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16. Abstract A study was conducted on the character and significance of highway runoff waters for the Washington Department of Highways and the Federal Highway Administration. This preliminary appraisal of runoff quality consisted of a literature review and critique plus a limited amount of field sampling on SR 520. Although a large amount of information is present in the literature concerning urban runoff, there is very little strictly related to highways and their rights-of-way. Highway runoff is similar to urban area runoff but may be higher in heavy metals and oil. A significant fraction of the heavy metals, oil and nutrients are adsorbed to the dust and dirt fractions and then may be removed by sedimentation. Runoff from the lake bridges should have a very insignificant effect on Lake Washington in comparison with the urban runoff to the lake. Recommendations are made for mitigating runoff effects and for conducting an intensive study of highway runoff water quality and its significance.				13. Type of Report and Period Covered Final Report May - December 1972	
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CHARACTER AND SIGNIFICANCE OF HIGHWAY RUNOFF WATERS

A PRELIMINARY APPRAISAL

A Study

Prepared for the

WASHINGTON STATE HIGHWAY COMMISSION

DEPARTMENT OF HIGHWAYS

and the

FEDERAL HIGHWAY ADMINISTRATION

by

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December 29, 1972

Mr. H. R. Goff, Assistant Director for
Planning, Research and State Aid
Washington State Highway Commission
Department of Highways
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Olympia, Washington 98504

Re: Agreement Y-1441

Dear Mr. Goff:

We are pleased to submit herewith our study on the "Character and Significance of Highway Runoff Waters, A Preliminary Appraisal", as per Agreement Y-1441, Problem Area Highway Research - Task #1, with the University of Washington.

Since your review of the preliminary draft copy of October 30, we have completed the analysis and evaluation of other previously collected data on runoff from S. R. 520. This primarily includes the heavy metals, sedimentation rates and general runoff water quality. These additional data have been incorporated into the text and the appendices.

In the final preparation of this report, careful consideration was given the draft review comments received from the FHWA, Highway Administrative Offices in Olympia, and District No. 7.

We hope that you find this study of value in your consideration of environmental impacts from highway runoff.

Sincerely yours,



R. O. Sylvester, Professor and Head
Water and Air Resources Division

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The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Washington State Department of Highways or the Federal Highway Administration. This report does not constitute a standard, specification or regulation.

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I SUMMARY

A study on the character and significance of highway runoff was conducted for and financed by the Washington State Highway Commission, Department of Highways and the Federal Highway Administration. It consists essentially of a literature review together with observations made on a limited amount of field sampling done on the runoff and particulate emissions from the State Highway 520 bridge over Portage Bay in Seattle. To this information has been added the observations and critiques of the authors.

The literature contains a wealth of information on urban runoff quality but very little on runoff specifically from highways and their rights-of-way. Information obtained from the literature and from field sampling are insufficient for the development of definite conclusions as to highway runoff and its possible effect on receiving waters. While highway runoff does contain significant quantities of oils, heavy metals, dust and dirt, substances from vehicle wear, litter, and algal nutrients, it does not appear to be very much different in general quality from urban area runoff. Preliminary results indicate that heavy metal concentrations may be higher in highway runoff, but sufficient data are lacking in this regard.

The field investigations conducted as a part of this study involved the calculation of the daily road surface pollutant accumulation in mg/m^2 , an evaluation of these accumulations and subsequent runoff, algal assay tests, settleable solids characteristics, floatable solids characteristics, airborne particulates, and heavy metals. A major portion of vehicle emissions are apparently carried off the road surface by air currents and by splashing. The large sized particulates settle close to the road surface. If they settle on a soil surface, it is likely that most of them

are retained in the soil and do not appear in the right-of-way runoff. This observation needs further checking. A significant portion of the oils, heavy metals and nutrients are adsorbed to particulates and other solids. Removal of these particulates and solids from runoff water will thus also remove the adsorbed oil, heavy metals and nutrients.

As related to the Lake Washington bridges and I-90 runoff into Echo Lake, it was shown with data available that deicing salts should have no significant effect on either Lake Washington or Echo Lake and that bridge runoff into Lake Washington is insignificant as compared to urban area drainage to the Lake.

Recommendations are made for street sweeping on the lake bridges, for the possible installation of a sedimentation basin at Echo Lake, and for a comprehensive study on highway and right-of-way runoff quality and significance.

II INTRODUCTION

Highways, and freeways in particular, require careful consideration of and adequate provision for rainfall runoff to protect the vehicles, the roadbed, adjacent property, and waters of the State that receive the drainage. This study has addressed itself to the latter, the possible impact of freeway use and runoff on receiving waters.

The objectives of this study were: 1) to ascertain the state of knowledge regarding the quality and quantity of highway runoff waters that can be anticipated in the post construction phase under varying conditions of climate, highway usage, antecedent rainfall, topography, soil and vegetation, and type of highway usage; 2) to evaluate the significance of these in respect to different types of waters receiving the runoff; 3) to relate and assess this information to Washington highways with particular reference to I-90 Echo Lake vicinity, SR 509 Duwamish River crossing, the existing Lacey V. Murrow Bridge, and the new Lake Washington bridge; 4) to determine what additional research, data, etc. if any, is required to properly assess the character and significance of highway runoff as related to Washington highways; and 5) to determine what actions might be taken by the Department to mitigate highway runoff problems if and where they are found to be of concern.

During the construction phase, there are many environmental quality problems that must be handled to minimize adverse effects. One of these is the problem of runoff erosion control. Since this is a one-time problem separate from normal freeway usage and drainage, it is not considered in this study. Furthermore, it is a situation with different causes and

effects.

The construction and use of a freeway introduces two general perturbations into the environment as related to runoff water. The first involves a change in the quantity of runoff due to the creation of large impervious areas, changes usually in local drainage patterns, the rate of runoff and the concentration of runoff into point, or multiple point sources. The second involves a change in runoff water quality because of a change in the character of the right-of-way surface and because of the depositions from vehicular traffic; residues from burned and unburned fuel and wearing tires, flushing of vehicle underbody accretions and components, lubricants, road material erosion, and the deposit of litter. Table 1 gives a more complete listing of those items affecting freeway runoff water quality. Atmospheric fallout is not directly related to freeway use but is a factor to consider in the overall assessment.

The procedure in this study consisted essentially of a literature review and the collection and analysis of 94 freeway runoff samples, from a bridge area of S. R. 520, to obtain a gross idea of their constituents since very little data were found in the literature.

Table 1. Sources and Constituents That Affect Freeway Runoff Water Quality

Source	Constituent
1 Vehicles	Lubricants, hydraulic fluids, coolants, rubber from tires, dirt carried on under carriages and fenders, wearing vehicle components, fuel residue, particulate exhaust emissions, brake and clutch lining materials.
2 Street surface material	Asphalt and its decomposition products, Portland cement, aggregates, road marking paint, expansion joint compounds, crack fillers.
3 Atmospheric fallout	Deposited airborne materials.
4 Runoff from adjacent areas	Silt, leaves, grassclippings, soil stabilizers, growth control compounds.
5 Litter	Tobacco and numerous other items.
6 Spills	Oil spills, chemical spills, etc.
7 Ice control compounds	Salt and additives.

III LITERATURE REVIEW

The environmental impact of transportation has primarily been studied from the standpoint of air pollution because it is responsible for about 42% of all pollutants discharged into the atmosphere (Hoffman, 1970). The emission from the motor vehicle specifically accounts for approximately 39% of all emitted air pollutants. As a large part of the emissions are concentrated near highways, several studies have been conducted to measure the air pollution from highways (Middleton and Ott, 1968). However, the impact highways may have on water and soil has never been studied extensively. The possible detrimental effects of highways on water quality can both be the result of vehicle emitted airborne matter that settles and reaches the surface of adjacent waterways, and from rainwater that washes pollutants from the highway surface or right-of-way area and is discharged into a nearby lake or stream. Pollution, mainly erosion, may also be generated during construction of highways.

It is virtually impossible to precisely estimate the amount of pollutants that reach the road surface from source emission calculations alone, because the pathways that the pollutants travel are highly variable and unmeasured. Therefore, it is more precise to measure the amount of pollutants that are washed off the road surface during a rainstorm and to measure the vehicle released airborne matter that settles out. Very few studies have been made in this respect. Most of the runoff quality studies relate to urban areas and not specifically to roadway runoff. Street and paved area runoff is not directly comparable to freeways or highways because runoff onto the city streets from adjacent land areas

differs from most right-of-way runoff and there are different air turbulence patterns. The only studies that have computed pollutant loadings from a specific area expressed on a weight-time-area basis are studies that measure the pollutants in storm drains from a relatively large area that is usually urbanized. In such a situation the pollutants are generated from paved and unpaved areas where the percentage of roadsurface and its pollution contribution is relatively small compared to that from roofs, lawns, sidewalks, parking areas, etc. Two studies have been undertaken that measured the contaminants from street surfaces collected during street sweeping and two studies (in addition to the one by the authors) are reported where the runoff quality was measured directly from the highway surface. These latter studies were quite limited in scope.

A large number of papers and reports were reviewed as shown in the list of references herein. The discussion below reports typical data from the literature.

A. Direct Highway Runoff:

Soderlund et. al. (1971) measured the concentrations in meltwater from a 55,000 vehicles-per-day highway in Stockholm. Maximum volatile¹ dissolved solids reached a concentration of 1600 mg/l (1 mg/l VDS approximately equals 1 mg/l COD) while the SS reached 1250 mg/l, lead 100 mg/l, and the oil 105 mg/l, which were about twice the values recorded for meltwater from residential blocks. The BOD, total-N and total-P concentrations were similar to those for the residential areas. The mean lead and oil concentrations were 18 and 21 mg/l respectively. Use of studded tires on asphalt was given as one of the reasons for the high runoff concentra-

1. See Appendix C for Glossary

tions. In extended research, Soderlund and Lehtinen (1972) compared the loading of the pollutants (in $\text{mg}/\text{m}^2\text{day}$) with loadings of residential areas. As shown in Table 2, they found higher loadings for highways than for residential areas, but a comparison of the residential areas in Stockholm with similar values in the US indicates much higher loading contributions in the US, probably due to more disciplined attitudes in Sweden towards refuse and litter disposal.

In a preliminary study for the Municipality of Metropolitan Seattle, Dalseg and Farris (1970) found mean concentrations of 557 mg/l COD, 355 mg/l SS, 44 mg/l oil, 1.54 mg/l inorganic-N and 0.26 mg/l ortho-P in runoff water from the 73,000 vehicles/day northbound section of I-5. Median total and fecal coliform values were 3400 and 130/100 ml respectively. During the first runoff "flush" the COD and SS could reach concentrations of 3000 mg/l and 3700 mg/l respectively. Because of the limited nature of this study no attempt was made to compute the pollution load of the highways and the accumulation of pollutants during periods in between rainfalls. In both studies, no attempt was made to calculate the rate of wash-off of the accumulated pollutants nor did they measure most of the various heavy metals that might be present.

B. Urban Street and Arterial Runoff:

Table 3 summarizes literature data for runoff constituent concentrations originating from paved and unpaved areas. It is apparent that only a few studies involved road surface sample collection and these were affected in some instances by flow contributions from adjacent land areas.

Table 2. Pollutant Loadings From Urban Stormwater, Highways and Street Sweepings

Author	Weibel et al (1964)	Wilkinson (1956)	Friedland et al (1971)	Avco (1970)	Burm et al (1968)	APWA (1969)
City	Cincinnati (2)	Oxney(GB)	San Fran.	Tulsa (Old)	Ann Arbor	Chicago (1)
Land Use	Residential	Resid.	Urban	Urb/Resid	Urb/Resid	Urb/Resid
Constituent (mg/m ² day)						
Susp, Solids	215.0(3)	30.2	367.0	367.0	1230	3260
Floatable solids			3.25			
Settleable solids					950	
COD	70.8		165.0	59.0		170.0
BOD	9.7	1.95		7.98	37.7	12.0
Total-P	0.24				3.42	0.053
Ortho-P			1.18	0.74	1.1	
Total-N	2.62		8.25		2.32	1.63
Org, NH ₄ -N				0.48	1.34	
Oil			17.7			
Total salts						
Cr						
Cu						
Zn						
Pb						
Ni						
Hg						
Use intensity (4)	22 $\frac{\text{inh}}{\text{ha}}$	5 $\frac{\text{inh}}{\text{ha}}$	97 $\frac{\text{inh}}{\text{ha}}$	27.5 $\frac{\text{inh}}{\text{ha}}$		

(1) amount collected in street sweepings within 15 ft. of curb.

(2) constituents of rainfall are SS: 13.0 mg/l, COD: 16 mg/l, inorg. N: 1.3 mg/l, Total-P: 0.24 mg/l.

(3) 69% from dustfall.

(4) $\frac{\text{inh}}{\text{ha}} = \frac{\text{inhabitants}}{\text{hectare}}$

Table 2 continued.

Author	Sartor et al (1972)	Johnson et al (1966)	This Study	Soderlund and Lehtinen (1972)			Bryan (1972)
City	Chicago (1)	Seattle (2)	Seattle	Stockholm			Durham N.C.
Land Use	Urb/Resid	Urb/Resid	Highway	Highway	Terrace Housing	Resid.	Urban
Constituent (mg/m ² day)							
Susp. Solids		158.0	155.0	325	48	170	4900(4)
Floatable solids			5.08				
Settleable solids			56.2				
COD	287	41.0	82.0	166(3)	18	49	320
BOD	60			27.5	3.85	11.9	25.8
Total-P			0.125	0.06	0.01	0.04	1.12
Ortho-P	3.6	0.088					
Total-N	12	0.37	4.4	1.4	0.38	0.95	
Org, NH ₄ -N							
Oil			12.5	14.2	0.03	0.66	
Total salts		44.8		68.0	63.0	36	
Cr	1.2		<0.01				
Cu	2.4		0.09		0.04		
Zn	7.8		0.95		0.05		
Pb	5.3		2.35		0.20		
Ni	0.5		0.08				0.68
Hg	0.8						
Use intensity			39,000 cars per day	65,000 cars per day	35 <u>inh</u> ha	100 <u>inh</u> ha	22 <u>inh</u> ha

- (1) amount collected in street sweepings within 15 ft. of curb.
(2) amount collected in dustjars.
(3) assuming 1 mg VDS equals 1 mg/l COD.
(4) Total solids

Table 3. Runoff Constituent Concentrations From Paved and Unpaved Areas
(values in mg/l unless otherwise noted)

Author	Site	City	COD	BOD	Total Solids	Suspended Solids
Palmer (1950)	downtown street catchbasins	Detroit		96-234	310-914	
Palmer (1963)	"	"				102-213
Wilkinson	runoff from estate	Oxney (GB)		100*		2045*
Shigorin (1956)	downtown streets	Moscow (USSR)		186-285		1000-3500
		Leningrad (USSR)		36		14541
Sylvester (1960)	residential streets, parks	Seattle	188	10	300	
Akerlinch (1960)		Stockholm		17		
Stander (1961)	residential	Pretoria (SA)	29	30		
	business res/comm.	"	28	34		
Weibel et al (1961)		Cincinnati	99	19		210
APWA (1969)		San Fran.		87		613
"		L. Angeles		161		
"	catchbasins	Wash. D.C.		126		2100
Mische (1971)	resid. area	Tucson	185		1394	
Escritt (1954)		Sheffield (GB)				263-1335
		Heywood				180-2380
AVCO (1970)	res/downtown	Tulsa	85.5	11.8	545	367
Dunbar and Henry (1966)		Toronto		12-19		150-430
Weston et al (1972)		Welland		19		58
		Wash. D.C.		19		1697
Soderlund et al (1971)	highway	Stockholm		22*		1250*
Angino et al (1972)	campus	Lawrence	41	11.4	1180	974
Pravoshinsky and Gatillo (1969)	streets	Minsk (USSR)		6.1-223		30-8300
Burmetal (1968)	res/comm.	Ann Arbor		42	2430	1370
Simpson and Curtis (1969)	res/comm.	Cleveland	35	15		30
Dalseg and Farris (1970)	highway	Seattle	557	71		355

* max. concentration

** Organic N

Table 3. Runoff Constituent Concentrations From Paved and Unpaved Areas
(values in mg/l unless otherwise noted) (cont'd)

Author	Site	City	Oil	Total N (NO ₃ , NO ₂)	Lead Pb	MPN/100ml Coliform	Total P (Ortho)
Palmer (1950)	downtown street catchbasins	Detroit				2.5-93x10 ⁴	
Palmer (1963)	"	"					
Wilkinson	runoff from estate	Oxney(GB)				0.23-43x10 ⁴	
Shigorin (1956)	downtown streets	Moscow (USSR)					
Sylvester(1960)	residential streets, parks	Leningrad (USSR)					
Akerlinch(1960)	residential	Seattle	59	11.8		1.6lx10 ⁴	1.4(0.78)
Stander (1961)	business res/comm.	Pretoria (SA)		5.4**		0.4x10 ⁴	
Weibel et al (1961)	res/comm.	"		3.5**		24x10 ⁴	
APWA (1969)	catchbasins	Cincinnati	1	2.75		23x10 ⁴	(0.26)
"	res. area	San Fran.		(0.45)		5.8x10 ⁴	
Mische (1971)	res. area	L. Angeles				1.2x10 ⁴	
Escritt (1954)	res/downtown	Wash. D.C.		(1.6)		42	<1.0
AVCO (1970)	res/downtown	Tucson					
Dunbar and Henry (1966)	highway	Sheffield (GB)		0.85**		8.7x10 ⁴	(1.15)
Weston et al (1972)	highway	Heywood		2.1			1.3
Soderlund et al (1971)	campus	Tulsa	12*	0.9*	18*		0.09*
Angino et al (1972)	streets	Toronto		(4.4)			
Pravoshinsky and Gatillo (1969)	streets	Welland					
Burmetal (1968)	res/comm.	Wash. D.C.					
Simpson and Curtis (1969)	res/comm.	Minsk (USSR)	8-223				
Dalseg and Farris (1970)	highway	Ann Arbor		2.6(1.1)		120x10 ⁴	1.3(0.44)
		Cleveland		3.1(0.1)			0.7
		Seattle	44	1.54		0.34x10 ⁴	(0.26)
				(1.37)			

* max concentration

** Organic N

Palmer (1950) measured the concentration of several pollutants in downtown street catchbasins and some short studies were conducted in the USSR. Sylvester and Anderson (1960, 1964) took 35 runoff samples from gutters of heavily travelled arterials, arterials, and residential streets during a six-month period. In several cases the samples were collected within an hour from the start of the rainfall but for some it had already rained for several hours. The authors were not able to catch the most concentrated first flush and also did not correlate their reported concentrations with traffic intensity. As part of this study a re-evaluation was performed of their data using City of Seattle traffic data and correlating these with the pollutant concentrations. It was found that better coefficients of correlations are obtained when pollutant concentrations were correlated with the logarithm of the traffic intensity. The highest coefficients in this study were obtained with the total P, turbidity and oil (Table 4).

Table 4. Co-efficient of Linear Correlation Between the Logarithm of the Traffic Intensity and the Concentration of Pollutants in the Runoff Water (Sylvester and Anderson, 1960) and the Concentration of Pollutants in Streetsweeping (APWA, 1969)

Author	Pollutant								
	SS	COD	BOD	Tot-N	Tot-P	Turb	Oil	Salts	Mean
Sylvester and Anderson (1960)				0.31	0.49	0.46	0.36		0.41
APWA (1969)	0.13	0.12	0.29	0.05	0.28			0.32	0.20

Similar computations were performed with APWA (1969) data of traffic intensity and concentration of pollutants in street sweepings which gave the highest coefficients for total P, BOD and salts. The lowest coefficients were found for total N and COD, which may indicate that these pollutants are more influenced by other factors such as landuse, dustfall and dirt accumulation. This conclusion is corroborated by the fact that Sylvester and Anderson reported that the total N concentrations (especially the NH_3 and organic fraction) increased sharply with an increasing dry period prior to the runoff.

The relatively lower coefficients in the APWA study may indicate that street sweeping does remove a considerable part of the larger sized particles that would appear in runoff water, but not the smaller particles that are generally associated with some of the pollutants. (Sartor et al 1972, conclude that..."it appears that the sweeping operation has moved much of the material out of the gutter but has tended to redistribute it on areas which were, prior to sweeping, somewhat cleaner.")

It is also interesting that their lowest coliform concentrations were obtained either after a long dry period or after a period of extensive rainfall. Apparently the drying out of the dirt and dust diminishes the coliform concentrations as would be expected. After extensive rainfall, the coliforms have been washed away.

C. Urban Area Runoff Quality:

Numerous studies have measured pollutants in stormwater from urban areas, a majority being shown in Table 3. Only five of these studies have

measured the pollutant loading (weight/area) from the measured area (Table 2). Most notable is the Cincinnati study (Weibel et al 1964) which showed that the stormwater contribution, compared to that of municipal sewage from the same area, indicated that the SS contribution on a kg/h. year base was 140 per cent of the municipal sewage load, VSS 44, COD 25, BOD 6, total P 9 and, total N 11 per cent.

Data from Table 2 indicate that the constituents of the different areas are in reasonable agreement with each other and also an increase in loading is observed with increasing population density.

The coliform organisms found in the urban runoff water indicated the presence of excreta from warm blooded animals since both fecal coliforms and fecal streptococci were found in a ratio of 0.5, 0.1 and 0.59 (Geldreich et al 1968, Cleveland et al 1969, Burm and Vanyhan 1966 respectively). These fecal coliforms probably originated mostly from pets and birds. It is unlikely that freeway right-of-way runoff with its coliform bacteria content would have any sanitary significance since human access to freeway rights-of-way is carefully restricted.

In the Cincinnati study Weibel et al (1964) measured the reduction in the concentration of the constituents when portions were allowed to settle for 20 min. The range of SS reduction was 27 to 53 per cent, depending on the raw concentration. Similarly, reductions of VSS, BOD and COD ranged from 17-50, 3-17, and 5-34 per cent respectively.

More extensive tests on runoff water from 50 storms (Evans et al, 1968) showed SS reduction of 38 per cent and BOD, VSS and COD reduction of 13, 37, and 19 per cent respectively after 20 min. sedimentation. The SS removal would increase to 70 per cent after four hours of sedimentation.

Data are not shown on the reduction in oil, metals and floatables through use of high-rate sedimentation units.

In the studies reported in Tables 2 and 3, several constituents were measured that clearly originated from vehicles. High oil concentrations were, for example, reported by Friedland et al (1970). Angino et al (1972) also found bromide and iodide from oil additives present in most samples of University of Kansas campus runoff. The latter two constituents could reach concentrations of 5 mg/l and 1.3 mg/l respectively. Lead was not found in any filtered sample but was present in every suspended matter sample. Analysis gave a mean lead concentration of 0.31 per cent in the sediment load. This may indicate that the suspended solids can scavenge trace metals from the water. Dalseg and Farris (1970) found freeway runoff water colored a bright yellow due to calcium bromide, a gasoline additive.

D. Vehicle Exhaust Emissions - Exhaust, Wear, Spills

Several studies have been conducted that measured the amount of pollutants in vehicle exhaust emissions. A summary was presented by Duprey (1968) and is shown in Table 5. These data and other however, do not show what fraction of the emissions are retained on the road surface or the right-of-way. It is expected that some of the larger particulate matter (larger than 1-10 μ) may settle out and may also deposit some substances that are adsorbed to it.

Tufts (1959) using a microscopic spot test, found a large number of particles in the 1-5 micron (μ) range on samples taken within 10 feet of moving automobiles but noted no significant mass of lead in particles

larger than 1μ . Mueller et al. (1964) also concluded that up to 68 per cent of the mass of lead in exhaust aerosol particles was contained in particles less than 0.3μ in diameter. From 62-80 per cent of the particulate mass consisted of particles below 2μ . In more recent studies Lee et al (1971) reported 95 per cent of the measured lead in auto exhaust being associated with particles smaller than 0.5μ . As a result of irradiation by sunlight the percentage of soluble lead in the particulate matter increased from 70 to 85 per cent. The exhausted nitrate was associated with even smaller particles.

Also numerous particulates are discharged through the blow-by which consist almost entirely of unchanged lubricating oil (anon, 1962). Cukor et al (1972) measured particulate matter concentrations of $39-206 \mu\text{g}/\text{m}^3$ near a freeway and found that the benzene extractable fraction, ranging from 2.2-12.1 per cent of the particulate matter, closely resembled lubricating oil.

In a particulate matter survey of five major cities (Anon, 1969) an average of 19.2 per cent of the particulate matter emitted by motor vehicles was emitted by diesel powered vehicles that amounted to two per cent of the traffic intensity.

Lead has been added to most gasoline since 1923 (Hall 1972) as an antiknock agent in the form of tetraethyllead or tetramethyllead. Today, the amount of TEL ranges from 2 to 4 g/gal. gasoline. The antiknock fluid contains lead alkyls and organic scavengers, ethylene dichloride, and dibromide, whose function is to combine with the lead to form inorganic lead salts, chiefly bromochloride. These inorganic lead salts are mostly retained in the exhaust system at low speeds and then discharged in

increasing quantities as the vehicle speed increases. The discharged lead is deposited along the roadway, the right-of-way, and some fraction is carried away, all being dependent upon the roadway configuration, traffic speed, and meteorological conditions. Environmental Science and Technology, 4, 3 (March, 1970) carries a number of articles relating lead in soils and plants adjacent to highways.

Table 5. Emission Factors for Automobile Exhaust (Duprey, 1968)

Type of emission	Emissions		
	pounds per 1000 vehicle-miles	pounds per 1000 gallons of gas	pounds per vehicles-day
Aldehydes (HCHO)	0.3	4	0.007
Carbon monoxide	165.0	2300	4.160
Hydrocarbons (C)	12.5	200	0.363
Oxides of nitrogen(NO_2)	8.5	113	0.202
Oxides of sulfur(SO_2)	0.6	9	0.016
Organic acids(acetic)	0.3	4	0.007
Particulates	0.8	12	0.022

Prince, 1957, reported the lead content of soils near highways to range between 14 and 96 ppm. Singer and Hanson (1969) found mean accumulations of 240 ppm lead at a distance of 1.5 m. from highways but it reached a constant value of 75 ppm at a distance greater than 15 m. from the roadside. A sample 1.5 m from the roadside with the highest traffic volume (64,000 cars/day) had a concentration of 700 ppm while the highway with the lowest traffic (1900 cars/day) gave a concentration of 128 ppm.

Lagerwerff and Specht (1970) found concentrations of 0.94 ppm Cd, 7.4 ppm Ni, 540 ppm Pb and 162 ppm Zn in top soil 8 m away from the 48,000 car/day Washington-Baltimore Parkway. The metal concentration gradients with increasing distance followed the order Cd>Pb>Zn>Ni. The concentrations of N, P and Cl also decreased as a function of distance from traffic. The authors ascribed the Pb from combustion of leaded gasoline, the Ni from atmospheric abrasion of Ni containing automobile parts. The joint presence of Zn and Cd was traced back to the common lubricating oil additive; antioxidant Zn-dithiophosphate, which resulted in a Cd concentration in lubricating oil of 0.20-0.26 ppm. Use of technical Zn-oxide and Zn-diethyl or dimethyl carbonate in rubber vulcanization may also introduce Cd as an impurity. Cadmium concentration in rubber ranges from 20-90 ppm.

Similar findings are being reported by Toukada (1972) of the University of Washington who calculated a Pb accumulation of 150 kg/year in the bottom muds of Hall Lake, a small lake adjacent to I-5. However, when the particles with which the lead is associated keep in suspension, the lead may accumulate in the foodchain. Pagenkopf (1972) reported for example, an increased lead content in trout in the West Gallatin River where it runs adjacent to I-191 in Montana.

The effect of nutrients in surface runoff on lake eutrophication has been documented. Goldman and Armstrong (1969) found that a stream draining urbanized areas into Lake Tahoe stimulated algal growth in the later spring. However, Emery et al (1972) found no stimulation from runoff into Lake Sammamish possibly due to the presence of inhibitory substances or an excess of nutrients already present prior to the urban runoff input.

Accidental spills can occur on highways as a result of the transport

of some 68,000,000 tons of petroleum products and 6,000,000 tons of chemicals (Scheidt, 1967, Burke, 1964) and several instances have been reported that nearby groundwater wells were polluted due to penetration of spilled substances in the groundwater.

E. Deicing:

Snow and ice control on highways involves ploughing, use of abrasives and salts. These salts, such as sodium chloride and calcium chloride, are usually mixed with and distributed with the abrasives (sand). Special additives are found in some deicing salts. These include complex cyanides for anti-caking effects and chromate or phosphate compounds for corrosive inhibition (Anon 1971). In some locations these deicing salts have had adverse effects on roadside vegetation and on surface and groundwater supplies. Salt causes a taste problem in water; small amounts of the toxic cyanides and chromates harm water biota and are cause for rejection of public water supply use; and the phosphates may stimulate undesirable aquatic growths. The effect of these deicing salts in any given instance is dependent upon the rate of application, the amount of diluting water receiving the runoff, the rate of runoff, and the nature of the roadside vegetation. Dumping of large quantities of snow and ice, containing the deicing chemicals and other roadsurface contaminants, into bodies of water for disposal may greatly increase the adverse effects (not a practice of the WSHD).

Road salts are usually applied at rates of 400-1200 pounds of salt per mile per application, which may result in over 100 tons per mile being applied per season to some critical highway areas (Anon 1971).

F. Heavy Metals:

Only one study listed heavy metals (Sartor, 1972) that were specifically collected from road surfaces and were not a composite of urban drainage. Sartor's et al data (see Table 2) were collected in ten cities (representing different street usage and areas served) by analyzing street sweepings from along the gutter and including the road surface within 15 feet of the gutter. They found the average removal effectiveness of street sweeping to be 56 per cent for the dirt/dust fraction, 44 per cent for the heavy metals, and 38 per cent for BOD etc. These values show a significant amount of toxic material that can be washed into a receiving water, particularly if rainfall washoff removes more than the sweeping process and if it also includes highway originated metals from the adjacent right-of-way that were deposited there by air currents.

IV FIELD INVESTIGATIONS

The literature search revealed a dearth of information on water quality for runoff waters originating solely on road surfaces or highways and their right-of-way. To better define the runoff quality problem, or lack thereof, a limited study was made on freeway runoff quality and quantity as part of this investigation.

A. Procedure:

Runoff samples were collected from six drains on the bridge section of State Highway 520 over Portage Bay and near the southern edge of the University Campus. Figure 1 illustrates the sampling site. Meteorological data were obtained from the Portage Bay station of the National Weather Service Air Pollution Observation Unit, located about 50 meters north of the sampling site (Table 6).

Runoff samples were collected from the six drains during four June, 1972 rainstorms, the first occurring after a 16-day dry spell. During each storm the runoff water was collected in 1 m³ boxes lined with plastic. An integrated sample was taken about every 10 minutes after which the large box was emptied again. Because the first runoff flush contains most of the settleable and floatable solids, the entire content of the boxes containing the initial flush was set aside and the floatable solids were removed from the liquid with a skimmer. The settleable solids were collected after 30 minutes of settling. Both fractions were dried for further testing. The water samples were filtered through a Whatman 42 filter to determine suspended solids (SS) and analysed for NO₂ and NO₃ nitrogen (N), and ortho-

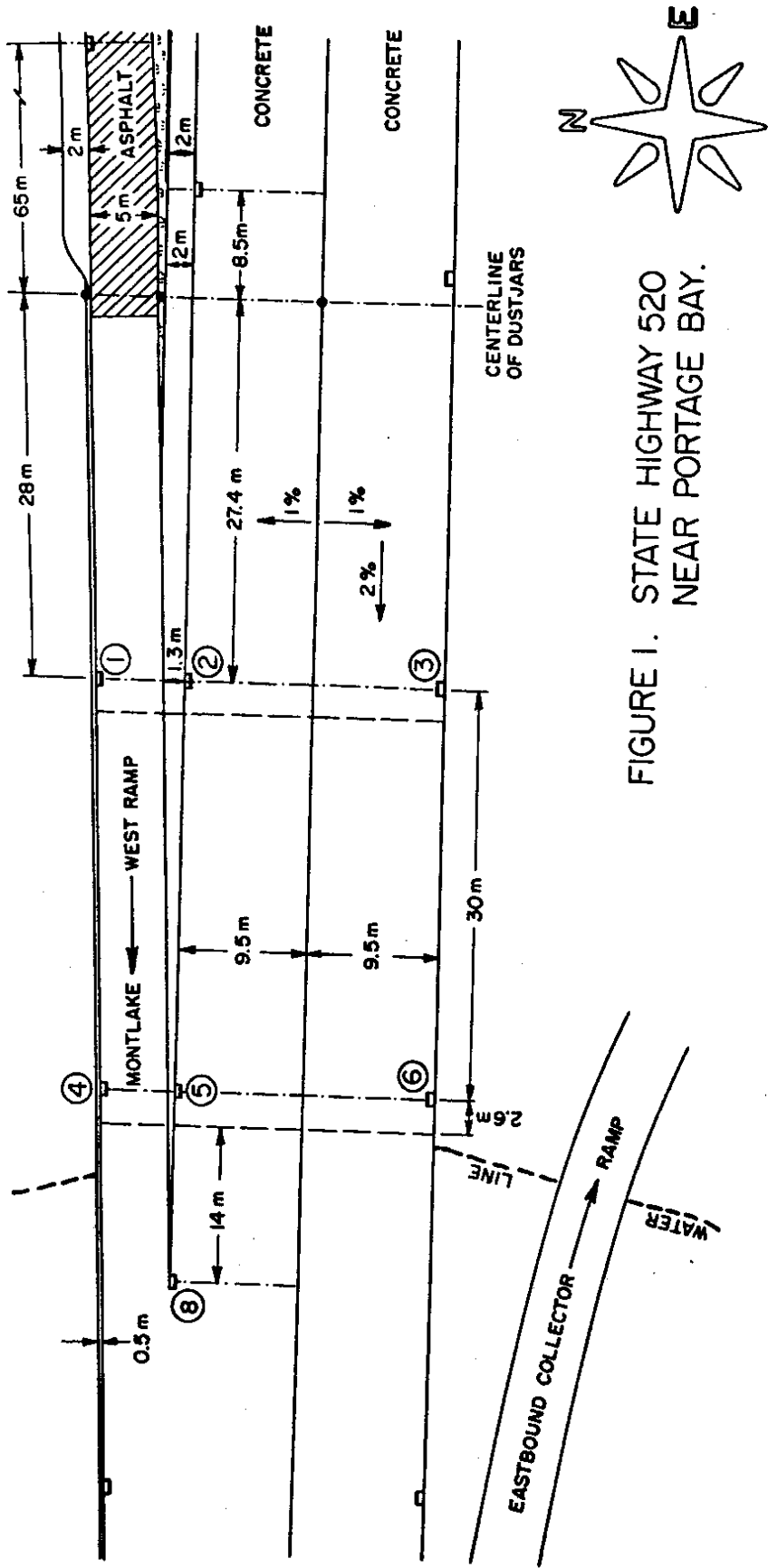
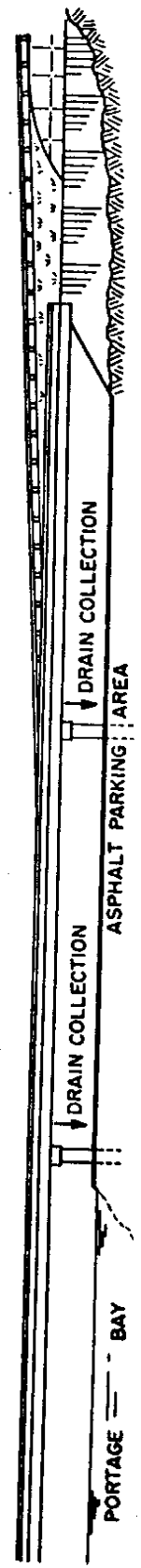


FIGURE 1. STATE HIGHWAY 520 NEAR PORTAGE BAY.



PROFILE OF HIGHWAY 520 AND MONTLAKE WEST RAMP

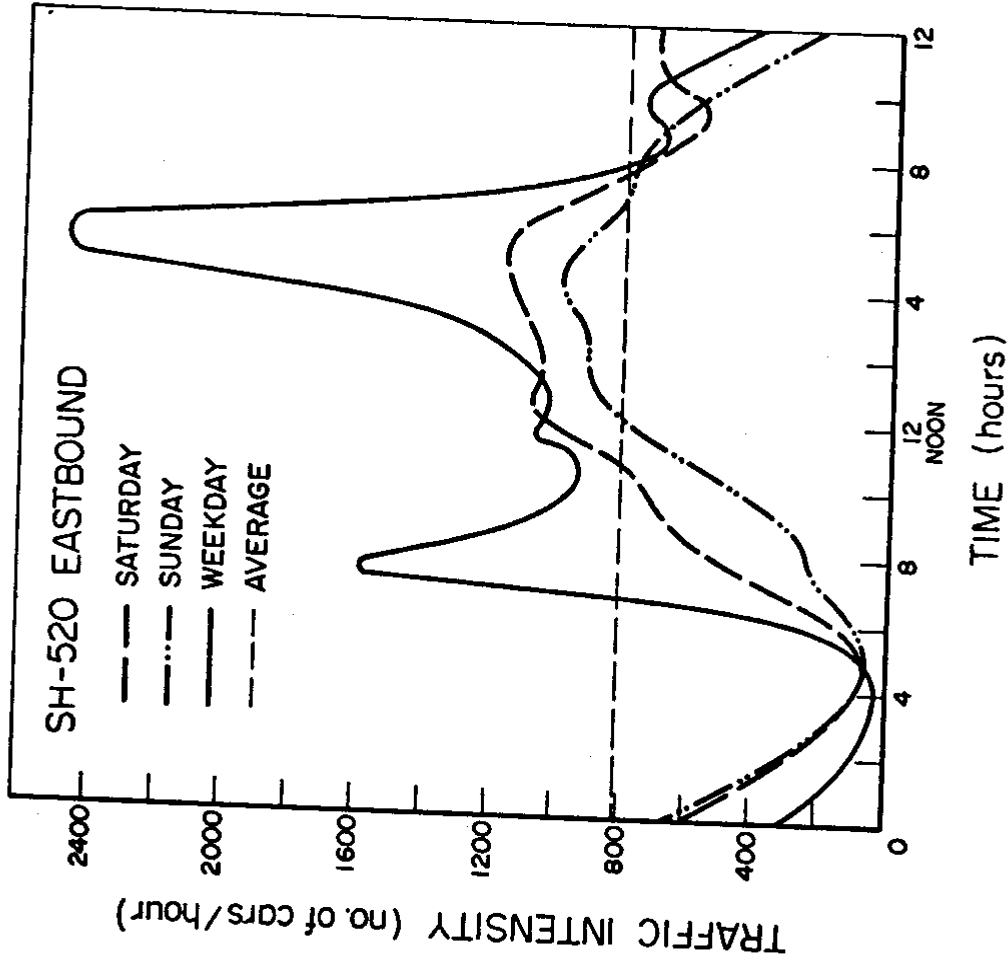
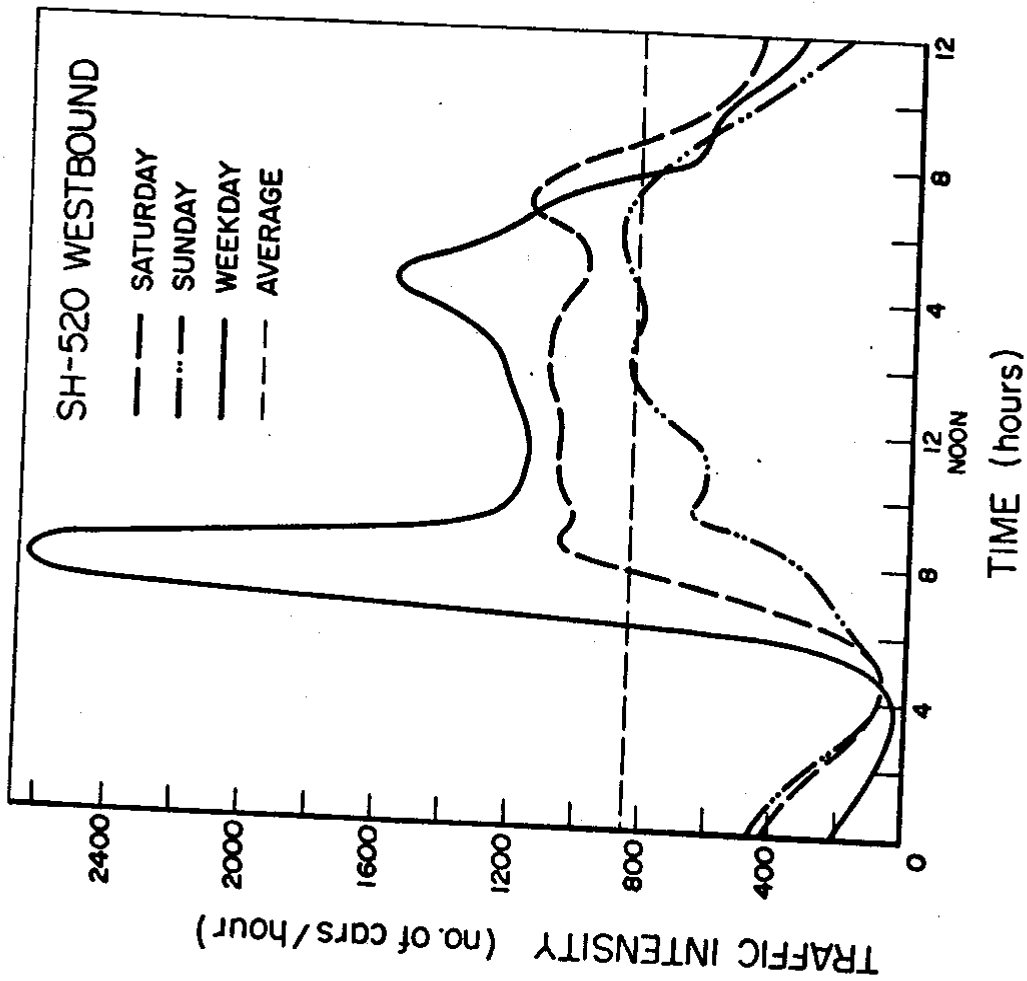


FIGURE 2. TYPICAL TRAFFIC INTENSITY DURING THE DAY FOR THE EAST & WESTBOUND LANES OF STATE HIGHWAY 520 NEAR PORTAGE BAY.

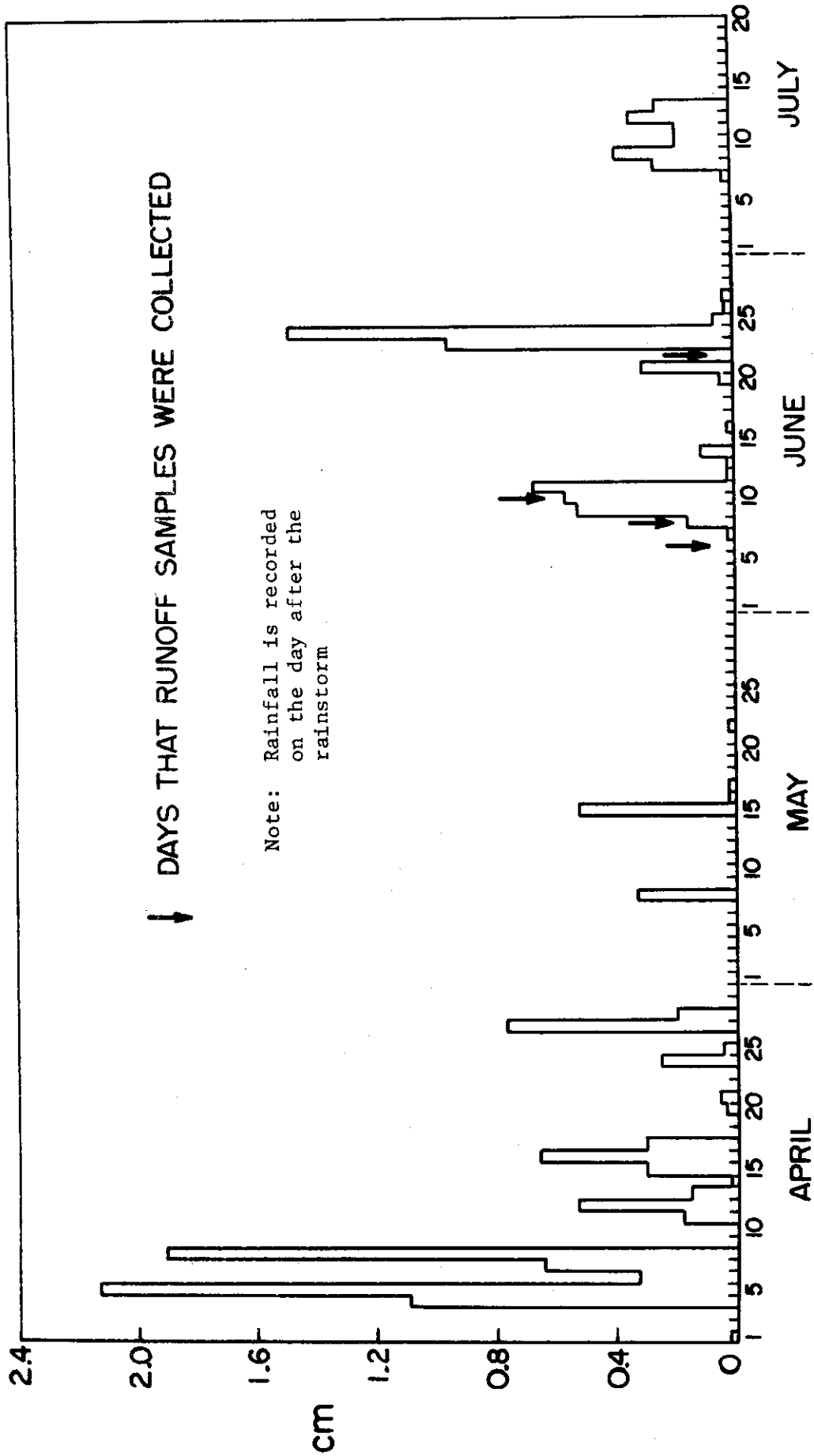


FIGURE 3. TOTAL RAINFALL AT THE PORTAGE BAY STATION.

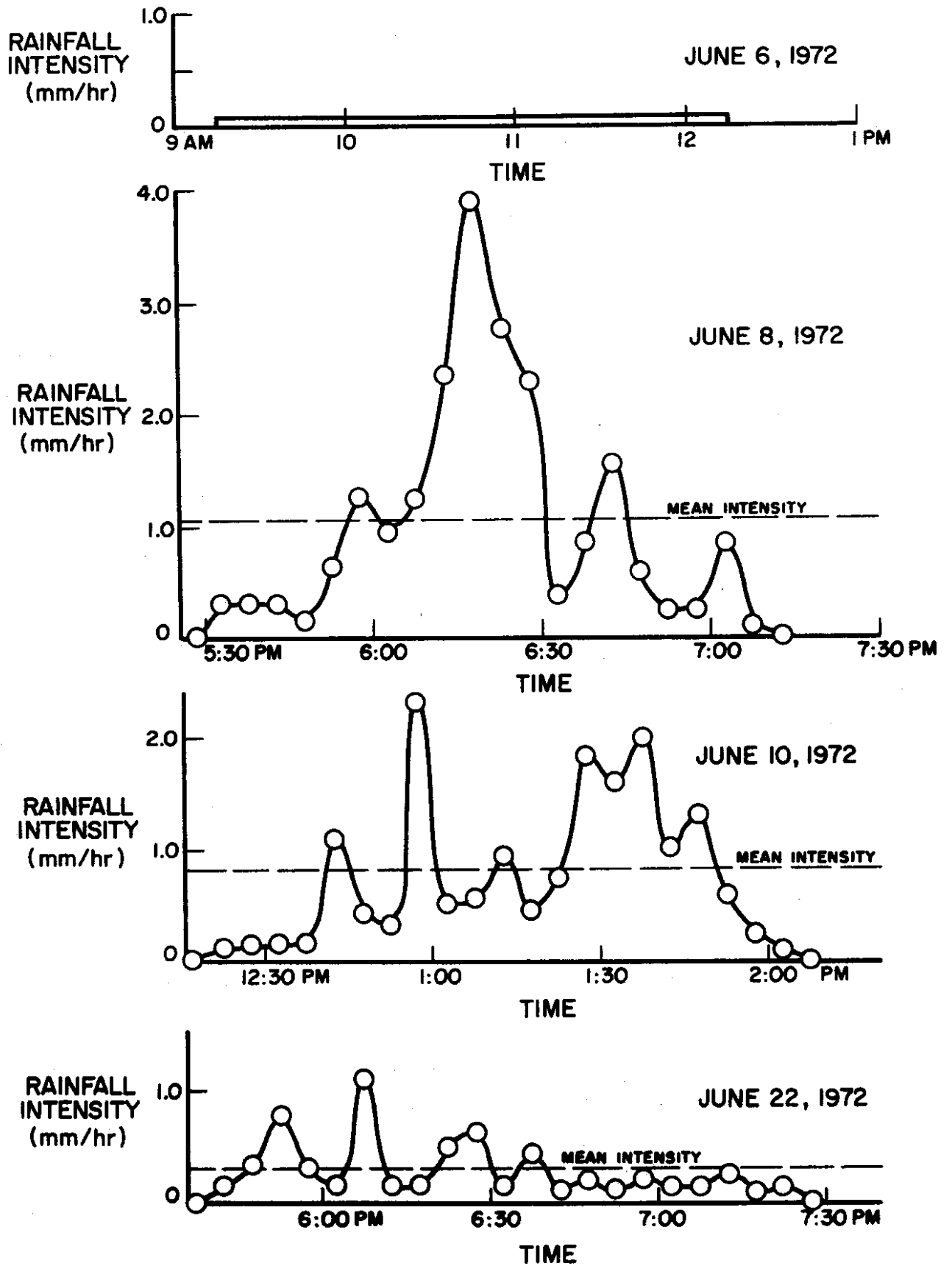


FIGURE 4. RAINFALL INTENSITY ON THE FOUR DAYS THAT RUNOFF SAMPLES WERE TAKEN.

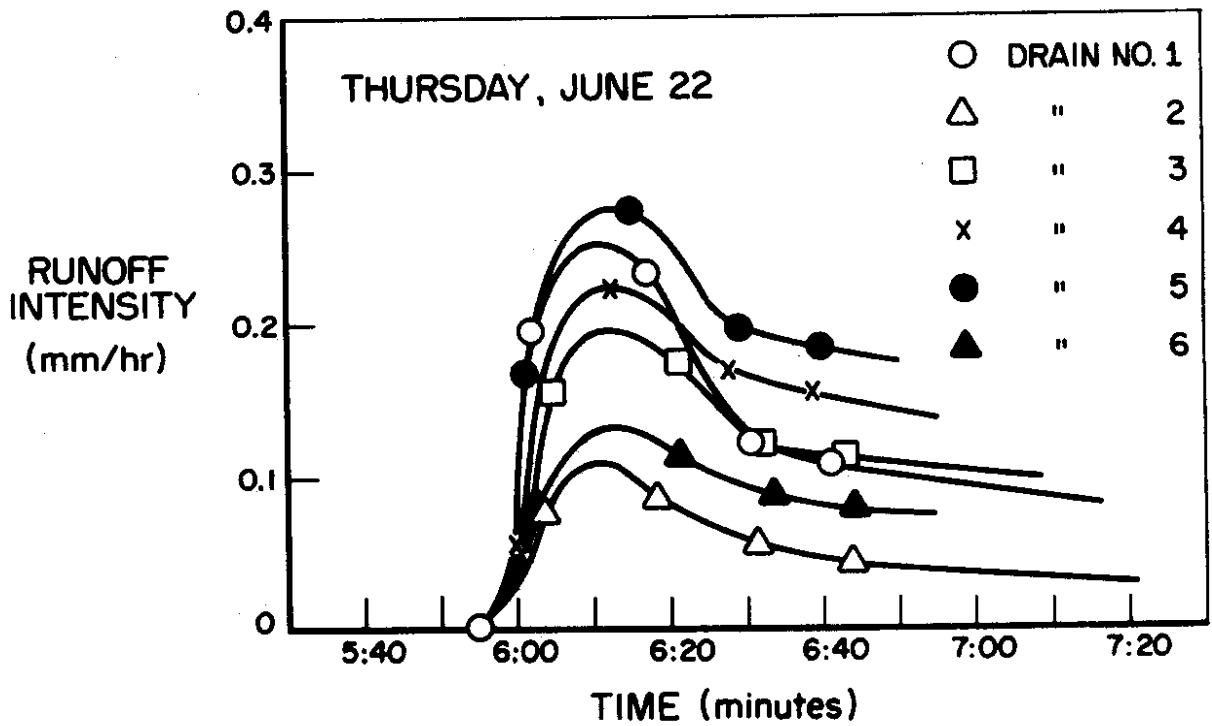
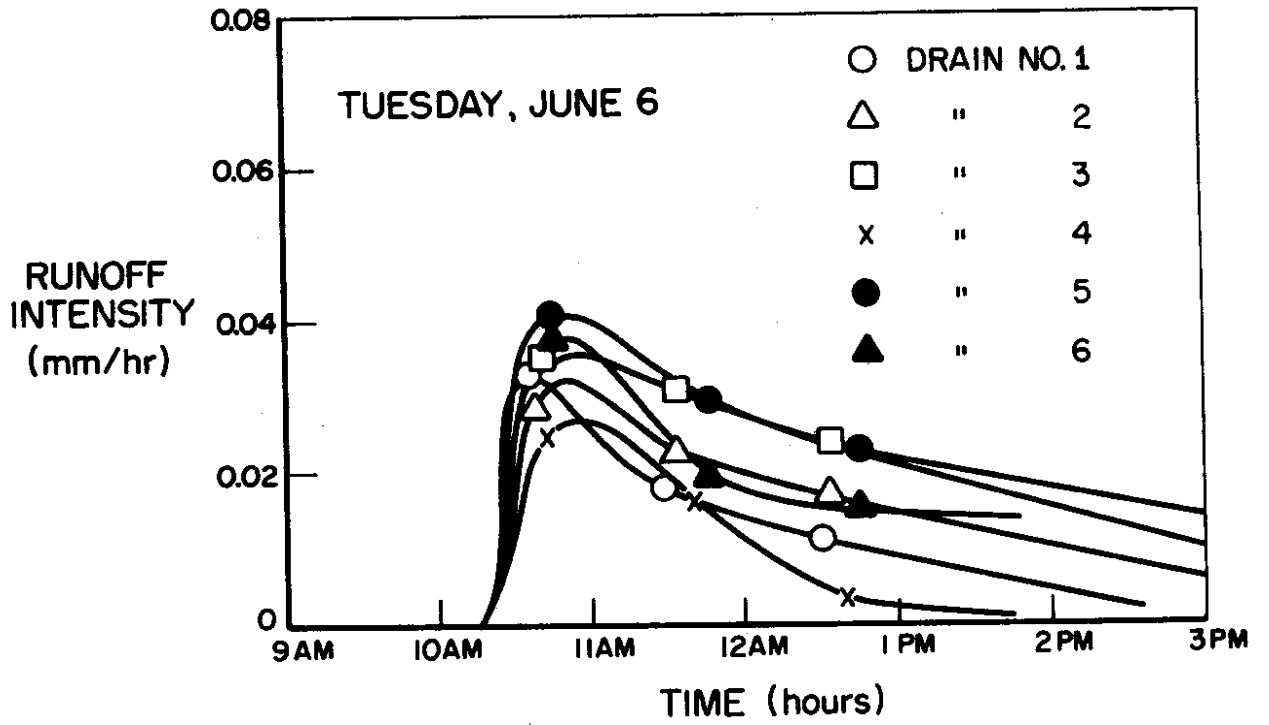


FIGURE 5. RUNOFF HYDROGRAPH OF THE RUNOFF COLLECTED FROM 6 DRAINS DURING THE RAINFALLS ON JUNE 6 AND JUNE 22.

phosphate (P) with a Technicon auto analyser (Armstrong, 1967). The samples were then subsequently irradiated with UV light for 30 minutes at 80°C which converts all the organic and $\text{NH}_3\text{-N}$ into $\text{NO}_3\text{-N}$ which reflects then the total-N concentration. All the phosphorus (P) was converted into ortho-P which also reflects the total-P concentration and the samples were again run on the auto analyser.

The oil concentrations were determined by petroleum ether extraction. Subsequent evaporation left the oil residues behind which were tested with a Beckman IR-4 to confirm the presence of lubricating oil. Heavy metals were measured with a Perkin Elmer atomic adsorption unit.

The other determinations were performed according to "Standard Methods for the Examination of Water and Wastewater" (American Public Health Association, 1971). Algal assay tests were performed using the alga, Selenastrum capricornutum, according to the PAAP procedures (Weiss and Helms, 1971).

Floatable solids collected during the first rainfall were separated into individual fractions and their presence as percentage of weight was recorded. A leaching test was performed on the different fractions to measure the amount of carbon, nitrogen and phosphorus that dissolved during a one hour suspension in distilled water.

The dried settleable solids were sieved with Taylor sieves and their size distribution was calculated. A leaching test was performed on all the fractions collected on June 6 from drain no. 4.

Solids samples were collected from catchbasins on State Highway 518, Interstate Highway 5, and State Highway 520. The density, percentage volatile matter and oil were measured on the finer fractions. Several

solid samples were digested with H_2O_2 and HNO_3 and tested for heavy metals.

Dustjars were located at different distances from the highway and placed on supports one meter in elevation above the road surface and initially filled with 200 ml of distilled water. Total solids, N, P and heavy metals were measured in the solution after a 14-day exposure.

To estimate the particulate matter emission on highway 520, it was assumed that 2 per cent of 39,500 cars/day consisted of diesel powered vehicles that emit 2.06 kg matter/1000 vehicle-km. as compared to only 0.225 kg/1000 vehicle-km for gasoline motors. With the road width of 19 meters, this results in a total emission of 545 mg matter/ m^2 day, assuming nothing is deposited on adjacent land. Since only 10 per cent of the matter is larger than 1μ (Lee et al, 1971) and may settle out, an amount of 54 mg/ m^2 /day or less may reach the road surface. (See previous discussion).

B. Discussion of Field Observations:

1. Rainfall, runoff and traffic conditions: Average traffic intensities on the east and westbound lanes of State Highway 520 are represented in Figure 2 and Table 7. Very characteristic are the early morning and late afternoon peaks illustrating the large presence of commuter traffic.

The days that runoff samples were collected are indicated in Figure 3 and clearly show the long antecedent dry weather period before the first collection period. It should be realized that the amount is always recorded the day after the rainfall. Further detailed information is shown in Figure 4 and Tables 6 and 7.

The total quantity of runoff water collected (Table 8) was approxi-

Table 6. Weather Data During the Four Days That Runoff Samples were Collected.

Date	Rainfall during runoff period studied (mm)	Mean rain intensity mm/hr	Windspeed m/sec	Wind direction	Air Temp.; °C, (°F)
June 6	0.25	0.17	2.2	ENE	20°C (67°F)
June 8	1.77	1.05	5.8	S	21°C (70°F)
June 10	1.48	0.82	3.1	N	17°C (51°F)
June 22	0.52	0.29	3.1	NW	18°C (59°F)

Table 7. Mean Traffic Intensity During the Collection of Runoff Samples. (Average day in June: 21,914 E.B.; 20,900 W.B.)

Date	Start of rain	Traffic intensity WB (cars/hr)	Traffic intensity EB (cars/hr)
June 6	9:15 am	1600	880
June 8	5:45 pm	1060	1920
June 10	12:20 pm	1220	1100
June 22	5:30 pm	1060	2950

Table 8. Amount of Runoff Water Collected From the Different Drains During the First and Last Rainfall That Runoff Samples Were Collected.

Date	Runoff Water Collected From Different Drainage Areas (mm)						Cum. Rain-fall (mm)	Per cent Collected
	Drain No. 1	No. 2	No. 3	No. 4	No. 5	No. 6		
June 6	0.0505	0.0854*	0.0896*	0.0428	0.0936*	0.0820*	0.074	29
June 22	0.1458*	0.0584	0.1315*	0.1318*	0.1713*	0.0802	0.1200	23

* Runoff water exceeding calculated mean value

mately 29, and 23 per cent of the total rainfall tributary to the drains being sampled. This indicates that a large part of the rain ran off along the steepest slope westwards to the lowest point of the bridge, and that it did not run sideways along the less steep slope towards the side drains. Also, some rain will remain on the road surface and some will be lost through evaporation. Finally, some rain will be collected by the vehicles and some may be splashed over the bridge railing.

2. Theoretical bases for calculations: The calculation to obtain the total amount of pollutants that are washed away was determined according to a modification of a method developed by Metcalf and Eddy (1971). The theory assumes that the amount of a particular pollutant on the surface " P_0 " (in mg/m^2) that is washed away in any time interval dt , is proportional to the amount remaining on the ground:

$$-\frac{dP}{dt} = -k'P \quad (1)$$

which integrates to

$$P_0 - P = P_0 (1 - e^{-k't}) \quad (2)$$

where $P_0 - P$ = amount washed away in time t

If it is assumed that k' (the logarithmic removal constant, hr^{-1}) is dependent on the rain intensity, k' can be replaced by $b \times r$ in which " b " is a constant and " r " the rain intensity, mm/hr . The theory was modified in this study by assuming that the amount of a particular pollutant on the surface, " P_0 " (in mg/m^2), that is washed away by any increment of the total rainfall, " dL ", is proportional to the amount remaining on the ground:

$$-\frac{dP}{dL} = -kP \quad (3)$$

which integrates into

$$P_0 - P = P_0 (1 - e^{-kL}) \quad (4)$$

where k = logarithmic removal constant, cm^{-1} .

This modification assumes that the amount of pollutants washed away is more dependent on the accumulative amount of rainfall in a given rainstorm than on the time period in that given rainstorm. When the amount of pollutants remaining on the ground is plotted versus the accumulative rainfall, the resulting relationship is a logarithmic decreasing function. A similar approach was used by Pravoshinsky and Gatillo (1969) who showed that about 99 per cent of the BOD build-up in urban areas of $33 \text{ mg/m}^2 \text{ day}$ could be washed away by a cumulative amount of rainfall of 16 mm., from which a logarithmic removal constant of 1.25 cm^{-1} can be calculated. Metcalf and Eddy (1971) assumed that a uniform runoff of 1.27 cm would wash away 90 per cent of the pollutants in one hour which would result in a removal constant of 0.79 cm^{-1} . In this study it was possible to reconstruct how much cumulative rain it took to wash off the pollutant build-up since the pollutants in the runoff water were measured after a long, dry, antecedent period followed by three days of rainfall in close succession.

3. Calculation of the daily pollutant accumulation: For purposes of calculation, the runoff to the drains being sampled during the sampling period was taken as 10 per cent of the total runoff (Table 8 shows 25 per cent of the rain being collected and 75 per cent therefore flowing past sampling drains to others further down the slope). It was assumed that the lagtime between the rain striking the pavement surface and its collection from the drain outlet, as measured at the start of the rainfall and the beginning of the discharge of the runoff water through the drain, remained

constant throughout the rainfall. This assumption was tested by plotting both rainfall and runoff (on a 100% basis) versus time for June 6 and June 22. During the first, the lagtime of 60 minutes (low intensity rainfall) persisted throughout the entire runoff time. On June 22 the initial lagtime of 25 minutes remained constant halfway through the rainfall then decreased slightly and finally increased again, from which it can be concluded that the assumption was valid. Since the time of sample collection was known, it was then possible to calculate in how much rainwater the pollutants were dissolved between the sampling intervals. Through back calculations and summation of logarithmic decreasing concentrations (Figures 6-10), it was possible to calculate the amount of pollutants (in mg/m^2) on the ground before they dissolved in that amount of rain. A sample calculation to convert mg/l into mg/m^2 is shown in Appendix A.

Tables 9 through 15 show the results of these calculations and there is indeed evidence that the initial runoff in a given rain period removes most of the pollutants with logarithmically decreasing amounts removed with increasing accumulative rainfall. Now such a value of the initial amount of a pollutant present at the roadsurface was chosen that when the amount remaining at the surface was plotted versus the accumulative rainfall on log-normal paper a straight line would evolve. The daily accumulation after the first rain was also taken into account. Figures 6 through 10 depict this. Once when the initial amount (in mg/m^2) was established the value was divided by the number of dry days prior to June 6 which was used to calculate the daily accumulation. The final results are represented in Table 16 which also shows the calculated removal constants.

4. Evaluation of the accumulation and runoff calculations: Results

obtained in this study were compared with the loading values computed by Soderlund and Lehtinen (1970). Although the Stockholm highway had a one and a half times higher traffic intensity, the general values are comparable with this study results. Their values for SS and COD are higher than found herein probably due to the higher traffic intensity and probably because some of the right-of-way area drained into the highway drains at the cloverleaf junction where they sampled. Their values for total-N and total-P are several times lower than found in this study. The value for the oil is in the same range as found in this study.

The calculated daily accumulations were also compared with similar "loading" values of pollutants found in urban runoff studies in the U. S. (Table 2). Values for SS, COD, N and P from this study are within the range of reported urban loading and are generally in the lower part of these values.

Although only a limited number of samples were analyzed for heavy metals in this study, results from the dustjars and the analysis of the suspended matter in the runoff samples suggest that a large percentage is associated with the solids (see subsequent discussion). Based on the SS calculation, a preliminary estimate was made for the heavy metal loadings and are shown in Table 2. The results, compared with those of Sartor et al (1972), indicate that larger amounts of heavy metals are collected in street sweepings; however, the area loadings of all constituents in that study are surprisingly high. Area loading of heavy metal concentrations in the Soderlund study was also estimated based on similar data from the SS (Table 2). The results indicate relative low area loading values. A similar conclusion can be reached from Bryan's study in which the Pb

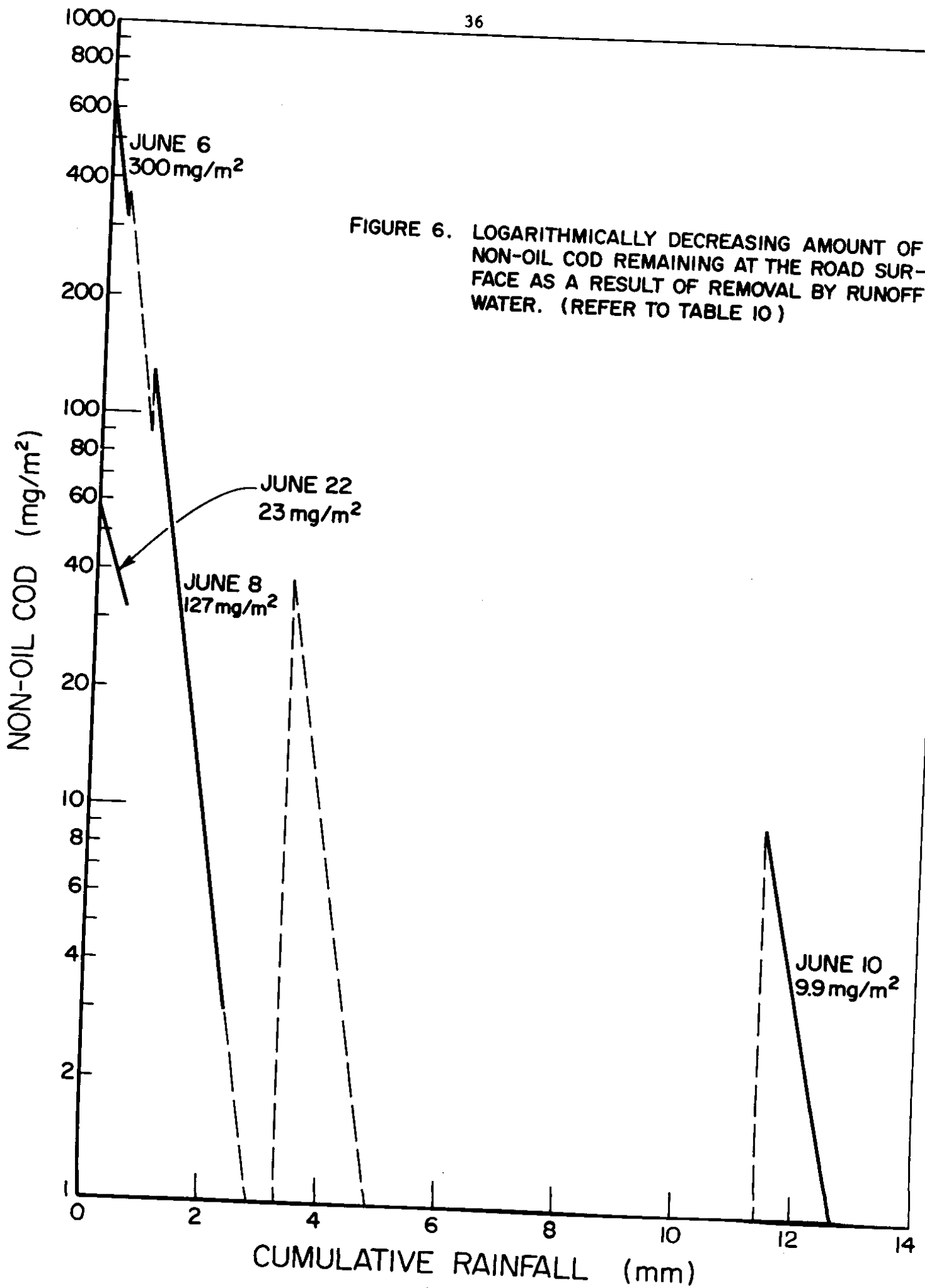


FIGURE 6. LOGARITHMICALLY DECREASING AMOUNT OF NON-OIL COD REMAINING AT THE ROAD SURFACE AS A RESULT OF REMOVAL BY RUNOFF WATER. (REFER TO TABLE 10)

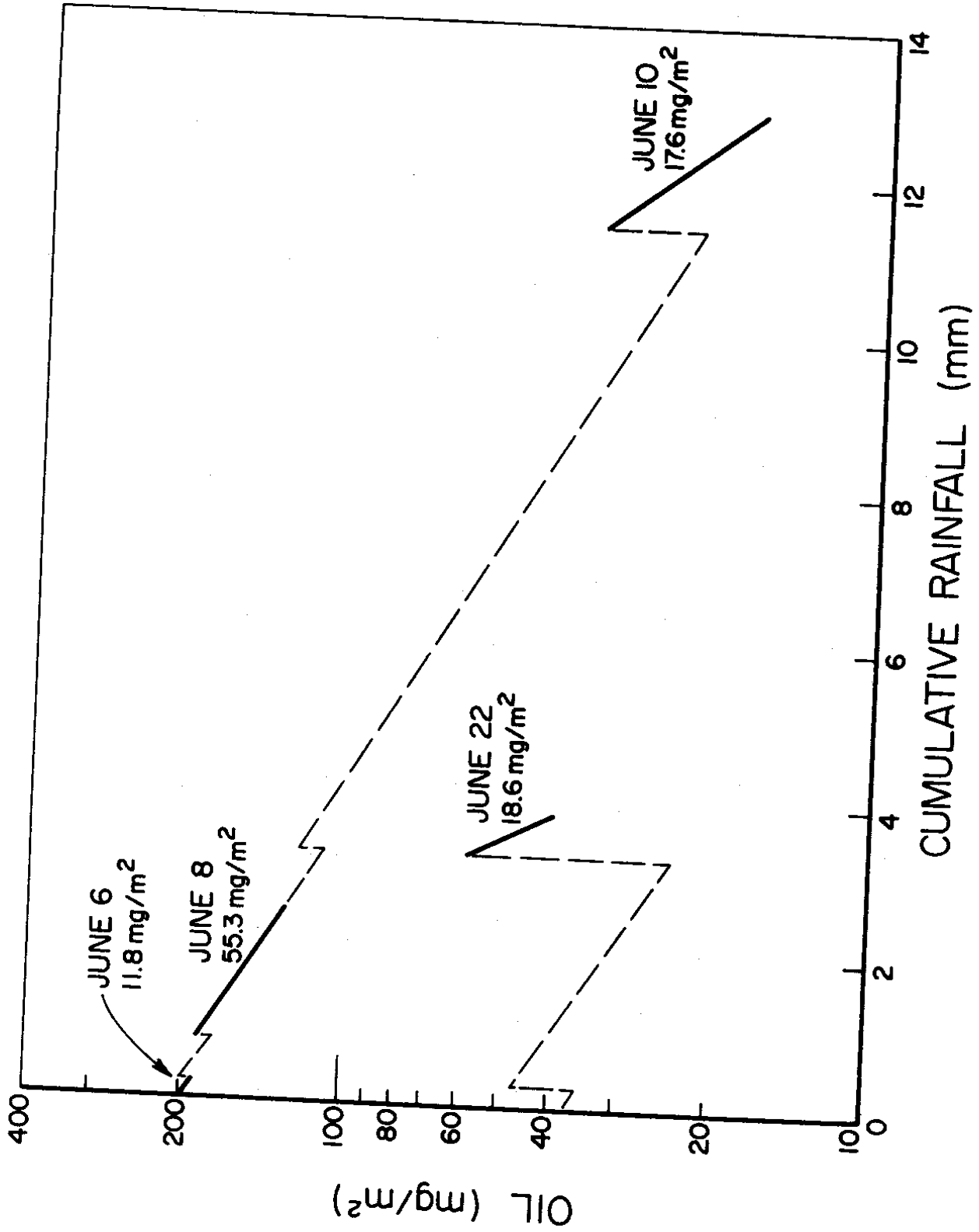


FIGURE 7. LOGARITHMICALLY DECREASING AMOUNT OF OIL REMAINING AT THE ROAD SURFACE AS A RESULT OF REMOVAL BY RUNOFF WATER. (REFER TO TABLE II)

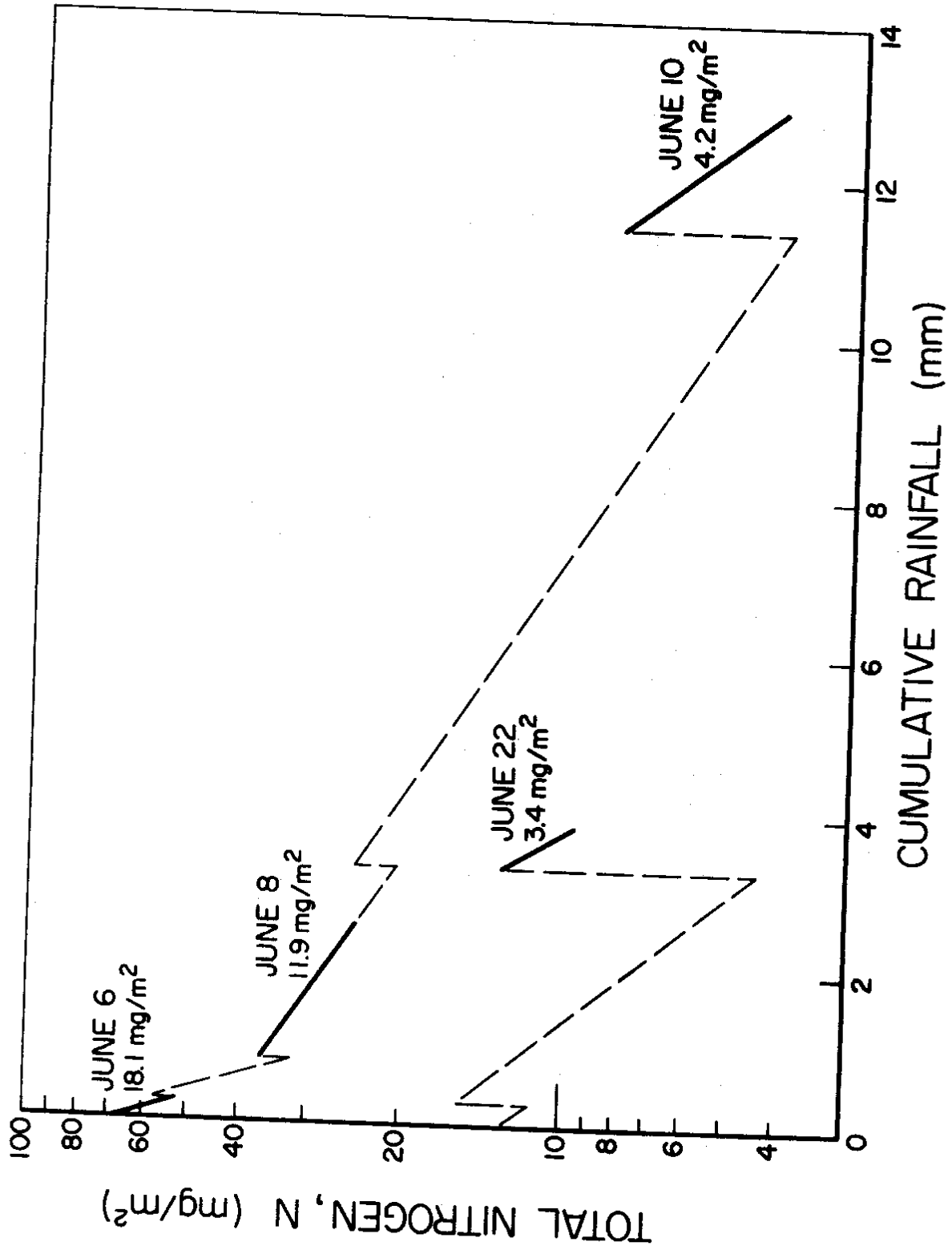


FIGURE 8. LOGARITHMICALLY DECREASING AMOUNT OF TOTAL NITROGEN REMAINING AT THE ROAD SURFACE AS A RESULT OF REMOVAL BY RUNOFF WATER. (REFER TO TABLE 12)

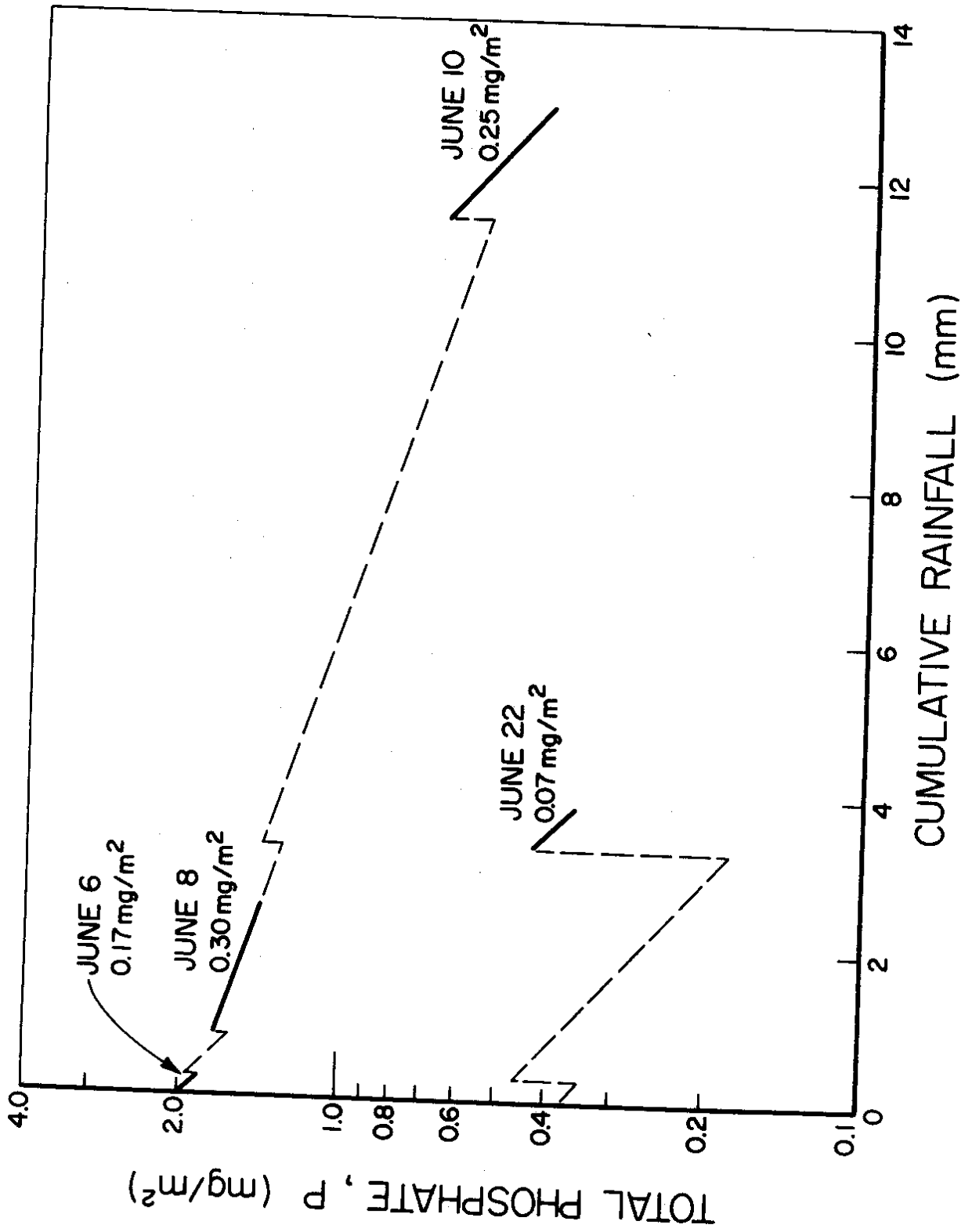


FIGURE 9. LOGARITHMICALLY DECREASING AMOUNT OF TOTAL PHOSPHATE REMAINING AT THE ROAD SURFACE AS A RESULT OF REMOVAL BY RUNOFF WATER. (REFER TO TABLE 13)

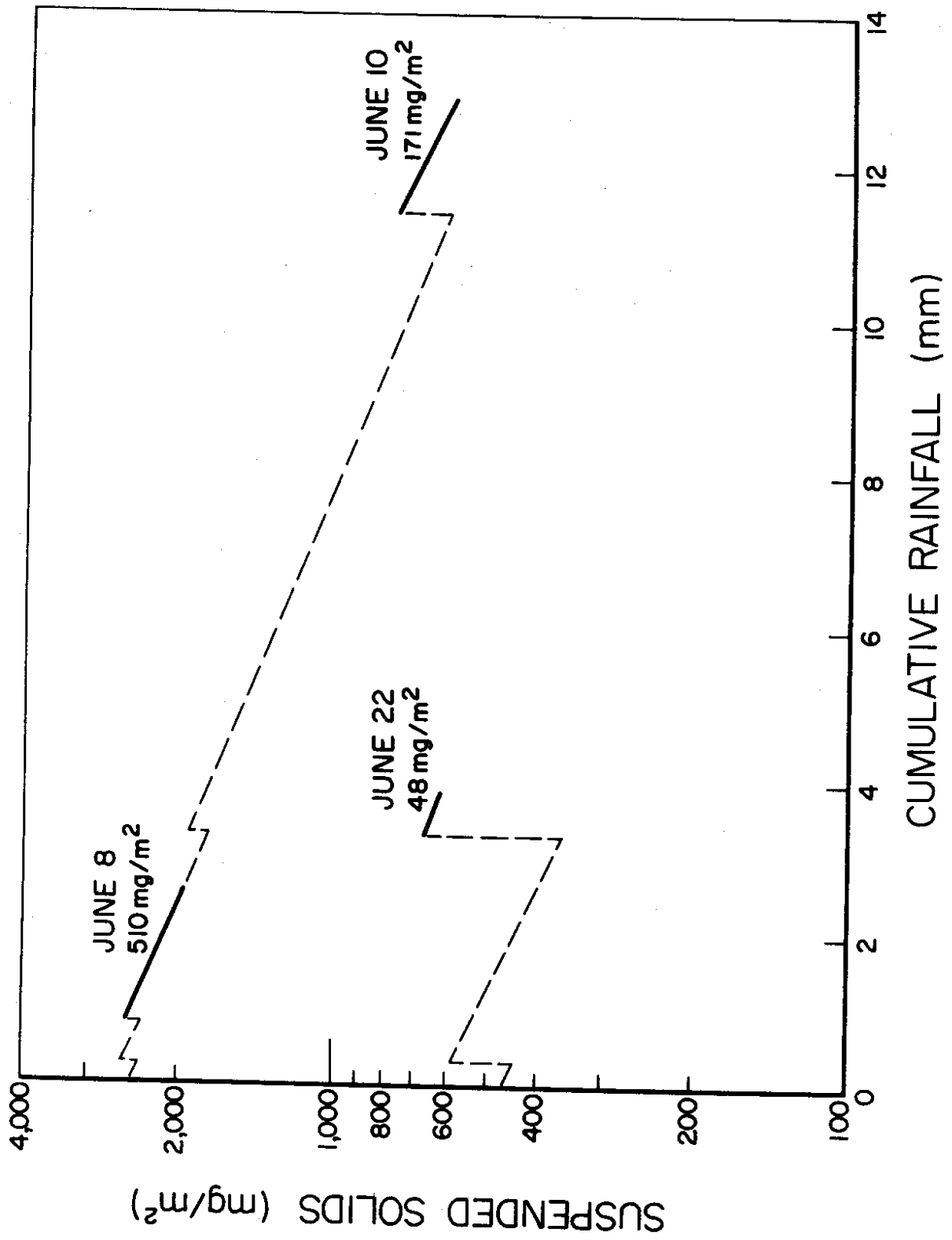


FIGURE 10. LOGARITHMICALLY DECREASING AMOUNT OF SUSPENDED SOLIDS REMAINING AT THE ROAD SURFACE AS A RESULT OF REMOVAL BY RUNOFF WATER. (REFER TO TABLE 14)

Table 9. Amount of COD Removed as Calculated From the Concentration in the Runoff Water.

Date \ Drain	Amount of COD Removed (mg/m^2)						Mean
	1	2	3	4	5	6	
June 6	358*	255	304	585*	348*	190	340
June 8	296	215	328*	378*	217	370*	310
June 10	68	82*	74*	70*	57	65	69
June 22	92	79	104*	87	85	105*	92

* above the mean value of that day

Table 10. Amount of Non-Oil COD Removed as Calculated From the Concentration in the Runoff Water. (See Fig. 6).

Date \ Drain	Amount of Non-Oil COD Removed (mg/m^2)						Mean
	1	2	3	4	5	6	
June 6	325*	215	270	545*	295	150	300
June 8	156*	40	133*	164*	155*	113	127
June 10	15.5*	4.4	11.7*	8.9	7.3	11.7*	9.9
June 22	42.4*	7.8	27.5*	32.0*	12.4	16.6	23

* above the mean value of that day

Table 11. Amount of Oil Removed as Calculated From the Concentration in the Runoff Water (See Fig. 7).

Drain Date	Amount of Oil Removed (mg/m ²)						Mean
	1	2	3	4	5	6	
June 6	13.2*	10.4	9.3	11.5	15.1*	11.6	11.8
June 8	40.0	40.0	55.5*	61.0*	62.0*	74.0*	55.3
June 10	16.0	18.7*	21.8*	18.4*	14.5	15.9*	17.6
June 22	11.4	20.4*	22.5*	12.4	20.4*	24.6*	18.6

* above the mean value of that day

Table 12. Amount of Total N Removed as Calculated From the Concentration in the Runoff Water (See Fig. 8).

Drain Date	Amount of Total-N Removed (mg/m ²)						Mean
	1	2	3	4	5	6	
June 6	12.2	16.6	13.1	24.2*	23.0*	19.3*	18.1
June 8	6.5	9.4	20.1*	9.8	13.8*	10.4	11.7
June 10	2.2	5.0*	4.2	3.5	4.5*	5.9*	4.2
June 22	3.0	2.7	3.4	4.0*	1.10*	3.4	3.4

* above the mean value that day

Table 13. Amount of Total P Removed as Calculated From the Concentration in the Runoff Water (See Fig. 9).

Drain Date	Amount of Total-P Removed (mg/m^2)						
	1	2	3	4	5	6	Mean
June 6	0.06	0.12	0.27*	0.16	0.25*	0.17	0.17
June 8	0.27	0.26	0.35*	0.27	0.14	0.54*	0.30
June 10	0.29*	0.19	0.15	0.11	0.30*	0.37*	0.25
June 22	0.07	0.08*	0.06	0.07	0.06	0.08*	0.07

* above the mean value that day

Table 14. Amount of Suspended Solids Removed as Calculated From the Concentration in the Runoff Water (See Fig. 10).

Drain Date	Amount of Suspended Solids Removed (mg/m^2)						
	1	2	3	4	5	6	Mean
June 6	-	-	-	-	-	-	120 (est)
June 8	560*	485	375	510	365	765*	510
June 10	217*	120	145	327*	200*	107	171
June 22	72*	53*	34	52*	34	45	48

* above the mean value that day

Table 15. Amount of Floatable and Settleable Solids Removed as Calculated From the Concentration in the Runoff Water.

Date \ Drain	Cum. Amount of Floatable Solids Removed (mg/m^2)						
	1	2	3	4	5	6	Mean
June 6	68.2	-	-	221.0	126.0	49.0	77.4
June 22	9.1	-	-	21.5	8.8	10.8	8.4

Date \ Drain	Cum. Amount of Settleable Solids Removed (mg/m^2)						
	1	2	3	4	5	6	Mean
June 6	493.0	-	-	2850.0	1390.0	660.0	899.0
June 22	0.84	-	-	6.75	15.4	18.9	7.0

Table 16. Daily Accumulation of the Different Pollutants on the Roadsurface and Their Logarithmic Removal Constants (Higher the "k" value, the more easily removed).

Parameter	Accumulation	Removal Constants (k)
SS	155 mg/m^2 day	0.85 cm^{-1}
Total N	4.4	2.4
Total P	0.125	1.36
Oil	12.5	0.93
COD	82.0	9.1 (non-oil COD)
Floatable solids	5.08	>10
Settleable solids	56.2	>10

loading was only $0.68 \text{ mg/m}^2 \text{ day}$. Therefore, it would appear that the heavy metal loading from highways and arterial street sweepings are higher, on a unit area basis, than loadings from general urban areas, which would be expected.

The values of the removal constants (Table 16) show that the floatable and settleable solids are most easily washed away followed by the non-oil COD. It may well be that the non-oil COD is mostly derived from dust or dirt that adheres only loosely to the roadsurface and is easily washed away. The total-N generated as part of the combustion process may be associated with small unburned particles that adhere it more strongly to the roadsurface. The total-P, oil, and SS are apparently even more strongly adhered. It may well be that small dirt or sand particles adsorb phosphates and oil at the same time that will result in similar low removal constants. Evidence for this hypothesis was also given by the fact that the >400 mesh sieve fraction ($>38\mu$) of the settleable solids contained an average of 5.7 per cent oil which is 72 per cent of the volatile matter of that fraction. The dirt and sand particles that collect under the bottom of the vehicle will be in contact with the lubricating oil that is present. Aside from dirt particles, the phosphates can also come directly from lubricating oil that contains ditrisphosphates or cresol phosphoresters as additives.

Testing with infrared established the presence of lubricating oil in the runoff. In the petroleum ether extracts of the samples already filtered for SS, a large peak was present between 9 and 10μ , indicating the presence of silicate or sand particles; these particles also increased the density of the oil from a theoretical 0.93 to 1.21 g/cm^3 .

5. Algal assay tests: These tests were conducted using runoff samples collected on June 8 and 10 with various quantities of Portage Bay water as the diluent. Nitrogen and phosphorus were added to some of the samples (Table 17) to determine whether or not Portage Bay water by itself or with various quantities of runoff water was nutrient deficient. The alga, Selenastrum capricornutum, was used as the inoculum with a measure of the total organic carbon (TOC) present to indicate algal growth differences and the possible presence of toxicity in the runoff water.

Since these algal assay tests were limited, it is not appropriate to draw significant conclusions from them. They do indicate, however, that available phosphorus (P) is more limiting to growth than nitrogen (N) in both the Portage Bay water by itself and in the Portage Bay water with runoff additions. The June 8 runoff water contained significantly more N and P than the June 10 runoff and thus one might expect more algal growth. This was not observed except when available N and P were added to the culture, indicating that the N and P present in the runoff water were not available for growth or that there was some growth inhibitory substance(s) present whose effect was mitigated by the N and P additions. Growth inhibition or toxicity is suggested in the runoff water, particularly from the June 8 runoff, since unfortified samples showed no TOC increase or less TOC increase than in the plain Portage Bay water.

6. Settleable solids characteristics: The settleable solids collected during the first rainstorm show similar particle size distribution curves (Figure 11). In the drain 1 and 4 samples there are relatively more smaller particles probably as a result of the steeper slope of the on-ramp where the drains are located. Also, the traffic moves downward on the slope

Table 17. Results of the Algal Assay Test Conducted With Portage Bay Water and Added Runoff Water, mg/l.

Sample Tested	Additives	Total N	Total P	TOC after 15 days	Increase in TOC due to 15-day algal growth*	TOC after 30 days	Increase in TOC due to 30-day algal growth*
100 ml Portage Bay Water	Collected on July 6, no additives	0.38	0.16	14.2	2.5	23.8	7.2
	+ 0.05 mg/l-P	0.38	0.21	13.2	1.5	22.5	5.9
	+ 1.00 mg/l-N	1.38	0.16	13.0	1.3	21.8	5.2
	+ 0.05 mg/l P + 1.00 mg/l-N control (without algae inoc.)	1.38	0.21	22.6	10.9	48.5	31.9
90 ml Portage Bay Water + 10 ml Runoff	June 8, Drain 4, no additives	3.08	0.16	30.4	1.3	31.3	0
	+ 0.05 mg/l-P	3.08	0.21	46.0	16.9	38.7	6.8
	+ 1.00 mg/l-N	4.08	0.16	26.6	0	30.0	0
	+ 0.05 mg/l-P + 1.00 mg/l-N control (without algae inoc.)	4.08	0.21	40.0	10.9	104.0	72.1
80 ml Portage Bay Water + 20 ml Runoff	June 8, Drain 4, no additives	5.78	0.17	45.6	0	46.0	0
	+ 0.05 mg/l-P	5.78	0.22	46.8	0.9	65.3	17.6
	+ 1.00 mg/l-N	6.78	0.17	45.2	0	95.0	47.3
	+ 0.05 mg/l-P + 1.00 mg/l-N control (without algae inoc.)	6.78	0.22	46.6	0.7	110.1	62.4
80 ml Portage Bay Water + 20 ml Runoff	June 10, Drain 4, no additives	1.08	0.13	15.6	0	29.4	10.4
	+ 0.05 mg/l-P	1.08	0.18	24.0	8.3	35.2	16.2
	+ 1.00 mg/l-N	2.08	0.13	14.0	0	53.2	34.2
	+ 0.05 mg/l-P + 1.00 mg/l-N control (without algae inoc.)	2.08	0.18	31.6	15.9	43.4	24.4
Cultures at 13°C		1.08	0.13	14.0	-	17.3	-

Cultures at 13°C

*1.7 mg/l total organic carbon (TOC) subtracted for algal inoculum

Table 18. Volatile Matter, Oil Content and Density of the Smallest Sieve Fractions of the Settleable Solids Collected on June 6.

Drain No.	Sieve Fraction	% VS	% Oil	Density (g/cm ³)
2	200 mesh	4.56%	0.67%	2.63
4		4.84	0.52	
6		5.39	0.60	
7		6.49	0.90	
2	400 mesh	10.90	1.28	(2.89)
4		11.97	1.65	2.36 (2.86)
6		10.31	1.39	(2.85)
7		10.21	0.02	
2	>400 mesh	11.85	5.18	2.54 (2.84)
4		9.12	7.25	1.44 (8.74)
6		13.07	3.56	2.61 (2.84)
7		7.57	6.83	(3.34)

which is not the case with drain 6. The smallest sieve fractions of the settleable solids were analyzed for volatile matter, oil and density. The latter was very accurately determined with a pycnometer. The results in Tables 18 and 19 clearly show an increasing percentage of volatile matter and oil and decreasing density with decreasing particle size. The density of sand is normally 2.65 and decreases by adsorption of low density compounds such as oil.

Samples of settled solids collected from catchbasins (Table 19 and Figure 11) show characteristics similar to those collected from the Freeway drains as discussed immediately above. This suggests that the Highway 520 samples were representative and that settling basins of proper design can be used to remove much of the suspended matter in the runoff. This does not

Table 19. Volatile Matter and Oil Content and Density of the Smallest Sieve Fractions of Samples Collected From Catchbasins.

Location	Sieve Fraction	% VS	% Oil	Density
520 WB	200 mesh	3.45%	0.57	
520 EB		3.45	0.06	
I-5 NB		3.49	0.04	
I-5 middle		2.31	0.43	
518 WB		2.95	0.71	
520 WB	400	8.28	1.53	
520 EB		6.90	0.36	
I-5 NB		10.08	1.91	
I-5 middle		5.17	0.52	
518 WB		7.12	1.17	
520 WB	>400	10.66	1.13	2.62
520 EB		7.42	1.65	2.49
I-5 NB		14.05	2.32	2.36
I-5 middle		12.50	2.35	2.60
518 WB		12.54	6.74	2.85

Table 20. Composition by Weight of the Floatable Solids (collected June 6).

Drain	Cigarettes*	Insects	Needles	Grass	Wood	Leaves	Paper	Total weight, gr.	Total/unit area, mg/m ²
1	12.4%	3.6%	18.1%	29.7%	17.4%	13.0%	5.6%	40.776	68
4	14.4	2.8	18.3	40.2	17.7	5.7	1.0	33.146	221
5	10.7	5.8	12.6	18.0	51.0	20.7	15.9	35.784	126
6	31.6	3.3	2.0	17.2	42.4	2.9	0.7	14.051	49

* average weight of 87 butts was 0.207 g/butt

Table 21. Total Carbon, Nitrogen and Phosphorus Dissolved in Distilled Water from Floatables and Settleables of June 6.

Items	C	N	P
Cigarettes	209 mg/1	9.76 mg/1	1.02 mg/1
Insects	191	11.00	10.79
Needles	40	1.78	1.23
Grass	105	4.18	4.24
Wood	28	1.24	0.51
Leaves	68	3.21	1.79
Drain 4 - 20 mesh	22	1.52	0.46
Drain 4 - 35 mesh	14	0.80	0.19
Drain 4 - 200 mesh	16	1.19	0.22
Drain 4 - 400 mesh	12	0.66	0.12
Drain 4 - >400 mesh	18	1.56	0.17

(When 1 gram dry matter of each fraction is suspended in 102 ml distilled water for 1 hr, the resulting concentration is the same as if the solids of a 25-day period were suspended in 0.12 mm of rainfall for 1 hr.)

imply that the existing catchbasins are efficient removers of settleable solids.

On June 6 and June 22, three separate runoff samples were collected for a sedimentation analysis of the suspended solids. This analysis was not conducted until early July because of the press of other duties. After resuspension of the solids, aliquots were withdrawn exactly 5 cm below the water surface from the undisturbed solution at specific time intervals and the results were inserted in the Stokes equation which describes the sedimentation of particles with a constant velocity:

$$v = \frac{g}{18} \left(\frac{\rho - \rho_0}{\eta} \right) d^2 \quad (5)$$

ρ = density of solid particle (g/cm³)
 ρ_0 = density of fluid (g/cm³)
 d = diameter of particle
 g = gravity
 η = kinematic viscosity of fluid

The densities of the particles were determined with a pycnometer and were found to be 1.81 g/cm³. By knowing the velocity of subsidence (5 cm divided by time of start of experiment till the subsequent sampling time) the particle diameter could be calculated.

Although the solids of the June 6 samples had initially the same appearance as the solids of the June 22 sample, the long storage of about 30 days gave them a more fluffier look. Also the June 6 solids had a tendency to stick to the wall of the container. Comparison of the size distribution curves of the two samples (Figure 12-a) confirms the visual observation and shows clearly that only about 30 per cent of the solids in the three June 22 samples are smaller than 10 μ , while for the June 6 samples this percentage is about 80 per cent. The solids of the June 6

samples are all smaller than about 20 μ while for the June 22 samples this is closer to 100 μ to 500 μ . This postulated size reduction may well be the result of biological degradation of oily substances that otherwise would tend to agglomerate the individual dirt particles. A reduction in particle size will greatly reduce the settling velocity (Figure 12-b). This has the consequence that, as suspended solids settle out in a catch-basin during runoff periods and the particles disintegrate during the subsequent following dry period, new runoff could disturb these settled solids and, because of the reduced sedimentation velocity, could easily carry them away with the effluent from the settling unit. Care should therefore be taken in design so that incoming flow will not disturb the sediments.

7. Floatable solids: The floatable solids were separated in different fractions and their composition by weight was calculated (Table 20). The on-ramp drains were usually characterized by a high percentage of grass clippings and needles assumed to originate from the nearby right-of-way plantings. These values are probably typical of pavement runoff under these conditions but would not be typical of combined runoff from both pavement and adjacent right-of-way soil surfaces. Their values would differ greatly depending upon location, antecedent rainfall and road surface cleaning.

Floatable and settleable solids collected during the June 6 rainstorm were placed in distilled water for one hour (simulating a sedimentation basin) to obtain a rough approximation of the nutrients (carbon, nitrogen and phosphorus) that might be leached therefrom. Table 21 indicates that appreciable quantities of these nutrients would be leached into a receiving

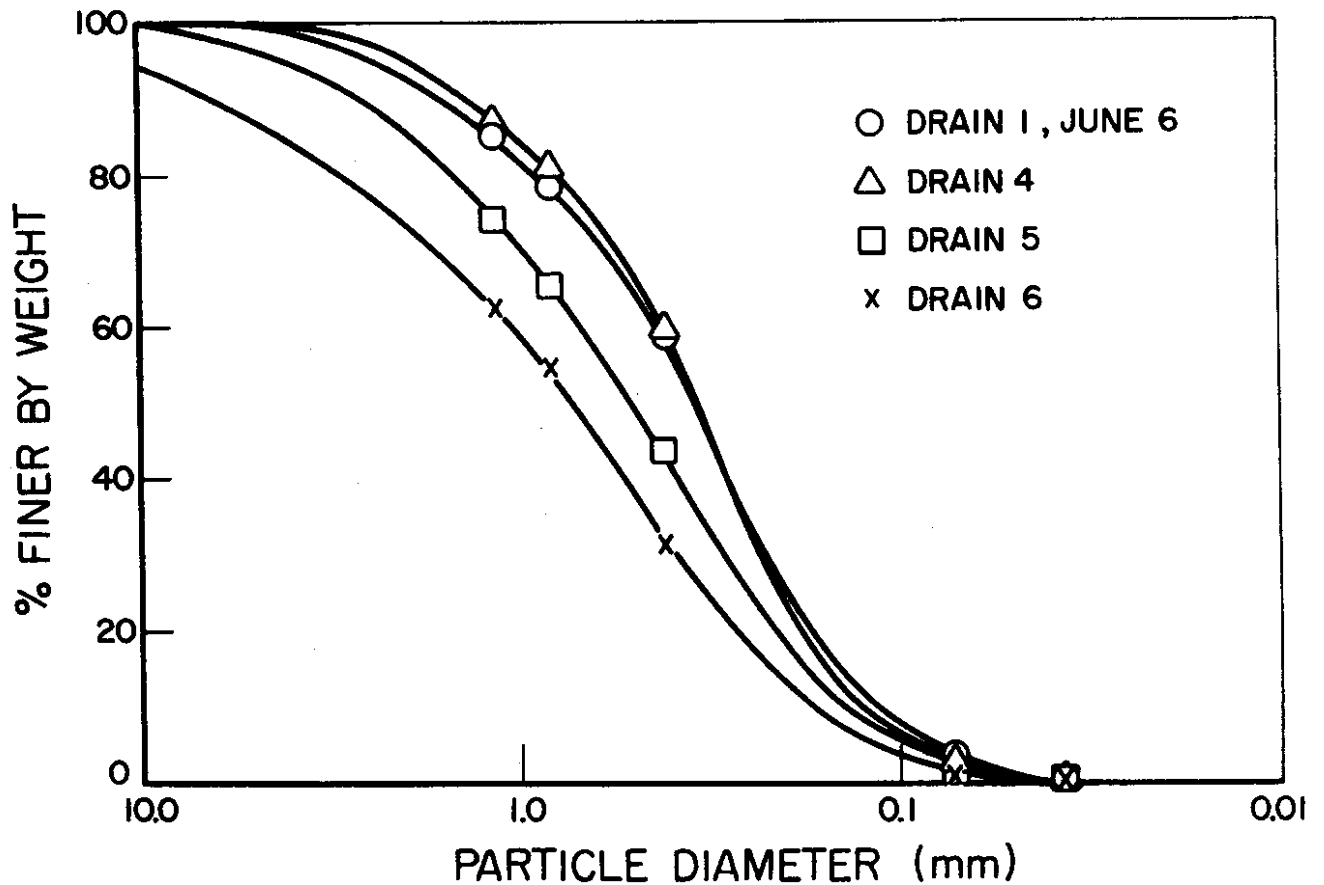
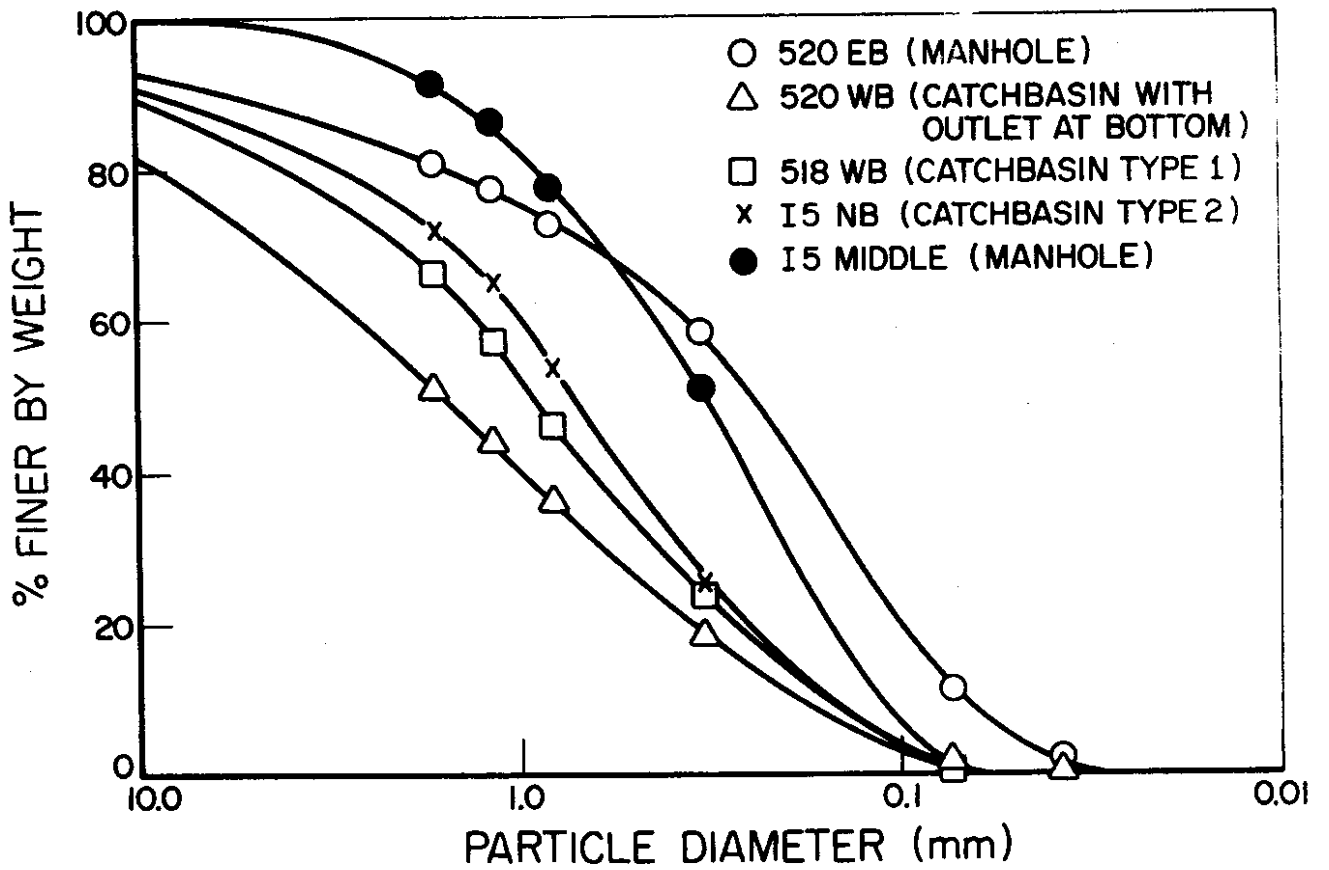


FIGURE 11. PARTICLE SIZE DISTRIBUTION OF SETTLEABLE SOLIDS COLLECTED IN RUNOFF AND OF SOLIDS COLLECTED IN CATCHBASINS AND MANHOLES.

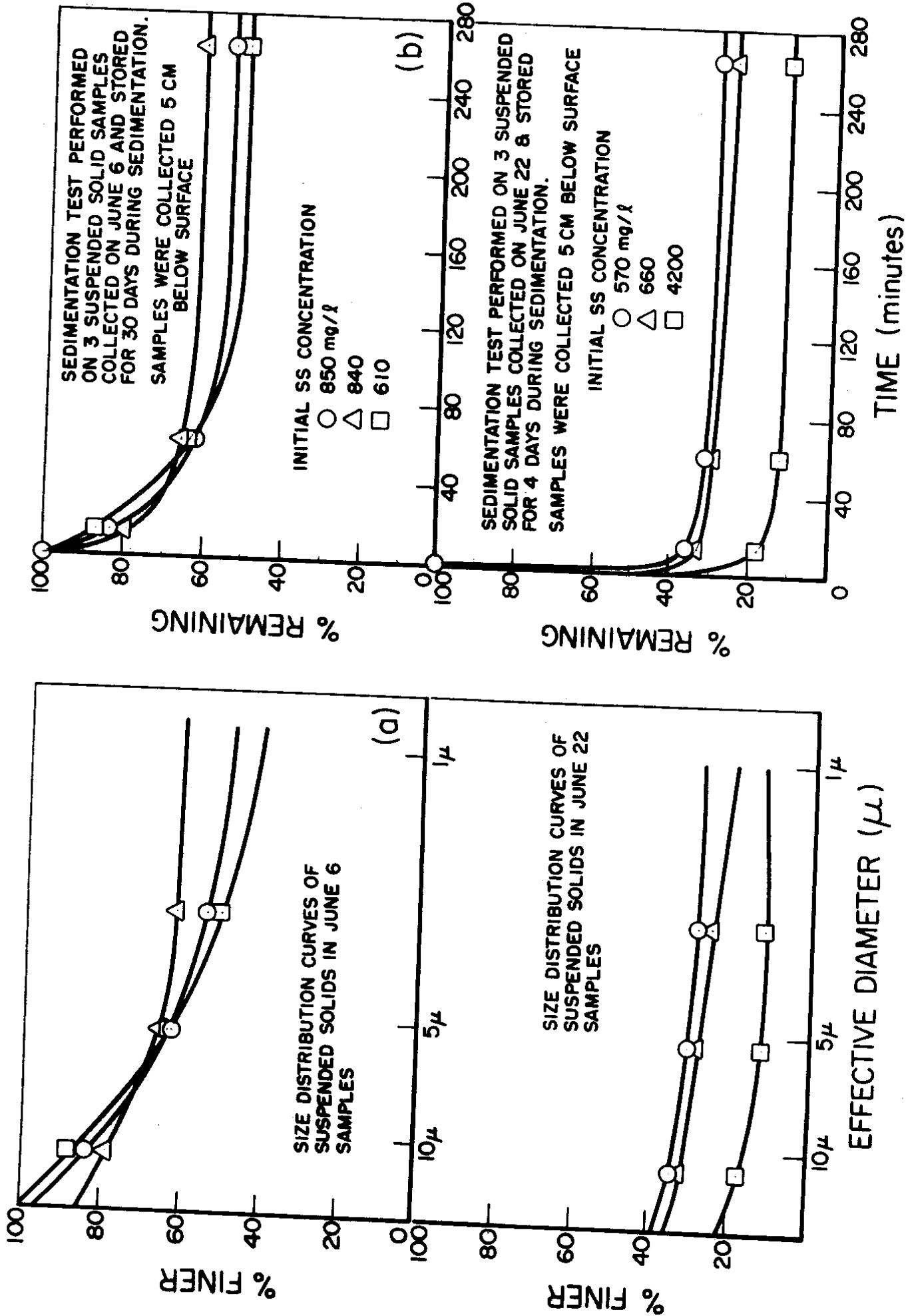


FIGURE 12. SEDIMENTATION TESTS USING SUSPENDED SOLIDS SAMPLES.

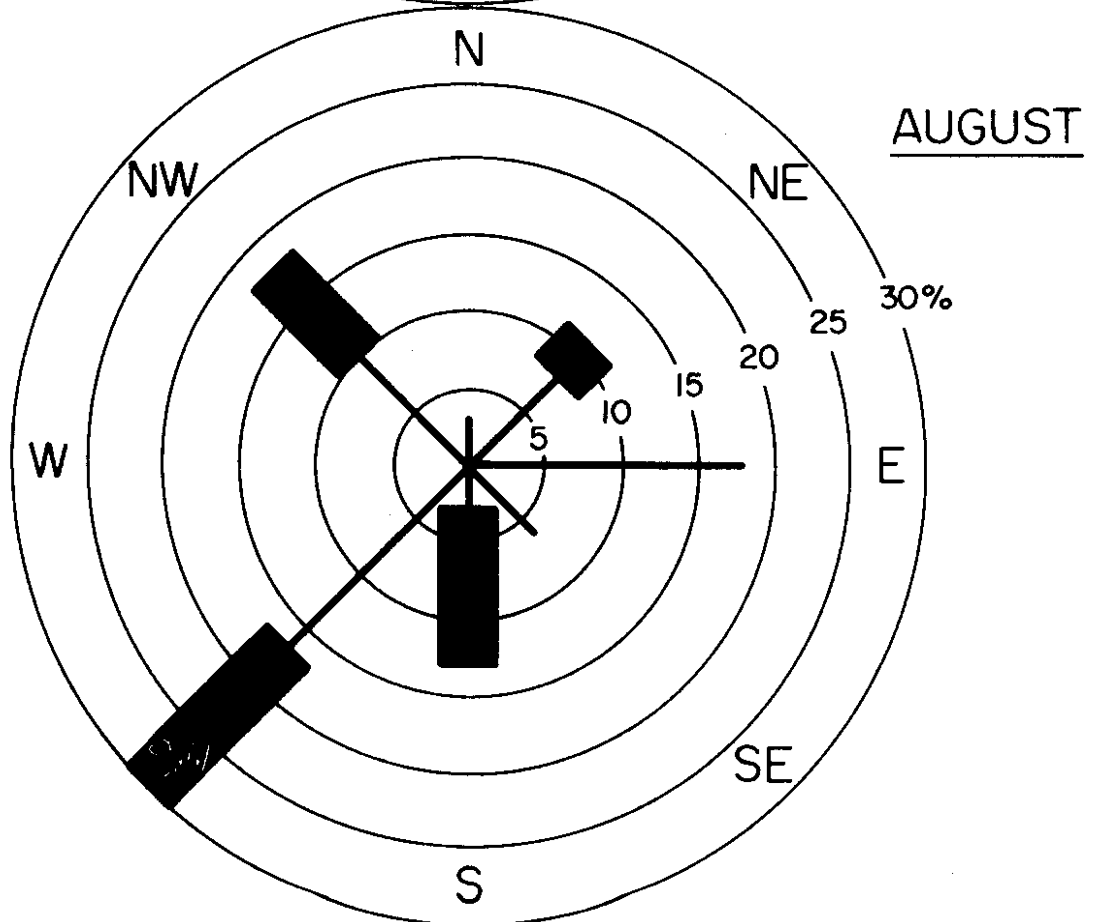
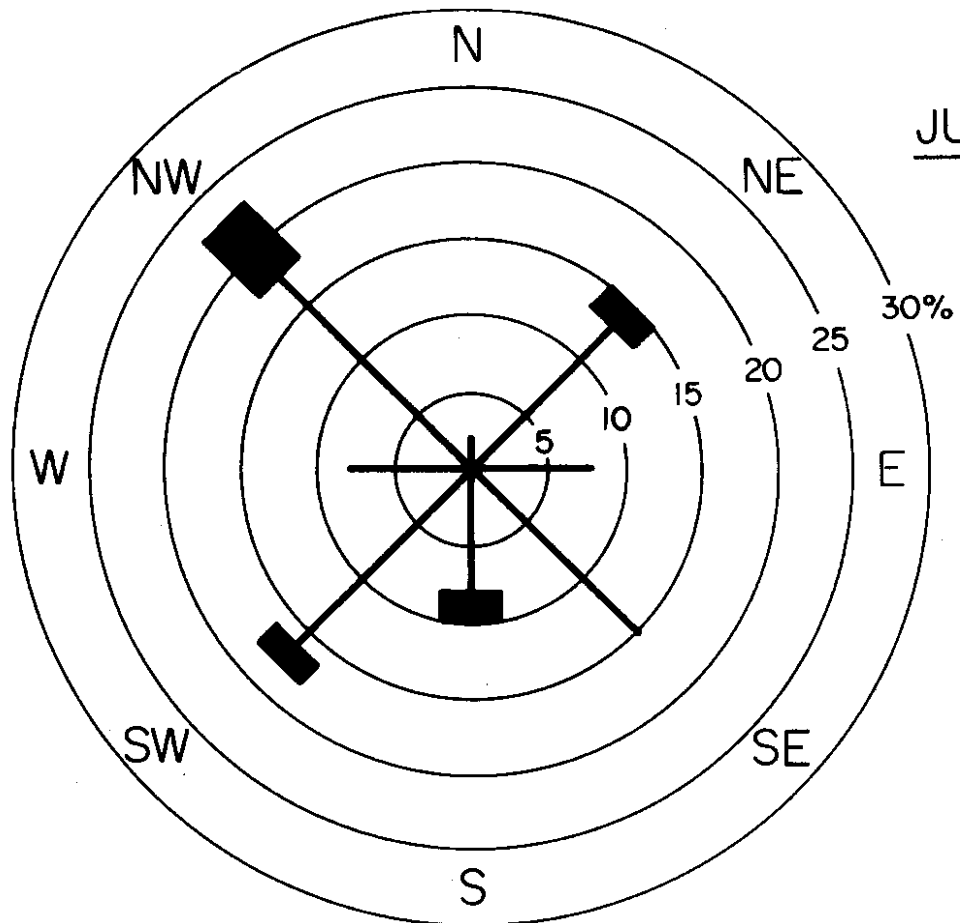


FIGURE 13. WINDROSES FOR JULY & AUGUST — PERIOD OF DUSTJAR INSTALLATION.

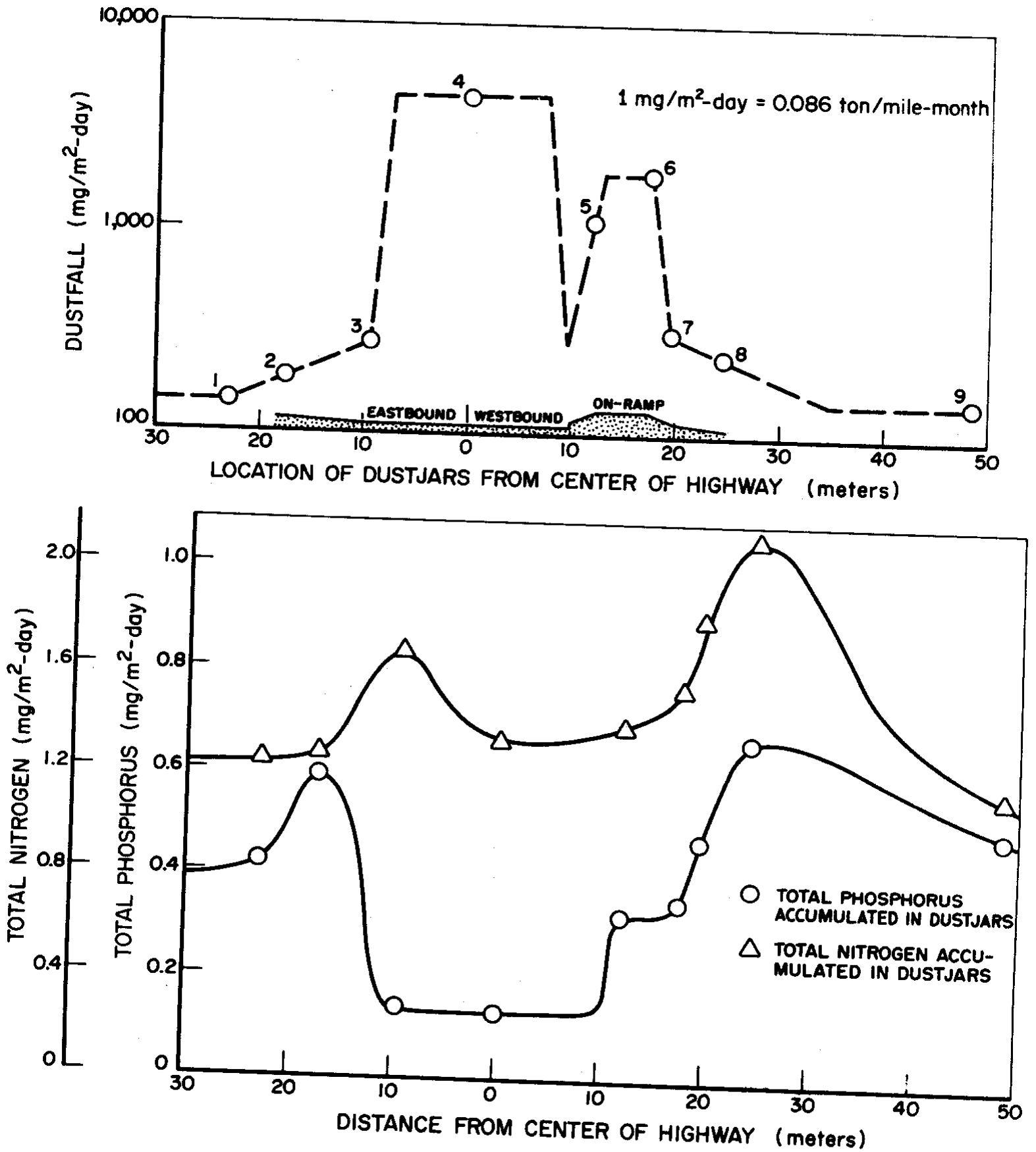


FIGURE 14. POLLUTANTS COLLECTED AT DIFFERENT DISTANCES FROM THE CENTER OF HIGHWAY 520.

water from these floatables and settleables.

8. Air-borne pollutants: Nine dustjars were placed at right angles to Highway 520 as shown in Figure 14 and Table 22. They ranged from the center of the highway to 48 meters distant. Table 22 and Figure 14 show that insoluble dust particles are collected in relatively large quantities in the middle of the road with rapidly decreasing amounts with distance from the roadway. The fact that such an amount accumulates in the most turbulent area indicates that they are relatively heavy particles, probably sand or inorganic dust, which was corroborated by visual observation and microscopic examination. Also, the decreasing percentage of volatile matter (Table 22) hints in this direction. These particles may be removed aerodynamically from a car driving at high speed. Once they hit the road-surface, vehicle caused air currents will sweep them to the roadside gutter and right-of-way area. Comparison of the largest solids value of $4450 \text{ mg/m}^2 \text{ day}$ with the total amount of suspended, settleable and floatable solids of $216 \text{ mg/m}^2 \text{ day}$ (Table 16) indicates that a majority of the solids do not appear in the runoff. One explanation is that they are transported into the right-of-way areas where they become trapped and cannot be removed by runoff water.

An almost reversed picture appears with the dissolved N and P which indicates that these constituents are in general associated with smaller particles that only will subside in areas with less turbulence. The total P shows larger variations than the total N, probably because the P is associated with larger particles than is the N. The total amount of P that settles in the middle of the highway ($0.134 \text{ mg/m}^2 \text{ day}$) is about equal to the P that is removed by runoff ($0.125 \text{ mg/m}^2 \text{ day}$, Table 16). For N the

amount collected in the dustjars is several times less than appears in the runoff. This would indicate that much of the runoff N is associated with non-air-borne substances. Both for N and P, it appears that significant amounts settle in the right-of-way areas that may later be flushed into the highway drainage system.

9. Heavy metals: Analyses were conducted for heavy metals retained in the dustjars set at different distances normal to S. H. 520 (Figure 14), from S. H. 520 runoff samples, and from catchbasin sediments on I-5 and S. H. 518. Results of these analyses are shown in Tables 23-27.

Table 23 lists the heavy metals adsorbed to the particulate solids found in the dustjars as carried by air currents from passing vehicles. These values relate well to the dustfall concentrations shown in Figure 14 and indicate a predominance of southerly winds (Figure 13). As would be expected, the greatest concentrations are found between the W. B. and E. B. lanes followed by locations adjacent to the roadway. Concentrations of lead were by far the greatest, followed in descending order by zinc, chromium, copper, nickel and cadmium. Together, they consist in this example of about 1.1 per cent by weight of the fallout, the remainder being inorganic and organic particulates wafted from the roadway and passing vehicles. Data are not shown for dustjars 1, 2, 8 and 9 since insufficient dust was accumulated for measurement.

Table 24 lists the heavy metals extracted from the distilled water placed in the dustjars. All values are lower than those in Table 23 indicating that the majority of heavy metals are adsorbed to particulate matter, a portion of which may settle out if it strikes a water surface or be retained in the soil if it settles along the right-of-way. Zinc is the

predominate heavy metal found in solution followed by lead (32 and 4 per cent of the total zinc and lead respectively are soluble).

Table 25 lists the heavy metals adsorbed to the suspended solids in S. H. 520 runoff, all taken from the first flush on the four June rainstorms that were sampled. Succeeding samples would be expected to have a logarithmic decreasing order of magnitude. Lead again is highest, followed by zinc, copper and nickel. Cadmium and chromium concentrations are very small.

The total heavy metal concentrations in the early stages of runoff are listed in Table 26. The results indicate that a larger portion of the heavy metals are in solution or suspension and not adsorbed to the suspended particles. Of the drain sampled on June 6, 23 per cent of the Pb is in solution as compared to 3.9 per cent for soluble Pb in the dustjar. For Zn the percentages are 55 to 32.2 and for Ni 76 to 32. This indicates that a sedimentation unit may not be effective in removing a majority of the heavy metals present in the runoff. It is also interesting to see only a limited decrease with progressing runoff.

Table 27 lists the heavy metals found adsorbed to the very fine (<400 mesh) settleable solids taken from the first flush in two drains of S. H. 520 and from catchbasins on I-5 and S. H. 518. While these percentage by weight values are higher than those found in the dustjars, they are not directly comparable since Table 27 values are for only the very fine solids that will settle in a water medium. The values in this table do indicate however, that a significant portion of the heavy metals in runoff can be removed from the runoff water through sedimentation. Also, higher percentages were found with increasing traffic intensity.

For a highway traversing land with adjacent vegetation and exposed soil, it would be expected from these data that a majority of the heavy metals emitted along the highway would be carried off the highway to become incorporated in the soil and vegetation. Where a highway crosses a lake, it would be expected from these data that a majority of the heavy metals would reach the lake surface and then settle to become incorporated in the sediments.

10. Summary Remarks: In reviewing the data given in Chapters III and IV herein, it should be realized that numbers shown by all researchers represent only those conditions found at the time of sampling. These data are limited and they may or may not be representative. The character of highway runoff water at any given time and place is dependent upon many variables, such as; the rate of rainfall, duration of rainfall, number of antecedent days of no rainfall, slope of pavement surface, traffic volume and type, speed of traffic, type of road surface, street sweeping, wind velocity, maintenance practices such as deicing, and runoff contributions from the entire right-of-way area or other.

Table 22. Pollutants Collected in Dustjars Perpendicular to State Highway 520.

Dustjar No.	Distance from center(m)	Total SS from dust mg/m ² day	% NVS dust	Total-P mg/m ² day	Total-N mg/m ² day
1	23.0	146.0	-	0.420	1.240
2	17.5	190.5	-	0.588	1.273
3	9.5	278.0	72.3	0.139	1.670
4	0	4450.0	94.0	0.134	1.335
5	12.0	1120.0	81.3	0.325	1.380
6	17.5	1870.0	87.5	0.350	1.537
7	19.5	318.0	75.0	0.473	1.805
8	24.5	251.0	-	0.662	2.120
9	48.5	150.0	-	0.490	1.128
aver.				0.398	1.413

(2.51 cm rainfall was collected in the dustjars during the 14-day collection period.)

Table 23. Heavy Metals Adsorbed to Particulates Found in Dust Jars¹

Jar No.	Lead, Pb		Zinc, Zn		Nickel, Ni		Copper, Cu		Cadmium, Cd		Chromium, Cr	
	Conc.	%	Conc.	%	Conc.	%	Conc.	%	Conc.	%	Conc.	%
3	2.44	0.88	0.371	0.134	<0.132	<0.048	0.106	0.038	<0.011	*	<0.026	<0.009
4	28.90	0.65	2.530	0.057	0.142	0.003	0.425	0.010	<0.008	*	1.82	0.041
5	8.68	0.78	1.296	0.116	<0.118	<0.011	0.212	0.019	<0.009	*	0.850	0.076
6	26.10	1.39	1.940	0.104	0.231	0.012	0.315	0.017	0.019	0.001	1.330	0.071
7	2.88	0.91	0.839	0.264	0.163	0.051	0.140	0.044	<0.009	*	<0.023	<0.007
Av.		0.92		0.135		0.025		0.026				0.041

1. Heavy metals extracted from particulates by digestion with H₂O₂ and HNO₃ after filtering out particulates.
 2. Concentration in mg/m²/day of highway surface
 3. Heavy metal concentration expressed as per cent of weight of total SS retained in the jar
 4. Jars not shown did not have enough particulate fall out to measure.
- * Below detectable limit.

Table 24. Amount of Soluble Heavy Metals Collected in Dust Jars Perpendicular to the Highway and Soluble Amount Expressed as Percentage of Total Amount (Soluble + Insoluble + Adsorbed) Collected in Dust Jars

Dust Jar No.	Pb		Zn		Ni		Cu		Cd		Cr	
	mg/m ² ·day	soluble amount as % of total amount of HM collected in the dust jars	mg/m ² ·day	%	mg/m ² ·day	%	mg/m ² ·day	%	mg/m ² ·day	%	mg/m ² ·day	%
1	<0.185		0.093		<0.093		<0.019		<0.007		<0.019	
2	"		0.148		"		"		"		"	
3	"	<7.0	0.277	40.5	"		"	<15.2	"		"	
4	0.185	0.6	0.222	8.0	"	<39.5	0.037	> 8.0	"		"	<1.0
5	0.518	5.6	0.352	21.3	0.148	>55.6	<0.019	< 8.2	"		"	<2.2
6	0.185	<0.7	0.830	30.0	<0.039	<28.4	<0.019	< 5.9	0.019	>50.0	"	<1.4
7	"	<5.7	1.314	61.0	"	<36.4	0.019	12.0	<0.007		"	
8	"		0.869		"		0.110		"		"	
9	"		0.185		"		0.093		"		"	
aver.		~3.9		~32.2		~32.0		~9.9		~50.0		~1.5

Table 25. Heavy Metals Adsorbed to the Suspended Solids in Highway 520 Runoff¹

Date 1972	Drain No. 2	Lead, Pb		Zinc, Zn		Nickel, Ni		Copper, Cu		Cadmium, Cd		Chromium, Cr	
		Conc. 3	% 4	Conc.	%	Conc.	%	Conc.	%	Conc.	%	Conc.	%
6-6	5-1	4.310	0.861	1.00	0.201	<0.045	<0.009	0.219	0.044	0.010	0.002	<0.005	<0.001
6-6	6-1	3.99	0.800	0.788	0.158	0.094	0.019	0.166	0.033	<0.005	<0.001	<0.010	<0.002
6-8	2-1	3.78	0.450	0.285	0.034	0.025	0.003	0.042	0.005	<0.008	<0.001	<0.008	<0.001
6-8	5-1	4.16	0.208	0.321	0.016	0.104	0.005	0.040	0.002	<0.020	<0.001	<0.060	<0.003
6-10	2-1	0.290	0.120	0.113	0.047	0.010	0.004	0.014	0.006	<0.002	<0.001	<0.002	<0.001
6-22	6-1	0.790	1.040	0.140	0.184	0.005	0.007	0.018	0.023	0.001	<0.001	0.006	0.008
Avg.			0.580		0.076		0.008		0.019		--		--

1. Samples filtered through Whatman #42 filter paper and digested with H_2O_2 and HNO_3
2. First number is the drain and second number represents the collection sequence for that drain
3. Concentration is in mg/l.
4. Heavy metal as per cent by weight suspended solids

Table 26. Total Heavy Metal Concentrations (soluble and particulate) in SH 520 Runoff in June 6, mg/l.

Drain	Pb	Zn	Ni	Cu	Cr	Cd
4-1	8.45	2.16	0.27	0.15	0.01	0.02
4-2	5.60	1.16	0.14	0.14	<0.01	0.01
5-1	5.60	2.24	0.19	0.17	<0.01	0.01
5-2	2.18	0.93	0.13	0.11	<0.01	0.01
5-3	3.41	1.64	0.13	0.13	0.02	0.009
6-1	4.30	1.93	0.19	0.12	<0.01	0.02

Table 27. Heavy Metals in Settleable Solids Collected from SH 520 Drains and I-5 and SH 518 Catchbasins ¹ (Per cent by weight of dry settleable solids in sample)

Metal	SH 520 6-6-72		I-5 N.B.	SH 518 W.B.
	Drain 4-1	Drain 7-1		
Lead	1.680	1.603	0.770	0.300
Zinc	0.100	0.147	0.443	0.089
Nickel	0.007	0.026	0.007	0.011
Copper	0.034	0.039	0.048	0.019
Cadmium	0.001	0.004	0.001	0.001
Chromium	0.046	0.017	0.016	0.003
Traffic Intensity	39,000	39,000	73,000	615,000

1. Settleable solids <400 mesh.

V SIGNIFICANCE TO WASHINGTON HIGHWAYS

A. Areas of Local Concern

The general observations that have been made in this study are of course no more significant to Washington highways or freeways than they are to any other system. However, there is immediate local concern in District 7 as to the possible significance of freeway runoff on I-90 as related to the present Lacey V. Murrow Floating Bridge over Lake Washington, the proposed Third Lake Washington Floating Bridge and for the Echo Lake vicinity. District 7 has provided the following runoff areas and traffic volumes for these locations:

1. Lacey V. Murrow Floating Bridge I-90

- a. Roadway runoff - 8.87 Ac. ($3.59 \times 10^4 \text{ m}^2$, or 3.59 hectares)
 Sidewalk runoff- 1.57 Ac. ($6.35 \times 10^3 \text{ m}^2$, or 0.64 hectares)

b. Existing traffic volumes

AM peak hour - East	1060 (VPH)
West	4200 (VPH)
PM peak hour - East	4120 (VPH)
West	950 (VPH)
24 hour total East and West	50,760 (ADT)

2. Proposed Third Lake Washington Floating Bridge I-90

- a. Roadway runoff - 12.49 Ac. ($5.05 \times 10^4 \text{ m}^2$, or 5.05 hectares)
 Sidewalk runoff- 1.62 Ac. ($6.56 \times 10^3 \text{ m}^2$, or 0.66 hectares)

b. Estimated traffic volumes in 1990 when both floating bridges are operational:

AM peak hour - East	3600 (VPH)
West	8900 (VPH)
PM peak hour - East	8900 (VPH)
West	3600 (VPH)
24 hour total East and West	100,000 (ADT)

3. Echo Lake Vicinity I-90

- a. Roadway runoff - 7.72 Ac. ($3.12 \times 10^4 \text{ m}^2$, or 3.12 hectares)
 Non-roadway runoff 29.06 Ac. ($11.75 \times 10^4 \text{ m}^2$, or 11.75 hectares)

- b. Estimated 1975 traffic volumes:

AM weekday peak hour - East	1500 (VPH)	
West	1300 (VPH)	
PM weekday peak hour - East	1300 (VPH)	
West	1500 (VPH)	
24 hour total East and West		11,000 (ADT)

Weekend volumes during skiing season

PM peak hour - East	400 (VPH)
West	3925 (VPH)
AM peak hour - East	2600 (VPH)
West	350 (VPH)

B. Maintenance and Drainage

1. Cleaning: Freeways in Washington are cleaned through the use of sweepers that operate on different schedules, depending upon the local need and the availability of equipment. Outside of the metropolitan areas the frequency of sweeping is approximately bi-monthly with a higher frequency in the heavily traveled metropolitan areas. In addition to sweeping, there is a continuous surveillance of and collection of hazardous materials on the roadway itself. The rights-of-way are periodically policed for the collection of litter.

2. Drainage: Highway drainage design is in accordance with the Department Highway Hydraulic Manual. Runoff waters are collected in gutters, ditches and other drainage facilities and discharged directly or by storm sewers to a nearby drainage channel or watercourse. The rate of storm water runoff is a function of the geographical area (rainstorm intensity); the imperviousness, slope and nature of the drainage surface; and it is also a function of the contributing area. In the consideration

of a possible pollutant carried by runoff into lakes, one is more concerned with the total quantity of runoff water with its weight of dissolved and suspended material than with the rate of runoff. With receiving streams, the rate of runoff is important in calculating the possible dilution afforded under different flow conditions. Runoff factors or coefficients for paved areas can be taken as 0.90 and 0.30 for adjacent right-of-way (see Highway Hydraulic Manual or other hydraulic reference).

3. Deicing: In relation to deicing, Donald R. Anderson, Assistant to the Director of Highways for Maintenance, has stated by correspondence (Sept. 25, 1972) that:

- a. The major deicing chemical used is sodium chloride (NaCl) with minor amounts of calcium chloride (CaCl_2) (less than 1 per cent).
- b. No corrosion inhibitors are used with the deicing salt.
- c. The amount of chemical material applied to the roadway surface depends on conditions, i.e. temperature, class of road, assigned priority and horizontal and vertical alignment.
- d. The estimated number of times applied each season ranges from five times in moderate climate areas to approximately 50 times per season in Snoqualmie Pass.

The Department of Highways Directive for Snow and Ice Control (No. D 54-42 (MR), August 25, 1972) lists the application rates of chemicals in pounds per lane mile as a function of temperature. For salt (NaCl), the recommended rates are 400-550 lbs for below 10°F ; 250-400 for $10-15^\circ \text{F}$; and 200-250 lbs per lane mile for $25-32^\circ \text{F}$. Highway maintenance reports that I-90 near Echo Lake receives 30 applications per season @ 225 lbs per lane mile and the floating bridges, ten applications @ 200 lbs

(lbs. estimated by authors as not in maintenance report). The salt runoff in tons would be as shown below in Table 28, allowing for an estimated 75 per cent of salt runoff near Echo Lake and 100 per cent on the bridges and approaches.

Table 28. Deicing Salt Runoff, Tons Per Season²

Highway Section	No. of Lanes	Length of Section Miles	No. Applic. per Season	Lbs. per Applic. per Lane Mile	Seasonal Salt Runoff Tons ²
I-90 Echo Lake	8	0.333	30	225	6.8
I-90 Morrow Bridge	4	1.63	10	200	6.5
I-90 Proposed Third Bridge	6	1.62	10	200	9.7

1. Season is December through February

2. 100 per cent salt runoff from bridges, 75 per cent at Echo Lake

Water currents or exchange in Lake Washington have not been carefully studied and they can be expected to shift significantly with changes in wind stresses, Cedar River runoff and discharge through the ship canal. As a conservative approach to the salt solution question, it is assumed that salt runoff from the bridges would be diluted in an amount of water equivalent to one half the Cedar River discharge during the period of December through February. In this period the mean Cedar River flow at Renton would approximate 1000 c.f.s. (mean annual flow at Renton is 719 c.f.s.) or 90,000 acre-feet for half the flow. The salt runoff from both I-90 bridges (16.2 tons per season of December-February) mixed into this volume results in a mean salt concentration of about 0.1 mg/l which is insignificant¹. If a heavy rain were to wash off the bridges, all

1. Drinking water standards limit Cl^- concentrations to 250 mg/l.

the salt from one application in a period of 12 hours, the resulting salt concentration would be about 4.9 mg/l. This salt concentration is also insignificant as related to the various water uses including aquatic life. At the points of runoff into the lake, salt concentration would be higher prior to dispersion and mixing. If the flow assumptions taken herein are only within 50 per cent of reality, the salt concentrations in the lake from deicing would still remain of no significant concern. Deicing salt of course will also enter Lake Washington from the Evergreen Bridge and through storm runoff from municipal streets whose drainage enters the lake.

Echo Lake on I-90, about 2 1/4 miles southwest of Snoqualmie, is at elevation 910 and has a surface area of about 19.8 acres (Wolcott, Lakes of Washington, Vol., Western Washington, Washington Department of Conservation, 1961). It drains to the Raging River, has a small catchment area, and no records could be found as to its bathymetry. The lake appears to be relatively shallow and eutrophic. A reasonable assumption at present might be that Echo Lake has a mean depth of about ten feet and a water inflow-outflow exchange rate of about once yearly. With these assumptions, the discharge of 6.8 tons of salt yearly from I-90 into this 198 acre-feet of water would give a salt concentration in the Lake of about 25 mg/l. Mitigating this effect is the relatively high rate of spring flushing that could be expected. A salt concentration of 25 mg/l should not be harmful to Echo Lake. If the lake were deeper, the concentration would be less.

C. Comparison of Highway Runoff Water Quality

Storm water runoff from rural areas will contain all the impurities common to highway runoff with the exception of heavy metals, oil, deicing

salts, rubber and man-originated litter. Since streets and highways occupy a large percentage of urban surface areas, it can be expected that urban storm water runoff will contain at least the same impurities as highway runoff (See Tables 2 and 3) but not necessarily in the same concentrations. Relative amounts washed into adjacent waters will be dependent upon the nature of the urbanization, the type of sewer system and the degree of wastewater treatment.

In regard to the runoff from the Lake Washington bridges, it is necessary to place this in perspective with runoff from the adjacent urbanized areas. Seattle, as an example, has a combined sewer system that collects residential and commercial wastewater as well as runoff from the streets, lawns, parking areas and from roof drains. This system intercepts the dry weather flow along the Lake Washington shoreline and carries it westward for disposal into Puget Sound. When it rains, the system cannot carry the large amounts of combined sewage and the system overflows at numerous points into adjacent water courses, such as Lake Washington. To reduce this combined sewer overflow, Seattle has a program underway of sewer separation. In the Lake Washington drainage area, some 6400 acres north of the Canal have been separated and some 1700 acres south of the Canal. These separate storm sewers will handle street drainage but not roof drainage.

In Seattle there are some 4656 acres sewered south of the Canal and 13,070 north of the Canal that have their natural drainage tributary to Lake Washington. Thus, nearly 50 per cent of the street drainage will go directly to the Lake and a significant portion of the remaining will overflow to the Lake when it is raining heavily. Therefore, runoff from the

approximately 35 acres of existing and proposed bridges crossing Lake Washington should have a very small effect on water quality as compared to the adjacent land area runoff, particularly when one considers that nearly all of the Lake shoreline is urbanized.

The foregoing is not true for Echo Lake where the roadway and right-of-way runoff will contribute runoff constituents not present in the normal rural runoff as previously discussed.

VI MITIGATION OF HIGHWAY RUNOFF

The reduction or mitigation of pollutants originating from highways could be done by a combination of five actions: 1) reduction in the use of deicing chemicals; 2) reduction in the additives to gasoline, particularly lead; 3) more frequent surface sweeping and the development of better cleaning methods; 4) better control over truck traffic to minimize spills and; 5) runoff water treatment.

A. Deicing, Lead and Spill Control

In regard to the use of deicing chemicals, there is no present evidence that the use of these are having any significant deleterious effect to either vegetation or receiving water quality in Western Washington where the winters are mild. Lead as an additive to gasoline will probably essentially disappear in the next few years because of its build-up in the soils and sediments, its numerous potentially harmful effects, and because as a gasoline additive it represents an unnecessary resource loss. Methods of controlling spills of various items along the highways is not within the scope of this report.

B. Street Sweeping

As indicated previously, street sweeping as presently conducted is fairly effective in removing litter and the larger sized bits of debris along the roadway, but is not very effective in removing most of the other street surface particulates. Since significant portions of the oil and heavy metals deposited on the roadways are adsorbed to

particulates, an effective street sweeping process conducted prior to predicted rainfall periods would help materially in keeping these substances out of runoff water.

C. Runoff Water Treatment

Treatment of runoff water from highways would be practicable only for the removal of floatables and settleables and this only in those areas where the runoff water can be concentrated and where it may pose a possible receiving water quality problem. The most effective sedimentation basin for the removal of floatables and settleables is one that has a large surface area, is well baffled and has a large detention period. An ordinary catchbasin is not suitable for use herein.

For use along highways, the best type of sedimentation unit would probably be a diked earthen basin. Where this is not practicable, a basin of reinforced concrete could be constructed, preferably along the right-of-way with an exposed water surface, rather than beneath the roadway. A reasonable design, with the information at hand, would be a basin designed for the average rate of surface runoff with a surface loading rate of not over 1200 gal/ft² day and a detention period of about two hours. Baffles should be used to prevent short circuiting and to retain the floatables. Catchbasin cleaning equipment, or other, should be used frequently for removal of sediments and the floatables could be removed by hand skimming. It is likely that the oil and other hydrocarbons retained on the basin surface would largely disappear within a few days or weeks, depending upon conditions, due to biological degradation and volatilization.

A basin of the type described above should remove essentially all of

the litter that might otherwise be discharged to a receiving water; a significant portion of the particulate fractions with their adsorbed metals and oil; and it should remove most of the oily substances. It would have no appreciable effect on substances in solution or on discrete colloidal particles. There exists a large body of knowledge on the performance of sedimentation units but little as related to their effectiveness specifically for highway runoff water treatment.

VII CONCLUSIONS

1. There exists an insufficient body of knowledge regarding highway runoff quality and significance to permit definite conclusions. Enough is known, however, to permit some tentative conclusions.

2. The runoff quantity and quality is changed over the natural from the same area due to the impervious surface and drainage systems, emissions from passing vehicles, the erosion or solution of substances from the road materials and from deicing substances. Vehicle emissions include oil and grease, dirt, wear of parts and tires, litter, the additives to fuel, and heavy metals, particularly lead.

3. A significant portion of the potential substances emitted along a highway are from the vehicle exhausts. Present data indicate that a major portion of this is swept off the road surface area to later deposit along the roadside or to be carried away by air currents. Those fractions deposited on a right-of-way soil surface are probably largely retained in the soil although there is no specific evidence to corroborate this hypothesis other than the large amounts of lead that have been found in the soil adjacent to highways.

4. Substances found in highway runoff are similar in type and quantity to those found in storm water runoff from urban areas for the usual parameters measured; oil, nutrients, solids, COD, BOD and coliform bacteria. Preliminary data on heavy metals show a higher concentration in highway runoff.

5. The quantity and quality of substances washed from a roadway is primarily a function of the number of vehicles passing, their speed, the

number of dry days preceding a given rainstorm and the quantity of rainfall. The first flush from a rainstorm contains the largest concentration of pollutants which then diminish logarithmically as the rainstorm continues.

6. In the limited algal growth tests conducted, the runoff water did not stimulate algal growth, possibly due to the presence of growth inhibiting substances.

7. The use of deicing chemicals on Lake Washington bridges and on I-90 by Echo Lake appear from calculations to have little significance as related to Lake Washington and Echo Lake water quality.

8. When compared to the urban runoff into Lake Washington from the City of Seattle, the runoff from the Lake Washington bridges is of little significance.

9. Street sweeping is not usually effective in removing other than the litter and coarser particles. It was shown to be 56 per cent effective for the dust and dirt fraction, 44 per cent for the heavy metals left on the roadway and 38 per cent for BOD. A possible cleaning improvement for confined areas, such as the floating bridges, could be the use of a large vacuum device similar to those used by the Boeing airplane company.

10. In general, a reduction in the pollutants from highway runoff could be accomplished through: a) minimal use of deicing chemicals; b) reduction in the additives to gasoline, particularly lead; c) more frequent surface sweeping and the development of better cleaning methods; d) better control over truck traffic to minimize spills; and e) runoff water treatment.

11. In certain limited problem areas, sedimentation basins can be

constructed to remove floatables (including oil) and settleable solids. A significant fraction of the heavy metals, oil and nutrients would be removed as they apparently are adsorbed to dust and dirt fractions.

VIII RECOMMENDATIONS

1. From the data available, runoff water quality control from the Lake Washington bridges should be limited to effective street sweeping. This sweeping should be on a frequent schedule and should be done in particular on those days preceding a predicted 50 per cent or greater chance of a rainstorm.

2. Research is needed on better methods and equipment for street sweeping. A larger portion of the fines should be collected as these will contain adsorbed quantities of heavy metals, oil and nutrients.

3. The impact of freeway runoff into Echo Lake can be lessened (although there is no evidence available to the writers that the Lake is being harmed or its quality threatened) through the installation of a sedimentation basin of adequate size and construction (see discussion).

4. Studies are needed to better qualify and quantify the character and significance of highway runoff. These should be done under different traffic conditions in both rural and suburban areas and they should distinguish between road surface runoff and runoff from the adjacent right-of-way. The studies should be conducted over a period of at least one year as a minimum. Automatic sampling equipment would be required.

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APPENDIX A

Calculation of Runoff in Units of Milligrams Per Square Meter (mg/m^2)

Calculation of Runoff in Units of Milligrams Per Square Meter (mg/m^2)

Rainfall is measured in millimeters (mm)

Runoff constituents are measured in milligrams per liter (mg/l)

Roadway surface is measured in square meters (m^2)

One meter (m) equals 1000 mm.

One square meter equals 1000 (1000) = 10^6 mm^2

One mm depth over one square meter = (1) (1000) 1000 = 10^6 mm^3

One cubic centimeter (cc) = 10 (10) 10 = 1000 mm^3

One liter equals 1000 cc = 1000 (1000) = 10^6 mm^3

Therefore, rainfall depth of one mm over one m^2 = one liter,

or, $1 \text{ mm}/\text{m}^2 = 1 \text{ liter}; 1 \text{ mm} = 1 \text{ liter}/\text{m}^2$

and, $1 \text{ mm (mg/l)} = \frac{1 \text{ liter}}{\text{m}^2} \times \frac{\text{mg}}{1}$

thus, mm of rainfall x (mg/l) = $\frac{\text{mg}}{\text{m}^2}$

APPENDIX B

**Constituents in SR 520 Runoff Water, June 6, 8, 10, 22, 1972
(mg/l or "Standard Methods" normal units)**

Table 1. Constituents in SR 520 Runoff Water, June 6, 1972 (mg/l or "Standard Methods" normal units)

Time	Sample	Cond	pH	Ortho P	Total P	NO ₃ N	Total N	COD	SS	Oil	Alkal	Turb.	Coliform	
													TC	FC
1055	1-1	1700			0.52	2.89	42.09	1812	630	50.3			<2300	<2300
1200	1-2	1150			0.16	2.50	61.10	1272		38.9				
1300	1-3	1200			0.16	0.72	39.92	1388		37.2				
1100	2-1	1700			1.04	2.53	75.33	1016		56.9				
1205	2-2	1300			0.45	1.46	74.26	1003		40.1				
1305	2-3	1300			0.16	0.81	51.20	1003		38.3				
1105	3-1	1650			0.16	2.76	53.16	1272		48.3				
1205	3-2	1350			0.16	2.40	52.80	1113		30.1				
1310	3-3	1350			0.16	1.79	48.80	1205		35.3				
1110	4-1	2300			1.30	2.00	108.40	4373	372	61.3			9100	3600
1210	4-2	1400			0.55	0.61	95.81	1432		40.2			23000	3600
1310	4-3	1400			0.18	0.80	84.80	1509		40.9			3000	<2300
1115	5-1	1750			1.60	2.51	113.51	1780	340	69.9				
1215	5-2	1350			0.52	0.24	100.24	1084		52.5				
1315	5-3	1400			0.33	0.60	56.60	1277		57.3				
1115	6-1	1600			1.47	0.57	67.77	871	498	58.6				
1215	6-2	1400			0.33	0.90	90.50	690		39.2				
1315	6-3	1400			0.20	1.53	68.73	690		41.0				

Table 2. Constituents in SR 520 Runoff Water, June 8, 1972 (mg/l or "Standard Methods" normal units)

Time	Sample	Cond	pH	Ortho P	Total P	NO ₃ N	Total N	COD	SS	Oil	Alkal	Turb.
1815	1-1	1160	4.70	0.04	0.18	9.76	11.40	424	1612	28.3		22
1825	1-2	1000	6.10	0.10	0.14	3.29	4.32	176	578	22.5		18
1835	1-3	980	6.75	0.06	0.15	2.56	3.65	159	179	20.5		17
1850	1-4	820	6.80	0.08	0.13	1.97	3.05	142	221	21.0		17
1905	1-5	910	8.65	0.06	0.16	2.22	3.17	159	230	24.9		15
1816	2-1	2250	7.15	0.07	0.18	11.0	12.66	251	840	41.0		21
1826	2-2	1110	7.40	0.06	0.11	3.15	3.63	132	520	38.1		21
1836	2-3	1100	7.50	0.08	0.08	2.83	4.12	121	394	32.0	42.0	15
1851	2-4	1000	7.50	0.09	0.15	2.49	5.25	106	243	25.4		15
1906	2-5	1140	7.05	0.04	0.18	2.81	4.23	117	101	26.2		18
1817	3-1	2300	7.10	0.11	0.29	12.33	23.98	197	937	39.2		21
1827	3-2	1600	7.30	0.06	0.24	6.47	12.70	208	283	32.2	54.0	21
1837	3-3	1550	7.40	0.05	0.18	4.78	10.60	210	146	28.6		15
1852	3-4	2350	7.20	0.05	0.19	4.23	10.63	175	177	30.2	58.0	18
1907	3-5	1550	6.70	0.04	0.20	4.25	9.90	182	122	32.5		15
1818	4-1	3320	6.40	0.20	0.21	15.66	17.70	770	2003	47.2	128.0	23
1828	4-2	1600	6.90	0.12	0.17	5.03	6.25	225	450	39.7	44.7	17
1838	4-3	1320	7.05	0.09	0.17	3.66	4.85	182	148	39.0		17
1853	4-4	1250	6.60	0.07	0.15	3.28	5.02	164	133	33.2		15
1908	4-5	1200	6.20	0.03	0.14	2.73	4.00	159	80	28.7		17
1819	5-1	2720	7.05	0.04	0.09	14.57	14.84	358	688	35.5		17
1829	5-2	2000	7.45	0.04	0.09	4.06	4.97	145	453	32.1		15
1839	5-3	1800	7.45	0.02	0.08	1.65	2.19	136	137	33.2		15
1854	5-4	1700	6.70	0.03	0.08	7.59	9.50	128	111	35.7		14
1820	6-1	2600	6.20	0.11	0.38	13.04	13.89	507	3715	63.0	78.8	31
1830	6-2	2180	7.20	0.06	0.24	4.85	5.91	210	262	43.0		17
1840	6-3	2200	7.30	0.05	0.23	4.18	5.30	221	166	40.8		17
1855	6-4	1920	6.80	0.07	0.28	3.68	5.02	170	128	39.8		15

Table 3. Constituents in SR 520 Runoff Water, June 10, 1972 (mg/l or "Standard Methods" normal units)

Time	Sample	Cond	pH	Ortho P	Total P	NO ₃ N	Total N	COD	SS	Oil	Alkal	Turb.
1300	1-1	1050	8.50	0.03	0.20	5.12	7.14	84	135	12.0		15
1315	1-2	810	7.30	0.02	0.18	1.33	1.89	67	134	11.2		13
1325	1-3	810	6.55	0.03	0.18	1.02	1.57	59	124	10.8		13
1340	1-4	720	6.67	0.02	0.16	0.69	1.06	42	198	11.0		13
1310	2-1	525	7.10	0.03	0.16	2.28	4.44	57	241	13.8	43.0	14
1315	2-2	510	7.70	0.05	0.17	2.89	5.56	45	91	12.0	31.2	13
1330	2-3	540	8.10	0.04	0.15	2.22	4.04	47	56	13.2		14
1345	2-4	310	7.10	0.02	0.12	0.62	2.91	43	66	12.0	32.8	13
1305	3-1	395	7.50	0.03	0.17	1.56	3.47	47	113	13.0		13
1315	3-2	350	7.70	0.03	0.17	1.80	4.21	70	182	16.4	36.0	14
1330	3-3	330	7.80	0.05	0.15	1.40	3.50	66	69	15.8		13
1345	3-4	265	7.25	0.02	0.14	0.82	2.56	49	117	14.3	32.0	13
1255	4-1	255	7.15	0.03	0.12	3.15	6.14	103	1510	11.9	37.2	14
1310	4-2	150	7.50	0.02	0.11	2.13	4.48	83	225	13.7	32.0	14
1325	4-3	90	7.40	0.11	0.11	1.16	2.76	42	86	12.2		14
1340	4-4	75	7.20	0.03	0.08	0.88	1.96	56	144	13.3		13
1250	5-1	180	6.95	0.25	0.27	2.66	5.41	140	561	18.5	54.0	15
1310	5-2	160	6.80	0.03	0.13	1.42	3.15	54	144	15.8		15
1325	5-3	73	7.90	0.05	0.16	2.36	5.62	35	156	9.2		14
1340	5-4	60		0.07	0.18	0.91	3.03	32	120	9.6		13
1310	6-1	330	8.20	0.07	0.22	4.10	6.91	37	71	9.8		13
1315	6-2	205	8.30	0.02	0.18	2.79	5.52	57	85	12.1		13
1330	6-3	195	7.50	0.07	0.21	1.88	4.16	62	82	13.0		13
1345	6-4	120	7.20	0.13	0.21	1.37	3.42	48	78	11.8		13

Table 3. Constituents in SR 520 Runoff Water, June 22, 1972 (mg/l or "Standard Methods" normal units)

Time	Sample	Cond	pH	Ortho P	Total P	NO ₃ N	Total N	COD	SS	Oil	Alkal	Turb.
1810	1-1	510	6.80	0.16	0.16	5.77	7.78	214	123	25.6	51.2	14
1824	1-2	220	7.00	0.14	0.14	3.42	5.01	159	180	20.5		13
1837	1-3	210	6.85	0.06	0.10	2.98	4.95	154	188	18.0		15
1845	1-4	240	6.90	0.03	0.11	3.20	4.88	157	142	19.0		17
1812	2-1	405	7.10	0.16	0.17	5.89	6.30	150	66	40.1	48.0	25
1825	2-2	335	7.50	0.12	0.17	4.79	5.88	125	162	38.0		21
1838	2-3	320	7.30	0.11	0.14	4.33	5.62	124	81	35.0		17
1846	2-4	305	7.30	0.08	0.13	4.57	6.04	155	96	37.0		19
1815	3-1	380	7.40	0.11	0.11	4.83	6.57	220	62	45.0		19
1826	3-2	377	7.50	0.11	0.11	4.80	6.56	156	62	44.0		20
1839	3-3	375	7.60	0.11	0.11	4.83	6.70	166	63	37.0		18
1847	3-4	425	7.60	0.11	0.11	5.05	6.82	187	63	38.2		21
1805	4-1	570	6.80	0.14	0.15	7.65	10.39	216	130	37.5		17
1820	4-2	410	7.00	0.07	0.13	5.91	8.70	164	143	30.0	46.8	21
1835	4-3	350	7.10	0.08	0.13	4.56	7.54	166	154	34.0		17
1843	4-4	360	7.20	0.08	0.12	4.39	6.99	144	63	20.0	55.0	19
1808	5-1	480	7.30	0.13	0.13	7.09	9.25	192	76	42.8	54.0	14
1822	5-2	360	7.50	0.09	0.11	4.74	7.27	131	114	38.0		14
1836	5-3	330	7.50	0.09	0.11	4.95	8.20	146	67	35.9		15
1844	5-4	350	7.40	0.12	0.12	4.75	7.67	158	41	36.3		15
1815	6-1	350	6.50	0.16	0.17	6.09	7.36	215	141	48.2	78.8	16
1827	6-2	360	7.20	0.09	0.15	4.68	6.32	150	67	43.0		15
1840	6-3	370	7.35	0.08	0.16	4.48	6.22	178	65	45.2		15
1848	6-4	410	7.40	0.08	0.14	5.05	6.77	203	61	47.3		15

APPENDIX C

Glossary of Quality Constituents

BOD:	Biochemical oxygen demand - a measure of the rate of molecular oxygen utilization by microorganisms in the degradation of organic matter at a given temperature.
COD:	Chemical oxygen demand - a measure of compounds (usually organic) that are capable of being oxidized by a strong oxidant. Value is normally several times larger than the BOD.
Total Solids:	Sum of all the impurities present in the water.
SS:	Suspended solids; these plus the TDS (total dissolved solids) equal the total solids.
Settleable solids:	That fraction of the suspended solids that will settle from solution in a given time period.
VDS:	Volatile dissolved solids; that fraction of the dissolved solids that can be volatilized through the application of high temperatures (usually mostly organic matter).
VSS:	Volatile suspended solids; that fraction of the suspended solids that can be volatilized through the application of high temperatures (usually mostly organic matter).
NVS:	Non-volatile solids; essentially mineral matter.
Coliform bacteria:	A group of bacteria used to indicate the sanitary quality of water, reported usually as the number per 100 ml of sample. Test methods may or may not differentiate between those of fecal and non-fecal origin. The bacteria itself is essentially harmless.
Fecal coliforms:	Those coliform bacteria probably originating from the body wastes of any warm blooded animal. Their presence, if from humans, indicates the possibility of pathogenic bacteria being present.
Total P:	Total phosphorus; the sum of the soluble, poly and organic forms of phosphorus. Of interest because it is frequently considered to be the limiting nutrient for algal growth.
Ortho P:	Ortho or soluble phosphorus; the form readily assimilable by algae.

- Total N: Total nitrogen; the sum of the ammonia nitrogen (measured as NH_3 or NH_4), organic nitrogen (nitrogen contained in organic matter), nitrites (NO_2), and nitrates (NO_3). Nitrogen is a key nutrient for algal and other plant growth.
- Oil: This includes all oils and greases that can be extracted using a particular organic solvent.
- Kg/h: Kilograms per hectare. A hectare equals 10,000 sq. meters or 2.47 acres.
- Turb: Turbidity; caused by suspended matter and measured by the ability of a sample to transmit light.