OIL AND GREASE IN URBAN STORMWATERS

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ABSTRACT: A study of oil and grease in urban stormwaters was performed on a small watershed in Richmond, Calif., with the objective of determining the amount of oil and grease discharged into San Francisco Bay. Five sampling stations were selected at various places in the watershed that were indicative of specific land uses, and runoff from seven storms was sampled and analyzed. The results of the survey indicated that oil and grease concentration was highly dependent upon land use, ranging from 4.1 mg/L in residential areas to 15.3 mg/L in parking lots. A statistical analysis of oil and grease and storm characteristics showed that oil and grease concentration was independent of all storm characteristics, except that mass of oil and grease discharged was proportional to total rainfall. Qualitative analysis of the oil and grease by gas chromatography indicated that it most resembled used automobile crankcase oil. Several samples showed evidence of spills of specific compounds. A simulation of management techniques indicated that a 90% reduction in discharge from commercial properties and parking lots, which represented only 9.6% of the total surface area, would result in a 53% reduction in total oil and grease discharge. Growth simulation predicted a potential 27% increase in discharge if 5% of the watershed were converted from open land to commercial property.

INTRODUCTION

Over the past several years there has been an increasing concern about wet-weather pollution control. For separate sewer systems a variety of management alternatives exist, which include treatment, storage, land use regulation, dispersion of runoff, and combinations of all methods. Development of the best management alternatives requires an extensive understanding of wet-weather flow characteristics, pollutant runoff characteristics, and the relationship between land use and pollutant mass discharge.

Areawide planning has indicated the need for a better understanding of stormwater characteristics with respect to land use. Work over the past decade has shown that, in many areas, the most significant pollution contribution to local receiving waters is from stormwaters, and not from municipal or industrial effluent. Undoubtedly, as secondary treatment plants become more widespread and industrial discharge is reduced, the relative contribution of stormwater pollution will increase.

The objective of this investigation was to determine the relationship between land use and oil and grease pollution in urban stormwater, in order to develop a program limiting pollution into San Francisco Bay. A small watershed in Richmond, Calif. was selected for a field study during the wet period of 1980–1981. Sampling stations representing various land uses were located in the watershed and monitored over a seven-

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storm sequence. Results from the field study were analyzed to determine oil and grease concentration, and based upon these results and other land use and watershed characteristics, management policies were evaluated. This study was part of a larger, 208-area planning study.

PREVIOUS WORK

There is a large body of literature concerning the pollution contribution of urban stormwater runoff to rivers and oceans (4, 5, and 11, among others); however, information on oil and grease and hydrocarbon pollution is much less extensive. The oil and grease contribution from urban stormwaters to the oceans has been estimated at approximately 5% of total input (20), although more recent data (9,10) suggest a greater contribution. Undoubtedly, the relative magnitude of this contribution will increase as point source controls are developed.

Sources of hydrocarbons to urban stormwaters include accidental spills, deliberate dumping of waste oil and fuels, emissions from engines during normal operation (primarily uncombusted exhaust hydrocarbons and crankcase drippings), fallout from atmospheric particulates, spillage of refined products during refining and transportation, natural seepage and erosion of sedimentary rocks, and natural biogenic sources (9,16,27). Wakeham (27) has shown that natural hydrocarbons are only a minor contributor to urban runoff. Oil and grease emissions from vehicles, most notably from crankcase oil emissions, have been shown to be a major contributor (15,17,27). Table 1 shows a review of previously reported oil and grease concentrations for various areas with various types of land use. It is obvious that there is a very large range of concentration, which varies with land use and location.

The types and nature of hydrocarbons present in stormwater vary significantly. Eganhouse and Kaplan (9) measured 88% aliphatics, while Hunter, et al. (15) measured only about 70% aliphatics. Hydrocarbons are frequently associated with suspended solids in stormwater, with the bulk of hydrocarbons being adsorbed or otherwise attached to particulates. Sheehan (22) found that 81% of the hydrocarbons were associated with suspended solids, while Hunter, et al. (15) found 96%, and Eganhouse and Kaplan (10) found 85%. The concentrations of hydrocarbons found in stormwater also appears to be related to storm characteristics. Hunter, et al. (15) found that the total discharge of hydrocarbons was related to total runoff and noted a "first flush" effect, which they attributed to washing or scouring of hydrocarbons on pavements and other surfaces. Soderlund and Lehtinen (23) did not find a "first flush" effect. Others have noted relationships between storm characteristics and oil and grease pollution in stormwater; e.g., Asplund, Mar, and Ferguson (1) noted a relationship between rainfall intensity and suspended solids production, suggesting a similar relationship with oil and grease.

Petroleum-derived hydrocarbons are regularly released into the environment in stormwater runoff in proportion to surrounding urbanization and technological development (5); however, most of the work done on the biological effects of oil and grease on aquatic life has been in response to oil spills. Both the quantity and quality of hydrocarbons from spills may differ significantly from that in urban runoff, resulting in substantially different effects on the environment. While little information is now available concerning the effects of hydrocarbons from runoff on marine and estuarine environments, monoaromatics have been found regularly in fish and shellfish tissue and in open water in the San Francisco Bay (7). Whipple, Eldridge, and Benville (30) report that monoaromatics may be contributing to the current decline of the striped bass (*Morone saxatiles*) and other fisheries in the Bay (8).

TABLE 1.—Previously Measured Values of Oil and Grease Concentration

Place (1)	Description (2)	Hydrocarbon fraction (3)	Concentration, in Milligrams/Liter		
			High (4)	Low (5)	Mean (6)
Philadelphia, Pa.[a]	Urban runoff	Aliphatic			
		Particulates	3.41	1.12	2.28
		Soluble	0.50	0.12	0.29
		Aromatic			
		Particulates	1.65	0.49	1.01
		Soluble	0.19	0.04	0.11
Seattle, Wash.[b]	Bridge runoff	Aliphatic	24.0	6.0	12.0
	Bridge runoff	Total	96.0	0.0	27.0
	Urban runoff	Aliphatic	7.5	0.2	1.2
	Urban runoff	Total	16.0	1.0	10.0
	Freeway runoff	Total	60	10	44
Stockholm, Sweden[c]	Terrace houses	Total	70		30
	Suburban	Total	100		47
	Highway	Total	100		58
	Mixed	Total	70		41
Los Angeles, Calif.[d]	River (100% stormwater)	Aliphatic			11.5
		Aromatic			1.6

[a] Hunter, et al. (15).
[b] Wakeham (27).
[c] Soderlund and Lehtinen (23).
[d] Eganhouse and Kaplan (9).

Only a few investigators have chemically characterized the oil and grease contained in urban stormwater. Of these investigators, most have used gas chromatography to determine the distribution of compounds that are found in urban stormwater. The most extensive analysis performed to date is the work of Eganhouse and Kaplan (9,10) who used gas chromatography/mass spectroscopy to further identify these compounds. Very few low molecular weight hydrocarbons exist in stormwaters, and most compounds present are C_{13} or larger. Typical GC results indicate a broad envelope from C_{13} to C_{36}, which constitutes over 80% of the total oil and grease mass. Some of these compounds included normal alkanes; branched homologues including isoprenoids, iso, and anteisoalkanes; alicyclic and polycyclic compounds such as cyclohexanes; steranes; diterpanes; triterpanes; and a variety of aromatics and polynuclear aromatics such as pyrene, chrysene, and benzopyrene. A variety of fatty acids have been found in stormwaters, and these have been attributed primarily to biogenic sources, since petroleum hydrocarbons usually contain very few fatty acids (10).

EXPERIMENTAL FIELD PROGRAM

The field study was conducted in a 2.5 sq mile (6.58 sq km) watershed in Richmond, Calif., a small city located to the northeast of San Francisco that borders on San Francisco Bay. This watershed was selected because it contains a variety of land uses, has identifiable boundaries, and empties into the Bay in a convenient and accessible location.

The watershed was characterized and measured using aerial photography. The various subareas were placed into categories according to the land uses shown in Table 2. Five sampling stations were selected within the watershed; they are described in Table 3. Station 1 was located at the mouth of the watershed, where all storm flows are routed through a trapezoidal channel to San Francisco Bay. Station 2 was located just outside the property limit of a large trucking center for a grocery distribution center, where the storm sewer enters a small creek through a 30-in. (0.118-m) diameter culvert. Station 3 was located in a commercial department store parking lot. Station 4 collected runoff from a gasoline filling station, several commercial retail stores, and a small residential area. It had no identified sewer entrance, and it was necessary to collect samples along a street curb. Station 5 was located in a small creek that drained a residential area.

Samples for oil and grease analysis were collected in 1-gal (3.78-L), solvent-cleaned bottles. Sampling points were selected at turbulent locations to insure a uniform sample. Samples and flow measurements [using the Manning equation or appropriate weir formula (3)] were taken routinely during each storm event. Sampling frequency was approximately 30 min, but varied from 20 to 40 min due to the unavoidable delays and circumstances associated with the sampling crew traversing the watershed.

Oil and grease was analyzed using direct extraction with Freon 113, followed by infrared analysis as described in *Standard Methods* (24). The infrared method was selected because low oil and grease concentrations were expected. Selected samples were prepared for further analysis using gas chromatography, by drying the extract from the oil and grease analysis using high purity nitrogen, and redissolving in 100–200 µl of pesticide quality dichloromethane. After redissolution, 1-µl aliquots were analyzed using a Tracor model 760 gas chromatograph with a hydrogen flame ionization detector. A 6-ft-long, 1/4 in. (6.35 mm)-diameter glass column, packed with 10% sp-2100 on 100/120 Supelcoport was used. Injector temperature was 300° C, and column temperature was programmed at 50° C for the initial 2 min, then rising at a rate of 80° C/min to a maximum of 350° C.

TABLE 2.—Land Use in Richmond Watershed

Land use (1)	Percentage of total area[a] (2)
Undeveloped	5.2
Industrial property and parking	4.3
Large-scale commercial parking and property	6.0
Small-scale commercial and industrial property and parking	5.8
Single family residential	70.6
Multi-family residential	2.1
Freeways, trains, and BART[b]	3.6
Impervious non-auto	2.4

[a] Total land area = 2.541 sq mile (6.58 sq km).
[b] Bay Area Rapid Transit (Electrical Rail System).

TABLE 3.—Sampling Station Description

Station (1)	Site description (2)	Land uses (3)	Drainage area, in square feet (4)	Approximate distance to mouth of basin, in feet[a] (5)	Elevation above sea level, in feet (6)
1	Mouth of watershed	Composite of all uses in watershed	7.08×10^7	0	12
2	Trucking distribution center	77% industrial property and parking 23% impervious non-auto	1.17×10^6	2,000	10
3	Parking	100% large-scale commercial property and parking	2.92×10^4	6,250	60
4	Portion of commercial street and 3 service stations	70% residential 30% small-scale commercial property and parking	8.71×10^5	9,800	103
5	Upstream residential area	95% residential 5% undeveloped	5.70×10^6	10,500	98

[a] Measured as distance to Station 1.

Note: To convert sq ft to sq m, multiply by 0.0929; to convert ft to m, multiply by 0.3048.

Two settling column tests were performed during the fifth storm to assess the feasibility of gravity separation as a runoff treatment technique. Some 45 L of water were allowed to settle in a glass column with internal diameter, 15 cm, and height, 1.6 m. Samples were withdrawn from ports located at the column mid-depth, at about 30 cm below the water surface and about 30 cm above the column bottom at 1, 2, 5, 10, and 30 min after initial mixing. After the 30-min sample was taken, additional samples, approximately 1 L in volume, were withdrawn from both the surface and bottom of the water column, and analyzed for oil and grease.

Seven storm events were monitored during the rainy winter period of 1980–1981, as shown in Table 4. Rainfall was measured using the rainfall

TABLE 4.—Description of Storm Events

Storm (1)	Date (2)	Days since previous storm (3)	Storm duration, in hours (4)	Total rainfall, in inches (5)
1	12/3/80	11	15.5	2.01
2	12/21/80	18	4.5	0.33
3	1/17/81	1	4.5	0.07
4	1/20/81	1	1.0	0.40
5	1/13/81	5	3.5	0.35
6	3/4/81	4	6.0	0.24
7	3/18/81	3	7.0	0.53

gage at the Richmond City Hall, located near the center of the watershed. As can be observed from this table, not all storms were sampled. Rainfall readings of less than 0.04 in./day (1.0 mm) were not considered storms. Storm 1 represented the first large storm of the rainy season. Unfortunately, the first 6 hr of this storm were missed. Rainfall began about 3:00 AM but sampling was delayed until 8:00 to 9:00 AM.

EXPERIMENTAL RESULTS AND DISCUSSION

Tables 5 and 6 show the mean and variation in oil and grease concentration and mass load for the five stations over the seven-storm sequence. Measured values varied greatly, but variations within stations were not so great as to obscure the differences between stations. The mean hydrocarbon load factor (the product of flow and oil and grease concentration divided by the drainage area of each station integrated over the storm period) was calculated to relate the mass of oil and grease to land use. Parking lots had the highest load factor of 3,463 lb/sq mile-in. of rainfall (239 kg/sq km cm), which was approximately 25 times higher than the runoff from residential areas.

A statistical analysis of the data was made using SAS (25) to test and evaluate various hypotheses. Sampling station, and therefore land use, was found to be the most significant parameter affecting oil and grease concentration. Using sampling station as a blocking factor showed significance at the 99.90% level of confidence for all stations, except Station 1, for all storm events. Since Station 1 receives runoff from all parts of the watershed, it was not expected that oil and grease concentration would differ significantly from upstream sampling stations.

After establishing land use as the most important parameter affecting oil and grease concentration, other parameters were evaluated using analysis of variance with sampling station as a blocking factor. Oil and grease concentration was found to be independent of total runoff flow rate, total rainfall, instantaneous flow rate, time since storm beginning, time since last storm, and rate of rainfall. Total oil and grease runoff mass, calculated as the integral with respect to time of the product of oil and grease concentration and runoff flow rate, correlated significantly with total rainfall. No other significant statistical relationships were found.

An interesting observation was made with respect to oil and grease concentration and time since storm beginning, even though no significant relationship was found by the analysis of variance. Neglecting the data from storm 1 (since the first 6 hr were not observed), it was found that 24 oil and grease concentration profiles declined with time, while 6 showed an increase with time. Of the 24 profiles that declined as a function of time, 7 were judged to be significantly different at the 90%

TABLE 5.—Mean Oil and Grease Concentrations for Each Station and Storm Event

		Oil and Grease Concentration, in Milligrams/Liter		
Station (1)	Storm (2)	n^a (3)	Mean (4)	Standard deviation (5)
1	1	9	3.56	3.35
	2	8	3.53	0.57
	3	11	5.28	3.25
	4	7	5.76	2.46
	5	6	9.10	6.14
	6	7	12.14	7.53
	7	8	15.71	28.13
2	1	10	5.32	3.30
	2	8	3.01	1.52
	3	12	7.93	6.29
	4	7	6.90	3.48
	5	6	8.83	6.59
	6	7	9.37	4.00
	7	8	9.51	6.03
3	1	10	11.99	3.69
	2	8	19.14	7.99
	3	13	11.77	5.93
	4	7	7.94	3.74
	5	6	31.33	28.88
	6	7	15.77	9.15
	7	8	15.00	6.78
4	1	10	14.05	7.00
	2	8	8.30	6.32
	3	13	9.45	7.38
	4	7	14.14	3.08
	5	6	11.37	2.91
	6	7	9.76	6.61
	7	8	9.03	2.98
5	1	10	13.47	5.54
	2	8	1.65	1.08
	3	13	1.68	0.85
	4	7	0.80	0.23
	5	6	2.53	1.89
	6	7	5.67	3.95
	7	8	1.65	2.07

[a] n = number of observations.

TABLE 6.—Mean Oil and Grease Mass Discharge for Each Station and Storm Event

Storm (1)	Total Mass Load per Station, in Pounds 1 (2)	2 (3)	3 (4)	4 (5)	5 (6)
1	2,870	94.9	29.4	165	237
2	81.1	2.83	0.48	4.17	2.06
3	103	1.99	0.06	0.73	0.33
4	14.8	0.94	0.05	0.58	0.22
5	121	11.9	0.52	5.43	2.91
6	253	11.8	0.73	5.95	11.09
7	704	22.3	1.46	19.6	7.36
Station mean	592	20.9	4.67	28.8	37.3
Standard deviation	1,030	33.5	10.9	60.4	88.3

level of confidence. Two of the profiles that increased with time were significant. This observation was considered as modest evidence to support the existence of a "first-flush" effect, which has been noted by other investigators. Oil and grease mass discharge rate did not show a pronounced first-flush effect. Fig. 1 shows a typical profile of oil and grease mass as a function of time for all stations for storm 4. The delayed peak for Station 1 (mouth of the watershed), indicating a transportation lag, was observed for most storms.

The results of the GC analysis were largely inconclusive since few identifiable compounds were found in the sample extracts. Table 7 shows the results of an audit of all the GC results. Peaks and retention times shown in Table 7 were determined by comparing sample peaks to peaks from known standards for various compounds. The table indicates that very few of the extracts contained compounds containing less than 10 carbons, which was partly to be expected since a purge and trap analytical procedure was not used. A peak corresponding to anthracene was found in most samples. Peaks in the C_{24} to C_{32} range were also found in most samples. Fig. 2 shows a typical chromatogram for a sample extract. The broad, unresolved envelope appears to be typical of results obtained by many other investigators and is similar to chromatograms of automotive crankcase dripping and hydrocarbon exhaust particulates (28,29).

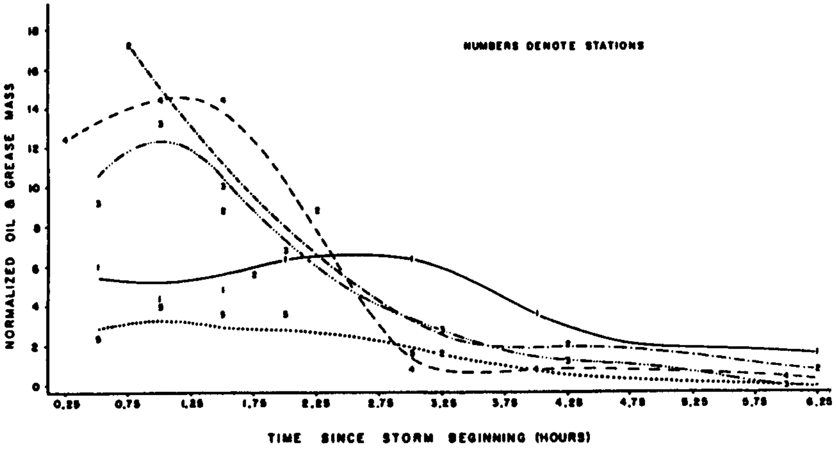

FIG. 1.—Typical Oil and Grease Mass Profiles

TABLE 7.—Distribution of Oil and Grease Compounds in Stormwater Samples as Determined by Gas Chromatograph (X = Present in Sample. Number in Parenthesis = Retention Time, in Minutes)

Sample number (1)	$<n$-C_{10} (2)	C_{10} (4.75) (3)	n-C_{10} to n-C_{16} (4)	n-C_{16} (10.14) (5)	n-C_{16} to anthracene (6)	Anthracene (21.68) (7)	Anthracene to n-C_{24} (8)	C_{24} (32.30) (9)	C_{24} to C_{32} (10)	C_{32} (40.22) (11)	C_{32}+ (12)	Oil and grease concentration, in milligrams/liter (13)
1-1-2					X	X(21.72)	X	X(32.37)	X		X	3.0
1-1-6							X		X		X	12.0
1-1-8					X	X(21.61)	X		X		X	0.8
1-6-1					X		X		X	X(40.16)	X	13.0
1-6-3					X	X(21.56)	X		X	X(40.25)		27.0
1-6-5					X			X(32.76)	X	X(40.18)	X	6.8
1-6-7					X	X(21.61)	X		X	X(40.20)		16.0
2-1-0					X	X(21.62)	X	X(32.36)	X		X	8.8
2-1-2					X		X	X(32.35)	X		X	4.9
2-1-6	X	X(4.76)			X	X(21.71)	X	X(32.23)	X	X(40.17)	X	12.0
2-1-8							X		X		X	0.7
2-6-1						X(21.63)	X	X(32.39)	X	X(40.16)	X	8.6
2-6-3	X	X			X	X(21.73)	X	X(32.37)	X		X	9.2
2-6-5		X			X		X	X(32.28)	X	X(40.21)	X	12.0
2-6-7					X	X(21.55)	X		X		X	17.0
3-1-0					X		X	X(32.29)	X		X	10.5
3-1-2					X		X	X(32.34)	X	X(40.28)	X	11.0
3-1-6					X		X	X(32.25)	X		X	9.5
3-1-8					X	X(21.64)	X	X(32.20)	X	X(40.23)	X	8.9
3-5-2		X					X	X(32.27)	X		X	88.0
3-6-1	X				X	X(21.71)	X	X(32.40)	X		X	9.4
3-6-3	X	X			X			X(32.28)	X	X(40.17)	X	20.0
3-6-5		X			X	X(21.77)	X		X	X(40.24)	X	12.0
3-6-7					X		X	X(32.23)	X		X	35.0
4-1-0					X	X(21.74)	X	X(32.24)	X	X(40.27)	X	13.5
4-1-2		X			X		X	X(32.27)	X	X(40.23)	X	11.0
4-1-6	X X(4.87)	X			X		X	X(32.24)	X	X(40.16)	X	19.0
4-1-9							X	X(32.24)	X	X(40.16)	X	19.0
4-6-1					X	X(21.71)		X		X(40.19)	X	16.0
4-6-3			X		X	X(21.66)	X	X(32.25)		X(40.10)	X	9.8
4-6-5					X	X(27.72)	X		X	X(40.25)	X	8.0
4-6-7	X		X		X	X(21.59)	X	X(32.29)	X		X	21.0
5-1-0					X	(21.69)	X	X(32.23)	X	X(40.17)	X	16.0
5-1-2					X		X	X(32.27)	X	X(40.21)	X	17.0
5-1-6						X(21.70)		X(32.22)	X		X	16.0
5-1-8						X(21.77)			X	X(40.27)	X	5.5
5-6-1					X	X(21.60)	X	X(32.21)	X	X(40.15)	X	6.4
5-6-3					X		X		X			6.3
5-6-5	X		X		X		X	X(32.35)	X		X	13.0
5-6-7					X		X		X	X(40.32)	X	1.7

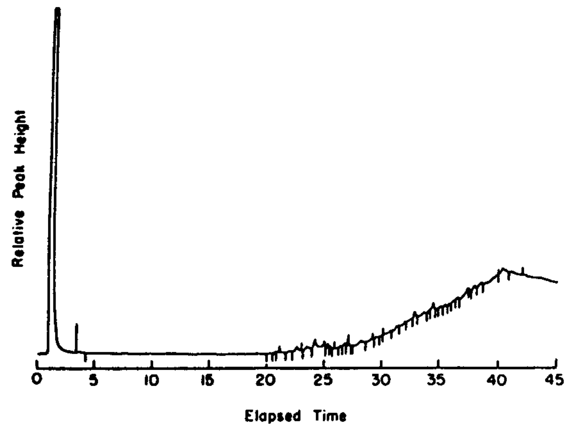

FIG. 2.—Typical Oil and Grease Gas Chromatogram

The identification of the compounds present in the extracts, and the identification of oil and grease source, should only be considered tentative, since chromatography of such a complicated sample is imprecise. Also, the retention times of known compounds used for comparison in Table 7 will not correspond precisely with compounds with an equivalent number of carbon atoms, since isomer compounds containing the same number of carbons will have different retention times.

The results of the settling tests indicated very little tendency for oil and grease to separate from runoff over a 30-min period, as shown in Table 8; however, oil and grease concentration was somewhat higher in the final sampling of the very bottom layer of the water column, perhaps reflecting an association with the suspended solids visible near the column bottom. Unfortunately, these test results are complicated by the relatively large retention of oil and grease on the glassware, as evidenced by the oil and grease concentration in the freon used for final glassware rinse.

Several samples collected in the study showed evidence of spills of specific compounds. Fig. 3 shows a chromatogram which reveals an obvious spill or dumping of material into the storm water system. Spills were detected in two storm events.

SIMULATION AND RECOMMENDATIONS OF OIL AND GREASE CONTROL STRATEGIES

TABLE 8.—Land Use Parameters for Simulation Model

Land use (1)	Area, in acres (2)	K_u[a] (3)	C_u,[b] in milligrams/liter (4)
Open land	85	0.02	0.0
Residential property	1,221	0.19	3.89
Industrial property	70	0.76	7.10
Commercial property	98	1.00	13.13
Parking lots	94	0.94	12.81
Freeways and railroads	59	0.90	7.04

[a] Rational runoff formula coefficient.
[b] Oil and grease concentration.
Note: To convert acres to sq m, multiply by 4,046.8.

A simulation model, ABMAC (18), was used to simulate the implications of land use on oil and grease control techniques. The ABMAC model was used because of its simplicity. The input parameters to the model are the land use characteristics of the watershed, rational runoff coefficients for each land use type, pollutant concentrations per unit of land per unit of rainfall, and a time series of rainfall rate. The model does not consider routing, and the rational runoff coefficients and pollutant parameters are time and space independent. The particular program used in this study allowed for 6 land uses and 99 subareas.

Parameters were developed for the Richmond watershed, as one subarea. Rainfall data were obtained for the years 1975–1980, and oil and grease concentration parameters for runoff water were calculated from the field survey results, shown previously in Tables 5 and 6. Values of rational runoff coefficients and oil and grease concentration for each land use were determined, as shown in Table 8, and used as inputs to the ABMAC model. A rational runoff coefficient of 0.02 was assumed for open land based upon current information taken from the Los Angeles County Flood Control District.

The model was verified by comparing measured and predicted results for Station 1, and all were within 50% of the measured results. The residuals were uniform in that the model both overestimated and underestimated oil and grease mass discharge and runoff discharge, with no trend in the residuals with respect to time or amount of rainfall. This level of model error was judged satisfactory for the intended use of the

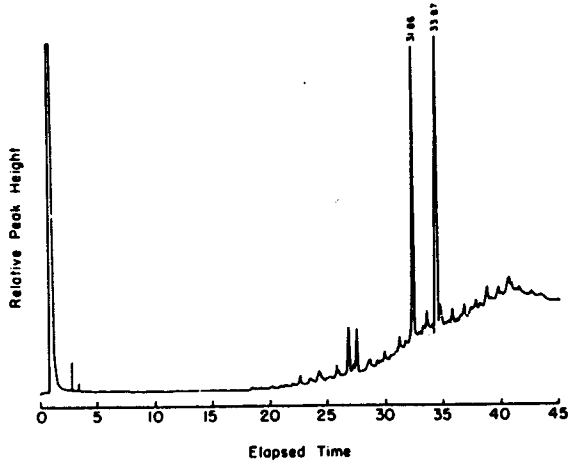

FIG. 3.—Chromatogram Showing an Obvious Spill of Specific Compounds

TABLE 9.—ABMAC Mitigation Simulation—90% Reduction

Model parameters (1)	Annual Pollutant Load (10^3 lb) 1975 (2)	1976 (3)	1977 (4)	1978 (5)	1979 (6)	1980 (7)	Average (8)	Total percent reduction (9)	Percent reduction, percent area (10)
Rainfall, in inches	20.10	9.91	16.08	25.48	27.86	18.01	19.57		
Pollutant load from actual concentrations	18.55	9.15	14.84	23.52	25.71	16.62	18.06		
Pollutant load after 90% reduction in:									
Residential	14.85	7.32	11.88	18.83	20.59	13.31	14.46	19.9	0.27
Industrial	17.00	8.38	13.60	21.55	23.57	15.23	16.56	8.3	1.93
Commercial	13.27	6.54	10.62	16.83	18.40	11.89	12.93	28.4	4.73
Parking lots	13.91	6.86	11.13	17.63	19.28	12.46	13.55	25.0	4.32
Freeways and tracks	17.02	8.39	13.61	21.57	23.59	15.25	16.57	8.3	2.31
Commercial and parking lots	8.63	4.26	6.91	10.94	11.97	7.74	8.41	53.4	4.53

TABLE 10.—ABMAC Growth Simulation

Model parameters (1)	Annual Pollutant Load (10^3 Pound) 1975 (2)	1976 (3)	1977 (4)	1978 (5)	1979 (6)	1980 (7)	Average (8)	Increase, as a percentage (9)
Rainfall, in inches	20.10	9.91	16.08	25.48	27.86	18.01	19.57	
Pollutant load from actual concentrations	18.55	9.15	14.84	23.52	25.71	16.62	18.06	
All open land becomes commercial	23.63	11.65	18.91	29.96	32.6	21.18	23.07	27.7
20% residential becomes commercial	32.32	15.94	25.86	40.97	44.80	28.96	31.98	74.3

Note: To convert annual pollutant load in 1,000 lb to kg, multiply by 454.5.

model results, and no further calibration was attempted.

The model was used to determine the potential results of mitigation and control techniques. Tables 9 and 10 show the results of a series of simulations. Table 9 shows the base case for no controls, and a hypothetical case assuming that 90% reduction in oil and grease discharge from selected land uses could be obtained. As expected, reducing emissions from parking lots and commercial properties produces the most profound effect on overall emissions. Col. 10 in Table 9 is the quotient of percent reduction and percent land area, which is a relative indicator of the potential effectiveness and cost of mitigation techniques. These results show that control of residential areas is the least favorable alternative, based upon mass of oil and grease discharge and land area to be controlled. The data also show that controlling discharges from parking and commercial property, which represents only 11% of land area, would reduce oil and grease emission by over 50%. The growth simulations shown in Table 10 indicate that even a small growth, resulting in the conversion of all open land to commercial property (5% of the watershed area) would increase oil and grease emissions by 25%. The simulations have obvious value for land use planning and environmental impact assessments.

CONCLUSIONS

Oil and grease pollution from urban stormwaters is an important and growing water quality problem. The most significant single identified factor that affects oil and grease pollution in urban runoff is land use. Runoff from commercial properties and parking areas contained an oil and grease concentration nearly three times higher than runoff from residential property. Since commercial and parking properties usually have higher rational runoff coefficients, the mass of oil/grease pollution per unit area for these types of land uses will typically be more than 10 times greater than pollution from open land or residential areas. The hydrocarbon load factor for residential property in this study was 142 lb/sq mile-in. rainfall (9.80 kg/sq km cm), dramatically lower than the hydrocarbon load factor for parking property of 3,460 lb/sq mile-in. rainfall (239 kg/sq km cm).

Oil and grease pollution was found to be independent of all storm characteristics, with the exception of total rainfall. Rate of rainfall, days between storm events, and length of storms had no significant effect on oil and grease concentration, although there was an indication of a modest "first flush" effect.

Oil and grease concentrations were frequently greater in urban runoff than the 15 mg/L standard normally allowed for industrial dischargers to San Francisco Bay. Several studies have shown the presence of toxic hydrocarbon compounds in stormwater runoff, including monoaromatics and polynuclear aromatics (10,17,27). Monoaromatic hydrocarbons have been found regularly in Bay water and in fish and shellfish tissue (7,8,30). Whipple, et al. (28,29,30) have reported that monoaromatics may be contributing to the current decline of the striped bass (*Monroe saxatiles*) and other fisheries in the Bay. Thus the relatively high levels of oil and grease found in urban runoff in this study, and the potential for introduction of aromatics, may indicate that stormwater is a significant pollution contributor to San Francisco Bay.

Simulation of the Richmond watershed indicates that the most favorable mitigation techniques would be those addressing land uses that have high hydrocarbon load factors. For the Richmond watershed, controlling approximately 10% of the land area could result in a 50% decrease in hydrocarbon emission. Future development in the watershed could result in a substantial increase of oil and grease. Potential mitigation techniques applicable to various land uses have been reviewed by Finnemore and Lynard (12) and by Stenstrom, Silverman, and Bursztynsky (26).

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