BEST MANAGEMENT PRACTICES FOR CONTROLLING OIL AND GREASE IN URBAN STORMWATER RUNOFF

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ABSTRACT. Reducing the quantify of oil and grease in urban stormwater runoff is necessary to protect the quality of San Francisco Bay. Traditional technologies designed for industrial settings and municipal wastewater treatment do not have the capability to remove oil and grease from stormwater on a cost-efficient basis given the sporadic nature of discharge and relatively low pollutant concentrations. Innovative control strategies are described that could easily be implemented following pilot study evaluations. Most of these strategies could be applied to relatively little drainage, and substantial overall reductions in oil and grease loading would result. Alternatively, there is some opportunity for basin-wide controls, which would restrict input to the watershed and end-of-pipe treatment of runoff immediately preceding its discharge into the Bay.

INTRODUCTION

Stormwater runoff from urban areas is known to carry substantial pollutant loads. Unlike discharge from point sources of pollution, such as industrial effluents and municipal wastewater treatment plants, the quality of stormwater runoff is largely unregulated. Furthermore, the major sources of pollutants in runoff can be scattered throughout a watershed, making detection and prevention of pollutant discharge difficult. While the U.S. Environmental Protection Agency (U.S. EPA) is planning to include stormwater discharges as part of the National Pollutant Discharge Elimination System (NPDES) permit program, it is unclear how these discharges can be controlled, given the sporadic and diverse nature of these non-point sources of pollution.

Various studies have shown that San Francisco Bay is facing serious problems. Fisheries are on the decline; for example, the adult striped bass population has been reduced to about 25 percent of levels found in the mid-1960s (Stevens et al., 1985). The Bay once was used extensively for commercial oyster and crab harvesting; today the only remaining commercial fishing is for herring and anchovies (Nichols et al., 1986). A variety of factors contribute to these problems in the San Francisco Bay, including large water diversions to the central and southern portion of California, which changes the pattern of flow and prevents adequate Bay flushing; loss of juvenile fish through entrapment in pumps used for obtaining local irrigation and cooling water as well as pumping for out-of-region use; and the effect of water quality pollutants.

Hydrocarbons are suspected as one of the major pollutants adversely affecting the Bay. Hydrocarbons have been found in elevated concentrations in animal tissue and in the water column (DiSalvo and Guard, 1975; DiSalvo et al., 1975; Jung and Bowes, 1980; Greenberg and Kopec, 1985). While no causal relationships have been shown between fisheries and water quality effects in the Bay, researchers have suggested that the high incidence of skin lesions, tumors, and parasitism in striped bass may be indicative of elevated concentrations of hydrocarbons (Whipple et al., 1981).

Stormwater runoff from the local drainage area (Figure 1) has been shown to be a major source of various pollutants. Russell et al. (1982) calculated that about 25 percent of the suspended solids and about 35 percent of the heavy metals entering the Bay come from local runoff, with percentages expected to increase as point sources continue to be regulated and flow from the Delta decreases.

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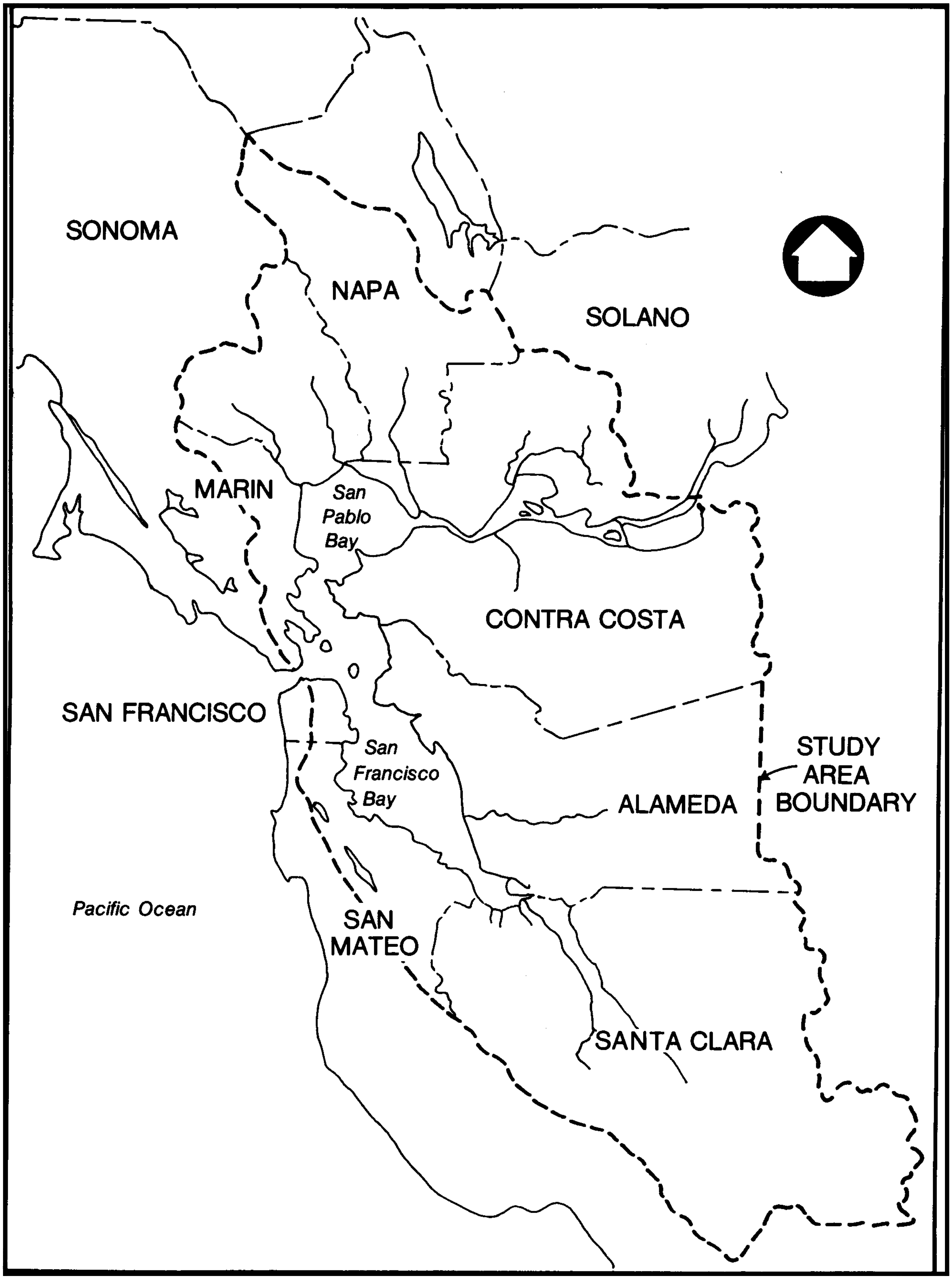

Figure 1. Local Drainage in San Francisco Bay.

Studies of oil and grease in local Bay Area runoff showed that concentrations often dramatically exceeded 10-15 mg/l, levels typically permitted for point source dischargers (Stenstrom et al., 1982, 1984; Silverman et al., 1985). Total non-point source oil and grease loading to the Bay has been estimated to be between 5 and 10 million pounds in a year, with average rainfall compared to about 11 and 15 million pounds annual discharge from point sources (Silverman et al., 1985).

Examination of annual loading rates can be somewhat misleading when evaluating potential environmental effects. Loading from non-point sources is very sporadic, with almost all of the input concentrated into a relatively few days during and following precipitation. At similar annual loading levels, biota near stormwater outfalls usually experience much greater acute exposure than biota near point sources of discharge. Thus, short-lived precipitation events may have disproportionate significance on environmental quality, particularly if events correspond to critical life stages such as spawning.

The levels of oil and grease characteristic of runoff in this area clearly indicate a potential threat to the Bay and the need to implement remedial action. The object of the study reported here was to determine practical methods for implementing controls in the San Francisco Bay Area.

CONTROL STRATEGY DEVELOPMENT

While attempts to control non-point source pollution have generally not been successful, a multitude of devices are routinely used to control oil and grease from other sources. Typical industrial processes to remove oil and grease from wastewater include skimming, gravity differential systems, filtration, dissolved air flotation, coalescence/filtration, and sorption. Containment and adsorption techniques employing a variety of devices for containing the material, followed by the use of a variety of adsorbents, are routinely used to clean up oil spills. Since both industrial and adsorptive recovery techniques are used to remove oil and grease in relatively high concentrations, their performance at the much lower concentrations associated with stormwater runoff is problematic.

In addition to a lack of control measures, the problem of controlling oil and grease in stormwater runoff is exacerbated by the stochastic nature of the discharge. Runoff events may be extreme, are highly variable and are both short- and long-lived. Technology capable of handling the large range of runoff levels normally expected would have to be extremely versatile. Treatment processes generally maximize efficiencies at selected process rates, suggesting the need for storage to equalize flow or for parallel sets of controls.

Although non-point sources of pollution come from diverse sources, inputs are concentrated in certain areas with respect to specific pollutants. In general, concentrations of oil and grease increase with urbanization and technological development (Browne, 1980). Examination of oil and grease concentration and mass loading from different land uses within an urban watershed in Richmond, California (draining into San Francisco Bay), showed that loading from industrial and commercial areas was much greater than from other land uses (Stenstrom et al., 1982; 1984). In this watershed, if oil and grease discharge from parking and commercial property, which represents only 11 percent of the land area, were reduced by 90 percent, total oil and grease emission from the watershed would decrease by over 50 percent (Table 1). If reductions of only 60 percent could be obtained from commercial and parking areas, overall watershed reductions would still be over 35 percent. A look at the Bay Area's future indicates that projected industrial and commercial development of 14,300 acres of land by the year 2000, representing only about 16 percent of the total development in the local drainage (ABAG, 1984), will account for 87 to over 98 percent of the predicted increase in loading of 0.8-1.3 million pounds (Silverman et al., 1985). Thus, this non-uniformity of stormwater quality, varying as a function of land-use type, appears to offer a tool to control much of the pollutant load while placing control burdens on a relatively small fraction of the watershed.

We reviewed and evaluated techniques for controlling oil and grease on the basis of removal efficiency, potential for implementation, and cost. Particular consideration was given to those areas characterized by higher input concentrations. Techniques were classified as favorable, marginal, and unfavorable. Each technique was further classified as structural or non-structural, as an indicator of the type of activity needed for implementation.

Structural control measures include techniques requiring additional equipment or materials or using existing resources in a new manner requiring capital investment. Structural control measures to control oil and grease usually would be employed after the material is deposited rather than reducing the input into the watershed. A financial commitment would usually have to be made to implement structural control measures, requiring a substantial capital investment.

Non-structural control measures comprise techniques utilizing existing technology and physical facilities to discourage the release of oil and grease into the environment, as well as to reduce the detrimental effects of any released materials. These measures can include mechanisms for limiting oil and grease discharge at its sources, cleaning oil and grease deposits prior to incorporation into stormwater, and modifying areas of deposition to

Table 1

Results of Simulating 90% Reduction in Oil and Grease Loading from Different Land Use Type in Richmond Watershed (Stenstrom et al., 1984).

Model Parameters	Annual Pollutant Load (Tons) — Year 1975	1976	1977	1978	1979	1980	Average	Total Percent Reduction	Percent Reduction % Percent Area
Rainfall (inches)	20.10	9.91	16.08	25.48	27.86	18.01	19.57		
Pollutant load without mitigation	9.3	4.6	7.4	11.8	12.9	8.3	9.0		
Pollutant load after mitigation by 90% reduction in:									
Residential	7.4	3.7	5.9	9.4	10.3	6.7	7.2	19.9	0.27
Industrial	8.5	4.2	6.8	10.8	11.8	7.6	8.3	8.3	1.93
Commercial	6.6	3.3	5.1	8.4	9.2	5.9	6.5	28.4	4.73
Parking lots	7.0	3.4	5.6	8.8	9.6	6.2	6.8	25.0	4.32
Freeways & Tracks	8.5	4.2	6.8	10.8	11.8	7.6	8.3	8.3	2.31
Commercial & Parking lots	4.3	2.1	3.5	5.5	6.0	3.9	4.2	53.4	4.53

minimize harm. Non-structural control measures often take the form of economic incentives or penalties and government regulation. The major difficulties inherent in selecting appropriate non-structural control measures are determining the effectiveness and associated costs of any proposed measure and determining how to select measures that are equitable among the affected parties.

CONTROL MEASURE EVALUATION

We conducted an initial investigation to identify control measures that offered a reasonable potential for effectively limiting oil and grease from urban storm drainages. From this initial investigation, fifteen controls were selected for subsequent study. We evaluated each of these measures for their potential for cost effective removal of oil and grease at levels normally found in urban stormwater runoff and rated them as favorable, marginally favorable, or unfavorable.

Lack of data necessitated these evaluations to be largely qualitative. This was sufficient, however, to clearly indicate the inappropriateness of several of the control options. The lack of quantitative data are more critical to the further evaluation of recommended control measures; additional research is vital before recommending widespread implementation.

Eight control measures were identified as offering the best potential for reducing oil and grease loading from urban areas: Improving street and parking surface cleaning, using porous pavements in parking lots, channeling stormwater into vegetated areas, using adsorbents in sewer inlets, encouraging the recycling of used motor oils, and incorporating an inspection of oil leaks into existing automotive emission testing programs. All appear to be viable mechanisms for keeping oil and grease from running into storm sewers. And the use of either dispersion devices or wetlands at the end of storm drains as "end of pipe" treatment could reduce the effects of oil and grease in runoff.

Described below are each of these recommended measures and short discussions of four controls rated as marginally favorable and three controls rated as unfavorable. Shown on Table 2 is a summary of costs, benefits, and potential for oil and grease removal of the recommended control measures.

Table 2

Summary of Recommended Control Techniques

	Mitigation Technique and Control Area	Projected Oil and Grease Removal Potential	Direct Costs	Associated Benefits	Associted Costs
1.	Oil and Grease Recycling: Entire Watershed	Unknown: Upper limit of 60 million gallons available for recycling in California (1980)	Negligible	Energy conservation Aesthetics Reduction of associated toxic material	Small individual cost of transporting used oil to recycling center.
2.	Leak inspection element to emissions program: Entire Watershed	Unknown	Small	Safety during emissions testing	Some additional training and enforcement
3.	Surface Cleaning: Parking areas and commercial streets	Assuming 60% process efficiency, maximum reduction over 35% in developed watershed	Industrial broom sweeper costs \$30/hr for 100,000-200,000 sq. ft. coverage (1982)	Aesthetics Reduction of other pollutants	Administrative cost to ensure compliance
4.	Porous Pavements: Parking Areas	Assuming 60% process efficiency reduction of over 15% in developed watershed	Similar to costs of conventional pavement. Very expensive in developed areas	Aesthetics Reduction of other pollutants Reduction of runoff volume	Minimal performance record Uncertain durability Need to determine pollutant fate
5.	Wetlands: Entire Watershed	Unknown: Upper limit entire discharge from watershed	Low construction costs Major expense is land requirements—highly variable	Aesthetics Reduction of other pollutants Recreation Wildlife	Maintenance Uncertain performance Need to determine pollutant fate
6.	Greenbelts: Parking areas	Assuming 60% process efficiency, maximum reduction over 15% in developed watershed	Low construction costs Major expense is land requirement-highly variable	Aesthetics Reduction of other pollutants Reduction of runoff volume	Need to determine pollutant fate. Uncertain performance Maintenance
7.	Adsorbents in Sewer Inlets: Parking areas and commercial streets	Assuming 60% process efficiency, maximum reduction of 35% in developed watershed	Installation cost low	Labor rather than material intensive Can be applied selectively	Routine maintenance replacement adsorbent
8.	Dispersion Devices: Entire Watershed	No removal	Capital costs several hundred thousand dollars, depending upon size	Dispersion of other pollutants	Operating and maintenance costs

Cleaning of Surface Material

A program designed to clean parking lots, commercial streets, and other heavily used areas could capture pollutants before they become entrained in runoff. Conventional sweeping practices are of unknown efficiency in reducing oil and grease pollution. One might expect significant removals, since over 80 percent of the hydrocarbons in runoff are typically found associated with particulates (Sheehan, 1975; Hunter et al., 1979; Eganhouse and Kaplan, 1981), with most pollutants associated with very fine particulates (Sartor et al., 1974). Sartor et al. (1974) also report that traditional sweepers leave behind much of this fine material (85% of material finer than 43 um and 52% of material finer than 246 um). Thus, the particles most likely to be left behind by traditional sweeping techniques are those containing the most oil and grease.

A practical method of oil and grease control may result from using sophisticated cleaning techniques to remove fine particulates. Advanced cleaning methods would probably also improve aesthetics and reduce other contaminant loading to the watershed. A difficulty inherent in a program to clean areas of high vehicle activity is the lack of information concerning techniques capable of effective sweeping and their associated expense. Considerable modification of existing equipment may be required, which would probably result initially in high costs. If standard systems were designed and employed over large areas, economies of scale might result in a cost-effective approach to pollutant limitation.

A method of street cleaning that appears promising is a wet-sweeping technique using specially designed street sweepers. The street sweeper would first spray a small area with water containing biodegradable soaps or detergents which solubilizes the oil and grease deposited on pavement surfaces. The sweeper would remove the water with a combination sweeping and vacuum action. A sophisticated version of a sweeping truck could contain a filtration system that would treat the recovered water and reduce the volume of oil and grease solution. This proposed sweeping machine is a hybrid of existing technologies, to our knowledge never before proposed, and it has not been tested. A series of prototype machines should be developed and evaluated prior to any widespread adoption.

Porous Pavement

The use of porous asphalt pavement may provide a practical means of modifying surface pavement parking material to provide a reduction in pollutant loading. Porous asphalt pavements provide a high rate of rainfall infiltration by omitting fine particles during pavement construction. Water is retained in the base and pavement materials, providing an opportunity for pollutant adsorption and degradation. This pavement also reduces the magnitude of total peak runoff, providing flood control benefits.

The major difficulty in evaluating the anticipated performance of porous asphalt pavements is the lack of data from which to determine effectiveness and applicability to various situations. Little is known about the maximum safe rate of pollutant loading before the assimilatory capacity is exceeded. Care would have to be taken to ensure that oil and grease were being degraded, rather than transferred through the soil into groundwater.

While the initial costs of porous asphalt pavements are estimated to be about 50% greater than for conventional pavement (Diniz, 1980), much of this expense may be attributed to the unfamiliarity of contractors with construction requirements; porous asphalt pavements construction materials and techniques do not appear inherently more expensive than conventional methods. The anticipated reduction in the need for runoff control devices such as sewers, catchment basins, and gutters may offset its additional expense.

Another important unknown quality of porous pavement is its durability. Without an existing long-term record, it is difficult to assess how long this pavement can be used without restoration, a vital economic consideration. The characteristics of oil and grease on porous pavement also are unknown; the oil may "plug" the pavement, reducing its porosity.

Other types of porous pavement may also be practical as parking area surface material, including concrete block type materials, which allow vegetative growth directly in the parking area, and gravel infiltration areas. These systems offer many of the same advantages and disadvantages of porous asphalt pavement and suffer the same lack of proven history as effective pavement material. They offer the additional feature of improving the aesthetics of parking areas. Research is progressing using these materials, with preliminary results indicating that they will at minimum be effective for selected applications.

Oil Sorption Systems

Oil sorption systems have been developed using a variety of types of materials in order to clean-up oil spills on open waters. Sorbent materials include naturally occurring materials, such as straw and hay, and synthetic material, such as polymethane foam. Lengthy evaluations of sorptive techniques have been reported by Cochran et al. (1973), Miller et al. (1973), and Gumtz (1973); however, these reports all address spills where very high concentrations of oil are present. In urban stormwater concentrations are much lower. Therefore an experimental program is needed before widespread use can be recommended.

The experimental programs required to develop the sorption system should not be costly or lengthy. The previously cited studies show the sorptive capacity of polymethane foams is very large; consequently, the problem of sorbing oil and grease from stormwater will become one of designing an appropriate hydraulic structure to provide intimate contact between foam and stormwater without causing flooding.

These structures probably could be designed to fit within the confines of existing catch basins without major structural modification of existing sewers. Routine maintenance would be required, but it would be simple and involve mainly replacing sorbent and removing debris.

Greenbelts

Vegetated areas could be designed to catch runoff with relatively high oil and grease concentrations from large paved areas such as parking lots. Percolation through soil and underlying layers would result in hydrocarbon filtration and adsorption, encouraging degradation by naturally occurring soil bacteria.

The use of greenbelts for oil and grease control is a new concept; consequently, design must be based largely on analogies to land treatment. Furthermore, most of the literature on treatment of water by land applications concerns wastewater, with a greenbelt combining aspects of several of the standard application methods (Rich, 1980).

A hypothetical application of a greenbelt to a parking lot is shown in Figure 2. The lot would be graded so that all runoff waters are channeled into one or more greenbelts. The greenbelt could consist of an upper layer of topsoil supporting plant life resting on a layer of sand, which in turn lies on a thick bed of gravel. Runoff waters would percolate through the top layers. According to Rich (1980), such percolation removes essentially all suspended solids and would also reduce hydrocarbon concentration. The gravel layer would act both as a drain, keeping the upper layers from saturation, and as a reservoir where stormwater would be stored while it percolates into the surrounding soils at depth. Since the soil underlying the parking lot would be isolated from surface infiltration, percolation out of the gravel bed should be quite rapid. For large or very intense storms beyond the design capacity of the greenbelt, a storm drain inlet would be constructed on the far side of the belt. In this manner, the waters in excess of the treatment capacity would be removed, although the greenbelt would absorb the first-flush waters of all storms.

The major cost involved in using greenbelts would be the land requirement. The price of the land and the proportion of land needed to control runoff would be highly variable, depending upon local land values, soil conditions, and rainfall pattern and quantity. Construction costs would be relatively low for greenbelts in developing areas and would require mainly gravel, sand, topsoil, and concrete. Building greenbelts in existing parking lots would be more expensive, often requiring regrading and modification of existing storm sewers. Maintenance of the greenbelts could also be a significant cost, requiring trash collection, gardening service, and perhaps dry season watering. Aesthetic benefits would provide additional incentives for greenbelt construction and maintenance.

Dispersion Devices

Diffusers could reduce the impact of oil and grease from runoff without reducing mass emissions. A diffuser does not reduce the amount of pollution discharged to the receiving body, but dilutes the concentration of the pollutants. For this reason, many environmentalists are opposed to diffusers and prefer treatment methods. In the case of urban stormwater, treatment systems are very expensive and are used intermittently, which results in poor performance and reliability. Diffusers can work well on an intermittent basis and can be fully automated, which reduces operating costs. Furthermore, for small and medium rains, the diffuser may be able to discharge all stormwater without pumping. The need for pumping will depend on the tidal cycle and topography.

The major costs of using dispersion devices are the construction costs and, should pumping be required, the operating costs. To obtain specific cost estimates, it would be necessary to select a site, since runoff quantity and pipe length would be highly site specific. Based on costs of a rainwater pumping facility (Hansen et al., 1979), the capital requirements of a diffuser facility would be expected to be approximately several hundred thousand dollars plus \$25/ft of diffuser pipeline. Additionally, some routine maintenance would be required to keep debris from clogging the system and the pumps in good working order.

Unknown costs would be imposed on the environment due to the spreading of pollution. Since the dispersion device is intended to remove pollutants away from critical near-shore areas with subsequent dilution in off-shore areas, environmental costs imposed by the diffuser must be significantly lower than the existing environmental damage imposed by runoff in order to justify the system.

Wetlands

Wetlands offer a mechanism for treating stormwater runoff after its contamination with oil and grease but prior to its discharge. The general application of this technique is quite limited and site-specific because of the requirement of suitable land. The San Francisco Bay Area includes many

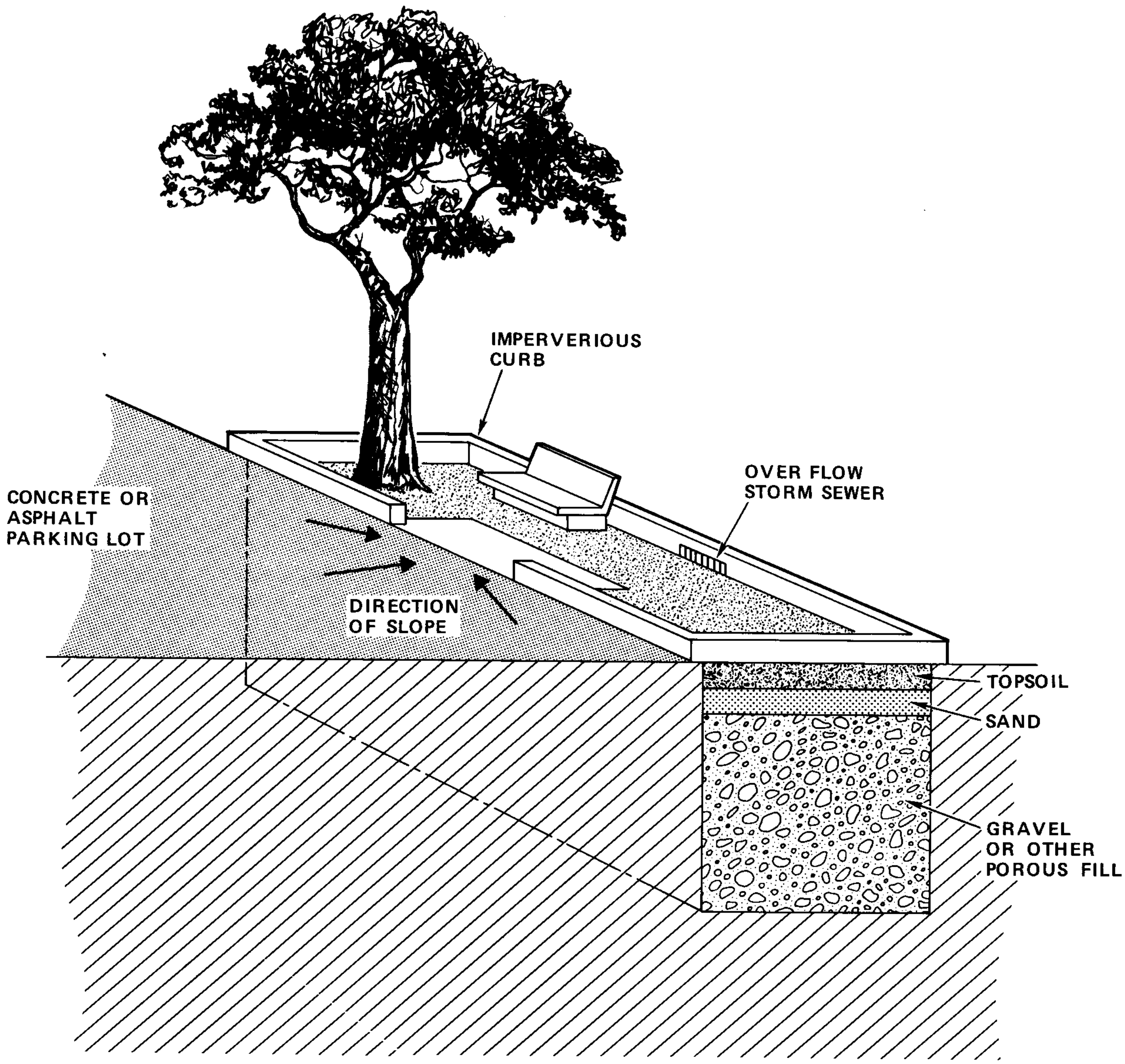

Figure 2. Hypothetical Application of a Greenbelt in a Parking Area.

sites where marshes have been dredged, filled, and/or channeled and which could be developed as wetlands.

Little information is available regarding the effectiveness of wetlands in removing oil and grease from stormwater runoff (Chan et al., 1981). Since the majority of oil and grease in runoff is normally found associated with particulates, it is reasonable to assume that wetlands would act primarily as a sedimentation trap. Pollutant removal from the water column would occur as the particulates settle, with degradation responsible for their ultimate elimination. The removal of other pollutants besides oil and grease would also be anticipated. An accurate assessment of oil and grease removal potential could not be made until pilot studies were conducted.

The costs of wetlands appear relatively high. Wetlands require a substantial quantity of land. Construction costs for the first wetland areas would probably be higher than those for wetlands built after the technology was fully developed because of the increased safety factors needed to account for design uncertainties. But the high initial construction costs usually would be less than the cost of conventional wastewater treatment plants.

While wetland development would be relatively expensive, its value would not be limited to water treatment. Wetlands are being restored and developed around the Bay Area because of their aesthetic, wildlife and recreational values. In some cases, integrating water quality considerations into plans for enhancing wetland resources could provide the additional justification needed to implement wetland projects.

Oil Recycling

Vehicular oils have been shown to be the main source of oil and grease typically found in urban stormwater runoff (Stenstrom et al., 1982, 1984; Hunter et al., 1979; MacKenzie and Hunter, 1979; Wakeham, 1977). This material can be introduced to the watershed through tailpipe emissions, leakage, or dumping. Promoting oil recycling provides the possibility of reducing this input, thus reducing oil and grease concentrations in stormwater.

About 1.3 billion gallons of automotive oil were sold in the United States during 1983, with about 10 percent of this volume sold in California (Stone et al., 1985). In California, about 31 percent of this volume was recycled, with an estimated additional 17 percent used as bunker fuel oil in transport ships. The quantity of non-recycled oil being disposed of through direct dumping is unknown. Since a majority of used oil is not being recycled, a substantial quantity of oil probably is being dumped in gutters, storm sewers, vacant lots, and other areas where it will be washed out during a storm. As regulations governing methods for disposing of waste oil continue to be made more restrictive, we might expect additional illegal dumping to avoid disposal costs.

The oil recycling industry has not been operating at, or near, full capacity, indicating a substantial ability for increased re-refining of used oils (Moskat, 1980). Because there is little financial incentive for individuals to recycle (particularly at the present time with a severely depressed price for raw crude oil), opportunities for recycling need to be made as convenient as possible. Thus, the key for increasing oil recycling appears to be through public education programs and numerous high visibility recycling centers. Through greater awareness of the potential of oil and grease to degrade the environment, coupled with readily available opportunities to recycle, some of the oil currently ending up in runoff could be returned to productive use.

Vehicle Inspection and Maintenance Programs

Another unquantified but potentially significant source of oil introduction into a watershed comes from vehicular leakage and exhaust. A program is currently in place in many parts of California (and other parts of the nation with air quality problems) requiring regular vehicle inspections for air emissions. Thus, reducing hydrocarbons from exhaust is already a major goal of this program. Expanding the program to include oil leakage would provide an additional tool to limit oil and grease input into a watershed.

A check for oil leakage could consist of visual inspection of the vehicle, perhaps preceded by steam cleaning of the engine if a more accurate inspection is desired. Complicating issues in determining the effectiveness of leak inspections is the subjective nature of visual inspection and the maximum cost that could reasonably be required to fix an oil leak.

Perhaps the most promising method would be to control only grossly leaking vehicles, as was done in a pilot program in Riverside, California (Bureau of Automotive Repair, 1976). Prior to emissions testing, incoming vehicles were examined to determine if a puddle of oil at lease three inches in diameter could be detected to have leaked after one minute. Of the incoming vehicles, 0.01 percent were rejected for oil leaks, 1.2 percent for coolant leaks, and 0.3 percent for fuel leaks. While these percentages were low, this program does indicate that there is some potential for applying gross tests to vehicles to identify those with major leaking problems. Since this gross testing was conducted for safety purposes during the inspections, incorporation of a formal program to reject vehicles with major leaks would serve dual purposes at little cost.

Marginally Favorable Control Techniques

Marginally favorable control techniques include recently developed, efficient wastewater treatment in conjunction with a stormwater storage system. Included among these treatment techniques are dissolved air flotation, corrugated or parallel plate separators, and high rate filtration, using either mixed or multimedia filbers. The stochastic nature of storms makes the treatment of stormwater solely through treatment plants inefficient and uneconomical. Also considered marginally favorable are oil and grease trap systems.

Corrugated or parallel plate separators are an effective means of treating free oil and grease, particularly when the concentrations of free oil and grease are high. In the case of urban stormwater, the concentrations are relatively low, and a large portion of the oil and grease is colloidal or dissolved. Therefore, the highest obtainable efficiency for this type of treatment is only as high as the free oil and grease portion, which is typically 40-60% in stormwater (Eganhouse and Kaplan, 1981; Stenstrom et al., 1982, 1984). These types of treatment systems would require frequent cleaning, due to the build-up of silt and grit. Oil/water separators of this type would have to be specially designed to allow removal of silt and grit, which is not normally found in oily process water.

Dissolved air flotation and high rate filtration are slightly more attractive than oil/water separators, since their efficiency can be higher and the surface area requirements would be lower. The reduced area requirements result because of the high loading rates (5 gpm/ft^2) which are possible in a filter or dissolved air flotation unit. The cost of filtration or flotation equipment would be higher than the cost of simple oil/water separators. To obtain maximum efficiency, it would be necessary to use a coagulant. Unfortunately, this increases the operational expertise required and presents a special problem due to the highly variable nature of stormwater.

A combined treatment/storage system would be slightly more effective since hydraulic equalization can be provided, optimizing the efficiency of treatment while reducing the required size. Storage facilities also would provide added retention time to enhance the breakdown of oil and grease. They present the advantage of being simple in structural design and operation, and their construction could be done in stages. They would improve reliability of the treatment system through attenuation of dramatic changes in flow and water quality.

Disadvantages of the combined storage-treatment system include the large physical size of the storage facilities, the need for periodic removal of sediments, and the high costs of building and operating the system.

The best combination of the marginally favorable treatment systems might be constructed in conjunction with a diffuser, which would be the best choice for controlling oil and grease if a valuable natural resource were in extreme danger. It would not be possible to justify the high cost of those control measures for most other circumstances.

We considered oil and grease traps marginally favorable because they would be less efficient than the oil sorption systems discussed previously and would cost virtually the same. Scattering adsorbent material over large areas would not be effective unless used in combination with sweeping machines, which were discussed previously, and which are a better alternative.

Unfavorable Control Techniques

Conventional oil waste treatment systems, such as API-type oil/water separators, conventional secondary treatment, and combining stormwater with sanitary wastes offered the lease potential for cost effective control of oil and grease in stormwater. Conventional API-type oil/water separators are best suited for higher concentrations for oil and grease such as oil process water, which would clog or disrupt other types of separators. They would be more expensive than other treatment alternatives for treating runoff.

Conventional secondary treatment usually removes free oil and grease and a portion of the colloidal or dissolved oil and grease, depending upon the type of compounds present. Eganhouse et al. (1981) and Eganhouse and Kaplan (1982) found that hydrocarbons comprise the largest portion of oil and grease in urban stormwater and that hydrocarbons are poorly removed in secondary treatment. Furthermore, the cost of secondary treatment would be higher than the marginally-favorable treatment techniques.

Combining stormwater with sanitary wastes appears the poorest of all alternatives and probably would result in additional pollution of the Bay, due to overflows of the combined water during heavy storms. Increasing the size of secondary facilities to accommodate stormwater would be more expensive than the marginally favorable treatment techniques.

CONCLUSIONS

Control measures are available to limit the mass loading and effect of oil and grease in urban stormwater runoff discharging into San Francisco Bay. These controls are needed because oil and grease in runoff from the local drainage areas pose a substantial threat to the health of the Bay. As inflow from the Delta decreases and point sources of pollution are controlled, the relative significance of non-point source pollution will increase, placing an additional demand for preventative and remedial action. Traditional control strategies developed for municipal and industrial discharge will not be effective on stormwater runoff, due to the sporadic nature of the flow (in terms of both quality and quantity), the sporadic nature of pollutant introduction into the watershed, and the lack of accountability on the part of the polluters.

Many of the recommended control measures concentrate on areas receiving high vehicle use; by controlling these high input areas relatively little of the total watershed needs to be managed to gain substantial reduction in total loading. Alternatively, "end of pipe" controls may be feasible in some situations, although care must be taken that these controls do not result in a transfer of pollution problems to a new environment. Before any of these control measures are implemented, comprehensive pilot studies need to be conducted.

Implementation of these recommended control measures face several obstacles. It is not clear who would pay for initial development of each measure or who would pay for upkeep, although developing EPA regulations should clarify responsibilities regarding stormwater quality. The actual performance of these controls have never been tested with regard to stormwater runoff; additional research needs to be done before widespread implementation can be recommended.

Equally important to economic and physical obstacles to control measure development may be a perceptional problem. Most of the recommended measures are "soft" solutions, using a decentralized site specific approach rather than developing a major hi-tech facility. Most individual control devices will have little overall effect on watershed runoff quality; only the composite contribution from many small controls will result in the desired reduction in pollutant loading. Thus, it will be very difficult to evaluate system performance. In contrast, a traditional wastewater treatment facility has a known input water quality and known effluent quality, making evaluation of system performance simple. It is clear, however, that the diverse pollution sources found in a watershed cannot economically be mitigated through traditional control devices. Thus, the use of alternative control measures, such as recommended here, needs to be seriously considered to maintain adequate water quality in San Francisco Bay and in other waters offshore from major urban centers.

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