental impact of oil and grease loadings from urban stormwater runoff. One approach is to look at various constituents found in oil and what their individual effects might be. As lubricating oil represents the major portion of petroleum runoff it would be interesting to analyze its polluting characteristics. One such study found used crankcase oil to contain fairly high levels of zinc, nickel, lead and copper (Shaheen 1975). There is much evidence that these metals can

cause negative effects upon aquatic life (U.S. EPA, 1986; Moore and Ramamoorthy, 1984).

Hydrocarbons, which are lighter than water, are normally associated with the rainbow colored film on the water's surface. However, they have also been found in bottom sediment of lakes and estuaries (Wakeham, 1977; Tanacredi and Stainken, 1981). Pollutants found in the sediment often work their way into areas where there are limited aerobic processes. Anaerobic conditions lengthen the time pollutants remain in the environment.

Regulations and Standards

Federal and State

The U.S. EPA implements the federal Clean Water Act, including water quality criteria and certain discharge limits. Currently these federal discharge limits apply to commercial, industrial, or municipal sewage treatment plant discharges as regulated by the NPDES permitting process. The EPA has proposed a general regulatory program for stormwater discharges, but it does not propose setting national standards for the quality of these discharges. The time at which the federal program regulations will become effective is not yet known. At the time of this writing, the EPA has not yet published its final stormwater NPDES rule.

Complementary to the pending federal stormwater NPDES program and as part of implementation of the Puget Sound Water Quality Management Plan, the Washington State Department of Ecology is currently formulating a Stormwater Management Manual which will apply to drainage systems in the Puget Sound basin. The manual identifies specific business types and public agencies where API or CPS type separators (see later descriptions for definitions) are required for stormwater treatment. Ecology is also developing a Stormwater Management Rule which will require local governments to have stormwater management programs. In addition, Ecology is formulating a Highway Runoff Program rule that will apply to state highways in the Puget Sound region.

The state has set current guidelines (for commercial, industrial and NPDES regulated municipal discharges) for oil concentration in stormwater runoff as follows: 10 mg/L average daily concentrations with maximum concentrations not to exceed 15 mg/L. These measurements are based upon grab samples taken every hour of the discharge for the first four hours. The draft EPA rules propose modification of this sampling approach: permit applicants would have to provide "first flush" pollutant grab sample concentrations and average storm event concentrations based on a flow-weighted composite sample of the entire storm. In lieu of the flow-weighted composite sample, the EPA will accept quantitative data from individual samples taken during a "representative storm event."

Local Drainage Ordinances

Local jurisdictions approach water quality issues pertaining to oil and grease from different perspectives. Generally, local governments do not address oil and grease directly. They sometimes use the permit and design review process to assess needs for oil and grease controls for stormwater quality attainment. Where controls are required, jurisdictions tend to specify technological requirements and not quality criteria. However, in special situations, jurisdictions have initiated more aggressive approaches to oil and grease regulation. The following are representative of approaches to oil and grease controls which are found locally.

King County

King County maintains a comprehensive surface water management program. It employs a "Surface Water Design Manual" (1990) which specifies conditions under which a particular treatment method must be employed. The county requires that detention facilities be employed for all projects which require drainage review. Detention facilities include baffle and spill control type oil-water separators. In addition, the Design Manual specifies that a coalescing plate oil-water separator must be used if the

"project will construct more than 5 acres of impervious surface that will be subject to: a) petroleum storage or transfer; OR b) high vehicular use (more than 2,500 vehicle trips per day); OR c) heavy equipment use, storage or maintenance...."

The City of Seattle

The City of Seattle's Land Use Code specifies that best management practices (BMPs) may be required to protect the quality of surface and ground water. As an aid to attain this end, the city has developed a Water Quality Best Management Practices Manual (Seattle, 1989). Use of BMPs as presented in the manual is not mandatory, however permit writers from Seattle's Department of Construction and Land Use may choose to require certain BMPs as suggested in it. The manual specifies business groups or land uses where oil-water separation systems should be employed. Three gravity oil-water separation system types have been specified: Spill-Control, American Petroleum Institute ("API" or baffle), and Coalescing Plate Interceptor separators. The business groups which have been identified as needing API or coalescing plate separators include: industrial machinery and equipment; trucks and trailers; fleet vehicle owners; gasoline service stations; retail general merchandise; wholesale petroleum; equipment repair; vehicle maintenance and repair; and asphalt paving contractors. The manual further identifies parking lots and outside storage areas as needing some stormwater control system, however it allows the business to choose the treatment method.

The City of Bellevue

The City of Bellevue's Storm and Surface Water Utility addresses stormwater quality issues. Its development standards specify when oil-water separation devices must be used. The standards specify that oil separation devices (spill control, baffle, or coalescing plate separators) must be provided when "... parking is provided for more than 20 vehicles, or [when] any paved parking or access roadway [is located] within one quarter

mile of any open waterway or stream...." Furthermore, the standards specify that "effluent discharged from any oil removal treatment device to the storm sewer or surface water system shall contain less than 10 parts per million total oil and be in compliance with State Department of Ecology regulations...."

The City of Redmond and others

The City of Redmond uses policy definitions which define water quality goals without specifying contaminants or methodologies. This provides its Public Works Department with room to interpret these policies and implement water quality controls based upon assessment of needs. However, the city does not single out oil and grease criteria or related treatment technology. This is typical of most of the other smaller cities in the region.

Design Considerations

Rainfall characteristics

As was mentioned earlier, precipitation in the Seattle-King County area results in billions of gallons of runoff per year. In addition to this issue of volume, other points to consider when addressing water quality issues include the distribution of rainfall over time, storm size and storm frequency.

Table 1 provides monthly 30-year average precipitation compared to the 1988-1989 season rainfalls. Note that the majority of rain (more than 80 percent) falls in the months October through April. This general fact is illustrative of the cyclic nature of rainfall in this region - an issue worth noting especially as it pertains to stormwater quality. As pollutants collect on surfaces during the drier period (May through September), a higher concentration of them may wash into the environment during the first period of more rainfall, typically the month of October.

In addition to gross quantity rainfall estimates, intensity and duration -- the two components defining the size of storms --are

Table 1. Comparison of 1988-1989 Precipitation Data to 30-Year Average (1959-1988)

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
AVG RAINFALL	3.4	5.6	6.3	6.0	4.2	3.6	2.4	1.6	1.4	0.7	1.3	2.0
1988-1989	2.2	8.4	3.5	2.8	3.4	5.8	2.8	2.8	0.8	0.6	0.9	0.5

Source: National Weather Service at Seattle-Tacoma International Airport

important factors. The 2-year, 24-hour precipitation "design storm" for King County, shown in Figure 1, represents the amount of rainfall which will fall in a 24 hour period for a storm magnitude which is expected once every two years. (This particular illustration was used as an example; see discussion below on design storm size.) A treatment facility is normally designed using an arbitrary storm size. The design storm size ultimately affects the design dimensions of the oil-water separator. However, sizing a facility using a storm of this rarity may result in underutilization of its capabilities and unnecessary added cost.

Storm frequency also affects water quality issues. As contaminants fall to the ground, they are washed away with the next precipitation. More frequent storms tend to spread concentration levels over time, while infrequent storms could increase the acute pollutant concentration effects. An analysis done by Hoffman and Quinn (1987) found hydrocarbon discharges to be a function of storm hydrography. (Oil and grease contains a wide array of pollutants, including mainly hydrocarbons.) Figure 2 shows the hydrologic representation for an interstate highway location. Notice in the figure that hydrocarbon concentrations are highest during the first small peak in rainfall intensity but <u>before</u> the main peak in rain intensity. This phenomenon has been termed the "first flush effect" in urban runoff literature.

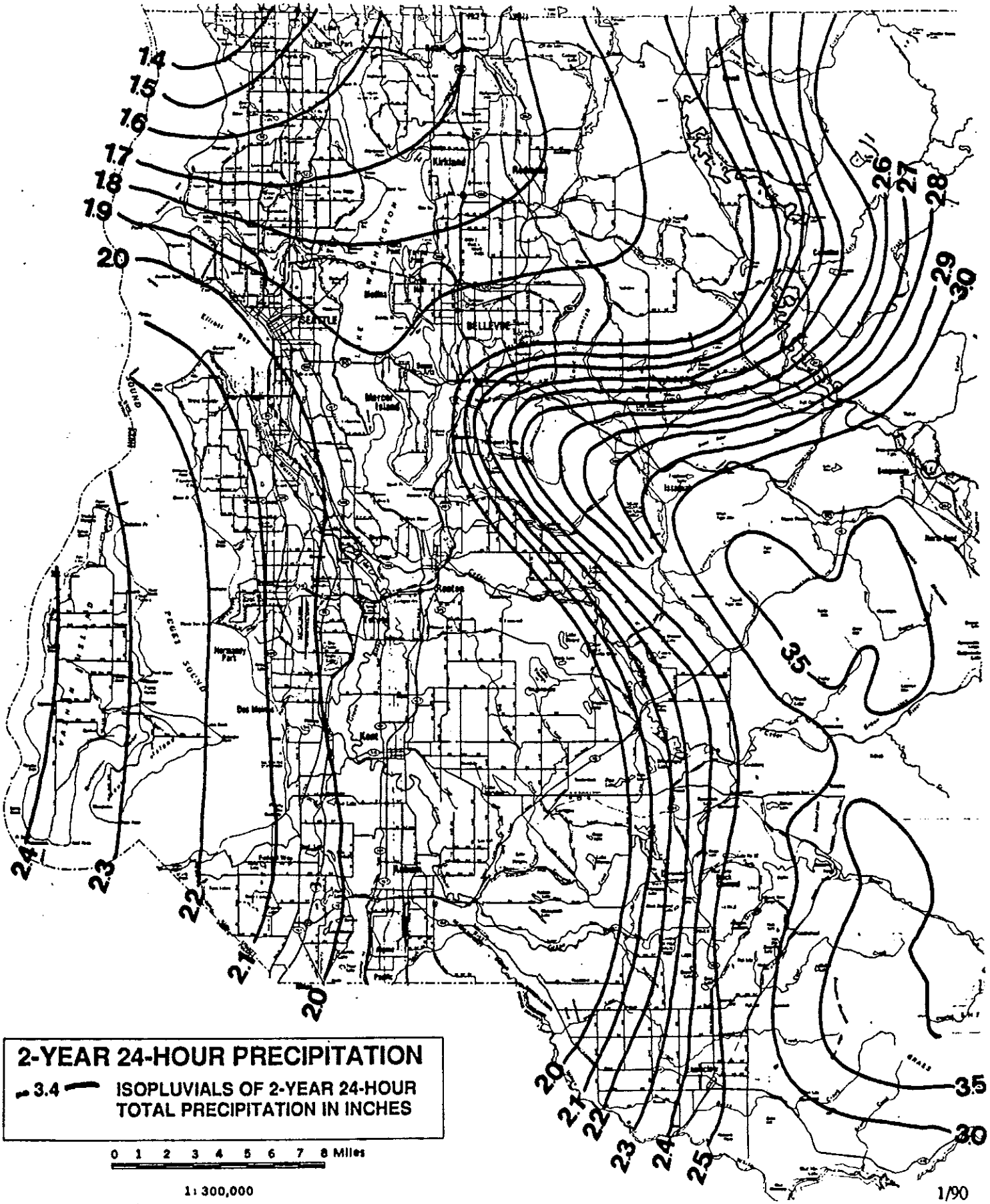
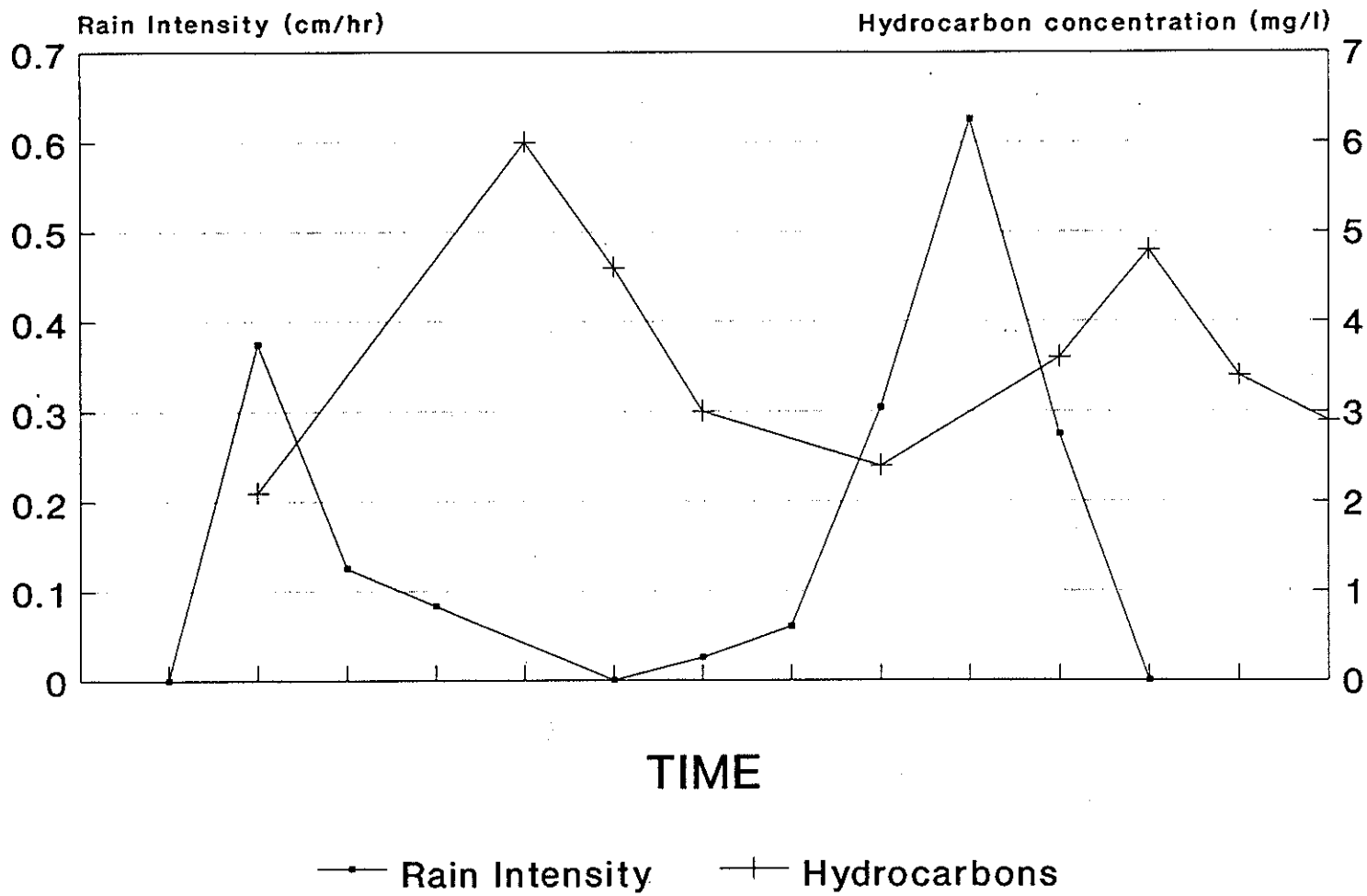


Figure 1. King County Precipitation

Source: King County, Washington, 1990.

Figure 2. First Flush Effect: Rain Intensity and Hydrocarbons



Adapted from Hoffman et al., 1983

(Note: It is important to distinguish between the first flush effect as described here for individual storms and the effect of the concentration of pollutants for the first storm following an extended dry period.) Lettenmaier and Richey conducted a study in 1985 which verified this effect in the Seattle region. However, this conclusion differs from the analysis of Stenstrom and others (1984) in a San Francisco study which found little significance to this initial flushing effect. Local runoff studies have found mixed results on first flush and there is debate as to the extent of this effect in the Pacific Northwest due to the nature of the rainfall here; storm events do not generally follow a pattern of dramatic increase in precipitation, but generally rain lightly over long periods of time.

Design Storms

Historically, surface water management design has focussed on drainage systems utilizing large, infrequent storm events (10-, 25-, 50-, or 100-year storms) as models. This approach, although effective for water quantity control and curtailing flood damage, may not be the most efficient use of resources for controlling water pollution. Current design practices for water quality pollution control issues lean toward small, frequent design storms. Illustrative of this point is Table 2 which shows that the percentage of precipitation contributed by small storms accounts for the majority of the total rainfall. Notice that water associated with a 6-month storm event and smaller storms accounts for 91 percent of the water, water from 1-year and smaller storms accounts for 95 percent, and water from up to a 2-year storm accounts for 98 percent of the total annual water, based on the 28 year period of record (Washington State Department of Ecology, 1990). Thus, if surface water drainage systems were designed with quality controls using the 6-month standard, approximately 91 percent of the water would be treated; using the 1-year storm, approximately 95 percent would be treated, etc. Assuming that surface water treatment would result in pollutant removal, design storm size could affect total

Table 2. Analysis of Rainfall from 1950 to 1977

Storm Event Size	Precip. Amount	No. of Events	Total Rainfall from These and Smaller Events	Proportion of Total[1]
1-month, 24 hr.	0.65"	390	685"	62%
6-month, 24 hr.	1.35"	58	999"	91%
1-year, 24 hr.	1.60"	31	1045"	95%
2-year, 24 hr.	2.00"	9	1077"	98%

1. The total rainfall from 1950 to 1977 was 1,100". The proportion of total represents the amount of rainfall accounted for by that storm size, and smaller sizes. For example the 1-month, 24-hour storm, and smaller storms, accounted for (685 - 415)/1,100 = 62%.

Source: Seattle-Tacoma rainfall. Adapted from Washington State Department of Ecology, 1990.

pollutant loading reduction percentages. Therefore, stormwater quality treatment should focus upon smaller, frequent storm events, resulting in processing the largest percentage of potential pollutants on an annual loading basis.

Currently the Washington Department of Ecology specifies the 25-year storm for oil-water separator design. However, as previously mentioned, Ecology is, at the time of this writing, preparing a "Stormwater Management Manual for the Puget Sound Basin," scheduled for completion in May, 1991. A draft copy of the manual that was shared with Metro takes into account the above described methodology of storm size selection for stormwater quality management. This draft manual states that "as a first approximation, it seems reasonable to select the 6-month, 24-hour design storm as the Water Quality design storm."

Selection of the 6-month, 24-hour storm presents a problem when estimating rainfall because typical isopluvial precipitation maps (such as shown in Figure 1) do not provide values for less than the 2-year storm. As a result, the draft copy of the manual derives a "rule of thumb method" for extrapolating the precipitation of the 6-month storm from the 2-year isopluvial map. The manual states that "the 6-month, 24-hour design storm

can be estimated for any location within the Puget Sound basin as 0.64 times the 2-year, 24 hour storm value."

The foregoing discussion regarding design storm size has some serious ramifications upon stormwater quality treatment systems. The larger the storm selected for design of the quality-related system, the greater the potential flow rate and total treated volume on a per event basis. This would ultimately translate into larger treatment systems which may consume resources without commensurate benefit.

Monitoring methods

As mentioned earlier, current EPA NPDES regulations require that pollutant quantitative data be collected based upon one grab sample each hour of discharge for the first four hours of the storm event. A grab sample is usually obtained by collecting stormwater at a discharge point. However, this approach may not be representative of the pollutant loading. This is due to the nature of storm hydrology and the pollutant constituent interaction. Once again referring to Figure 2, the relationship of stormwater runoff volume to pollutant concentration over a period of time is not a constant; oil and grease concentrations will vary over the course of the storm event and will vary with different types (intensity, duration) of storm events, as well as from the antecedent conditions. Clearly, taking a grab sample at different points of the curve will not necessarily be representative of the total or average pollutant levels. The samples only represent that point of the curve sampled.

The proposed EPA rules may change the monitoring requirements. Pollution quantitative data may be required to be submitted at two levels; during the first flush of the pollutants and again for flow-weighted average storm event concentrations.

The first flush sample is to be defined as a grab sample taken during the first 20 minutes of the storm event. The flow weighted sample is collected by taking samples over a time period based upon the flow volume. In other words, numerous samples are

taken on a volume basis and then summed. This yields an average concentration level for more of the storm event interval. This sampling method for determining average storm concentration represents a more accurate representation for calculating pollutant loading and will impact treatment methods. As the sampling techniques become more accurate, the treatment methods and designs utilized can be more fine-tuned to the problems being addressed.

The Information Gap: What We Know Versus What We Need to Know

Recent studies

Few studies have been conducted about oil-water separator effectiveness for stormwater runoff treatment. A 1983 study of an API type separator in series with a wet detention pond in Bellevue, Washington, found the combination inadequate for oil and grease treatment (Lettenmaier and Dally, 1983). The study, however, did not consider the effectiveness of the API separator by itself, but the combination of the two treatment methods. In fact, the study found the oil and grease levels at the outflow to be greater than those at the inflow for several storm events. More importantly, the concentration levels at the outflow were often higher than the allowed 10 mg/L Washington state guideline. Though no explanation was provided for this phenomenon, it may be concluded that the higher concentration levels were due to the flushing of oils and grease which were already resident in the separator/detention system.

Another study by Lettenmaier attempted to determine the effectiveness of a coalescing plate separator for stormwater runoff application at the same location (Lettenmaier and Richey, 1985). The study expresses the mean oil and grease removal efficiency to be 56 percent, dealing with a range of concentrations between 1.8 and 33.0 mg/L for seven different storm events based upon time-composited and time-discrete samples. This indicates that the discharge would not meet state water quality guidelines for some storms.

In a study conducted by Horner and Wonacott (1985) at another Bellevue site, an analysis of a detention basin in combination with a coalescing plate separator (CPS) was conducted. The study did not determine CPS efficiency at the low influent oil and grease concentration levels encountered. These levels were normally below 6 mg/L -- too low to ascertain the usefulness of the particular CPS studied, which was designed to achieve an output level of 15 mg/L at much higher influent concentration levels.

In a recent manual published by the American Petroleum Institute (1990), conventional API and CPS separators have been analyzed based upon their uses in industrial or bilge-water treatment. However, no study referenced in the manual found effluent levels below the 10 mg/L requirement or utilized oil and grease influent concentration levels as low as those found in stormwater runoff.

Storm Size

As mentioned earlier, current thought regarding stormwater quality management when no quantity treatment is required has focussed upon treating the smaller, more frequent storms. Livingston and Roesner (1990) have concluded from analysis of 39 years of sequential hourly rainfall data in Cincinnati that treatment of the 2-month storm runoff would amount to capturing more than 90% of the annual runoff in that area. Presently, various local jurisdictions in the Northwest have taken different positions regarding this matter. There is discussion as to whether a 6-month, 1-year or 2-year design storm is appropriate.

Although it has been shown that treating the smaller storms captures most of the runoff, it has not been determined empirically if this runoff represents the major portion of pollution loading. Determination of pollution effects is not a trivial matter, as they are affected by storm seasonality, intensity, duration, and time since antecedent storm. Further analysis should be conducted to determine pollutant loading as a function of these parameters.

First flush - does it apply?

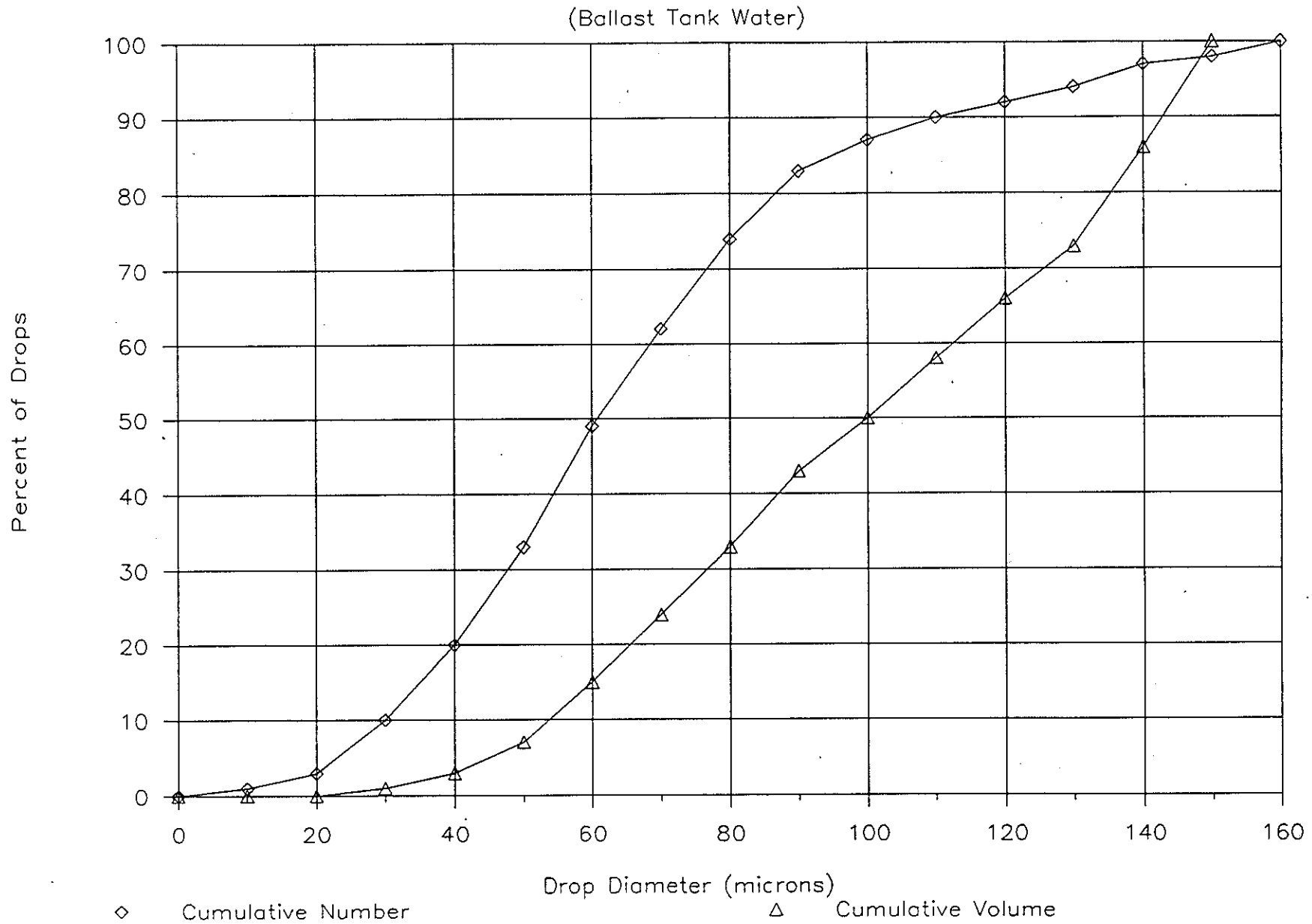
It has been mentioned that the effect of the greater intensity of the runoff flow as characterized in Figure 2 constitutes the first flush effect. However the rain in the Pacific Northwest, inherently more frequent and less intense, may limit this effect. Before adequate treatment methods for local stormwater are prescribed, it would be useful to characterize pollutant concentration levels. In doing so, concentration thresholds would determine treatment methodology and performance.

It is important to note that cleaning chemicals, antifreeze and other emulsifying agents accumulate in separators during periods of low flow and may emulsify material trapped in separators, allowing escape during higher flow periods.

Oil and grease droplet sizes

The application of Stokes' law illustrates that oil and grease droplet size plays a significant role in the design and effectiveness of gravity oil-water separators. (See Appendix A for more discussion.) However, little is known regarding the oil and grease droplet size in stormwater runoff. A study has been conducted which profiles oil droplet size from the ballast water of a tanker carrying heavy crude oil (Branion, 1987). The cumulative number and volume of the droplets are shown in Figure 3. It is important to look at both volume and number of droplets because numerical data can be misinterpreted: a "...150 micron droplet contains 27 times as much oil as a 50 micron drop and 422 times as much oil as a 20 micron drop" (Branion, 1987). Notice in Figure 3 that droplet diameters greater than 60 microns represent the majority of oil volume (greater than 85%) in this example while representing only 50% of the actual quantity. As drop size decreases below 60 microns, the change in the marginal oil volume decreases. This results in diminishing the marginal pollution treatment benefits (or volume treated) as designs utilize these smaller droplet sizes. Therefore, it would appear best to design an oil-water separator to remove 60 micron

Figure 3. Oil Drop Size Distribution



Source: Branion, 1987

droplets and greater. Finally, although this is characteristic of ballast tank water, it may not be characteristic of runoff. Additional study of droplet size in stormwater must be conducted to verify appropriate application of treatment technology.

VARIOUS OIL-WATER SEPARATION METHODS AND LOCAL APPLICATIONS

Introduction

There are a variety of oil-water separators which have been used for applications ranging from laboratory environments to marine oil spill clean-up. Historically, oil-water separators have been used by the oil industry, particularly in applications associated with petroleum processing and transport, as in ballast oil removal from tankers.

The problems associated with removal of oil and grease from industrial applications versus stormwater runoff are different. As previously mentioned, stormwater runoff pollution constituents are difficult to characterize and their occurrences are difficult to predict. Oil and grease concentrations associated with industry are generally more predictable in terms of flow rate, concentration range, and frequency of occurrence. Furthermore, influent concentration levels of oil and grease used for testing purposes are normally in the range indicative of industrial applications (e.g. 50 mg/L or more) and not within the lower concentration range generally indicative of stormwater runoff.

Industrial applications also present another perspective. Often the separation system is used where maintenance is easily conducted or energy sources (e.g. electricity, gases, etc.) are readily available. Stormwater applications are generally not found in an easily accessible, controlled environment. This dictates application of passive systems for most runoff applications -- ones which have no induced moving parts, electrical power requirements, or frequent (daily or weekly) maintenance requirements. Stormwater systems are often installed underground, making access for maintenance more difficult. It is important to consider the costs of various technologies and the ease of maintenance in addition to removal efficiencies.

As the result of the above conditions, it is generally concluded that passive oil-water separators are more practical and less costly than enhanced, energy-consuming devices for stormwater runoff applications. However, included here is a

brief mention of a few enhanced devices, should a given application differ from this conclusion, in addition to a more in-depth discussion of the prevalent, passive systems, the latter divided into two classes: gravity treatment methods and biofiltration.

Enhanced oil-water separation methods

Enhanced oil-water separators as defined here use components which require some sort of external energy source, are a combination of several treatment methods, or introduce agents to the oil-water mixture. Rotational separators introduce energy to accelerate the flow rate, utilizing devices such as pumps and centrifuges to accomplish this. Chemically enhanced separators mechanically agitate the mixture and introduce chemical additives to demulsify the oil and cause it to float. Gas flotation methods infuse gases, normally air, in combination with chemicals to accelerate the demulsification and separation of oil (Dull, 1984).

Some passive systems that may be effective yet will not be discussed in detail follow. Filtration using sand has been used to remove suspended materials from oil-water mixtures. Often this method is found as pretreatment to gravity separation systems (see descriptions below). Other filtration systems utilize a fine mesh material to screen out oil and grease droplets larger than the mesh pore size. These filters cannot be utilized when the mixture contains large particulate matter which can clog the filter. Finally, microorganisms which digest the oil and grease can be introduced to the polluted runoff. However, this method has not been widely used in any oil pollution applications and never, to our knowledge, in routine stormwater runoff treatment.

Gravity treatment methods

There are primarily three types of gravity or passive oil-water separators used by local jurisdictions for stormwater runoff treatment: **spill control, American Petroleum Institute**

(API or baffle type), and **coalescing plate separators (CPS)**. Following is a description of each type.

Spill Control Separator

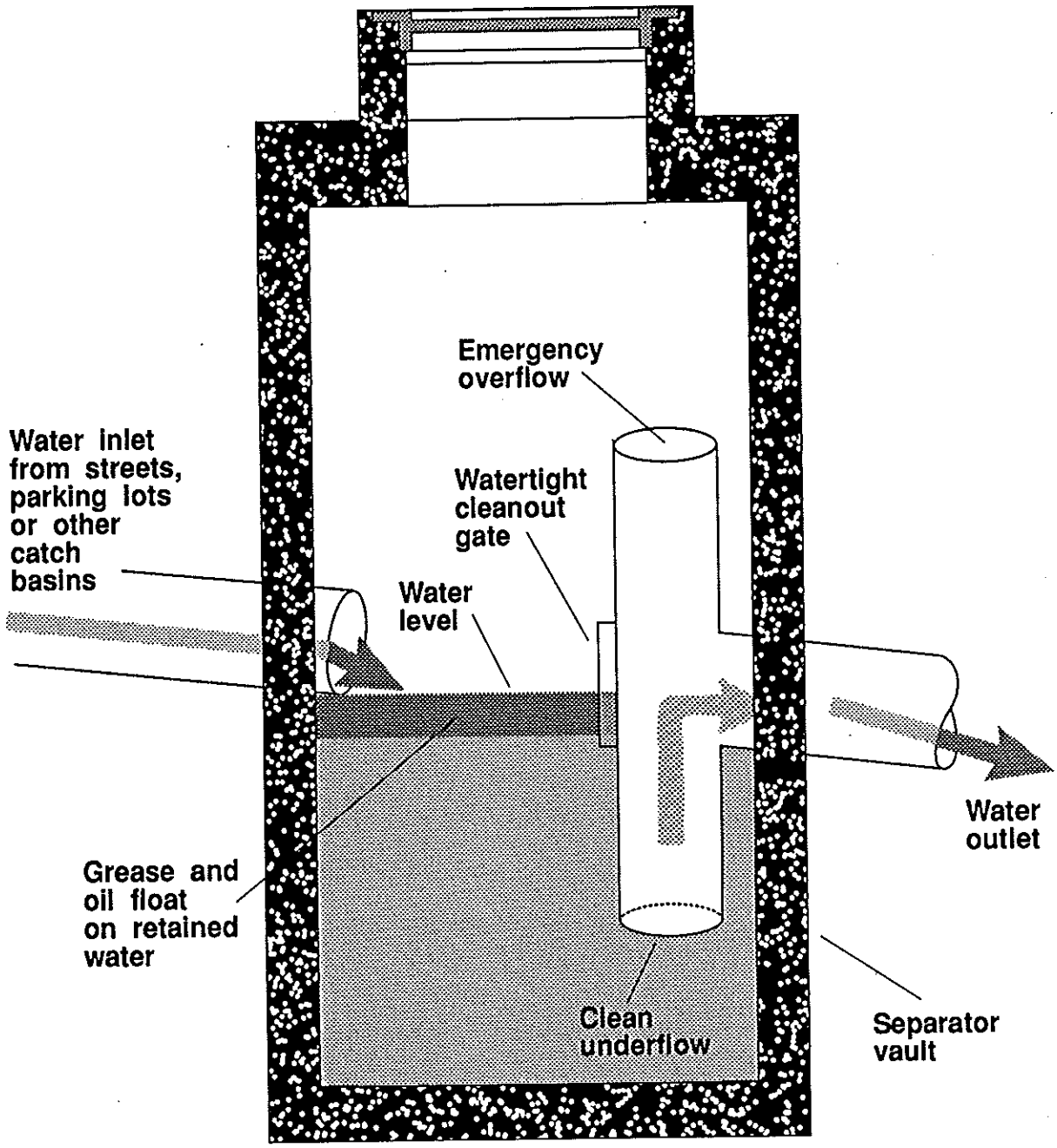
Design. Most jurisdictions use some type of spill control device for stormwater treatment. Figure 4 illustrates a simplified version of the device. Stormwater will enter the chamber through the inflow. As the chamber fills and the water is detained, the oil and grease should float to the top. The outflow location is the orifice at the bottom of the t-shaped configuration. The flow rate which the separator can accommodate is a function of the orifice diameter and the height of the T.

Effectiveness. The separator is designed so the water line will stay above the orifice. Therefore, only water should flow out. Obviously if oil and grease quantities fill the chamber to a point below the orifice level (remember, oil floats to the top of the chamber), the oil and grease can escape. This may occur if the chamber is not maintained, leaving oil and grease to accumulate over a long period of time, or during an extended dry period. Under such conditions, as water from a storm is flushed through the separator, it would carry the resident oil and grease along with it through the outflow.

Another problem inherent with unmaintained SC separators is one of re-suspension or re-emulsification of oil. Any amount of oil sitting on the surface of the accumulated water in the separator can be stirred up and carried out the discharge by the turbulence of new storm flow entering the device. Metering or using baffles at the inlet may help alleviate this situation. In addition, emulsifying agents (i.e. detergents, antifreeze, etc.) discharged to the separator can re-emulsify any oil and grease within it.

Variations of the design attempt to prevent the above problems from occurring, although no proof of effectiveness has been determined. King County specifies modified catch basin devices

Figure 4. Spill Control Separator



for enhanced oil and grease treatment, yet requires a more sophisticated separator (e.g., API or Coalescing Plate, see below) for treatment at locations which expect appreciable quantities of oil and grease. (See the 1990 King County Surface Water Design Manual for details.)

General perception among local professionals is that spill control separators are not effective for oil-water separation in stormwater runoff applications. Yet if properly maintained, they can serve to intercept illicit dumping (if the dumped or spilled oil is promptly removed before the next rain event).

No studies have been identified that show quantitative effectiveness of spill control separators.

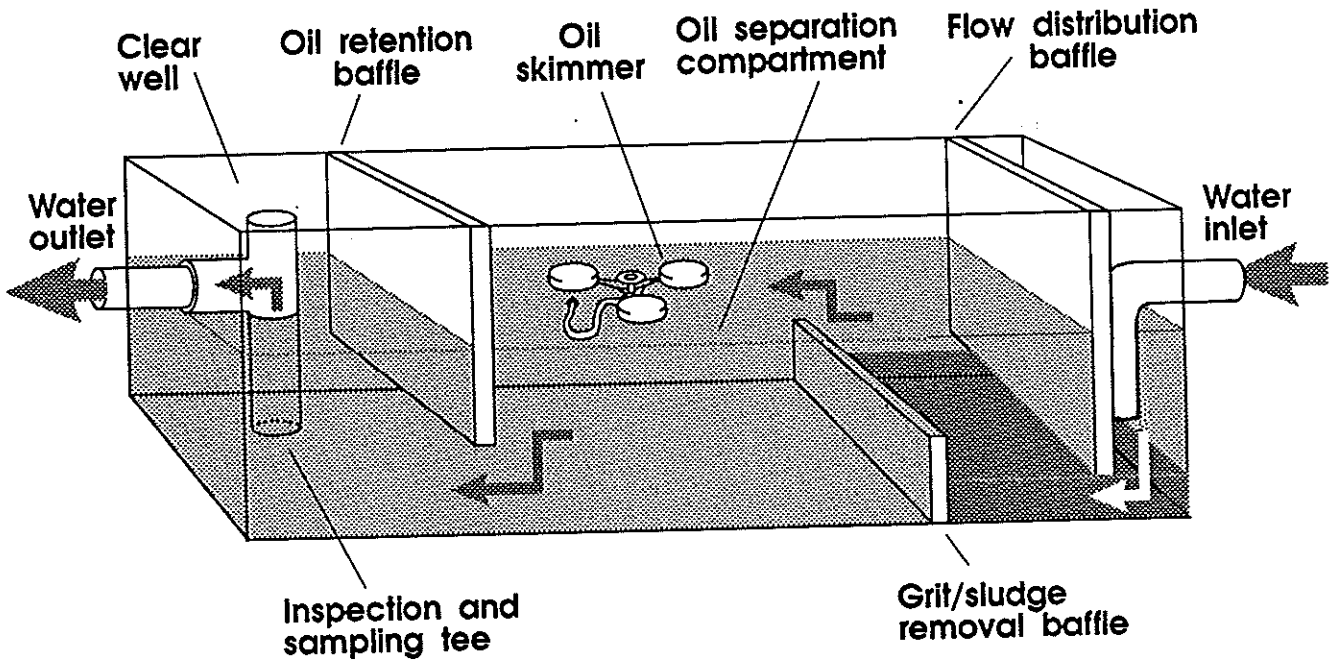
API (American Petroleum Institute) Separators

Design. Figure 5 depicts a typical API oil-water separator. There are three chambers separated by 2 baffles. (API separators are often called "baffle" separators.) The baffles are placed within the chamber to block oil flow out of the separator and to limit turbulence. Oil-water separation occurs in the first and center chambers. Oil floats to the top of the chamber and sludge to the bottom. Another baffle or weir is fastened to the bottom to trap the sludge at the bottom of the separator. It is also recommended that a turn-down elbow be placed at the influent port and sample-T at the effluent port. The turn-down elbow prevents emulsification and resuspension of floating oils in the first compartment, and the sample-T traps oils in the third compartment and allows for monitoring of effluent.

(An oil skimmer device could be installed so that it would float at the top of the water and remove the oil. If a skimmer is used, it should be connected to a remote waste oil tank allowing for gravity flow of the oil to the tank.)

It is important to match separation size and shape to anticipated flow volume. American Petroleum Institute (API) recommends that the "length should be adjusted to be at least five times its width, to minimize the disturbing effects of the

Figure 5. API Separator



inlet and outlet zones" (API, 1990). In addition, it has been determined that the residence time for an API separator should range from 30 to 45 minutes.

For a detailed description of API type design procedure, see the "Monographs on Refinery Environmental Control - Management of Water Discharges: Design and Operation of Oil-Water Separators" published by American Petroleum Institute, February 1990.

Effectiveness. API research has determined that baffle type separators are most effective at removing oil droplets with a diameter of 150 microns or greater (API, 1990). Earlier (see Figure 3) we saw that the major volume of oil occurs for droplet sizes of 60 microns and larger. Due to this limiting characteristic, this method should be used to separate free oil whose droplet size characteristics are within this 150 micron range. (Analysis specific to oil droplet size in stormwater is not available. However, it has been assumed that the oil droplet size for general stormwater runoff applications is in the 60 micron or larger range. Therefore, the effectiveness of API separators for stormwater applications can only be determined by regular monitoring of the effluent oil and grease concentrations.)

An effective maintenance schedule for API type separators which do not employ skimmers and which discharge to the sanitary sewer has been determined by experience at Metro's transit bases to be every two weeks (conversation with Dave Waddell). However, this land use may expect heavier oil and grease concentrations than would normally be encountered in general stormwater applications, and this maintenance frequency may not be necessary.

Coalescing Plate Separators

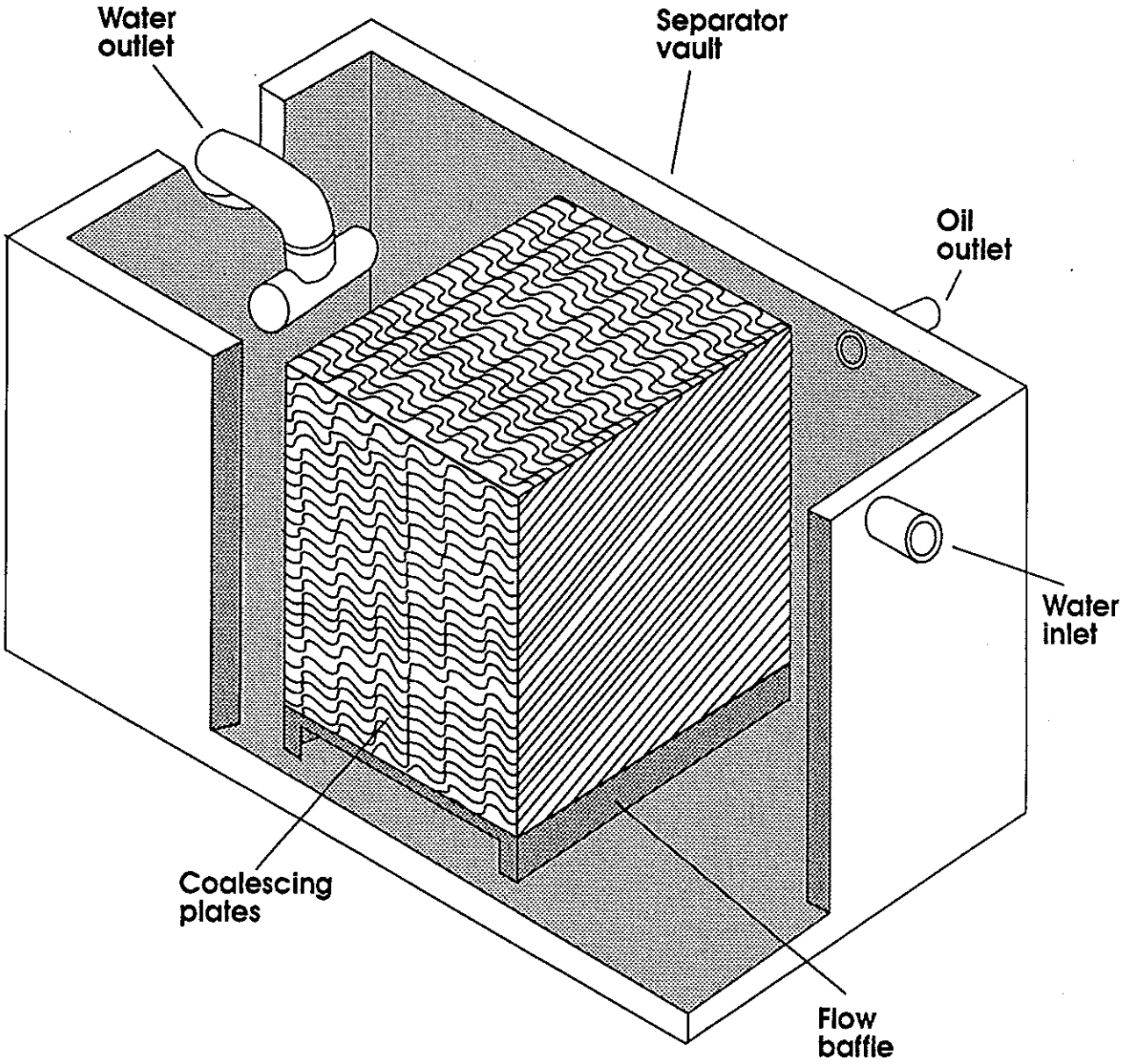
Design. The distance a droplet must travel and the size of the droplet are directly related to separation efficiency. It is stated in Stokes' law that the vertical velocity of a droplet is

proportional to the square of its radius. (See description of Stokes' Law in Appendix A.) This means that a 40 micron droplet will rise four times faster than a 20 micron droplet. The coalescing plate separator (Figure 6) makes use of this phenomenon associated with Stokes' law. Coalescing plates are installed which intercept the oil droplets as they move into the oil separation chamber. As the droplets come in contact with these plates, they coalesce with other droplets thereby forming larger droplets. These larger droplets then rise more quickly. The greater the surface area the oil-water separator offers, the more oil and grease will coalesce and be separated. Corrugated shaped plates, stacked in an array to form a pack, provide greater surface area with which the flow makes contact. The plates are normally made of an oleophilic (oil attracting) material such as polypropylene which enhances the oil separation process. As a result, this allows the same amount of separation with less utilization of space. It is recommended that the coalescing plates be placed at an angle of 45 to 60 degrees to the horizontal so that particulate matter (i.e. silt, sand, etc.) will not become trapped between plates (Seattle, 1989). This recommendation, however, is based upon local experience and manufacturer advice regarding maintenance issues and does not necessarily improve oil separation effectiveness.

As is the case for the API separator, once the oil has collected at the top of the vault, a skimming device can be used to remove the oil from the top and can then be fed through a pipe to a waste oil tank.

Effectiveness. Due to its increase in effectiveness by means of increased surface area and materials, CPS separation can be accomplished for droplet sizes of 60 microns or larger (API, 1990). This implies that the coalescing plate separator is more effective for oil separation than any previously discussed device because the greatest percentage of oil droplet sizes fall within this range. However, as is the case with all gravity type separators, the CPS must be maintained at regular intervals to

Figure 6. Coalescing Plate Separator



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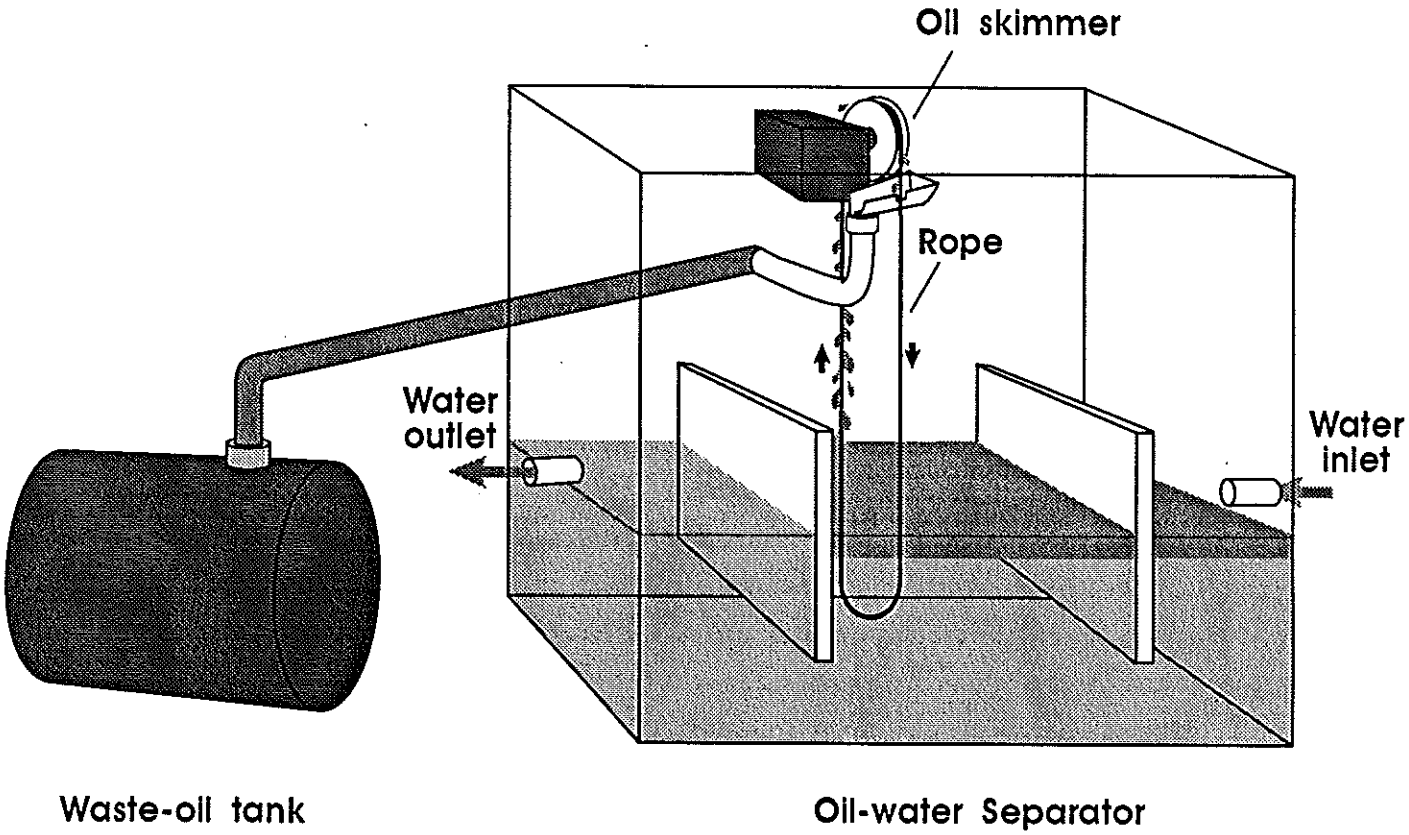
insure that the coalescing plates do not accumulate too much residue on the surfaces, thereby diminishing performance. (A pretreatment vault may be used to allow particulate material to be removed before entering the oil-water separator.) Manufacturer recommendations for scheduled maintenance (for cleaning of the coalescing plates) for CPS are twice per year or when the gap between horizontal plates has been reduced by forty percent. Metro transit currently follows this maintenance recommendation but is investigating the need for more or less frequent cleaning by studying increases in effluent toxicity and oil and grease levels over time (conversation with David Waddell).

Oil Skimmers

Oil skimmers are generally used in combination with API or CPS separators to remove the collected oil floating on top of the water from the separator. There are a variety of skimmers available, however there are only a few in use that have been found effective. A **floating skimmer** (see Figure 5) floats on the surface of the liquid within the separator and is connected to a waste-oil tank by a pipe which runs into the separator chamber. These skimmers have been found to be effective at removing excess oil from the tank, and at reducing the frequency of maintenance of the separator.

A **rope skimmer** (Figure 7) utilizes a looped rope which extends into the separator chamber and passes through the collected oil. The rotating mechanism is a motor and pulley mounted above. The oil and grease adhere to the rope as it passes through the liquid. The oil is skimmed off of the rope at the height of its rotation and is channelled to a waste oil tank. Although this system requires an energy source, Metro has found that it requires little maintenance and is effective where a power supply is available. A timer allowing four hours of operation per day is also recommended to avoid the accumulation of water in the waste-oil tank as the oil in the separator is depleted, to

Figure 7. Rope Oil Skimmer



prolong the motor life and to save energy. Both floating and rope skimmers have been found to be effective at Metro transit bases.

Another type of skimming device of interest is the **filter bucket.** Although use of this device has not been witnessed in practice and its effectiveness has not been tested, it offers interesting application for system maintenance. The opening of the bucket is covered with a screen which is both hydrophobic and oleophilic. As the bucket is lowered into the collected oil, the screen allows the oil and grease to pass while repelling the water. Once the bucket is filled with oil, it is raised out of the separator. Metro will be testing this method to determine if the filter bucket is effective for manual oil and grease removal from its transit separators (conversation with David Waddell).

Biofiltration

There is some question as to whether biofiltration or passive gravity oil-water separators are more effective for oil and grease treatment of stormwater. The data at present for oil and grease removal are inconclusive. Biofiltration systems have been found to be effective for the removal of suspended solids and associated contaminants and are becoming widely used in local jurisdictions for stormwater pollution control.

Grassy Swales and Filter Strips

Design. A biofiltration swale is a shallow vegetated (commonly grasses) channel which acts to remove pollutants as water passes along it and through the vegetation. Swale design emphasizes a shallow, relatively slow velocity of flow allowing pollutants, including oil and grease, to be filtered out as the stormwater passes through the swale vegetation. Due to the narrow channel dimensions, it is best used where runoff has been collected and concentrated. Little and others (1983) conducted a study which found between 67 and 93 percent reductions in oil and grease in a

180-foot long, unmown swale. More investigation of swales is needed and underway, but the one study does suggest effectiveness (Horner, 1988).

Filter strips are broad areas covered with vegetation over which water flows. However, contrasting with swale design, the water is allowed to flow in a diffused sheet-flow manner. A biofiltration filter strip is best employed where runoff has not been concentrated or channelled.

Vegetation species which have been used for biofiltration applications include grasses, common wetland species and synthetic materials (Horner, 1988). The vegetation could be naturally propagated or could be applied by means of seeding, planting or sodding. Selection of the vegetation type should consider the aesthetic influence upon the surrounding area, pollution tolerance, the availability of emergent wetland species and climatic tolerance.

Effectiveness. The Seattle Best Management Practices manual rates various filtration systems for oil and grease separation. It is suggested that likely oil spill locations must first be fed through a gravity spill device (i.e., API-separator, Coalescing Plate) before entering a biofilter. It has rated API separators as fairly effective for treatment of dispersed oil; CPS separators as good; biofilters as fair; and spill control separators as having no effect.

For a more comprehensive discussion on the topic of biofilters, the report, "Biofiltration Systems for Storm Runoff Water Quality Control" by Richard R. Horner (1988) is the best available resource.

Local Applications of Oil-Water Separation

A few examples of noteworthy local applications of oil-water separators follow. It is not the intent to provide an exhaustive search and description of all oil-water separators found locally,

but to include some perspectives which may be useful to the reader.

Metro - South Base

System Design

Metro Transit Department's South Base employs what may be considered the "state of the art" oil and grease contamination prevention strategy, including both a variety of separator facilities and comprehensive maintenance methods. There are two adjacent locations of interest at this base. The first location involves stormwater from the employee parking lot which drains into a detention pond where the water flow follows a snake-like pattern to increase water retention time and surface area contact with vegetation, and to prevent short-circuiting of the flow directly from inlet to outlet (Figure 8). (Short-circuiting would diminish treatment of the runoff.) Pollutant-tolerant plant life (e.g., rushes) have been planted in and along the channel within the pond to act as biofilters.

The other location at South Base is the parking and movement areas for the Transit fleet. The runoff from the large asphalt surface area passes through two parallel coalescing plate separators, equipped with skimmers, whose plates are arranged at 45^0 angles. The CPSs were designed with features to minimize maintenance, including: (1) a large sediment storage area at the bottom of the CPS; (2) accessibility so that the separator can be hosed out while remaining in place; and (3) an oil outlet to skim off surface oil. The outflow from these separators also discharges into the detention pond described above. An oleophilic boom has been strung across the edge of the pond where the discharges from the CPSs enter it. The boom serves to further intercept any oil or grease which has not been filtered by the separators. Two API separators in series receive the water leaving the pond. A final boom precedes discharge to the Duwamish River.

The transit base's asphalt surface is washed every two months. During parking lot washing, the drainage system is manually

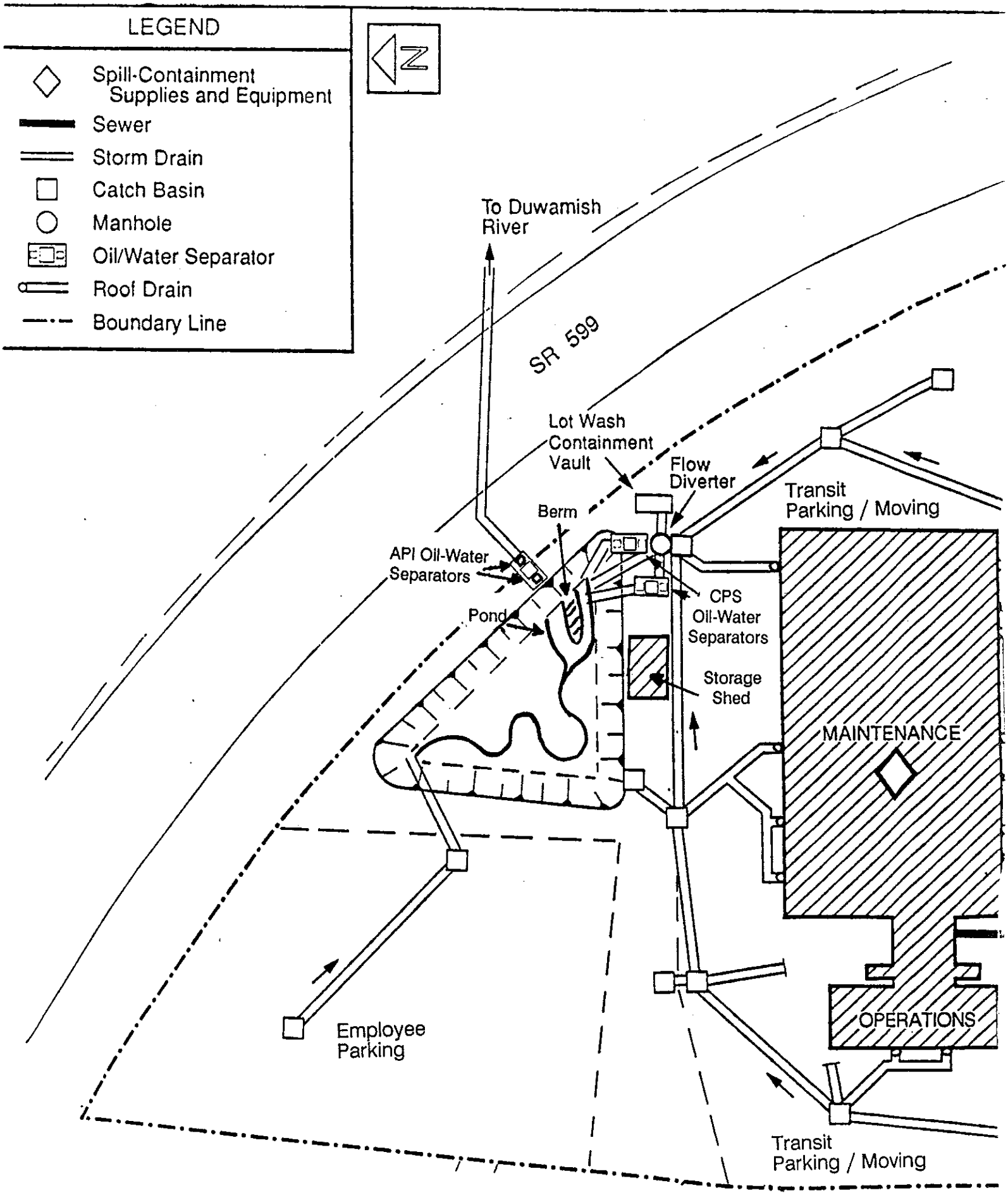


Figure 8. South Base Pollution Control System

switched so that the runoff is directed away from the parallel separators to a separate vault which has no outflow point. The capacity of the vault, approximately 10,000 gallons, is sufficient for each washing. Between washings, water is left to settle in the vault allowing for sludge and oil separation and demulsification to take place. The vaults are then cleaned by removing water and sludge with an eduction truck. (See Maintenance, below.)

Metro has also designed an oil skimmer which floats on the surface of the water in the two CPS vaults and feeds into a waste oil tank by means of an articulating PVC pipe (articulation allows for water level fluctuations). The inflow pipe to the waste oil tank is situated at a point lower than the position of the skimmer allowing gravity oil flow.

Maintenance

Metro has implemented a comprehensive maintenance program at South Base. It maintains its coalescing plate separators and supplemental API-type separators twice per year. This schedule is based upon the monitoring program which identified maintenance as affecting system performance and compliance to regulations. By adjusting the maintenance schedule to occur at the end (June) and beginning (mid October) of the rainy season, system performance was found to improve (conversations with David Waddell).

The resources required to conduct maintenance on a CPS are 5 people, 1 boom truck, 2 eduction trucks and 2 pick-up trucks for approximately 5 hours on each separator installation. One eduction truck, the "dirty truck", skims off the dirty oil for proper disposal. The second eduction truck pumps out the remaining water to the sanitary sewer. Then the "dirty truck" removes the sludge from the bottom of the separator. The boom truck is used to hoist the coalescing plate medium from the CPS vault. The pack is placed into a pick-up with a plastic lined bed and then taken to a wash building. The pack is washed with a fire hose to remove sediment, oil and grease which have

accumulated on the plates. This water drains into a detention vault and is left for several weeks so that the contaminants can settle out. This vault is then educted using the two-eduction-truck method described above. If the CPS contains a second pack, it is placed into the second pick-up and the same procedure is followed.

Metro has found that the oleophilic boom on the detention pond must be changed every 3 weeks.

Effectiveness

Although the API and CPS type separators have been effective at Metro's current locations, this is the result of implementation of a more comprehensive monitoring and maintenance strategy. As time increases, the coalescing plates become plugged with sediment, oil and grease. This prevents the plates from making contact with the water, thereby decreasing effectiveness; a direct result of maintenance frequency. Moreover, any oil and grease solvent (e.g., a detergent) that enters the separator can emulsify the oil. Gravity separators are not effective for removing emulsified oils from water, which end up being flushed through the outflow.

Monitoring of the outflows from the separators has found that discharges are in compliance with state regulations. Based upon experience, Metro is reasonably certain that the CPS installation and maintenance practices have been responsible for this in that previous oil and grease concentration levels were much higher than regulated standards (some found to be 100 mg/L or more) prior to installation of the systems and implementation of more frequent maintenance activity.

As part of the maintenance program, Metro conducts regular checks of the oil and grease levels in the separators. Oleophilic paste and a large measuring stick (long enough to extend to the bottom of the separator compartment from outside the separator) are used. The stick is initially lowered into the water to determine total depth of the fluid in each compartment of the separator. A line of the orange oleophilic paste is then

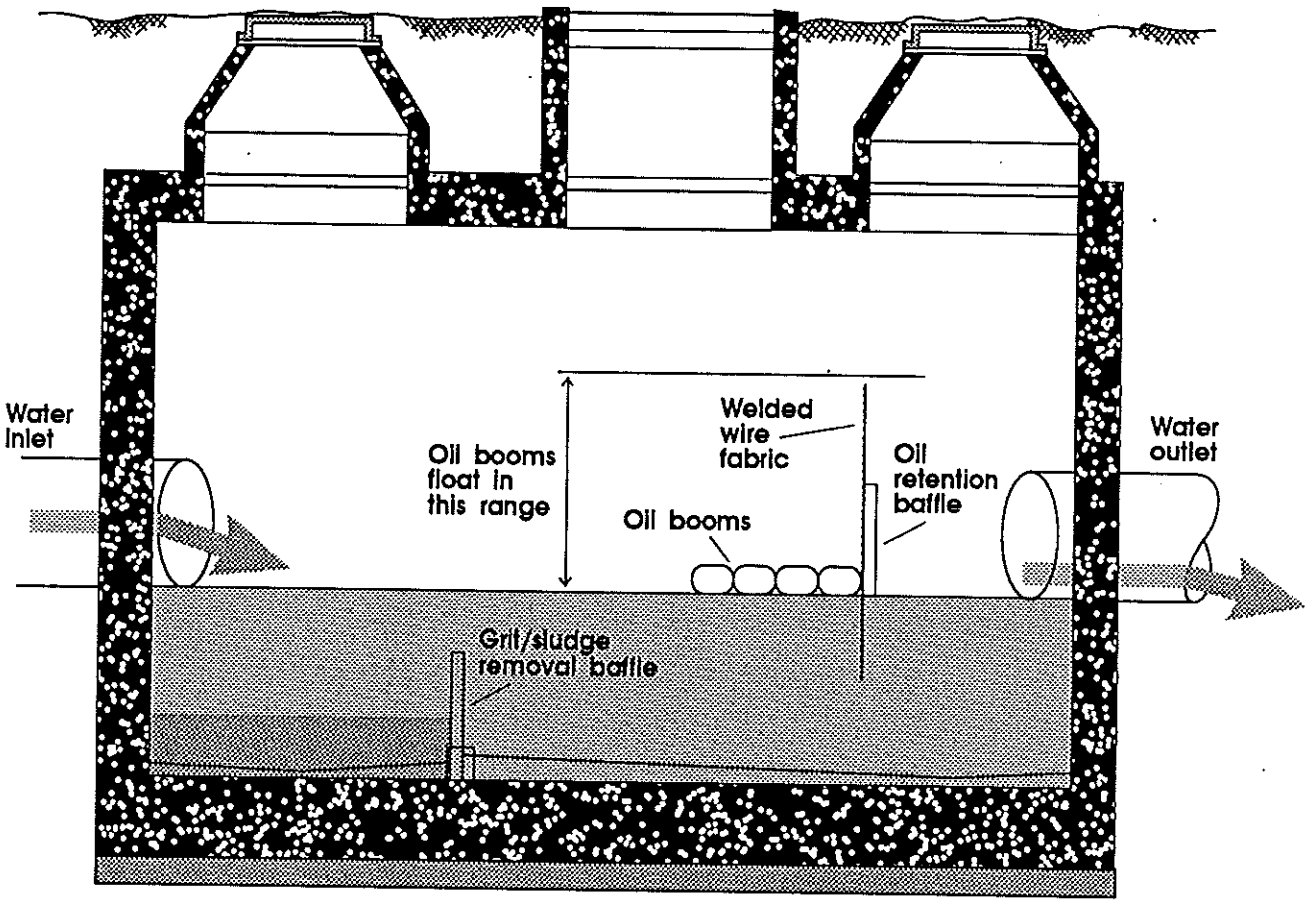
laid down on the graduated side of the measuring stick. The stick is once again placed into the liquid and left in that position for about five minutes. (This allows enough time for the reaction to take place.) The stick is then removed. The paste turns pink along the stick where oil came in contact with it. This is representative of the oil depth within the separator compartment. Metro has found that for API separators with skimmers, the separator requires oil eduction if the first (inflow) compartment contains more than 10 inches of oil, the second (center) compartment contains more than 1 inch, and the third more than 1/2 inch. CPS types usually do not collect enough oil to merit use of oil skimmers in the applications at Metro. It has been found that these type separators should be educted if there is 1 inch of oil or more in the compartment which houses the coalescing plate pack.

City of Seattle -- Longfellow Creek

Design

Seattle has recently designed and constructed a large API type separator for a problem location in West Seattle, the Longfellow bypass project. The separator is fed directly from the drainage system which originates at the top of a slope. The designer used the 2-year design storm as a parameter, incorporating a bypass for water flows greater than that which would result from this storm size. The API contains three chambers separated by two baffle plates (See Figure 9). Oleophilic booms are used in the middle chamber to absorb separated oil. The lower baffle serves to retain sludge, while the upper serves as a retaining screen for oil and the booms. The floor of the separator is sloped to the points under the manhole covers. This allows sediment to collect under the covers which may ease its removal. The design includes a 5 to 1 length-to-width ratio as recommended by the American Petroleum Institute.

Figure 9. City of Seattle API Separator



Maintenance

Use of the oleophilic booms may not have been appropriate. The booms weigh approximately 200 pounds when saturated with oil, and require two persons for replacement. In addition, the booms must be removed and disposed as hazardous waste. A system without oleophilic booms is being considered for retrofit which would eliminate this problem.

Effectiveness

At the time of this investigation, the system had been operating for 2 months and was already "full of oil", although exact quantity had not been measured. In addition, no performance data had been collected. The engineer who designed the system attributed much of the oil to illicit dumping in the residential areas which the system served. When the design engineer was asked what he may have done differently, he said that since the separator filled with oil and grease more quickly than anticipated, oil and grease monitoring should have been conducted at the site before designing the system. This may have predicted the quantities of oil and grease present which the design could have accommodated. Possible design changes would include the adjustment of the chamber sizes within the separator. Specifically the first stage could be increased in size and the entire separator capacity increased to compensate for oil and grease expectations. A different skimming method than the boom would also be considered, such as an oil skimmer and waste oil tank to remove excess oil and grease.

Vendors, Manufacturers and Distributors

In a study conducted in 1984 by Metro, a broad range of treatment technologies for oil-water separation was investigated as applied in the transit industry (Dull, 1984). As a result, several manufacturers of oil-water separators were researched. Included in Appendix B is an updated list of local and other

manufacturers of these systems.

RECOMMENDATIONS

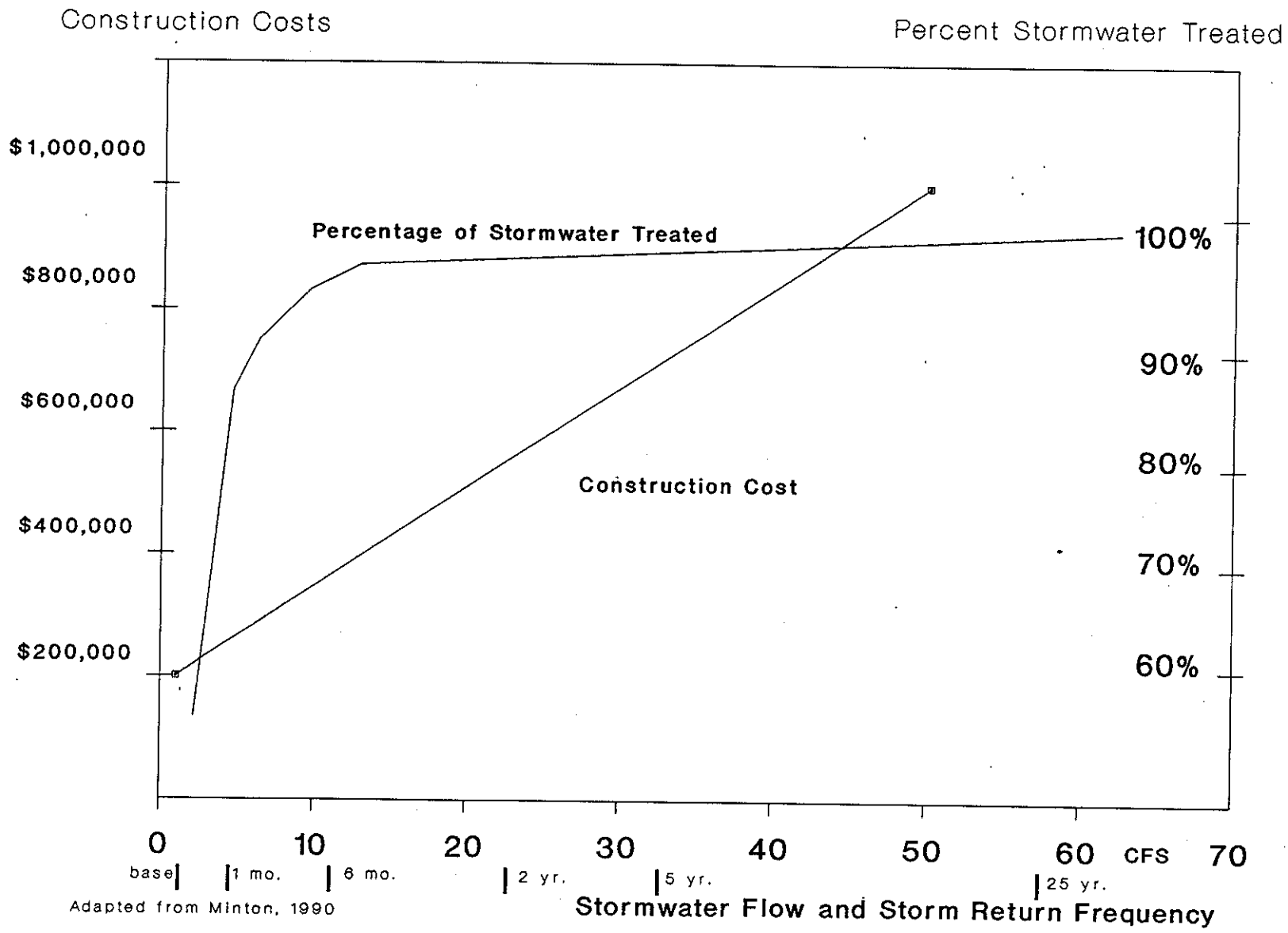
Based upon the foregone discussion, some general guidelines for oil-water separation design, implementation, maintenance, alternative controls and research can be proposed. The recommendations are based upon local experience with existing applications and analysis of current design methods. In addition, although costs associated with smaller storm technology is less, for storms smaller than 6 months (e.g., 1 month) the percentage of treated stormwater diminishes rapidly. Although these recommendations are based upon the best available evidence, their applications are not meant to be incontestable.

1. Design.

The current understanding of stormwater characteristics offers little evidence for definitive design standards, yet does offer basis for general design guidelines. Although empirical investigation is not conclusive, oil droplet distribution and design storm size are influential parameters which affect oil-water separator design.

In previous discussion it was determined that design storm size selection affects the design flow rate. A larger design storm standard translates into a larger flow rate and larger capacity treatment system. A larger capacity treatment system has direct cost ramifications. More specifically, as the percentage of the treated stormwater for a single storm event increases, construction costs also increase. Figure 10 shows construction costs and percentage of stormwater treated for an oil-water separator system in the City of Redmond. Although design and cost parameters vary for different applications, it is included here to illustrate the general affect of design storm size upon costs. Notice that for design-storm sizes greater than the 6-month storm, the *incremental* proportion of treated stormwater in the long term diminishes. **Hence, upon selection of design storm, consideration should be given to the cost-benefit relationship of stormwater treated versus construction costs.**

Figure 10. Separator Construction Costs vs Stormwater Treated



Adapted from Minton, 1990

Earlier it was concluded that stormwater quality treatment should focus upon smaller, frequent storm events. It is recommended that such an analysis be conducted for any substantial stormwater runoff treatment project. **In this case, the 6-month, 24-hour storm would be cost effective as the water quality design storm standard.** This selection is also consistent with Ecology's proposed recommendation per the draft version of the "Stormwater Management Manual for the Puget Sound Basin."

Distribution of oil droplet size and volume in stormwater runoff also affects oil-water separator design. Greater than 85 percent of the oil volume in commercial applications is represented by droplets that are 60 microns or larger. Although this characteristic may not be true of stormwater runoff, use of this value in design practice is a conservative choice, and should result in processing the majority of oil. Guidelines for API separators utilize 150 micron droplet size or larger as design criteria while coalescing plate separators use 60 microns or larger as design criteria. Smaller droplet sizes may be more representative of stormwater. **It is therefore recommended that CPSs be used in places where relatively high oil and grease concentrations are expected: service stations; storm drains serving heavily traveled roads; heavy equipment repair; large, heavily utilized parking lots; and petroleum related industries.**

API and CPS type separators should also be designed with a turn-down elbow inside the first chamber at the inflow pipe and a sample-T at the outflow pipe. The elbow serves to reduce resuspension of floating oils by not disturbing the surface; the sample-T serves to facilitate sampling the effluent and trapping floating oils in the last chamber.

Several alternatives for collection of accumulated oil from the separator vaults are available. **A floating or rope oil skimming device which removes oil from the oil collection chamber of the separator and drains to a waste-oil tank offers a combination of practicality, reasonable cost and effectiveness.** These configurations require little or no maintenance for oil removal, eliminating the concern for hazardous waste disposal and

capacity saturation present with other methods (e.g. oleophilic buoys). The oil which accumulates in the waste-oil tank can be removed and recycled when it becomes filled without degrading system performance between removals. (It is important to note that if the collected oil and grease is not recycled, disposal should comply to proper waste disposal practices.)

The first flush effect also influences separator design. Although it is impractical to design a system to treat the runoff from a large storm, a system designed for a minor storm could easily be overwhelmed by a major storm. Theoretically, a major storm is preceded by a relatively minor storm, which first flushes the pavement and carries the majority of debris and oil and grease into the system. The pollutants collected during the minor storms, especially in spill control, API and CPS oil-water separators, are cleaned out during the first flush. **Therefore, it is good practice, where design parameters allow, to install a flow controlling structure upstream of an oil-water separator which regulates the amount of water getting into the separator.** When a major storm finally arrives, the excessive runoff which would result in flushing out the accumulated pollutants, can be diverted through an overflow rather than into the oil-water separator.

Design consideration must be given to the relative location of both the water table and the outflow from the separator to the receiving water body at the installation site. The level of the water table may be higher than required for installation of an underground system or the system outflow pipe may be situated in a location which could be affected by backflow from the receiving water body.

2. Implementation Strategy

Placement of pollution controls in the appropriate locations is important. It has been presented earlier that the most contaminated or highly utilized land uses (e.g., service stations, heavy equipment repair, large highly utilized parking lots, etc.) are best served by coalescing plate separators, yet

other factors affecting oil separation efficiency must also be considered. **In particular, locations which present the possibility of oil emulsification such as car washes and industries which utilize detergents should be identified. The runoff from these sites should be prevented from entering the storm drains.** This can be accomplished by diverting the runoff from these land uses (and the potentially emulsified oil carried along with it) to the sanitary sewerage system (with appropriate pretreatment and where capacities and permits allow) or by first detaining the mixture in a settling facility resulting in demulsification of the oil-water mixture. Further treatment could then be conducted as needed.

Finally, it would be beneficial to monitor the characteristics of the application site in advance of system design to better define the runoff pollutant concentration profile. Data including oil and grease concentrations, possible other organic or metal pollutant concentrations, flow rates, and pollution concentrations during the first flush would be useful in designing solutions which best address the pollution problem. By collecting additional empirical evidence of runoff characteristics, treatment methods can be adjusted to incorporate these characteristics.

3. Maintenance

Little can be said regarding oil-water separator effectiveness without addressing the issue of maintenance, the removal of accumulated oil and grease and the replacement of damaged or worn-out parts from the separators. **Most water quality specialists in the region believe that maintenance practices highly affect the performance of oil-water separators. Without adequate maintenance practices, oil-water separator systems may be more damaging to the environment than no pollution controls at all.** If the oil accumulates in the separator chamber and is subsequently flushed out, the potential arises for a discharge of more highly concentrated oil, which may be more harmful than the

unprocessed gradual release of lower concentrations of oil into the environment.

Lack of or too infrequent maintenance can lead to damaged separator components and degraded performance. The weight of accumulated oil and sediment on the coalescing plate separator's corrugated plates can cause them to crack, thereby diminishing their separation effectiveness. Sludge accumulation at the bottom of the separator chamber can be washed up into the water mixture and can subsequently be carried out with the flowing water. Clogged inlet and outlet pipes also restrict flow and can result in the reduced capacity of the separator.

Separators must be maintained on a regular basis to be effective. Maintenance is dependent upon loading (with pollutants), capacity of the device and budget committed to the activity. (Remember, routine maintenance requires a large budgetary commitment.) **Therefore, it is recommended that API and CPS separators should be monitored regularly and educted based upon this monitoring to assure compliance with the 10 mg/L state guideline.** It has been Metro's experience for transit industrial application that APIs should be monitored weekly to determine oil and water quantities. However, the practicality of monitoring a large number of devices this often may not be plausible. A simplified "spot check" could serve to fulfill monitoring requirements for determining when maintenance should be conducted. This can be accomplished using oleophilic paste on a dipping stick. Metro has found that for API separators in an industrial application with skimmers, maintenance should be conducted if there is more than 10, 1 or 1/2 inches of oil in the first, center and third compartments respectively. CPS types should be educted when more than 1 inch of oil has collected in the compartment which houses the coalescing plate pack. (See further description under Metro - South Base herein.) Maintenance required for spill control separators is much more frequent and difficult to administer as they must be cleaned out after each spill before the next storm flushes the accumulated oil out.

4. Source Control

The most effective and least costly method of pollution control is to prevent the pollutants from entering the drainage system or environment in the first place. The further downstream from the source that the pollution is treated, the greater the potential for pollution damage and clean-up costs; it is much more inefficient to remove oil from the lakes, streams and marine environment than it is to prevent it from being introduced initially.

One aspect of source control requires tracing of the pollutant back to where it may have originated. **One way to facilitate tracing is by monitoring to identify where unusually high pollutant levels are evident.** This may identify illicit discharges to the storm drains where subsequent corrective action can be taken to eliminate the source of the pollution. This often occurs at commercial or industrial businesses which may have been established prior to implementation of pollution control regulations. Often industries whose activities may contribute to oil and grease stormwater contamination as previously identified (service stations, heavy equipment, etc.) have no adequate pollution treatment facilities in place due to age of the facility. At the time of construction there was no knowledge of the pollution hazard associated with stormwater runoff or jurisdictional requirement. **Therefore, in the cases where age has allowed adequate pollution control to be bypassed, refurbishment programs should be initiated to eliminate these common sources of pollutants.**

Vehicles which leak crankcase oil onto the roadways have been presented as major pollutant sources. **By use of leak prevention technology or through mandatory vehicle inspections, this pollutant source could be reduced.** The latter could be accomplished concurrently with automobile air pollution inspections now conducted in much of the Puget Sound area.

Another widespread source of oil in stormwater runoff is the home automobile "do-it-yourselfer". Although all "do-it-yourselfers" may not be responsible or malicious, those who dump

used motor oil down a storm drain contribute to the pollution problem. This activity may be reduced by implementing public awareness programs. Examples of public awareness programs are the stenciling of storm drains with appropriate warnings (e.g., "Dump no waste, empties to river, stream or lake"), posters, mailings, signs (especially at auto supply outlets where motor oil is sold), radio and television public announcements (they are often free and effective) or any promotional alternative available. This may ultimately raise general public awareness and promote behavioral patterns which are commensurate with pollution abatement goals.

Certain legislation might also be appropriate. Such measures could include a requirement for cash deposits for oil containers which would be refunded upon return of the used oil, much the same as the automobile battery core refund system currently administered. Doing so would provide incentive to return the potential pollutant to the appropriate retail facility for proper handling.

Finally, businesses often do not properly inform or train their employees regarding appropriate waste disposal methods. Good "house-keeping" practices often may be the difference between pollution and pollution control. For example, if employees have not been exposed to good waste disposal practices, they may allow - intentionally or not - pollutants to be dumped into the storm drains. **Businesses should be encouraged to educate their employees regarding pollutant sources and proper waste management practices.**

5. Other Considerations

Applications of stormwater control are site specific and require a comprehensive understanding of all factors affecting pollution control decisions. These include technical issues regarding design of the oil-water treatment system. For example, consideration of backwater effects due to flooding, water table saturation and sediment upstream of the facility may influence system design. **In addition to the technical aspects of design**

methodology, less tangible effects should also be considered, namely the practicality of installation, accessibility for maintenance and the congruence of the design with the surroundings. Installation and maintenance are affected by the space available, contour and composition of the ground and accessibility by construction and maintenance equipment; the design should reflect these considerations. The design should also include protection from vandalism (via locks in the case of gravity oil-water separators) and consideration of potential retrofitting with improved technology. In addition, introduction of a pollution treatment system should coincide with the aesthetics of the surrounding area.

6. Research

Although the above recommendations have been proposed based on analysis of the available scientific evidence, further investigation is needed to refine our understanding of oil-water separator effectiveness. The following "wish list" of applied research is proposed; resulting information could provide more definitive parameters for separator design and application:

- **Effectiveness of SC, API and CPS separators as applied in the Pacific Northwest environment for removal of oil and grease;**
- **Oil and grease droplet distribution as found in stormwater runoff for all land uses, including highway runoff;**
- **Characteristics of oil in stormwater especially as it pertains to the first flush effect and design storm size;**
- **Environmental effects of oil and grease as it is found in stormwater runoff;**
- **The effect of maintenance practices upon oil-water separator performance;**
- **Effectiveness of alternative methods of control such as biofiltration, porous pavement and microbial digestion;**

- Effectiveness of oil-water separator technologies at removing other contaminants found in the stormwater runoff;

- Investigation of new cost effective technologies.

AFTERWORD

It had been the initial intention of this report to provide conclusive evidence of oil-water separator performance for oil and grease removal from stormwater runoff. We have by necessity, however, presented the problem in light of much uncertainty representative of the complex nature of this issue and lack of stormwater-specific oil separation studies. Nevertheless, the investigation has determined that oil-water separator technology, if properly designed, monitored and maintained, can serve to diminish the amount of oil which enters the lakes, rivers, streams, groundwater and sound. There is little conclusive evidence available to support more than very general statements regarding the effectiveness of treatment methods. To ease this uncertainty, applied research is needed to investigate the effectiveness of all readily-available, applicable technologies to local stormwater quality management applications. Such research would serve to assure the use of technology that is worth the expenses incurred, and that is in true compliance with pollution standards. Finally it is hoped that this document has served as a fuel for the desire to gain a deeper understanding of the issue, thereby resulting in refinements to local strategies to address the water pollution problems in the region.

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APPENDICES

APPENDIX

STOKES'' LAW - SIMPLY STATED

As occurs in the API-type separator, oil and grease in a water solution will separate over time. This time is related to Stokes' law which represents the rise velocity of a particle which has a different density than its carrier fluid. For the purpose of this discussion, the particle is an oil droplet and the carrier fluid is stormwater. Stokes' law stated mathematically is :

$$V_r = (G/18n)\ (d_o - d_w)\ D^2$$

where V_r is the rising velocity of the droplet

G is the gravity constant

n is the absolute viscosity of water

d_o is the density of oil

d_w is the density of water

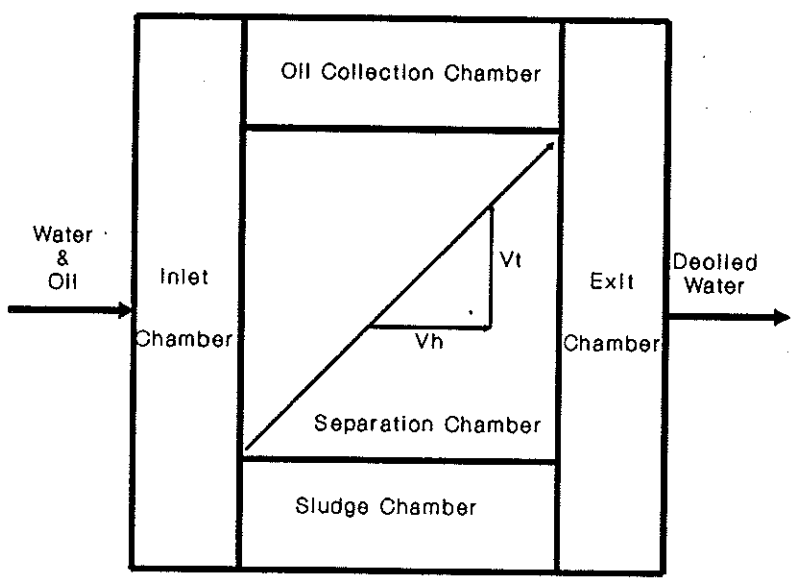
D is the diameter of the oil droplet.

More simply stated, the velocity at which an oil droplet will separate from water is dependent upon the viscosity of the water, the densities of the oil and water, the temperature (which affects water viscosity, and water and oil density), and oil droplet diameter size. It is apparent that the diameter of the droplets is important since the term appears squared in the formula. As a result, the rate of rise of an oil droplet is most dependent upon droplet diameter (Osamor and Ahlert, 1978). As droplet size becomes smaller, residence time and the resultant space requirement for a separation system increases. In conjunction with this phenomenon, American Petroleum Institute research has determined that API type separators are most effective at removing oil droplets with a diameter of 150 microns or greater (API, 1990). Due to these limiting criteria, simple gravity methods should be used to separate free oil whose droplet size characteristics are within this range. In addition, designs

should include residence time, the time an oil droplet remains in the separation zone, to range from 30 to 45 minutes.

Figure A represents graphically the five zones of a simple API type separator. The 45^0 line represents the trajectory of an oil droplet. Any droplet which falls above the line will be collected in the oil collection zone and will not be carried into the exit zone and ultimately into the outflow. It can be shown that the separator width and depth are functions of flow rate, which can be broken into the horizontal (V_h) and vertical (V_t) droplet velocity components as defined by Stokes' law. V_t and V_h are used to calculate separation time, total surface area, cross sectional area and length of the separator. In addition, the residence time that a droplet must remain in the separation zone so that it arrives within the oil removal zone and is separated can be derived by means of Stokes' law.

Figure A. Drop Trajectory
in an API Type Oil/Water Separator



Source: Brenion 1987

APPENDIX B - OIL-WATER SEPARATION TECHNOLOGY MANUFACTURERS AND DISTRIBUTORS.

The following list is not intended to be comprehensive or to express endorsement of any references contained herein. It is supplied as a resource for readers who want to pursue more details from manufacturers or distributors of oil-water separators. Some companies are contacts originally listed in Appendix D of "Survey of Oil-Water Separating System Technologies or Methods and Their Applications in Controlling Pollutants of Concern in Wastewater from Transit Bases" (Dull, 1984). The contact list has been updated where possible, but no attempt has been made to confirm stormwater applications of products.

Local Manufacturers and Dealers

1. B&M Enterprises, Inc.
   10729-3 So. A Street
   Tacoma, Washington 98444
   531-7132 or (800) 562-3255
   Contact: Jerry Hamm

B&M recommends the Hotsy separator for stormwater runoff. The maximum system configuration capacity is 44 gallons per minute which may not be enough for most drainage applications. As the systems contain pumps and require electrical connection, they may not be suitable for most stormwater applications. The manufacturer guarantees effluent oil and grease concentration of 15 ppm with documented proof of 5 ppm.

2. Beaver Equipment Specialty Company, Inc.
   P.O. Box 1921
   Bellevue, Washington 98009
   451-3862 FAX 454-6531
   Contact: Nik Quesnell

Beaver supplies vaults and coalescing plate medium manufactured by B.F. Goodrich Company. The medium is a "plastic fixed film" (PVC compound) which is manufactured with a downward slope of 60° minimum with the horizontal.

3. Landa, Inc
   5013 Pacific Hwy. East, Suite 5
   Fife Washington 98424
   926-0592 or (800) 244-2042
   Contact: Rocky Hall

Landa, based in Portland, Oregon, specializes in a system for water treatment called the "Water Maze". The system is composed of three stages: a coalescing separator, emulsified separator and a treated water storage tank. The system is designed to reclaim

Local Manufacturers and Dealers (continued)

all treated water so that it can be reused. For general runoff application, the CPS stage is recommended. However, the capacity of this stage is only 25 gallons per minute, which may not be enough for most drainage applications.

4. McTighe Industries, Inc.
   Local Distributor: Pratto Sales Inc.
   309 So. Cloverdale B-17
   Seattle, Washington 98108
   322-1903 FAX 763-2293

McTighe manufactures above ground and below ground self-contained Oil-Water separators. The capacity of the ready made systems ranges from 40 to 4500 gpm. Larger capacity systems can be custom made upon request. The systems typically are divided into two chambers, the first for sediment containment and the second containing coalescing plate medium and a skimmer device. An optional "Petro-Pak" can be added to improve separation performance. Independent test data for the CPS with Petro-Pak which is provided by McTighe indicate effluent oil and grease levels of 4 ppm or less. Without the Petro-Pak, data provided by McTighe indicate effluent concentration levels were measured between 4 and 12 ppm. The Petro-Pak must be periodically removed and cleaned, especially "after heavy rainstorms", which may be an undesirable maintenance issue for storm drain application.

5. Pacific International Pipe & Engineering, Inc. (PIPE, Inc.)
   P.O.Box 9156
   Tacoma, Washington 98409
   475-8888 FAX 474-7631
   Contact: Larry Johnson

PIPE manufactures vaults for API and CPS type separators with capacities ranging from 8 to 2300 gallons per minute. CPS systems utilize a Purification International, Inc. inclined (60° to the horizontal) coalescing plate pack.

6. Utility Vault Company
   P.O.Box 588
   Auburn, Washington 98071
   839-3500 FAX 735-4201
   Contact: Gary Venn

Utility Vault manufactures vaults for API and CPS type separators with capacities ranging to 500 gallons per minute which meet their 15 ppm effluent concentration standard. The coalescing plate medium is manufactured by Facet Quantek (formerly FRAM) and is oriented horizontally.

APPENDIX B (continued) - Oil-Water Separation Technology Manufacturers and Distributors.

Other Manufacturers and Local Representatives

7. Fram Industrial Filter Corporation
   Currently called: Facet Quantek, Inc.
   P.O.Box 50096
   Tulsa, Oklahoma 74150
   (800) 888-9129 FAX (918) 836-7383

   Local Representative:
   Northwest Power Technical Sales Associates
   2366 Eastlake E., Suite 234
   Seattle, Washington 98102
   324-6880 FAX 324-8331
   Contact: John Leonard

8. Monarch Separators, Inc.
   6827 Signat
   Houston, Texas 77041
   (713) 466-1974 FAX (713) 466-3014
   Contact: James Shoppe

9. Oil Skimmers, Inc.
   12800 York Road
   Cleveland, Ohio 44133
   (216) 237-4600
   Contact: Kenneth Gray

   Local representative:
   Zee Enterprises
   P.O.Box 142
   Indianola, Washington 98342
   297-3630
   Contact: Bob Zarilla

10. WEMCO
    P.O.Box 15619
    Sacramento, California 95852
    (916) 929-9363
    Contact: Greg White

    Local Representative:
    WEMCO
    400-1501 W. Broadway
    Vancouver, British Columbia V6J4Z6
    (604) 736-3806 FAX (604) 766-7837
    Contact: Michael Lane

WEMCO manufactures coalescing plate separators and recommends them for stormwater applications. (WEMCO has purchased Pacesetter Separator Company.)

APPENDIX B (continued) - Oil-Water Separation Technology Manufacturers and Distributors.

Other Manufacturers and Local Representatives (continued)

11. Donaldson Company
    1400 West 94th Street
    Bloomington, Minnesota 55431
    (612) 887-3131

    Local representative:
    Air Flow Systems, Inc.
    6265 South 143rd Place
    Tukwilla, Washington
    431-0670

12. Enquip, Inc.
    3319 North Lewis
    Tulsa, Oklahoma 74110
    (918) 599-8111
    Contact: Michael Ross

Enquip manufactures CPS media that are either corrugated or flat, both of which are oriented 45° with the horizontal. The company claims that the flat medium offers less likelihood of sediment accumulation.

13. C-E Natco
    Combustion Engineering, Inc
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