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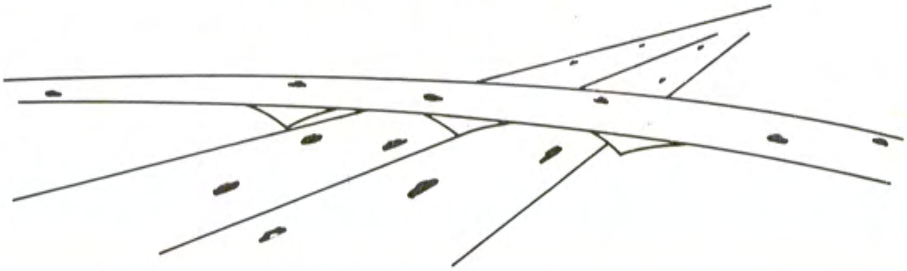

DEPARTMENTAL RESEARCH

Report Number [redacted] 1224-1F
per TxDOT

ATMOSPHERIC PARTICULATE ANALYSIS AND IMPACT OF HIGHWAY RUNOFF ON WATER QUALITY IN TEXAS

IN COOPERATION WITH
U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

STATE DEPARTMENT OF HIGHWAYS
AND PUBLIC TRANSPORTATION

Please note the change in report number. According to the Texas Department of Transportation Catalog of Research Studies and Reports, page 214, project 1-8-78-191 was renumbered as Study 0-1224. It is *not* related to Study 0-191, "Alternative Highway Expenditure Strategies Under Changing Revenue Conditions".
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This study was conducted in cooperation with the U.S. Dept. of Transportation, Federal Highway Administration.

16. Abstract
This experiment was designed to monitor water quality, air quality, traffic, and metorology along an elevated, impervious section of interstate highway in Dallas, Texas, with a closed storm sewer system. Volume of flow, rainfall, and pollutants discharged were monitored automatically during rainstorms. Particulate was sampled at three locations and subjected to X-ray fluorescent analysis. Particulate levels varied substantially and appeared to decrease sharply after rainshowers. All elements sampled followed the same general pattern of variation with some individual differences. It was difficult to establish a relationship between particulate levels and wind direction. Precipitation seemed to be the most significant factor with a rapid buildup in particulate levels following shower activity.

17. Key Words
Water Quality, Air Quality, Highway Runoff, Particulate, X-ray Fluorescence, Flow Rate, Rainfall, Pollutant Load

18. Distribution Statement
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FORWARD

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

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." Dr. Byron N. Lord is the Project and Task Manager.

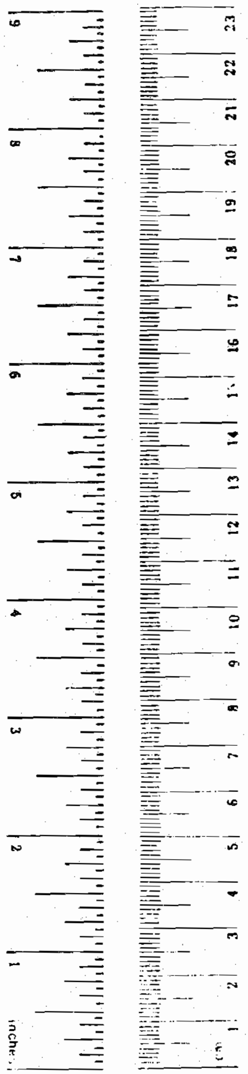
The data used in this study were collected in 1978 and 1979 by the Texas State Department of Highways and Public Transportation in cooperation with other concerned agencies. The collection program was specifically designed to measure the amounts of various water pollutants washed off a highway during natural rainfall events and their influence on particulate air quality.

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

METRIC CONVERSION FACTORS

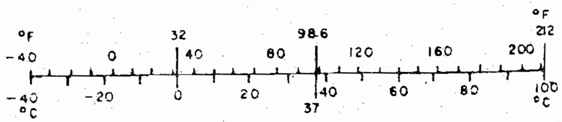
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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Acknowledgement 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 interpretation of flow 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.

District 18 of the State Department of Highways and Public Transportation installed the traffic loops and assisted in administration, equipment procurement, facilities, and storage. Mr. Charles Little gave us work and storage space in his laboratory. Mr. Milton Watkins arranged for cleaning the storm sewer system and Mr. Billy Lay and his maintenance crew helped us immensely on a number of occasions on short notice.

Mr. Jack Lougheed collected samples, checked equipment, and kept things running throughout the project. His dedication in his spare time was exceptional.

Mr. Robert Stuard, Mr. Roger Wayson, Mr. Joe Wise, and Mr. Joe Mlsna of the Highway Design Division in Austin assisted with equipment installation and maintenance of equipment.

Dr. Troy King of the Trinity River Authority analyzed the water samples.

Dr. Byron Lord of the Federal Highway Administration supplied encouragement, advice, equipment, personnel, and technical knowhow.

Dr. Mahendra Gupta, Dr. Nick Kobrigger, and Mr. Dave Gruber of Envirex, Milwaukee, Wisconsin, who helped install a flume and flow meter and provided much needed technical advice.

The Texas Air Control Board performed X-ray fluorescent and gravimetric analysis of particulate samples without charge. Personnel involved were: Dr. Jimmy S. Payne, Ms. Rose Irizarry, Mr. Jesse Guerra, Ms. Hazel Vallarino, and Mr. Scott Mgebroff. Mr. Stuard Dattner assisted with statistical analysis of particulate data for minimum levels of detection.

Mary DeLeon of the Highway Design Division typed the manuscript.

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INTRODUCTION

Non-point sources such as highways are often blamed for water pollution. Comparisons are often made with solids from sewage treatment plants, surely a more biologically active waste product. Concern over non-point sources has increased as point sources are gradually brought under control.

The Federal Highway Administration is involved in a four phase program to identify and quantify the effects of this runoff from highway sources and develop measures to mitigate these effects. They published six volumes to define phase 1 for the identification and quantification of the constituents of highway runoff [1]. The other three objectives now being studied are to:

1. identify the sources of these pollutants and migration paths from the highway to the receiving water.
2. analyze the effects of these pollutants in receiving waters.
3. develop the necessary abatement/treatment methodology for objectionable constituents.

As a supplement to the original FHWA study, a study was begun at IH 45 and Forest Avenue in Dallas, Texas in 1977. A report covering that study was given limited distribution to researchers in the fall of 1978 [2]. This study is a continuation of the 1977 study for two more years.

A major objective of this second study is to further refine the results of the first study and evaluate a water quality model developed by Envirex, the water quality contractor for FHWA.

Concern has also been expressed about the influence of particulate from roadways on human health in our major urban areas. It is believed by some that resuspended dust from roadways is preventing many cities from achieving National Ambient Air Quality Standards for total suspended particulate. One factor that may influence particulate levels along roadways is precipitation. This study attempted to determine the relationship between particulate and precipitation and other meteorological factors along roadways. The number of dry days may be as important to air pollution as it is to water pollution.

Conclusions:

Any study of particulate along a roadway should include a recording rain gauge with a record at least two weeks prior to and during measurement of particulate. Rainfall amount and intensity should be recorded because of its significant influence on washoff of pollutants from the roadway and resuspension of particulate. Experiments meant to validate source strength and dispersion of particulate should incorporate water quality measurements. Where models are not being validated and the results are less critical, the accumulation rate can be modeled using predictive procedures such as the one developed by FHWA [1]. This procedure appears to be applicable to Texas sites, at least for relatively impermeable sites uninfluenced by surrounding vegetation.

Another critical factor for environmental studies of this kind is maintenance activity along the roadway. A complete record of all construction and maintenance activities along roadways should be kept for all water pollution or airborne particulate studies since activities such as street sweeping or sand blasting can have a profound effect on concentrations over the short term.

In the absence of successive large storm events, pollutants tend to accumulate on the roadway. Light to moderate rains of low intensity or short, intense rains do not clean the roadway completely and airborne particulate increases at a relatively constant rate for pollutants such as lead, bromine, and calcium. The number of dry days since successive large storm events can have a profound effect on airborne particulate levels as well as water pollutant concentrations. A previous study [2] at this same site showed many water pollutants increase linearly with the number of dry days. The same trend is apparent for airborne particulate, subject to other fluctuations due to precipitation and other meteorological effects.

Wind effects near an elevated section with vertical walls are difficult to evaluate. Climatological weather data from a nearby airports are a poor sustitute for on site continuous monitoring. Vertical walls force channelization of the wind along the walls and make it difficult to evaluate the influence of wind speed or direction on particulate loading. A site best suited for water quality monitoring is not necessarily well suited to air monitoring of particulate. In any event the particulate concentration along one side of the elevated section is no more than 2.3 times the other side regardless of wind direction, variability, or particle size.

The overall average concentration of inhalable particulate is 6.75×10^{-4} ug/m^3/day/vehicle which is equivalent to 1.09×10^{-3} ug/m^3/day/vehicle of total suspended particulate. The average lead concentration was 2.49×10^{-5} ug/m^3/day/vehicle, 63% of which is in the fine fraction.

Recommendations for Further Research

The FHWA Predictive Procedures for water quality should be further refined and tested since pollutants deposited on and along the roadway have a perfound effect on both air and water quality. Combined air and water quality studies should be accomplished at suitable sites in all four seasons with careful attention to recording precipitation and wind on site.
Particulate should be sampled daily for inhalable portions including

weekends. Technical personnel should be located nearby so they are able to react quickly during storm events. Any maintenance or construction activity nearby should be recorded. If a proposed site is heavily sanded during the winter season, the roadway should be swept at the end of the winter season. If sand is washed into the storm sewer system, some way must be found to remove the material from the storm sewer. Reliable equipment should be purchased and operational checks of that equipment made frequently. Records should be safeguarded at all times consistent with their use and copies transferred to a safe place as they accumulate. Remote supervision is usually unsatisfactory. Frequent visits to the site by supervisory personnel are a must. All chart records and printers should be checked and marked daily.

Implementation of Research

The FHWA predictive procedure is suitable for making estimates of water pollutant concentrations in Texas. Where a roadway construction site is environmentally sensitive or highly controversial, the use of the FHWA predictive procedure along with detailed climatological rainfall records of amount, intensity, and duration should give a reasonably accurate assessment of the impact of the roadway on runoff and receiving waters.

Roadway particulate requires a great deal more careful study before it can be modeled with reasonable precision. Some interesting attributes of roadway inhalable particulate have been determined in this study, but require further testing. The percentages of different pollutants in inhalable particulate should be realistic for the date when samples were taken. Some reduction in lead and bromine should be anticipated in later years as fewer lead additives are added to automotive fuel and the number of cars that can utilize leaded fuels decrease.

This study says nothing about the fate of pollutants washed off the roadway. This is being covered in ongoing FHWA research.

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 drainage 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 Fort Worth Subdistrict of the U.S. Geological Survey under the supervision of Mr. Eugene Gann.

In January 1979 the weir was replaced with a Palmer-Bowlus flume constructed within the exit sewer of Manhole J.2.

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 funished 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 received, 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 Table 10.

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 mechanical 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.

In January 1979 the flow meter system and triggering mechanism for the ISCO samplers were replaced with a bubble flowmeter, printer, and recorder. Dustfall buckets were replaced with U.C. Davis stacked filter units for the particulate sampling and in June 1979 a weather tower was added for local wind measurement. A recording rain gauge was used for precipitation measurement. Traffic counters recorded traffic volume data for each lane.

PROCEDURES

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 or working at another full time job. This system has proven the most satisfactory way of manning the site. It allows quick reaction to storm events at minimum cost. 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 Tranportation 10 miles (16 km) east of the site. Flow rates were calculated using tables prepared by the U.S. Geological Service (Table 10) and the amount of sample selected from each bottle depended on the flow rate calculated at the time the sample was acquired.

After the composite samples were prepared and labeled, the samples and forms requesting appropriate tests were delivered to the Trinity River Authority Lab about 30 miles (48 km) distant. Samples which could not be prepared or delivered immediately were refrigerated.

Careful coordination with the supporting laboratory is needed to ensure the 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 holding time which is critical for some parameters.

The use of a checklist 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.

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 gauge measures the time of onset of rainfall, total amount of rainfall, and its duration. From this information, rainfall rate can also be calculated.

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 eliminated "crosstalk" by shifting the resonant frequency of the tank circuit. Traffic counters were used to normalize the data for variations in traffic flow.

The Stephens A-35 flow meter records gauge heights in feet which are converted to flow rate in cu. ft./sec. (2.8316 liters/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 mile (.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 line 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 for the first study. It had been in service about one year at the time these first 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. Data for this study were collected between September 1977 and September 1979. Pavement wear should be a lesser problem for this follow on study.

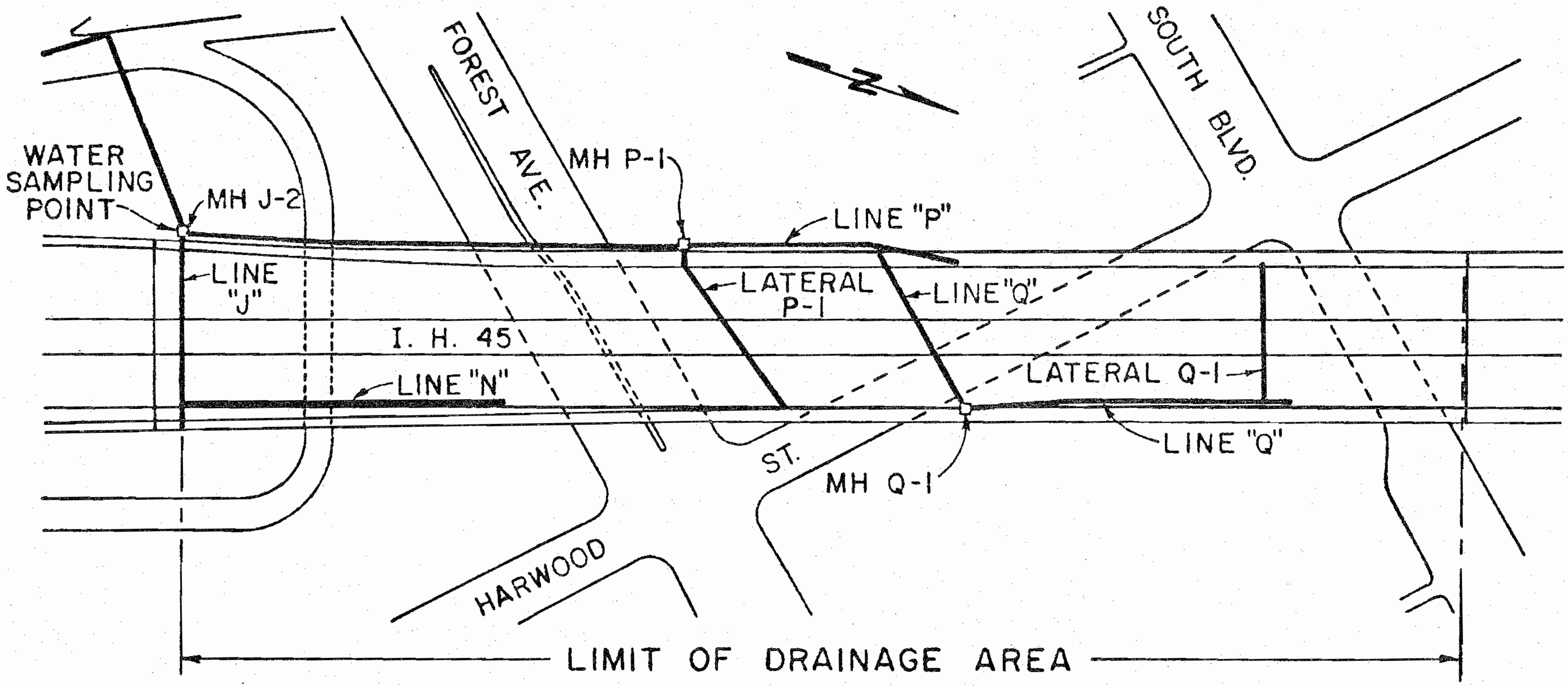

Figure 1 IH-45 STORM SEWER SYSTEM

Analysis of Results:

Water Quality

Table 11 and Table 12 in the Appendix list storm events 1-19 with water pollutant concentrations for the tests and substances monitored for water quality. Table 11 gives the water pollution results for the first year of the study and Table 12 and the next two years. In most cases samples were taken at both one minute and ten minute intervals simultaneously. At the bottom of each table are statistical summaries for both sample intervals with minimum and maximum values, arithmetic mean ($\bar{X}$) and standard deviation (σ). The value for iron in storm 13 is probably spurious and in error. All other values seem reasonable.

In Table 1 a comparison is made between average values for the first year of the study (1-12) and the second two years (13-19). In this summary the high iron value in SE 13 was not included. Suspended solids (SS), Total Dissolved Solids (TDS), and Total Solids are appreciably greater in SE 13-18 than SE 1-12. In fact the first values were 48-67% of the later ones. Iron and sulphates were also lower in the first study. Otherwise the concentrations appear to be very similar for both studies

TABLE 1
WATER POLLUTANT CONCENTRATION SUMMARY
(One Minute Sample Interval)

Pollutant or Test		SE 1-12	SE 13-18	SE 1-18
Fe	(ug/l)	2578	4002	2878
Pb	(ug/l)	727	876	828
Zn	(ug/l)	335	495	393
Cd	(ug/l)	15.5	18.8	17.3
SS	(mg/l)	143	214	168
TVS	(mg/l)	63.5	52	62
TDS	(mg/l)	196	407	271
TS	(mg/l)	402	677	499
COD	(mg/l)	245	200	227
TOC	(mg/l)	50.5	47.9	49.5
Kjeldahl Nitrogen	(mg/l)	4.0	3.6	3.8
Nitrate Nitrogen	(mg/l)	0.71	0.82	0.78
BR	(ug/l)	-	-	-
SO_4	(ug/l)	19.3	79.9	43.5
Cl	(ug/l)	-	-	-
Organic HG	(ug/l)	-	-	-
Inorganic HG	(ug/l)	-	-	-
Ni	(ug/l)	-	424	424
pH		7.12	7.7	7.35

In Table 2 a precipitation summary has been prepared from rain gauge records. Dry days are the number of days since an appreciable amount of rain has fallen. There is only one large event in SE 13-19, SE 13 which occurred at 3/24/78. A large event is described as over one inch of rainfall at a rate of 0.5 inch per hour. This definition is used in the FHWA publications [1]. The events at the bottom of this table are used to analyze particulate data.

In Table 3 composite concentrations of total solids are converted to pollutant loadings in pounds, pounds per inch and pounds per inch per hour. The methodology is extracted from the FHWA reports [1]. Runoff duration is calculated from rainfall duration and runoff from measured flow.

$FD = 1.12\ RD + 0.69$ where:
FD = flow duration
RD = rainfall duration

The equation was derived from a regression analysis by FHWA [1].

Concentration in mg/l of total solids is converted to pounds from:

$C(\text{mg/l}) \times 6.37 \times 10^{-5} \times V\ (\text{ft}^3) =$ Total pounds of runoff where: C is concentration and V is volume of runoff.

TABLE 2
PRECIPITATION SUMMARY

Storm Event	Date	R (in) Rainfall	RD (hr) Rainfall Duration	RI Rainfall Intensity (in/hr)	Dry Days
13	3/24/78	1.09	2.25	0.48	17
14	7/27/78	0.10	0.167	0.60	50
15	8/29/78	0.05	0.416	0.12	33
16	3/18/79	2.10	8.0	0.263	-
17	4/17/79	0.92	10.0	0.082	11
18	5/21/79	0.42	8.0	0.053	9
19	5/22/79	0.30	0.333	0.90	1
	4/3/78	0.30	0.67	0.448	10
	4/10/78	0.72	5.25	0.137	7
	5/1/78	0.30	0.67	0.448	21
	5/2/78	0.80	2.25	0.356	1
	5/11/78	0.45	1.0	0.45	9
	5/21/78	1.60	6.0	0.267	10
	5/22/78	1.00	3.5	0.286	1
	5/24/78	0.70	1.5	0.467	2

1 in = 2.54 cm
1 in/hr = 2.54 cm/hr

TABLE 3
COMPOSITE CONCENTRATIONS AND LOADINGS

		RUNOFF		RAINFALL						SUSPENDED SOLIDS		
Storm Event	Date	Volume (ft^3)[1]	(in)[2]	Duration (hr)	Amount (in)[2]	Rate (in/hr)[3]	TQ (hr)	QI (in/hr)[3]	C (mg/l)	(lbs)[4]	(lbs/in)[5]	(lbs in/hr)[6]
13	3/24/78	8674	1.05 (1)	2.25	1.09	0.48 (2)	3.21	0.32 (2)	228 (1)	126 (1)	120 (1)	250 (1)
19	5/22/79	2398	0.29 (2)	0.33	0.30	0.91 (1)	1.06	3.66 (1)	919 (2)	27 (2)	93 (2)	102 (2)

1 ft^3 = 28.316 l.
2 in = 2.54 cm
3 in/hr = 2.54 cm/hr
4 lbs = 453.6 g.
5 lbs/in = 178.6 g/cm
6 lbs/in/hr = 178.6 g/cm/hr

The pounds of suspended solid discharged are much less for SE 19 than SE 13 (126 versus 27), but the pounds of discharge per inch of runoff are almost the same (120 versus 93). This is due to a higher runoff rate (QI) for the second storm. This shows the shock loading of small intense storm events. Each of the important attributes are ranked by a number in parentheses.

In Table 4 runoff-rainfall ratios (Q/R) are calculated and several of the factors ranked in parentheses for all storm events for which flows were measured. The storm at 7/27/78 with a low Q/R of 0.48 was an exceptionally short storm with little rainfall. The largest runoff occurred with the heaviest rain and a fairly high average rainfall intensity (RI), namely SE 13.

TABLE 4
RUNOFF (Q) AND RAINFALL (R)

SE	Date	R (in)	RD (hr)	RI (in/hr)[2]	Q (ft^3)[3]	R (ft^3)[3]	Q/R
13	3/24/78	1.09 (1)	2.25	0.48 (3)	8674 (1)	8942	0.97
	4/3/78	0.30 (4)	0.67	0.45 (4)	1970 (6)	2461	0.80
	4/10/78	0.72 (3)	5.25	0.14 (6)	3900 (3)	5906	0.66
	5/1/78	0.30 (4)	0.67	0.45 (4)	2158 (5)	2461	0.88
	5/2/78	0.80 (2)	2.25	0.36 (5)	4006 (2)	6563	0.61
	7/27/78	0.20 (5)	0.167	1.20 (1)	792 (8)	1641	0.48
	8/29/78	0.20 (5)	0.416	0.48 (3)	1456 (7)	1641	0.89
19	5/22/79	0.30 (4)	0.33	0.91 (2)	2398 (4)	2461	0.97

1 in = 2.54 cm
2 in/hr - 2.54 cm/hr
3 ft^3 - 28.316 l.

In Table 5 pollutants accumulated (P) discharged (P_d), and remaining after discharge (P_o) are calculated using inches of runoff (Q), rainfall (R), rainfall duration (RD), and flow duration (FD), to calculate runoff rate (R) and P, P_o, and P_d. The methodology used is the same as developed in the FHWA reports [1]. In making these estimates it is assumed that there was a 20 day accumulation prior to a large storm 17 days prior to a 3/24/78. The predictive procedure developed by FHWA appears to work well although we have no measured pollutant concentration at the end of the period to serve as a check. Later in this report the relationship of pollutants remaining on the roadway to the particulate measured in the air will be discussed. The graph in Figure 2 is a plot of P, P_d, and P_o. Note that three consecutive rains at the end of the period virtually clean the highway. (Rainfall amounts are indicated at dashed arrows pointing down)

TABLE 5
WATER QUALITY MODEL

Date 1978	Q (in)	DD (Days)	R (in)	P (lb)[2]	RD (hr)	FD (hr)	r (in/hr)[3]	$-K_2r$	e^{-K_2r}	$1-e^{-K_2r}$	P_d (lbs)[2]	P_o (lbs)[2]
3/24	1.06	20	1.09	360	2.00	2.93	0.36	-1.8	0.1653	0.8347	300	195
4/3	0.27	10	0.30	157	1.00	1.81	0.149	-0.745	0.4747	0.5253	82.4	74.6
4/10	0.68	7	0.72	142.8	7.5	9.09	0.075	-0.375	0.6873	0.3127	44.7	98.1
5/1	0.27	21	0.30	293	0.67	1.44	0.188	-0.94	0.3906	0.6094	178.6	114.5
5/2	0.76	1	0.80	124.2	3.167	4.24	0.180	-0.9	0.4066	0.5934	73.7	50.2
5/11	0.42	9	0.45	137.9	1.167	2.0	0.21	-1.05	0.3499	0.6501	80.7	57.2
5/21	1.53	10	1.60	154.6	6.0	7.41	0.206	-1.03	0.3570	0.6430	99.4	55.2
5/22	0.95	1	1.0	64.8	7.0	8.53	0.111	-0.555	0.5741	0.4259	27.6	37.2
5/24	0.66	2	0.7	56.7	1.5	2.37	0.278	-1.39	0.2491	0.7509	42.6	14.1

1 in = 2.54 cm
2 lb - 453.6 g
3 in/hr = 2.54 cm/hr

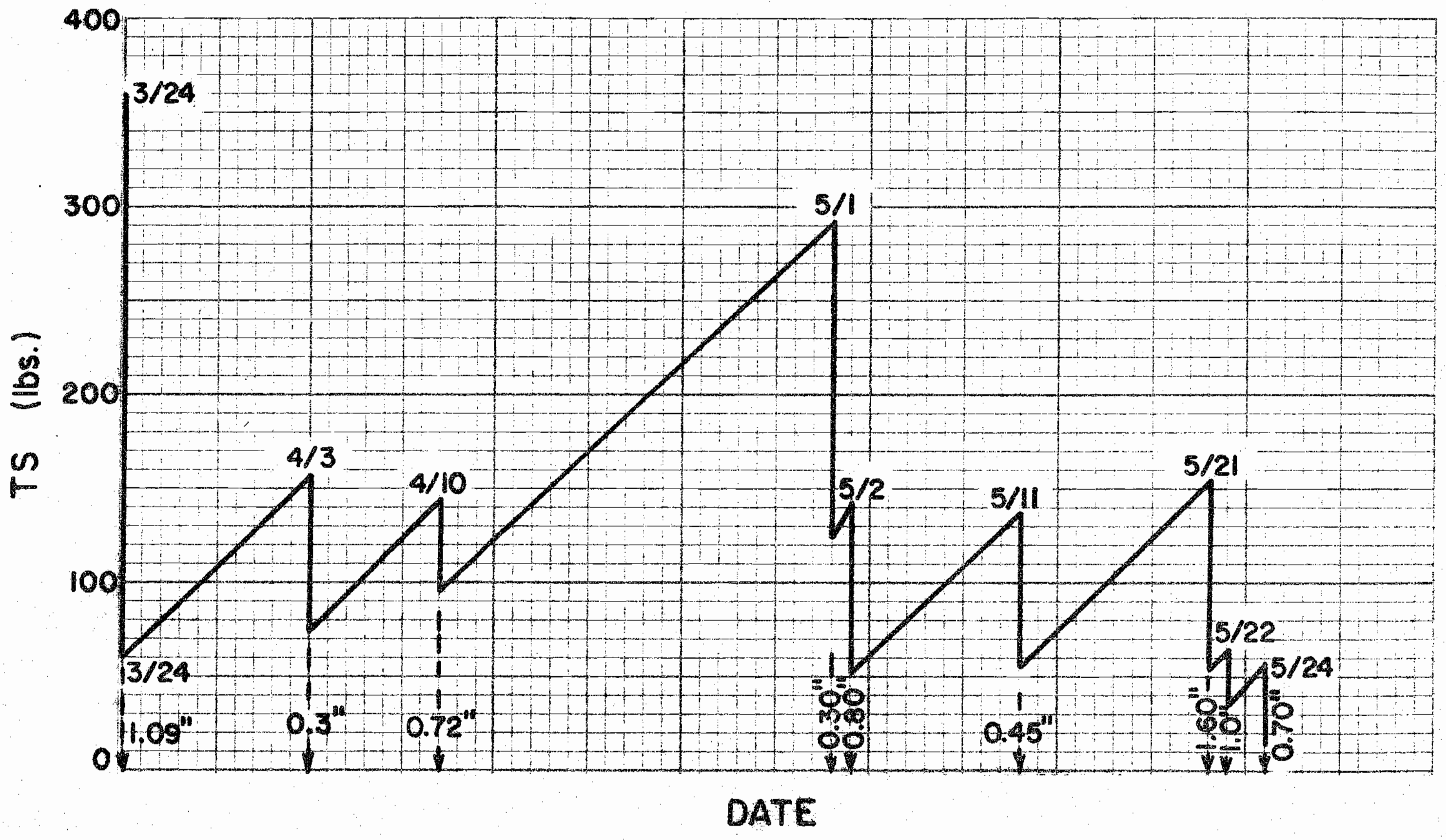

Figure 2. SURFACE TOTAL SOLIDS LEVEL, DALLAS-IH 45 AT FOREST AVE.

Inhalable Particulate

In the analysis of the coarse and fine particulate filters, many of the filters were loaded below minimum detectable limits. The minimum detectable mean of random error was used to screen out results deemed below significant levels as described by Dattner [3]. In this method the student's "t" distribution at the 0.001 probability level is used to establish the confidence interval of the random error. All elemental weights below this confidence level are not shown and negative values are shown as zero in Table 13 in the appendix. The complete data set can be made available to those who desire it.

There was a great deal of variation in the particulate results from one monitoring period to the next and a great deal of consistency between samples taken on the same day. Three samplers were installed with a coarse and fine filter for each. One sampler was mounted near the west wall about 10 feet (3 m) above the roadway and the other two were mounted fifty feet (15 m) away from the 20 foot (6 m) vertical wall on different sides of the elevated section. Sampler 1 was the westernmost one, two was 10 feet (3 m) over the west shoulder of the roadway, and three was 50 feet (15 m) east of the roadway. Samples were taken every 1-4 days. Flow rates were checked at the beginning and end of each sample. Samplers used were U.C. Davis stacked filter units designed by Dr. Tom Cahill of the University of California at Davis and they were equipped with Nuclepore filters.

Gravimetric and X-ray fluorescence techniques were used to analyze the filters by the Texas Air Control Board at no charge to a sister state agency. Table 13 in the appendix describes the basic data and indicates the normalization process. Seven elements were found at detectable levels.

The gravimetric analysis is summarized in Table 6. Arithmetic means have been calculated for each type of filter for each sampler, for both filters on each sampler, for all of the coarse or fine filters separately, and for all filters. Standard deviations have been calculated for all samples, coarse and fine filters each day, and all samples each day.

A few days show strikingly high values: 3/28, 4/17 and 4/24. On 4/24 the coarse values are very high (51.1 ug/m^3) and the fine values are not (5.2 ug/m^3). For the other two days with exceptionally high values, both the coarse and fine are high. Street sweeping was reported along this section of highway on 3/28.

TABLE 6
GRAVIMETRIC SUMMARY

Date	Day	No.	$\overline{X}_c$	$\overline{X}_f$	$\overline{X}$	$\overline{X}_1$	$\overline{X}_2$	$\overline{X}_3$	X_{1c}	X_{1f}	X_{2c}	X_{2f}	X_{3c}	X_{3f}	σ_c	σ_f	σ
3/24	F	1	7.4	8.1	7.6	-	3.1	9.9	-	-	3.1	-	11.6	8.1	6.04	-	4.27
3/25	SA	2	1.1	1.9	1.5	1.1	1.2	1.8	1.1	-	-	1.2	1.0	2.6	0.07	1.00	0.75
3/27	M	1	0.6	2.7	1.9	1.8	2.4	1.0	1.0	2.6	0.1	4.6	-	1.0	0.64	2.00	1.78
3/28	T	1	55.2	31.5	43.4	48.1	40.1	41.2	62.4	33.8	48.0	33.7	55.2	27.1	7.20	3.84	14.0
3/29	W	1	34.8	22.3	28.6	31.6	27.4	43.5	35.0	28.2	35.9	18.8	33.6	19.8	1.16	5.16	7.65
3/30	TH	4	14.2	6.9	11.3	8.4	10.6	18.4	11.5	5.3	12.7	8.5	18.4	-	3.69	2.26	5.66
4/3	M	1	16.8	18.9	17.9	20.8	11.1	21.8	16.8	24.7	14.1	8.0	19.5	24.0	2.70	9.45	6.32
4/4	T	2	13.8	10.0	11.9	12.6	10.9	12.2	13.8	11.4	12.6	9.2	15.0	9.3	1.20	1.24	2.37
4/6	TH	1	23.0	24.8	23.9	25.8	19.7	26.3	22.5	29.0	21.0	18.3	25.4	27.1	2.24	5.71	4.01
4/7	F	4	2.1	2.8	2.4	2.2	2.9	2.3	1.5	2.8	2.7	3.1	2.1	2.4	0.60	0.34	0.57
4/11	T	2	10.5	5.4	8.0	8.1	5.0	10.8	10.9	5.3	4.8	5.2	15.7	5.8	5.46	0.32	4.42
4/13	TH	4	2.5	1.3	2.2	2.7	2.4	1.9	2.7	-	2.4	-	2.4	1.3	0.17	-	0.75
4/17	M	1	58.2	34.7	46.5	45.0	27.9	66.6	57.4	32.5	30.4	25.3	86.8	46.4	28.2	10.73	23.0
4/18	T	1	20.9	6.3	13.6	12.0	6.7	22.1	16.4	7.6	7.6	5.8	38.7	5.4	16.03	1.17	12.9
4/19	W	1	14.6	14.5	14.5	15.0	11.2	17.5	13.4	16.5	10.6	11.7	19.8	15.2	4.72	2.48	3.37
4/20	TH	3	6.4	3.3	4.9	5.4	3.2	6.1	8.7	2.1	3.2	3.1	7.3	4.8	2.86	1.37	2.61
4/23	SU	1	15.5	12.9	14.2	12.5	-	15.9	13.6	11.4	-	-	17.3	14.4	2.62	2.12	2.44
4/24	M	1	51.1	5.2	32.7	25.5	34.9	43.0	46.9	4.1	63.4	6.3	43.0	-	10.83	1.56	26.3
5/2	T	1	7.8	10.9	9.7	7.7	14.3	9.4	6.7	8.6	-	14.3	8.9	9.9	1.56	2.99	2.83
5/3	W	1	4.5	9.3	6.9	7.5	3.0	10.4.	5.4	9.6	1.5	4.4	6.7	14.0	2.71	4.81	4.37
5/4	TH	1	7.7	9.7	8.3	-	7.4	10.2	-	-	5.1	9.7	10.2	-	3.61	-	2.81
5/5	F	3	2.4	1.8	2.1	2.6	2.2	1.5	2.5	2.6	1.9	2.5	2.7	0.2	0.42	1.36	0.96
5/8	M	2	19.2	9.0	14.1	14.4	13.2	14.8	21.3	7.4	17.1	9.2	19.2	10.3	2.10	1.46	5.83
5/10	W	1	9.7	10.2	10.0	10.0	5.2	14.8	9.0	11.0	5.6	4.7	14.6	14.9	4.54	5.15	4.35
5/11	TH	1	11.3	9.7	10.5	10.0	10.8	10.9	10.1	9.9	10.9	10.6	13.0	8.7	1.50	0.96	1.43
5/12	F	3	2.7	1.2	1.8	1.4	0.8	3.0	-	1.4	0.8	0.8	4.5	1.5	2.62	0.38	1.54
5/22	M	1	13.4	12.6	13.0	6.2	23.4	9.6	0.9	11.4	33.1	13.6	6.3	12.8	17.24	1.11	10.93
5/23	T	1	7.9	13.0	10.5	11.1	8.4	12.0	7.7	14.5	6.2	10.6	9.9	14.0	1.86	2.12	3.32
5/24	W	2	4.7	6.2	5.5	5.8	4.5	6.2	5.0	6.5	3.7	5.2	5.4	7.0	0.88	0.93	1.17
5/26	F	3	3.1	4.2	3.7	3.8	3.0	4.3	2.9	4.6	2.1	3.9	4.4	4.1	1.17	0.36	0.97
ARITHMETIC MEAN			14.8	10.4	12.8	12.8	10.9	15.6	15.1	11.7	13.4	9.3	17.9	11.6			
STANDARD DEVIATION			15.6	8.5	11.6	12.3	10.5	15.2	16.7	9.8	15.9	7.6	18.6	10.4			

The X-Ray fluorescence analysis has been summarized in Table 7 for each filter and for each element. Arithmetic means of all filters for each element and for each type of filter have been calculated with their standard deviations. The ratio of bromine to lead is 0.3144 for coarse and 0.3178 for fine. The ratio of fine to coarse lead is 0.5855 and fine to coarse bromine is 0.5792. This indicates that bromine and lead samples are closely related and probably come from only one source, motor vehicles. It also indicates the aerosol is fresh since bromine deteriorates rapidly with time, especially in summer as shown by Cahill [4]. The bromine-lead ratio is typical of a fresh aerosol. Although there are lead smelters and battery recovery plants in Dallas, as reported by Crosby [5], none of them appear to be a significant source at this location.

Table 8 presents the percentage of each element for each filter location and for coarse versus fine and coarse divided by fine. Most of the iron and calcium is in the coarse fraction and most of the sulfur is fine. Variability from sample to sample is relatively low.

The element ratios of each XRF element with respect to lead and calcium are shown in Table 9 for each filter and for all coarse or all fine filters with standard deviations for coarse and fine filters. The bromine-lead ratio shows a low variability for both coarse and fine filters and essentially the same mean value for both coarse and fine. This is further verification of the close relationship of bromine and lead and the freshness of the bromine aerosol sampled along the roadway. This portion of the aerosol evidently came from this roadway or some neighboring roadway and was either straight from automobile exhaust or resuspended from a recent deposition on the roadway. It is highly unlikely that lead and bromine came from some other point source.

TABLE 7
X-RAY FLUORESCENCE - SUMMARY

		$\overline{X}_{1c}$	$\overline{X}_{1f}$	$\overline{X}_{2c}$	$\overline{X}_{2f}$	$\overline{X}_{3c}$	$\overline{X}_{3f}$	$\overline{X}_{c}$	$\overline{X}_{f}$	COV_c	COV_f
Ca	X	2.2882	0.3008	1.9027	0.2642	2.4735	0.4100	2.2215	0.3659	0.1310	0.3982
		2.7736	0.2751	2.5998	0.2027	2.6737	0.5328	0.2912	0.1457		
K	X	0.1493	0.0889	0.2241	0.0782	0.3028	0.1201	0.2254	0.0957	0.3407	0.2278
		0.2319	0.1073	0.4189	0.0759	0.3225	0.1391	0.0768	0.0218		
S	X	0.7520	1.8157	0.6967	1.5786	0.6688	2.0768	0.7058	1.8237	0.0599	0.1366
		1.5260	1.1777	1.4348	0.8913	1.2092	1.1339	0.0423	0.2492		
Zn	X	0.0150	0.0090	0.0316	0.0087	0.0168	0.0118	0.0211	0.0098	0.4313	0.1734
		0.0263	0.0083	0.0805	0.0070	0.0220	0.0128	0.0091	0.0017		
Fe	X	0.3084	0.0858	0.2787	0.0933	0.3956	0.1060	0.3276	0.0950	0.1856	0.1074
		0.4047	0.0929	0.4232	0.1257	0.4760	0.1560	0.0608	0.0102		
Pb	X	0.3748	0.5672	0.3163	0.5512	0.3384	0.6403	0.3432	0.5862	0.0860	0.0810
		0.6563	0.4272	0.5082	0.3682	0.4057	0.4384	0.0295	0.0475		
Br	X	0.1138	0.1652	0.0957	0.1801	0.1142	0.2137	0.1079	0.1863	0.0982	0.1331
		0.2380	0.1857	0.1891	0.1707	0.1393	0.1821	0.0106	0.0248		
Total (ug)		3.9865	3.0326	3.5458	2.7543	4.3101	3.5787	3.9525	3.3083		
Sampler Total (ug)		7.0191		6.3001		7.8897		7.2608			

COV = Coefficient of Variation $\frac{\sigma}{\overline{X}}$

TABLE 8
PERCENTAGE OF PARTICULATE

Element	1C	1F	2C	2F	3C	3F	C	F	C/F
Ca	57.4	9.9	53.7	9.6	57.4	11.5	56.2	11.1	5.1
K	3.7	2.9	6.3	2.8	7.0	3.4	5.7	2.9	2.0
S	18.9	59.9	19.6	57.3	15.5	58.0	17.9	55.1	0.3
Zn	0.4	0.3	0.9	0.3	0.4	0.3	0.5	0.3	1.7
Fe	7.7	2.8	7.9	3.4	9.2	3.0	8.3	2.9	2.9
Pb	9.4	18.7	8.9	20.0	7.9	17.9	8.7	17.7	0.5
Br	2.9	5.4	2.7	6.5	2.6	6.0	2.7	5.6	0.5

TABLE 9
ELEMENT RATIOS

Element Ratio	1C	1F	2C	2F	3C	3F	C	F	σ_C	σ_F
Br/Pb	0.304	0.291	0.303	0.327	0.337	0.334	0.314	0.318	0.019	0.023
Fe/Pb	0.819	0.150	0.888	0.170	1.165	0.168	0.954	0.164	0.183	0.011
Zn/Pb	0.043	0.016	0.101	0.015	0.051	0.017	0.057	0.017	0.031	0.001
S/Pb	2.011	3.203	2.202	2.865	1.962	3.240	2.057	3.113	0.126	0.207
K/Pb	0.394	0.155	0.708	0.140	0.886	0.190	0.655	0.164	0.249	0.177
Ca/Pb	6.106	0.529	6.034	0.480	7.266	0.642	6.460	0.627	0.691	0.083
K/Ca	0.064	0.293	0.117	0.292	0.122	0.296	0.101	0.261	0.032	0.002
S/Ca	0.329	6.051	0.365	5.969	0.270	5.043	0.319	4.964	0.048	0.560
Zn/Ca	0.007	0.030	0.017	0.031	0.007	0.026	0.009	0.027	0.006	0.003
Fe/Ca	0.134	0.283	0.147	0.354	0.160	0.261	0.148	0.261	0.013	0.049
Pb/Ca	0.164	1.889	0.166	2.083	0.138	1.557	0.155	1.595	0.016	0.266
Br/Ca	0.051	0.545	0.050	0.677	0.045	0.522	0.048	0.505	0.003	0.084

An analysis of wind direction and its relationship to particulate loading was performed for coarse and fine filters from four component directions and calm winds. A comparison was made of lead three (Pb_3) and lead one (Pb_1) and the mean gravimetric X_3 and X_1 expressed as a simple ratio. The object was to determine whether or not wind direction had a significant effect on particulate concentration for an elevated expressway (IH 45). Winds were obtained from climatological data at the Dallas-Fort Worth Regional Airport some 20 miles (32.2 km) from the monitoring site. These winds may not be representative of the winds at IH 45 and Forest Avenue in South Dallas. N = number of samples and C and F are coarse and fine ratios.

		W			E			S			N			Calm	
	N	C	F	N	C	F	N	C	F	N	C	F	N	C	F
$\frac{Pb_3}{Pb_1}$	9	2.21	1.50	4	1.01	2.24	13	1.59	1.23	1	0.33	1.12	1	1.21	0.05
$\frac{X_3}{X_1}$	5	1.37	1.02	4	1.28	1.27	12	1.24	0.93	1	0.84	2.29	1	1.08	0.08

In the one calm case the fine particulate was very low in concentration. This may be due to its acting like a gas and rising vertically from the roadway in the heat from automotive exhaust. Bullin has reported this phenomena in another study [6]. An east wind for lead shows a high ratio for fine and a west wind shows a high ratio for coarse.

The high ratio for a west wind and coarse particulate may be due to the backwash of pollutants on the east side of the highway and entrainment of pollutants from State Highway 75 about one block away. The high concentration of fines with an east wind cannot easily be explained nor the high concentration of fines for a north wind.

The elevated highway section has vertical walls which tend to channelize all winds along the roadway. In addition, seldom do winds blow from one side of a highway to another continuously. Horizontal wind data generally show considerable variability in wind direction, the variability a function of the stability of the air mass.

It is difficult to evaluate the effect of wind direction on particulate concentration when evaluating an elevated section with vertical walls. On the other hand, it is difficult to evaluate water pollutants without using an elevated section.

A time series graph of particulate concentration has been plotted for gravimetric results, total XRF, and each XRF element in Figures 3-11. The particulate amounts in ug/m^3 are an average of all six filters for each day with the exception of lead which is a plot of coarse and fine values for location 3 only.

The gravimetric results in Figure 3 show several sharp peaks at 3/28, 4/6, 4/17, and 4/24. These peaks do not appear to be influenced by rainfall amounts (dashed lines with arrows pointing down). We do know that on 3/28 street sweeping was underway along this section of roadway. We can only speculate on the reason for the other peaks, but it seems likely that some sort of construction or maintenance activity caused these sharp increases in particulate concentrations since they decrease as quickly as they rise. The fine over coarse ratio at 4/24 is 0.09 from Table 13 which is much lower than the average value of 0.68. The large increase of these data appears to be wholly in the coarse fraction.

It is interesting to note that each time a significant storm event takes place the particulate concentration decreases appreciably. The only really large storm event occurred on 3/24. All other storm events were moderate and many of short duration. The rainfall of 0.72" on 3/24 had the lowest intensity (RI) of any storm in this period as shown in Table 2. It should have been much less efficient in removing pollutants from the roadway than some of the more intense events. Two or three events in quick succession appear remarkably efficient in lowering particulate concentrations, for example, at 5/2-5/3 and 5/21-5/24.

The parallelism of "total XRF" in Figure 4 with gravimetric analysis in Figure 3 is striking, especially the peaks at 3/28 and 4/24 and the general pattern of most of the remainder of the data. Significant differences are no peak for total XRF for 4/6 and a much lesser peak at 4/17.

The lead at location 3 (Pb_3) in Figure 5 shows a sharp peak at 3/28 and an increasing trend upward in the overall pattern through 4/24. Although not shown there was a trace of rain reported on 4/17 with thundershowers in the area. The close relationship of lead concentrations to rainfall is particularly clear. In additon, if a line is drawn through peaks at 4/3, 4/11 an imaginary peak at 4/17, a slope of 0.063 ug/m^3/day is apparent in a period of relatively light or less intense precipitation. This is believed to be the increase in lead concentration for increasing deposition of pollutants on the roadway. If a line is drawn through the troughs at 4/17, 4/13, and 4/20 a similar, but somewhat shallower slope is achieved. The variability within this envelope is believed to be due to meterological influences, stability, synoptic weather conditions, and light precipitation. This increase may vary with season, but is probably linear with traffic volume. For a traffic volume of 37,300 vehicles per day, the normalized value of increase of lead is 1.69×10^{-6} ug/m^3/day/vehicle. Although the data base is small, there appears to be a close relationship between the buildup of pollutants on the roadway and lead levels measured in the ambient air alongside an elevated roadway. The rate established here requires further verification.

If we look at bromine in Figure 6, the peaks at 3/28 and 4/24 are evident and a line drawn through 4/18, 4/11, and an imaginary peak at 4/4 gives a slope of 0.0052 ug/m^3/day, One would expect less increase in bromine than lead because bromine is more reactive and decreases in roadway dust with time. Note that the general pattern of bromine tracks that of lead very closely and the trend approximately parallels that of lead.

Calcium in Figure 7 has large peaks at 3/28 and 4/24 and the trend from 4/4 to 4/17 is identical with that of lead, 0.063 ug/m^3/day. The general pat-

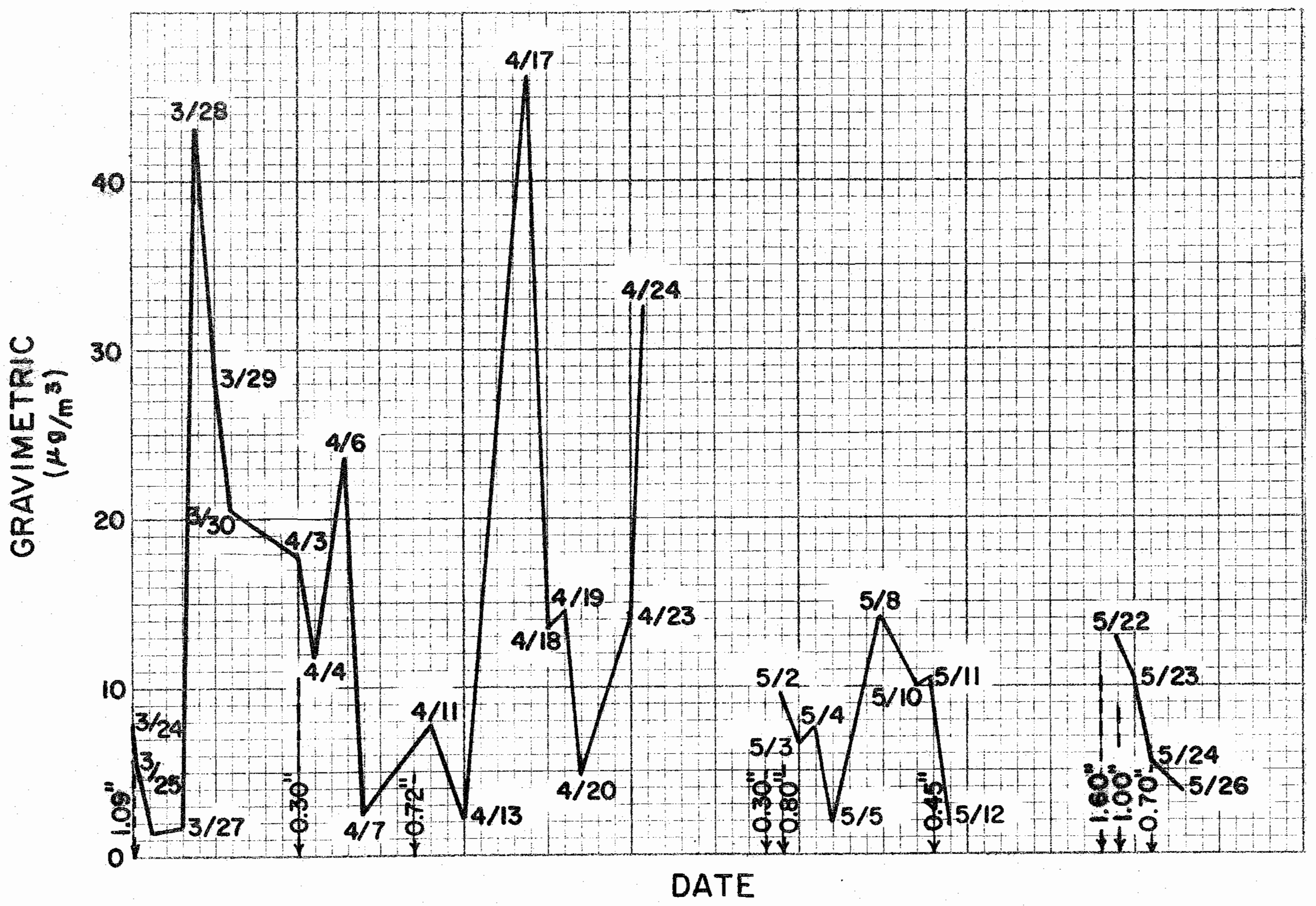

Figure 3. GRAVIMETRIC TIME SERIES

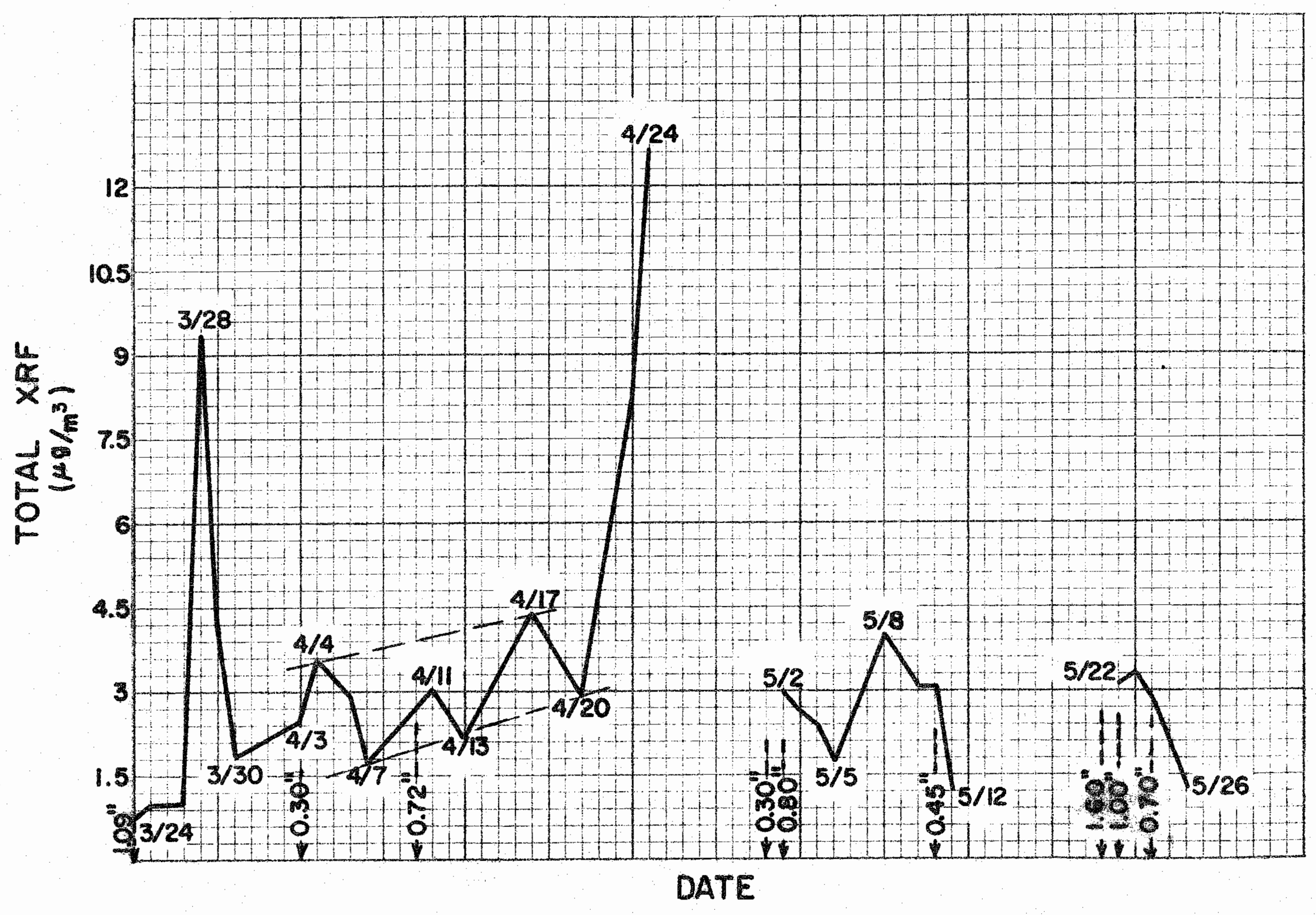

Figure 4. TOTAL XRF TIME SERIES

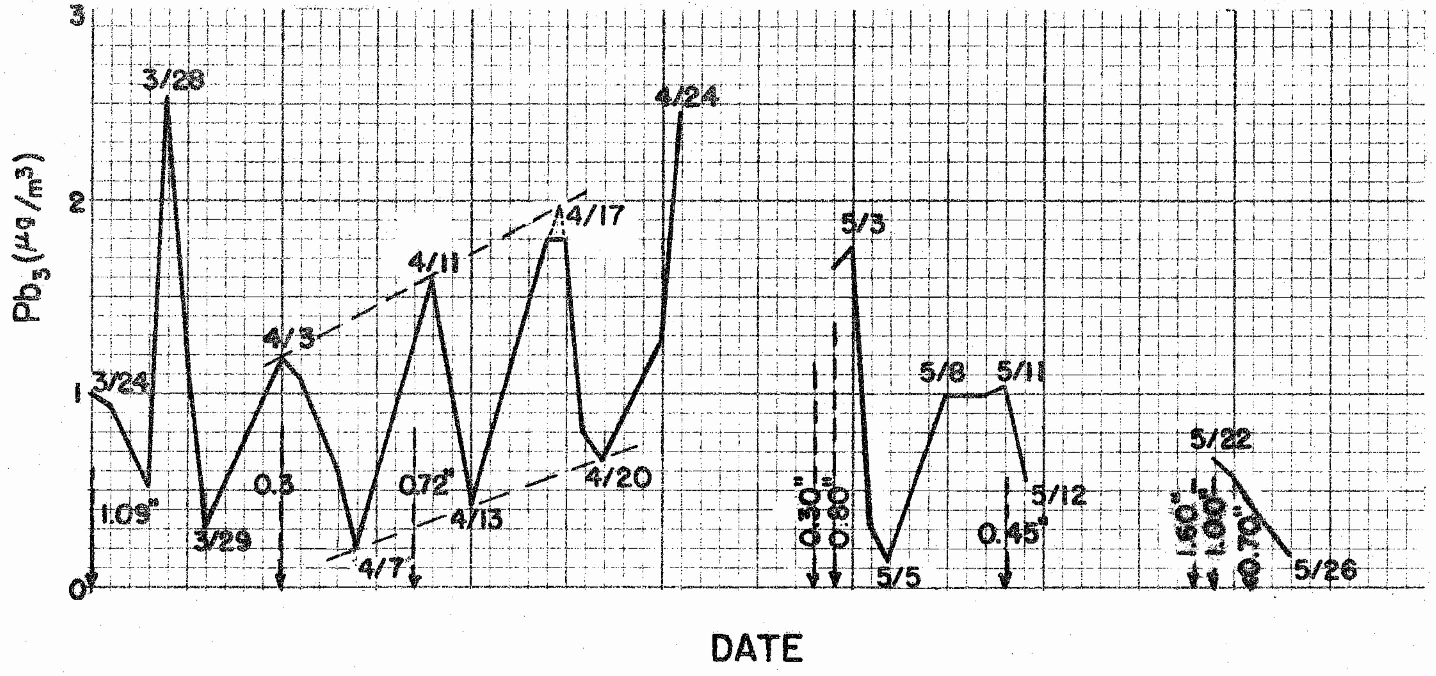

Figure 5. LEAD 3 TIME SERIES

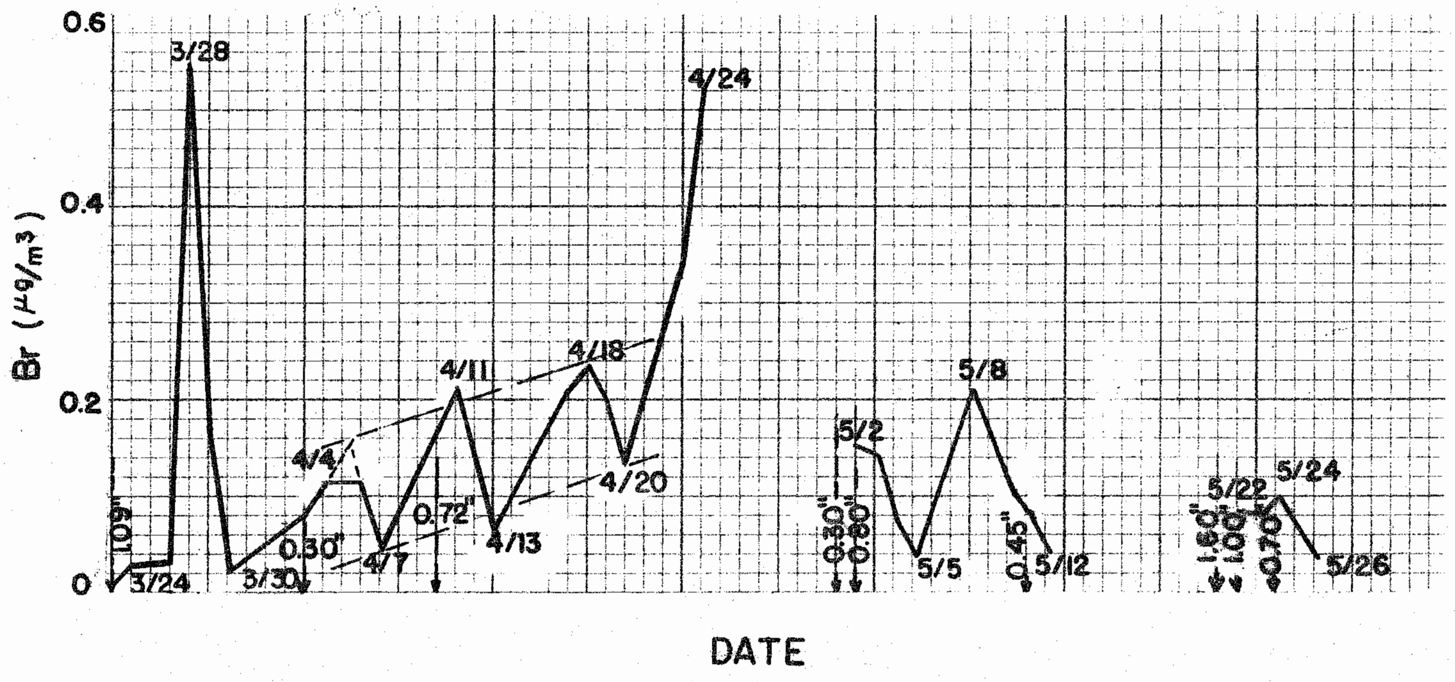

Figure 6. BROMINE TIME SERIES

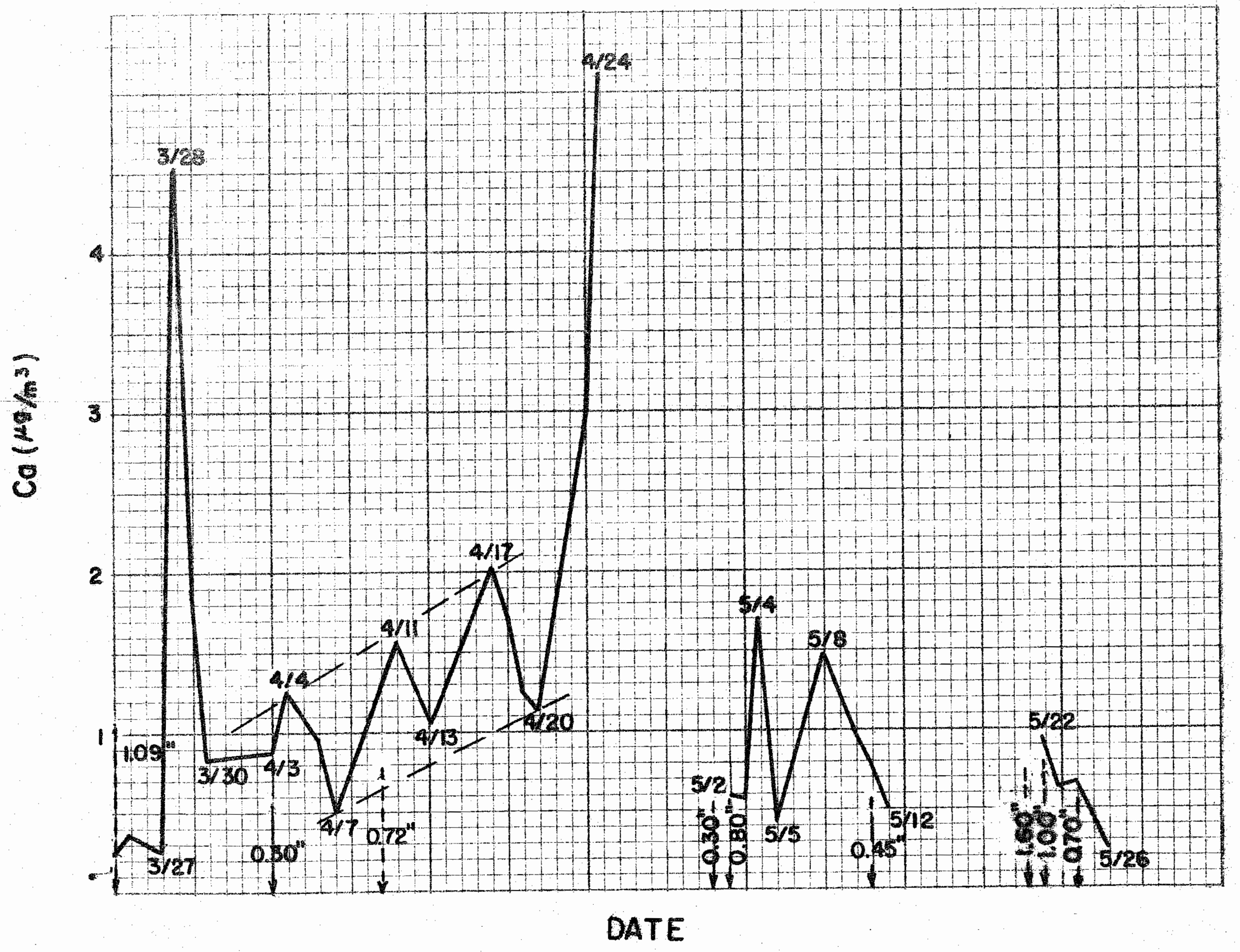

Figure 7. CALCIUM TIME SERIES

tern is very similar to lead and bromine.

Potassium in figure 8 has large peaks at 3/28, 4/4, 4/17, 4/24, and 5/11. Although this element is very close to the limit of detectability, it decreases sharply at most rainfall events and the general pattern tracks the other elements and the gravimetric analysis. Potassium should be closely related to Calcium in the pavement surface.

Sulfur is mostly fine with a coarse over fine ratio of 0.3 in Table 8, the lowest of the seven elements measured with XRF. Like bromine it is reactive and may appear as SO_2, H_2SO_3, H_2SO_4, and other sulfates such as $(NH_3)_2SO_4$. Some of it occurs as a result of the chemical industry and invisible power plant plumes. In Dallas the main influence other than the catalytic converters of automobiles will probably be power plants. Sulfur represents 18% of the coarse and 55% of the fine particulate in these samples. The trace in Figure 9 shows peaks at 3/28, 4/6, and 4/24 and a similar pattern to the other elements except that the increasing trend between 4/3 and 4/17 is not clear in these data. Wet deposition is evidently fairly effective when storm events are large or after successive moderate rainfalls.

Zinc in Figure 10 is closer to the level of detectability than any other element displayed with most of the data below 0.02 ug/m^3. The most outstanding peak occurs at 4/24 as is true of many of the other elements. There is no increasing trend between 4/3 and 4/17. Zinc occurs in galvanized parts of automobiles and in oil and grease additives. It is very closely related to lead in water pollutants washed off the highway as shown in this and the previous study.

Bullin [7] has reported higher levels of iron in Dallas than San Antonio because of earth crustal components. Most of the iron here is probably from the underside of vehicles, although some may have been tracked onto the roadway. Iron shows major peaks at 3/28, 4/17, and 4/24 in Figure 11. Trend information may be supported between 4/3 and 4/17, but the pattern is not as clear as lead, bromine, and calcium. This may be because some of the iron is earth crustal in nature and not strictly a function of traffic. Other than the height of the peaks at 4/11 and 4/17, the overall pattern tracks that of lead very closely.

If we draw a line between 4/4 and 4/17 for total XRF, a slope of 0.065 ug/m^3/day is measured and parallels a line drawn through the troughs at 4/7, 4/13, and 4/20. This is almost identical to the slopes determined for lead and calcium.

A close relationship has been demonstrated between gravimetric analysis and seven elements determined by X-ray fluorescence techniques with significant amounts of precipitation. In relatively dry periods a gradual increase in air pollution has been demonstrated with time for some elements and for the sume of those elements found at significant levels by XRF.

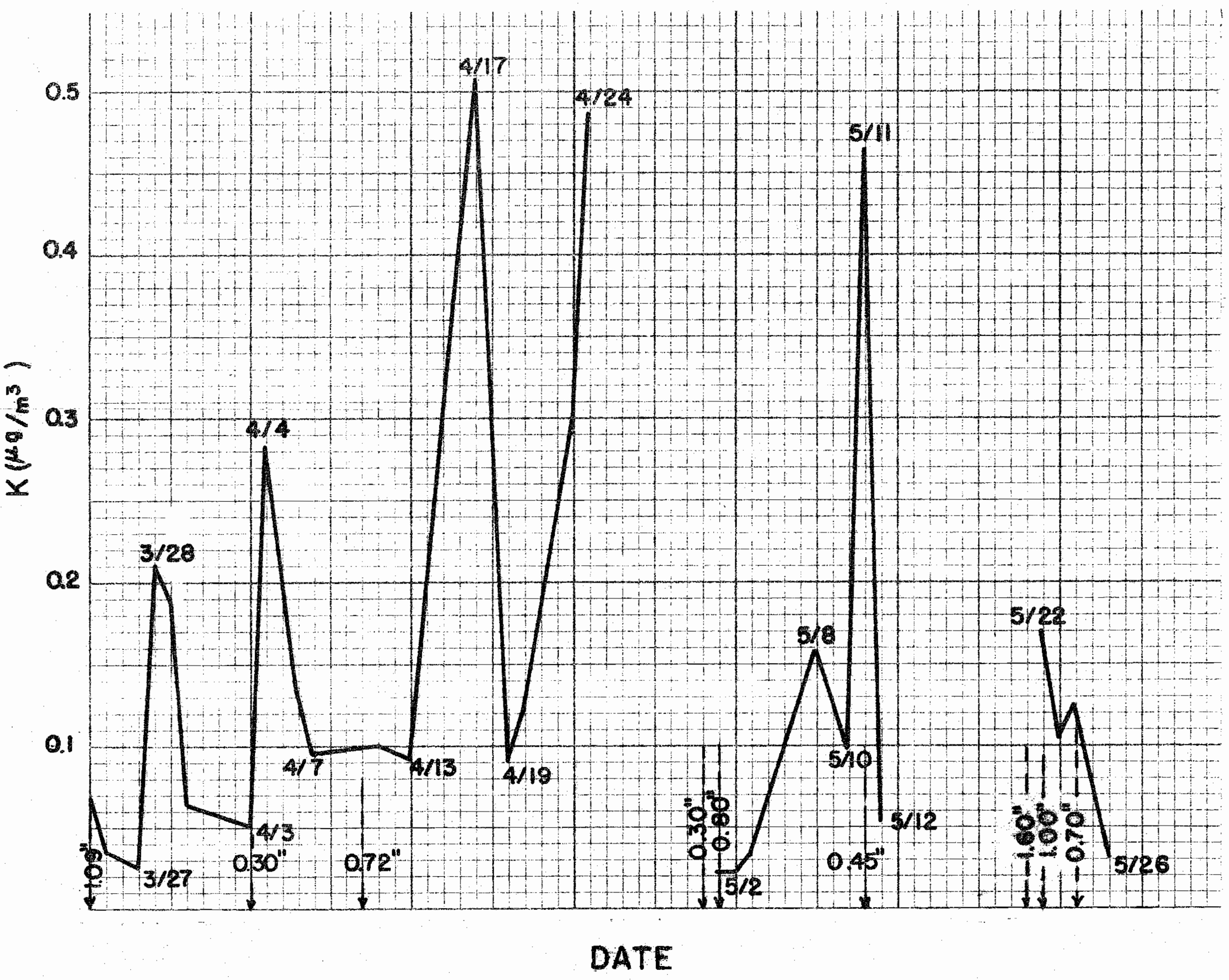

Figure 8. POTASSIUM TIME SERIES

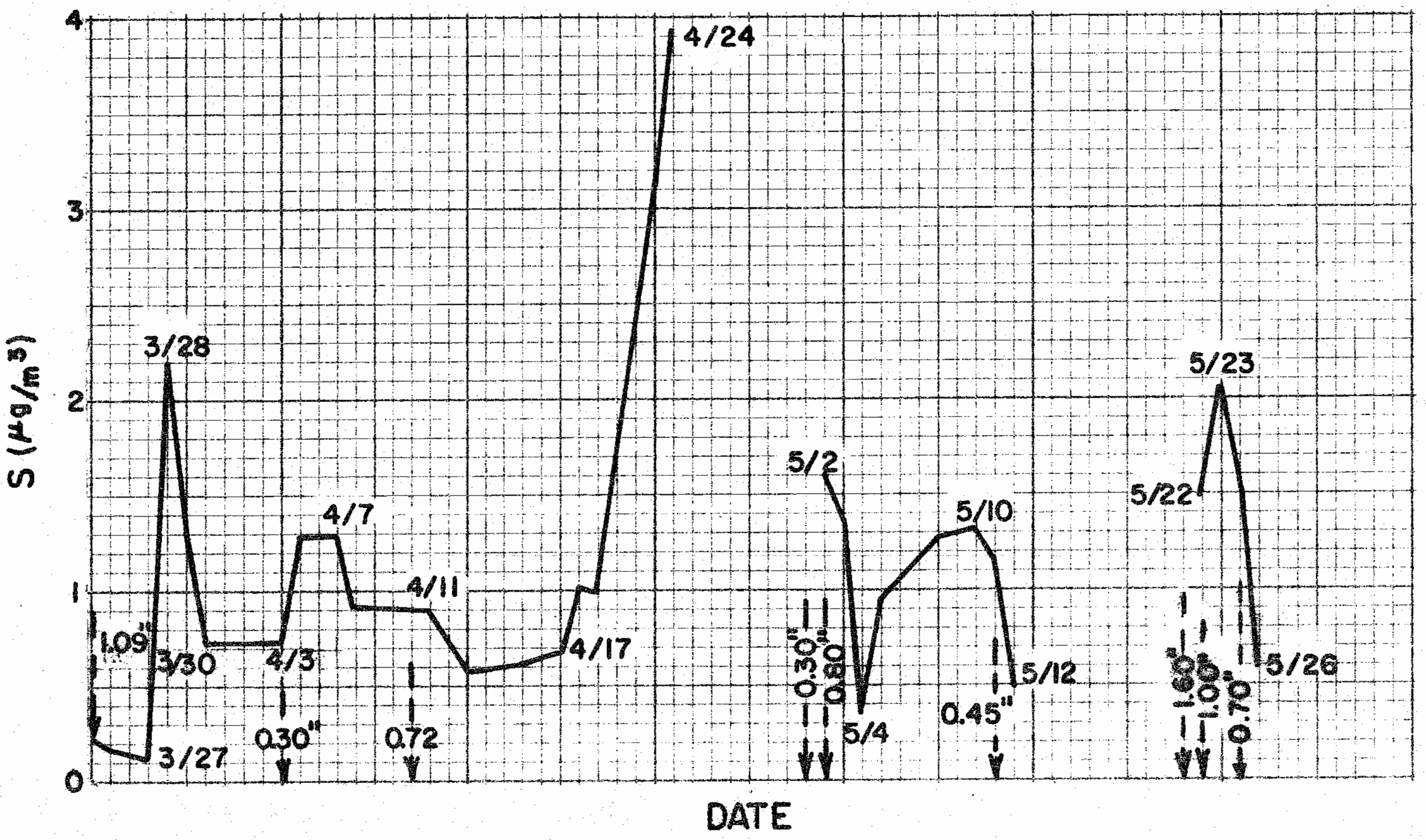

Figure 9. SULFUR TIME SERIES

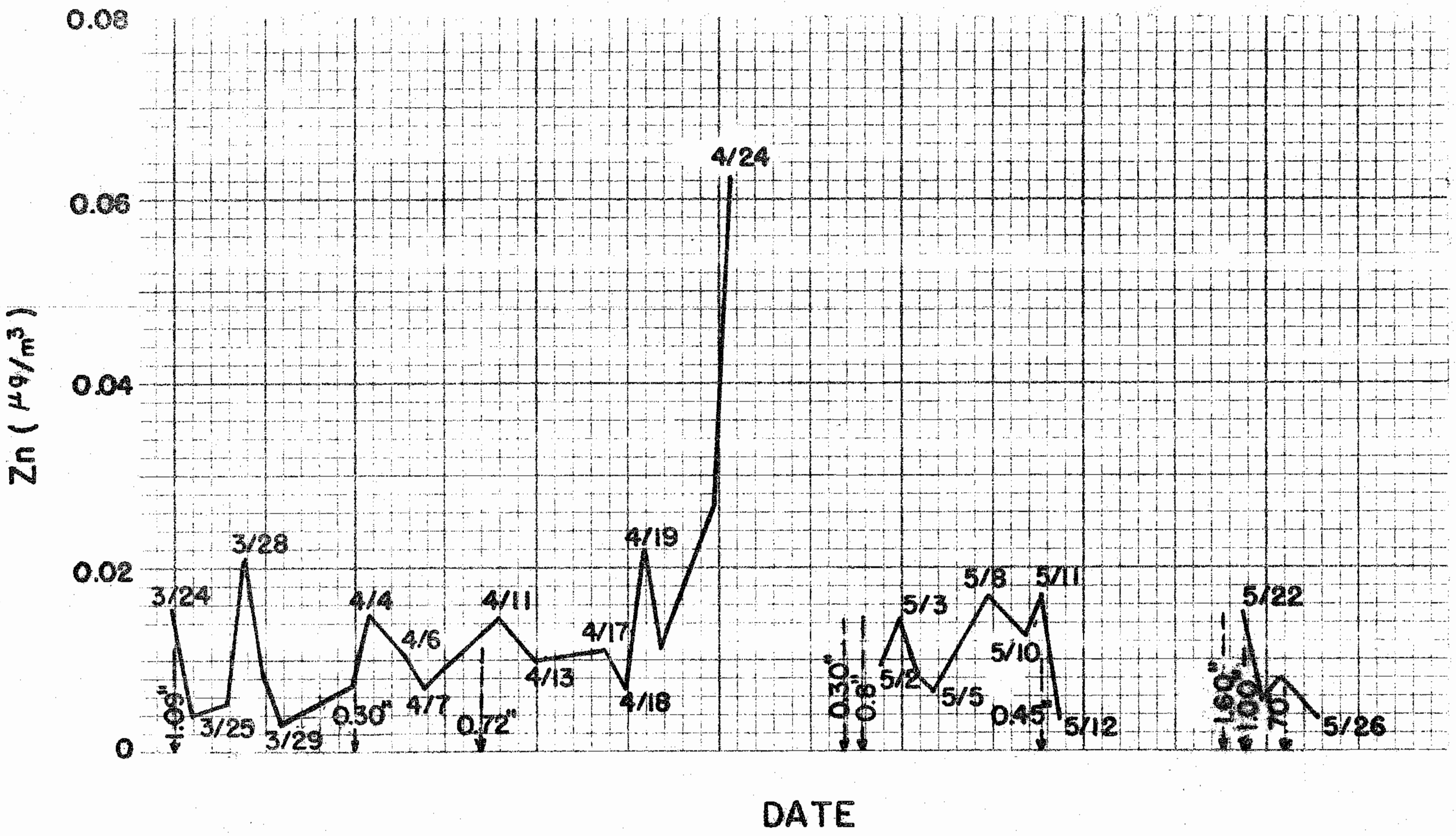

Figure 10. ZINC TIME SERIES

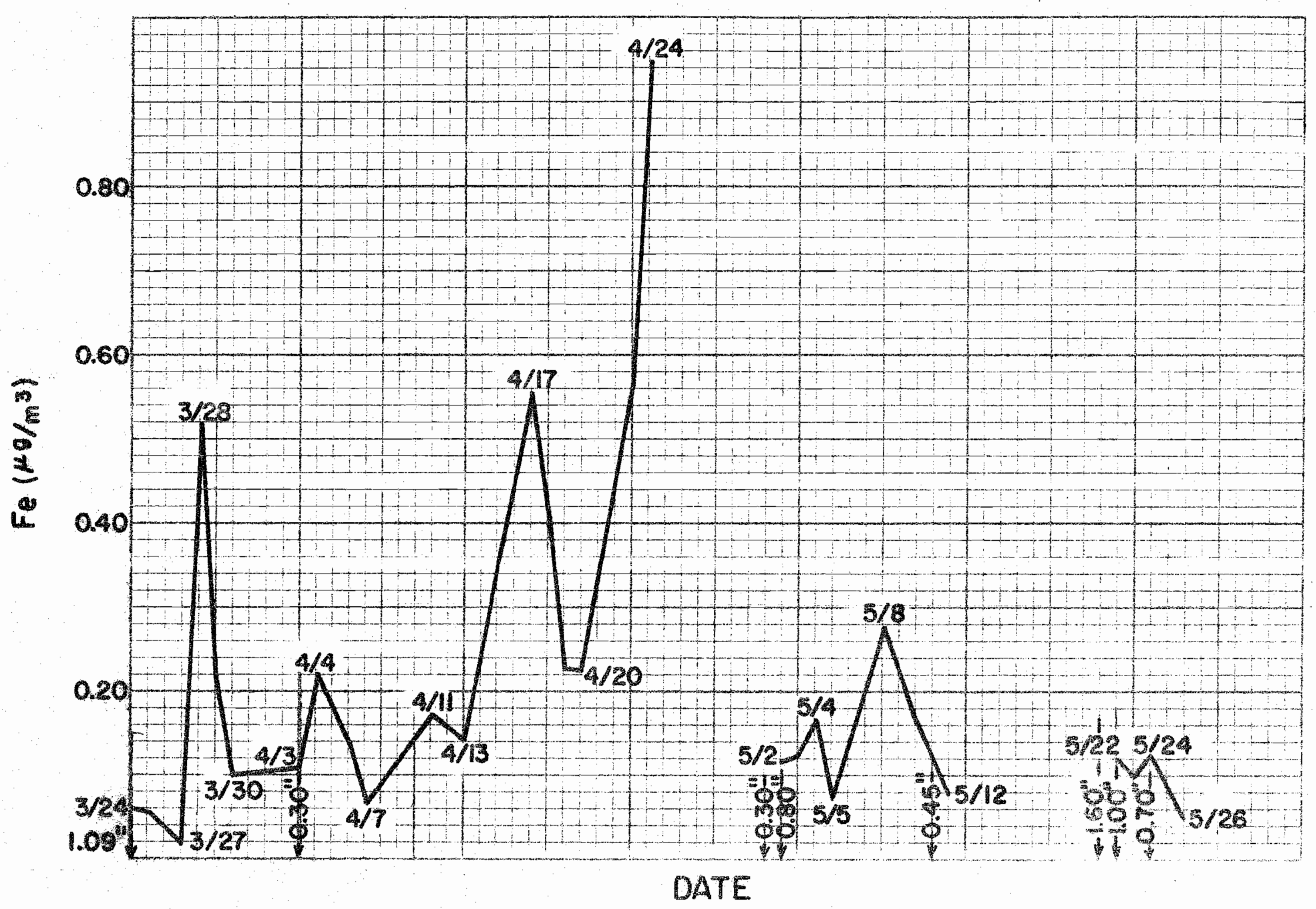

Figure 11. IRON TIME SERIES

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APPENDIX

TABLE 10
FLOW RATE FOR SHARP CRESTED WEIR

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

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.

APPENDIX
TABLE 11
WATER POLLUTANT CONCENTRATION SUMMARY (1977)

Results:

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	88	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	1870	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

	Fe	Pb	Zn	Cd	TSS	TVS	TDS	TS
MINIMUM	920	209	78	3.0	26	13	27	79
MAXIMUM	5900	1574	752	38.0	533	280.1	714	1527.1
:01								
ARITHMETIC MEAN	2578	727	335	15.5	143	63.5	196	402
STANDARD DEVIATION	1882	445	202	14.3	146	75.2	191	392
MINIMUM	506	335	155		20	9	42	114
MAXIMUM	1860	438	395		76	42	230	336
:10								
ARTITHMETIC MEAN	1080	377	222		48.6	22.8	166	237
STANDARD DEVIATION	659	65	120		22.8	13.5	72.6	86.4

TABLE 11
WATER POLLUTANT CONCENTRATION SUMMARY (1977)

Storm Event	Sample Interval	COD (mg/l)	TOC (mg/l)	Kjeldahl Nitrogen (mg/l)	Nitrate Nitrogen (mg/l)	Bromine (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	30.9	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
MINIMUM		102	25.5	3.87	0.42	-	13.8	6.9
MAXIMUM		437	127.1	5.90	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	1.03	0.48	-	18.7	0.40

TABLE 12
WATER POLLUTANT CONCENTRATION SUMMARY (1978-1979)

Storm Event	Date	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)
13	3/24/78	:01	99700	1340	1220	10	228	37	654	919
14	7/27/78	:01	13700	2250	1000	10	446	87	264	797
15	8/29/78	:01	530	780	40	6	200	65	298	563
16	3/18/78	:01	1200	700	300	50	185	52	488	725
		:10	1000	700	400	10	150	31	236	417
17	4/17/79	:01	300	140	100	20	50	27	596	673
		:10	460	110	100	10	73	31	340	444
18	5/21/79	:01	2190	217	230	11	98	39	48	185
		:10	4700	45	310	16	178	62	143	383
19	5/22/79	:10	3450	336	190	9	81	25	86	192

MINIMUM	300	140	40	6	50	27	48	185
MAXIMUM	99700	2250	1220	50	446	87	654	919
:01								
ARITHMETIC MEAN	19603	876	495	18.8	214	52	407	677
STANDARD DEVIATION	39569	789	500	16	137	21	229	187

MINIMUM	460	45	100	9	73	25	86	192
MAXIMUM	4700	700	400	16	178	62	340	444
:10								
ARITHMETIC MEAN	2403	298	250	11	169	37	201	310
STANDARD DEVIATION	2461	296	132	3	115	17	111	140

TABLE 12 (Continued)
WATER POLLUTANT CONCENTRATION SUMMARY (1978-1979)

Storm Event	Date	Sample Interval	COD (mg/l)	TOC (mg/l)	KJELDAHL NITROGEN (mg/l)	NITRATE NITROGEN (mg/l)	Br (mg/l)	SO_4 (mg/l)	PH	CL (ug/l)	ORG. HG (ug/l)	INORG. HG (ug/l)	Ni (ug/l)
13	3/24/78	:01	108	3.4	0.65	0.12	-	4.4	7.1	-	-	5.1	30
14	7/27/78	:01	180.5	46.3	4.4	2.965	-	40.2	8.1	-	-	-	2450
15	8/29/78	:01	250	61.9	3.7	-	-	41.5	7.9	-	-	-	30
16	3/18/79	:01	323	89.3	4.45	0.3	-	96.8	7.5	-	-	0.6	-
		:10	108	39.9	0.12	1.45	-	28.8	7.6	-	-	0.6	-
17	4/17/79	:01	163	30.9	2.85	0.45	-	124	7.8	-	-	5.0	8.0
		:10	153	39.4	0.8	0.21	-	59.4	7.3	-	-	-	50
18	5/21/79	:01	147	21.4	8.77	0.06	-	28.5	7.6	-	0.30	0.01	24
		:10	176	56.6	5.93	0.29	-	172.3	7.5	-	0.20	0.01	37
19	5/22/79	:10	22.5	20.8	4.69	0.03	-	31.4	7.8	-	0.43	0.01	34
MINIMUM			22.5	3.4	0.65	-	-	4.4	7.1	-	-	-	
MAXIMUM			323	89.3	8.77	2.965		96.8	8.1	-	0.30	0.6	2450
:01													
ARITHMETIC MEAN			195	42	4.1	0.6	-	56	7.7	-	-	-	424
STANDARD DEVIATION			78	31	2.7	1.2	-	45	0.4	-	-	-	993
MINIMUM			22.5	20.8	0.12	0.03	-	28.8	7.3	-	-	-	-
MAXIMUM			176	56.6	5.93	1.45	-	172.3	7.8	-	0.43	0.6	50
:10													
ARITHMETIC MEAN			115	39	2.9	0.5	-	73	7.6	-	-	-	30
STANDARD DEVIATION			68	15	2.9	0.6	-	68	0.2	-	-	-	21

TABLE 13

PARTICULATE X-RAY FLUORESCENT AND GRAVIMETRIC ANALYSIS

No.	Date 78	Start Time	Ca	K	S	Zn	Fe	Pb	Br	Wt. (ug)	Time (min)	Flow Rate (l/min)	Flow (m^3)	Conc (ug/m^3)	Conc /Day (ug/m^3 /day)	$\overline{X}$	σ	F/C
M																		
378 C 1	5/22	1724	0.9094	0.0039	0.2866	0.0214	0.1286	0.0655	0.0236	16	1474	12.5	18.4	0.9	0.9			
482 F 1			0.1017	0.2185	2.3731	0.0006	0.0359	0.4362	0.1032	215				11.7	11.4			
541 C 2		1711	2.6878	0.0488	0.8816	-	0.2921	0.4269	0.0751	628	1476	12.5	18.5	33.9	33.1			
526 F 2			0.2862	0.2121	2.0547	0.0183	0.0652	0.4652	0.1389	257				13.9	13.6			
364 C 3		1734	1.0190	0.3671	0.3671	0.0116	0.1464	0.1315	0.0368	118	1471	12.5	18.4	6.4	6.3			
525 F 3			0.6053	0.1724	2.7315	0.0231	0.0436	0.5313	0.1210	235				12.8	12.5	13.0	10.9	0.93
T																		
348 C 1	5/23	1802	0.8851	-	0.2387	0.0045	0.1100	0.1426	0.0361	135	1415	12.5	17.7	7.6	7.7			
561 F 1			0.1321	0.1304	3.9113	0.0036	0.0609	0.5284	0.1181	257				14.5	14.8			
353 C 2		1750	0.9942	0.0326	0.3285	-	0.1323	0.0983	0.0303	109	1413	12.5	17.7	6.2	6.3			
560 F 2			0.1508	0.0794	3.3995	-	0.0267	0.5880	0.1035	187				10.6	10.8			
352 C 3		1807	1.3312	-	0.3174	0.0080	0.1954	0.1081	0.0714	172	1423	12.3	17.5	9.8	9.9			
559 F 3			0.2537	0.1846	4.2374	-	0.0671	0.4638	0.1243	241				13.8	14.0	10.6	3.4	1.66
W																		
330 C 1	5/24	1738	1.1305	-	0.1846	0.0078	0.1778	0.1499	0.0490	182	2917	12.5	36.5	5.0	5.0			
483 F 1			0.2698	0.1798	3.2707	0.0085	0.0552	0.6720	0.1694	239				6.5	3.2			
583 C 2		1725	1.1838	0.1467	0.4518	0.0070	0.2182	0.2404	0.0651	136	2916	12.5	36.5	3.7	1.8			
575 F 2			0.0971	0.0404	2.4667	0.0102	0.0275	0.5685	0.1523	189				5.2	2.6			
581 C 3		1752	1.227	0.1420	0.2127	0.0101	0.2040	0.0532	0.0572	195	2907	12.3	35.8	5.4	2.7			
574 F 3			0.1371	0.1263	2.4778	0.0031	0.0585	0.3539	0.0916	249				7.0	3.5	3.1	1.1	0.97
F																		
376 C 1	5/26		0.3998	0.0686	0.1023	0.0004	0.0506	0.0550	0.0120	161	4374	12.5	54.7	2.9	1.0			
519 F 1			0.0542	0.0076	1.0218	0.0035	0.0174	0.2534	0.0630	253				4.6	1.5			
377 C 2			0.4158	0.0143	0.1558	-	0.0737	0.0520	0.0260	116	4366	12.5	54.6	2.1	0.7			
492 F 2			0.0340	0.0327	0.8703	0.0037	0.0094	0.2477	0.0571	213				3.9	1.3			
371 C 3			0.5814	0.0381	0.2140	0.0069	0.0958	0.0382	0.0249	239	4385	12.5	54.8	4.4	1.4			
489 F 3			0.0407	0.0195	1.1526	0.0032	0.0286	0.1272	0.0221	226				4.1	1.3	2.9	4.0	1.33

TABLE 13
PARTICULATE X-RAY FLUORESCENT AND GRAVIMETRIC ANALYSIS
(Contd.)

No.	Date 78	Start Time	Ca	K	S	Zn	Fe	Pb	Br	Wt. (ug)	Time (min)	Flow Rate (l/min)	Flow (m^3)	Conc (ug/m^3)	Conc /Day (ug/m^3 /day)	$\overline{X}$	σ	F/C
M																		
502 C 1	5/8	1932	2.7100	0.1873	1.0613	0.0216	0.4168	0.7422	0.3033	705	2808	11.8	33.1	21.3	10.9			
570 F 1			0.1450	0.0168	2.1311	0.0107	0.0379	0.4507	0.1153	246				7.4	3.8			
513 C 2		1910	2.5303	0.1799	0.6900	0.0249	0.3638	0.4304	0.1637	601	2811	12.5	35.1	17.1	8.8			
518 F 2			0.1931	-	1.3231	-	0.3638	0.8097	0.3923	324				9.2	4.7			
591 C 3		1942	2.9384	0.2360	0.6166	0.0164	0.4171	0.3026	0.0997	662	2806	12.3	34.5	19.2	9.9			
494 F 3			0.3261	-	1.6700	0.0108	0.0637	0.6834	0.1986	354				10.3	5.3	7.2	3.0	0.47
W																		
593 C 1	5/10	1822	1.4722	0.1150	0.5022	0.0200	0.2504	0.1596	0.0511	151	1385	12.5	17.3	8.7	9.0			
571 F 1			0.3400	0.0729	2.1996	0.0140	0.0906	0.4264	0.1114	183				10.6	11.0			
584 C 2		1804	1.1475	0.0914	0.2905	0.0228	0.1695	0.1499	0.0382	94	1387	12.5	17.3	5.4	5.6			
491 F 2			0.2277	0.0695	1.8779	0.0076	0.0841	0.5862	0.1317	78				4.5	4.7			
588 C 3		1830	2.2036	0.0972	0.5929	0.0192	0.3245	0.1668	0.0815	238	1382	12.3	17.0	14.0	14.6			
567 F 3			0.4343	0.1528	2.5193	0.0033	0.0798	0.8229	0.2024	243				14.3	14.9	10.0	4.4	1.05
TH																		
343 C 1	5/11	1729	1.3215	0.0946	0.4172	0.0106	0.1689	0.0416	0.0398	183	1446	12.5	18.1	10.1	10.1			
566 F 1			0.2716	0.2005	1.4657	0.0212	0.0552	0.4286	0.0575	180				9.9	9.9			
344 C 2		1823	1.6317	1.9964	1.4554	0.0320	0.1984	0.3139	0.0361	212	1504	12.3	18.5	11.4	10.9			
565 F 2			0.2215	0.1996	1.3739	0.0128	0.0482	0.3726	0.0882	205				11.1	10.6			
587 C 3		1833	1.1367	0.1552	0.4397	0.0204	0.1697	0.1998	0.0767	241	1459	12.5	18.2	13.2	13.0			
564 F 3			0.2447	0.1519	2.0190	0.0044	0.0750	0.8381	0.2177	160				8.8	8.7	10.5	1.4	0.86
F																		
589 C 1	5/12	1737	0.5158	0.0199	0.1139	0.0002	0.0805	0.0402	0.0136	-	4304	12.5	53.8	-	-			
479 F 1			0.1981	0.0373	0.7712	0.0024	0.0394	0.2023	0.0460	228				4.2	1.4			
598 C 2		1825	0.3812	0.0331	0.1749	0.0003	0.0609	0.0813	0.0340	151	4243	12.5	53.0	2.5	0.8			
480 F 2			0.0531	0.0227	0.4112	0.0010	0.0116	0.1023	0.0384	128				2.4	0.8			
597 C 3		1753	1.7187	0.1777	0.7048	0.0138	0.3136	0.2697	0.0858	715	4299	12.5	53.7	13.3	4.5			
481 F 3			0.0538	0.0456	0.6977	0.0045	0.0135	0.2687	0.0504	240				4.5	1.5	1.8	1.5	0.38

TABLE 13
PARTICULATE X-RAY FLUORESCENT AND GRAVIMETRIC ANALYSIS
(Contd.)

No.	Date 78	Start Time	Ca	K	S	Zn	Fe	Pb	Br	Wt. (ug)	Time (min)	Flow Rate (1/min)	Flow (m^3)	Conc (ug/m^3)	Conc /Day (ug/m^3 /day)	$\overline{X}$	σ	F/C
T																		
516 C 1	5/2	1856	0.9442	-	0.1716	0.0091	0.1542	0.1916	0.0421	112	1417	12.0	17.0	6.6	6.7			
434 F 1			0.2146	-	2.6126	0.0124	0.0765	0.4161	0.1454	145				8.5	8.6			
504 C 2		1813	0.7544	-	0.2330	0.0101	0.1235	0.1072	0.0313	-	1455	12.5	18.2	-	-			
438 F 2			0.1757	-	2.3291	0.0004	0.0962	0.4959	0.0989	262				14.4	14.3			
503 C 3		1859	1.3229	0.0150	0.4695	0.0046	0.1651	0.3498	0.1149	154	1440	12.0	17.3	8.9	8.9			
487 F 3			0.1407	0.0296	3.9109	0.0205	0.0699	1.2893	0.4814	172				9.9	9.9	9.7	2.8	1.19
W																		
592 C 1	5/3	1857	1.0635	0.0067	0.2539	-	0.1007	0.0913	0.0623	87	1348	12.5	16.9	5.1	5.4			
527 F 1			0.0934	-	2.1308	0.0221	0.3287	0.3287	0.0808	152				9.0	9.6			
508 C 2		1831	0.3915	-	0.1970	-	0.0350	0.0504	0.0153	24	1339	12.5	16.7	1.4	1.5			
490 F 2			0.2234	0.0362	1.6242	0.0104	0.0360	0.2855	0.0636	69				4.1	4.4			
601 C 3		1901	1.5553	-	0.5854	0.0204	0.2077	0.3951	0.1269	107	1353	12.5	16.9	6.3	6.7			
528 F 3			0.1770	0.0238	3.2465	0.0036	0.0386	1.3414	0.5119	223				13.2	14.0	6.9	4.4	0.68
TH																		
586 C 1	5/4	1722	1.9429	0.0328	0.3756	0.0079	0.1834	0.2105	0.0741		1535	12.3	18.9					
600 C 2		1653	1.0761	-	0.4277	0.0095	0.1026	0.1680	0.1053	103	1548	12.0	18.6	5.5	5.1			
599 C 3		1736	2.0715	-	0.2570	0.0153	0.2135	0.1632	0.0433	202	1525	12.0	18.3	11.0	10.2	7.7	3.6	1.90
F																		
510 C 1	5/5	1854	0.7649	0.0321	0.2697	0.0070	0.1129	0.0947	0.0312	319	4356	9.8	42.7	7.5	2.5			
569 F 1			0.1155	0.0727	1.6733	-	0.0295	0.3742	0.0776	342				8.0	2.6			
509 C 2		1848	0.6505	0.0468	0.2276	0.0049	0.1057	0.0872	0.0277	232	4338	9.3	40.3	5.8	1.9			
572 F 2			0.0653	0.0916	1.4418	0.0109	0.0227	0.2841	0.0518	302				7.5	2.5			
499 C 3		1903	0.7689	0.0686	0.3438	0.0057	0.1291	0.1144	0.0434	328	4357	9.3	40.5	8.1	2.7			
521 F 3			0.0596	0.0741	1.6467	0.0033	0.0206	0.0169	0.0072	20				0.5	0.2	1.9	1.1	0.75

TABLE 13
PARTICULATE X-RAY FLUORESCENT AND GRAVIMETRIC ANALYSIS
(Contd.)

No.	Date 78	Start Time	Ca	K	S	Zn	Fe	Pb	Br	Wt. (ug)	Time (min)	Flow Rate (l/min)	Flow (m^3)	Conc (ug/m^3)	Conc /Day (ug/m^3 /day)	$\overline{X}$	σ	F/C
W																		
511 C 1	4/19	1843	2.5168	0.0656	0.4273	0.0078	0.4041	0.2405	0.0690	221	1377	12.5	17.2	12.8	13.4			
412 F 1			0.4282	0.1116	1.6587	0.0324	0.1254	1.0156	0.4336	272				15.8	16.5			
515 C 2		1824	1.2085	0.0642	0.2038	-	0.1709	0.1869	0.0328	178	1382	12.6	17.4	10.2	10.6			
413 F 2			0.3951	-	1.8153	0.0330	0.1309	0.8567	0.3958	195				11.2	11.7			
512 C 3		1850	2.5530	0.1045	0.3309	0.0046	0.3673	0.1558	0.0398	325	1374	12.5	17.2	18.9	19.8			
414 F 3			0.5335	0.1172	1.7627	0.0278	0.1473	0.6423	0.2259	249				14.5	15.2	14.5	3.4	0.99
TH																		
445 C 1	4/20	1741	2.9284	0.2535	1.1166	0.0192	0.4740	0.5543	0.2179	1098	4366	9.5	41.5	26.5	8.7			
428 F 1			0.1006	0.0113	0.6486	0.0106	0.0477	0.4159	0.1893	264				6.4	2.1			
467 C 2		1730	1.3762	0.0991	0.4305	0.0092	0.2123	0.1713	0.0591	459	4356	11.0	47.9	9.6	3.2			
429 F 2			0.1670	0.0617	1.5521	0.0154	0.0610	0.5454	0.1485	445				9.3	3.1			
441 C 3		1746	2.1368	0.2362	0.4603	0.0134	0.4587	0.1854	0.0657	917	4369	9.5	41.5	22.1	7.3			
416 F 3			0.1844	0.0865	1.7876	0.0025	0.0592	0.4661	0.1305	611				14.7	4.8	4.9	2.6	0.52
SU																		
453 C 1	4/23	1829	2.2459	0.1651	0.2645	0.0111	0.3197	0.3008	0.0899	257	1476	12.5	18.5	13.9	13.6			
421 F 1			0.2029	0.0156	3.1260	0.0010	0.0980	1.1193	0.2896	216				11.7	11.4			
448 C 2		1810	13.6459	1.2994	8.0306	0.1169	2.3266	2.7684	1.0502	-	1474	11.8	17.4	-	-			
435 F 2			0.4680	0.0829	3.4750	0.0079	0.1535	1.3719	0.3201	-				-	-			
457 C 3		1836	2.6231	0.1775	0.5233	0.0153	0.3642	0.1935	0.0923	320	1473	12.3	18.1	17.7	17.3			
411 F 3			0.2580	0.0469	3.3582	0.0110	0.1184	1.0688	0.2114	266				14.7	14.4	14.2	2.4	0.83
TH																		
495 F 2	5/4	1653								193	1548	12.0	18.6	10.4	9.7			
M																		
451 C 1	4/24	1854	12.9705	1.1237	8.2855	0.1441	2.1474	3.5618	1.2820	1920	1432	9.5	41.2	46.6	46.9			
486 F 1			0.3720	0.0209	1.7727	0.0301	0.1653	0.9309	0.3896	170				4.1	4.1			
500 C 2		1820	2.7299	0.1486	0.4510	0.0135	0.4626	0.2450	0.1234	2671	1470	9.5	41.3	64.7	63.4			
431 F 2			0.2664	0.1157	2.5387	0.0123	0.1431	1.1915	0.3048	255				6.2	6.3			
497 C 3		1855	13.7979	1.3884	6.7990	0.1249	2.4335	2.0184	0.6257	1792	1456	9.5	41.2	43.5	43.0			
410 F 3			0.7148	0.1346	3.9042	0.0503	0.3394	1.4466	0.3862	-				-	-	32.8	26.3	0.09

TABLE 13
PARTICULATE X-RAY FLUORESCENT AND GRAVIMETRIC ANALYSIS
(Contd.)

No.	Date 78	Start Time	Ca	K	S	Zn	Fe	Pb	Br	Wt. (ug)	Time (min)	Flow Rate (l/min)	Flow (m^3)	Conc (ug/m^3)	Conc /Day (ug/m^3 /day)	$\overline{X}$	σ	F/C
T																		
465 C 1	4/4	1101	2.4514	0.2000	0.6823	0.0183	0.3424	0.1058	0.0381	640	1767	11.8	37.8	16.9	13.8			
422 F 1			0.3673	0.4111	3.5373	0.0130	0.0749	0.5781	0.1163	529				14.0	11.4			
446 C 2		1044	3.5573	0.2683	0.8698	0.0108	0.3998	0.1960	0.0766	615	1756	12.5	40.0	15.4	12.6			
418 F 2			0.2869	0.2756	2.2930	0.0038	0.0743	0.5035	0.1545	449				11.2	9.2			
456 C 3		1108	2.6570	0.2375	0.6777	0.0265	0.3161	0.2216	0.0818	700	1772	11.8	37.9	18.5	15.0			
419 F 3			0.4312	0.3098	3.2282	0.0187	0.1191	0.8708	0.2375	436				11.5	9.3	11.9	2.4	0.72
TH																		
462 C 1	4/6	1627	1.8637	0.0612	0.6018	0.0192	0.2559	0.0842	0.0426	218	1053	12.5	13.2	16.5	22.5			
420 F 1			0.2641	0.1225	2.6910	-	0.0507	0.5192	0.1528	280				21.2	29.0			
464 C 2		1559	1.7142	0.1227	0.2660	-	0.2932	0.1285	0.1001	204	1065	12.4	13.2	15.5	21.0			
469 F 2			0.2449	0.1539	1.7220	0.0016	0.0070	0.4534	0.1718	178				13.5	18.3			
459 C 3		1639	1.3868	0.0249	0.4913	-	0.2140	0.1027	0.0794	242	1047	12.5	13.1	18.5	25.4			
470 F 3			0.1497	0.3331	2.0703	-	0.0265	0.4983	0.1592	258				19.7	27.1	23.9	4.0	1.08
F																		
447 C 1	4/7	1006	0.5255	0.0394	0.2287	0.0018	0.0655	0.0623	0.0259	282	5379	9.5	51.1	5.5	1.5			
471 F 1			0.2085	0.1383	1.2897	0.0065	0.0417	0.2506	0.0868	524				10.3	2.8			
458 C 2		0954	1.2891	0.0864	0.4655	0.0086	0.1429	0.1165	0.0441	516	5395	9.5	51.3	10.1	2.7			
472 F 2			0.1558	0.1346	1.9065	0.0185	0.0606	0.3322	0.0928	588				11.5	3.1			
444 C 3		1101	0.6212	0.0325	0.2367	0.0086	0.1008	0.0418	0.0128	392	5372	9.5	51.0	7.7	2.1			
473 F 3			0.0764	0.1552	1.3717	0.0016	0.0288	0.1405	0.0484	458				9.0	2.4	2.1	1.0	1.33
T																		
468 C 1	4/11		2.7802	0.1465	0.7196	0.0340	0.3227	0.4595	0.1296	655	2659	12.4	33.0	20.2	10.9			
474 F 1			0.1932	-	1.5711	0.0104	0.0518	0.6921	0.2416	323				9.8	5.3			
461 C 2			1.1289	0.0262	0.5205	0.0053	0.0148	0.2415	0.0474	287	2645	12.4	32.8	8.8	4.8			
475 F 2			0.1851	0.0273	1.3755	0.0061	0.0591	0.6918	0.2389	311				9.5	5.2			
440 C 3			4.8169	0.2432	0.0285	0.0285	0.5636	0.7445	0.2842	956	2663	12.4	33.0	29.0	15.7			
408 F 3			0.2190	0.0620	1.1524	0.0038	0.0465	0.8455	0.3242	311				10.7	5.8	8.0	4.4	0.51

TABLE 13
PARTICULATE X-RAY FLUORESCENT AND GRAVIMETRIC ANALYSIS
(Contd.)

No.	Date 78	Start Time	Ca	K	S	Zn	Fe	Pb	Br	Wt. (ug)	Time (min)	Flow Rate (l/min)	Flow (m^3)	Conc (ug/m^3)	Conc /Day (ug/m^3 /day)	$\overline{X}$	σ	F/C
TH																		
450 C 1	4/13	1220	2.2085	0.1474	0.7279	0.0172	0.2795	0.2442	0.0968	1038	7595	9.5	72.2	14.4	2.7			
476 F 1			0.1072	0.0166	0.5079	0.0086	0.0300	0.2296	0.0677	-				-	-			
449 C 2		1200	2.1039	0.1376	0.7511	0.0140	0.2433	0.2365	0.0859	920	7600	9.5	72.2	12.7	2.4			
477 F 2			0.0217	-	0.1217	0.0015	0.0075	0.0859	0.0227					-	-			
466 C 3		1231	1.8024	0.1340	0.3457	0.0111	0.2724	0.1290	0.0435	906	7591	9.5	72.1	12.6	2.4			
478 F 3			0.1429	0.0245	1.0690	0.0071	0.0451	0.2846	0.0699	508				7.0	1.3	2.2	0.6	0.54
M																		
505 C 1	4/17	1855	2.5758	0.5449	0.3955	-	0.6000	0.1849	0.0463	423	938	12.5	11.3	37.4	57.4			
426 F 2			1.0957	0.3627	1.1066	0.0060	0.4120	0.5596	0.2334	239				21.2	32.5			
501 C 2		1844	1.5017	0.4543	0.1784	0.0096	0.4091	0.0926	0.0469	242	961	12.4	11.9	20.3	30.4			
427 F 2			0.8739	0.2080	0.6927	-	0.3902	0.3338	0.1262	201				16.9	25.3			
514 C 3		1903	3.2547	0.8022	0.6676	0.0046	1.0040	0.5480	0.2213	663	941	12.4	11.7	56.7	86.8			
424 F 3			2.8678	0.6902	1.7418	0.0233	0.8257	1.2437	0.6307	355				30.3	46.4	46.5	23.0	0.60
T																		
498 C 1	4/18	1841	1.9295	0.3558	0.6002	0.0017	0.4240	0.2724	0.0948	512	1904	12.4	23.6	21.7	16.4			
417 F 1			0.7088	0.0730	0.6683	-	0.1616	0.6844	0.2618	238				10.1	7.6			
506 C 2		1830	2.0556	0.4779	0.4094	0.0053	0.4984	0.1492	0.0501	463	1903	12.4	23.6	10.1	7.6			
433 F 2			0.5493	0.0632	0.7535	0.0026	0.1104	0.4665	0.2263	179				7.6	5.8			
507 C 3		1848	4.6552	0.8182	1.2090	0.0197	1.1200	0.9620	0.4322	1208	1907	12.4	23.6	51.2	38.7			
409 F 3			0.5563	0.0849	0.8563	0.0053	0.1301	0.8391	0.3522	167				7.1	5.4	13.6	12.9	0.30
F																		
349 C 1	3/24	1125	-	-	0.6643	0.0001	-	0.1020	0.0076	-	1733	12.5	21.7	-	-			
316 F 1			0.1189	0.0102	0.0767	0.0076	0.0197	0.0036	-	-				-	-			
334 C 2		1106	0.1596	-	-	-	0.0238	-	-	88	1729	13.8	23.9	3.7	3.1			
386 F 2			0.0313	-	0.1926	-	-	-	-	-				-	-			
332 C 3		1145	0.1006	-	0.0895	-	0.0076	-	0.0125	299	1723	12.5	21.5	13.9	11.6			
306 F 3			0.7105	0.1291	-	0.0413	0.1847	0.3926	-	209				9.7	8.1	7.6	4.3	0.70

TABLE 13
PARTICULATE X-RAY FLUORESCENT AND GRAVIMETRIC ANALYSIS
(Contd.)

No.	Date 78	Start Time	Ca	K	S	Zn	Fe	Pb	Br	Wt. (ug)	Time (min)	Flow Rate (l/min)	Flow (m^3)	Conc (ug/m^3)	Conc /Day (ug/m^3 /day)	$\overline{X}$	σ	F/C
SA																		
370 C 1	3/25	1625	0.2744	0.0072	-	0.0022	0.0548	0.4652	0.0358	41	2915	6.5	18.9	2.2	1.1			
399 F 1			0.0474	-	0.2010	0.0026	0.0090	0.3584	0.0010	-				-	-			
358 C 2		1506	0.5706	0.0716	0.0017	0.0074	0.0764	0.5015	0.0322	-	2830	6.5	18.4	-	-			
309 F 2			0.4364	0.0289	0.3075	-	0.0887	0.5351	0.0669	43				2.3	1.2	1.2	0.1	-
M																		
442 C 1	3/27	1552	0.4396	0.0084	0.0379	0.0073	0.0689	0.5216	-	14	1285	12.4	15.9	0.9	1.0			
436 F 1			0.2313	0.0298	-	0.0068	0.0028	0.4946	0.0319	36				2.3	2.6			
460 C 2		1511	0.3912	-	-	0.0037	-	0.6189	0.0546	1	1318	12.4	16.3	0.1	0.1			
437 F 2			0.1666	0.0443	0.2276	0.0085	0.0094	0.4874	-	69				4.2	4.6			
357 C 3		1604	0.1849	-	-	-	0.0019	0.4117	-	-	1301	12.5	16.3	-	-			
400 F 3			0.1309	0.0314	0.0666	0.0020	0.0150	0.5449	0.0266	14				0.9	1.0	1.9	1.8	6.8
T																		
356 C 1	3/28	1609	9.6288	0.4217	1.6888	0.0248	0.9449	0.9553	0.3088	824	1267	11.8	15.0	54.9	62.4			
315 F 1			1.1026	0.0846	4.0035	0.0079	0.2019	2.2903	0.9444	445				29.7	33.8			
325 C 2		1554	7.7180	0.3139	1.6071	0.0398	0.7788	0.9760	0.3065	673	1269	12.4	15.7	42.3	48.0			
320 F 2			0.7252	0.0555	2.0178	0.0159	0.1779	1.6415	0.7581	412				26.2	33.7			
331 C 3		1631	7.0852	0.2884	1.0572	0.0285	0.8875	0.9197	0.3239	740	1254	12.3	15.4	48.1	55.2			
396 F 3			0.8695	0.1041	2.7820	0.0064	0.1181	1.6121	0.6582	364				23.6	27.1	43.4	14.0	0.57
W																		
342 C 1	3/29	1319	4.5989	0.1874	1.0653	0.0020	0.5268	0.6360	0.1092	535	1219	11.8	18.1	29.6	35.0			
317 F 1			0.7033	-	1.8679	-	0.0961	0.9548	0.3307	432				23.9	28.2			
341 C 2		1306	0.7981	0.3844	0.5730	-	0.1406	0.0293	0.0394	583	1218	12.5	19.2	30.4	35.9			
314 F 2			0.4804	-	1.8718	0.0005	0.0511	0.8140	0.2622	305				15.9	18.8			
350 C 3		1325	3.9034	0.1457	0.6237	0.0165	0.4043	0.3783	0.0533	538	1221	12.3	18.9	28.5	33.6			
397 F 3			0.5788	0.0364	1.8811	0.0258	0.0959	0.8025	0.2347	317				16.8	19.8	28.6	7.6	0.64

TABLE 13

PARTICULATE X-RAY FLUORESCENT AND GRAVIMETRIC ANALYSIS

(Contd.)

No.	Date 78	Start Time	Ca	K	S	Zn	Fe	Pb	Br	Wt. (ug)	Time (min)	Flow Rate (l/min)	Flow (m^3)	Conc (ug/m^3)	Conc /Day (ug/m^3 /day)	$\overline{X}$	σ	F/C
TH																		
336 C 1	3/30	1457	0.8433	0.0737	0.1415	0.0015	0.1176	0.0387	0.0055	875	1219	12.5	90.0	9.7	11.5			
398 F 1			0.1557	0.0208	0.9392	-	0.0243	0.0730	0.0173	401				4.5	5.3			
380 C 2		1442	1.8528	0.1055	0.3395	0.0036	0.1754	0.0504	0.0145	909	1218	11.8	85.2	10.7	12.7			
430 F 2			0.2089	0.0347	0.3190	0.0031	0.0310	0.1503	0.0366	610				7.2	8.5			
354 C 3		1511	1.6406	0.1359	0.2543	0.0059	0.2216	0.0966	0.0172	1334	1221	11.8	85.21	15.6	18.4			
423 F 3			0.2163	0.0236	1.4397	0.0028	0.0305	0.2190	0.0517	-				-	-	20.7	11.0	0.57
M																		
463 C 1	4/3	1518	1.1714	-	0.5589	-	0.1414	0.3050	0.0320	202	1177	12.5	14.7	13.7	16.8			
415 F 1			0.3790	0.1474	3.4279	0.0098	0.0482	0.7779	0.0655	297				20.2	24.7			
455 C 2		1503	1.3329	0.0727	0.2899	0.0012	0.1851	0.3758	0.0407	169	1177	12.5	14.7	11.5	14.1			
425 F 2			0.2736	0.0171	2.4247	0.0058	0.0605	0.6925	0.1027	243				16.5	8.0			
452 C 3		1535	1.7423	0.0082	0.4799	-	0.1535	0.3286	0.0498	228	1165	12.4	14.4	15.8	19.5			
432 F 3			0.3656	0.0139	3.3661	0.0189	0.0788	0.8478	0.2055	280				19.4	24.0	17.9	6.3	1.13

Overall 0.68