PROBLEMS WITH URBAN STORMWATER - CONTRIBUTIONS OF CONTAMINANTS TO THE ENVIRONMENT

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ABSTRACT

The intent of this paper is to provide a review of contaminants, noted in urban stormwater, which can enter streams and lakes, some of their toxic effects, and management practices. Particular emphasis is placed on hydrocarbons and heavy metal contaminants. A discussion is provided with information on the type and concentration of contaminants that may be expected. Though the paper is intended to be primarily technical in nature, references will are made to regulatory issues, as well as to current and possible management practices.

BACKGROUND AND INTRODUCTION

Each year, large quantities of sediments and other contaminants enter surface waters due to rainwater runoff and snowmelt. Bennett, et al, (I 981) notes that "contributions of organic pollutants and suspended matter from stormwater are significant and are quite important for highly developed areas. Stormwaters produce instantaneous shock loadings on a stream and result in short-term very high pollutant concentrations."

In the United States, much of the water that falls during rainstorms goes directly to surface bodies of water by dedicated storm sewers. Some rain flows directly into the surface water by streams and culverts, and some of the water enters the surface water by Combined Sewer Overflows (CSOs).

Oil and grease, heavy metals, and other contaminants found in rain water and snowmelt can be very toxic to aquatic life and detract from the pleasurable use of streams, lakes, and bays. Many communities, especially the largest ones, utilize surface water for drinking water supplies and contaminants can be very difficult to remove to drinking water standards.

The purpose of this paper is to discuss the quantity and form of these contaminants (basically those capable of removal by physical means) found in stormwater runoff and snowmelt, as well as to discuss the available means of treating the water to remove them.

It is recognized that floating trash, dissolved materials (pesticides, nutrients, and benzene) are also contaminants, and Coliform bacteria from Combined Sewer Overflows (CSOS) and leaking septic systems can be public health problems, but these subjects have been extensively discussed elsewhere. It is also recognized that contaminants from stormwater and snowmelt may contribute to contamination of ground water, but this is a large subject in itself. For these reasons, the scope of this paper has been limited to discussions of sediments, metals, and hydrocarbons in stormwater and snowmelt.

REGULATORY AND LEGAL CONSIDERATIONS

Until recently, stormwater discharges were not regulated in part because these discharges are basically non-point in nature, and in part because industrial and POTW discharges produced large and readily defined and regulated flows. As regulation of point sources has progressed, regulators have increasingly turned to regulating non-point sources, such as stormwater discharges. This effort began in 1987, where amendments to the Clean Water Act (CWA) prohibited non-stormwater discharges to storm sewers and dry weather discharges from industrial sites without an NPDES permit (Buchholz, 1994). Subsequent regulations have required municipalities to apply for stormwater discharge permits and to implement some Best Management Practices (BMPs) to obtain these permits.

Regulations range from very detailed ones, such as the Puget Sound Stormwater Management Manual (which is over 1,000 pages), to very simple ones. The City of Tulsa, Oklahoma, Stormwater permit, for example, requires street sweeping periodically, some sampling, and a program to reduce illicit connections to storm sewers.

The St. John's River Water Management District (SJRWMD) in Florida, which comprises of fourteen counties in an environmentally sensitive coastal area, requires that new stormwater systems shall "be designed to achieve at least 80% reduction of the average annual load of pollutants that would cause or contribute to violations of state (Florida) water quality standards." Also, that an erosion and sediment control plan must be provided as part of the permit application (SRJWMD, 1994).

Other countries, as well as state and local governments, have differing regulations that are based on local requirements and sentiments. Some of these requirements along with typical concentrations of contaminants are provided below.

TOXIC EFFECTS OF CONTAMINANTS

Various contaminants have been shown to have adverse effects on human beings as well as on aquatic life. Concentration levels as low as 10 to 100 micrograms per liter have been shown to adversely affect aquatic organisms by altering processes, such as feeding or reproduction (Romano, 1990). Table 1 below shows some possible adverse effects and recommended criteria.

TABLE I
TOXIC EFFECTS OF STORMWATER CONTAMINANTS

Contaminant	Effect on Humans	Recommended Criteria	
		Drinking Water	Aquatic Life
Lead	Nephritis	50 μg/liter	0.01 LC_{50}
Zinc	Metallic taste	5 mg/liter	0.01 LC_{50}
Copper	Liver damage	1 μg/liter	0.01 LC_{50}

Table adapted from Krenkel and Novotny, 1980

Five categories or groups of impurities that are hazardous to aquatic life include (Fair, et all, 1971):

1. Matters that settle and deprive fish of food by depositing a polluted carpet on the bottom of streams and lakes
2. Substances that exert sufficient oxygen demand to lower the dissolved oxygen (DO) content below the level needed

3. Compounds that raise pH above 8.4 or lower it below about 6.8, more or less, may be directly lethal. Changes in pH may reduce tolerances of fish to high temperatures and low DO levels
4. Wastes that increase salinity and with it, osmotic pressures, such as oil-well brines
5. Specifically toxic substances such as pesticides

CONTAMINANTS IN STORMWATER

Contaminant loadings from urban stormwater may be related to land use and the following major causative factors (Krenkel and Novotny, 1980):

1. Percent impervious area directly connected to a channel
2. Population density
3. Dry and wet atmospheric fallout
4. Litter accumulation
5. Traffic density
6. Curb height and density
7. Percent open area
8. Average wind velocity
9. Street cleaning practices and effectiveness
10. Average number of dry days preceding a rain
11. Depression and interception storage

As data on contaminant levels was accumulated, regulations were written to take into account, not only the public health aspects of stormwater contamination, but also adverse effects on the environment. The result was that regulations have become more stringent. Table 2 below provides some data on typical contaminant concentrations in stormwater and the matching regulations. Please note that the metallic contaminants in the water are found mostly in the particulate matter carried by the water.

TABLE 2
COMPARISON OF TYPICAL STORMWATER POLLUTANT CONCENTRATIONS TO WATER QUALITY CRITERIA CONCENTRATIONS

Concentrations, µg/l or ppb					Particulate Fraction	USEPA/Washington Dept of Ecology Standards, Freshwater	
Pollutant	Commercial	Industrial	Residential	Highway		Acute	Chronic
Cadmium	5	5	<3	<3	60%	0.60	0.32
Copper	245	105	20	100	60%	3.9	3.0
Lead	380	245	210	1780	90%	10.5	0.41
Zinc	275	275	120	400	60%	30.0	27.0
Oil/Grease	15 ppm	480(5)	<5(5)	90(5)		10 ppm	
Fecal Coliforms	980 orgs /100 ml					50 orgs /100 ml	

Notes: 1) Particulate fraction values apply to concentration date for commercial and industrial uses only
2) Acute Criteria for freshwater at a hardness of 20 ppm
3) Standards are receiving eater standards except oil and grease
4) Oil and grease and coliform standards Washington State Department of Ecology
5) Source: City of Seattle Engineering Dept. (Paston, 1994)

Source: Stormwater Management Manual for Puget Sound Basin, 1992

Types of Contaminants found in Urban Stormwater

Contaminants most often mentioned in urban stormwater are sediment, hydrocarbons, and heavy metals. Contaminants found in rural stormwater would more likely be nutrients and pesticides, although sediments would also be present. Because hydrocarbons and heavy metals are often found in the sediments of urban stormwater, it is difficult to separate discussions of these contaminants, but the following is an attempt to discuss them as separate issues.

Sediments:

Muddy water, roiled by suspended clay and other sediments, is both troublesome to fish and obnoxious to people, especially people who do not live in areas, where, according to Mark Twain, every tumbler of river water holds an acre of land.

Buchholz (1 994) notes that in many stormwater monitoring programs, "sediments were the most critical and frequently observed pollutant in stormwater flows." The State of Washington Department of Ecology notes that "sediment from erosion was the primary stormwater quality problem" (Washington Stormwater Management Manual for Puget Sound, 1992). Livingston, (I 989) notes that "excessive sediment blocks stormwater conveyance systems, plugs culverts, fills navigable channels, impairs fish spawning, clogs the gills of fish and invertebrates, and suppresses aquatic life."

In a study done in Philadelphia, PA, Hunter, et al, (1979) reported suspended solids content from 26 to 118 mg/L, with an average of 87 mg/L. It is likely that in many areas, sediment contents are even greater.

Snowfall is not as important a source of solids because suspended solids loading for snowfall precipitation are approximately one half those for rainfall (Bennett, et al, 1981).

Since researchers have found that hydrocarbons tend to partition to the solids in a stormwater stream, and many of the particles are automotive exhaust particles (Eaganhouse, 1981), removal of sediments should also tend to help reduce the hydrocarbon content of the stormwater. Conversely, failure to remove the particles from the stormwater should allow some of the hydrocarbons to pass through a separator. Sediments also contain heavy metals, and may contain pesticides.

Heavy Metal Contaminants:

Heavy metals that are of concern include Copper, Lead, and Zinc. Heavy metal concentrations seem to be related to pH and hardness of the stormwater (EPA, NURP, 1983).

A recent report by the EPA (EPA, 1992), on the San Francisco Estuary Project, indicated that most pollutants in the estuary were due to agricultural and forest management activities, but that urban runoff was the most significant contributor for lead and hydrocarbons. Buchholz (1994) agrees that lead in stormwater is most significantly contributed by urban environments. A private study made of samples of street gutter sediment collected at sites in the city of Coral Gables, Florida, showed copper contents of 40-350 mg/kg, lead contents of 60-500 mg/kg, and zinc contents of 500-1600 mg/kg (Gamble, 1994). This indicates that street sediment may be a significant contributor of metals.

Heavy metals are much less toxic to fish in hard water than they are in soft water. This is mostly because of complex formation between heavy metals and carbonate and bicarbonate ions, although complexing with organic agents such as humic and fulvic acids also occurs. As an example, below pH 6.5, copper in water can exist as free copper ion. At higher values, it will tend to complex as $CuCo_3$. Because the hardness of the water affects the carbonate available to complex, copper in water is more toxic to fish in softer water than in harder water (Snoeyink and Jenkins, 1980). In addition, Krenkel and Novotny (1980) note that hardness decreases the toxicity of heavy metals.

Hydrocarbons:

Most of us have seen an oil slick "rainbow" on the water runoff in a parking lot during a rainstorm. Buchholz (1994) notes that urban runoff (as opposed to agricultural or other non-point sources) is the most significant contributor to the environment of hydrocarbons. In addition to runoff from parking lots, rainwater runoff from service stations, highways and bridges, and industrial sites contributes to the hydrocarbon content of the rainwater.

A private, unpublished, study by Mohr Separations Research, Inc. (McDowell, 1995), concerning separation of used motor oil from water, indicated that some hydrocarbons were attached to the solid particles in the oil. Microscopic evaluation indicated that these particles were mostly iron oxide and carbon, evidently from engine wear and carbonization of the oil, although some of the particles were probably solids removed from the combustion air. This study partially confirms data from Hoffman, et al (1982), which indicates that hydrocarbons in stormwater are primarily associated with particulate material. The McDowell data leads to the conclusion that there is a limit to the amount of oil that may be attached to the solids present in water, and that additional hydrocarbons (the greater percentage in some stormwater) exist as free droplets.

The hydrocarbons discussed in the Hoffman study were in low ppm concentrations, and those in the McDowell study were above 100 ppm (inlet), so the data tends to confirm the above conclusion.

Hunter, et al., (1979) report "The storm-sewer loading from an area representing 0.83% of the total Philadelphia urban area represented three quarters of one of the seven refineries in the same area. Their calculated hydrocarbon pollutant loading for the study area was 22.9 lb/year/acre. This data would tend to support the assertion made above that stormwater is a very important source of hydrocarbons in the environment. It is also recognized that hydrocarbons exist in snowmelt runoff, but not to as great of an extent as those that are found in rainwater (Bennett, et al, 1981).

Nutrients and Pesticides:

Nutrients in stormwater have not been discussed much in this paper because the contribution of nutrients, nitrogen, and phosphorous are relatively small for (urban) stormwater flows (Bennett, et al., 1981). Pesticides, while of some importance in urban stormwater, are much more important in agricultural and forest management stormwater.

BEST MANAGEMENT PRACTICES

The following are some non-structural and structural Best Management Practices (BMPs) that may be effective with these contaminants.

Non-Structural BMPS

Non-structural BMPs include any BMP that does not require building or repairing any structural item. The City of Tulsa Stormwater Permit (EPA, 1994) requires:

1. Street sweeping of arterial streets eight times per year and of residential streets four times per year
2. The city must support a program to collect and recycle batteries, used motor oil, automotive oil filters, and antifreeze
3. A program to locate and eliminate illicit discharges and improper disposal into the stormwater sewer system
4. An "Industrial and High Risk Runoff Monitoring Program" for landfills and industrial facilities

The most effective and least costly method of pollution control is to prevent the pollutants from entering the environment in the first place. Other non-structural means of preventing contamination, such as recycling days and municipal acceptance of household hazardous waste, have been shown to remove the possibility of contamination by removing possible contaminants. Many cities use extensive environmental education programs which seem to have had effect on reducing certain types of pollution, notably lifter. Environmental education is probably the most effective means of reducing excess pesticides in urban stormwater.

Livingston (1989) suggests that in most cases, "a combination of limited grading, limited time of exposure, and a judicious selection of erosion control practices and sediment trapping systems will prove to be the most practical method of controlling erosion and the associated production and transport of sediment."

Structural BMPs

Some structural BMPs used to reduce contaminants and reduce peak flows are:

Detention Basins	Recharge Basins	Wetlands
Grassy Swales	Oil-water Separators	

Detention Basins:

Detention basins are particularly useful where large quantities of stormwater can cause flooding or overload the storm sewer systems. This condition may occur in any low-lying coastal area where there is not sufficient slope in the storm sewer systems to allow for quick evacuation of stormwater. A typical detention basin is shown below in Figure 1.

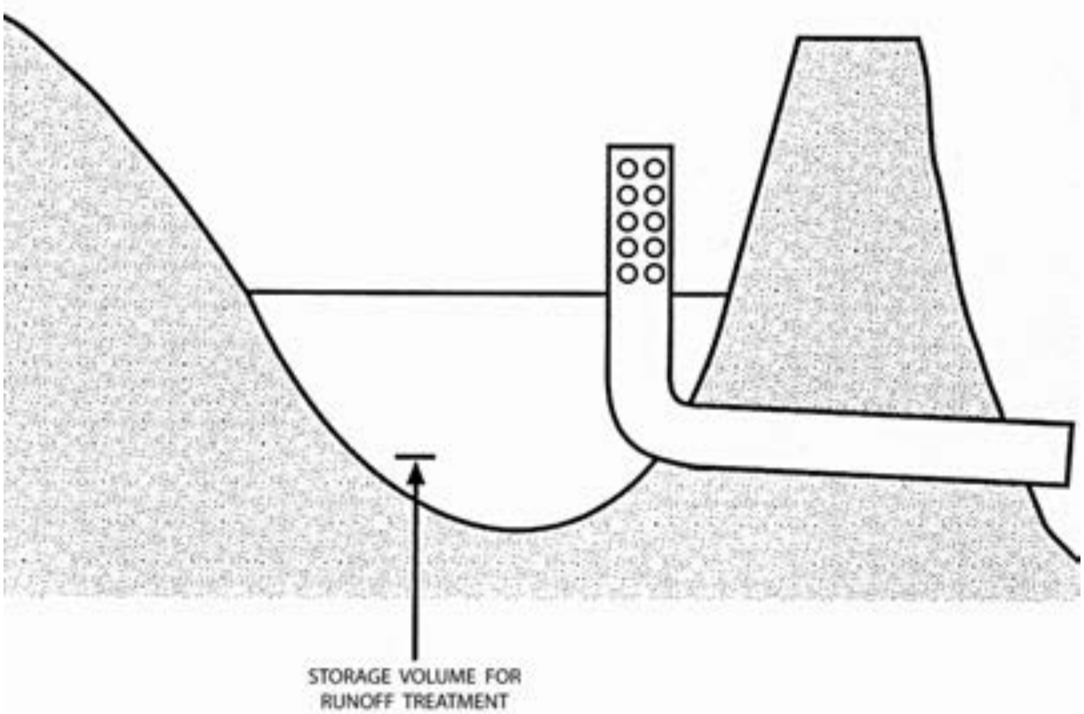

FIGURE 1
DETENTION BASIN

Detention basins, grassy swales, recharge basins, and wetlands appear to reduce flow, solids, nutrients, and metals (EPA, NURP, 1983). The SJRWMD manual requires at least first flush off-line detention of the first 1 inch of runoff or 2.5 inches from the impervious area, whichever is greater.

Recharge Basins:

Recharge basins are similar to detention basins, but instead of simply delaying the runoff of the stormwater, they are designed to minimize the impact of stormwater by allowing as much as possible to migrate into the groundwater, thereby recharging the aquifers. Such designs have advantages and disadvantages. Among the advantages are the simplicity of design and the desirability of recharging the aquifers. Among the disadvantages is the possibility of contaminating the aquifer with pollutants from the stormwater. Considerations such as these can become quite important in localities such as San Antonio. In Texas for example, most of the city drinking water comes from the Edwards aquifer under the city. A typical recharge basin is shown below in Figure 2.

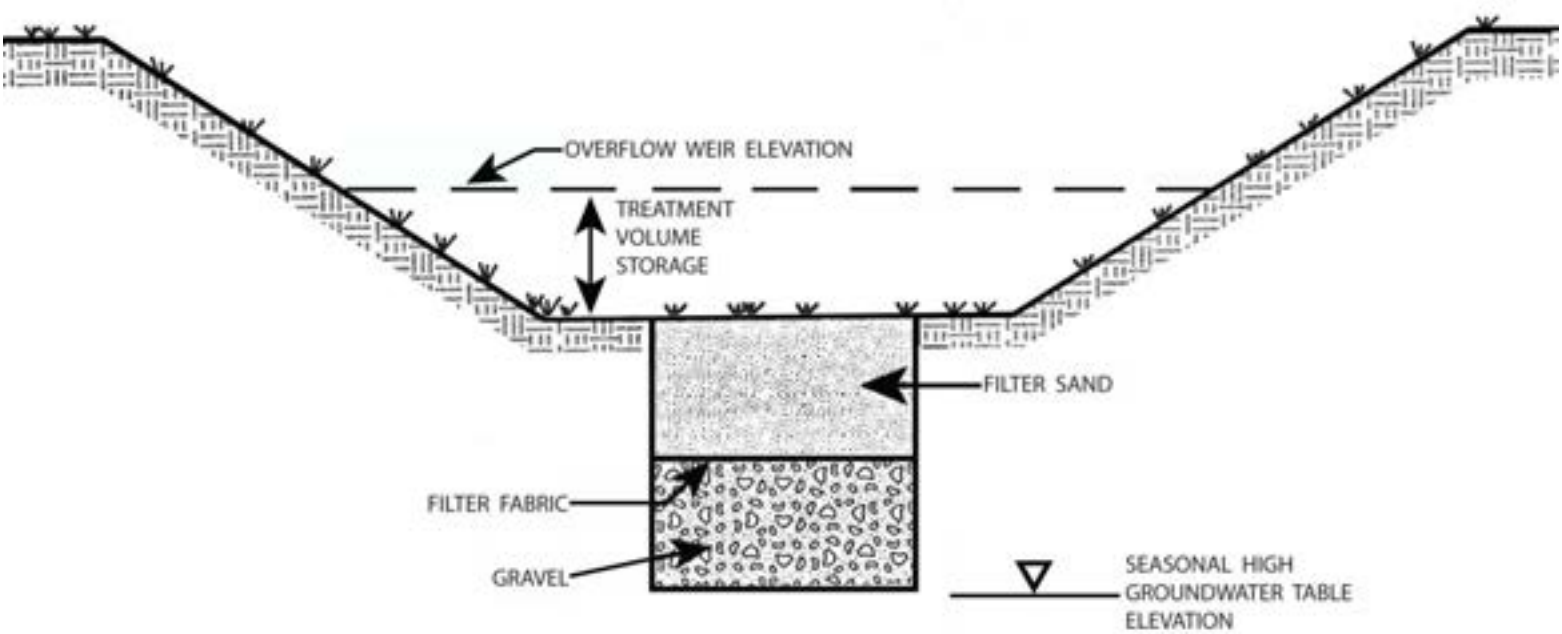

FIGURE 2
RECHARGE BASIN

Retention systems provide excellent removal of stormwater pollutants. Substantial amounts of suspended solids, oxygen demanding materials, heavy metals, bacteria, some varieties of pesticides and nutrients, such as phosphorous, are removed as runoff percolates through the vegetation and soil profile. These systems should not be installed within a 100 feet from any public supply well according to Florida law (SJRWMD, 1994). One disadvantage of such systems is that care must be taken to ensure that the bottoms of retention basins are pervious and flow is not blocked by the deposit of fine materials.

Grassy Swales:

A swale (usually a grassy swale) is a man-made trench (wider than it is deep), that is normally dry, and is planted with stabilized vegetation. Design of a swale must take into account the soil erodibility, percolation, slope, slope length, and drainage area, so as to prevent erosion and reduce pollutant concentrations. A typical grassy swale is shown below in Figure 3.

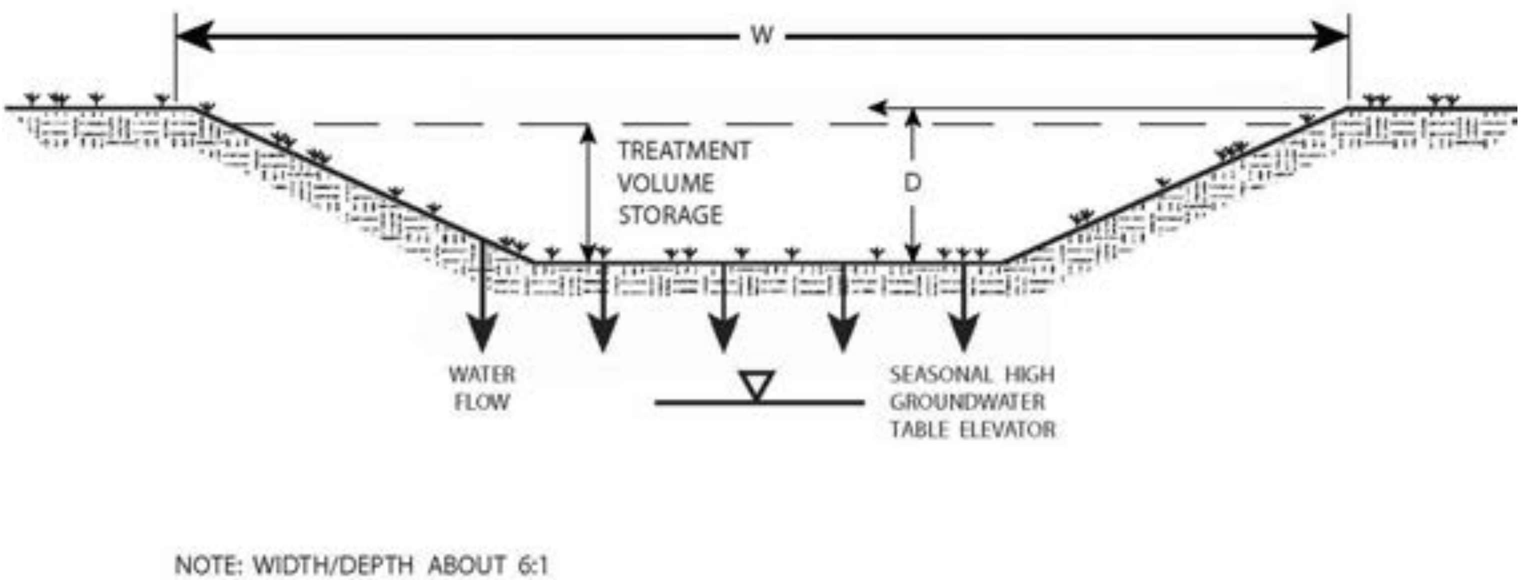

FIGURE 3
GRASSY SWALE SYSTEM

Swales are designed to remove contaminants, and have been shown to have the effect of doing so. It should be noted that swales remove toxic metals, but these are not removed from the environment, only deposited in the bottom of the swale where they mix with the soil. This increases the volume of contaminated material.

Wetlands:

Much discussion about wetlands has been made as a removal system for contaminants, and the results are promising. The disadvantage of wetlands as a disposal medium is the very large amount of wetland required. In many situations, this may not be so economical.

Oil-Water Separators:

Corrugated Plate Separators should be used in places where relatively high oil and grease concentrations are expected. These include service stations, freeway storm drains, heavy equipment repair, large heavily utilized parking lots, and petroleum related industries (Romano, 1990). One important advantage of such separators is that sediments, hydrocarbons and heavy metals are removed in concentrated form, either as separated oil or as sludge. This also means that metallic contaminants may be removed completely from the environment instead of becoming part of the soil matrix in a grassy swale, or perhaps, even entering the groundwater through a recharge basin. A typical oil-water separator is shown below in Figure 4.

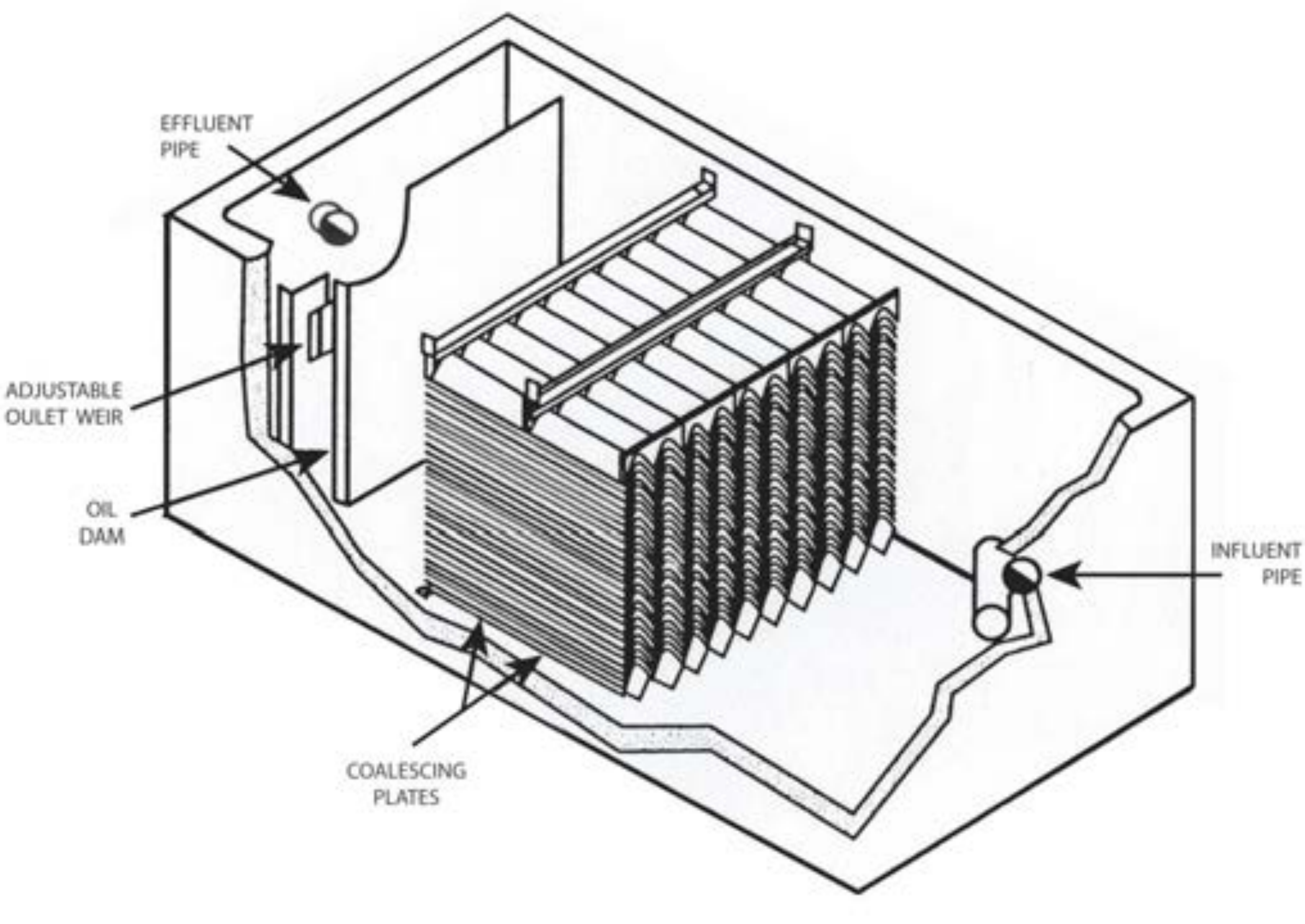

FIGURE 4
TYPICAL VAULT

Other BMPs:

Other BMPs, such as stormwater catch basin filters and centrifugal separators for removal of grit, are under testing in various parts of the country. It is likely that the economics and not the effectiveness of any of these BMPs will determine the system viability.

Maintenance:

For any structural and most non-structural BMPs, maintenance is permanently required, and provisions must be made to ensure that the maintenance is carried out. The SJRWMD requires that a permanent maintenance program be filed with any building permit application. Romano (1990) observes that "most water quality specialists in the (Puget Sound) region believe that maintenance practices highly affect the performance of oil-water separators. Without adequate maintenance practices, oil-water separators may be more damaging to the environment than no pollution controls at all."

SUMMARY AND CONCLUSIONS

Stormwater is not simply pure rainwater, and urban stormwater contains significant impurities in the form of sediments, heavy metals, and hydrocarbons. These toxic compounds can harm aquatic life, destroy the aesthetic and recreational values of receiving waters, as well as pose a human health hazard. It is possible through both structural and non-structural BMPs to remove or reduce contaminants entering both surface and ground waters. Some of these BMPs are very inexpensive, while others can be very costly. The use of different BMPs is likely to be determined by local conditions, particularly the economic and aesthetic costs involved, if contaminants are not controlled. Grassy swales and other systems have value for removing sediments. Oil-water separators have uses in recovering hydrocarbons and oil from stormwater. The EPA found that “the impacts of stormwater discharges varied widely and were mostly affected by upstream pollution sources and the assimilation capacity of specific receiving waters" (EPA, 1983). Note: Italics added by author. This further argues for the following conclusions:

1. Stormwater best management practices should be locally determined
2. In areas where the receiving waters are especially sensitive such as Puget Sound and other coastal waters, greater efforts must be made to remove contaminants

Maintenance of any BMP is essential to ensure that it will operate as designed and not release any captured contaminant into the environment.

The current decade is certainly not one flush with Federal monies to solve the stormwater problem in the same way that the POTW discharges were improved, so more innovative and less expensive means will be required.

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