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CHARACTERISTICS OF HIGHWAY RUNOFF IN TEXAS

September 1978
Final Report

Prepared for
FEDERAL HIGHWAY ADMINISTRATION
Offices of Research and Development
Washington, D.C. 20590

FOREWORD

This report presents an investigation of rainfall-runoff from an elevated highway bridge structure including quantitative measurements of washed off pollutants. The report will be of interest to researchers involved in evaluation of highway contributions to non-point sources of water pollution.

Research in Water Quality Changes due to Highway Operations is included in the Federally Coordinated Program of Highway Research and Development as Task 3 of Project 3E, "Reduction of Environmental Hazards to Water Resources Due to the Highway System." Mr. Byron N. Lord is the Project and Task Manager.

The data used in this study were collected in 1977 by the Texas State Department of Highways and Public Transportation in cooperation with other concerned agencies. The collection program was specifically designed to measure the amounts of various water pollutants washed off a highway during natural rainfall events.

A limited distribution of this report has been made to researchers involved in the study of highway runoff.

Charles F. Scheffey
Director, Office of Research
Federal Highway Administration

ACKNOWLEDGEMENTS

Acknowlegement is given to several agency's representatives, as well as individual experts, who provided assistance and guidance during this study.

Mr. E.E. Gann and Mr. R.M. Slade, Jr. of the U.S. Geological Survey provided considerable guidance in water sampling methods and interpretations of low meter data. The U.S.G.S. supplied a 4'(1.2192m) x 4'(1.2192m) steel building, a Thompson Recording Flow Meter, a U-shaped weir and an event marker solenoid.

Mr. David Gill of the Texas Water Resources Board provided technical expertise in sampling methods, the composition of samples, and also arranged for laboratory analysis by the Trinity River Authority.

District 18 of the State Department of Highways and Public Transportation installed the traffic loops and assisted in administration, equipment procurement, and sample collection and processing.

Mr. Jack Lougheed collected most of the samples, composited them, and carried the samples to the Trinity River Authority Wastewater Lab.

Dr. Jerry Bullin, Mr. John Polasek, and Mr. James Miculka assisted with the air quality study of gases and particulate.

Dr. Byron Lord and Mr. Robert Prochaska of the Federal Highway Administration supplied expert advice and administrative support.

Mr. Mahendra Gupta and Dr. Nicholas Kobrigger, of Envirex, an FHWA contractor, provided technical advice on procedures and statistical analysis of data.

Mr. Joe Wise, Mr. Roger Wayson, Mr. Joe Mlsna, and Mr. Robert Stuard assisted with the operation and maintenance of the water sampling equipment and analysis of the data. Ms. Gwendolyn Wade prepared the manuscript.

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16. Abstract

This experiment was designed to measure the amounts of various water pollutants washed off an elevated highway bridge structure during natural rainfall events. Water samples were acquired behind a sharp crested weir using automatic water samples set at one and ten minute sampling intervals. Flow rates were established using a relationship of head rise to discharge. Rainfall amounts were measured as well as traffic volumes. Dustfall buckets were used for particulate sampling. The ratio of pollutant concentrations to each other measured at one minute sampling interval was remarkably consistent. The increase of pollutant concentration with increase in number of dry days is linear for many pollutants such as heavy metals. For suspended solids it appears to accelerate with increase in dry days. The heaviest pollutant loading occurred when two large rainfall events occurred in quick succession. Rainfall events of one inch or more result in a characteristic loading. Rainfall events of lesser amount result in another characteristic level as measured in pounds of pollutant/acre of drainage area.

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INTRODUCTION

Vehicles travelling highways are often blamed for polluting lakes and streams. Highways and city streets are termed non-point sources and the discharge of materials washed from them through open channels and storm sewers to nearby lakes and streams are often compared to allowable discharge from sewage treatment plants, perhaps an unfair comparison since the solid material washed off roadways may not be as biologically active as sewage sludge.

This study was designed to determine what pollutants are washed off a highly impervious bridge structure which is part of a major interstate system in an urban area, IH-45 at Forest Avenue in Dallas, Texas. It was not designed to determine the source of these pollutants or their ultimate fate, but merely to establish the nature and amount of water pollutants reaching the storm sewer system.

In any study of natural runoff, the data acquired depends on the vagaries of the weather. The experiment was designed in such a way that essentially all of the rainstorm washoff was sampled automatically and the amount of water flowing through the storm sewer system was gaged so that concentrations in the composite samples acquired could be related to the pounds of washoff of the various pollutants.

One objective of the research was to relate the ratio of the pollutants to each other to see if that ratio remained constant for different amounts of rainfall and rainfall rates. Another objective was to look at the amount of pollutant that accumulated since the last significant rain and see how that varied with the number of dry days.

Studies of the amount of dust resuspended by moving vehicles have shown a sharp decrease in the amount resuspended into the air following a significant rainfall event. This leads to the belief that pollutants accumulate along a roadway in the dry season until they are washed off the roadway by a rain and this accumulation influences air pollution levels.

Since this organization was already doing research under FHWA contract DOT-FH-11-9238, this water quality study was designed to give some information useful to the air quality study and some data were collected simultaneously with these goals in mind. Dustfall samples were taken with all water quality data to attempt to evaluate resuspended dust when wind direction was relatively constant.

Since water quality studies involve a completely different technology from those used in air quality, we enlisted assistance from the U.S. Geological Survey, the Texas Water Quality Board, District 18 of the State Department of Highways and Public Transportation, and the Trinity River Authority. It was through their cooperation and technical assistance, in addition to that of the FHWA and Envirex, that we were able to put together in short order a water quality experiment which produced good measurements of water and air pollutants, although flow measurement was occasionally erratic.

A total of eleven storm events were monitored in a period of four months. Rainfalls were mainly small and intense. Because of the imperviousness of the concrete bridge and the absence of other street level drainage, a unique opportunity to sample water under "worst" conditions was presented. High quality data on the characteristics of pollutants in highway runoff are seriously lacking in the state of Texas.

Conclusions

The accumulation of roadway pollutants subject to washoff in rainstorms appears to be a linear function of the number of days since it last rained for many of the heavy metal pollutants such as iron, lead, and zinc. On the other hand, it appears from these data to be a curvilinear function for solids, sulphates, and some of the organic indicators. The increasing rate of washoff with increase in number of dry days for the latter bears further investigation.

Although the pollutant levels are relatively high for a highway section covering 2.26 acres (.9146 Ha), it should be remembered that this is a worst case situation because of the highly impervious concrete deck of an elevated structure and the resultant quick concentration of washoff through a water-tight storm sewer system. Even short rains with little rainfall can effectively clean much of the roadway if the rainfall intensity is great enough. Many of these rains would not meet the rainfall amount criteria normally used for a significant rain, yet many of the smaller rains were almost as effective as the larger ones in flushing pollutants from the roadway. Short, intense rains should probably be included in any analysis of impervious sites such as this one.

Total pounds of pollutants of washoff per storm event were related to the number of days since the last significant rainfall. It was found that relatively small rains resulted in very few pounds of washoff per dry day. Rainfalls of an inch or more resulted in about four times as much washoff, and if the heavier rains occurred in quick succession, the washoff per dry day was double those of heavy storms with more than one or two days between storms. It is presumed that wet pavement may accumulate pollutants at a faster rate than dry pavement. This factor should probably be considered when modeling highway washoff rates if verified by further research.

RECOMMENDATIONS

Additional data need to be gathered to verify the data already collected. This is being done in a follow on HP&R Research Study [1]. The data need to be normalized for roadway traffic, total discharge, rainfall amount, and surface area. Additional rains need to be evaluated for the mean discharge/rainfall (Q/R) ratio.

This research says nothing about the impact of these pollutants on receiving waters. A detailed study for an entire watershed needs to be made with a strong emphasis on model development. The effectiveness of earthwork structures such as catch basins, holding ponds, and drainage ditches in removing pollutants should be investigated and modeled.

The air/water quality tradeoffs require further investigation. Particulate samplers such as U.C. Davis Stacked Filter Units [2] should be used instead of the dustfall buckets used in this study. Better analytical methods of testing water samples should be developed which can relate comparable amounts of air and water pollutants to each other and also permit discrimination of particle size, a critically important parameter for modeling dispersion of air pollutants.

A complete study of the resuspension of air pollutants along a roadway should consider the influence of highly variable rainfall on the dust lying in the roadway since this is easily resuspended by the turbulence created by vehicle moving along it. The sources and ultimate sinks of many compounds need to be determined.

Implementation

These data, when supplemented by data from the follow on HP&R study, can be used to estimate the pollutant washoff from highly impervious, elevated concrete structures in Texas. Since the character of the site has been shown by Envirex to have a great effect on the amount of pollutant washoff [3], these data should only be used for similar sites with equivalent rainfall patterns, unless suitable factors are introduced to take account of site variation. This study was a useful shakedown of an efficient automatic water sampling station. Although the data are limited, they appear remarkably consistent and should have reasonably good validity.

Experiment Design

The site chosen for this experiment was an elevated bridge structure in South Dallas on Interstate Highway 45 at Forest Avenue. A section of the bridge was chosen whose drainage passed through a single manhole without any apparent contamination from other sources. All of the water on the bridge passed through curb inlets to an enclosed storm sewer system. The area drained was 2.26 acres (.9146 Ha) or 0.0053 square miles. Rainwater draining from the bridge was collected by 21 inch (53.34 cm) and 15 inch (38.1 cm) storm sewers meeting at right angles at a 36 inch (91.44 cm) manhole (Manhole "J.2") with a 21 inch (53.34 cm) exit sewer. The U-shaped, sharp crested weir was bolted and cemented to the manhole end of the exit sewer pipe (See Appendix B) by personnel of the Ft. Worth Subdistrict of the U.S. Geological Survey under the supervision of Mr. Eugene Gann.

A standard 4' (1.2192 m) x 4' (1.2192 m) U.S.G.S. steel building was installed over the manhole to provide instrument security and protection of the instruments from the elements. The building was furnished with 110VAC power for trickle type chargers for 12V marine batteries which powered the automatic water samplers.

Two ISCO automatic water samplers were installed inside the building. One of these was set to sample once a minute within one minute after a sampler actuation signal was recieved, while the other sampled once every 10 minutes. These periods were chosen to permit a representative sample to be taken for both long and short storms. Each sampler collected 28 consecutive samples and then shut down automatically.

An A-35 Leupold-Stevens mechanical recorder provided by U.S.G.S. was also installed inside the steel building. It was used to record flow in terms of head above the weir height. Tables used to convert head to discharge rate can be found in Appendix A.

Two stilling wells of 4" (10.16 cm) PVC pipe were securely fastened alongside the manhole ladder. One of these was used for a float which actuated the pen of the recorder tracing the head on a chart driven by a mechnical clock. The float was carefully counterweighted to give the required sensitivity and keep tension on the line attached to the float. A gauge was supplied for setting the recording pen at the correct chart level.

The other stilling well was used to actuate a sump pump switch which supplied a ground to the pump motor thereby energizing the samplers. The sampler actuation also amplified the logic signal to energize an event marker relay, which caused a pen to mark the A-35 recorder chart whenever the pumps started to draw a sample. Guidance from the ISCO factory was received on the design of electronic circuits to initiate the sampler and activate the event marker.

PROCEDURES

The draft copy of the Procedural Manual for Monitoring of Highway Runoff [4] being developed for the Federal Highway Administration was used extensively for developing procedures and proved most helpful.

Equipment checks were made three times weekly on Monday, Wednesday, and Friday, by a person residing near the site and working approximately one-half time while going to school. This sytem has proven the most satisfactory way of manning the site. It allows quick reaction to storm events at minimum cost. The student frequently arrives at the site when it starts to rain, so he can acquire grab samples while the storm is in progress. The need for frequent checks of the equipment cannot be overemphasized. The marking of charts and synchronizing them with the correct time is of utmost importance. A log book at the site also proved invaluable in documenting progress of the research and difficulties which might influence interpretation of the data.

Samples were composited in the District 18 Laboratory of the State Department of Highways and Public Transportation 10 miles (16.093 km) east of the site. Flow rates were calculated using tables prepared by the U.S. Geological Service (Appendix A) and the amount of sample selected from each bottle depended on the flow rate calculated at the time the sample was acquired. At times there was not enough sample acquired in a single bottle when rainfall rates were intense. To increase the sample size, both samplers were sometimes set at one minute intervals and the samples for the same time combined.

After the composit samples were prepared and labeled, the samples and forms requesting appropriate tests were delivered to the Trinity River Authority Lab about 30 miles (48.28032 km) distant. Samples which could not be prepared or delivered immediately were refrigerated.

A list of the laboratory tests made at the Trinity River Authority, preservation conditions, sample size, and holding time is included in Appendix B.

Careful coordination with the supporting laboratory is needed to ensure that appropriate tests are made in a timely manner and the sample bottles marked in a mutually agreed fashion. A laboratory should be chosen reasonably close to the monitoring site to cut down on the holding time of samples which is critical for some parameters.

The use of a checklist such as the one in Appendix "D" is advisable as a reminder to personnel unfamiliar with procedures. A copy of the checklist should be filed at the site with the log book which serves as a complete chronicle of research happenings.

Also in Appendix "D" is a form which can be of assistance in preparing composit samples. It is used to calculate the aliquots to be drawn from each sample bottle based on the flow across the weir at the time the samples were drawn.

A Belfort 7-day Automatic Recording Rain Gauge, using a 24-hour gear to furnish an expanded scale for greater accuracy, was mounted on the bridge structure outside the guard rail near the drainage area. The rain gage measures the time of onset of rainfall, total amount of rainfall, and its duration. From this information, rainfall rate can also be calculated. Dustfall buckets equipped with bird rings were mounted 10 feet (3.048 m) above the surface of the roadway and 50 feet (15.24m) either side of the structure 10 feet (3.048 m) above ground. Dustfall buckets are used to assess the net contribution of resuspended dust from the roadway when winds blow consistently from one side of the roadway to the other. Upwind values must be subtracted from downwind.

Six Streeter-Amet traffic counters programmed for 15 minute counts were connected to separate traffic loops to record traffic for each lane. Capacitors wired in parallel across the loops vary in size from one counter to another. This eliminates "crosstalk" by shifting the resonant frequency of the tank circuit. Fischer-Porter Traffic Counters borrowed from the State Department of Highways and Public Transportation were used in the early stages of the experiment. Traffic counters are used to normalize the data for variations in traffic flow.

The Stephens, A-35 flow meter records gage heights in feet which are converted to flow rate in ft^3/sec. (2.8316 liter/sec.). The flow rate established is used to prepare composite samples and calculate mean discharge in gallons or inches of depth.

Description of Research Site:

IH-45 is a major urban Freeway between Houston and Dallas. There is an interchange with IH-30 and the Central Expressway (US 75) in Dallas one mile (1.609 km) north of the site. The traffic lanes are bounded by curbing 6" (15.24 cm) high and a 4' (1.22 m) median barrier. There are three traffic lanes in each direction and an exit ramp southbound. The Trinity River lies one mile (1.609 km) south of the site. The surface drainage area is 2.26 acres (.9146 Ha) or 0.00353 square miles (.009146 Sq km). It consists of an elevated bridge structure with six IH-45 traffic lanes 20 feet (6.096 m) above Forest Avenue and South Boulevard in South Dallas, Texas.

All drainage from the bridge is collected by lines N, P, Q, and J at manhole J-2. (See Figure 1) The manhole is the sampling location. Line J is a 15 inch (38.1 cm) storm sewer with a slope of 0.66% which meets Line P, a 21 inch (53.34 cm) storm sewer with a slope of 0.69%, at right angles at Manhole J-2. Line J leaving Manhole J-2 is a 21 inch (53.34 cm) pipe with a slope of 0.89%.

The bridge structures were constructed between 1973 and February 1976. Data were collected between May and September 1977. It had been in service about one year at the time these data were collected. Since, in the first year of a new pavement's life, the wear rate of the pavement is relatively high, the solids data from this site may be biased on the high side when compared with highways which have older pavement surfaces.

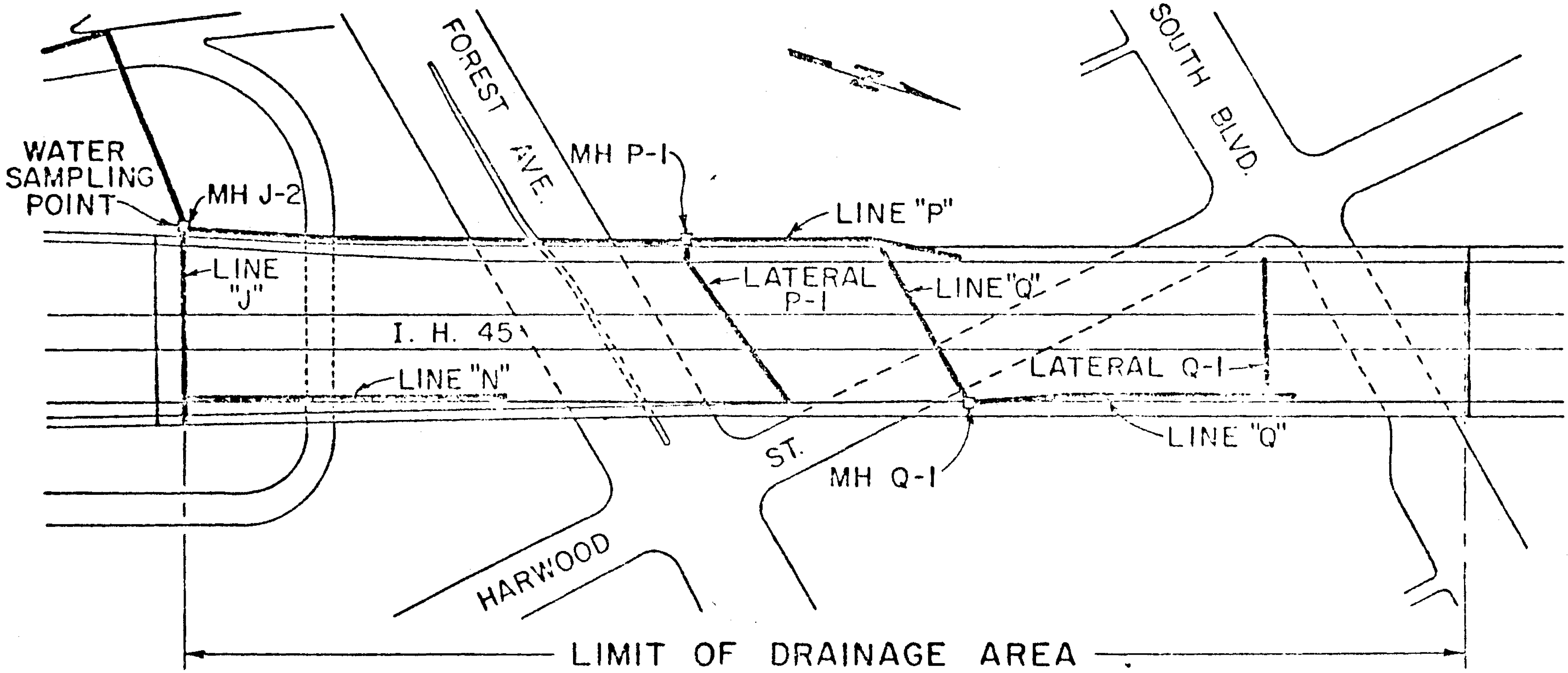

FIGURE 1 IH-45 STORM SEWER SYSTEM

Analysis of the Results:

In seeking to determine a pattern in the relation between the concentration of one minute composite samples and rainfall characteristics, the concentrations of 12 pollutants for which we hold the most data were ranked in decreasing order of concentration and an overall rank determined for each storm event, (See Table 1). Storm event #1 had the highest concentration for each pollutant analyzed. A great deal of consistency is shown througout, especially in the metals, solids, carbons, and sulphates. The nitrogen and nitrate tests appear less consistent with the other tests in concentration ranking: The standard deviation of the concentation ranks was less than 3.0 for all pollutants and each storm event. Storm event (S.E.) 2 was relatively low in iron and 5 high. SE 5 was relatively rich in metals. Otherwise the data are remarkably consistent in concentration ranking. This is shown by the close relationship between the overall rank of the concentrations for each storm event with the arithmetic mean of the individual ranks and the relatively small standard deviations. This indicates some relationship between concentration and certain characteristics of that particular storm event.

Rainfall data were then assembled in order of concentration rank (See Table 2). Here dry days are the number of days since significant, more than a trace, of rain fell. Almost all of the storms had a high rainfall rate. The exceptions were SE 4 and 11 with 0.22 (.5588 cm) and 0.17 inches (.4318 cm) per hour. Note that the four events with the greatest number of dry days also had the greatest concentrations as measured by a composite sample acquired in the first thirty minutes. On the other hand, the four storms with least number of dry days had the lowest concentrations as shown in Table 2. It should also be noted that the storm with the highest concentrations (SE 6) had the greatest number of dry days and the lowest rainfall, while the storm with the greatest rainfall (SE 9) had the lowest concentration and very few dry days. No samples were prepared for SE 10 because the rainfall was insignificant.

One might hypothesize that SE 6 with its low rainfall amount (0.08") (.2032 cm) and short duration (five minutes) represents the rich first flush from the roadway. This does not seem to be the case, since the rainfall rate of about one inch per hour should be sufficient to remove a great deal of the loose material from the impervious bridge structure and carry it through the relatively tight storm sewer system. The flow meter indicated a sharp single peak as the runoff collected rapidly.

TABLE 1

Ranking of Concentration

~~Overall~~ Rank	Storm Event	Fe	Pb	Zn	TSS	IVS	TDS	TS	COD	TOC	K-N	NO_3	SO_4	Arithmetic Mean (A.M.)	Standard Deviation σ
9	1	9	6	6	6	4	9	9	9	7	8	4	7	7.00	0.14
2	2	10	4	3	4	2	6	2	2	1	7	1	2	3.67	2.74
4	3	-	-	-	3	5	5	3	8	5	3	3	-	4.38	1.77
8	4	4	8	8	8	8	3	7	7	-	-	-	8	6.78	1.92
7	5	3	2	4	11	10	3	8	4	6	6	9	6	6.00	2.95
1	6	1	1	1	1	1	1	1	1	-	-	-	1	1.00	0.00
3	7	2	3	2	2	5	7	6	3	2	4	7	3	3.83	1.95
10	8	6	9	9	9	9	8	10	10	8	9	5	9	8.42	1.51
11	9	8	10	10	9	11	10	11	11	9	1	6	10	8.83	2.86
5	11	5	5	5	10	3	6	5	5	4	2	2	5	4.75	2.09
6	12	7	7	7	5	6	2	4	6	3	5	8	4	5.33	1.83

TABLE 2

CONCENTRATION RANKING AND RAINFALL

CONCENTRATION RANK	STORM EVENT #	RAINFALL (IN)[1]	RATE(IN/HR)[2]	DURATION (MIN)	DRY DAYS
1	6	0.08	0.96	5	16.6
2	2	0.10	0.60	10	9.9
3	7	1.05	1.80	35	11.7
4	3	1.00	0.60	100	12.2
5	11	0.16	0.17	55	3.4
6	12	0.18	1.1	10	5.8
7	5	0.19	1.14	10	7.4
8	4	0.40	0.22	110	3.2
9	1	0.34	1.36	15	0.9
10	8	1.13	1.51	45	4.7
11	9	1.35	1.01	55	1.6

1 in. = 2.54 cm
2 in./hr. = 2.54 cm

One could also hypothesize that the volume of rainfall determines the concentration since SE 6 with the highest concentration had the least rainfall and SE 9 with the least concentration had the greatest amount. Although this may be a factor, it is not an overriding one, since other storms with relatively large amounts of rainfall and long durations do not necessarily rank low in concentration if they have a large number of dry days; for example, SE 3 which ranks 4 produced an inch (2.54 cm) of rain over 100 minutes after 12.2 dry days. On the other hand, SE 11 ranked five with only 3.4 dry days. It had a relatively small amount of rainfall (0.16 inches) (.4064 cm) spread over 55 minutes for the lowest rainfall rate (0.17 inches/hr.) (.4319 cm) of any of the storms.

On page 47 in Appendix E rainfall is plotted versus rainfall rate for all storm events. Several storms with higher rainfall rates than SE 11 and about the same amount of rainfall appear to be significant storm events while SE 11 does not fit the pattern of the other storms because of its low rate of rainfall. It would appear from the plot that a rainfall rate somewhere between 0.17 inches (.4319 cm) per hour for SE 11 and 0.60 inches (1.524 cm) per hour for SE 2 would constitute a minimum for a significant storm event in terms of amount and intensity of rainfall. The concentration data for SE 11 should be used with caution. All other storms should qualify as significant storm events because of their high rainfall intensity and the imperviousness of the site and collection system.

Another stratification of the data which proved useful in checking the internal consistency of the data base was one in which ratios of the pollutant concentrations within each storm were compared with other storms. This was done to show outliers due to poor sample handling, degradation of samples, inaccurate compositing, inaccurate laboratory analysis, or unwarranted assumptions. The metals were checked against each other and then against the solids (See Table 3). Ratios calculated from the arithmetic means at the bottom of each column may be used to check variations from that mean.

Ratios between iron and lead are consistent with the exception of the first two storms. This may be due to delays in acidizing the samples. Ratios between zinc and lead are extraordinarily consistent except for SE 2. Zinc and iron ratios are consistent except for the first two storms. This leads to the conclusion that iron values are low for the first two storms. Sulphates are higher for the ten minute sample interval over the one minute, in fact at least double the shorter sample interval type. The heavy metals appear to be the most consistent data source and those most closely related to motor vehicles as a source of water pollutants. This is inferred from knowing that leaded gasoline is the most likely source of lead and the consistent ratios between lead and zinc or iron.

TABLE 3

WATER POLLUTANT RATIOS

	Sample Interval	Fe/Pb	Zn/Pb	Zn/Fe	TSS/Pb	TVS/Pb	TDS/Pb	TS/Pb	TSS/TS	TDS/TS	COD/Pb	TOC/Pb	KN/Pb	N-N/Pb	SO_4/Pb
1	:01	1.66	0.44	0.26	181	95.3	77.3	354	0.51	0.22	128	282	2.25	0.91	11.2
	:10	1.67	0.46	0.28	152	62.6	125	340	0.45	0.37	181	45.4	2.30	0.75	26.9
2	:01	1.26	0.62	0.50	246	120	242	608	0.40	0.40	475	139	7.65	2.20	47.6
	:10	1.19	0.93	0.78	150	98.4	447	695	0.22	0.64	881	251	1.32		119
3	:01								0.44	0.44					
	:10								0.10	0.84					
4	:01	5.94	0.47	0.08	139	69.3	537	745	0.19	0.72	522	-			12.6
	:10	4.51	0.42	0.09	105	29.2	640	772	0.14	0.83	490	-			93.5
5	:01	2.87	0.36	0.13	221	13.4	181	216	0.10	0.84	262	38.8	1.89	0.08	18.0
6	:01	3.75	0.48	0.13	339	178	454	970	0.35	0.47	470	-			57.9
7	:01	5.00	0.42	0.08	200	45.2	62.7	306	0.65	0.20	281	53.7	3.31	0.15	28.8
8	:01	5.84	0.44	0.07	156	56.3	156	369	0.42	0.43	228	63.4	4.40	1.84	15.3
9	:01	4.69	0.37	0.08	187	62.2	129	378	0.49	0.34	155	27.8	47.8	2.20	17.2
11	:01	3.04	0.43	0.14	144	80.3	255	479	0.30	0.53	396	77.1	7.76	1.60	34.5
	:10	4.27	0.47	0.11	174	68.5	525	767	0.23	0.68	566	132	1.35	3.49	68.7
12	:01	3.41	0.59	0.17	151	97.6	641	890	0.17	0.72	537	136	9.00	0.371	62.0
	$\bar{x}$	3.51	0.49	0.21	181	76.9	319	564	.323	.542	398	90.2	9.99	1.36	43.8
-	σ	1.63	.143	.202	57.4	40.8	212	243	.165	.215	207	68.3	13.8	1.04	32.9

TABLE 3
WATER POLLUTANT RATIOS

	Sample Interval	Fe/Pb	Zn/Pb	Zn/Fe	TSS/Pb	TVS/Pb	TDS/Pb	TS/Pb	TSS/TS	TDS/TS	COD/Pb	TOC/Pb	KN/Pb	N-N/Pb	SO_4/Pb
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2	:01	1.26	0.62	0.50	246	120	242	608	0.40	0.40	475	139	7.65	2.20	47.6
	:10	1.19	0.93	0.78	150	98.4	447	695	0.22	0.64	881	251	1.32		119
3	:01								0.44	0.44					
	:10								0.10	0.84					
4	:01	5.94	0.47	0.08	139	69.3	537	745	0.19	0.72	522	-			12.6
	:10	4.51	0.42	0.09	105	29.2	640	772	0.14	0.83	490	-			93.5
5	:01	2.87	0.38	0.13	221	13.4	181	216	0.10	0.84	262	38.8	1.89	0.09	18.0
6	:01	3.75	0.48	0.13	339	178	454	970	0.35	0.47	470	-			57.9
7	:01	5.00	0.42	0.08	200	45.2	62.7	308	0.65	0.20	281	53.7	3.31	0.15	28.8
8	:01	5.84	0.44	0.07	156	56.3	156	369	0.42	0.43	228	63.4	4.40	1.84	15.3
9	:01	4.69	0.37	0.08	187	62.2	129	378	0.49	0.34	155	27.8	47.8	2.20	17.2
11	:01	3.04	0.43	0.14	144	80.3	255	479	0.30	0.53	396	77.1	7.76	1.60	34.5
	:10	4.27	0.47	0.11	174	68.5	525	767	0.23	0.68	566	132	1.35	3.49	68.7
12	:01	3.41	0.59	0.17	151	97.6	641	890	0.17	0.72	537	136	9.00	0.371	62.0
	$\bar{x}$	3.51	0.49	0.21	181	76.9	319	564	.323	.542	398	90.2	9.99	1.36	43.8
	σ	1.63	.143	.202	57.4	40.8	212	243	.165	.215	207	68.3	13.8	1.04	32.9

Graphical Plots of Concentration Versus Dry Days

It should be remembered that all of the data points plotted are concentrations from samples acquired with a one-minute time interval; in other words, 28-29 minutes after the weir is topped by water collected at the manhole or within 30 minutes after it starts raining at the bridge structure if the onset was intense, as it almost always was.

As a result of these two numerical exercises, concentrations for each pollutant parameter were plotted against the number of dry days preceding each storm event (Appendix F). This resulted in linear plots for iron, lead, zinc, Kjeldahl nitrogen and dustfall, and curvilinear plots for total suspended solids, total solids, sulphates, total organic carbon, and chemical oxygen demand. No plot could be determined for nitrate nitrogen since the distribution appeared to be random in nature.

The linearity of the data plots throughout six of the curves and through the first 8-10 dry days for the other four is striking (See Appendix F). The closest linear fits were those for zinc and lead with iron showing a somewhat greater dispersion. Storm event 11 appears to be higher in concentration than the other events in most cases. This is probably due to low rainfall intensity. The only plot which appears to curve throughout is the one for total suspended solids. This is the only line which would curve if SE 6 was omitted. The curvature of TSS is supported by 3 storm events other than SE 6.

Why the plots curve upwards, or accelerate with time, is difficult to hypothesize. It could be due to changes in the nature of the deposition on the highway. For example, in the absence of rainfall, a film of oil is often deposited on the highway. This film can trap resuspended dust and particulate from vehicle exhaust. Another factor could be increased roadway abrasion and wear when a pumice like layer of dust is deposited. A third possibility is an outside influence such as fallout from wind driven soil exposed after one to two weeks of no rain.

Analysis of samples collected at 10 minute intervals shows concentrations about 2/3 those collected at one minute intervals. Examination of the sample bottles for particulate shows most of the particulate matter passes through the storm sewer system and across the weir in the first few minutes.

The hydrograph trace usually peaks very rapidly followed by a quick return to a relatively low head which diminishes very slowly. It is often difficult to determine when the influence of a short storm event has passed because of the long tail on the hydrograph trace.

(See Appendix G) The long tail on the hydrograph indicates a very slow decrease in the flow rate in the latter stages of the storm. Since the storms were usually short showers, this slow decrease in flow does not seem realistic.

One important factor that might have caused long tails on the hydrograph traces may have been sediment washed into the storm sewer system after sanding of the pavement surface by highway maintenance crews following ice storms. Sediment in the sewer can act like a long sand filter retarding the runoff. It can also interfere with the operation of floats and create errors in discharge rate estimates.

Accurate calibration of the pen position is important to reduce errors. If sampling takes place longer than water flows over the weir, results would be biased by the lesser pollutant concentrations in water stored behind the weir. On the other hand, if a storm is composed of several showers, the 10 minute sample interval may be more appropriate for characterizing pollutant concentrations. Since most of these storms consisted of single showers, the one minute interval was deemed most suitable.

Dustfall is a crude method of measuring particulate aerosol. Those data points which showed a significant difference between upwind and downwind samples were plotted. These were TDS and TS for SE 6 and TDS for SE 3. The TS for SE 3 was extrapolated from the ratio of TS to TDS for SE 6. The results are tenuous and further measurements are required before they can be assumed to have a reasonable validity.

Runoff-Rainfall Ratio

Total discharge was calculated from each hydrograph trace. The tables calculated by USGS in Appendix A were used to convert head above the weir to discharge in cubic feet per second. It was often difficult to calculate the exact area under the curve for sharp peaks or very shallow slopes. It was also difficult to tell when flow over the weir had ceased.

The discharge Q was calculated as a mean discharge over one day by multiplying the total discharge in cubic feet per second by the number of seconds in one day:

$$Q(ft^3/sec \text{ or } 2.8316 \text{ Liter/sec}) \quad 8.64 \times 10^4 \left(\frac{sec}{day}\right) = Q(ft^3/day \text{ or } 2.8316 \text{ Liter/day})$$

This can then be converted to inches of depth over the area and divided by the area to obtain a normalized factor in inches/acre/day.

TABLE 4

Runoff-Rainfall Ratios

SE	Rainfall (in.)[1]	Rainfall Intensity (in./hr.)[2]	Rainfall Duration (hr:min)	Total Flow (ft^3)[3]	Mean Q Flow (ft^3/sec.)[4]	Runoff R (in./day)[5]	Runoff Duration (hr:min)	Runoff Intensity (in./hr.)[6]	Q/R
1	0.34	1.36	:15	18.3	0.032	0.334	4:12	0.080	0.98
2	0.10	0.60	:10	6.6	0.011	0.120	4:15	0.028	1.20
3	1.00	0.60	1:40	55.1	0.096	1.000	4:30	0.233	1.00
4	0.40	0.22	1:50	14.6	0.025	0.266	7:59	0.033	0.67
5	0.19	1.14	:10	34.3	0.060	0.625	11:55	0.005	3.29
6	0.08	0.96	:05	11.6	0.020	0.212	9:41	0.022	2.64
7	1.05	1.80	:35	11.1	0.020	0.213	:54	0.237	0.20
8	1.13	1.51	:45	71.1	0.123	1.300	2:46	0.470	1.15
9	1.35	1.01	1:20	79.4	0.138	1.450	8:42	0.167	1.07
12*	0.18	1.08	:10	10.1	0.178	0.184	7:10	0.026	1.02

1 in. = 2.54 cm
2 in./hr. = 2.54 cm per hour
3 ft^3 = .028317 m^3
4 ft^3/sec. = .028317 m^3/sec.
5 in/day = 2.54 cm
6 in./hr. = 2.54 cm

* There was insufficient rainfall for SE 10 and no samples because of equipment malfunction for SE 11.

$$Q(ft^3/day \text{ or } 2.8316 \text{ Liter/day}) \ \frac{2.75 \times 10^{-4}}{A} = Q(in./acre/day \text{ or } 1.6387^{-2} \text{ Liter/day})$$

For this drainage basin of 2.26 acres (.9146 Ha) the Q(ft^3/sec or 2.8316 Liter/sec) was multiplied by 10.5 to arrive at Q(in./acre/day or 6.24×10^{-2} cm/km/per day).

When Q in inches/acre has been determined, the Q/R, or runoff versus rainfall ratio can be determined for each storm event. The runoff should be almost equal to the rainfall over an impervious drainage basin with a tightly enclosed storm sewer system such as this one.

When the runoff-rainfall ratios (Q/R) are calculated for each storm event (Table 4), there are four events which do not appear to fit the pattern, SE 4, 5, 6, and 7 with Q/R values of 0.67, 3.29, 2.64, and 0.20. The remaining values range from 0.98-1.20 with an arithmetic mean of 1.07 and a standard deviation of 0.11. Although this 1.07 Q/R indicates more runoff than rainfall, a small systematic error may be presumed for these data which appear reasonably consistent overall.

SE 6 with a Q/R of 0.67 had the lowest rainfall intensity of any storm (Table 4) with 0.22 inches/hour (.5588 cm) and the largest rainfall duration of 1:50. This indicates a slow drizzle with greater losses due to evaporation and penetration of surrounding soil or losses due to leaks in the system. The usual sinks for runoff should be more apparent for this type of storm.

On the other hand, rainfall patterns do not explain the exceptionally High Q/R for SE 5 and 6 which was three times the rainfall or SE 7 which was one-fifth of the rainfall. Since the results for storm events before and after these events seem reasonable, there must be some intermittent cause. One possibility is a buildup of sediment in the storm sewers.

A characteristic of a sharp-crested weir is its tendency to trap sediment behind the weir. If sufficient sediment enters the stilling well, it can prevent the float from returning to a level which indicates water is no longer passing over the weir. If even more sediment is washed around the base of the stilling well, the float can be buried in the sediment and fail to rise. This interference with the float action by sediment can result in extension of the time of flow, elevated discharge rates, delayed onset of discharge, or failure of the storm to be recorded or the samples to be initiated.

TABLE 5

Ranking of Rainfall and Runoff Values

	R-Rainfall(in./day)[1] SE	Q-Runoff(in./day)[2] SE	Q/R SE
1	(6) 0.34	(5) 0.334	(6) 0.98
2	(9) 0.10	(9) 0.120	(1) 1.20
3	(4) 1.00	(4) 1.000	(5) 1.00
4	(5) 0.40	(6) 0.266	(7) 0.67
5	(7) 0.19	(7) 0.204	-
6	(10) 0.08	(10)(8) 0.086	-
7	(3) 1.05	(3) 1.123	-
8	(2) 1.13	(2) 1.300	(2) 1.15
9	(1) 1.35	(1) 1.450	(3) 1.07
12	(8) 0.18	(8) 0.184	(4) 1.02

1 in./day = 2.54 cm
2 in./day = 2.54 cm

In the case of SE 5 and 6 it is believed that excessive runoff may have been indicated on the hydrograph trace and for SE 7 too little. The bottom of the manhole was cleaned after SE 9 when excessive sediment buildup was noticed.

Looking at Table 4, the runoff duration varied from :54 for SE 7 to 11:56 for SE 5. SE 4 with 7:59 and SE 6 with 9:41 were also long flows. The first three storms had durations of slightly more than four hours. This may mean the gradual buildup of sediment may have influenced the mean daily discharge through SE 9 when the sediment was removed. Of course, another possibility is an error in calibration of the hydrograph pen, a critical factor in measurement of flow.

In Table 5 rainfall (R), runoff (Q) and Q/R were ranked. It was noted that the highest Q/R of 1.20 occurred in SE 2 with the lowest runoff. This may have been because external infiltration had a larger effect on the smallest volume of runoff. The four smallest storms in terms of rainfall (2, 5, 6, 12) were also the four storms with the least amount of runoff and the four storms with the largest rainfall (9, 8, 7, 3) had the greatest runoff.

Runoff Calculations:

The runoff Q in cubic feet per second from Table 4 can be converted to cubic feet per day and gallons. An assumed Q can be developed for SE 5, 6, and 7 by use of the mean Q/R value 1.07 and conversion of inches to cubic feet per second (See Table 6). The mean Q/R can in this way fill important gaps in the data. Since an average Q/R value greater than unity is obviously unrealistic, it is probable that flow rates, size of drainage basin, or rainfall amounts are in error. Errors in flow rate and flow duration are most probable. This will be verified by further research.

Water Quality Data

Concentration in mg/liter can be converted to pounds of pollutant as described in an Envirex Report [5]:

$$\text{Total pounds} = C(\text{mg/l}) \times 6.37 \times 10^{-5} \times V(\text{ft}^3)\ (2.8316\ \text{Liter})$$

where: C = Concentration
V = Runoff volume

TABLE 6

Runoff Summary

SE	Q(ft^3/sec.)[1]	Q(ft^3/day)[2]	Q(gallons/day)[3]
1	0.032	2,765	20,682
2	0.011	950	7,109
3	0.096	8,294	62,046
4	0.025	2,160	16,158
5	0.019	1,642	12,280
6	0.008	691	5,169
7	0.107	9,245	69,156
8	0.123	10,627	79,497
9	0.138	11,923	89,191
12	0.018	1,512	11,311

1 ft^3/sec. = 0.028317 m^3
2 ft^3/day = 0.028317 m^3
3 gallon/day = .0037854 m^3

Pounds of pollutant have been calculated for each storm event for total solids and lead in Table 7 and Table 8. Also calculated are pounds of pollutant per inch of runoff (normalized for the drainage area), pounds of pollutant per runoff intensity, and pounds of pollutant per dry day.

The pounds of solids in Table 7 are greatest for events 3 and 7. These are the first two storms with at least an inch of rainfall. If SE 7 effectively cleaned the bridge, SE 8 and 9 which followed closely thereafter would have fewer pounds of solids to remove. It is interesting to note that SE 6 with the highest concentration had a relatively small pollutant load in pounds of solids when compared with SE 3 and 7.

The pounds per inch of runoff is high for SE 7 and relatively low for SE 5, 8, and 9. SE 6 ranks second. This leads to the hypothesis that SE 6 with a rainfall of 0.08 inches (.2032 cm) did not remove all of the available pollutants from the highway, while SE 7 with a rainfall of 1.05 inches (2.667 cm) and a rainfall intensity of 1.80 inches (4.572 cm) per hour was much more effective in cleaning the roadway since more pollutants per runoff inch were produced with SE 7.

The pounds per runoff intensity was very high for SE 6, 7467 pounds (3.3869 Metric Tons) per inch/hour. This is probably due to the buildup of sediment in the storm sewer which delayed the runoff and gave a low runoff intensity of 0.009 inches/hour (.02286 cm). SE 6 was a very short, intense storm with a long runoff duration.

One of the most interesting statistics in Table 7 is the pounds of pollutant per dry day. These may be divided into three categories. Two storms had about 38 pounds (17.24 kg) (SE 1 and 9), three had about 18 pounds (8.165 kg) (SE 3, 7, and 8), and four had about four pounds (1.184 kg) (SE 2, 5, 6, and 12). The remaining storm, SE 4, was the slow drizzle with a Q/R of 0.67 which when converted to a normal rainfall runoff ratio of 1.07 would be close to 18 pounds per dry day. The two with the highest pounds per dry day had the least number of dry days, SE 1 with 0.9 days and SE 9 with 1.6 days. All of the storms with 17 (7.711 kg) or more pounds had more than one inch (2.54 cm) of rainfall except SE 1 which had the least number of dry days and 0.34 inches (.8636 cm) of rain. All storms with less than 0.2 inches (.508 cm) of rain had about 4 pounds (1.814 kg) of total solids per dry day.

TABLE 7

Total Solids

SE	C_{ts} (mg/l)	Pounds (lbs) 1	Runoff (ft^3) 2	Pounds / Runoff (lbs./in.) 3	Runoff Intensity (in./hr.) 4	Pounds / Runoff Intensity (lbs./in./hr.) 5	Dry Days (days)	Rainfall (in.) 6	Pounds / Dry Day (lbs./day) 7
1	(8) 197	(8) 34.7	(5) 2,765	(7) 103.9	(6) 0.080	(7) 434	(10) 0.9	(6) 0.34	(1) 38.6
2	(2) 445	(10) 26.9	(9) 950	(4) 224.2	(8) 0.028	(5) 961	(4) 9.9	(9) 0.10	(10) 2.7
3	(3) 429	(1) 226.7	(4) 8,294	(3) 226.7	(3) 0.233	(4) 973	(2) 12.2	(4) 1.00	(3) 18.6
4	(6) 301	(6) 41.4	(6) 2,160	(6) 155.6	(7) 0.033	(3) 1255	(8) 3.2	(5) 0.40	(6) 12.9
5	(7) 259	(9) 27.1	(7) 1,642	(9) 43.4	(4) 0.176	(10) 154	(5) 7.4	(7) 0.19	(9) 3.7
6	(1) 1527	(4) 67.2	(10) 691	(2) 315.5	(10) 0.009	(1) 7467	(1) 16.6	(10) 0.08	(8) 4.0
7	(5) 354	(2) 208.5	(3) 9,245	(1) 978.9	(1) 1.248	(6) 880	(3) 11.7	(3) 1.05	(4) 17.8
8	(9) 118	(3) 79.9	(2) 10,627	(8) 61.5	(2) 0.470	(9) 170	(7) 4.7	(2) 1.13	(5) 17.0
9	(10) 79	(5) 60.0	(1) 11,923	(10) 41.4	(5) 0.167	(8) 359	(9) 1.6	(1) 1.35	(2) 37.5
12	(4) 365	(7) 35.2	(8) 1,512	(5) 191.3	(9) 0.026	(2) 1354	(6) 5.4	(8) 0.18	(7) 5.5

1 lbs.= .45359237 kg
2 ft^3 = 0.028317 m^3
3 lbs./in. = 16.018377 kg/m^3
4 in./hr. = 2.54 cm
5 lbs./in./hr. = 0.17857967 kg/cm
6 in. = 2.54 cm
7 lbs./day = .45359237 kg

TABLE 8

Lead

SE	C_{Pb} (mg/1)	$Pounds_{Pb}$ [1]	Runoff (ft^3) [2]	Runoff (in.) [3]	Pounds / Runoff (lbs./in.) [4]	Runoff Intensity	Pounds / Runoff Intensity (lbs./in./hr.) [5]	Dry Days (days)	Rainfall (in.) [6]	Pounds / Dry Day (lbs./day) [7]
1	(5) 0.556	(6) 0.093	(4) 2,765	(4) 0.334	(5) 0.293	(5) 0.080	(5) 1.22	(9) 0.9	(5) 0.34	(1) 0.109
2	(4) 0.731	(9) 0.044	(8) 950	(9) 0.120	(3) 0.367	(7) 0.028	(3) 1.57	(3) 9.9	(8) 0.10	(8) 0.004
3	-	-	-	-	-	-	-	-	-	-
4	(7) 0.404	(8) 0.056	(5) 2,160	(5) 0.266	(7) 0.211	(6) 0.033	(2) 1.70	(7) 3.2	(4) 0.40	(5) 0.018
5	(2) 1.198	(4) 0.125	(6) 1,642	(3) 0.525	(8) 0.200	(3) 0.176	(7) 0.71	(4) 7.4	(6) 0.19	(6) 0.017
6	(1) 1.574	(7) 0.069	(9) 691	(7) 0.212	(4) 0.325	(9) 0.009	(1) 7.67	(1) 16.6	(9) 0.08	(8) 0.004
7	(3) 1.149	(1) 0.677	(3) 9,245	(6) 0.213	(1) 3.180	(1) 1.248	(8) 0.54	(2) 11.7	(3) 1.05	(3) 0.053
8	(8) 0.320	(2) 0.217	(2) 10,627	(2) 1.300	(9) 0.167	(2) 0.470	(9) 0.46	(6) 4.7	(2) 1.13	(4) 0.046
9	(9) 0.209	(3) 0.159	(1) 11,923	(1) 1.450	(2) 0.464	(4) 0.167	(6) 0.95	(8) 1.6	(1) 1.35	(2) 0.099
12	(6) 0.410	(10) 0.039	(7) 1,512	(8) 0.184	(6) 0.212	(8) 0.026	(4) 1.50	(5) 5.4	(7) 0.18	(7) 0.007

1 pounds = .4535923 kg
2 ft^3 = .028317 m^3
3 in. = 2.54 cm
4 lbs./in. = 16.018377 kg/m^3
5 lbs./in./hr. = .17857967 kg/cm
6 in. = 2.54 cm
7 dry day = 165/day

This leads one to believe that if enough storm events were monitored, all intense storms could be divided into several categories depending on rainfall amount, and less intense storms could be characterized by rainfall intensity. Then if a rainfall pattern was known from climatological data on rainfall amounts, time between storms, and rainfall intensity, the pounds of pollutants washed off an impervious section could be predicted. In this way the worst case assumption could be shown, because highways which are less impervious will produce fewer water pollutants. In addition, there are often many sinks between the highway and a receiving body of water. Sediments settle and some minerals such as lead are tightly bound by clay minerals or organic compounds. If an upper limit can be determined and the sinks modeled, the actual impact of the highway on receiving waters can be predicted for any scenario.

The pattern for lead in Table 8 is very similar to that found for total solids in Table 7. The two highest ranking storms in pounds/dry day are SE 1 and 9 and the amounts for the other storms are comparable. A close relationship has already been shown between lead, total solids, and most of the other pollutants. This suggests that the variations identified are real.

It is interesting to observe the exceptionally high washoff rate for heavy rains with the fewest dry days. This could be due to the higher collection efficiency of a wet pavement over a dry one. Most pollutants arising from vehicle exhaust and roadway abrasion are elevated and redistributed in the turbulent airstream around moving vehicles, except when the pavement is wet. The drainage system then becomes a sink for the vehicle source for those pollutants which normally settle alongside the roadway, or are carried away by wind if fine enough.

Implementation

The acquisition of additional data at this site and their analysis are recommended prior to implementation of these findings. If sufficient good quality data can be acquired, the pollutants which accumulate and are washed off the roadway can be determined for any rainfall scenario. These estimates of highway impact on water quality could then be applied to similar sites. They would also give a "worst case" estimate for runoff from highways and could be used in conjunction with modeling techniques developed by Envirex under FHWA contract to predict highway impact.

These data are also useful in assessing the tradeoffs between air and water pollution. Resuspended dust along roadways is being intensively studied because it is suspected to be an important nontraditional source of particulate. How much influence a significant rainfall has on dust resuspended by vehicular turbulence remains in substantial doubt. Resolution of this will require monitoring of air and water pollution simultaneously.

The automated water sampler is an effective tool for acquiring high quality data. A sharp crested weir is not very suitable in a storm sewer system because it traps too much sediment. A flume with a gradual slope before and after the throat would probably trap less of the sediment. If a flume is used, a bubble manometer will probably be needed to gage the discharge. In any event, efforts should be made in any study of highway runoff to clean the catchments of extraneous sediment and prevent its introduction into the drainage system if possible. If the highway is sanded heavily to improve vehicle traction in ice and sleet conditions, the sand should be removed with street sweepers before it enters the drainage system, if at all possible. If buildup in the storm sewer system becomes excessive, the weir or flume may need to be removed and the system cleaned by flushing or wait for rains to carry the sediment past the point of flow restriction.

RECOMMENDATIONS FOR FURTHER RESEARCH

Additional water quality data on highway runoff are badly needed. Models for accumulation and washoff need validation. Sources of water pollutants need to be identified and quantified. Sinks for water pollutants between the highway and receiving waters need to be identified and quantified. The relationships between resuspended dust and water quality need additional measurement in order to be able to assess the tradeoffs between air and water under different conditions. The objective should be to develop models which can predict highway impact on water quality for any set of conditions and place that impact in proper perspective.

APPENDIX

APPENDIX A

TABLE 9

DISCHARGE RATING TABLE

Sta. No.______

Rating table for

Outflow pipe in module D-2, I.H. 45 at Forest Ave., Dallas, Tex. Dated__________, 19______

from__________________ to________________; from______________ to________________

from__________________ to________________; from______________ to________________

Gage height	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09	Difference
Feet	Cfs	Cfs	Cfs	Cfs	Cfs	Cfs	Cfs	Cfs	Cfs	Cfs	Cfs
0.0				Discharge, in cubic feet per second							
.1											
.2	0	.02	.03	.04	.06	.08	.09	.10	.12	.14	.15
.3	.15	.17	.20	.22	.24	.26	.29	.31	.33	.36	.23
.4	.38	.41	.45	.48	.52	.55	.58	.62	.65	.69	.34
.5	.72	.76	.80	.83	.87	.91	.95	.99	1.0	1.1	.38
.6	1.1	1.2	1.2	1.2	1.3	1.4	1.4	1.4	1.5	1.6	.5
.7	1.6	1.6	1.7	1.6	1.8	1.8	1.9	2.0	2.0	2.0	.5
.8	2.1	2.2	2.2	2.2	2.3	2.4	2.4	2.4	2.5	2.6	.5
.9	2.6	2.6	2.7	2.8	2.8	2.8	2.9	3.0	3.0	3.0	.5
1.0	3.1	3.2	3.2	3.3	3.3	3.4	3.5	3.5	3.6	3.6	.6
.1	3.7	3.8	3.8	3.9	3.9	4.0	4.1	4.2	4.2	4.2	.6
.2	4.3	4.4	4.4	4.5	4.5	4.6	4.7	4.7	4.8	4.8	.6
.3	4.9	5.0	5.0	5.1	5.1	5.2	5.3	5.3	5.4	5.4	.6
.4	5.5	5.6	5.6	5.6	5.7	5.8	5.8	5.8	5.9	6.0	.5
.5	6.0	6.0	6.1	6.1	6.2	6.2	6.2	6.3	6.3	6.4	.4
.6	6.4	6.4	6.5	6.5	6.6	6.6	6.6	6.7	6.7	6.8	.4
.7	6.8	6.8	6.9	6.9	7.0	7.0	7.0	7.1	7.1	7.2	.4
.8	7.2	7.2	7.3	7.3	7.3	7.4	7.4	7.4	7.4	7.5	.3
.9	7.5	7.5	7.6	7.6	7.7	7.6	7.7	7.7	7.2	7.8	.3
2.0	7.6	7.8	7.9	7.9	7.9	8.0	8.0	8.0	8.0	8.1	.3
.1	8.1	8.1	8.2	8.2	8.2	8.2	8.3	8.3	8.3	8.4	.3
.2	8.4	8.4	8.5	8.75	8.5	8.6	8.6	8.6	8.6	8.7	.3
.3	8.7	8.7	8.8	8.8	8.8	8.8	8.9	8.9	8.9	9.0	.3
.4	9.0	9.0	9.1	9.1	9.1	9.2	9.2	9.2	9.2	9.3	.3
.5	9.3	9.3	9.4	9.4	9.4	9.5	9.5	9.5	9.5	9.6	.3
.6	9.6	9.6	9.7	9.7	9.7	9.8	9.8	9.8	9.8	9.9	.3
.7	9.9	9.9	10.0	10.0	10.0	10.1	10.1	10.1	10.1	10.2	.3
.8	10.2	10.2	10.2	10.3	10.3	10.3	10.3	10.3	10.4	10.4	.2
.9	10.4	10.4	10.4	10.5	10.5	10.5	10.5	10.5	10.5	10.6	.2

Computed by______________ 5/23 1972; Checked by ______ 5/23 1972 Remarks based on sharp crested weir flow conditions below 1.4 ft, orifice flow above 1.8 ft and smooth transition between 1.4 and 1.8 ft.

TABLE 9 (cont.)

DISCHARGE RATING TABLE

Sta. No.________

Rating table for

Outflow pipe from manhole [illegible] at [illegible] Dated________, 19______

from____________________ to____________________ from____________________ to____________________

from____________________ to____________________ from____________________ to____________________

Gage height	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09	Difference
	Discharge, in cubic feet per second										
Feet	Cfs	Cfs	Cfs	Cfs	Cfs	Cfs	Cfs	Cfs	Cfs	Cfs	Cfs
3.0	10.6	10.6	10.6	10.7	10.7	10.7	10.7	10.7	10.8	10.8	.2
.1	10.8	10.8	10.8	10.9	10.9	10.9	10.9	10.9	11.0	11.0	.2
.2	11.0	11.0	11.1	11.1	11.1	11.1	11.1	11.1	11.2	11.2	.2
.3	11.2	11.2	11.2	11.3	11.3	11.3	11.3	11.3	11.4	11.4	.2
.4	11.4	11.4	11.4	11.5	11.5	11.5	11.5	11.5	11.6	11.6	.2
.5	11.6	11.6	11.6	11.7	11.7	11.7	11.7	11.7	11.8	11.8	.2
.6	11.8	11.8	11.8	11.9	11.9	11.9	11.9	11.9	12.0	12.0	.2
.7	12.0	12.0	12.0	12.1	12.1	12.1	12.1	12.1	12.2	12.2	.2
.8	12.2	12.2	12.2	12.3	12.3	12.3	12.3	12.3	12.4	12.4	.2
.9	12.4	12.4	12.4	12.5	12.5	12.5	12.5	12.5	12.6	12.6	.2
4.0	12.6	12.6	12.6	12.7	12.7	12.7	12.7	12.7	12.8	12.8	.2
.1	12.8	12.8	12.8	12.9	12.9	12.9	12.9	12.9	13.0	13.0	.2
.2	13.0	13.0	13.0	13.1	13.1	13.1	13.1	13.1	13.2	13.2	.2
.3	13.2	13.2	13.2	13.3	13.3	13.3	13.3	13.3	13.4	13.4	.2
.4	13.4	13.4	13.4	13.5	13.5	13.5	13.5	13.5	13.6	13.6	.2
.5	13.6	13.6	13.6	13.7	13.7	13.7	13.7	13.7	13.8	13.8	.2
.6	13.8	13.8	13.8	13.9	13.9	13.9	13.9	13.9	14.0	14.0	.2
.7	14.0	14.0	14.0	14.1	14.1	14.1	14.1	14.1	14.2	14.2	.2
.8	14.2	14.2	14.2	14.3	14.3	14.3	14.3	14.3	14.4	14.4	.2
.9	14.4	14.4	14.4	14.5	14.5	14.5	14.5	14.5	14.6	14.6	.2
5.0	14.6										
.1											
.2											
.3											
.4											
.5											
.6											
.7											
.8											
.9											

Computed by ____AMS______5/22 1977 ; Checked by ______CTS___5/23/19__77__ Remarks____________

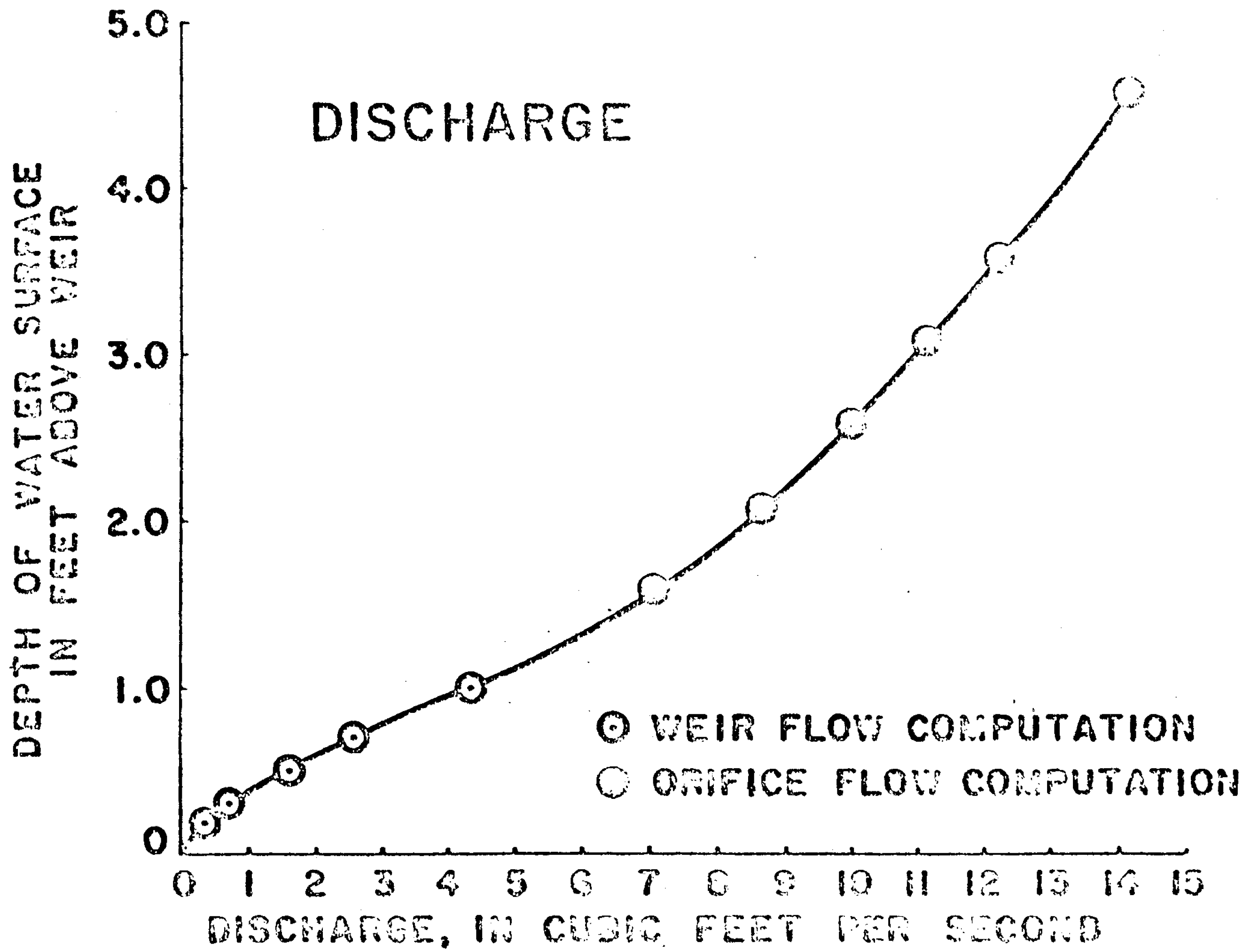


FIGURE 3 DISCHARGE CURVE

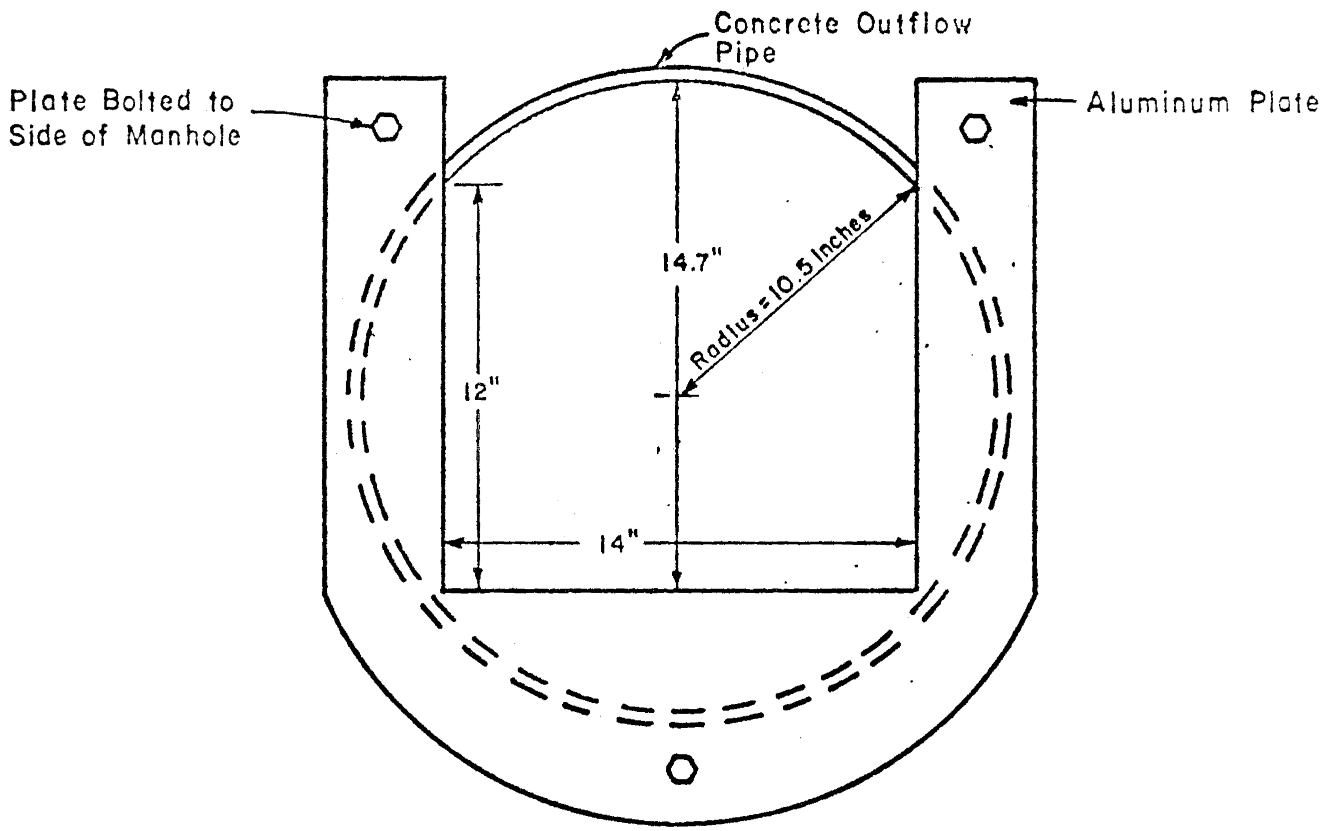


FIGURE 2
SHARP CRESTED WEIR

Construction of the Weir

The outflow pipe at the location of the research project is a 21 inch diameter pipe of field-spun concrete. The pipe has a slope of 0.89% downstream from the gaging site. A weir plate was placed on the outflow pipe to establish a means of determining the flow (discharge) through the pipe. A relationship was developed between the water surface elevation in the manhole and the discharge through the outflow pipe. The weir plate is made of 1/8 inch (.3175 cm) thick aluminum and was bolted on the upstream end of the pipe in the manhole. Below is an illustration representing the pipe and weir plate. The edges around the plate were sealed with epoxy to prevent water leakage around the plate. The plate on the pipe reduced the cross-sectional area of the pipe from 346 in^2 (2232.25 cm^2) to 194 in^2 (1251.61 cm^2) at the manhole, a reduction of 44%. See Figure 1.

Calculations of the Discharge

When the water surface elevation is less than the elevation of the top of the outflow pipe the water surface elevation-discharge computations are based on sharp-crested weir formulas in Chapter 4 of King. When the water surface elevation is above the top of the outflow pipe, the discharge is computed from orifice. Flow computations are outlined in Chapter 3 of King.

The formula for the weir flow condition is $Q=KLH^{3/2}$. "K" comes from Ch. 4 pg. 10 in King using P=0.5 ft (.1524 m). "L" is the length of the weir which is 14 inches (35.56 cm) or 1.17 ft (.3566 m). "H" is the head or depth of the water surface over the weir.

The formula for orifice flow conditions is Q=CS 2gh. "C" is a discharge coefficient, 0.65 in this case, due to the shape, composition, and physical environment of the opening. "A" is the area of the opening or 1.35 ft^2, (.1255 m^2) "g" is the acceleration of gravity, 32 ft/sec^2, (9.7536 m/sec) and h is the head or distance from the water surface to the center of gravity within the opening of flow. The center of gravity of the opening is about 0.58 ft. (.1767 m) above the weir elevation.

Appendix C

SAMPLING PROGRAM

	PARAMETER	NO. SAMPLES	SAMPLE TYPE	SAMPLE AMOUNT	PRESERVATION	HOLDING TIME
(1)	pH		Composite		Cool to 4°C	6 Hrs.
	Total Dissolved Solids		"		"	7 days
	Total Suspended Solids		"		"	"
	Volatile Suspended Solids		"		"	"
	Sulfate		"		"	"
	Bromine	1	"	1 QT.	"	24 hrs.
(2)	Chemical Oxygen Demand		Composite		Cool to 4°C and add H_2SO_4 to pH 2	7 days
	Total Organic Carbon		"		"	24 hrs.
	Total Kjeldahl Nitrogen		"		"	"
	Nitrate Nitrogen	1	"	1 Qt.	"	"
(3)	Lead		Composite		add HNO_3 to pH 2	6 mos.
	Zinc		"		"	"
	Iron	1	"	1 Qt.	"	"
(4)	Total Coliform		Grab		Cool to 4°C	6 hrs.
	Fecal Coliform		"		"	"
	Fecal Strep	3	"	Coliform Bottles	"	"
(5)	Oil & Grease		Grab		Cool to 4°C and add H_2SO_4 to pH 2	24 hrs.
		3		1 Qt.	Mason Jar - Aluminum Foil Lid	
(6)	Dustfall		Accumulated			
	Total Dissolved Solids	3		200 ML.	Cool to 4°C	7 days

APPENDIX C

DESCRIPTION OF LABORATORY TESTS

SOLIDS - Filtered and dried or volatilized and weighed

COLIFORM - Membrane Filter

Oil and GREASE - Freon Extraction

COD - Potassium dichromate - sulfate acid reflex system followed by titration with ferrous ammonium sulfate.

Nitrates - brucine sulphate method using a Spectronic 100.

Kjeldahl Nitrogen - digestion procedure followed by analysis using the ammonia specific ion probe.

Sulphates - barium chloride gravimetric procedure.

Bromides - carbon tetrachloride - potassium permanganate method

TOC - Dohrmon DC-52D Carbon Analyzer equipped with a flame ionization detector.

Metals - Perkins - Elmer 403 atomic absorption spectrophotometer.

APPENDIX D

RESEARCH STUDY FCIP 516 CHARACTERISTICS OF HIGHWAY RUNOFF

CHECKLISTS

EQUIPMENT MAINTENANCE TO BE PERFORMED BY DIST. 18 (MR. CHARLES LITTLE)

At a minimum of weekly intervals check these items of equipment:

1. Water Samplers
2. Batteries
3. Sump Pump Switch Sampler Actuator
4. Event Marker
5. Flow Meter
6. Dust Fall Buckets
7. Rain Gage
8. Traffic Counters

1. Sampler Actuator

   Check sump pump switch in closed (raised) position

2. Batteries

   Water level adequate
   Check battery voltage and recharge batteries if necessary

3. Water Samplers

   Check switch settings
   Sample bottle 1 position
   Bottles clean and dry

4. Event Marker

   Pen writing (check for storm events)
   Pen clean
   Refill ink supply

5. Flow meter

Clock running
Rewind (caution - do not overwind)
Synchronize time
(Record time errors on chart and reset)
Check chart supply and replace roll if necessary
Record gage height on flow meter chart
Set flow meter pen if necessary

6. Dust fall buckets

Refill one-half full of distilled water
Analyze results and reinitiate sampling if no storm events occur for one month

7. Rain Gage

Pen writing
Chart driving
Synchronize time
Reinstall chart weekly

8. Traffic Counters

Counting and tape driving
Check calibration of Loops
Synchronize time
Check battery voltage and recharge if necessary

9. Complete Log Book Entries.

Record actions taken
Record unusual circumstances or inoperative or ineffective equipment
Record highway maintenance activities which might influence either air or water quality

10. Report inoperative equipment by calling Rod Moe at (512) 928-1133 or TEX-AN 823-8574

Reference: Envirex Procedural Manual pp. 57, 58

Water Quality Monitoring To Be Performed by District 18 (Mr. Charles Little)

1. Check flow meter for significant storm event and event marker for sampler actuation.

2. Check to see if bottles are being filled 3/4 full. If not, and storm still is underway, adjust switch settings accordingly.

3. Collect (3) each grab samples during storm for:

   Coliform (Special Jar)
   Oil and grease (Mason Jar with foil under cover)

   Note: Try to collect grab samplers at beginning, middle and end of storm.

4. Replace bottles with clean ones and cap those filled.

5. Ice down samples collected if delay in delivery to TWQB is anticipated or samples have been standing for some time.

6. Reset sampler actuator (switch closed).

7. Collect flow meter chart for TWQB.

8. Reinstall flow meter chart, synchronizing time and making entries on chart
   a. date
   b. time
   c. operator
   d. time reset
   e. record gage height on flow meter chart
   f. reset pen if necessary

9. Cover 3 dust fall buckets and replace with fresh buckets one-half full of distilled water

10. Collect rain gage chart and reinstall a new one
Sychronize time
Record time errors

11. Collect traffic record for all counters
Record time errors
Replace tapes or charts
Resynchronize time
Forward traffic record to Rod Moe at D-8 P

12. Record samples taken and all pertinent information in the log book

13. Carry the following to the TWQB in Duncanville:

    Sample bottles, iced
    Flow meter chart
    Grab samples
    Dust fall buckets, covered
    Rain gage chart

14. Forward traffic tapes to Rod Moe

15. Make notes on unusual conditions or inoperative equipment in log book and contact Rod Moe concerning these as soon as possible.

Flow Compositing Sheet

Site:

Storm event number:

Time and date of storm:

Temperature of samples:

Flow composited by:

Approved by:

Time and date samples received and composited:

Site Sample Number	ESD No.	Time of Sample	Gage, Height Feet	Time Interval Between Samples Minutes	Flow cfs	Flow x Time Int. (cf x min)	Proportionate Volume, 3	Sample Volume to make 3 Quart composite, ml

FIGURE 4 FLOW COMPOSITING FORM

APPENDIX E

Results

TABLE 10
POLLUTANT CONCENTRATION SUMMARY

STORM EVENT	DATE	TIME	SAMPLE INTERVAL	Fe (ug/l)	Pb (ug/l)	Zn (ug/l)	Cd (ug/l)	TSS (mg/l)	TVS (mg/l)	TDS (mg/l)	TS (mg/l)
1	5/21/77	5:00 PM	:01	925	556	245	-	101	53	43	197
			:10	562	335	155	-	51	21	42	114
2	6/1/77	2:30 PM	:01	920	731	456	-	180	68	177	445
			:10	506	427	395	-	64	42	191	297
3	6/13/77	6:00 PM	:01	-	-	-	-	190	52	187	429
			:10	-	-	-	-	20	12	168.7	200.7
4	6/15/77	11:20 PM	:01	2400	404	193	-	56	28	217	301
			:10	1390	308	129	-	32.2	9	197	238.2
5	6/23/77	8:00 AM	:01	3440	1198	455	-	26	16	217	259
6	7/9/77	10:15 PM	:01	5900	1574	752	12.1	533	280.1	714	1527.1
7	7/21/77	3:35 PM	:01	5740	1149	483	8.0	230	52	72	354
8	7/27/77	7:00 AM	:01	1670	320	140	3.0	50	18	50	118
9	7/27/77	9:25 PM	:01	980	209	78	4.0	39	13	27	79
10	8/14/77	7:00 PM	-	-	-	-	-	-	-	-	-
11	8/18/77	5:15 AM	:01	2200	722	311	28.0	104	58	184	346
			:10	1860	438	207	300	76	30	230	336
12	8/28/77	5:00 PM	:01	1400	410	240	38.0	62	40	263	365
:01	MINIMUM			920	209	78	3.0	26	13	27	79
	MAXIMUM			5900	1574	752	38.0	533	280.1	714	1527.1
	ARITHMETIC MEAN			2578	727	335	15.5	143	63.5	196	402
	STANDARD DEVIATION			1862	445	202	14.3	146	75.2	191	392

TABLE 10 (cont.)

POLLUTANT CONCENTRATION SUMMARY

STORM EVENT	DATE	TIME	SAMPLE INTERVAL	Fe (µg/l)	Pb (µg/l)	Zn (µg/l)	Cd (µg/l)	TSS (mg/l)	TVS (mg/l)	TDS (mg/l)	TS (mg/l)
	MINIMUM			506	335	155		20	9	42	114
	MAXIMUM			1860	438	395		76	42	230	335
:10	ARITHMETIC MEAN			1060	377	222		48.6	22.8	166	237
	STANDARD DEVIATION			659	65	120		22.8	13.5	72.6	86.4

TABLE 10 (cont.)
POLLUTANT CONCENTRATION SUMMARY

STORM EVENT	SAMPLE INTERVAL	COD (mg/l)	TOC (mg/l)	KJELDAHL NITROGEN (mg/l)	NITRATE NITROGEN (mg/l)	BROMIDE (mg/l)	SULPHATE (mg/l)	pH
1	:01	118	26.1	2.08	0.84	0.0	10.4	7.33
	:10	102	25.5		0.42	0.0	15.1	6.9
2	:01	437	127.7	2.12	2.03	0.1	43.8	6.9
	:10	446	127.1	3.87	0.67	0.1	60.1	7.6
3	:01	194	55.2	4.86	0.86			7.1
	:10	107	36.9	5.14	0.86	0.001	13.8	
4	:01	211					5.9	
	:10	151					28.8	
5	:01	314	46.5	2.27	0.10		21.6	
6	:01	740					91.2	
7	:01	323	61.7	3.8	0.17	0.001	33.1	7.0
8	:01	73	20.3	1.4	0.59	0.001	4.90	7.2
9	:01	32.4	5.8	10.0	0.46	0.005	3.60	7.3
10								
11	:01	286	55.7	5.6	1.16	0.02	24.9	7.1
	:10	248	58.0	5.9	1.53	0.02	30.1	6.9
12	:01	220	55.8	3.7	0.152	0.02	25.4	7.0
	MINIMUM	73	5.8	1.4	0.10	0.0	3.60	6.9
	MAXIMUM	740	127.7	10.0	2.03	0.02	91.2	7.33
:01	ARITHMETIC MEAN	268	50.5	3.98	0.71	-	26.5	7.12
	STANDARD DEV.	196	34.8	2.66	0.62	-	26.3	0.15

TABLE 10 (cont.)

POLLUTANT CONCENTRATION SUMMARY

STORM EVENT	SAMPLE DESCRIPTION	COD (mg/l)	TOC (mg/l)	KJELDAHL NITROGEN (mg/l)	NITRATE NITROGEN (mg/l)	BROMINE (mg/l)	SULPHATE (mg/l)	pH
	MINIMUM	102	25.5	3.87	0.42	-	13.8	6.9
	MAXIMUM	437	127.1	5.95	1.53	-	60.1	7.6
:10	ARITHMETIC MEAN	211	60.4	4.97	0.87	-	29.6	7.1
	STANDARD DEV.	144	46.7	1.05	0.48	-	18.7	0.40

TABLE 11

DUSTFALL SUMMARY

STORM EVENT	TDS (mg/l)			TSS (mg/l)		
	1	2	3	1	2	3
3	49	76.6	20			
* 4	30	-	-	13	-	-
* 5	-	-	12			
6	42	233	146	5	232	98
7	53.5	9	25	8.5	6	3.3
8	2	2	1	7	12	2.8
9						
10						
11	21	31	15	28	68	6
MINIMUM	2	2	1	5	6	2.8
MAXIMUM	53.5	223	146	28	232	98
ARITHMETIC MEAN	34	68	41	12	80	28
STANDARD DEV.	22	91	59	11	105	47

NOTE: 1 downwind

2 above the elevated roadway

3 upwind

TABLE 12

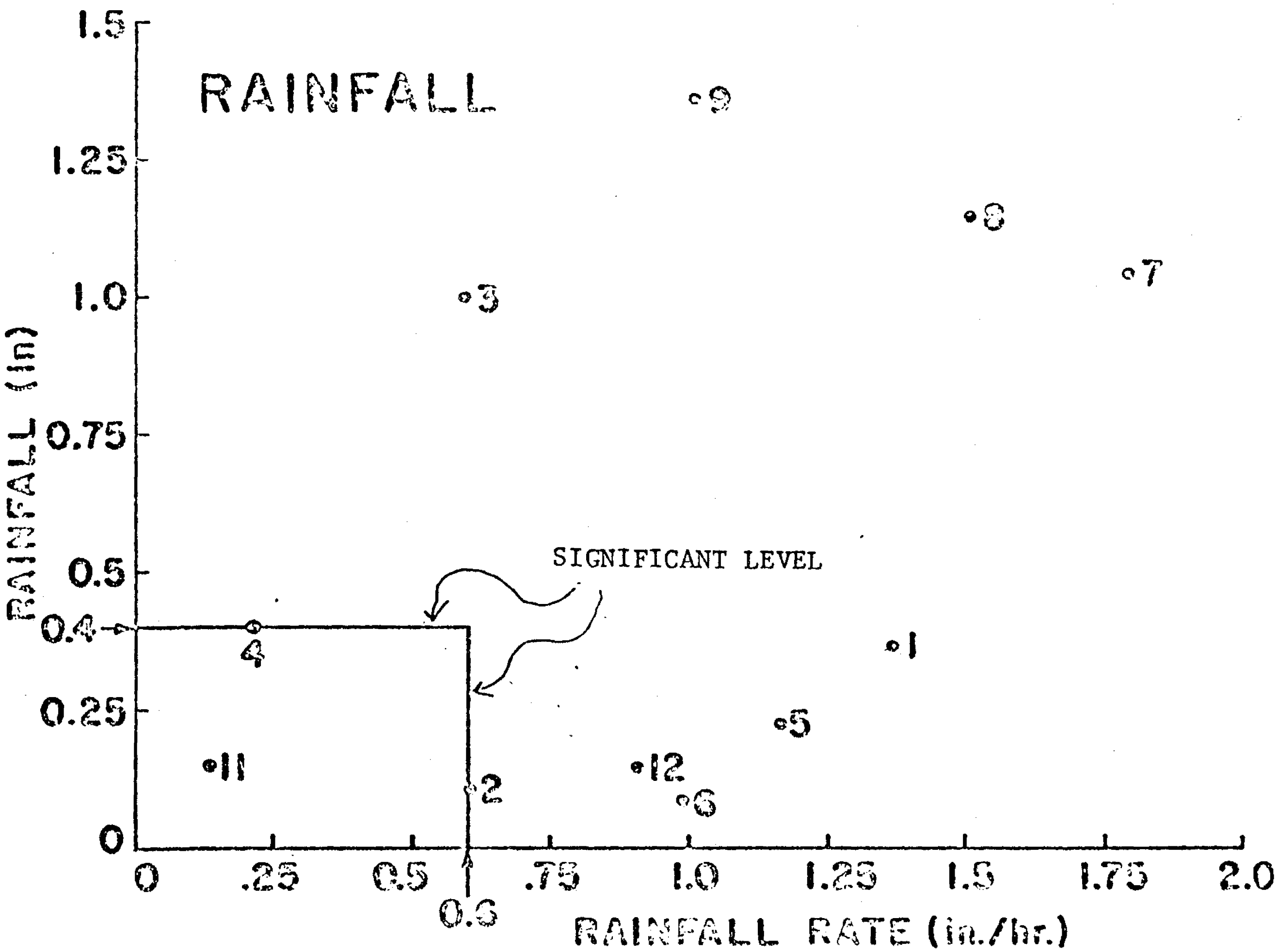
GRAB SAMPLE SUMMARY

STORM EVENT	DATE	TOTAL COLIFORM	FECAL COLIFORM	FECAL STREP	OIL & GREASE (mg/l)
7	7/21/77	7090	820	0	6.9
9	7/28/77	0	0	0	16.2
10	7/29/77	TNTC	TNTC	0	-
11	8/18/77	TNTC	TNTC	4800	13.5
	(LATE)	TNTC	TNTC	4600	7.4
MINIMUM					6.9
MAXIMUM					16.2
ARITHMETIC MEAN					12.2
STANDARD DEVIATION					4.78

RAINFALL DATA

STORM EVENT	DATE	TIME	RAINFALL (IN)[1]	DURATION	RAINFALL RATE (in/hr)[2]	DAYS BETWEEN RAINS
0	5/20/77	6:15 P.M.	-	:15	-	-
1	5/21/77	3:48 P.M.	0.34	:15	1.36	0.9
2	5/31/77	2:30 P.M.	0.10	:10	0.60	9.9
3	6/12/77	6:00 P.M.	1.00	1:40	0.60	12.2
4	6/15/77	11:20 P.M.	0.40	1:15	0.22	3.2
5	6/23/77	8:00 A.M.	0.19	:10	1.14	7.4
6	7/9/77	10:15 P.M.	0.08	:05	0.96	16.6
7	7/21/77	3:35 P.M.	1.05	:35	1.80	11.7
8	7/26/77	7:00 A.M.	1.13	:45	1.51	4.7
9	7/27/77	9:25 P.M.	1.35	1:20	1.01	1.6
10	8/01/77	4:15 A.M.	0.25	:45	0.33	-
	8/14/77	7:00 P.M.	TRACE	1:00	-	-
11	8/18/77	5:15 A.M.	0.16	:55	0.17	3.4
	8/20/77	2:17 A.M.	1.33	3:18	-	-
	8/22/77	3:18 P.M.	0.33	:16	-	-
	8/22/77	8:58 P.M.	0.24	:17	-	-
12	8/28/77	5:00 P.M.	0.18	:10	1.1	5.8
MINIMUM			0.08	:05	0.17	0.9
MAXIMUM			1.35	1:50	1.80	16.6
ARITHMETIC MEAN			0.52	:43	0.90	7.0
STANDARD DEVIATION			0.47	:37	0.52	5.0

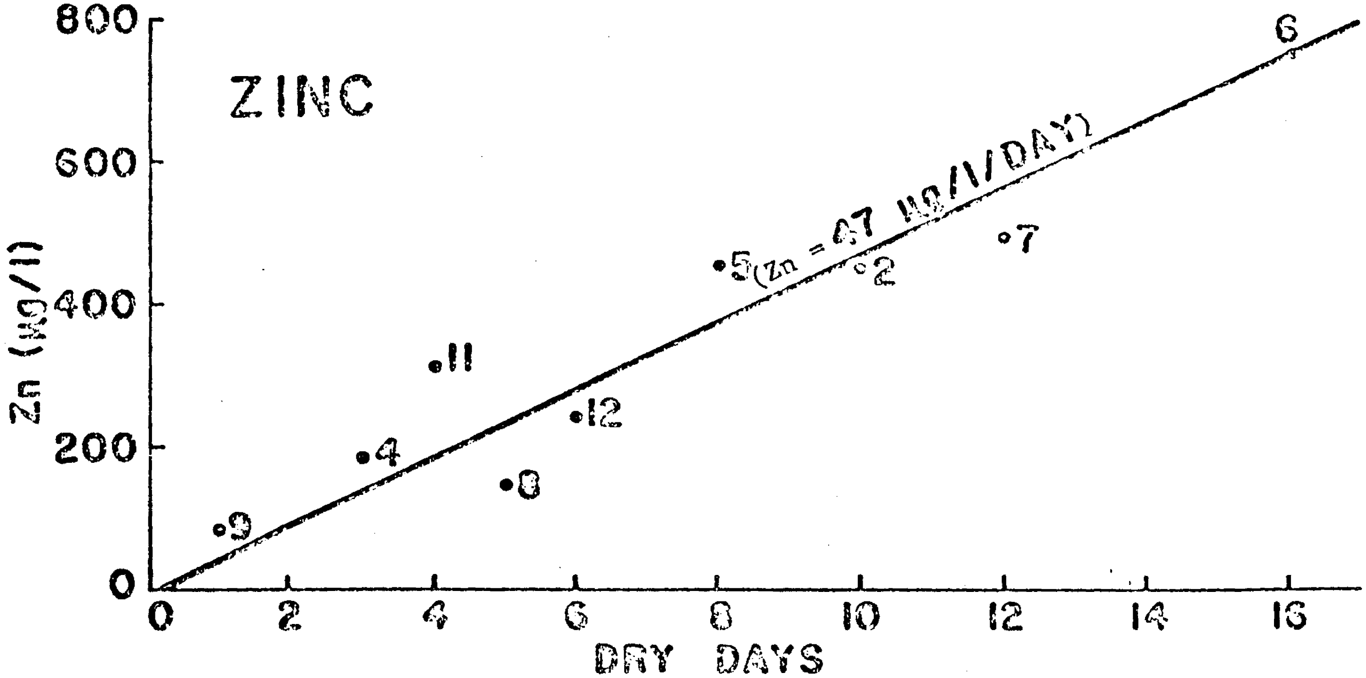
1 in. = 2.54 cm
2 in./hr. = 2.54 cm



STORM EVENTS •

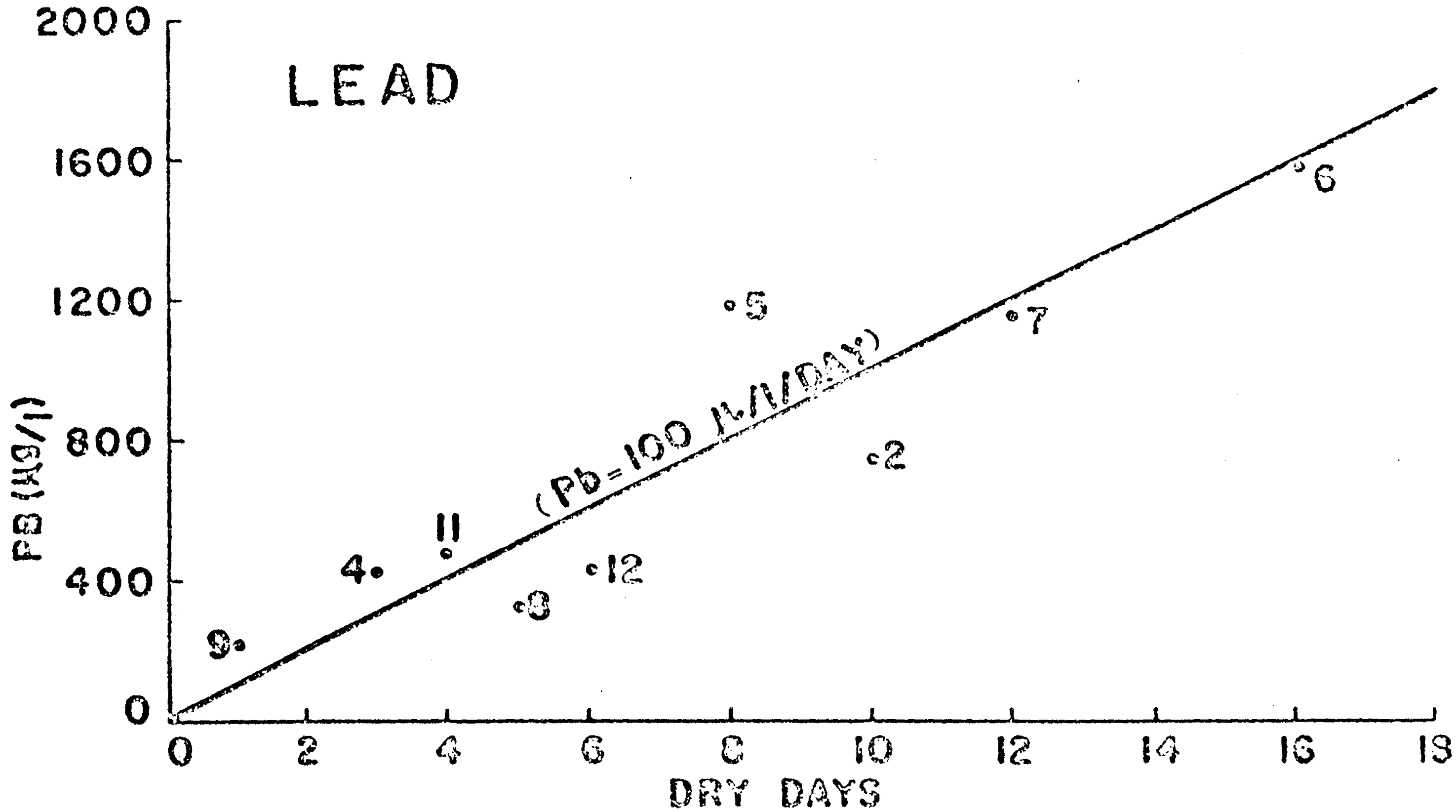
FIGURE 5 RAINFALL vs. RATE

APPENDIX F



STORM EVENTS •

FIGURE 6 ZINC



STORM EVENTS •

FIGURE 7 LEAD

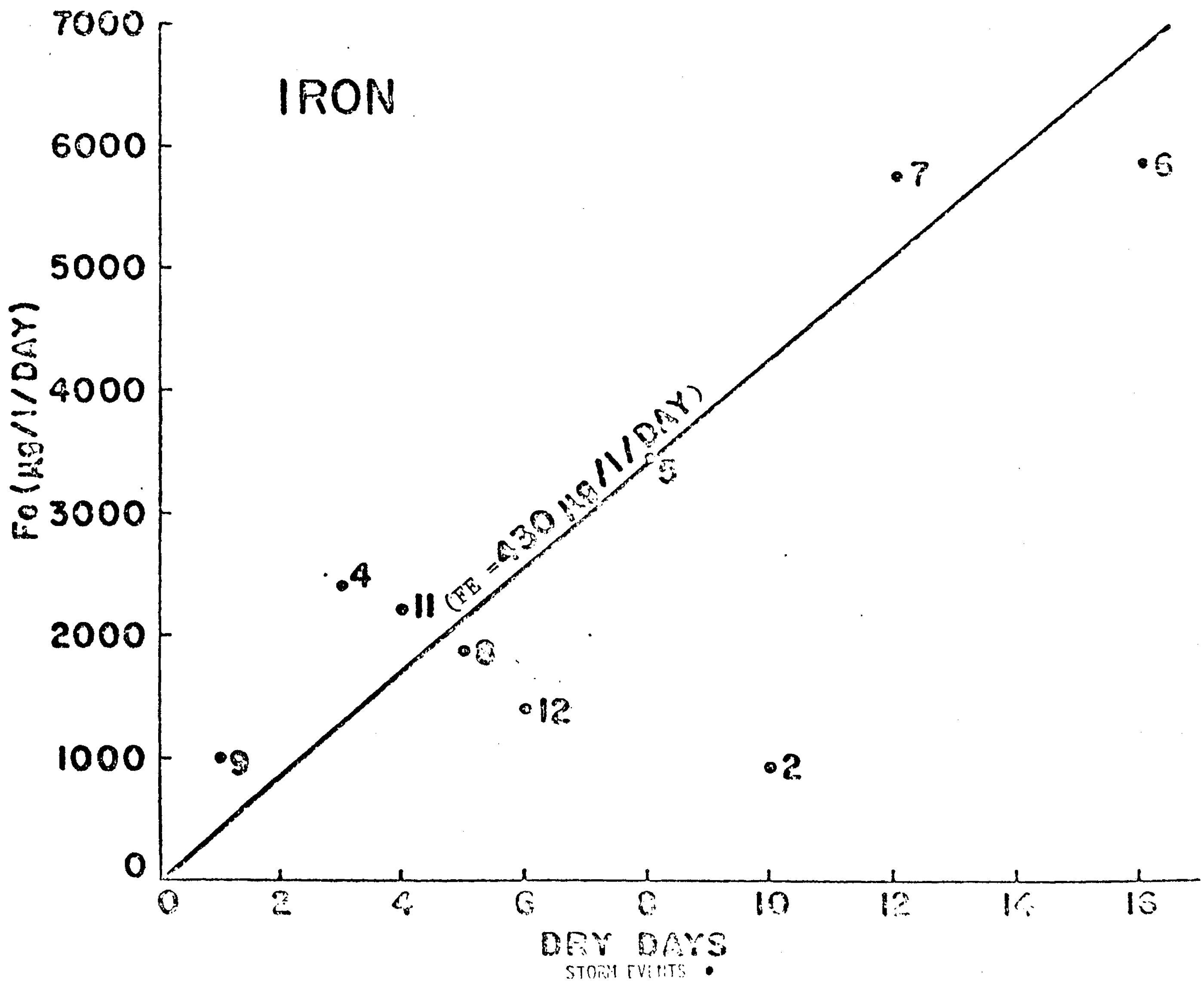


FIGURE 8 IRON

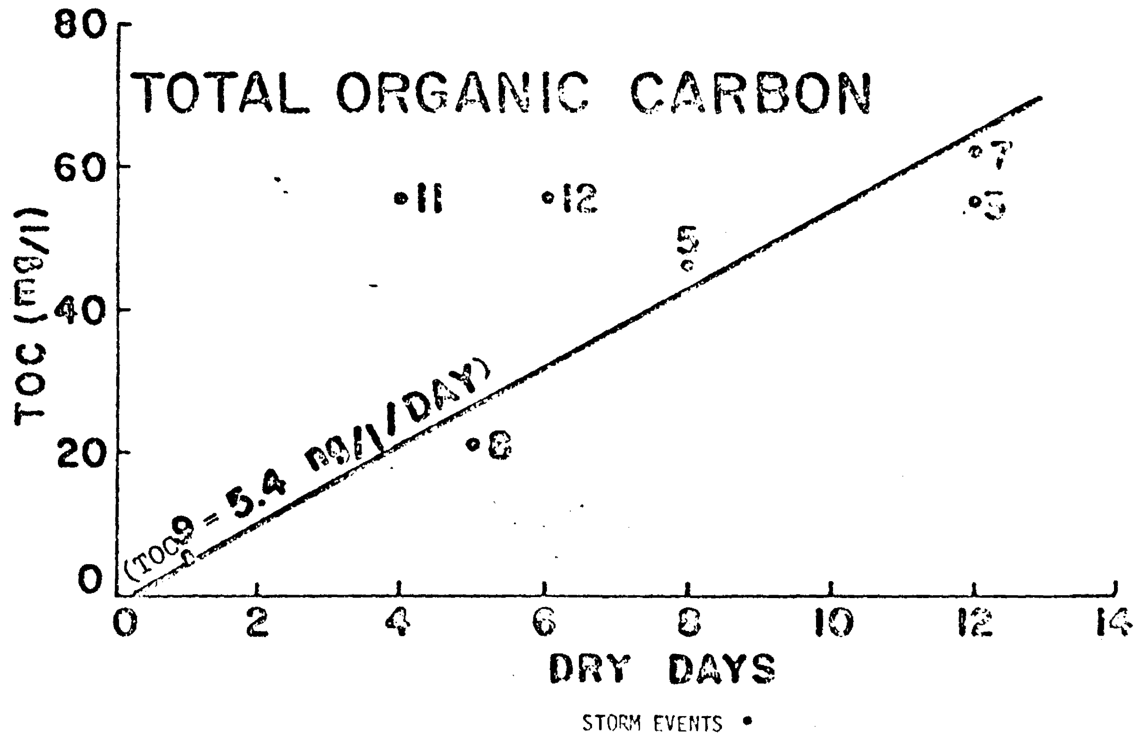


FIGURE 9 TOTAL ORGANIC CARBON

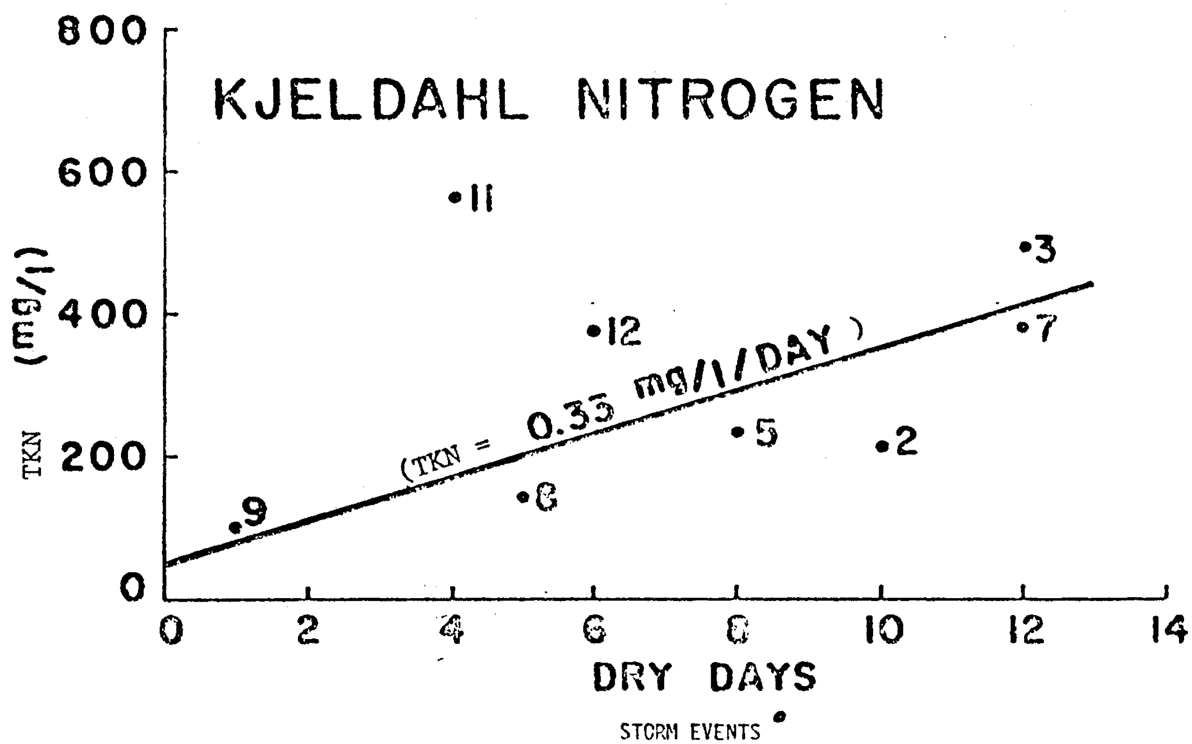


FIGURE 10 KJELDAHL NITROGEN

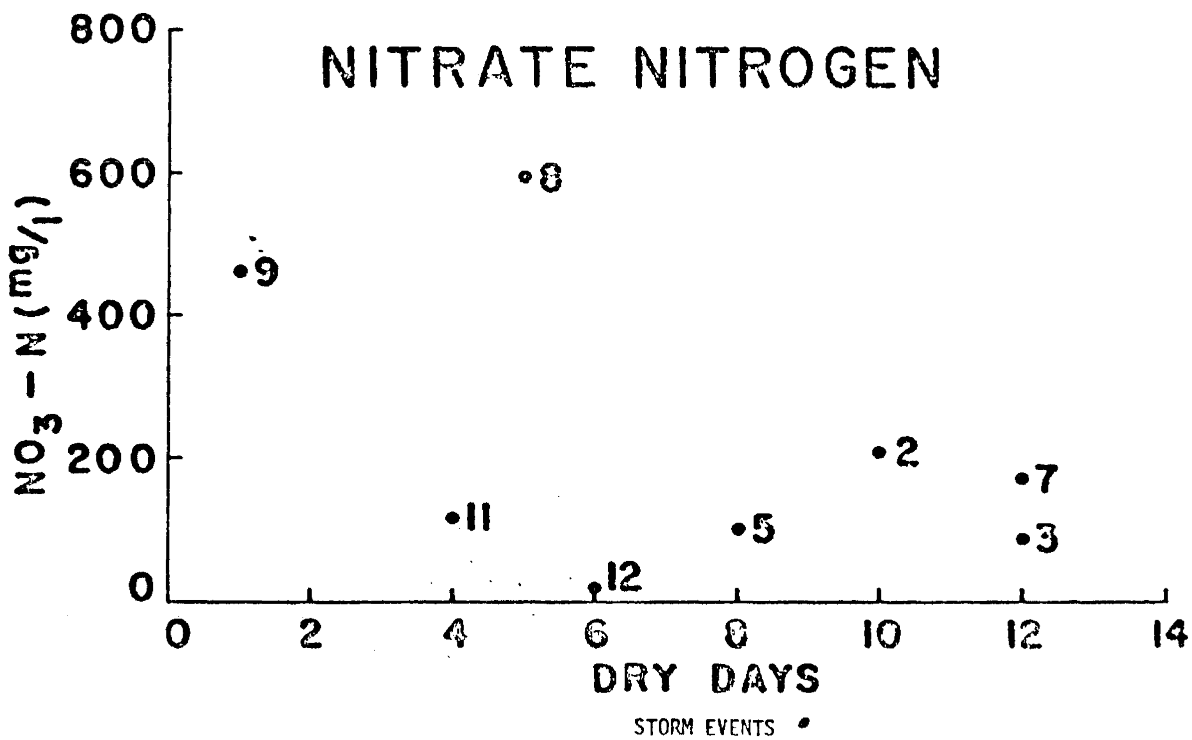


FIGURE 11 NITRATE NITROGEN

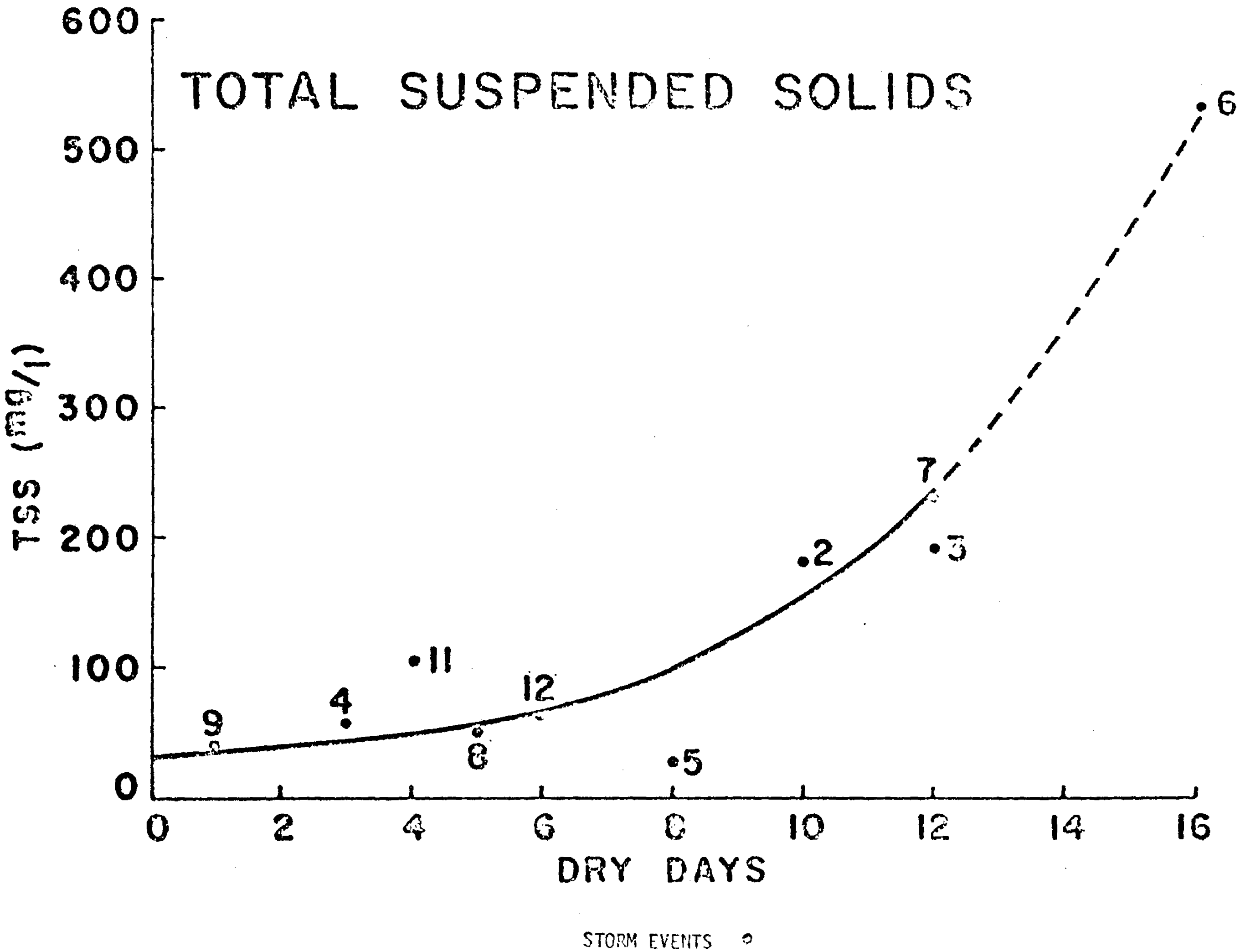


FIGURE 12 TOTAL SUSPENDED SOLIDS

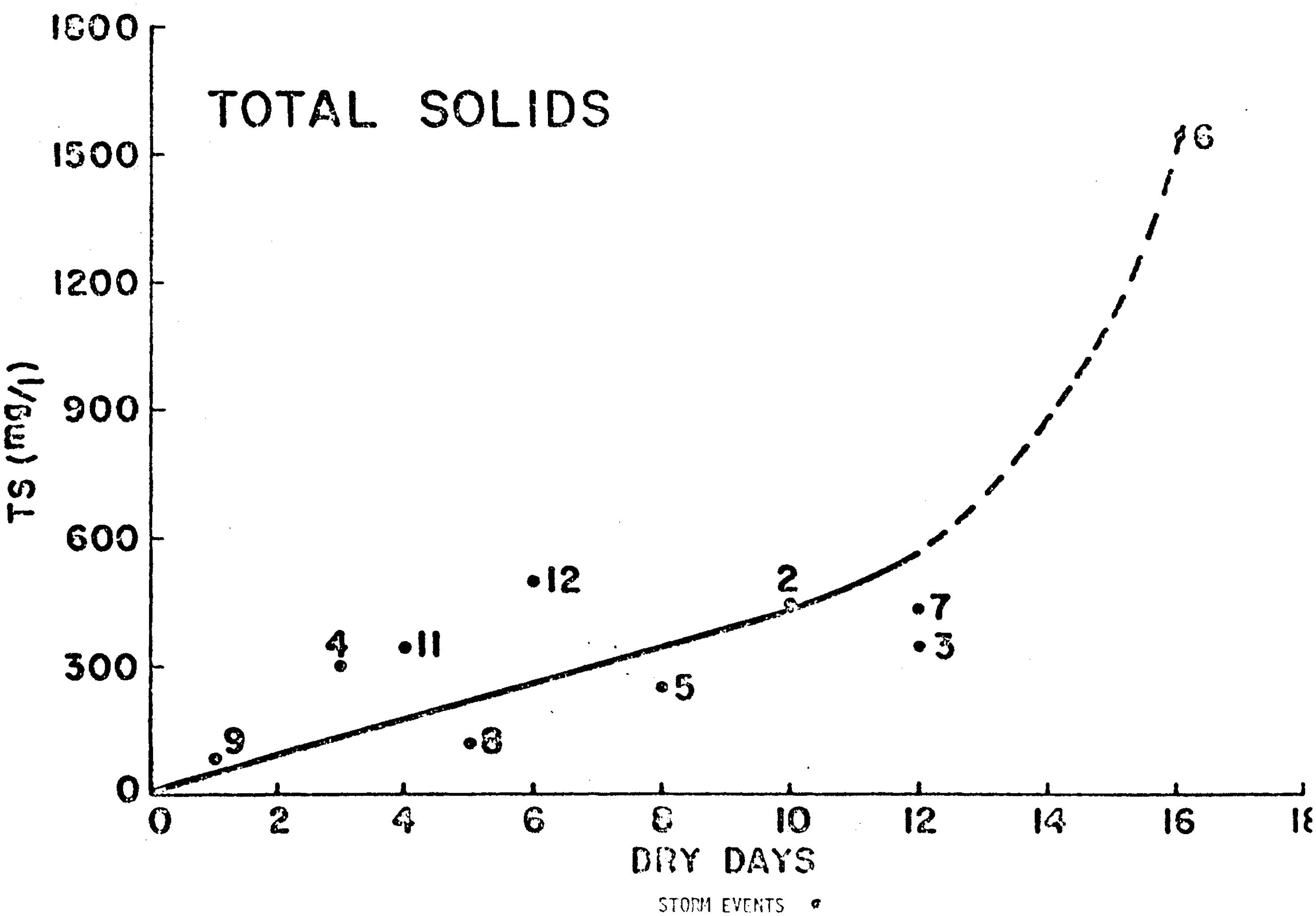


FIGURE 13 TOTAL SOLIDS

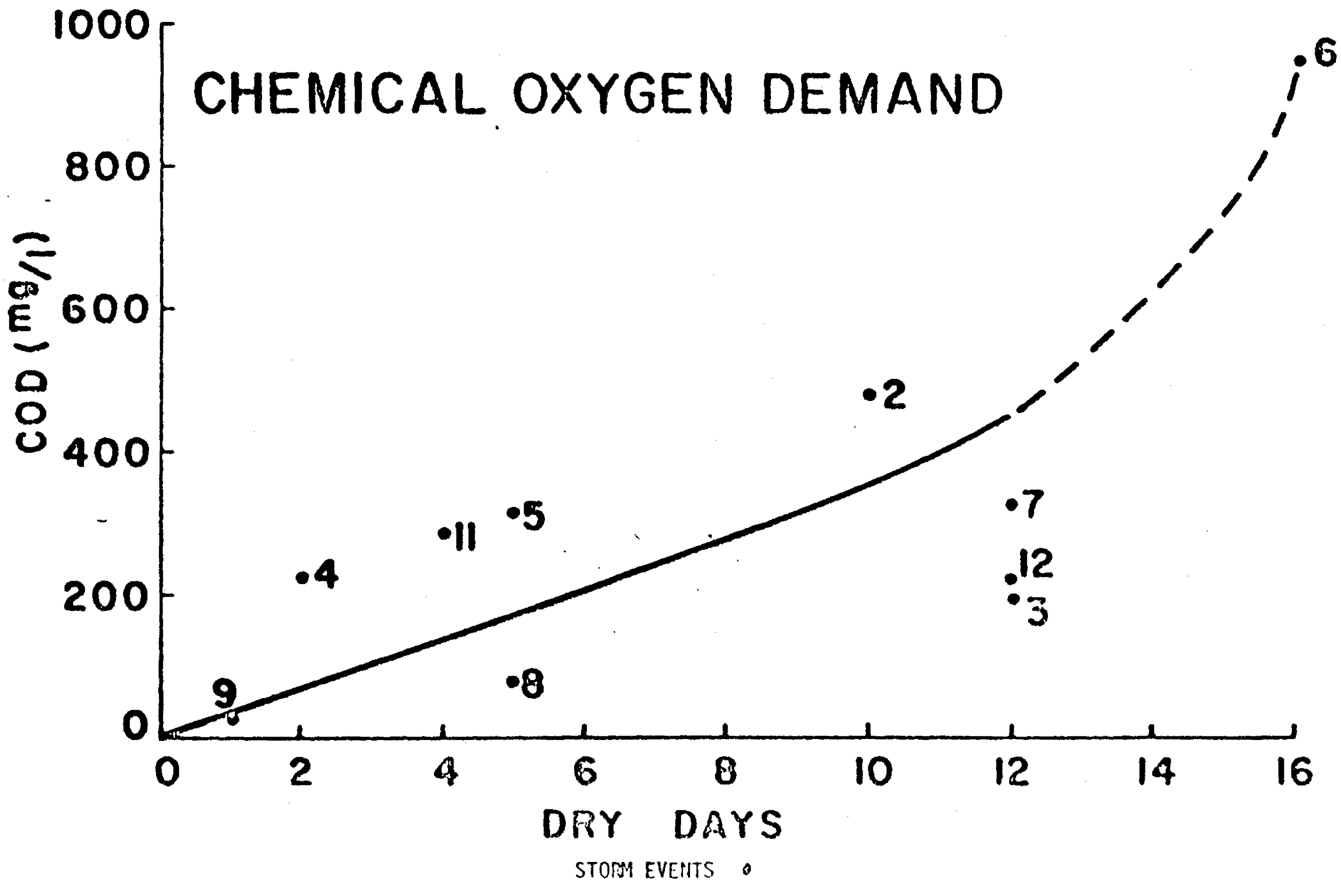


FIGURE 14 CHEMICAL OXYGEN DEMAND

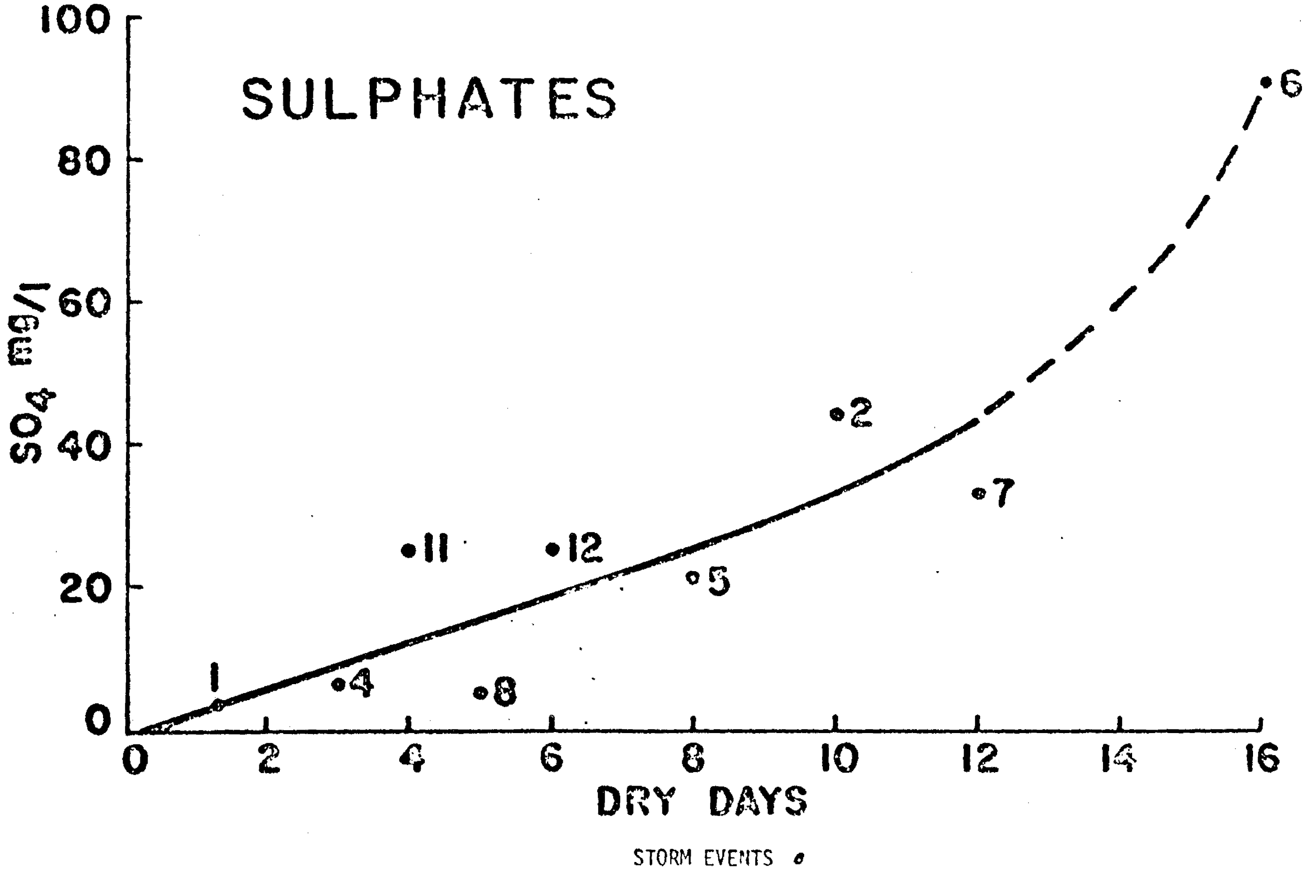
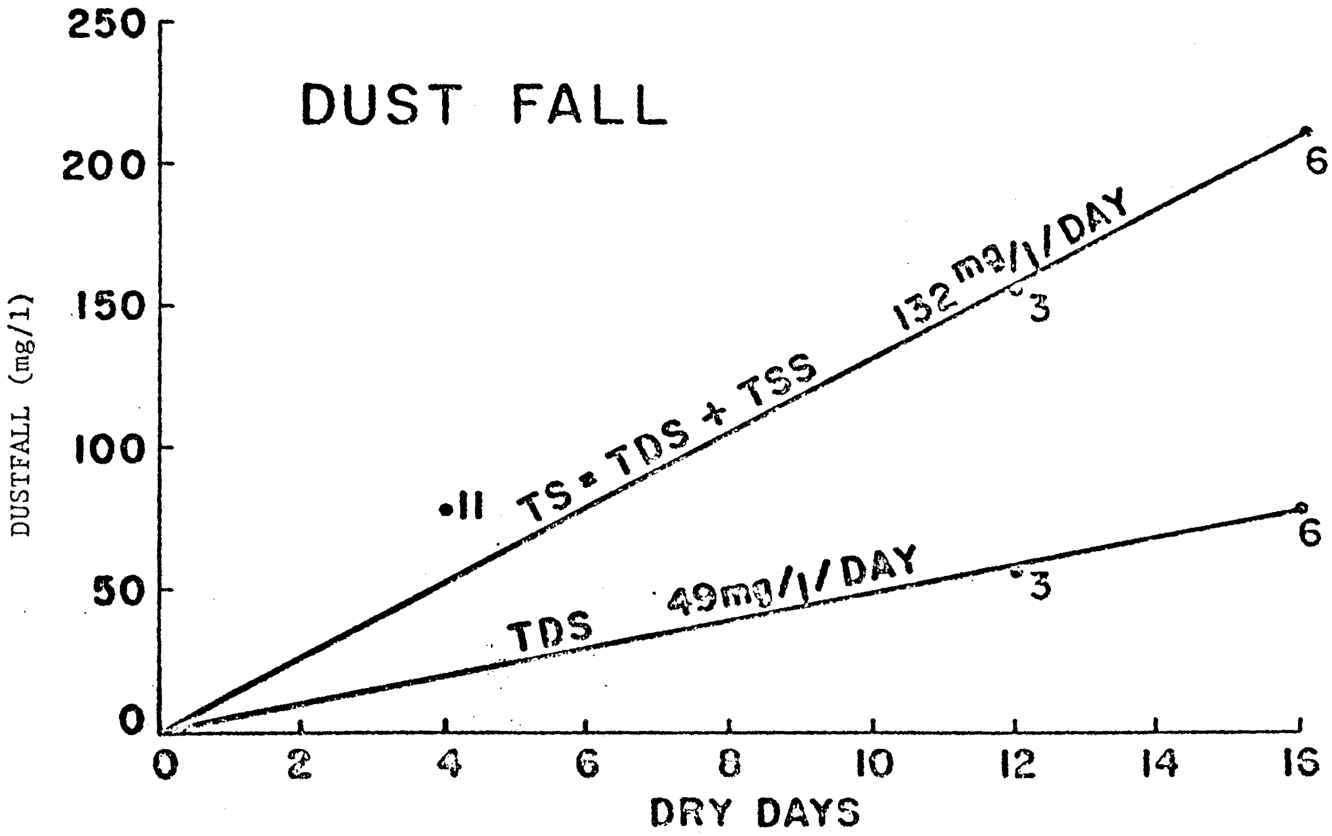


FIGURE 15 SULPHATES



STORM EVENTS•

FIGURE 16 DUSTFALL

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3. "Constituents of Highway Runoff, An Executive Summary" (Draft) by M. K. Gupta, July 1978, Contract DOT-FH-11-8600.

4. "Procedural Manual Draft," Contract DOT-FH-11-8600, February 1977.

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