# Proposed Best Management Practice to Prevent Stormwater Pollution Utilizing Coalescing Plate Separators for Oil Removal

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## Proposed Best Management Practice to Prevent Stormwater Pollution Utilizing Coalescing Plate Separators for Oil Removal

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***Background***

### Purpose

This guidance document provides information on a Best Management Practice (BMP) that can be used to remove oil and grease (and incidentally sediments) to comply with provincial and federal stormwater requirements for stormwater discharges. The BMP applies to facilities with roadways, bridges, vehicle fueling areas, and/or parking lots or other similar facilities subject to heavy outdoor vehicular traffic or storage where stormwater flow discharges to sensitive water bodies.

Users of this document will include engineers, designers, owners and/or operators of facilities covered under the state stormwater permit. Facilities that do not have a stormwater discharge to surface water, either directly or by storm sewer may use this document as guidance to prevent contamination of ground water.

### 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. It is estimated [1] that input of petroleum residues to the ocean via surface runoff is on the order of 1.9 million metric tons per year.

Oil and grease and other contaminants found in stormwater can be very toxic to aquatic life and detract from the pleasurable use of streams, lakes, and bays [2]. 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 [3]. Undesirable effects of hydrocarbons in water include taste and odor contamination in addition to toxicity. Petroleum hydrocarbons in concentrations as low as 0.5 mg/L can impart a perceptible unpleasant taste [4] whereas concentrations as low as 10 to 100 $\mu$g/L can adversely affect aquatic organisms [5].

### Organization of this Guidance Document

This guidance document has a text and an appendix section. The text contains background information on the necessity for and recommended BMPs for contaminant removal. The appendix contains a reference list, brief glossary, simplified method for calculating stormwater flows, and typical drawing for BMP specification.

### Baseline General Requirements

The requirement for discharge according to the Fisheries Act (Section 36.1a)[6] is that “no deleterious substance” shall be discharged into any water where fishing is carried on and these waters are further defined in Section 40.5b as all waters that cannot be proven to be *never* frequented by fish (paraphrase). This requirement is often interpreted as meaning that oil and grease discharges must be limited to 10 mg/l or less. Even if this stringent requirement is not adopted locally, no oil sheen would be permitted. It is generally considered that a sheen will be present if 15 mg/L or oil or more are present [7]. In addition to a stormwater discharge permit, it is also necessary to obtain any appropriate local building permit that may be required.

**Potential Pollutant Sources**

Most of the pollutants in stormwater from roadways and parking lots consist of lubricating oil that has leaked from trucks and automobiles. Some small amount of hydrocarbons are deposited from unburned fuel, especially diesel fuel, and the more volatile components often evaporate before being washed away with stormwater [8]. Stormwater runoff from fueling areas can also contain hydrocarbons, both fuel and lubricating oils from small spills. Additional amounts may be intentionally dumped into storm drains by amateur mechanics.

Some pollutants might be expected from runoff from contaminated soils, but it is expected that any runoff from contaminated soils would be treated separately for contaminant removal. It is not expected that significant pollutants will be found in roof runoff.

Wastewater discharges other than stormwater such as domestic wastewater, water from vehicle and parts washing must be recycled or conveyed to the sanitary sewer system (under an appropriate pretreatment permit).

**Potential Pollutants**

Among the possible pollutants in stormwater from parking lots and roadways are the following:

*Oil and grease* – This is a measure of waste oil pollutants.

*Biological oxygen demand (BOD)* – pollutants soluble in water than can biochemically reduce the oxygen content of the water.

*Suspended solids* – particulate solids in the water such as sediments, clay and sand.

*Chemical oxygen demand (COD*) - pollutants soluble in water than can chemically reduce the oxygen content of the water.

*Heavy metals* – Lead from gasoline, Copper, Zinc and Cadmium have been found in stormwater [9]. The main metals of concern are Copper, Lead, and Zinc[10].

*pH* – low pH could be caused by acid from automotive batteries or acid rain.

**Best Management Practices – General**

BMPs include both structural equipment and operating procedures. This guidance document emphasizes the use of source controls and exposure minimization, but also provides an effective method of removing oil and grease from stormwater.

**Selection of Best Management Practices:**

The general sequence to be followed in selecting BMPs is as follows:

1) Identify sources of pollutants and existing BMPs
2) Select operational, source control, and structural BMPs based on pollutants expected to be present in the stormwater and effluent quality required.
3) Refer to the *Strategies for treating stormwater* in the Appendix for a suggested method for making determinations of flow rates and information below for design methods.

**Significant Amount of Oil and Grease**

A significant amount of a pollutant is any amount that it is possible to treat (or to prevent entering the environment), or that has the potential to cause a violation of ground water or clean water quality standards. This amount of "oil and grease" is usually taken to mean 15 mg/L or more [7] as measured by an Environment Canada approved analytical method. As noted above, the Fisheries Act is often taken to mean 10 mg/L or less.

If a recurring or ongoing sheen is observed in the discharge or receiving waters, then the following approach is required to avoid possible violation of the Fisheries Act.

1) Investigate to determine source of pollutants – remove source if possible.
2) Conduct sampling to determine the extent of the non-compliance
3) Investigate additional BMPs to prevent sheen.
4) Provide additional BMPs as necessary.

**Required and Recommended BMPs**

The BMPs listed in this guidance document are recommended for use in general stormwater systems. The permittee has the option of using other BMPs if these can be shown to be better than those included in this guidance.

Treatment BMPs are required if the stormwater discharge contains or will contain a significant amount of pollutants (more than allowed by regulations).

***Operational BMPs***

Operational BMPs apply to all activities where stormwater from roadways, parking lots, or vehicle outdoor storage is processed to remove contaminants. Operational BMPs are required in addition to any structural BMPs provided.

**Pollution Prevention Team**

Each facility or organization operating stormwater processing BMPs must appoint a Pollution Prevention Team. The following Pollution Prevention Team activities are required:

1) One or more individuals must identified who are to be responsible for developing and implementing the Storm Water Pollution Prevention Plan (SWPPP).
2) The team must hold regular meetings to review the overall operation of the BMPs and the results of inspections.
3) The team must establish responsibilities for inspections, operation, and maintenance of all BMPs and record keeping.
4) The team must ensure training of all personnel involved in inspection, operation, record keeping, and maintenance of all BMPs.

**Good Housekeeping**

The following good housekeeping operations must (at a minimum) be completed.

1) Leaks and spills must promptly be cleaned up and contaminated materials disposed of properly
2) Catch basins must be inspected and cleaned regularly; at least once per year.
3) Sludge from catch basins and separators must be removed regularly; at least once per year. Note: analyses should be completed to determine whether or not these sludges should be considered hazardous.
4) Separator oil accumulations must be removed when the oil layer in the separator accumulates to a thickness of 3" or at least twice per year, whichever is more frequent.
5) High use parking lots (such as convenience store parking) must be swept monthly and washed twice per year with high pressure washing devices (without the use of detergents or soaps) to remove accumulations of oil and grease and solid particles.

6) Lesser use parking lots (such as church parking) must be swept once per year to remove accumulated solid particles.

**Preventative Maintenance**

The following preventative maintenance operations must (at a minimum) be completed.

1) Impervious areas must be constructed of Portland cement concrete or equivalent. Gravel shall not be used as a substitute for concrete or asphalt paving.
2) Promptly repair any cracks or other damage to paved or other impervious areas to ensure that all stormwater passes into the storm sewer system and does not enter the groundwater.
3) For weed/vegetable control
    a) Use minimal herbicides and pesticides
    b) Select least toxic herbicides possible
    c) Do not apply herbicides in close proximity to ditches or any channel that leads to open water.
4) Stencil signs “Dump no waste” at catch basins and inlets.

**Spill Prevention and Cleanup**

Thought must be given to planning for spill prevention and cleanup. Most spills will be caused by users of the facility who are not employees, and therefore little can be done to prevent spills by these users, but it is possible and necessary to plan for emergencies.

1) Keep emergency spill cleanup kits readily available
2) Ensure employees are adequately trained in the use of the kits
3) Do not flush absorbents down drains
4) Comply with local, provincial, and federal requirements for spill reporting.

**Employee Training**

Employees must be adequately trained in maintenance, inspection, and emergency procedures. Employee training must be conducted at least once per year as required by local and federal regulations and must include at least the following:

1) Understanding of the Storm Water Pollution Prevention Plan
2) Understanding of emergency spill response procedures
3) Understanding of good housekeeping and maintenance procedures

**Required Inspections**

Required inspections include mechanical and performance oriented inspections to ensure that the system is operating properly.

Mechanical inspections include (but are not limited to) inspection for cracks in concrete and piping and other mechanical defects that could cause leaks to groundwater or cause other mechanical problems with the system. If any mechanical or electrical equipment such as oil stop valves, double-wall tank interstitial monitoring equipment or tidal valve systems are provided, these must be inspected to ensure proper operation. Mechanical inspections must be conducted twice yearly – once during the dry season and once during the wet season.

Process inspections include (but are not limited to) inspection during a stormwater event discharge to visually look for floating materials, oil sheen, discoloration, undue turbidity or odor in the discharge. Process inspections must be conducted quarterly.

It is recommended, but not required, to sample effluents to ensure compliance with the law and as part of setting effluent limits. A simple sampling procedure is provided in the appendix. It is important to sample according to a proper procedure, because improper sampling and analysis techniques will produce incorrect data and may lead to incorrect actions[11]. More complicated sampling is beyond the scope of this document. It is suggested that the reader consult the excellent article by Atere-Roberts and Koon [12] for additional sampling information.

A process inspection should also be carried out periodically during a dry period to check for unpermitted non-stormwater discharges. These inspections should include visual observation of discharge water as well as grab sampling.

Inspection and sampling shall be performed only by employees who have been trained in inspection procedures.

**Record keeping**

All inspection records must be kept for a minimum of five years after completion of inspection. Inspection reports must include all observations as well as at least the following information:

1) Type of inspection and list of equipment inspected.
2) Date(s) of inspection.
3) Personnel conducting inspection.
4) If any samples are taken, date, time and exact place must be noted on the samples and this data included in the report.
5) Results of any analyses conducted on samples taken including the name and certification of analytical laboratory, analytical method used, and person performing the analysis.
6) Actions taken to correct any problems or inadequacies found.
7) Any observations that could cause a change to the SWPPP.

***Structural Source Control, Treatment and other BMPs***

**Contaminated Soil**

The best approach is to prevent soil contamination. This should include ensuring that rainwater from parking lots and roadways do not flow across any soil area. Note: An exception would be where use of grassy swales (not recommended because of the potential for metals contamination) is made. It is generally expected that any contaminated soils will be collected and removed for cleanup or disposal.

**Erosion and Sediment Control**

The best approach is to prevent soil erosion. This should include ensuring that sediment dams are provided at construction sites and soil areas are sodded, covered with crushed rock or seeded directly after construction and that the sod is maintained. Alternatively, covers such as geotextiles or impervious covers may be used to prevent erosion.

**Stormwater Collection and Conveyance System**

The stormwater collection and conveyance system is an important part of any stormwater management plan. It should be designed to do the following:

1) Separate contaminated and uncontaminated water (such as roof runoff water).
2) Collect and convey the contaminated water to an appropriate BMP.
3) Utilize impervious channels and piping such as plastic piping to ensure against groundwater contamination from the collection system.

Collection and conveyance systems should be designed using good engineering practice and following local codes. The design of the coalescing plate separator may be for a lesser volume than the hydraulic design of the conveyance system as noted in the discussion following.

**BMP Performance Testing**

Any BMP chosen to treat stormwater for removal of oil and grease must be proven to be a satisfactory BMP for the service. This proof shall be by testing according to an recognized test procedure carried out by an independent laboratory. Testing shall be conducted according to ASTM Standard D6104-97 or Environment Canada approved alternate.

**Coalescing Plate Type Oil/Water Separators for Hydrocarbon Removal**

**General**

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. One style of separator, the standard API (American Petroleum Institute) separator as used in refineries for many years is designed for about 45 minutes residence time. In the case of rainwater separators, this means providing a very large and costly tank.

Because of the size and expense of gravity separators 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. Coalescing plate separators offer a cost-effective means of removing the oil from stormwater.

**Plan for designing a BMP for removing oil from stormwater**

1) Determine the extent of the surface area to be served.
2) Determine the hydraulic flow rate for the sewer design. Use a computer program or the method in the Appendix.
3) Determine the flow rate required for the separator. Use the 10 year return period storm of 60 minutes duration as discussed in *Treatment Strategies* in the appendix or other design storm if required by the permit or local regulations. If possible, use the hydraulic flow rate because this is the maximum amount of flow treated.
4) If the hydraulic flow rate is so large that the separator would be unreasonable large, it may be possible to bypass some of the water. For suggestions, please see the *Treatment Strategies* in the appendix.
5) Estimate the inlet oil content (suggestions below).
6) Estimate the average droplet size. For suggestions, please see below.
7) Estimate amount of coalescing plate media required to meet the effluent requirements.
8) Prepare a separator design based on the above information.
9) Consider details of the system such as trash racks and other accessories required. Please see below for suggestions.

**Oil in the Water**

Oil may be present in the water in one of three forms:

a) Oil droplets.
b) Chemically or physically emulsified oil.
c) Dissolved hydrocarbons.

The first two of these may be treated physically, either by use of coalescing cartridges, coalescing plates, while the third must be treated by activated carbon or other chemical means.

The most common form of oil in stormwater is droplet form. Droplets may effectively be removed by the use of coalescing plate separators.

**Inlet Oil Content**

Research conducted by the City of Seattle Engineering Department indicates that a reasonable oil concentration in the inlet of an oil /water separator in normal runoff service is about 100 mg/L and for separators in heavy industrial stormwater service up to 400 mg/L may be used [13]. It is recommended that these values be used in lieu of local site information and its use should provide conservative sizing to account for possible variations in land use, weather, and inadvertent small spills.

**Inlet Oil Average Droplet Size**

It is recommended that an log-normal average droplet size of 130 micrometers be used for oil contents of 100 mg/L in rainwater and 240 micrometers be used for oil contents of 400 mg/L.

**Effluent Quality Required**

Effluent restrictions may be shown in the general or local stormwater discharge permit. Effluent discharge limits, if listed, 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 [14]. An oil content of about 15 ppm will cause a noticeable sheen on water. Even if no effluent limits in mg/L are listed, the Fisheries Act and other pollution control laws still apply, and no sheen may be discharged.

**Estimation of Amount of Media Required**

The hydrocarbons in the *influent* of a separator are present in a spectrum of droplet sizes. The hydrocarbon content of the separator *effluent* is made up of those small droplets that are not removed by the separator. The droplet size that must be removed to attain a given effluent concentration depends on the specific gravity of the hydrocarbons in the inlet, amount of hydrocarbons present, and the average droplet size present in the inlet stream.

To calculate the required size of a separator, it is first necessary to calculate the rise velocity of the oil droplets. The size of the separator is then calculated by considering the path of a droplet entering at the bottom of one end of the separator and exiting from the other end of the separator. Sufficient volume must be provided in the separator so that the oil droplets entering the separator at the bottom have time to rise to the surface (and be captured there) before the water carrying the droplets exits the opposite end of the separator.

$$Vp = \frac{G\left(dp - dc\right)D^2}{18\,\mu}$$

The droplet rise velocity is calculated by Stokes's Law [15]

Where: Vp = droplet settling velocity, cm/sec

G = gravitational constant, 980 cm/sec$^2$

μ = absolute viscosity of continuous fluid (water), poise

dp = density of particle (droplet), gm/cm$^3$

dc = density of continuous fluid, gm/cm$^3$

D = diameter of particle, cm

From the above equation it may be seen that the most important variables are the viscosity of the continuous liquid, density difference between the continuous liquid and the droplet, and the droplet size. After these are known, the rise velocity and therefore the size of separator required may be calculated. Stokes's equation was originally developed to describe the motion of solid particles falling in a liquid, so a droplet rise velocity is a negative number.

Conditions for the validity of Stokes's Law are:

1) Particles are spherical,
2) Flow is laminar, both horizontally and vertically, and
3) Particles are the same size.

For separation of oil droplets from water, these conditions can be met because:

1) Oil droplets are spherical because surface tension (more properly interfacial tension between the water phase and the oil) minimizes the surface area, making the droplets spherical.
2) In an enhanced gravity coalescing plate separator, flow is laminar because the separator is designed to retain the Reynolds Numbers under the laminar limit. It should be noted that this is very difficult or impossible to attain in an API separator due to the large size of such separators.
3) The oil droplets will not be the same size, unless specifically made in a single size in a laboratory, so it is necessary to do numerous rise rate calculations for the various sizes expected to be present in the influent.

The viscosity of the water is readily obtained from literature data. The design of such separators often requires design over a wide variety of temperatures (and therefore viscosities) to account for summer and winter conditions. Flow rates and hydrocarbon content of the water must be determined or estimated for the particular system.

Coalescing plate media is provided in packs or modules that are composed of plates arranged horizontally, vertically, or at an angle from the horizontal of 45-60 degrees. The plates are spaced evenly on approximately 8 mm to 75 mm center to center spacing. As the water flows between the plates, the droplets of oil rise up and meet the undersides of the plates where they are captured. The captured droplets form a film on the underside of the plates and eventually coalesce into large droplets that migrate upward through the plate pack to the surface of the separator. The oil layer that forms on the surface is skimmed off, either continuously by mechanical skimmers or periodically by vacuum trucks or pump.

One way of determining the amount of media required is to use a trial-and-error method. Using this method to determine the amount of media required, it is necessary to consider the rise rates of several sizes of droplets around the chosen mean droplet size. A quantity of media is chosen and the horizontal flow velocity through the media calculated. This allows calculation of the residence time within the media. Since the rise rates have been calculated, the residence time within the media can then be used to determine which droplets are captured. What amounts to a graphical integration of the volume of the total droplets that are not captured gives a total mg/L of oil escaping the media. If the effluent is not satisfactory, another amount of media must be estimated and the process repeated until a satisfactory answer is found. This very tedious calculation is best done by computer program.

**Separator Design**

After the amount of media is determined, it is then necessary to design the separator vessel or other container for the media. It is necessary to consider the size of the inlet chamber so that solids may be disengaged and captured as much as possible before the coalescing plate packs.

An oil dam or an outlet pipe with suitably sized dip tube must be provided downstream of the coalescing packs to ensure that the captured oil is not re-released to the environment. The invert of the horizontal section of the outlet pipe will positively set the water level in the separator under static conditions and ensure that the coalescing packs are always submerged.

Please see Figure 1 in the Appendix for a typical separator installation arrangement drawing. Figure 1 shows a typical separator installation, intended for use at service stations or other facilities where a separator is indicated.

**Trash and Floatables**

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 [16]. 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 with strainers in New York City[16] was that the strainers removed the floatables, but that a sufficient quantity of floatables were encountered to plug the strainers, which caused local flooding problems. For this reason, strainers should be used with care.

**Particulates and Heavy Metals**

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. It has been noted 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" [17]. Heavy metals have been noted in substantial quantities in roadside sediments as well [9].

Because they are purely physical devices, coalescing plate separators will not, however, remove any dissolved metals or other dissolved materials. COD and BOD will be removed only incidentally with removal of oil and solid particles and the stormwater pH will not be altered.

***Appendix:***

**Glossary**

Best Management Practices (BMPs): Schedules of activities, prohibitions of practices, maintenance procedures, and other physical, structural, and/or managerial practices to prevent or reduce pollution of water.

Coalescing Plate Media: The plate media, usually corrugated and often double corrugated, used to enhance the performance of a separator. The media is a substitute for additional residence time and serves both to cause the flow regime to be laminar and to capture oil droplets.

Oil Dam: A structural baffle situated downstream of the coalescing plate media intended to keep recovered oil from entering the outlet chamber of a separator, thus preventing the recovered oil from being passed downstream.

Plate spacing: The number of coalescing plates per vertical increment of coalescing plate pack. This may range from a narrow spacing of 8 mm to a very wide spacing of 75 to 100 mm.

Note: The above is a very abbreviated glossary listing only those terms particular to this subject.

An expanded glossary could be provided, but has been omitted here in the interest of brevity.

### Strategies for Treating Stormwater for Oil Removal

It is possible, by the methods discussed elsewhere in the appendix, to estimate what the peak flow of stormwater 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.

One method of determining how much flow to design the separator process for is to use for the separator design for a ten year storm return period as typically referenced in Canadian Provincial regulations. The amount of water to be bypassed is then the difference between the amount processed and the flow rate from the hydraulic design storm.

It is always possible to design separators to treat the entire amount of stormwater to be expected, and this is the safest method to ensure that oil will not enter the environment, but this can be very expensive. It is sometimes recommended in instances where large quantities of oil might be discharged to treat the entire amount.

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, and operate on the theory that in large rainstorms, the concentration of oil in the stormwater is very low and bypassing is acceptable. All of the methods utilize a weir to allow for overflows greater than the design flow.

Figure 2 is provided to show a typical method of providing this bypassing. It includes an integral bypass built into a concrete vault separator 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.

**Simplified method for calculating stormwater flows**

The "Rational Formula" may be used for relating the peak flow rate in a sewer to the rain intensity[18]. This formula is:

$$Q_p = CIA \quad \text{(liters/min or cubic feet per second)}$$

Where $Q_p$ = Peak flow
C = Runoff coefficient
I = Average rainfall intensity during a specified time interval called the time of concentration (mm/min or inches/hour)
A = Area, contributing drainage area ($m^2$ or acres)

Tables are provided in Imhoff, et al.[18], 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. Table I below is typical of such tables.

| TABLE I<br>RUNOFF COEFFICIENTS RELATED TO TYPE OF SURFACE | |
|---|---|
| *Surface Type* | C, *Runoff Coefficient* |
| Asphalt and Concrete Pavement | 0.70 - 0.95 |
| Brick | 0.70 – 0.85 |
| Note: Table adapted from Karl Imhoff's Handbook of Urban Drainage and Wastewater Disposal | |

Rainfall intensity and duration information for the United States and Canada are readily available.

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 [16]. One such model is the Storm Water Management Model, published by the USEPA. The ASCE and others offer workshops in the use of this model. A graphical method of designing stormwater systems is provided in "Designing Stormwater Handling Systems" [19]. Additional discussion of flow rates of stormwater is beyond the scope of this document, and the reader is referred to Imhoff, et al., and other literature for additional readings.

**Sampling and Analytical Methods**

Proper sampling methods are very important in obtaining correct information on separator performance. Samples should be taken in glass bottles with Teflon inserts in the lids. Do not use plastic bottles because the oil in the sample is more difficult to rinse off of the plastic during the analytical process. Do not rinse the sample bottle with sample because oil in the rinse will adhere to the inside of the bottle, thus giving a falsely high analysis.

Sampling and analyses should be done according to approved Environment Canada, USEPA, ASTM, or other approved methods by a certified laboratory. If analysis is not to be performed immediately, samples must be preserved with acid and salt per approved methods and should be refrigerated if possible.

**Figure 1 – Typical Separator Vault with bypass Installation Diagram**

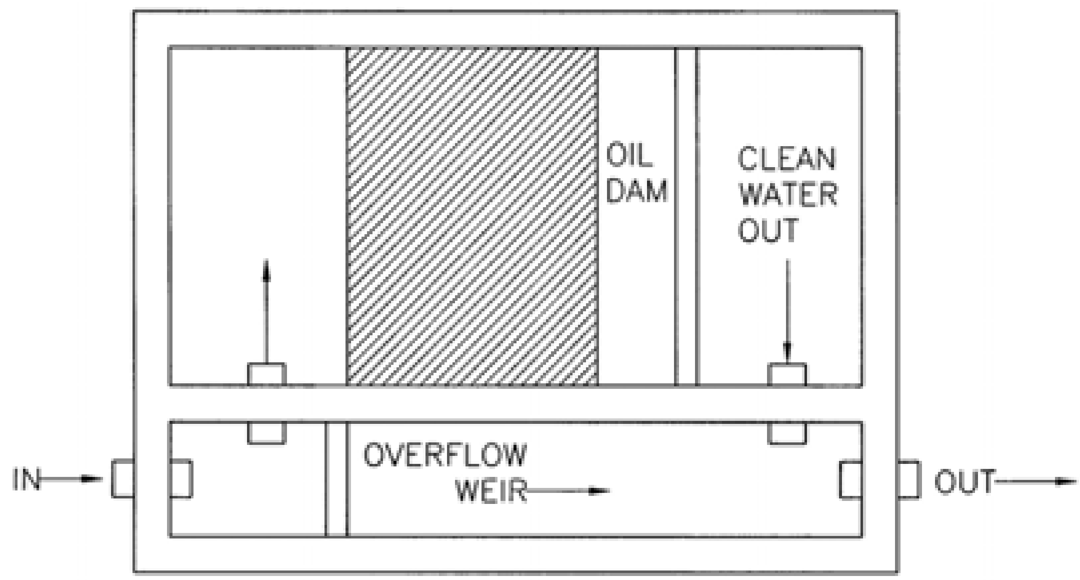


**Figure 1 – Separator Vault with Integral Bypass**

Reference List


1. Eganhouse, R. P.; Kaplan, I. R. *Environmental Science and Technology* **1981**, 310-314.

2. Laws, E. A. *Aquatic Pollution*; John Wiley & Sons: New York, NY, 1981.

3. Krenkel, P. A.; Novotny, V. *Water Quality Management*; Academic Press, Inc.: New York, NY, 1980.

4. Jorgensen, S. E. *Industrial Waste Water Management;* Elsevier Scientific Publishing Company: New York, NY, 1979.

5. 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 : Seattle, WA, 1990.

6. Government of Canada. 1978. Canadian Fisheries Act. Web Page, accessed Mar. 20, 2000.

7. Horenstein, B. The Appearance and Visibility of Thin Oil Films on Water US Environmental Protection Agency: Cincinnati, OH, 1972.

8. MacKenzie, M. J.; Hunter, J. V. *Environmental Science and Technology* **1979**, *13*(2), 179-183.

9. Gamble, K. G. Lab Test Results for Metals and Priority 13 Pollutants, City of Coral Gables 1994.

10. US Environmental Protection Agency *Results of National Urban Runoff Program (NURP)*; US EPA: 1983.

11. Kobylinski, E. A.; Hunter, G. L.; Quinlan, E. A. *Environmental Progress* **1993**, *121*(3), 169-174.

12. Atere-Roberts, S. O.; Koon, J. H. *Industrial Wastewater* **1993**, 38-49.

13. Paston, C., Letter to Kirby S. Mohr, June 4, 1994.

14. Washington State Department of Ecology *Stormwater Management Manual for the Puget Sound Basin;* Washington State Department of Ecology: Olympia, WA, 1991.

15. Perry, J. H.; Perry, R. H.; Chilton, C. H.; Kirkpatrick, S. D. *Chemical Engineers' Handbook;* 4 ed. McGraw-Hill Book Company: New York, NY, 1963.

16. Smith, R. *Stormwater and Combined Sewer Overflow Management and Control;* Kansas City, MO, 1993.

17. Stahre, P.; Urbonas, B. *Stormwater Detention;* Prentice Hall: Englewood Cliffs, NJ.

18. Novotny, V. *Handbook of Urban Drainage and Wastewater Disposal;* Imhoff, K.; Olthof, M.; Krenkel, P., John Wiley & Sons: New York, NY, 1978.

19. Elton, R. L. *Chemical Engineering* **1990**, 64-68.