STORMWATER TREATMENT FOR CONTAMINANT REMOVAL

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A paper presented at the 1995 *International Symposium on Public Works and the Human Environment*, Seattle Washington, 1995

Abstract:

Included in the paper are discussions of contaminants expected to be present in stormwater runoff, the expected concentrations of these contaminants, estimation methods for determining the amount of runoff water to be processed, and methods used to treat the water for contaminant removal. Information is presented on both US domestic and international treatment methods. Emphasis is placed on hydrocarbons in the stormwater and removal of these hydrocarbons to acceptable levels. A discussion is also provided concerning legal considerations in treating stormwater.

Keywords: Stormwater, runoff, contaminants, oil and grease, and treatment.

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BACKGROUND AND INTRODUCTION

Most of us have seen a small oil slick "rainbow" on the water runoff in a parking lot during a rainstorm. This constitutes a small but measurable amount of oil, and when multiplied by the hundreds of parking lots in a city can be a large amount of oil. Estimates indicate that as much as 1,200 tons per year of oil and grease enter the San Francisco Bay estuary every year, and other bodies of water receive as much or more. Eganhouse and Kaplan (1981) estimate that input of petroleum residues to the ocean via surface runoff are on the order of 1.9 million metric tons per year. The small oil slicks add up to a major worldwide problem.

In addition to runoff from parking lots, rainwater runoff from service stations, highways and bridges, and industrial sites contribute to the hydrocarbon content of the rainwater. 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) which include both stormwater and sewage.

Oil and grease and other contaminants found in rain water 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 f-or 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 type of oily contaminants found in storm water runoff and the available means of treating the water to remove them.

LEGAL CONSIDERATIONS

Congress has found it necessary over the years to regulate contaminants entering the "waters of the United States" under the powers provided in the Constitution. Much of this regulation is intended to control the water outfalls from industry and Publicly Owned Treatment Works (sewage treatment plants), especially under the Clean Water Act. The Clean Water Act was passed over a veto from then President Nixon, who denounced the expected $24 billion cost as "extreme and needless." Since 1972, Americans have spent more than $541 billion on water contaminant control, mostly for municipal and industrial controls (Knopman and Smith, 1993).

Having regulated the "point sources" by NPDES permits, Congress eventually turned its attention to "non-point sources" such as the roadways, parking lots, and industrial outdoor storage facilities that also contribute to pollution.

In accordance with Congress' instructions, in November, 1990, the EPA promulgated an expansion of the existing NPDES permit program to include certain stormwater discharges. The initial deadline for filing permits under this new program was November, 1991, and was extended to May, 1992 and eventually to October 1, 1992 for all industrial permits.

The new regulations specifically state that all industrial outdoor storage areas, either for finished goods or raw material must have stormwater treatment facilities. Included in this meaning are not only traditional manufacturing facilities such as auto and steel plants, but also auto salvage yards. Also included are construction sites. As an example, the California State Water Resource Control Board Construction Activity Permit (1992) requirements include a Stormwater Pollution Prevention Plan. Among the objectives of this plan are "To identify, construct, and implement storm water pollution prevention measures (control practices) to reduce pollutants in storm water discharges from the construction site both during construction and after construction is completed."

State and local governments have also begun regulating stormwater discharges, so it is difficult to make generalizations about legal requirements. Additional information on regulations was summarized by Chieu and Foster (1993). It is suggeted that each customer check with their state and local authorities to ensure compliance with the laws and regulations in force.

OIL AND GREASE IN THE STORMWATER

What is the composition of the "oil and grease" to be found in stormwater?

MacKenzie and Hunter (1979) studied stormwater in the- Philadelphia, PA, area and determined by chromatographic analysis that most of the hydrocarbons present are very similar to weathered used automotive crankcase oil. The stormwater samples analyzed in this study showed less diaromatics than used crankcase oil, so a weathering study was conducted to determine if weathering could cause the. loss of these compounds. The conclusions from the weathering study indicate that the missing compounds are lost in this manner. This may indicate that the specific gravity of the remaining hydrocarbons could be expected to be greater than that of the original lubricating oil.

What are the sources of "oil and grease" in stormwater?

Most of the hydrocarbons in stormwater from roadways and parking lots is lubricating oil that has leaked from trucks and automobiles. Some small amount of hydrocarbons are deposited from unburned fuel, especially diesel fuel, but these often evaporate before being washed away with stormwater. Additional amounts are intentionally dumped into storm drains by amateur mechanics and (to some extent) by professional mechanics. In King County, Washington, it is reported that citizen "do-it- yourself" mechanics use more than one million gallons of lubricating oil yearly and only about 15% of this is recycled (Romano, 1990). A similar study performed in Michigan found a great number of auto repair shops with illegal connections to storm sewers.

How much “oil and grease" may be expected in stormwater?

MacKenzie and Hunter (1979) found total petroleum hydrocarbon concentrations ranging from 3.7 mg/l to 5.06 mg/l. in samples from three different storm events.

Eaganhouse and Kaplan (1981) found concentrations of hydrocarbons in stormwater up to 19.5 mg/l, but noted that the sampling was done in a major storm that followed a long dry period in Los Angeles, CA.

Bennett, et al., (1981) found a flow weighted average of 42 mg/l oil and grease in stormwater and 69 mg/l in snowmelt water from a high population-density area in Boulder, CO, with lower averages in a low population density area. They concluded that the concentration in snowmelt was higher because of the "washing" effect on the undersides of vehicles by accumulated snow and slush. They also noted that the "nature of the particulates in snowmelt runoff is more colloidal, which results in lower pollutant removal for plain settling processes." It is possible that the colloidal nature of the solids in snowmelt is a result of the particles that the snow crystals formed on in the atmosphere. The snow crystals would then carry these extremely small particles to the ground where they would remain discrete and reappear when the snow melts.

To ensure that oil-water separators in stormwater service are adequately sized, It is recommended that designers use of 400 ppm inlet concentration of oil for sizing purposes. This exceeds information from the analyses of runoff water we have found, and should provide conservative sizing to account for possible variations in land use, weather, and inadvertent spills of oil.

STORMWATER QUANTITIES

How much stormwater do we have to treat?

To calculate the amount of water flow in storm sewers, civil engineers have used the "Rational Formula" for relating the peak flow rate in a sewer to the rain intensity. (Imhoff, et al., 1978) The "Rational Formula" is known in the United Kingdom as the Lloyd-Davies formula.

This formula is: Qp = CIA (liters/min or cubic feet per second)

Where Qp = Peak flow
C = Runoff coefficient
I = Average rainfall intensity
A = Area, contributing drainage area (square meters or acres)

Tables are provided in Imhoff, et al., and other sources of the Runoff coefficients to be used for different surface types. The Runoff coefficient can also be considered as an impermeability factor, and the Intensity is measured during a specific time interval called the time of concentration (mm/min or in/hour). Table I below is typical of such tables.

TABLE I
RUNOFF COEFFICIENTS RELATED TO TYPE OF SURFACE

Surface Type	C, *Runoff Coefficient*
Pavement	
Asphalt and Concrete	0.70 - 0.95
Brick	0.70 - 0.85
Roofs	0.75 - 0.95
Lawns - Relatively impermeable	
Flat (2% slope)	0.13 - 0.17
Average (2%-7% slope)	0.18 - 0.22
Steep (>7% slope)	0.25 - 0.35
Lawns - Sandy Soil	
Flat (2% slope)	0.05 - 0.10
Average (2%-7% slope)	0.10 - 0.15
Steep (>7% slope)	0.15 - 0.20

Table adapted from Imhoff, et al.

Rainfall intensity and duration information for the United States is published by the National Weather Service (NWS).

For small, well defined areas, this formula gives a satisfactory estimate of stormwater flows, but for larger areas and areas with complicated storm sewer configurations, a computer model of rainfall and flow configurations is recommended. One such mode is the Storm Water Management Model, written by two professors at the University of Florida and published by the-EPA. The ASCE and others offer workshops in the use of this model. A graphical method of designing stormwater systems is provided by Elton in "Designing Stormwater Handling Systems" (1980). Additional discussion of flow rates of stormwater is beyond the scope of this paper, and the reader is referred to Imhoff, et al., and other literature for additional readings.

EFFLUENT QUALITY

Effluent restrictions for industrial users are set by their National Pollutant Discharge Elimination System (NPDES) permit. This permit is issued by either the Environmental Protection Agency (EPA) or the state equivalent of the EPA. Industries that discharge through a publicly owned treatment works (POTW) are not required to have an NPDES permit as the POTW is the point of discharge into the surface waters and the POTW has a permit. The permit will clearly state the amount of pollutant allowed to be discharged into either surface waters or waterways that empty into surface waters. If the plant discharge is into a sanitary sewer system, the effluent requirement is usually set by agreement with the sewer system management. Effluent discharge limits will often be shown giving a maximum concentration in any given spot "grab" sample as well as an average concentration over a given period of time such as a month. Generally, the longer the averaging time, the easier it will be to meet the limitations.

Many jurisdictions require effluent qualities of 10 ppm or less, most require 15 ppm or less. An oil content of about 15 ppm will often cause a noticeable sheen on water. The IMO (International Maritime Organization) requires shipboard bilgewater separators to have effluents of less than 15 ppm. King County (Seattle) Washington requires discharges to be less than 10 ppm (Romano, 1990). only a few facilities will be able to emit an effluent of more than 15 ppm, and then only if the water is to be treated again in a sewer plant or other facility. Sometimes no discharge of hydrocarbon is allowed at all. In at least one plant in Canada, the effluent water is being treated to drinking water standards (basically no oil) before being routed to the inlet of a sanitary sewer plant. This plant utilizes a multiple-angle coalescing plate oil-water separator followed by activated carbon adsorption units. This processing scheme seems to be overkill, but the laws and regulations must be complied with. It is likely that future environmental regulations will be even more restrictive than current laws.

It is also necessary to sample effluents to ensure compliance with the law and as part of setting NPDES effluent limits. One important point, made by Kobylinski, et al., is that "Improper sampling and analysis techniques will produce poor data. Poor data will usually result in more strict permit limits." Sampling can be very complicated and time consuming and is beyond the scope of this paper. It is suggested that the reader consult the excellent article by Atere-Roberts and Koon for additional sampling information.

STRATEGIES FOR TREATING STORMWATER

It is possible, by the methods discussed above, to estimate the amount of stormwater that will result from a specific intensity storm, as well as what the peak flow from this storm may be expected to be. Three questions then arise:

1. Is it necessary to treat all of the stormwater that falls?
2. If it is not necessary to treat all of the water, what criteria should be used to determine how much water to treat?
3. How should the water to be treated be segregated from the water that is not to be treated?

The safest philosophy, from an environmental and regulatory point of view, is to treat all of the water that falls, thus ensuring the maximum reduction in contaminants entering the environment. This philosophy, however, leads either to very large oil-water separators to process the large flow rates or to holding ponds to accumulate peak flows for processing at lower flow rates over a longer time period.

Both large separators and holding ponds are expensive, so many engineers have attempted to find ways to process only a portion of the expected peak flows so as to minimize capital costs. Storms are characterized by frequency; that is, the most intense storm that could be expected to occur within five years is referred to as a "five year storm", and the most intense storm that could be expected to occur within a one hundred year period is referred to as a "hundred year storm". Smaller and less intense storms are more common than larger and more intense storms. A hundred year storm is therefore much more intense than the five year storm. The storm intensity for a given interval will vary with location. A hundred year storm for Seattle might be very different in nature than, for instance, Los Angeles. Information on these storm intensities is available from the NWS.

A study done by Romano (1990) balanced the amount of oil present against the amount of rainfall expected, and recommended that oil-water separators for stormwater processing be designed for the amount of water flow that might be expected due to a six months storm. Because the smaller storms are much more common, most of the total rainwater that falls is contained in these smaller storms. The reasoning behind the choice of a six months storm is therefore that most of the total quantity of rain will be processed, and because of the first flush effect, an even higher percent of the total amount of oil in the stormwater will be captured.

There has been some dissention within the scientific community about whether or not the "first flush" effect exists. The first flush is that amount of oil in the carried by the first small amounts of water into the stormwater system. Some scientists have not detected this effect, but the majority of studies seem to indicate that it is real and affects the operation of storm sewer systems. The first flush seems to depend a great deal on the surface of the area rained on as well as the intensity of the rain. If the area is very porous such as asphalt, it may take longer for the oil to float out of the pores and join the water stream than if the area is smooth concrete where the oil is taken up more quickly. It is also possible that after the first flush the remaining oil is slowly removed from the surface by the action of the passing water. In summary, the first flush seems to be a real effect, but not very quantifiable. The conservative approach to coping with this problem is to assume that the oil content of the water is fairly high and design a separator to handle it.

Segregating the water to be processed

Several methods of segregating the flows to allow for treatment of only part of the water have been used. These methods basically provide for bypassing of some of the water around the separator. Flows from roofs, lawns, and other areas that would not normally be expected to contain hydrocarbons can be directed to the stormwater sewers without passing through a separator. Even for areas that can be expected to have some hydrocarbons, bypassing can be used in some cases.

Figure I shows one method of providing this bypassing. It includes an integral bypass built into the vault so that if the flow is too large for the normal flow pattern to handle, the surplus water will flow over the overflow weir and exit the separator without disturbing the normal flow. This type of design would process a fixed flow rate of water, and bypass the balance. This design was common several years ago (the figure is patterned after one provided in a 1979 catalog).

Figure 2 shows a similar design, but with the bypassing arrangements in the external piping instead of internal to the separator. This system is preferred over the internal bypass system (if bypassing is to be used) because the amount of water to be bypassed in not always well defined, and it is better to design the separator for a specific flow rate and let all of the additional stormwater go through the bypass.

Figure 3 is a design based on the philosophy used by Australian regulators (Noonan, 1993). In Australia, the philosophy used to determine how much rainfall is to be processed is based on the "first flush" effect. The first flush is defined as the amount of water equivalent to ten L/m' of area drained unless other information (from local weather data) is available. The first flush water is captured to be treated or removed and all subsequent rainfall is directed to the storm sewers. This first flush treatment requirement pertains mostly to areas surrounded by dikes, such as oil storage tank farms as well as tank truck loading areas. Ordinary vehicle parking lots are not required to have treatment facilities, except for a "minor gross pollutant trap."

In Germany, design of oil-water separators is governed by the DIN Standard 1999, issued by the *Deutsches Institut für Normung* in Berlin. This standard covers rain water as well as waste water processing. It provides methods for simple calculations of separator size required as well as requirements for separator installation features. Among the requirements are that sludge traps must be provided upstream of interceptors (separators) and that automatic devices to prevent intercepted light liquids from exiting the separators must be provided.

METHODS OF HYDROCARBON REMOVAL

Hydrocarbons may be present in the water in one of four forms:

a) Droplets of oil.
b) Physically emulsified oil
c) Chemically emulsified oil.
d) Dissolved hydrocarbons.

The first two of these may be treated physically, either by use of coalescing plates or coalescing cartridges, while the third and fourth must be treated by activated carbon or other chemical means. Stormwater would not normally contain emulsified oil, so the balance of this discussion will involve removal of droplets of oil. Please note that some of the most troublesome compounds, notably Benzene, are at least partially soluble.

Removal of the oil and grease from the water may be done by various means, of differing effectiveness. The simplest method of removing oil from water consists of simply providing adequate disengaging time for the oil droplets in the water to separate by gravity from the water. In many cases, this may prove to be a very large amount of time. The standard API (American Petroleum Institute) separator as used in refineries for many years is designed for about 45 minutes storage time. An API separator will remove droplets down to about 150 microns in size. If used for stormwater separators, the resulting large volume can mean providing a very large and costly tank. The design of a standard API separator is shown in Figure 4.

Some separators for stormwater service are empty tanks, operating on the same principles as -API separators, but underground. Many of these do not have the residence time needed to separate incoming oil adequately. A typical empty tank separator is shown in Figure 5.

Because of the size and expense of gravity separators such as is typified by the API separators, methods were devised to reduce the size and cost of the separation devices by the use of gravity enhancing internals. For a discussion of many of these types of separators, please refer to Mohr (1992).

The latest and one of the best of enhanced gravity separators is the multiple-angle separator. The multiple-angle separator system works by enhancing the gravity coalescing of oil so that removal may be accomplished in a much smaller (and therefore less expensive) vessel than a pure gravity separator. A typical multiple-angle separator is shown in Figure 6.

To best understand how the system works, a short discussion of hydrocarbons and hydrocarbon coalescing may be useful:

USE OF MULTIPLE-ANGLE SEPARATORS TO REMOVE THE OIL FROM STORMWATER

One solution to the problem of efficiently removing the oil from stormwater is the use of multiple-angle coalescing plate modules. These coalescing packs include specially designed coalescing plates with provisions for capture of oil and solids from the water as well as for easy removal of the captured oil and solids from the plates. The following is a list of some of the reasons to utilize this system:

1. Oleophilic plates allow oil to adhere weakly, by molecular level Van der Waals attraction forces, not merely capturing oil by the rise of the oil, so in multiple angle packs made from oleophilic materials, the entire surface of the plates provides coalescing action.
2. The plates are provided in relatively narrow spacing, so as to provide the maximum amount of coalescing area without being so close as to plug easily with solids.
3. Removal of the oil from the water depends not only on the coalescing action of the-plates, but on the efficiency of removal of oil from the plates after capture. Please consider a section of the coalescing pack with-oily water flowing between the plates. Droplets of oil rise to the bottom of the next plate above, or impact or are attracted to the top surface of the plates. Because the plates are oleophilic, these droplets "wet out" on the surface and spread to some extent. As additional droplets impact on the surface, they coalesce into larger droplets and eventually form a film of oil on the plates. This completes the capture portion of the oil removal.

It is necessary, having captured the oil on the plates, to remove it from the plates in an orderly manner that does not re-entrain the oil into the water stream. The design of the multiple-angle separators is such that the coalesced droplets only have to travel 4-1/2" (maximum) before they encounter an oil port. These oil ports are vertically aligned so that when the droplets release from the plates they can rise directly to the surface. Because the plates are sloped in all directions, there is always a vertical driving force to cause the droplets to rise.

The droplets release from the plates when they become large enough that the buoyancy due to their size overcomes the attractive forces holding the droplet onto the plate.

There is always, of course, a tendency for the movement of the water horizontally through the plate packs to "tear off" the droplets from the plates. The forces holding the droplets and/or film onto the plates are due to molecular attraction and are proportional to the area of contact between the oil and the plate. The force trying to "tear off" the droplets is the frictional force due to the movement of the water. This frictional force is proportional to the surface area of the droplets and the flow velocity of the water.

In a conventional style pack, with plates that extend from one side of the separator all the way to the opposite side of the separator, any and all captured oil must progress along the entire length of the plate before exiting to the surface at the opposite side of the separator. In a large separator, this could be eight (8) feet or more. This means that the amount of oil running along the underside of the plates increases as it moves upward along the sloped under surface of the plates. This gives the flowing water additional opportunities to remove the oil from the plates and carry it downstream, especially if enough oil is captured to partially fill the space between the plates, thus locally increasing the velocity of the water. Even if the oil does not restrict the flow, larger droplets have more tendency to be removed from the plates. Droplets released into the flow from the front portion of the packs would probably be captured by the subsequent plates, but droplets released in this manner by the downstream end of the packs could exit the separator with the water.

The capture of droplets of oil by the plates is relatively predictable, but the release of captured oil from the plates has not been quantified, and because it depends on so many variables may be very difficult to quantify.

In any case, it is better to design systems that quickly release the oil from the plates in an orderly and systematic manner to allow the oil to float to the surface of the separator instead of forcing it to flow additional distances along the plates before it is released. The sooner the oil gets safely to the surface, the more sure it is to be separated permanently from the water.

In addition to the process advantages provided by this system, the packs are compact, sturdy, and easy to install. They can be cleaned in place if the solids loading is so great that their built-in solids removal capacity is not adequate, or maintenance is not as regularly done as would be advisable.

OTHER CONSIDERATIONS IN TREATING THE STORMWATER

In addition to hydrocarbons from runoff, stormwater may contain heavy metals, settleable solids, floatable trash, and in the case of CSOS, coliforms and other bacteria (Smith, 1993). These can have significant impact on the quality of the receiving waters and should be monitored as is possible. Control of bacteria should ideally be done at the source. Bar racks and basket strainers have been used for control of floatables in stormwater such as plastic cups and drinking straws with mixed success. The experience noted by Smith (1993) was that the strainers removed the floatables, but that sufficient quantity of floatables were encountered to plug the strainers and cause storm sewers to 'back-up" and flood basements and cause other flooding problems. For this reason, they are no longer used in New York City.

Coalescing plate separators, especially multiple-angle separators, are effective devices for the removal of solids and have been proposed as control devices to remove ' particulate heavy metals from stormwater streams. Stahre and Urbonas (1992) note that "pollutants appear to have a strong affinity to suspended solids and the removal of TSS will very often remove many of the other pollutants found in urban stormwater." Laboratory testing was very successful at removal of conventional solids such as soil and sand. Coalescing plate separators will not, however, remove any dissolved metals or other dissolved solids.

SUMMARY AND CONCLUSIONS

Oil and grease in stormwater continue to be a problem of global proportions. Many different methods can be used to attack the problem, once it is adequately defined, but no single practice has yet been settled on as the best by international authorities.

One solution that seems to work very well is to use the intensity of the six month storm for flow rate calculations, and process the resulting water with multiple angle separators installed in underground vaults. An auxiliary sludge-catching manhole or vault should be installed upstream of the oil-water separator. This solution provides the following advantages:

1) Process the optimum amount of water to ensure oil removal while minimizing the size and expense of the separators.
2) Provide predictable effluent qualities to ensure compliance with laws and regulations.
3) Provide easy removal access to the bulk of the solid particle accumulation due to the stormwater flow because these solid particles will settle out in the upstream manhole.
4) Allow for easy removal of any solids that make their way into the separator because the multiple angle plates are virtually self-cleaning and have solid accumulation storage space under the plates with access for removing the solids without removing the plate packs.
5) Plate packs small enough to be handled manually if necessary but designed to be cleanable in place. This means that the normal cleaning mode for this type plate pack would be to clean in place, but if it becomes so badly fouled that removal is necessary, this removal is relatively easy

While many solutions to the stormwater puzzle are available, multiple-angle coalescing modules offer a most predictable and economic solution for oil removal.

REFERENCES CITED:

Atere-Roberts, S., and Koon, J., "Meeting self-monitoring requirements for stormwater discharges from industrial facilities", *Industrial Wastewater*, April, 1993.

Bennett, E.R., Linstedt, K.D., Nilsgard, V., Battaglia, G.M., and Pontius, F. W., "Urban Snowmelt - Characteristics and Treatment", *Journal WPCF*, January, 1981.

Chieu, J., and Foster, S., "Improve Storm Water Management for Refineries", Hydrocarbon Processing, December, 1993/January 1994.

DIN Standard 1999, "Petrol Interceptors and Fuel Oil Interceptors", *Deutsches Institut für Normung*, Berlin, Germany, 1989.

Bevis, A., "Treatment of Oily Water by Coalescing", *Filtration & Separation*, Volume 29, No. 4, July/August, 1992.

Eaganhouse, Robert P., and Kaplan, Isaac R., "Extractable Organic Matter in Urban Stormwater Runoff - Transport Dynamics and Mass Emission Rates", *Environmental Science & Technology*, March, 1981.

Elton, R., "Designing Stormwater Handling Systems", *Chemical Engineering*, June 2, 1980.

Imhoff, K., Olthof, M., and Krenkel, P., Karl Imhoff's Handbook of Urban Drainage and Wastewater Disposal, V. Novotny Ed., John Wiley & Sons, New York, 1989.

Knopman, D., and Smith, R., "20 years of the Clean Water Act", *Environment*, January/February, 1993.

Kobylinski, E., Hunter, G., and Quinlan, E., "Implementing the New Water Quality Standards - Fitting the Puzzle Together", *Environmental Progress*, August, 1993.

MacKenzie, Moira J., and Hunter, Joseph V., "Sources and Fates of Aromatic Compounds in Urban Stormwater Runoff", *Environmental Science & Technology*, February, 1979.

Mohr, K., "A New Type of High Efficiency Oil-Water Separator for Better Water Quality Management", Proceedings, Pacific Northwest Pollution Control

Association Annual Meeting, Boise, Idaho, 1992.

Noonan, G., Private correspondence with Mr. R. Baldwin concerning Australian EPA Rgulations on Stormwater Processing, 1993.

Romano, F., "Oil and Water Don't Mix: The Application of Oil-water Separation Technologies in Stormwater Quality Management", Office of Water Quality, Municipality of Metropolitan Seattle, WA., 1990.

Smith, R., "Stormwater and Combined Sewer Overflow Management and Control", ASCE Seminar, Kansas City, Mo., 1993.

Stayre, P., and Urbonas, B., Stormwater Detention, Prentice Hall, Englewood Cliffs, NJ, 1990.

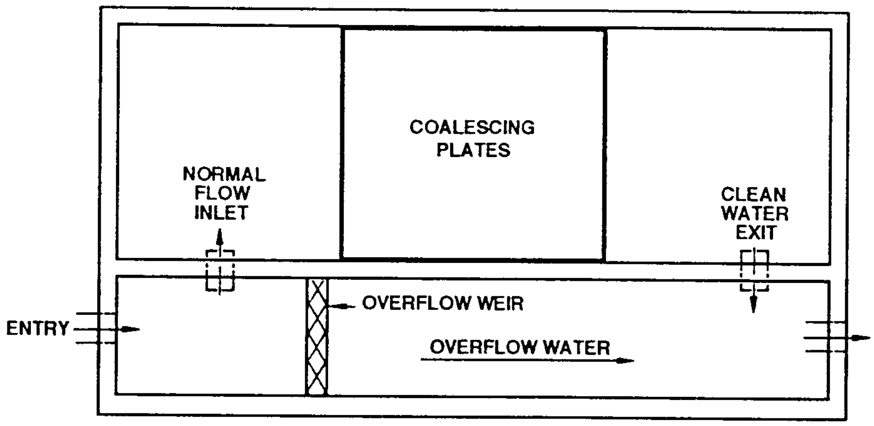

FIGURE 1

OIL-WATER SEPARATOR
WITH INTERNAL BYPASS

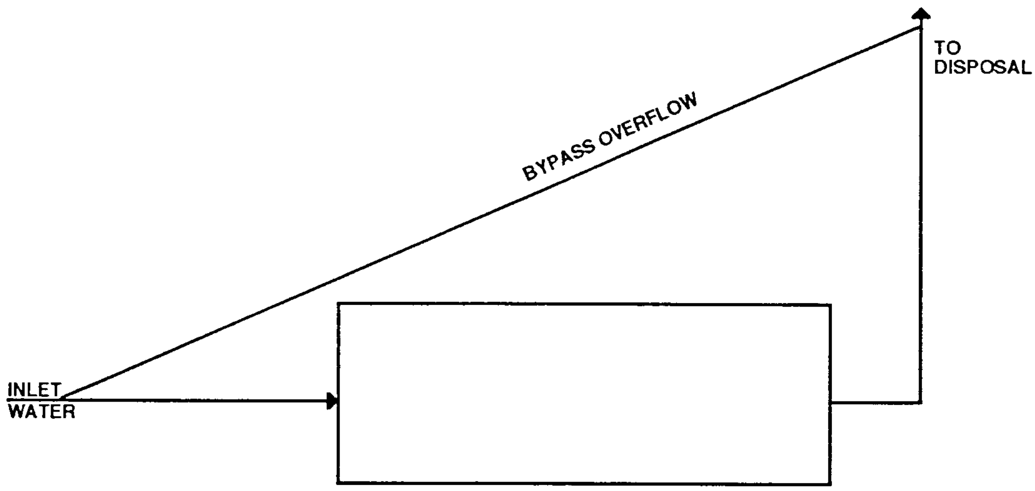

FIGURE 2

SEPARATOR WITH EXTERNAL BYPASS

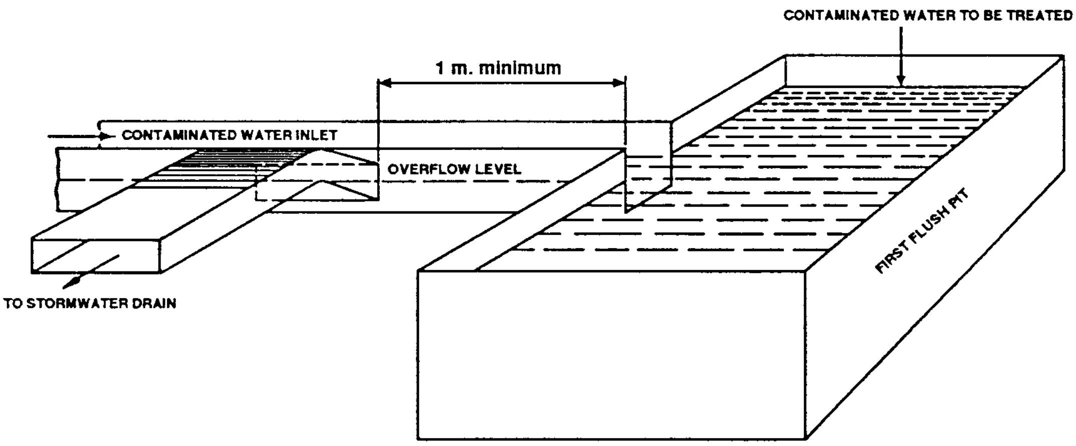

FIGURE 3

FIRST FLUSH COLLECTION PIT

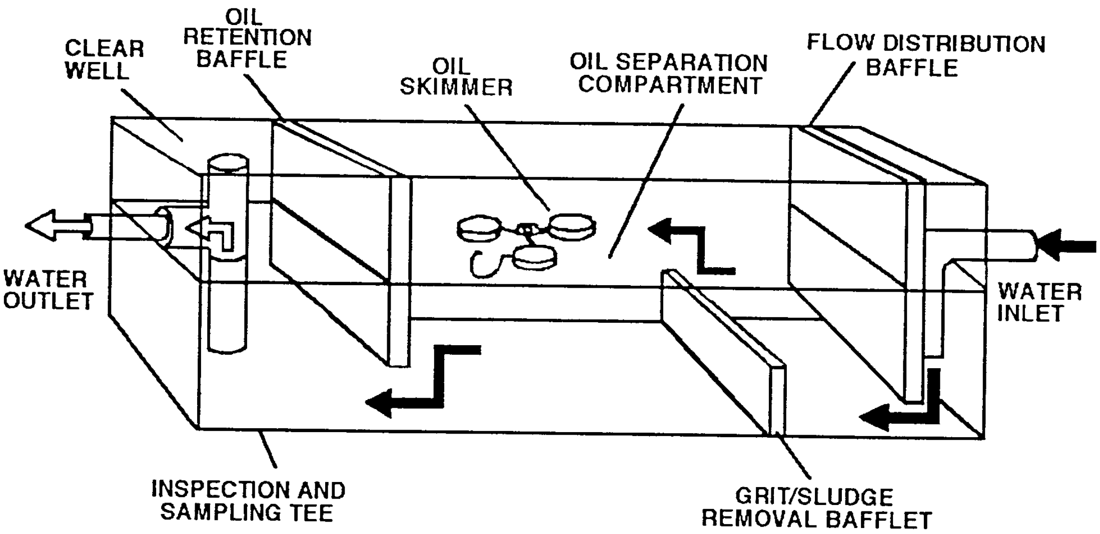

FIGURE 4

API SEPARATOR

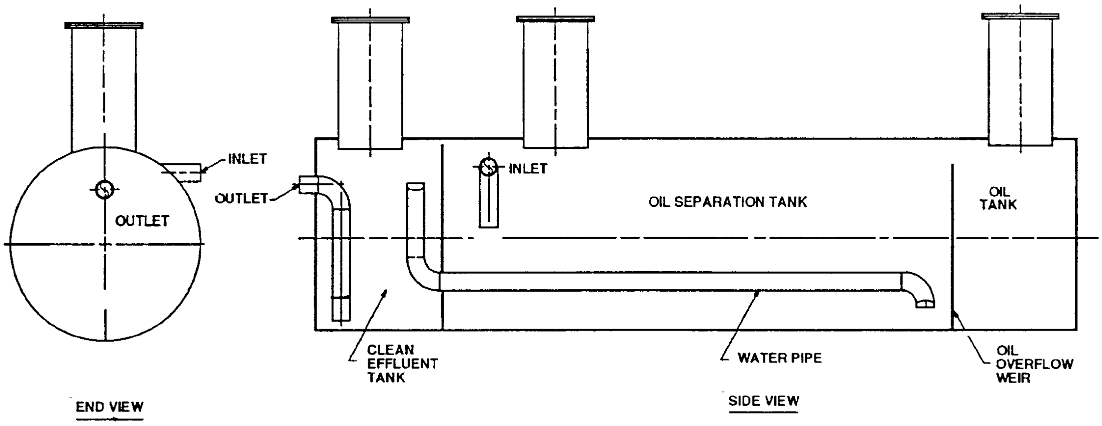

FIGURE 5

EMPTY TANK STORMWATER SEPARATOR (WITH OIL TANK)

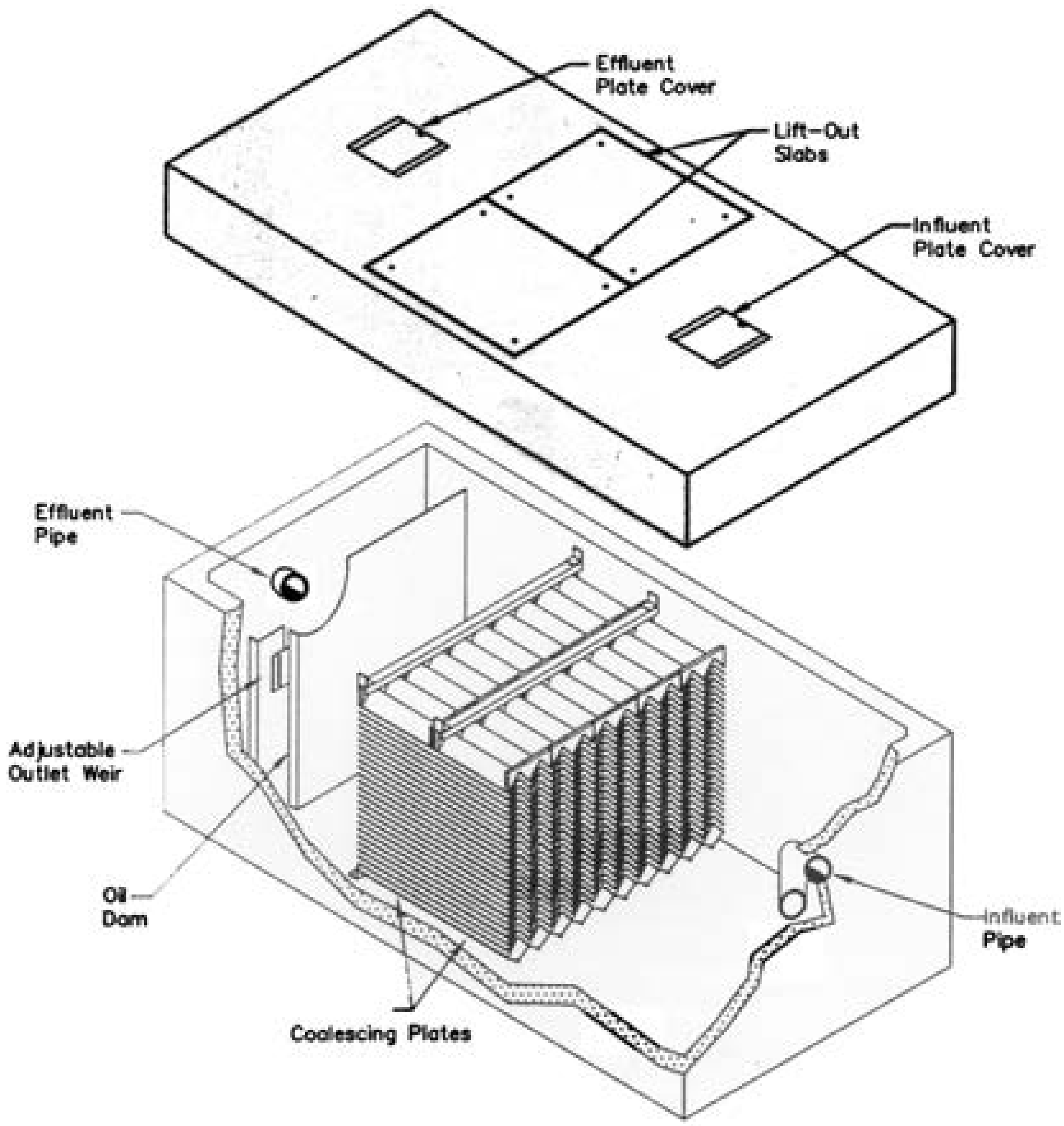

FIGURE 6

TYPICAL VAULT INSTALLATION