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J.A. Bullin, M. Hinz, S.C. Bower

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16. Abstract

Air quality measurements were made at two street intersections in Texas. Measurements of carbon monoxide and meteorological information were made at several heights both upwind and downwind of the intersections. In addition, detailed traffic information was also recorded. Tracer gas studies using SF_6 were performed at both sites and at the Texas A&M University Research Annex.

The one-hour average CO level was usually in the range of 2 to 6 ppm and the maximum instantaneous values were about 20 to 30 ppm. The SF_6 results were found to be scattered due primarily to the low number of passes with the release vehicle. Aerosol samples at the two sites showed a maximum value of about 140 $\mu g/m^3$ for a 6 to 8 hour average.

An air quality model called TEXIN for street intersections was developed in conjunction with FHWA Project 541. The model incorporates the MOBILE-2 and CALINE-3 computer programs with a set of established "short-cut" traffic and excess emission techniques.

17. Key Words
Computer controlled sampling, intersection, carbon monoxide, tracer gas, SF_6, particulate, Air Pollution Model, TEXIN, aerosol.

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Vehicle Emissions at Intersections

by

J.A. Bullin
M. Hinz
S.C. Bower

Chemical Engineering Department
and
Texas Transportation Institute
College Station, Texas 77843

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Implementation

Air quality data have been collected near two street intersections in Texas. The data have been arranged into 5-minute and 15-minute average records for use in model development and validation. A user-oriented computer model to predict the carbon monoxide near signalized intersections has also been developed. The model is written in FORTRAN and has been released along with a detailed user's guide.

Disclaimer

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Summary

Air quality measurements were made at two street intersections in Texas. The first site located in College Station had single-story residential and small businesses in the area while the other site, located in Houston, Texas, was in an area with multi-story buildings. Measurements of carbon monoxide and meteorological information were made at several heights both upwind and downwind of the intersections. In addition, detailed traffic information was also recorded. Tracer gas studies using SF_6 were performed at both sites and at the Texas A&M University Research Annex. All of the instruments except for the SF_6 samplers were interfaced to a Data General Nova 1200 minicomputer which allowed simultaneous readings at frequent intervals.

At the College Station site, the one-hour average CO level was usually 2 to 4 ppm and the instantaneous values rarely exceeded 12 to 14 ppm. At the Houston site, the one-hour average CO was usually in the range of 2 to 6 ppm and the maximum instantaneous values were about 20 to 30 ppm. The SF_6 results were found to be scattered due primarily to the low number of passes with the release vehicle. Aerosol samples at the two sites showed a maximum value of about 140 $\mu g/m^3$ for a 6 to 8 hour average.

An air quality model called TEXIN for street intersections was developed in conjunction with FHWA Project 541. The model incorporates the MOBILE-2 and CALINE-3 computer programs with a set of established "short-cut" traffic and excess emission techniques. The TEXIN Model was found to be slightly more accurate than the Intersection Midblock Model.

Chapter I

Introduction

Street intersections are being recognized as areas of potentially high pollution loads. When they are part of new roadway projects, the State Department of Highways and Public Transportation must include the intersections in the report assessing the project's impact on the environment. An evaluation of the air quality in the vicinity of each street intersection must be included in the report. Due to the diverse meteorological and topographical conditions near intersections, the estimation of air quality in the vicinity of intersections is considerably more complex than for straight roadways. The problem is further complicated by the irregular nature of the traffic flow which is one of decelerating, idling, and accelerating vehicles. These changes in velocity result in the generation of larger amounts of pollutants than from vehicles in uninterrupted flow. Furthermore, pedestrian traffic is most exposed to automobile pollutants around intersections. Therefore, prediction capabilities for the amount of pollutant produced by traffic in the intersection area and the dispersion pattern of the pollutant are needed.

A few attempts to develop mathematical models for carbon monoxide levels near street intersections have been made. Only two of these, the Intersection Midblock Model (IMM) and the Indirect Source Guidelines, have been applied to any significant degree. Several major problems exist in attempting to develop and validate intersection air quality models. The two most outstanding problems are the lack of a model to calculate vehicle emissions near intersections and the absence of complete air quality data near intersections. Very few experimental validation programs have been undertaken and, previously, only one has been successful.

Project 2250, "Vehicle Emissions at Intersections," for which this is the final report, addresses the following problems: 1) estimating the vehicle emissions near intersections and 2) modelling the air quality near intersections and acquiring experimental data for model validation. The development of the model for estimating vehicle emissions near intersections was undertaken by the Center for Highway Research at the University of Texas and will be in Report No. 3-8-79-250-1. The development of a simplified air quality model and the experimental work were performed by the Chemical Engineering Department and Texas Transportation Institute at Texas A&M University and are presented in this report. The measurements required for model validation are vehicle count, speed, delay time and type mix (car or truck), vehicle movements in the intersections (including right and left turns), traffic signalization, wind speed and direction, ambient temperature and carbon monoxide concentrations at several locations near the intersections. In this project, experimental data necessary for model validation were collected at the intersection of Texas Ave. and Jersey St. in College Station, Texas and at the intersection of Woodway Dr. and South Post Oak Ln. in Houston, Texas. Tracer gas experiments using sulfur hexaflouride were also performed at these two sites as well as at the Texas A&M University Research Annex.

Chapter II

Site Descriptions

Introduction

Data collection was carried out at three sites in Texas: the first in College Station, the second at the Texas A&M University Research Annex, and the third in Houston. Each site was chosen for certain site geometry and experimental procedure considerations as well as equipment constraints. Right-of-way space of 50 ft. X 20 ft. was required for the trailer housing the data acquisition system and 10 ft. X 10 ft. for each tower. Both the College Station and Houston sites were intersections oriented near north, south, east, and west with the major traffic flow running north-south in College Station and east-west in Houston. The Research Annex site was previously an airport runway oriented northwest-southeast. For all cases the prevailing wind was from the south thus maximizing crosswind conditions for data collection for east-west traffic flow. Data collection at the College Station site was purposely carried out mostly when the wind was south-westerly due to the predominate north-south traffic flow.

Site descriptions and instrument layouts for each site are as follows:

College Station Site

This site was located at the corner of Texas Avenue, Jersey, and Kyle Streets. Figure 1 shows the site geometry, and Table 1 lists the instrument placements. The terrain surrounding the intersection is generally flat. The northwest quadrant is a golf course of grass-covered ground and individual, scattered trees. The northeast quadrant consists of single family residences on wooded lots. An auto service station is located at the intersection in the southwest quadrant, and a small community shopping center consisting of one-story buildings runs along the western side of Texas Avenue 230 feet west in that quadrant. Single family residences are located at the intersection in the southeast quadrant with small one-story businesses east of Texas Avenue about 200 feet south from the intersection. Texas Avenue and Jersey Street are well-travelled, while Kyle Street has a relatively low traffic flow.

Towers 1, 2, and 3 were located in the southeast quadrant set back 35 ft. from Texas Avenue, 35, 125, and 355 ft. from Kyle Street respectively. Tower 4 was in the southwest quadrant 65 ft. from Texas Avenue and 220 ft. south of Jersey Street. Tower 5 was 120 ft. north and west of Texas and Jersey in the golf course. Also, two portable meteorological ground stations, A and B, were near the trailer site (northeast quadrant,

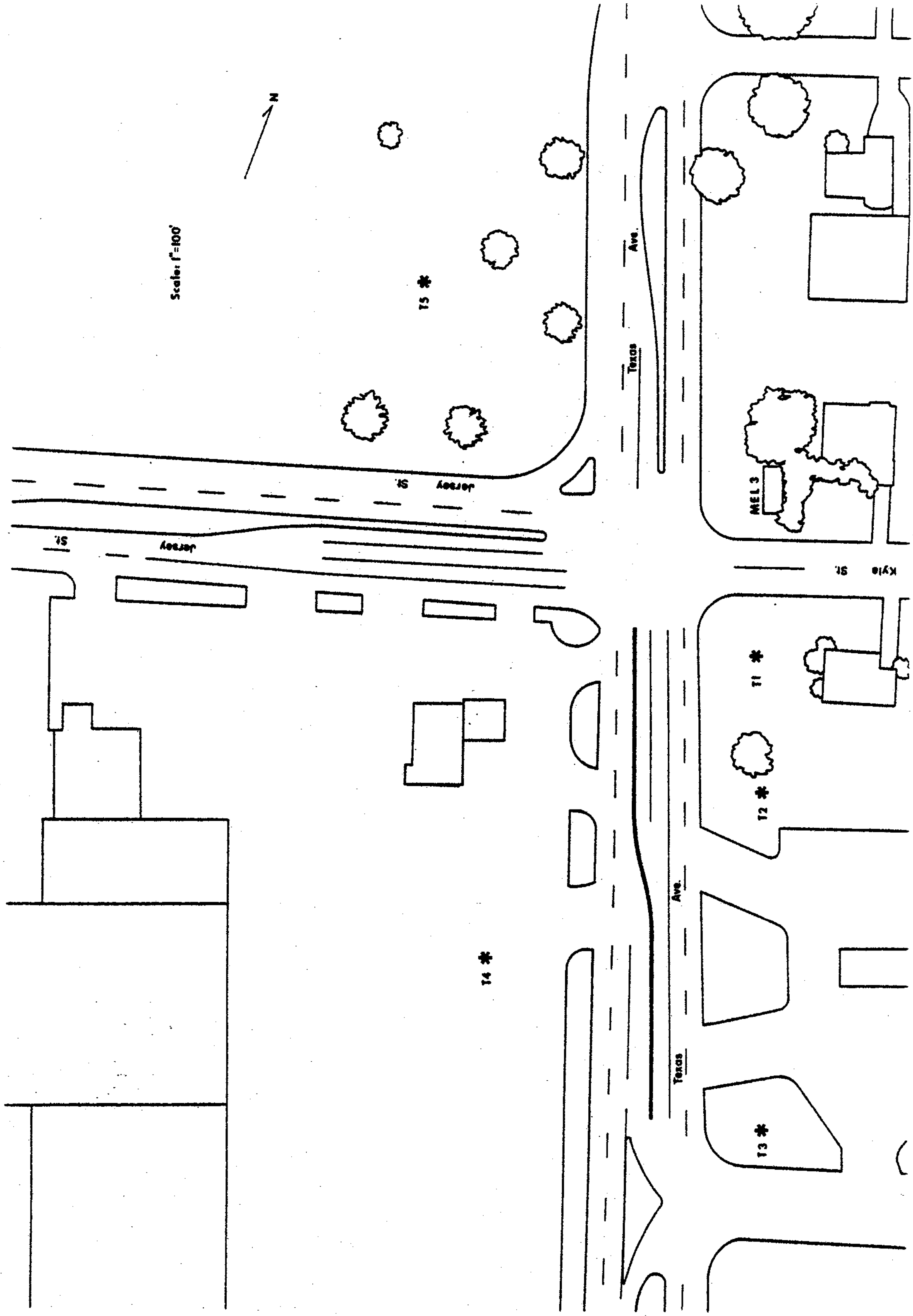


Figure 1

Site Geometry

College Station Site

Table 1

Instrument Identification and Location for College Station Site

NAME	CHANNEL NO.	DESCRIPTION	SCALE	SAMPLE INTERVAL (SEC)
VA3FA	11	VERT. ANEMO. 5FT at Trailer	0.1mph	2
VA3FB	12	" " 5FT at T1	"	"
VA15F	13	" " 15FT at T1	"	"
VA35F	14	" " 35FT at T1	"	"
HA3FA	15	HOR. ANEMO. 5FT at Trailer	1.0mph	8
HA3FB	16	" " 5FT at T1	"	"
HA15F	17	" " 15FT at T1	"	"
HA35F	18	" " 35FT at T1	"	"
WV5FA	19	WIND VANE 5FT at Trailer	Degrees	4
WV5FB	20	" " 5FT at T1	"	"
WV15F	21	" " 15FT at T1	"	"
WV35F	22	" " 35FT at T1	"	"
TM3FA	23	THERMISTOR 5FT at Trailer	°F	32
TM3FB	24	" 5FT at T1	"	"
TM15F	25	" 15FT at T1	"	"
TM35F	26	" 35FT at T1	"	"
RH3FA	27	REL. HUMIDITY 5FT at Trailer	% Rel Hum	64
RH35F	28	" " 35FT at T1	"	"
PYRAN	29	PYRANOMETER 15FT at Trailer	watts/M^2	32
CO1H	30	CO MONITOR 35FT at T1	PPM	8
CO1M	31	" 15FT at T1	"	"
CO1L	32	" 5FT at T1	"	"
CO2H	33	" 35FT at T2	"	"
CO2M	34	" 15FT at T2	"	"
CO2L	35	" 5FT at T2	"	"
CO3H	36	" 35FT at T3	"	"
CO3M	37	" 15FT at T3	"	"
CO3L	38	" 5FT at T4	"	"
CO4H	39	" 35FT at T4	"	"
CO4M	40	" 15FT at T4	"	"
CO4L	41	" 5FT at T4	"	"
TMP5D	46	THERMISTOR 5FT at T5	°F	4
TMP50D	47	THERMISTOR 50FT at T5	"	"
	48	NO INSTRUMENT	-	-
	49	NO INSTRUMENT	-	-
UUVW50	50	U-COMP. ANEMO. 50FT at T5	1.0mph	4
VUWW50	51	V " " 50FT at T5	1.0mph	4
WUVW50	52	W " " 50FT at T5	0.1mph	2
UUVW5D	53	U " " 5FT at T5	1.0mph	4

Table 1 (continued)

Instrument Identification and Location for College Station Site

NAME	CHANNEL NO.	DESCRIPTION			SCALE	SAMPLE INTERVAL (SEC)
VUVW5D	54	V-COMP.	ANEMO.	5FT at T5	1.0mph	4
WUVW5D	55	W	"	5FT at T5	0.1mph	2
UUVW35	56	U	"	35FT at T4	1.0mph	4
VUVW35	57	V	"	35FT at T4	1.0mph	4
WUVW35	58	W	"	35FT at T4	0.1mph	2
UUVW15	59	U	"	15FT at T4	1.0mph	4
VUVW15	60	V	"	15FT at T4	1.0mph	4
WUVW15	61	W	"	15FT at T4	0.1mph	2
	62		NO INSTRUMENT		-	-
	63		NO INSTRUMENT		-	-
	64		NO INSTRUMENT		-	-

COORDINATES FOR UVW ANEMOMETERS ARE:

U - Across Roadway
V - Parallel to Roadway
W - Vertical
The roadway is Texas Avenue.

30 ft. east of Texas and 100 ft. north of Kyle), and at the base of Tower 1. Meteorological stations A and B were portable so they could be secured when project personnel were not present. The project trailer was 30 ft. north of Kyle and 40 ft. east of Texas.

Towers 1, 2, and 4 were also used to support air samplers for SF_6 tracer and aerosol studies. The samplers were suspended at 5, 15, and 35 ft. opposite corresponding meteorological stations.

Traffic parameters were measured by 13 vehicle loop detectors as shown in Figure 2. The vehicle movements (also shown in Figure 2) were monitored from the traffic light controller box next to the project trailer. The loop data were also verified by time-lapse motion pictures taken from the 12th floor of the Oceanography and Meteorology Building on the TAMU campus, west of the golf course, three-fourths of a mile west of the intersection.

Houston Site

The Houston site was located at the corner of Woodway Boulevard and South Post Oak Lane, four blocks west of the West Loop (I-610). The site plan is shown in Figure 3 and an equipment description in Table 2.

In the northwest quadrant, a service station is located at the corner and the remainder of the quadrant is composed of two-story apartment buildings. The northeast quadrant is occupied by a seven-story condo-

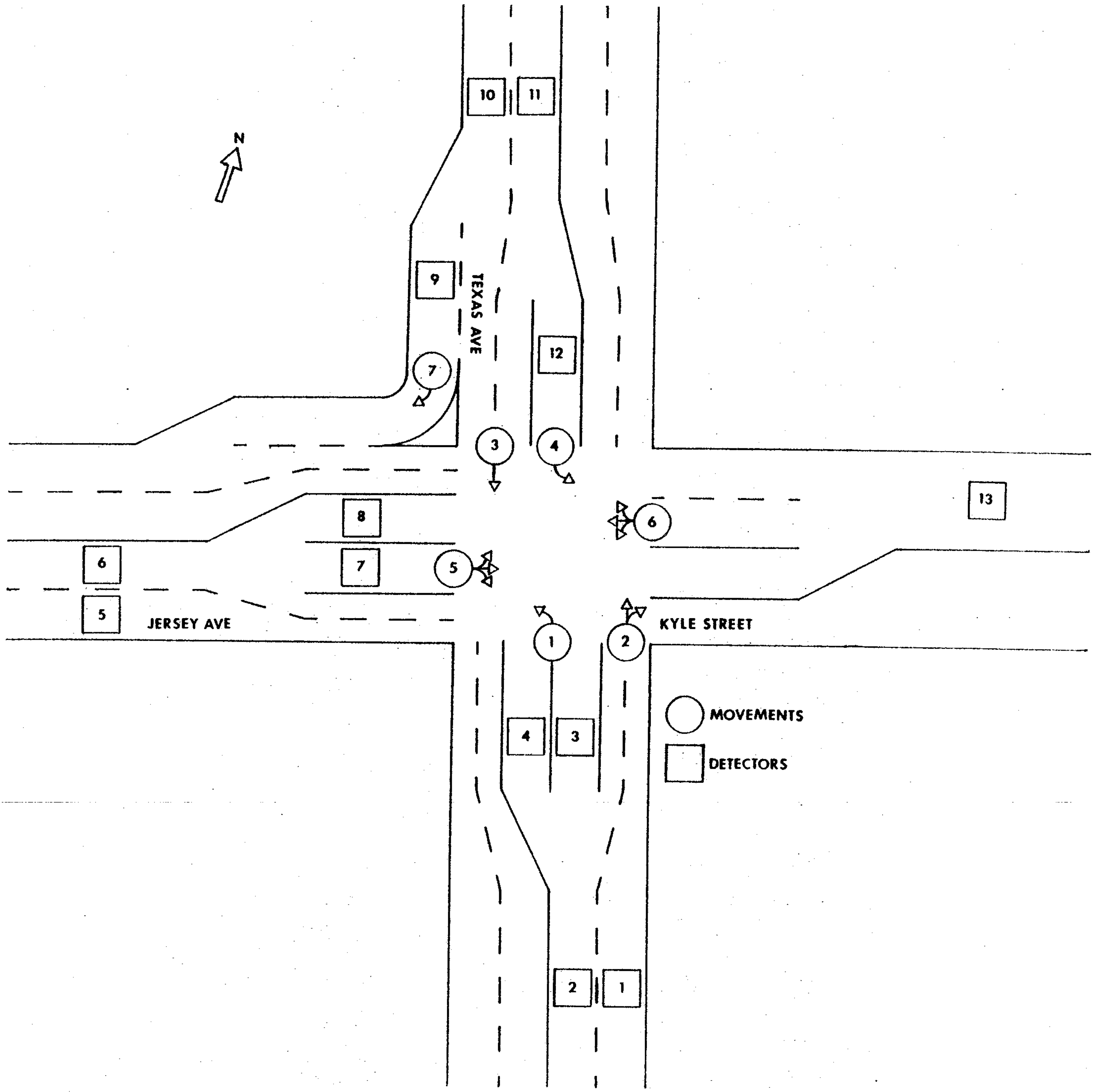


Figure 2
Traffic Parameters
College Station Site

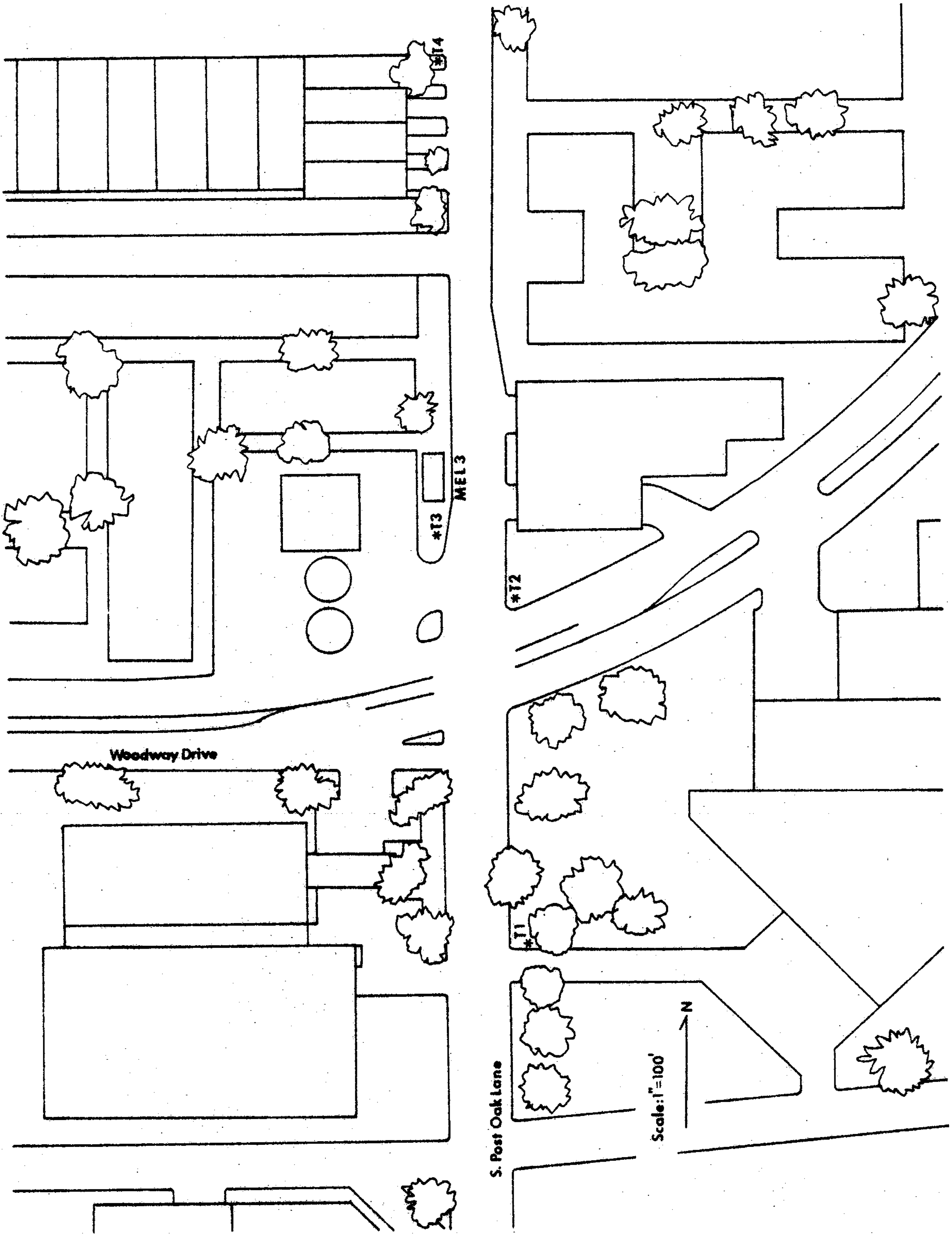


Figure 3
Site Geometry
Houston Site

Table 2

Instrument Identification and Location for Houston Site

NAME	CHANNEL NO.	DESCRIPTION	SCALE	SAMPLE INTERVAL (SEC)
AW2/05	11	VERT. ANEMO. 5FT at T2	0.1mph	1
AW3/05	12	" " 5FT at T3	"	"
AW3/20	13	" " 20FT at T3	"	"
AW3/35	14	" " 35FT at T3	"	"
HA2/05	15	HOR. ANEMO. 5FT at T2	1.0mph	8
HA3/05	16	" " 5FT at T3	"	"
HA3/20	17	" " 20FT at T3	"	"
HA3/35	18	" " 35FT at T3	"	"
WV2/05	19	WIND VANE 5FT at T2	Degrees	4
WV3/05	20	" " 5FT at T3	"	"
WV3/20	21	" " 20FT at T3	"	"
WV3/35	22	" " 35FT at T3	"	"
TMF/03	23	THERMISTOR 3FT at Trailer	°F	32
TM3/05	24	" 5FT at T3	"	"
TM3/20	25	" 20FT at T3	"	"
TM3/35	26	" 35FT at T3	"	"
RHF/04	27	REL. HUMIDITY 4FT at Trailer	%Rel Hum	4
RHP/08	28	" " 8FT at Trailer	"	64
PYRAN	29	PYRANOMETER 15FT at Trailer	watts/M^2	32
CO2/35	30	CO MONITOR 35FT at T2	PPM	8
CO2/20	31	" 20FT at T2	"	"
CO2/05	32	" 5FT at T2	"	"
CO3/35	33	" 35FT at T3	"	"
CO3/20	34	" 20FT at T3	"	"
CO3/05	35	" 5FT at T3	"	"
CO4/35	36	" 35FT at T4	"	"
CO4/05	37	" 5FT at T4	"	"
CO1/35	38	" 35FT at T1	"	"
CO1/05	39	" 5FT at T1	"	"
	40	NO INSTRUMENT	-	"
	41	NO INSTRUMENT	-	"
	42	NO INSTRUMENT	-	"
	43	NO INSTRUMENT	-	"
	44	NO INSTRUMENT	-	"
	45	NO INSTRUMENT	-	"
TP1/35	46	THERMISTOR 35FT at T1	°F	4
TP1/10	47	" 10FT at T1	"	4
TM4/15	48	" 15FT at T4	"	32
RH4/15	49	REL. HUMIDITY 15FT at T4	"	64
UA1/35	50	U-COMP. ANEMO. 35FT at T1	1.0mph	4
VA1/35	51	V " " 35FT at T1	1.0mph	4
WA1/35	52	W " " 35FT at T1	0.1mph	1
UA1/10	53	U " " 10FT at T1	1.0mph	4

Table 2 (continued)

Instrument Identification and Location for Houston Site

NAME	CHANNEL NO.	DESCRIPTION	SCALE	SAMPLE INTERVAL (SEC)
VA1/10	54	V-COMP. ANEMO. 10FT at T1	1.0mph	4
A1/10	55	W " " 10FT at T1	0.1mph	1
UA2/35	56	U " " 35FT at T2	1.0mph	4
VA2/35	57	V " " 35FT at T2	1.0mph	4
WA2/35	58	W " " 35FT at T2	0.1mph	1
UA2/20	59	U " " 20FT at T2	1.0mph	4
VA2/20	60	V " " 20FT at T2	1.0mph	4
WA2/20	61	W " " 20FT at T2	0.1mph	1
HA4/15	62	HOR. ANEMO 15FT at T4	1.0mph	8
WV4/15	63	WIND VANE 15FT at T4	Degrees	4
BRT/06	64	BAROMETER 6FT in Trailer	in.Hg	8

minium building. The southeast quadrant contains three tall office buildings (one 18-story, and two 24-story buildings). In the southwest quadrant, there is a 14-story condominium building.

Four towers were used at the site with T1 being the southernmost and T4 being the northernmost. T1 was in the southeast quadrant 120 feet south of Woodway and 20 feet back from South Post Oak. T2 was at the northeast corner 10 feet from Woodway and South Post Oak. T3 and T4 were both in the northwest quadrant 10 feet west of South Post Oak with T3 95 feet north of Woodway and T4 345 feet north. The project trailer was just north of T3.

Samplers intakes were located at 5, 20, and 35 feet on T2 and T3 and at 10 feet and 35 feet on T1. The locations varied from College Station due to equipment constraints.

The traffic parameters measured are shown in Figure 4. Only 8 loop detectors were needed, and 3 phases monitored from the controller box next to T2. Time-lapse pictures were also taken from the seventh level of the IBM Building's parking garage directly east 400 feet on Woodway.

TAMU Research Annex Site

This site was located on the northwest-southeast, 300 feet wide, runway at the deactivated Bryan Air Force Base which is now the Research Annex for Texas

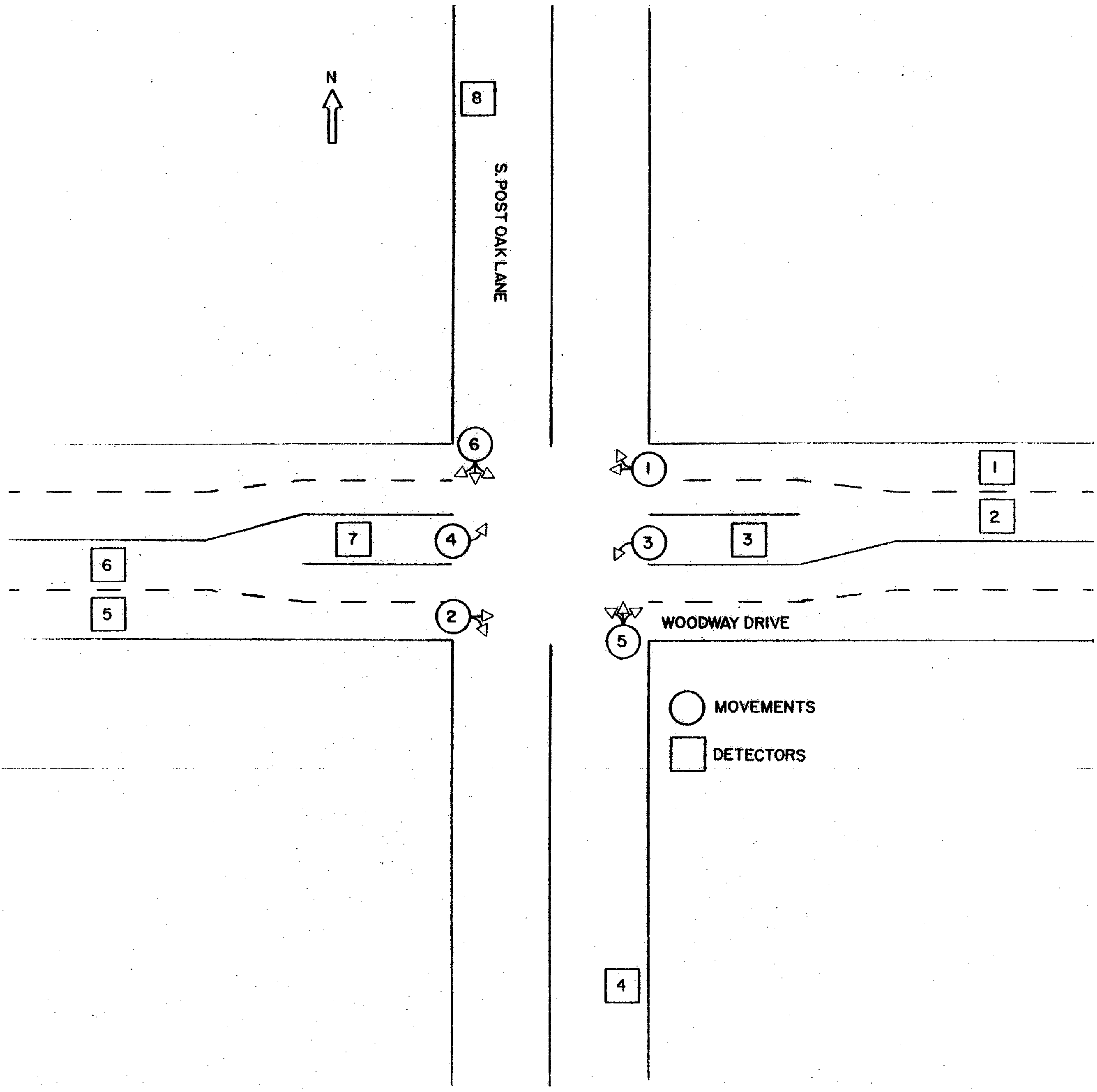


Figure 4

Traffic Parameters

Houston Site

A&M University. Table 3 shows the instrumentation used, and Figure 5 shows the site plan. The surrounding terrain is unbroken fields with a very sparse scattering of low trees and cows. The nearest building is northeast about 1 mile away.

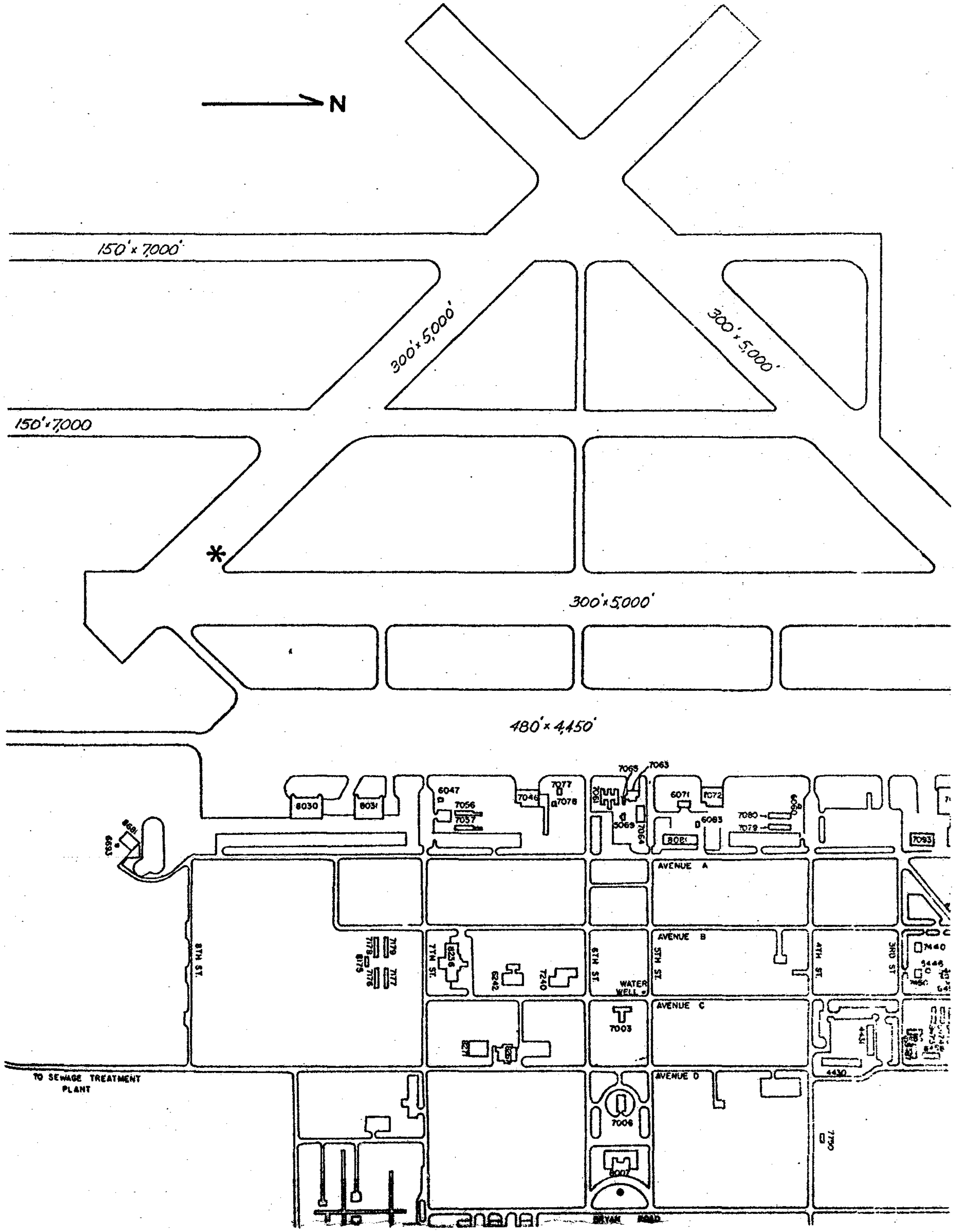
One tower was set up in the middle of the runway about 100 feet from the trailer which was at the edge. Meteorological stations were at 5, 15, 35, and 50 feet, and air samplers for SF_6 were located at all four heights. Only the meteorological conditions were recorded by computer due to the nature of the experiments. Traffic data were not recorded, since there was no traffic besides the research vehicle which was hand tallied.

Table 3

Instrument Identification and Location for Research Annex Site

NAME	CHANNEL NO.	DESCRIPTION	SCALE	SAMPLE INTERVAL (SEC)
VA15F	13	VERT. ANEMO. 15FT at T1	0.1mph	1
HA15F	17	HOR. ANEMO. 15FT at T1	1.0mph	8
WV15F	21	WIND VANE 15FT at T1	Degrees	4
TM3FA	23	THERMISTOR 5FT at T1	°F	32
RH3FA	27	REL. HUMIDITY 5FT at T1	% Rel Hum	64
RH35F	28	" " 5FT at T1	"	"
PYRAN	29	PYRANOMETER 5FT at T1	watts/M^2	32
TMP5D	46	THERMISTOR 5FT at T1	°F	4
TMP50D	47	THERMISTOR 50FT at T1	"	"
UUVW50	50	U-COMP. ANEMO. 50FT at T1	1.0mph	4
VUWW50	51	V " " 50FT at T1	1.0mph	4
WUVW50	52	W " " 50FT at T1	0.1mph	1
UUVW5D	53	U " " 5FT at T1	1.0mph	4
VUVW5D	54	V " " 5FT at T1	1.0mph	4
WUVW5D	55	W " " 5FT at T1	0.1mph	1
UUVW35	56	U " " 35FT at T1	1.0mph	4
VUVW35	57	V " " 35FT at T1	1.0mph	4
WUVW35	58	W " " 35FT at T1	0.1mph	1
UUVW15	59	U " " 15FT at T1	1.0mph	4
VUVW15	60	V " " 15FT at T1	1.0mph	4
WUVW15	61	W " " 15FT at T1	0.1mph	1

COORDINATES FOR UVW ANEMOMETERS ARE:
U - Across Runway
V - Parallel to Runway
W - Vertical



***RESEARCH SITE**

Figure 5

Site Plan

Research Annex Site

Chapter III

Experimental Methods

Introduction

An extensive program of data collection was performed under Project 250, "Vehicle Emissions at Intersections." The data included concentrations of carbon monoxide, sulfur hexafluoride tracer gas and aerosols near the intersection, along with extensive meteorological and vehicular data. The systems used to collect the samples and the data will be discussed in this chapter. The data handling techniques will be discussed in the next chapter.

Data Collection System

Data recording from the meteorological instruments, traffic loops, and the carbon monoxide, nitrogen oxides, and hydrocarbon sensors was performed by a Data General Nova 1200 minicomputer. Readings were taken via a Radian analog to digital converter and a 64 channel multiplexor. Data were stored on nine-track magnetic tapes. With this method, readings from all instruments were taken essentially simultaneously rather than sequentially. The computer read each instrument at a rate commensurate with that instrument's response time and the rate of data fluctuation. All sampling rates were adjusted to a power of two so that cross correlations and power spectra could be easily performed between any and all instruments. Table 1 gives each instrument's sampling rate, as well as the six-letter code used by the computer to identify it. The required software program was written by File D-19 of the State Department of Highways and Public Transportation in Austin, Texas. This software was modified in minor ways by project personnel to satisfy the particular need of each site.

Traffic Measurement

In order to perform any roadway air pollution model validation work it is necessary to know several parameters about the vehicles on the roadway. These include the vehicle count, the average vehicle speed, the heavy duty vehicle mix, and the vehicle age mix.

The traffic measurements were made using loop detectors cut into the pavement. For the approach lanes, the detectors were installed about 500 to 600 feet from the intersection. Additional detectors were installed in all left or right turn lanes as well. The loop detectors were equipped with amplifiers and were monitored by the computer. The vehicle count, vehicle dwell time over the loop detector and time of day were recorded on the nine-track magnetic tape along with the other data. Using an average vehicle length, a good estimate of the vehicle speeds can be obtained.

The status of the signal light for each leg of the intersection was also monitored by the computer and recorded on magnetic tape.

Meteorological Measurements

Windspeed and Direction:

Depending on the monitoring station location either six-cup anemometers (Model 2011A) and wind vanes (Model 2010A) manufactured by Texas Electronics or Weather Measure Model 173 UVW propeller anemometers were used to measure wind speeds and directions. The monitoring station where each of these instrument types were used is given in Tables 1 and 2. The starting threshold for the cup anemometers was 0.75 mph with an accuracy of ±1% of full scale. The wind vanes had a starting threshold of 1.0 mph and an accuracy of ±0.5%. The cup anemometers used the light chopper technique while the wind direction vanes used potentiometers in a one volt circuit. The UVW anemometers were of the DC generator type and had a starting threshold of 0.5 mph and an accuracy of ±1%.

Gill propeller anemometers (Model No. 27100) were used to determine the vertical wind speeds. This instrument had a starting threshold of less than 0.5 mph and an accuracy of ±1.0% full scale.

In order to obtain a good description of the wind profile, stations containing the horizontal windspeed and direction and vertical windspeed sensors were located at heights of 5, 15, and 35 ft. This equipment was largely trouble free.

Atmospheric Temperature and Humidity:

Ambient temperature measurements were made with Texas Electronics Model No. 2015 thermistors at several heights. These units had an accuracy of ±0.5% of full scale and were located at heights of 5, 15, 35 ft.

To obtain information on atmospheric stability, a pair of Weather Measure Model IS6 thermistors with motor aspirated radiation shields were used. These units had an accuracy of $\pm 0.25^{\circ}$F and were located at heights of 5 and 50 ft.

The relative humidity was measured at heights of 5 and 35 ft with Texas Electronics Model No. 2013 relative humidity systems. The psychrometers determined the relative humidity by utilizing the fact that a fiber, such as a hair, changes length in proportion to the amount of water vapor present in the air. An inductance change was induced in a coil by this change in length. The accuracy of this instrument was better than ±3% relative humidity.

Solar Radiation

The incoming solar radiation was measured with an Eppley Model No. 8-48 pyranometer. Due to the low voltage output of this instrument, an amplifier was constructed that fed an amplified signal to the analog to digital interface. This instrument was very trouble free.

Carbon Monoxide Sensors

Carbon monoxide concentrations were measured with Energetics Science Model 2600 Ecolyzers. These analyzers used acid electrochemical sensors to determine the carbon monoxide concentration in parts per million, with an accuracy of ±0.5 ppm. They were easily operated, but frequent instrument calibrations were required for span and zero drift. The accuracy of these instruments was also affected by the pH value of the acid in the cell. As the cell aged, the acidity of the cell decreased and the accuracy of the analyzer also decreased. With careful attention and frequent calibration these instruments had an error of no greater than 1 ppm of carbon monoxide.

To sample air from elevated stations, air was drawn through galvanized metal conduit tubing down to the Ecolyzers by small vacuum pumps located downstream of the sample withdrawal point for the Ecolyzers. In all cases, this tubing was allowed to weather in the sun for several days before actual use.

Tracer Gas Studies

Tracer gas studies were performed at all three sites in the study. Sulfur hexafluoride (SF_6) was emitted at a precisely measured rate into the exhaust pipe of a pick-up truck. During each experiment the truck would pass back and forth through the intersection at a constant speed for any traverse. The driver timed the turnarounds such that the vehicle always approached the intersection under a green light. The time and speed of each traverse were recorded as the experiment was in progress. The speed through the intersection was in the range of about 20 to 35 miles per hour. The turnaround points were located well over 1000 ft from the intersection.

Air samples for SF_6 analysis were collected using Developmental Sciences syringe samplers. These samplers were obtained on loan from General Motors Corporation and had been modified by GM. They were further modified at Texas A&M such that all three samplers operating at a tower were controlled by a single timer. The sampler would pull a sample into a syringe over a 15-minute period and then sequence to the next syringe.

The samples were analyzed using a Valco Instruments Co. gas chromatograph with a Model 140B electron capture detector. The chromatograph was calibrated with 2.0 ppb SF_6 standardized gas from Matheson. The calibration gas was also checked by Radian Corp. in

Austin, Texas by using a dilution method and comparing to another standard SF_6 gas prepared by Scott-Marrin. A copy of their report on the analysis is included in Appendix B.

The SF_6 emission rate, usually 0.30 liters per minute, was measured with a soap bubble flow meter and was accurate to within ±5%. The emission rate was also checked on one occasion by weighing the cylinder before and after the SF_6 was emitted. The amount emitted based on the soap bubble flow meter was about 4% below the amount based on weight.

Aerosol Sampling

University of California at Davis stacked filter units (SFU) were used for collecting samples of aerosols. This equipment is described in papers by Cahill, et al. (1977) and John, et al. (1978). Each unit consists of a PVC cap over a 60 mesh stainless steel screen and a PVC manifold. The screen provides for 50% capture of particles with an aerodynamic diameter of 20 μm. The length of the manifold is designed to provide uniform particle deposition on the upper filter.

The manifold was inserted into a commercially available filter holder made by Nuclepore Corporation. The holder contained two Nuclepore filters 47 mm in diameter. The top filter had pores 8.0 μm in diameter, while the lower filter had pores 0.3 μm in diameter.

The top filter collected the coarse size fraction corresponding to that caught by the upper respiratory tract, while the second filter collected the fine fraction corresponding to that caught by the lower respiratory tract (Cahill, et al., 1977).

The flow rate was controlled by a needle valve attached to the pump inlet. In addition to controlling the flow rate, the needle valve also acted as a high impedance to flow, thus ballasting the pump against flow rate changes due to filter loading. The flow rate of 21.3 l/min was calibrated using a spirometer calibrated orifice and a magnehelic gage. All pumps were operated at ground level and the SFU's were connected to the pumps via the necessary length of reinforced nylon tubing.

The aerosol samples were analyzed by the Air Quality Group located at the University of California at Davis (UCD/AQG) using the isochronous cyclotron located at Crocker Nuclear Laboratory. The particle induced x-ray emission (PIXE) system used an alpha particle beam to detect all elements heavier than neon with detection limits in the one ppm range. The alpha particle beam caused the emission of a characteristic x-ray line spectra. A Si(Li) cell was used as the solid state detector. Because of simpler and more accurate data analysis techniques useable with PIXE systems, the UCD/AQG analyses were not influenced by the total loading of the filters or the amount of the major constituent present. The alpha particle beam was 2.5 cm long by 0.75 cm wide. For a more complete description of the UCD/AQG PIXE system and the way it was operated as of January 1, 1975, see Cahill (1975).

All relevant sampling information is reported in Appendix A along with the analytical results. The information includes the site, date, sample location, sample start and end time, filter pore size and volumetric flow rate of air through the sampler.

Chapter IV

Data Handling

Introduction

A Data General NOVA 1200 minicomputer was used to collect the data and record it onto magnetic tape. It was therefore possible to collect data from each instrument type essentially simultaneously rather than sequentially and, because of this, show a dynamic response to traffic and meteorological conditions. However, this also means that data collection occurred at a prodigious rate; over 25,000 numbers per hour were recorded onto tape. This chapter is concerned with the methods used to collect the data and to manipulate it into a useful format.

Data Collection

The NOVA 1200 minicomputer used to collect data for this project was equipped with a nine-track tape drive, a teletype terminal, a Radian analog to digital converter and a 64 channel multiplexor. The computer read each instrument type at a rate commensurate with the response time of those instruments and the rate of data fluctuation. All sampling rates were adjusted to a power of two so that cross correlations and power spectra could be easily performed between any and all instruments. The sampling rate used with each instrument is given in Tables 1 and 2, along with the six letter code used by the computer to identify it.

After each instrument was read, the value was checked against maximum and minimum expected values for that instrument type. These values could be set by the operator. If a value fell outside the expected range, the operator was so informed on the teletype and a special record was entered on the tape.

The data were stored on nine-track magnetic tape in sixteen-bit word, variable-length record blocks. This means that each number (e.g., word) handled by the computer consisted of 16 binary bits and that the numbers were collected into groups, called records, before being stored on tape. These records were not all of the same length and were grouped together and placed on the tape in a block format. In order to do so, the computer stored data in a temporary file, called a buffer, before placing it on the tape. When the buffer was full, the contents of the buffer were placed on the tape in block form in one operation. A list of the records used to store data for each instrument type can be found in Table 4.

The length of type 0, 5, 11, ..., 17 records was determined by the amount of computer memory available after the program was set up. Type 2 and 3 records were special Ecolyzer calibration records. The Ecolyzers were calibrated at about two to four hour inter-

TABLE 4

Raw Data Records

Type	Record Format
0 - Initial Message	Length, Type, Time High, Time Low, ASCII Code (Message).
1 - Channel Definition	Length, Type, Time High, Time Low, Channel, Sample Interval, Path Type, Min. Expected, Max. Expected, Calibration Factor, Zero Adjustment Factor, ASCII Code (Channel Name).
2 - Begin Calibration	Length, Type, Time High, Time Low, Channel.
3 - End Calibration	Length, Type, Time High, Time Low, Channel.
4 - Out of Range	Length, Type, Time High, Time Low, Channel, Bad Time High, Bad Time Low, Bad Value.
5 - Operator Log	Length, Type, Time High, Time Low, ASCII Code (Message).
6 - Channel Enable	Length, Type, Time High, Time Low, Channel.
7 - Channel Disable	Length, Type, Time High, Time Low, Channel.
8 - (Unused)	
9 - Vehicle Residence Time (Over Loop)	Length, Type, Time High, Time Low, Loop No., Exit Time Low.
10 - Vehicle Counts	Length, Type, Time High, Time Low, (The next four repeat for each loop.), Non-Red Volume, Red Volume, Non-Red Occupancy, Red Occupancy, Red Delay, ...
11 - Vertical Anemometers	Length, Type, Time High, Time Low, Channel, Interval, Lost Data Count, Min. Expected, Max. Expected, Sample Value, ..., Sample Value.
12 - Horizontal Anemometers	
13 - Wind Vanes	
14 - Thermometers	
15 - Psychrometers	
16 - Pyranometers	
17 - CO Monitors	

vals since their zero and span readings tended to drift. The procedure followed was to issue a Begin Calibrate (Type 2) record, ground the A/D input for the channel, rezero the instrument, attach a bag of CO calibration gas, reattach the instrument to the A/D, wait 30 seconds, reground the A/D input, wait one minute, reattach the instrument to the A/D and issue an End Calibrate (Type 3) record for the channel.

The span drift was smooth and gradual as far as is known, so a linear correction factor could later be applied to the Ecolyzer data. These corrections were fairly small (<10%). On the other hand, however, it was found that the zero drift was occasional, sudden, and drastic and no correction factor could be applied to the data. Usually zero drift was small enough to be completely masked by minute-to-minute fluctuations in the CO level, although at very low CO concentrations, (e.g., 1 ppm or less) the zero drift could approach 30% of the instrument reading.

In addition to writing the raw data to tape, the computer also calculated 5-, 15-, and 60-minute averages for all channels. These averages were printed by the teletype for operator inspection. If any of the average values looked unusual, the operator could take corrective action and/or enter a Type 5 record onto tape detailing the problem.

Data Handling

The AMDAHL 470 V6 computer at Texas A&M University was used for data manipulation. The first step involved data translation; although the data were on nine-track tape, the data form used by the NOVA is incompatible with IBM (and AMDAHL) conventions. Because of this difference, the standard software used by the AMDAHL to unpack data blocks and break records down to get to individual numbers could not be used. The data blocks and records first had to be broken down by programmer written software and then repacked using IBM conventions. The program to do this has been labeled Set A and a copy can be found in Appendix D.

The second stage of the data reformatting operation was performed in two steps. The NOVA uses ASCII (American Standard Coding For Information Interchange) to represent all data, but the AMDAHL uses EBCDIC (Extended Binary Coded Decimal Interchange Coding) for the same purposes. Therefore, it was necessary to convert data from ASCII to EBCDIC coding with a user written program before any further data manipulation could be performed. This program has been labelled Set B and can be found in Appendix E. The Set B program also converted the integer formats of the raw data (i.e., 100 A/D counts) into more easily understood floating point numbers (i.e., 2.5 ppm). The restructured data were then stored on a temporary disk file and sorted using the standard IBM Sort/Merge Utility program. This packaged program sorted the data by date, channel (instrument), record type and time of day, in that order. The result from this last operation was then stored on standard nine-track tape.

Final Format of Data

Once in final order the data were restructured into 80 character card images and moved to disk files. From there the data were dumped onto paper for visual inspection by project personnel. Both steps were accomplished by a Set D program (a copy is in Appendix E). Data known to be bad for any reason (i.e., the vertical windspeed is 0 mph because the vertical anemometers were tangled in cable) were marked for deletion, but questionable data were not marked for deletion. In addition, all calibration readings were converted into the form of Type 7 cards. The Type 7 card contains the zero adjustment readings and calibration readings as shown in Table 5.

Data deletion and the addition of the calibration readings were accomplished while the data were stored on disk files using the WYLBUR text editing system available at Texas A&M University.

After data manipulation was completed, the data were again placed on nine-track tapes. As the data presently exist on tape, there are seven card formats used to store the data. The format types are:

Table 5

Data Card Format Types

First Twelve Columns (Standard for all data cards)

Columns	Format	Content
1-2	I2	hours value in a 24 hr day
3-4	I2	minutes of the time parameter
5-6	I2	seconds
7	1X	blank
8-9	I2	format identifier
10-12	I3	channel identifier

Format Type -1 Cards

They are compatible with any of the formats used for reading any other card. A Type -1 card is distinguished by a negative hours reading, 99 minutes, 99 seconds, and a channel of -1. (-999999 -1) Two terminators in succession signal the end of the data set.

Format Type 1 Cards

Columns	Format	Content
13-15	I3	data type
16-20	I5	sampling rate
26-30	I5	minimum expected integer value of the channel
31-35	I5	maximum expected integer value of the channel

36-40	I5	integer value of the unity reading
41-45	I5	integer offset value
46-52	A6	instrument name

Format Type 5 Cards

Columns	Format	Content
10-80	A	manually entered alphabetic messages

Format Type 7 Cards

Columns	Format	Content
13-15	I3	channel's data type
17	I1	the value 4 signifying that 4 data items follow
18-24	F7.2	channel reading with the A/D grounded
25-31	F7.2	instrument zero before adjustment
32-38	F7.2	instrument zero after adjustment
39-45	F7.2	calibration reading; the values are the raw A/D values plus the offset value (Cols. 41-45 on a Type 1 card). (If this value is exactly 0.00, then the reading is missing.)

Format Type 9 Cards

Columns	Format	Content
10-12	I3	traffic loop identifier
13-20	I8	residence time over loop (1/100 sec)

Format Type 10 Cards

Columns	Format	Content
10-12	I3	card no. (1-5); there are 5 cards or data per change of signalization
15-80	3(4I4,I6)	3 loops of data per card; 5 values per loop; non-red volume, non-red occupancy (1/50 sec), red volume, red occupancy (1/50 sec), total red delay (1/10 sec)

Format Type 11 Cards

Columns	Format	Content
13-15	I5	data type
16	1X	blank
17	I1	number of data items that follow (1-9)
18-73	(1-9) F7.2	1-9 data items

-1: used as a terminator to signal the end of data for a channel
1: the data parameters for a channel
5: alphanumeric message
7: calibration data
9-10: traffic data
11: general data

All seven format types have similar fields in the first twelve columns. The first six columns are devoted to a time parameter. Column 7 is left blank on all format types. Columns 8 and 9 hold the format identifier. The channel number is contained in Columns 10-12 on all cards except Type 5 cards. The use and format of each group on all format types are given in Table 5.

Chapter V

MODEL DEVELOPMENT

An air quality model for street intersections was developed as a part of Project 250 and in conjunction with Project FCIP-1-8-81-541. The model is called The Texas Intersection Model (TEXIN) for Air Quality. The development of the TEXIN Model required three major tasks: (1) estimation of various traffic parameters (queue length, time in queue, etc.); (2) estimation of vehicle emissions and their distribution; and (3) modelling of pollutant dispersion downwind of the intersection. Considerable emphasis was placed on developing a model that facilitated user application, yet achieved accuracy equal to or surpassing that of existing intersection models. Also, an effort was made to minimize the amount of computer time required.

BACKGROUND

Discussion of Previous Models:

In the past few years, several models have been developed which predict either: (1) composite vehicle emission factors, given such inputs as ambient temperature, vehicle mix and history, driving sequence and mode of operation; or (2) pollution dispersion and concentration given such inputs as emission factor, traffic volume, meteorological data and highway/receptor geometry. The most prominent emission rate models have been AP-42 (EPA, 1981), the Modal Analysis Model (Kunselman, et al., 1974), and MOBILE-2 (EPA, 1981). Two models describing atmospheric dispersion in general use today which are capable of modelling an intersection are the HIWAY-2 (EPA, 1980) and CALINE-3 (Benson, 1979) models. Both are based upon Gaussian dispersion assumptions.

For intersection analyses, several models have been developed which utilize combinations of the preceding models and assorted traffic engineering principles to predict pollutant concentrations. The EPA Hotspot Guidelines, the Intersection Midblock Model (IMM), the Indirect Source Guidelines, and MICRO are four composite models which will be considered in the following discussion.

Hot Spot Guidelines:

In 1978, the U.S. EPA published a series of manuals entitled The Carbon Monoxide Hot Spot Guidelines, Volume I, II and III (EPA, 1978). These guidelines present methods for the identification and analysis of carbon monoxide hot spots (locations where ambient concentrations may exceed National Standards). Development of the guidelines involved many assumptions and generalizations to achieve simplicity in use.

Intersection Midblock Model (IMM):

Volume V of the Hot Spot Guidelines describes the Intersection Midblock Model (EPA, 1978). The IMM is essentially a computer program that performs the same calculations outlined in Hot Spot Guidelines; however, fewer assumptions are made thus lending increased flexibility to the analyses. It is only intended for carbon monoxide pollution and is designed as a screening procedure to identify potential "hot spots" in urban situations. In 1980, the New York State Department of Transportation chose the IMM as its chief modelling tool but found it to be too limited and modified it for their use (Piracci, 1981). "Intersection Midblock Model (IMM)" refers to this modified version in the remainder of this work.

The IMM is a combination of signalization and vehicle queueing estimation procedures using accepted traffic engineering principles. It predicts emissions using the Modal Analysis Model and the MOBILE-1 program (EPA, 1978), and models dispersion with the HIWAY-2 model. The IMM requires a very extensive set of input data, some of which are difficult to determine and rarely available. The IMM treats each lane as a line source (or link) and thus for each lane, the geometry, lane capacity, volume, velocities into and out of the intersection, deceleration into and the acceleration out of the link must be supplied. Additionally, the signalization (type of control, number and length of phases, and approach speed during each phase) needs to be specified.

MICRO:

A study was conducted by the Colorado Department of Highways with the objective of determining the impact of traffic signaling decisions on air quality (Griffin, 1980). The first phase of this study was to determine automotive emission rates based on the mode of operation (accelerating/decelerating, idling or cruising). To accomplish this, the department obtained emission rate data which were used to update the original Modal Analysis Model and correlated these data with the product of the acceleration and speed associated with each test. These correlations, in conjunction with the intersection submodel of the regional air quality depersion model, APRAC-2 (Mancuso and Ludwig, 1972) (developed by Stanford Research Institute for estimating CO levels resulting from a city wide traffic network) were used by the Colorado Department of Highways as the basis for developing the program MICRO (Griffin, 1980).

Like the IMM, MICRO first calculates traffic parameters, then estimates emission rates, and subsequently models the dispersion of pollutants. MICRO assumes that non-stopping vehicles remain in the steady state cruise mode through the entire intersection and each link is arbitrarily divided into five sections over which emissions are distributed. These are: the steady state cruise, deceleration, decel-idle, accel-idle and acceleration sections.

Once the emissions have been calculated along each link, pollutant dispersion is modelled using a Gaussian point source formulation similar to that in the HIWAY-2 Model. The links are subdivided into numerous smaller sections, each of which is considered as a separate point source, and the contributions from the links are summed to give the pollutant concentration at a selected receptor.

Indirect Source Guidelines:

The EPA document, "Guidelines for Air Quality Maintenance Planning and Analysis - Volume 9 (Revised): Evaluating Indirect Sources" (EPA, 1978), presents a method to evaluate the impact of indirect sources (roadways, parking lots, airports, etc.) on air quality. The evaluation procedure is performed manually through a series of worksheets and flow charts with tables and nomographs to facilitate user application. The Indirect Source Guidelines can be used to model extended line sources, finite line sources and area sources. However, only its treatment of extended and finite line sources are applicable to intersections.

Discussion of Previous Data:

The data bases for intersection pollution analyses should include roadway/receptor geometry, carbon monoxide levels, and timely traffic and meteorological data. Several major studies involving the collection of data near simple signalized intersections (Patterson and Record, 1974), (Cohen, 1976), (O'Toole, et al., 1975), (Hanisch, et al., 1978), (Noll, et al., 1979), (Rosas, et al., 1980), (Geomet Technologies, 1980), (Benson, 1981), besides Project 250 have been performed. However, only two data bases were sufficiently comprehensive for use in this study. The Project 250 data base was from the sites in College Station, (Texas A&M-College Station) and Houston, (Texas A&M-Houston) Texas as discussed in the previous chapters. The California data (Benson, 1981) were collected by the California Department of Transportation (CALTRANS) at a Sacramento, California site.

CALTRANS Sacramento Study. During the months of February, March and April, 1980, The California Department of Transportation (CALTRANS) collected pollutant, traffic and meteorological data at the intersection of Florin Road and Freeport Boulevard in Sacramento. Measurements were taken around the clock for a continuous period of forty days.

The site surroundings consisted of bare or grass covered ground on all four quadrants for a distance of at least 50 metres (164 ft) from the travelled way. The terrain was level and occupied by scattered single-story residential developments. A small community shopping center was also located well back from the intersection in the northwest quadrant. The site offered a reasonably high traffic flow without the interfering background sources of gas stations and parking lots normally associated with busy intersections.

Fifteen carbon monoxide probe locations were chosen. Eight of these were in the northwest quadrant and seven in the southwest quadrant. Also, a sequential bag sampler was placed in the southeast quadrant. Meteorological instruments were located at several locations and traffic counts were obtained using pneumatic counters for inflow and outflow on each leg of the intersection. No measurement of the percentage of vehicles turning was made, nor was any attempt made to measure vehicle speeds.

The data base made available by CALTRANS consists of 6164 hourly averages (and standard deviations) for all of the recorded variables mentioned above. Additionally, hourly averages, for the Richardson Number and Bulk Richardson number were provided.

A detailed review of the literature has been presented in Report No. FHWA/TX-81/541-1.

OVERVIEW OF THE MODEL

The general flow diagram for the TEXIN Model is presented in Figure 6. The model requires a minimal set of four types of geometrical, meteorological, and traffic-related inputs, as shown in the figure. Initi-

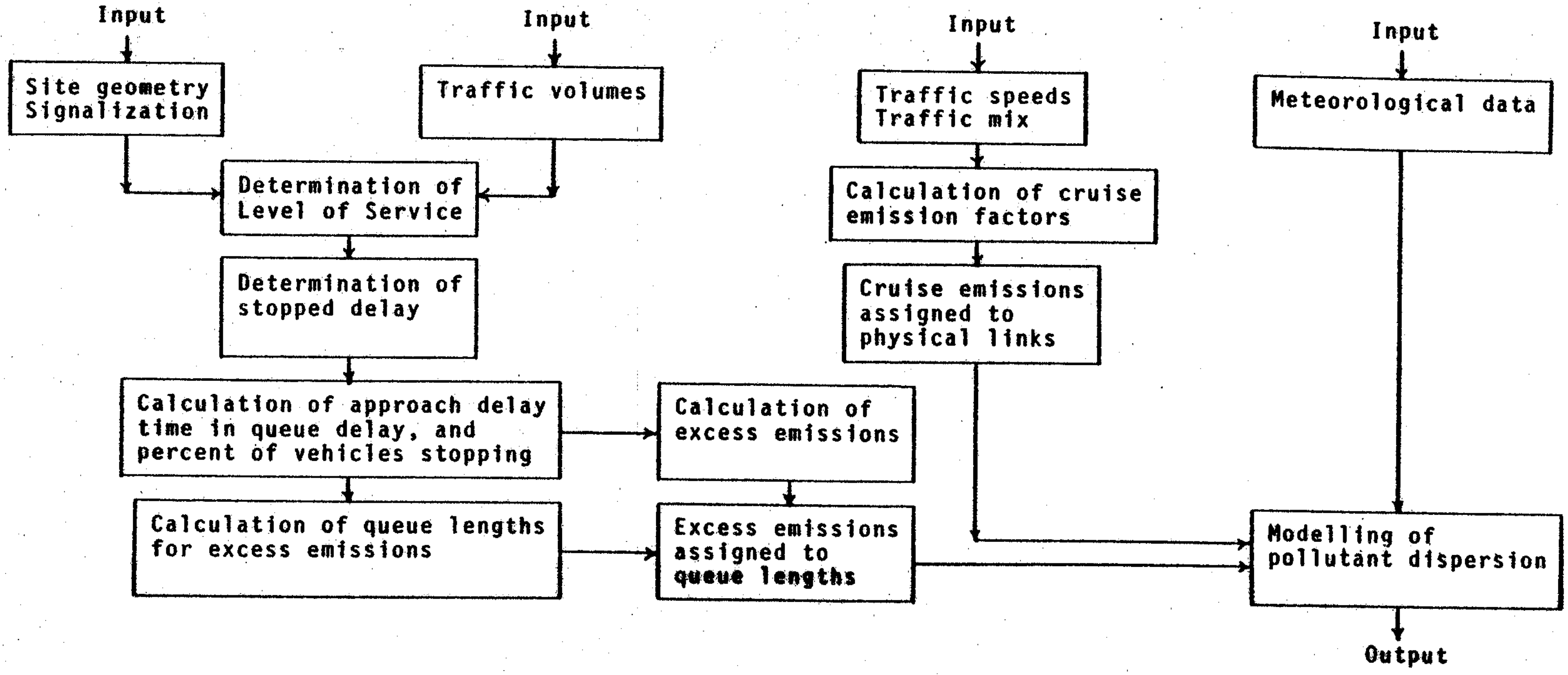


Figure 6
General Flow Diagram for the TEXIN Model

ally, the Level of Service for the intersection and the stopped delay associated with this level of service, are determined using a method known as "Critical Movement Analysis" for signalized intersections (a corresponding procedure is used for unsignalized intersections). The stopped delay is then used to calculate several other traffic parameters of interest, including approach delay, time in queue, percent of vehicles stopping, and queue length. Cruise emissions and the excess emissions due to vehicles slowing, stopping, and idling are then estimated. Cruise emissions are assigned to physical links within the intersection and the excess emissions are assigned to pseudolinks formed from the queue lengths. The dispersion of pollutants downwind of the intersection is subsequently modelled for the specific meteorological scenario, and the results are output in a convenient format. The detailed mechanics of each aspect of the model are described in greater detail below.

The TEXIN Model is flexible enough to handle most intersection configurations which would realistically be encountered by highway engineers. The program can model the basic case of a simple intersection (signalized or unsignalized) with four straight legs, as well as more complex situations where the legs of the intersection may be curved. In addition to modelling the major intersection, the program has the flexibility to concurrently model several minor intersections (controlled by stop or yield signs) arising from nearby side streets. It should be noted that the dispersion routines in the TEXIN Model are not intended for use with "street canyon" configurations between tall buildings in highly urban areas. In the current version, one way streets can be modelled by including a single vehicle in the opposite direction. This difficulty will be corrected in a later version of the model. A 4-way stop capability will also be added.

TRAFFIC PARAMETERS ESTIMATION

The first function performed by the program is that of traffic flow analysis. Initially, the traffic flow on the major intersection is evaluated and afterwards any minor intersections are handled. A complete description of the methodologies used in the TEXIN Model to perform the traffic flow analysis follows.

The primary factor normally considered by traffic engineers in determining the operating characteristics of an intersection is the "Level of Service" involved. The Level of Service is a measure of the mobility of an intersection and is stratified into the following six levels:

A - Free flow, low volume; high operating speed, high manueverability.

B - Stable flow, moderate volume; speed somewhat restricted by traffic conditions, high manueverability.

C - Stable flow, high volume; speed and manuever ability determined by traffic conditions.

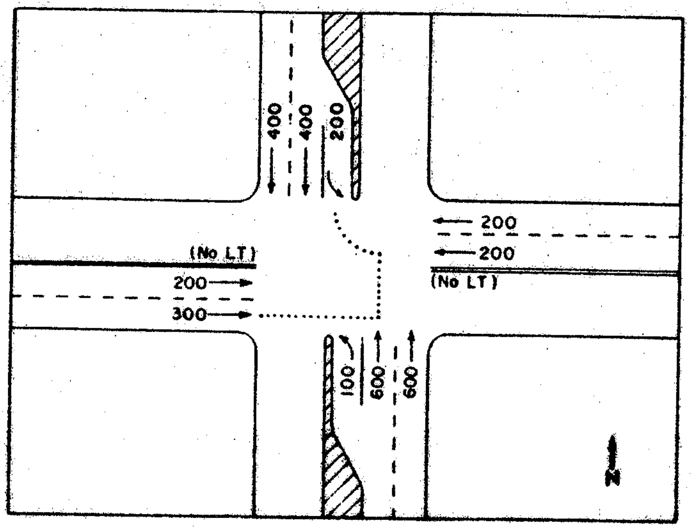
D - Unstable flow, high volume; tolerable but fluctuating operating speeds and manueverability.

E - Unstable flow, high volume approaching roadway capacity; limited speed (ca. 30 mph/48.3 kph), intermittant vehicle queueing.

F - Forced flow, volume lower than capacity due to very low speeds; heavy queueing of vehicles, frequent stoppages.

The Critical Movement Analysis technique (as presented in _Development of an Improved highway Capacity Manual, NCHRP 3-28_ [NCHRP, 1979]) was incorporated into the TEXIN Model to estimate the Level of Service for signalized intersections. Critical Movement Analysis is a procedure which permits the analysis of a signalized intersection as an entire unit. The basis of the analysis is the principle that at each signalized intersection a combination of conflicting movements (lane volumes) must be accommodated. The sum of these volumes in termed the "critical volume."

Figure 7 shows an example of critical movement combinations. The critical volumes are the volumes of travel represented by the highest lane volumes of op-



- Two and Three Lane Approaches
- Five Phase Actuated Signal
- Note: For the east-west street, the critical volume is 300 vph. For the north-south street the greatest demand for green time will occur with the conflicting movement totaling 800 vph (600 + 200 LT). The conflicting movement totaling 500 vph (400 + 100 LT) would require less green time and will be satisfied if the 800 vph critical volume is satisfied.
- Sum of Critical Volumes:
  300 + 800 = 1100 vph.

Figure 7
An Example of Critical Movement Summation

posing travel (through and left turn) for both the north-south and east-west directions. Once the critical volumes are determined for both directions, they are summed to give the "sum of critical volumes" which is compared to a benchmark intersection capacity to determine the Level of Service and volume to capacity ratio (V/C) for the intersection.

A number of elements can be considered in the calculation of the sum of critical volumes. These are: (1) lane width, (2) bus and truck volume, (3) bus stop operations, (4) left turns, (5) right turns with pedestrian activity, (6) parking activity and (7) peaking characteristics. Research has been conducted on these elements and has resulted in individual adjustment factors for each.

To minimize user input for the TEXIN Model only one adjustment factor of prime importance (that for left turns) was utilized. Left turning vehicles are treated in more detail for the simple reason that left turns (unless removed from through traffic by use of exclusive turn lanes) have a large impact on capacity. In the model, the effect of left turn vehicles is accounted for by using passenger car equivalency (PCE) values. PCE values are adjustment factors applied to the left turning traffic volumes. Table 6 gives PCE values for left turns from both left-through lanes and exclusive turn lanes (NCHRP, 1979).

Table 6

Passenger car equivalency (PCE) values
for left turn effects (NCHRP, 1979)

<u>Left Turns Allowed from Left-Through Lanes</u>

1.	No Turn Phase	Opposing Volume, in vph:	000-299	300-599	600-999	1000+
		1 left turn equals:	1.0 PCE	2.0 PCE	4.0 PCE	6.0 PCE
2.	With Turn Phase	1 left turn equals:	1.2 PCE			

<u>Left Turns Allowed from Left Turn Bays Only</u>

3.	No Turn Phase	Opposing Volume, in vph:	000-299	300-599	600-999	1000+
		1 left turn equals:	1.0 PCE	2.0 PCE	4.0 PCE	6.0 PCE
4.	With Turn Phase	1 left turn equals:	1.05 PCE			

Critical Movement Analysis is based on per-lane volumes; thus, it is desirable for the user to supply volumes for each lane. However, this is not always possible and adds to the complexity of user inputs. For this reason, a table of adjustment factors was incorporated into the present model. These factors are taken from a document on "Quick Response Techniques" published under the National Cooperative Highway Research Program (NCHRP, 1978). Table 7 presents lane-use factors to convert total directional movement into a lane volume. The lane-use factors exceed the inverse of the number of lanes in order to account for the unequal distribution of travel between lanes.

As part of the critical movement analysis technique presented in NCHRP 3-28 (NCHRP, 1979), a set of guidelines on Levels of Service, volume/capacity (V/C) ratios, average delay values and sums of critical volumes was recently published. Table 8 gives the recommended thresholds for the maximum sum of critical volumes for Levels of Service A through E. Table 9 shows the correlation between the volume/capacity ratio and delay values. These delay values relate to the mean stopped delay incurred by all vehicles entering the intersection. By linearly interpolating the volume/capacity ratio within the delay range for the given Level of Service, the stopped delay for any volume/capacity ratio can be determined. This stopped

Table 7

Lane-Use Factors (NCHRP, 1978)

Approach Lanes	Lane-Use Factor
1	1.00
2	0.55
3	0.40
4	0.30

Table 8

Level of Service Ranges (NCHRP, 1979)

Level of Service	Maximum Sum of Critical Volumes		
	Two Phase	Three Phase	Four or more Phases
A	1000	950	900
B	1200	1140	1080
C	1400	1340	1270
D	1600	1530	1460
E	1800	1720	1650
F	------------Not Applicable-----------		

Table 9

Delay and Level of Service (NCHRP, 1979)

Level of Service	Typical V/C Ratio*	Delay Range** (s/veh)
A	0.00-0.60	0.0 - 16.0
B	0.61-0.70	16.1 - 22.0
C	0.71-0.80	22.1 - 28.0
D	0.81-0.90	28.1 - 35.0
E	0.91-1.00	35.1 - 40.0
F	varies	40.1 or more

*Volume to capacity ratio

**Measured as "stopped delay" as described in reference (Reilly, et al., 1976). Delay values relate to the mean stopped delay incurred by <u>all</u> vehicles entering the intersection. Note that traffic signal coordination effects are not considered and could drastically alter the delay range for a given V/C ratio.

delay per vehicle is the basis for determining other traffic parameters in the TEXIN Model.

When the demand volume exceeds the capacity of the intersection (V/C>1) breakdown conditions exist (Level of Service - F). Under such conditions Critical Movement Analysis is not completely applicable and cannot accurately describe the traffic flow conditions under such circumstances (heavy queueing of vehicles, frequent stoppages, etc.). The model handles these situations by simply linearly extrapolating the stopped delay value beyond the applicable volume/capacity region (0.00 - 1.00). This gives stopped delay values above 40 seconds as is expected for breakdown conditions. However, the user is cautioned that the actual stopped delay value may not be the same as the value calculated, thus placing the model's results in question under these circumstances. The TEXIN program prints out a warning message when such situations occur.

The above methodology was applied for the traffic flow analysis of simple signalized intersections. A different procedure was necessary for unsignalized intersections because Critical Movement Analysis is only applicable to signalized intersections. The procedures used in the TEXIN model for unsignalized intersections are presented in NCHRP 3-28 (NCHRP, 1979). Only intersections controlled by two-way stop signs or yield signs can be treated by this analysis. Thus, uncontrolled and four-way stop sign controlled intersections are not included in the current version of TEXIN. These will be added in a later version.

VEHICLE EMISSIONS ESTIMATION

The second function performed by the model is the estimation of vehicle emissions. The emissions are modelled as the sum of two components: cruise emissions from free flowing traffic and excess emissions emitted by vehicles incurring delay (either slowing, stopping or idling). The cruise emissions are assumed to be uniformly distributed along the entire length of the roadway, while the excess emissions are taken to be emitted only over the queue length. The MOBILE-2 program was incorporated into the model to estimate the cruise emissions of free flowing vehicles. These are the most recent emissions rates available, and allow the user to either specify the specific scenario (VMT mix, cold/hot start fractions, etc.) or to use the default national average values.

To conserve computer time, sizeable portions of the extremely large MOBILE-2 program which were not needed by the TEXIN Model were deleted. A later version of TEXIN will include these as an option. The deletions included the nitrogen oxides and hydrocarbon emission factors, optional correction factors for inspection/maintenance programs, air conditioning and extra-load towing, and most of the input/output processing. These modifications resulted in an approximate two-thirds decrease in storage space as well as a similar decrease in the compilation and execution time required to process the MOBILE-2 program. It should be noted that the MOBILE-2 emissions model is merely a subroutine of the TEXIN Model. Users of the model who are familiar with FORTRAN can easily modify the model to include future versions of MOBILE-2 or of any cruise emissions estimation routines.

Since MOBILE-2 will only estimate average emissions for vehicles at an average route speed, a method for estimating excess emissions due to vehicles slowing and stopping had to be adopted. The method incorporated into the TEXIN model utilized the traffic parameters determined above and nomographs relating excess emissions due to speed changes, as suggested by Ismart, 1981. Excess emissions are calculated as the sum of three components: emissions due to vehicles stopping and returning to an initial speed, emissions due to vehicles slowing (but not stopping) and returning to an initial speed, and emissions due to vehicles idling.

The carbon monoxide emissions due to vehicles stopping is determined by the following equation from Ismart, 1981:

COST = PCST*TTEI*ER/1000 (1)

where: COST = total amount of excess CO emitted due to vehicles stopping, lbs/hr

ER = pounds of CO emitted per 1000 speed changes

1000 = factor to convert ER to pounds per speed change

The emission rate, ER, is determined using Figure 8 by considering the vehicle as going from the initial speed to zero speed and then returning to the initial speed. These emission rates are based on the most recent rates available (from work completed by Kearis in 1980). The rates were derived using at-grade data obtained in St. Louis, Missouri, and the 1977 Modal Analysis Model. They pertain to 100% light-duty, 100% hot stabilized, low-altitude, non-California vehicles for a base year of 1975. For the study, Kearis assumed an average acceleration/deceleration rate of 3 miles/hr/sec (1.3 m/s^2).

To account for the difference between the emission rates under the actual vehicle scenario and under the Modal Analysis Model vehicle scenario, a correction factor must be applied to these rates. This correction factor is calculated as the ratio of the MOBILE-2 composite emission factor for the inputted vehicle scenario to the MOBILE-2 composite emission factor for the Modal Analysis Model vehicle scenario. The

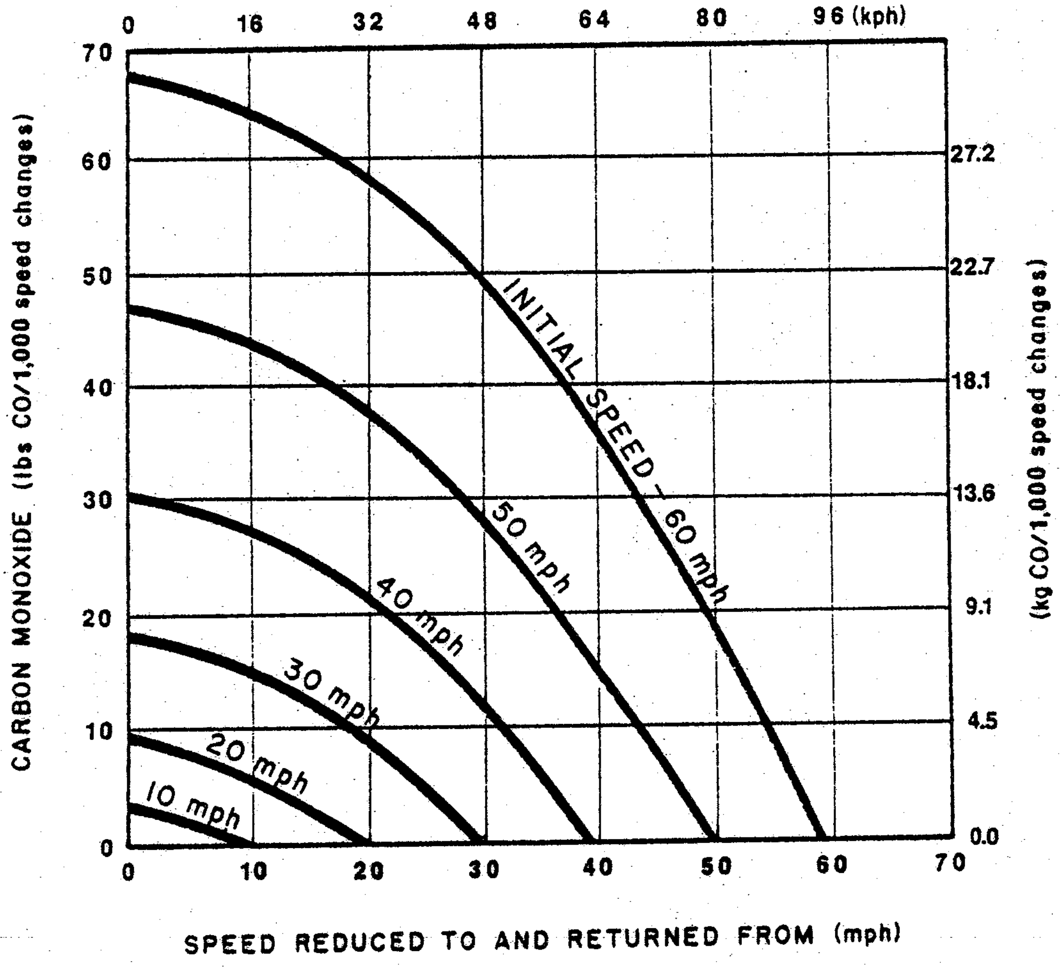


Figure 8
Carbon Monoxide Emissions for Vehicular
Speed Changes

emission rate obtained from Figure 8 is multiplied by this correction factor to give the correct emission rate for use in equation (1).

To determine the carbon monoxide emissions due to vehicles slowing, the following equation from Ismart, 1981 is used to calculate the time lost by vehicles slowing down but not stopping:

$$\text{Slowdown Delay} = \text{ADPV} - \text{TIQPV} \tag{2}$$

where: ADPV = aproach delay, s/veh

TIQPV = time in queue delay, s/veh

Once the slowdown delay per vehicle is determined, the excess emissions due to vehicles slowing, COSD, is estimated from an equation by Ismart, 1981:

$$\text{COSD} = \frac{(\text{ADPV} - \text{TIQPV})*\text{TTEI}*\text{ER}}{3600*\text{HRS}} \tag{3}$$

where: ER = pounds of CO emitted per 1000 speed changes

HRS = the excess hours consumed per 1000 speed changes

The value for HRS is obtained from Table 10 (Winfrey, 1969) using the initial speed and the speed reduced from and returned to. The emission rate, ER, is obtained once again from Figure 8 using the initial speed and the speed to which the vehicle slows. Once again, the correction factor is applied to the rate

Table 10

Excess hours consumed for vehicular speed
changes (hr/1000 speed changes), (Winfrey, 1969)

Initial Speed (mph)	Speed Reduced To and Returned From										
	Stop	5	10	15	20	25	30	35	40	45	50
5	1.02										
10	1.51	0.62									
15	2.00	1.12	0.46								
20	2.49	1.62	0.93	0.35							
25	2.98	2.11	1.40	0.80	0.28						
30	3.46	2.60	1.87	1.24	0.70	0.23					
35	3.84	3.09	2.34	1.69	1.11	0.60	0.19				
40	4.42	3.58	2.81	2.13	1.52	0.97	0.51	0.16			
45	4.90	4.06	3.28	2.57	1.93	1.34	0.83	0.42	0.13		
50	5.37	4.54	3.75	3.01	2.34	1.71	1.15	0.68	0.35	0.11	
55	5.84	5.02	4.21	3.45	2.74	2.08	1.47	0.94	0.57	0.28	0.09

obtained from Figure 8.

Ismart suggests that for simplifying purposes this slowdown speed be assumed equal to one-half the initial speed. Since this was an arbitrary assumption, its accuracy was checked using actual data from the Texas A&M College Station data. For this purpose, the initial speed was taken as the weighted average of the vehicle speeds obtained from the seven traffic loops located in the approach lanes (well upstream of the intersection), and the slow-down speed was taken as the weighted average of the speeds obtained from the six traffic loops internal to the intersection (in the right and left turn lanes). Initially it was assumed that there would be a strong relationship between the percent reduction in the initial speed and stopped delay per vehicle. However, when a regression analysis was performed little correlation between the two variables was found. Therefore, the relationship between the initial speed and the slow-down speed was examined. A regression analysis of these variables gave the equation:

$$\text{Slowdown speed} = 0.45\ (\text{Initial speed}) \qquad (4)$$

with good correlation ($r^2 = 0.90$). Since the value of 0.45 is in close agreement with Ismart's suggestion of 0.5, the 0.50 value was incorporated into the model.

Excess emissions due to vehicles idling are calculated from the stopped delay per vehicle and the idling emission rate using the following equation from Ismart, 1981:

$$COID = SDPV*TTEI*ER/(60*453.6) \tag{5}$$

where: COID = total amount of CO emitted due to vehicles idling, lbs/hr

SDPV = stopped delay per vehicle, s/veh

ER = idling emission rate, gm/veh-min

453.6 = conversion factor from grams to pounds

60 = conversion factor from minutes to seconds

The idling emission rate, ER, is determined using the MOBILE-2 program.

The total excess emission factor is then calculated using the values for COST, COSD and COID and the total queue length. The following equation was developed to calculate the total excess emission factor:

$$EF = \frac{(COST + COSD + COID)*453.6}{QL*3600} \tag{6}$$

where the emission factor, EF, is in gm/m-s. Since Critical Movement Analysis treats the entire (signalized) intersection as a whole, the values for COST, COSD, and COID as calcuated in equations (1) through

(5) represent the total excess emissions due to vehicular delay at the intersection QL is the product of the % vehicles stopping, total vehicles entering, the cycle time and 8/3600. Therefore the model does not distinguish between the various approach legs when determining the excess emissions. One excess emission factor is calculated for the entire intersection, and it applies to all legs. However, the method of distributing the excess emissions along the links treats each approach leg individually. The queue length for each separate approach leg is used as the length of roadway over which the excess emissions are emitted for that leg.

The emissions estimates for unsignalized intersections are presented in Texas State Department of Highways and Public Transportation Report No. 1-8-81-541.

POLLUTANT DISPERSION MODELLING

The Gaussian dispersion model, CALINE-3, was incorporated into the TEXIN Model to calculate the dispersion of pollutants downwind of the intersection. CALINE-3 requires less input than other models (i.e., HIWAY-2), and its performance in predicting concentrations for cases where experimental values are available has been shown by Rodden, et.al., 1981, to be the best among pollution dispersion models capable of handling intersection situations. CALINE-3 treats each leg of an intersection (both incoming and outgoing traffic lanes) as a separate link, rather than treating each individual lane as a link. This not only greatly simplifies the necessary input, but also complements the Critical Movement Analysis techniques and the rest of the analysis of traffic flow incorporated in the TEXIN Model.

Several minor modifications were made to CALINE-3, mainly to the input/output routines, so that it could handle the pseudolinks over which the excess emissions occur (and in the units calculated above). However, all the normal capabilities of CALINE-3 remain the same. As incorporated into the TEXIN Model, it will still handle depressed, fill or bridged sections, curved roadways, various receptors, raised source heights, and all related situations for which it was designed. CALINE-3 is not applicable to street canyon street configurations, however. In addition to modifications made to input/output routines, an attempt was made to make CALINE-3 applicable for lower wind speeds. The User's Guide for CALINE-3 states that the model has not been verified for wind speeds less than 1 m/s, and that assumptions of negligible along-wind dispersion and steady state conditions are questionable at such low wind speeds.

Examination of the Texas A&M data from the College Station site at extremely low wind speeds (less than 1 m/s, approximately 10% of the cases) showed that the measured concentration gradient between the low (5 ft.) receptors and the high (35 ft.) receptors was substantially less than for those cases corresponding to high winds. This suggests that at low wind speeds there is an increased rise of pollutants. This phenomena has also been researched by Chock, 1978. In studying the effect of plume rise at low wind speeds, Chock developed a line source model that allowed for plume rise. However, such a method would require substantial modification to the CALINE-3 model. Consequently, a simpler approach was adopted to account for plume rise by merely raising the source height. Chock reports an ambient plume rise speed of 0.15 m/sec for a crosswind road speed of 0 m/s. Using this value and the value for residence time as calculated by CALINE-3, the following equation was developed to calculate the height that the source is raised (above the inputted source emission height):

$$\Delta H = 0.15 \times TR \qquad (7)$$

This additional height, ΔH, can be thought of as the height that a pollutant emitted at the roadway centerline would rise by the time it reached the roadway edge. TR is the residence time calculated by CALINE-3.

The result of this modification on model performance will be discussed in Chapter IV.

SUMMARY OF MODEL INPUTS AND OUTPUTS

To summarize the input data required by the TEXIN Model and the output from the same, the procedure for modelling a sample intersection is presented. For a simple, signalized intersection with four right-angle corners, an X-Y Cartesian coordinate system is mapped onto the intersection with the axes lying coincident with the two perpendicular roadways. This places the center of the intersection approximately at the origin of the Cartesian coordinate system.

The first input required by the model is the geometry of the four links (approaches) representing the intersection. These inputs are data that are easily obtained and normally available, and consist of: (1) the upstream and downstream coordinates of each link, (2) the width of each link, (3) traffic volume for each link, (4) average vehicular speed for each link, (5) estimated percentage of cars turning right and left for each link, (6) the number of approach and turning lanes for each link, (7) the source (link) height, and (8) the link type (i.e., at-grade, fill, etc.). Next, the Cartesian coordinates (including the height) of the receptors must be specified. The meteorological conditions are required next and consist of wind speed, wind direction (measured clockwise with respect to the positive y-axis), the stability class, temperature, and the mixing height. In addition, the surface roughness and averaging time are required by the CALINE-3 program incorporated into the model. As an option, the user may specify the VMT mix and the percentage of hot starts/cold starts for use in the MOBILE-2 program. Otherwise, the national default values for these parameters are used. In addition, information on the signalization is required (e.g., number of phases, left turn phases and cycle length).

The primary output of the TEXIN Model is, of course, the predicted carbon monoxide concentrations at the receptors. Additional optional outputs can also be printed. These include a summary of the input data, the composite emission factors and idling emission rates (from MOBILE-2), the excess emission factors, the queue lengths and other traffic parameters of interest (stopped delay, etc.), as well as the CO concentration contribution from each individual link and psuedolink at the receptors.

Copies of the complete input and output files for three specific cases are included in the User's Guide which has already been published by the Federal Highway Administration as Report No. FHWA/TX-81/541-2F. For a more detailed explanation of model inputs and outputs, the reader is also referred to this User's Guide.

Chapter VI

Discussion of Results

Introduction

The discussion of results from Project 250 has been divided into several sections. These include (a) analysis of data accuracy, (b) discussion of experimental results including the tracer gas studies and aerosol samples and (c) results from model development work for intersection air quality.

Analysis of Data Accuracy

In any data collection endeavor, there are many sources of error. Every instrument has errors associated with it and, in addition, the entire data collection system has its own associated errors. Table 11 lists the overall accuracy of the data taken during this project, as far as is known. This section of the report details how these error limits were established.

A/D Error:

The data collection system for this project employed a 12 bit analog to digital converter (A/D). There are two possible errors in this unit. First, the span or gain could drift, causing any input to be interpreted as some factor greater or less than its actual value. This error is expressed as a fixed fraction of any particular reading. It reaches its maximum magnitude at the maximum data value and vanishes completely at a data reading of zero. The second type of error, the zero or offset drift is one by which a zero input produces an apparent voltage. This error is constant over the entire range of input values and is usually expressed as a fraction of the full scale reading.

In this project, the gain was checked in ten channels every time the project was moved. If there was any significant span drift in those channels, the

Table 11

Instrument Accuracy

	Instrument	Error
I.	A/D	0.6% span drift, 0.25% zero drift
II.	UVW Anemometers	1% of span*
III.	Vertical Anemometer	5% of span drift (max)*
IV.	Horizontal Anemometer	1% of zero drift (max)* **
V.	Wind Vanes	5°
VI.	Thermometers	1.5°F
	Aspirated Shielded Thermometers	0.25°F
VII.	Psychrometer	3% relative humidity*
VIII.	Pyranometer	15 watts/square cm
IX.	Ecolyzers	0.5 ppm CO**

*Manufacturers Ratings, not checked by project personnel
**See text for more detailed error description

entire A/D was checked and calibrated. However, span drift never exceeded eight counts out of an input value of 1331, or 0.6%. It was felt this low error would not warrant the effort required to correct it. The zero drift was checked daily in twelve channels. It never exceeded ten counts or 0.25%. This was judged to be negligible in light of the errors found in the instruments themselves.

UVW Anemometers:

These instruments were not checked by project personnel. The accuracy values quoted are from the operator's manual. The distance constant was 3.1 feet. The accuracy was ±1% or better for an axial position and ±3% for vertical position. The starting threshold was 0.5 miles per hour (0.26 meter/sec).

Vertical Anemometers:

These instruments were again not checked by project personnel. The values quoted here are those in the operator's manual. The primary source of error in these instruments is due to the fact that the propellers employed did not quite follow the cosine law with respect to wind angle. When the wind was within 2° of the horizontal (the vertical windspeed component was less than 3% of the horizontal component) the propeller stalled and did not turn at all. When the wind angle was at 45° with respect to the horizontal (the vertical component ws as large as the horizontal component) the instrument read 5% low. In view of the instability in the vertical windspeed, these errors were regarded as negligible. The starting threshold for these instruments was quite low, 0.5 mile per hour (0.26 meter/sec).

Horizontal Anemometers:

There were three sources of error in these instruments, only one of which was considered in the operator's manual. The starting threshold for these instruments was quoted as 0.75 mile per hour. This meant that in low windspeed conditions, typically found on late summer and fall mornings, the recorded windspeed was less than the actual windspeed. A second source of error was due to the mass of the anemometer cups. When a wind gust struck an instrument, it would spin at greater than the actual windspeed for some time thereafter. This meant that in gusty conditions, the recorded windspeed was higher than the actual windspeed. A third source of error had to do with the sensing of the windspeed. The instruments used a photo chopper and frequency to voltage converter to generate the required signal to the A/D. At windspeeds below 2 miles per hour, the output of the frequency to voltage converter began to break up into a series of spikes instead of a smooth voltage output. Since the A/D logged point values only, the wind appeared to be much more turbulent than was actually the case. Considerable care should be taken in low windspeed cases for this reason.

Wind Vanes:

The primary error in the wind vanes is due not to any error in the instrument, but instead to the alignment procedures used by project personnel. The vanes were aligned with the center line of the north-south street and then the bearings of these landmarks were used to compute correction factors. This procedure was accurate to within 5°. As the standard deviation of the wind direction was seldom below 15°, this error was considered negligible.

Thermometers:

The operator's manual stated that these instruments were accurate within 0.5°F (0.3°C). However, during a test where two instruments were placed on the east face of the 100 ft tower and two instruments on the west face, all at the 35-foot level, it was observed that those on the east face read 0.75°F (0.4°C) higher than those on the west face in the mornings and the thermometers on the west face read 1.1°F (0.6°C) higher than those on the east face in the afternoons. From this it was inferred that sunlight was causing a temperature rise in the instruments. The total error in the instruments was taken as the square root of the sum of the squares or 1.5°F (0.83°C).

Aspirated-Shielded Thermometer:

The operator's manual stated that these instruments were accurate within ±0.5°F. One unit was recalibrated by the manufacturer and side-by-side comparison with the other aspirated, shielded thermometer showed that they agreed within the specified 0.5°F accuracy.

Psychrometers:

The project personnel did not check the accuracy of the psychrometers. The operator's manual stated that the instruments were accurate to within 3% relative humidity.

Pyranometer:

The error in this data comes not from the instrument, but rather from an amplifier used to magnify the signal to a level acceptable to the A/D. The voltage must be boosted 41 times to be intelligible to the A/D. The amplifier used for this task had a maximum error of 1%. Since the maximum pyranometer reading expected in these latitudes is 1500 watts/sq cm, all pyranometer readings should be regarded as within 15 watts/sq cm of the correct value.

Ecolyzers:

Since the carbon monoxide concentrations were the primary purpose of this project, it was considered quite important to establish the limits of the instrument's accuracy. A preliminary test in College Station showed that both zero and span drift over a 24-hour period were severe enough to seriously degrade the quality of the data. Accordingly, a method was developed by which the Ecolyzers were recalibrated every 2 to 4 hours and the zero and span drifts noted. Later, a linear correction was assumed for the span drift and, if necessary, the zero drift. The success of this procedure was checked in an earlier study (Study No. 2-8-75-218). Two instruments were run side by side for several days during a previous experiments study. The instruments were treated no differently from any other Ecolyzer on the project. The standard program was used to apply the calibration factors. The results were most impressive. Figure 9 shows both instruments plotted against time. As can be seen the instruments tracked each other quite well. It is also interesting to note that the CO concentration varies quite rapidly in the near vicinity of roadways. This makes intermittant sampling instruments, such as gas

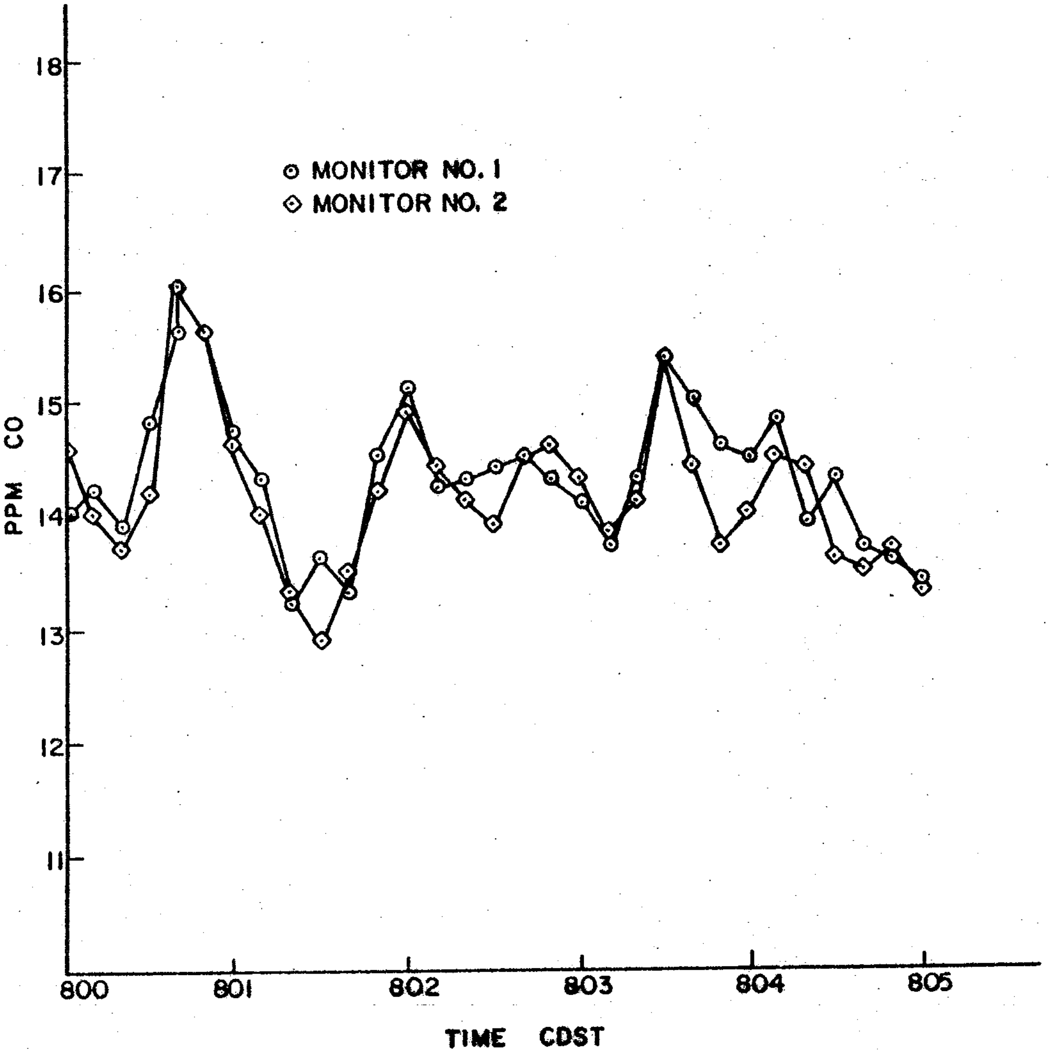


Figure 9
Comparison of Two Continous Monitors
on a Common Header versus Time

chromatographs, poor for this purpose unless some method is used to make the sample representative of the sampling time.

A comparison of the time averaged values shows results which are just as impressive. Figure 10 shows the 15-minute averages of one Ecolyzer against the other for two sampling days. Almost every point falls within the 1 ppm error limits. From a total of 101 fifteen-minute averages, the average error was 0.3 ppm ± 0.25 ppm. This is less than the manufacturer's ratings. To be on the safe side, the manufacturer's ratings were used as the stated error bounds.

Tracer Gas Studies:

The SF_6 emission rate was measured to within 5% by a soap bubble flow meter. A cross-check on the release rate by weighing the SF_6 cylinder agreed within 4%.

Stacked Filter Units:

The stacked filter unit, because of its symmetrical design, does not have any wind directional capture effects, but it does have variable wind speed capture anomalies. In an Environmental Protection Agency study by McFarland (1979), the aerodynamic particle diameter cutpoints for SFU of the design used in this study were found to be 17.0 μm at a windspeed of 2 km/hr and 8.1 μm at a windspeed of 8.0 km/hr.

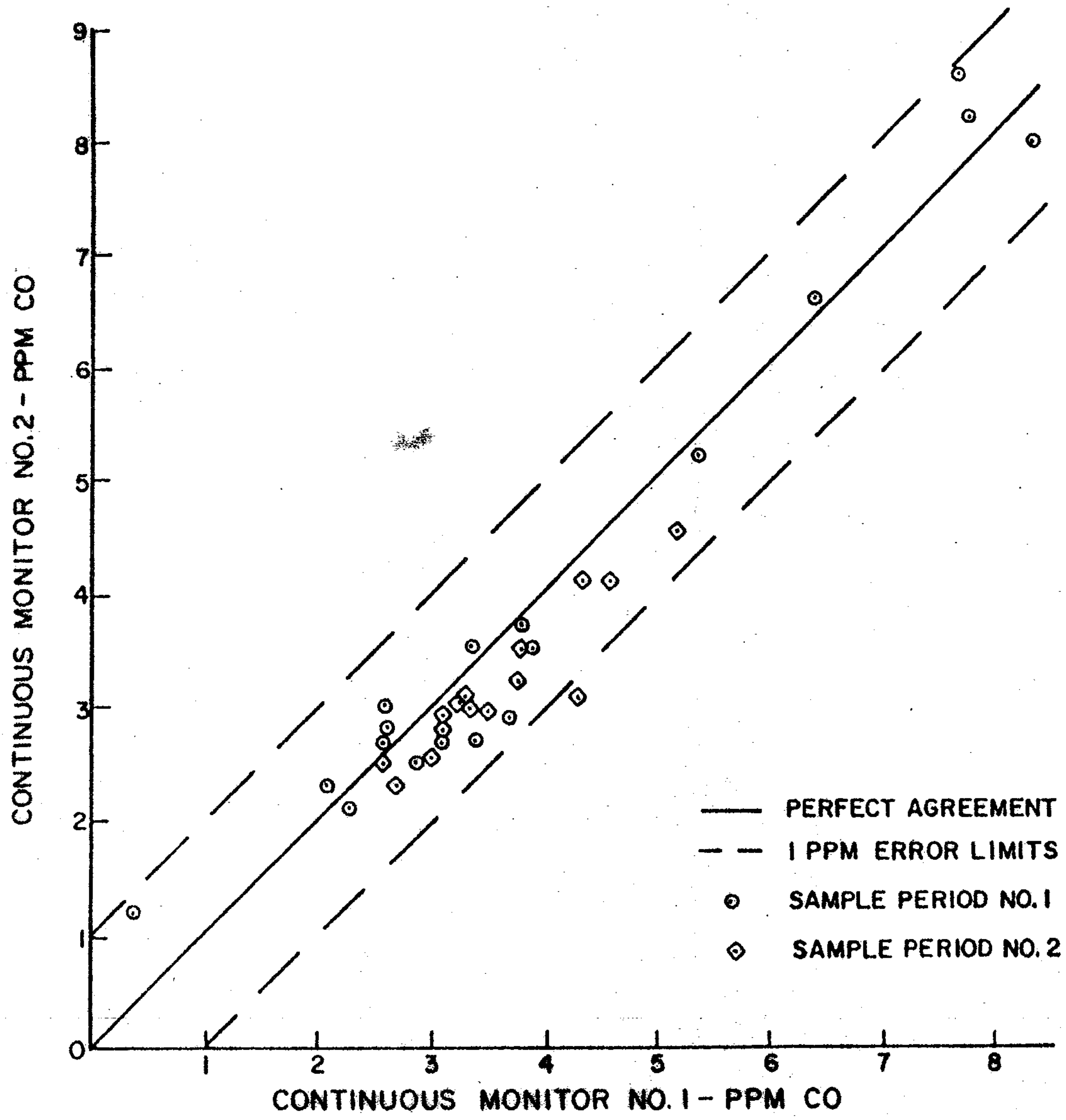


Figure 10
Comparison of Two Continous Monitors
on a Common Header

Another large error may come from uncertainty of the flow rate during an extended run. The pressure drop across the particulate filter will increase with time during a run, because increased particulate loading reduces the number of pores through which air can flow. The flow rate decreases nonlinearly with time because of nonuniformity of loading caused by changes in windspeed and direction and traffic flow. Simply averaging the startup and shutdown flow rates will probably produce an average flow rate different from the true average. To minimize this problem, the SFU were calibrated at startup and shutdown and about every two hours during the runs. The flow rate did not change greatly during any sampling period primarily because of the ballasting provided by the needle valves. The frequent calibrations maintained the average flow rate near the desired flow rate of 22.5 l/min. From the calibration curves for the two orifices used during the project and from the calibration record, it has been estimated that the error in the flow rate for the 22.5 l/min flow was no larger than 2 l/min. This represents a 10% error.

An error may be introduced into the analyses by the nature of the Nuclepore filters used in the SFU's. The surfaces of the filters had an Apiezon L coating to minimize particle bounce and falloff. The filters were always handled with the particulate covered surfaces up prior to their analysis.

Discussion of Experimental Results

Carbon Monoxide Results:

The experimental data showed that at the two intersections examined no carbon monoxide problem was found. The current National Ambient Air Quality Standard (NAAQS) is 35 ppm for a one hour average and 9 ppm for an eight hour average. At the College Station site, the one hour average CO level was usually 2 to 4 ppm and never exceeded 9 ppm during the times that data were taken. The instantaneous CO values rarely exceeded 12 to 14 ppm.

At the Houston site, the one hour CO average was usually in the range of 2 to 6 ppm. The maximum one hour average was about 14 ppm while the next highest average was about 10 ppm. The maximum instantaneous values were about 20 to 30 ppm. One of the reasons for the higher maximum values was that the sampling tower was located closer to the intersection. Another perhaps more important reason was the channelizing of the wind by the tall buildings in the vicinity of the intersections.

The carbon monoxide, traffic and meteorological data were collected at rates commensurate with the frequency of the variable being monitored. The monitoring frequencies were adjusted such that all sampling frequencies were a power of two. Thus statistical analyses such as cross correlations and power spectra can be easily performed. Samples of the instantaneous data are shown in Figures 11 and 12. The relationship between the various instantaneous values can be seen from these figures.

Tracer Gas Studies:

Sulfur hexafluoride (SF_6) tracer gas experiments were conducted at both intersection sites and also at the Texas A&M Research Annex. SF_6 was selected as a tracer since it has no natural sources and is not normally found in the atmosphere. As described in the Experimental Results section, 15-minute average air samples were collected by syringe samplers on towers at three different heights upwind and downwind of the roadway. The samples were analyzed by a gas chromatograph with an electron capture detector. The SF_6 vales along with the corresponding 15-minute average data for wind speed and direction are presented in Appendix C.

The tracer experiments were first performed at the College Station site. As can be seen from the data, good, well-defined SF_6 profiles were found downwind of the roadway and no SF_6 was found in the upwind samples in almost all cases. The mass balance technique which was developed under a previous project (Report No.

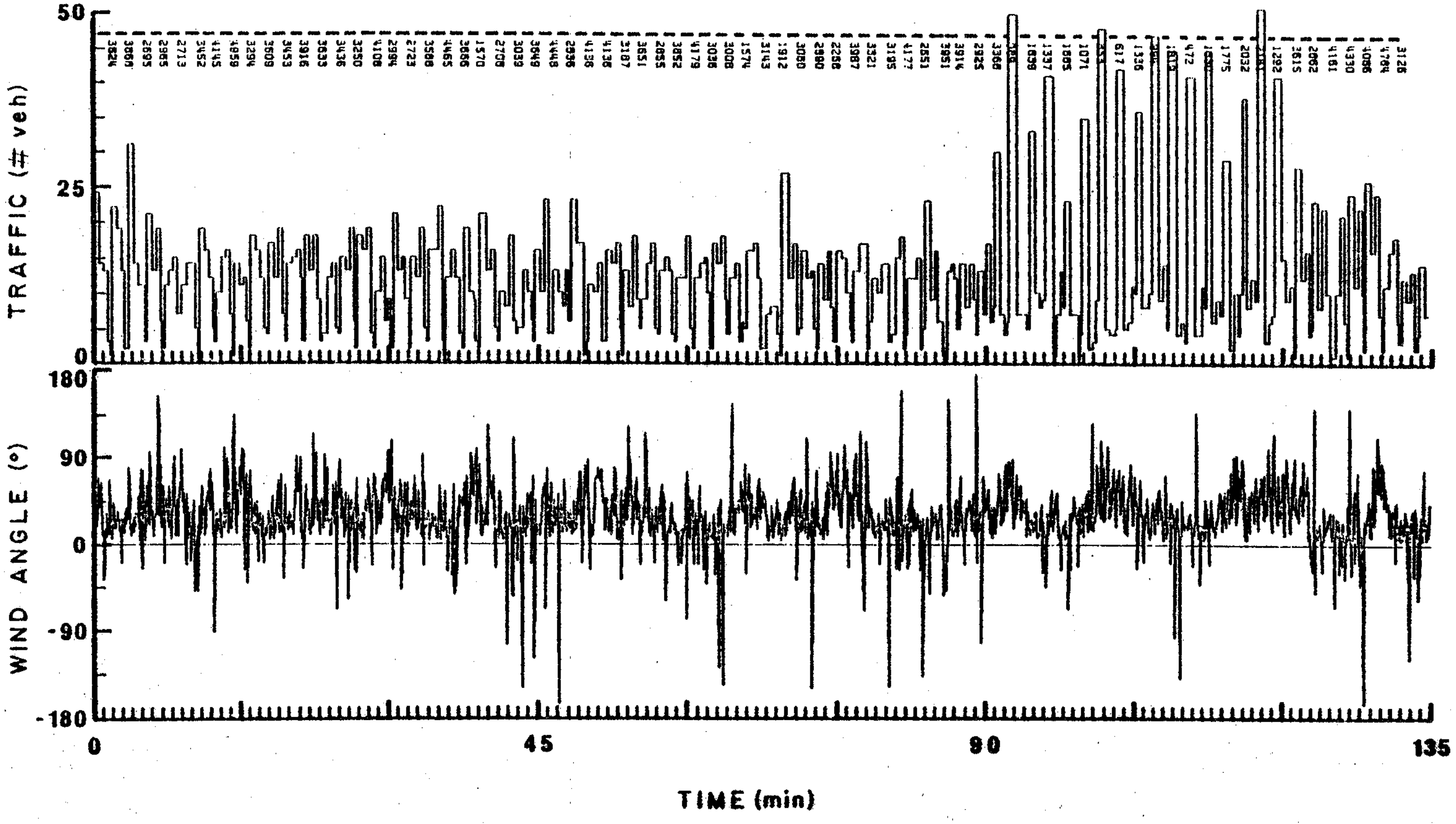


Figure 11
Variability of Traffic Volume, Delay,
Signalization and Wind Direction with Time

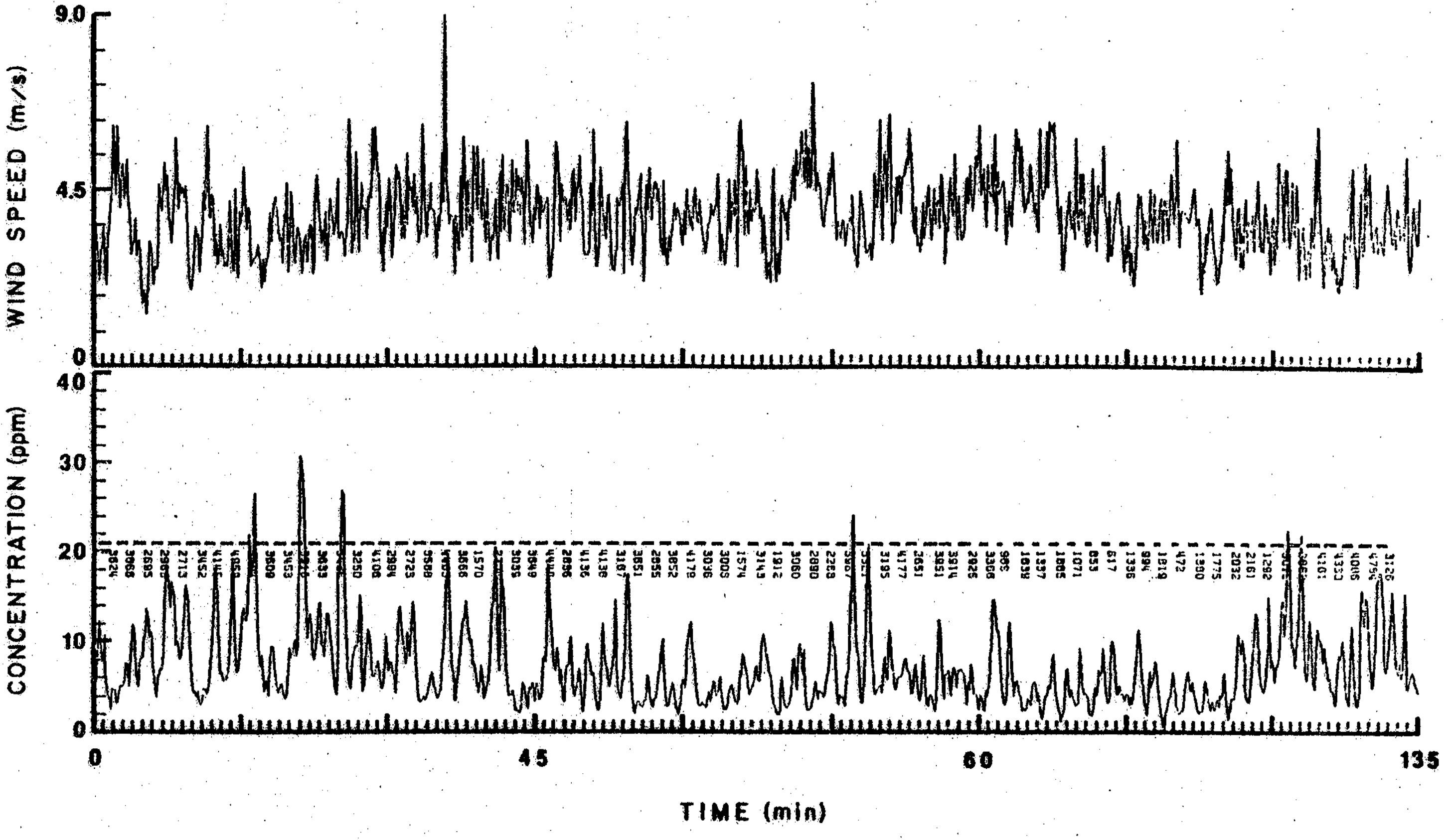


Figure 12
Variability of Wind Speed and Carbon
Monoxide Concentration with Time

2-8-75-218-4 by Bullin, Polasek and Green (1978)) was used to compare the amount of SF_6 flowing past the tower to the precisely measured emission rate. The mass balance technique is based on the principle that the amount of a particular pollutant flowing past any vertical plane downwind of a roadway minus the amount flowing past a vertical plane upwind of the roadway must equal the amount emitted along the roadway. Since many roadways may be assumed to be line sources, the planes on either side of the roadway may be reduced to lines. Since the SF_6 tracer was used only along one street, the line source assumption is valid for this intersection configuration.

The results from the mass balance calculations for the College Station site are shown in Table 12. As can be seen from this table the emission rate calculated from the downwind concentrations varied from 0.5 to 5.0 times the measured release rate. The release rate is defined as the precisely measured actual emission rate from the release vehicle. The detected or calculated rate is defined as the amount flowing past any sampling tower as computed from the concentration and wind profiles at the tower. The first set of mass balance ratios (detected/released) were calculated using only the crosswind component, U_x. These data are plotted in Figure 13 as a function of wind angle with respect to the roadway. The data did not follow the expected line

Table 12

SF_6 Mass Balance Results from College Station Site

Date	Period	Tower	Wind Angle (degrees)	U_x (mph)	Detected/ Released (from U_x)	Detected/ Released (from U)
11/03/80 A.M.	1	1	21.04	1.50	1.34	3.73
		2			0.97	2.70
	3	1	60.67	3.23	2.13	2.44
		2			2.07	2.37
	5	1	78.74	4.14	2.37	2.42
		2			2.46	2.51
	6	1	76.05	5.26	1.69	1.74
		2			1.77	1.82
10/03/80 P.M.	4	1	72.16	3.15	2.65	2.78
		2			4.62	4.85
12/05/80	2	1	17.86	2.90	0.41	1.34
		2			0.45	1.47
	5	1	11.27	2.26	0.22	1.13
		2			0.34	1.74
	6	1	11.96	2.50	0.48	2.32
		2			0.29	1.40
12/06/80	1	1	10.50	1.55	0.27	1.48
		2			0.21	1.15
	3	1	14.54	2.23	0.49	1.95
		2			0.20	0.80
	4	1	18.40	2.84	0.59	1.87
		2			0.31	0.98
5/08/81	2	1	25.85	4.52	1.40	3.21
		2			0.90	2.06
5/13/81	5	1	46.57	6.92	0.84	1.16
		2			0.49	0.67
	6	1	52.24	6.29	1.47	1.86
		2			0.40	0.51
5/18/81	2	1	74.08	5.82	1.44	1.50
		2			1.13	1.18
	4	1	88.79	5.57	1.67	1.67
		2			0.83	0.83

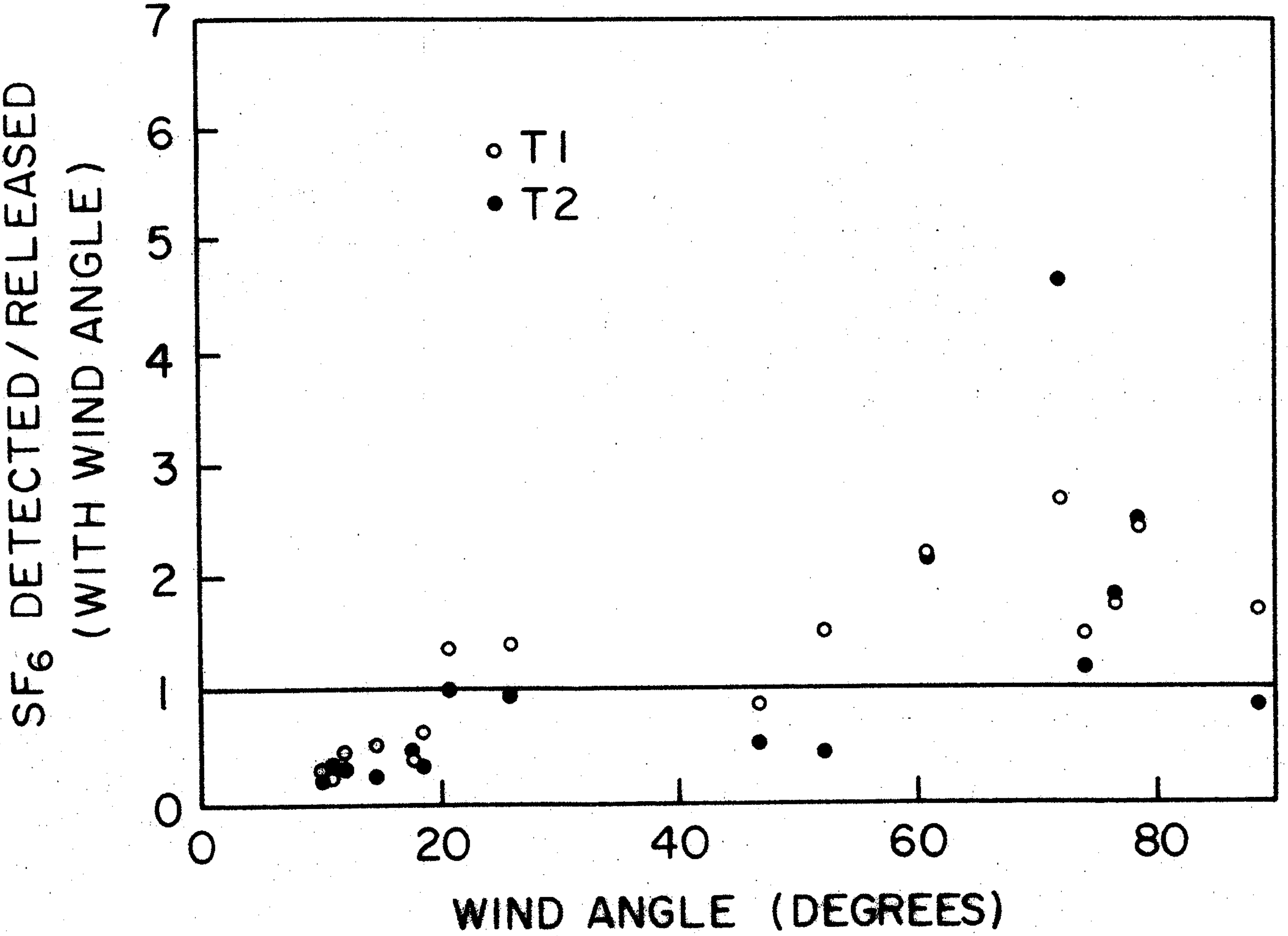


Figure 13

SF$_6$ Mass Balance Ratios versus Wind Angle for College Station Site (Ratios calculated using crosswind component wind speed, U_x)

of magnitude of Detected/Released = 1.0, but seemed to follow the sine of the angle. The ratios were then recalculated using the total wind speed, U_{in} and the results were plotted as shown in Figure 14. These results appear linear but with a large scatter not yet explained.

Because of the complexity of the College Station site and data, the tracer gas experiments were moved to the Texas A&M Research Annex where the parameters involved could be reduced and easily controlled.

The Texas A&M Research Annex was formerly the Bryan Air Force Base. The experiments were performed along one of the runways where the terrain was almost completely open and flat. The same calculations and analyses used on the College Station data were performed on the Research Annex data. The mass balance results are shown in Table 13 and plotted in Figures 15 and 16. Surprisingly, the results were a little more scattered but were completely consistent with the College Station results. However, only about half of the cases at the Research Annex had concentration profiles which were sufficiently well behaved to completely define the profile. As can be seen from the data in Appendix C, the shape of many of the tracer gas concentration profiles was very odd. For example, the SF_6 concentrations at the 42 foot height which was the top sampler, was often higher than any other

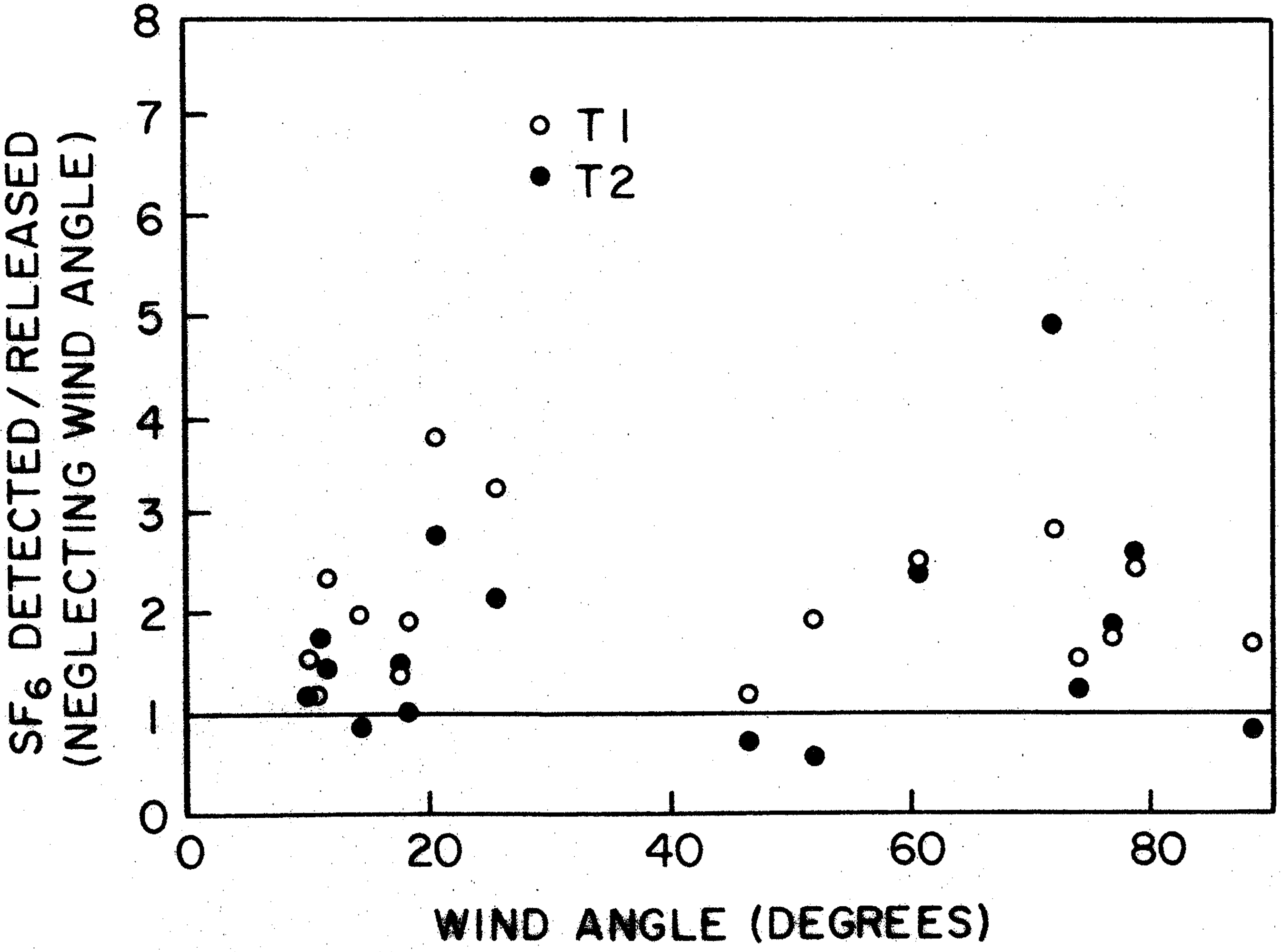


Figure 14

SF_6 Mass Balance Ratios versus Wind Angle
for College Station Site
(Ratios calculated using total horizontal
wind speed, U)

Table 13

SF_6 Mass Balance Results from Research Annex Site

Date	Period	Wind Angle (degrees)	U_x (mph)	Detected/ Released (from U_x)	Detected/ Released (from U)	Z/L (Z=29ft)
7/15/81 A.M.	4	88.5	2.7	5.35	5.35	0.720
	5	81.4	3.5	3.63	3.67	0.346
7/15/81 P.M.	2	74.6	3.5	2.22	2.30	0.670
	3	80.0	3.6	1.90	1.93	0.100
	5	78.2	5.1	4.68	4.78	0.0916
	6	69.6	2.9	1.50	1.60	-0.0616
7/17/81 P.M.	1	77.3	3.7	.9377	0.961	0.1426
	2	71.6	4.3	1.32	1.39	0.7650
7/21/81	1	54.5	3.3	1.82	2.24	-0.0019
	3	59.8	3.9	2.85	3.30	0.4427
	5	55.3	3.6	2.81	3.42	0.0600
	6	76.3	5.5	3.09	3.18	0.7139
7/23/81	2	84.52	5.3	1.01	1.01	0.0519
	3	78.22	5.8	1.36	1.38	-0.0878
	4	74.68	5.3	1.09	1.13	0.5524
	5	78.96	6.3	0.69	0.70	0.0093
7/24/81	1	22.34	1.2	0.22	0.58	-0.0130
	2	46.71	2.2	1.76	2.42	0.3214
	3	63.28	1.7	0.78	0.87	0.1343
	5	29.83	1.0	0.75	1.51	0.6112
	6	48.35	1.2	0.38	0.51	1.5402
7/27/81	1	47.75	2.1	0.63	0.85	0.2763
	2	86.79	4.1	1.21	1.21	-0.0483
	3	39.37	6.1	0.99	1.56	1.1024
7/28/81	1	33.94	3.2	1.00	1.79	0.0391
	2	39.59	3.6	0.70	1.10	0.2225
	3	44.28	3.6	0.87	1.25	0.0733
	5	30.00	3.1	1.01	2.02	0.0133

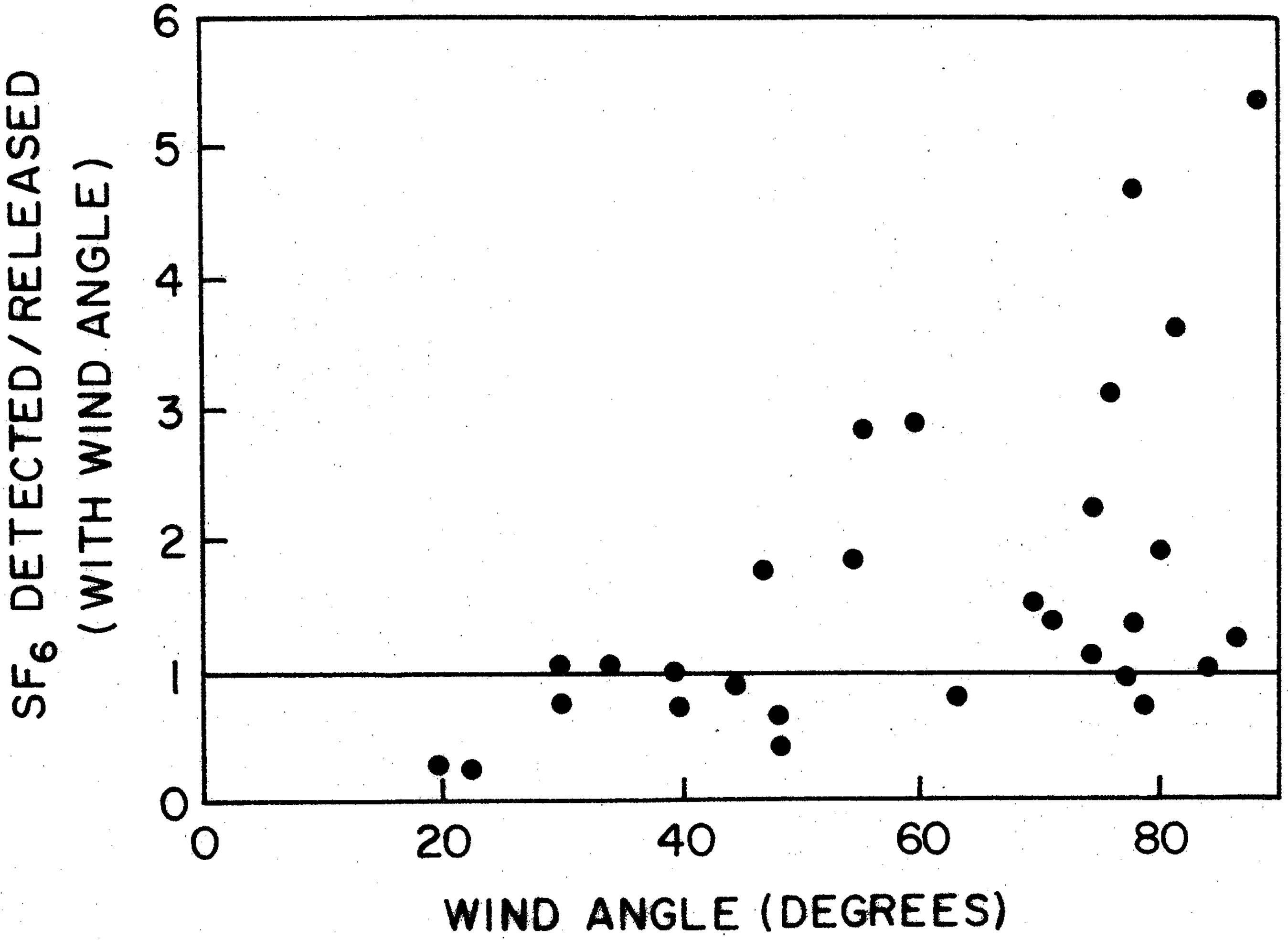


Figure 15

SF_6 Mass Balance Ratios versus Wind Angle

for Research Annex Site

(Ratios calculated using crosswind component

wind speed, U_x)

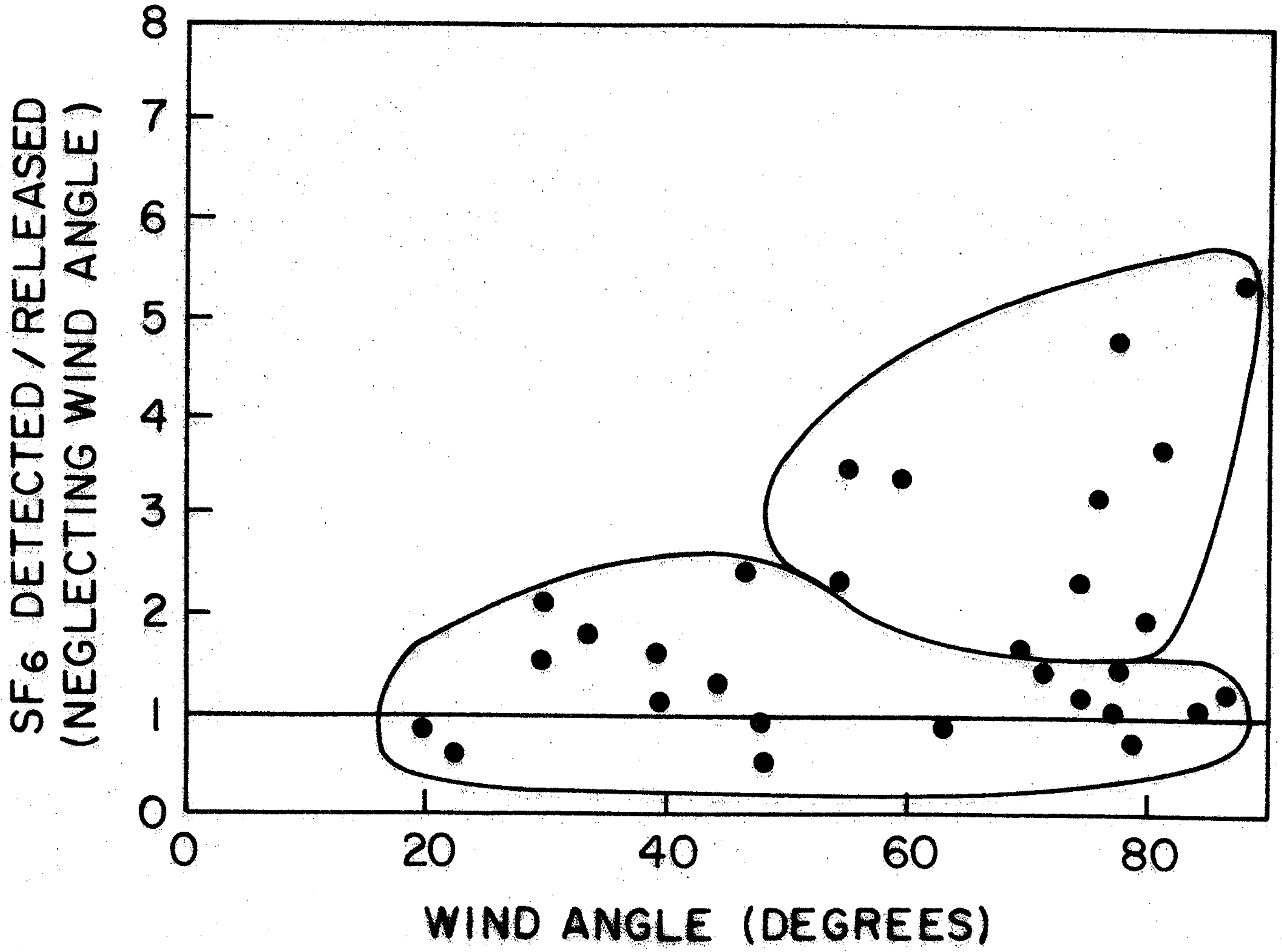


Figure 16

SF_6 Mass Balance Ratios versus Wind Angle
for Research Annex Site
(Ratios calculated using total horizontal
wind speed, U)

concentration along the tower. This suggests that the plume from the truck with the SF_6 rose rapidly, passed the tower near the top and was dispersed comparatively very little to the lower levels. In other cases, the plume seemed to pass the tower near its midsection since the concentrations were much higher in the middle than at either end of the tower. These experiments were performed in July and August when the weather was very hot. The concrete runway could cause intense heating of the air above the runway and subsequent large vertical movement of the air. The vertical anemometers on the tower verified that this was occuring.

Close examination of the Research Annex data showed that most of the points with a mass balance ratio over 2.0 on both Figures 15 and 16 were all of the points from 3 runs. Without these points the annex data produced the expected line of magnitude, 1.0, as shown in Figure 16. The data were then closely examined back to the original values including the instantaneous meteorological data.

Differences found between the two groups were in the SF_6 concentration profiles and vertical wind speed data. Theoretical concentration profiles were simulated using the TXLINE dispersion model. The profiles from the cases in mass balance (lower group in Figure 16) matched the model results closely. The cases with high ratios (upper group) had concentrations shifted upward and in excess of the simulated values. The vertical wind speeds were compared at various heights and the cases out of mass balance appeared to have much more active conditions. Classification of the data by a stability parameter was the next step.

The two quantitative parameters used to determine stability are the Z/L ratio (Z, height; L, Monin-Obukhov length) and the Richardson number. The Z/L ratio is the preferred parameter but is usually hard to determine. However, due to the exceptional quality of the Texas A&M data acquistion system Z/L parameters could be calculated from the vertical anemometer data. Using the auto-correlation function from one second samples of the vertical wind speed the method developed by P.K. Misra, 1979 was applied to find the Z/L values listed in Table 13. The Z/L values plotted against the mass balance ratios are shown in Figure 17. A positive Z/L represents stable conditions, while negative values represent unstable conditions. A Z/L near zero indicates a neutral condition.

The most obvious fact about the data is that most of the points are clustered about Z/L = 0 and Detected/Release = 1. Another point which should be noted is that only two data cases which did not balance were at neutral or slightly unstable conditions. This indicates that a neutral stability may be required for

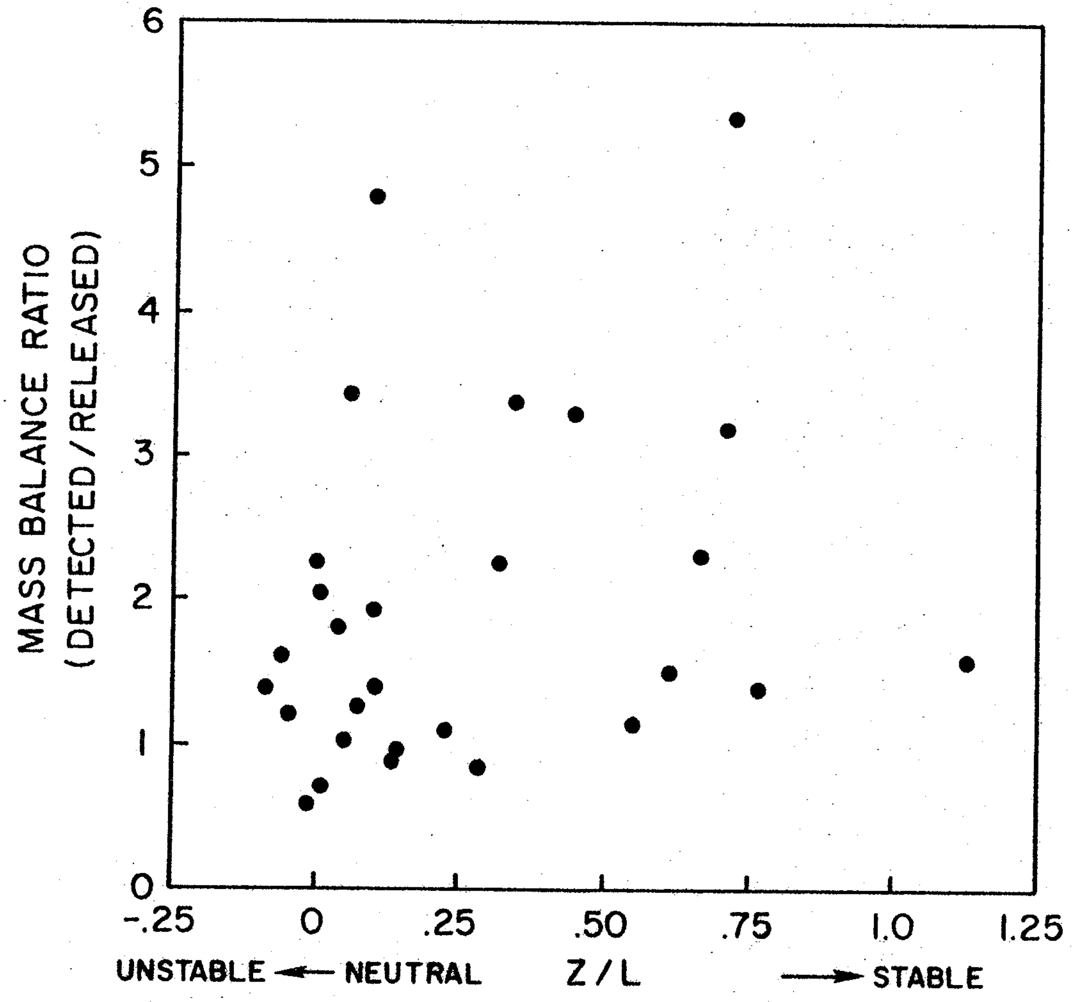


Figure 17

SF_6 Mass Balance Ratios versus Stability for Research Annex Site (Ratios calculated using total horizontal wind speed, U) application of the mass balance technique when the release occurs at relatively long intervals. If the tracer gas was released as a constant line source and if the tower was sufficiently tall to completely enclose the plume, only small fluctuations in the Detected/Released ratio should occur. In the present work only one release vehicle was used. This resulted in 16, 26 and 20 passes by the sampling tower for the College Station, Research Annex and Houston sites respectively.

The results from the tracer gas experiments at the Houston site are also given in Appendix C. These results showed that in almost every single 15-minute experiment, large concentrations of SF_6 were found on the upwind tower. As shown in Figure 3, this tower was about 120 ft upwind of Woodway Drive along which the SF_6 was emitted. In several cases the upwind concentration was greater than the downwind values. The only possible explanation for this behavior is that the large buildings near the intersection caused large amounts of backmixing where the SF_6 would be carried upwind. Tracer gas concentrations as high as 20 to 25 ppb commonly occurred at the Houston site. The concentrations at the other two sites were usually no more than 4 to 6 ppb. The large vertical wind speeds of 2 to 4 miles/hr (15-minute average) showed that very strong updrafts existed at almost all times during the experiments. This strong vertical movement was probably due to the very large buildings near the intersection. Due to the large upwind tracer gas concentrations, the mass balance calculations could not be performed for this site.

These tracer gas experiments should serve as a basis for extended study for several years to come. At this time, many questions about the diffusion, transport and concentration profiles still remain. The project staff were well aware of the unusual character of the data as it was being taken. As a result, the methods and practices were checked and doublechecked time and again. As mentioned in the experimental methods section, the calibration gas was checked by two different methods and was found to be correct. In addition, the soap bubble flow metering of the release rate was checked by weighting the cylinder before and after a release and was found to be in excellent agreement. All of the other experimental techniques were analyzed in the greatest of detail and found to be good. Thus, the project staff strongly believe the results are representative of the atmospheric processes which were occurring at the different sites.

Aerosol Results: The health effects of various size aerosols has become more known. In the breathing process, particles larger than 10 m are usually removed in the nasal chamber. Smaller particles penetrate the respiratory system to varying depths and may require long periods for removal.

In urban areas, vehicular traffic along streets has been recognized as a significant source of suspended particles or aerosols. The sources of the aerosols include engine emissions, vehicle wear and street surface erosion. As a vehicle travels along a street, aerosols emitted by the vehicle along with aerosols on the street become airborne. The aerosols then undergo a complex settling and dispersion process. The aerosols which settle back onto the street are resuspended by other vehicles until they are carried from the street by the wind, rain or street sweeping.

As a part of a study by Bullin, et al. (1982) on vehicle emissions near street intersections sponsored by the Texas State Department of Highways and Public Transportation, aerosol samples were collected at an intersection in College Station and in Houston. The aerosol results from the study are reported in this paper.

Total Suspended Particles: The national primary ambient air quality standards for total suspended particulate (TSP) matter are as follows: 75 $\mu g/m^3$, annual geometric mean; 260 $\mu g/m^3$, maximum 24 hr concentration not to be exceeded more than once a year. These standards use high-volume samplers as the reference method for measuring aerosol levels. In the current study, the TSP levels were measured only by the stacked filter units (SFU). In a previous study, Bullin and Moe (1982a) found that, near roadways, the TSP by SFU was 0.62 ± 0.10 times the TSP by high volume sampler. The lower SFU capture rate is expected since the SFU's capture particles 20 μm in diameter and smaller, while the high volume samples capture particles up to 100 m and larger.

At both the College Station and Houston sites, the TSP by SFU was generally in the range of 30-120 $\mu g/m^3$. Using the SFU/Hivol factor of 0.62, this range would correspond to 50-195 $\mu g/m^3$ for a high volume sampler. Bullin and Moe (1982b) found the TSP along expressways in Texas to be in the range of 80-150 $\mu g/m^3$ by high volume sampler and 40-90 $\mu g/m^3$ by SFU. All of the above aerosol samples including the present work were taken during daylight hours and usually during morning or evening heavy-traffic periods.

In the present study, the contribution of the streets to the TSP was in the range of 10 to 60 $\mu g/m^3$ based on SFU's. At the Houston site, building construction in the area contributed significantly to the TSP as evidenced by the high Ca levels. This will be discussed further in the section on element ratios.

TSP and Element Profiles: Aerosol data from five days at the Houston site were used to draw horizontal and vertical concentration profiles for lead, bromine, iron and TSP. With only one exception, the upwind vertical concentration profiles of lead, bromine, iron and TSP were flat to within about 25%. Representative vertical profiles for TSP at Tower 2 which was 10 ft downwind of Woodway Dr. in Houston are shown in Figure 18. Both the vertical and horizontal mixing at the Houston site were very good. Thus, by the time the air flow had reached T3 which was 95 ft downwind of Woodway, the vertical profiles had flattened considerably. The iron profiles closely resembled the TSP profiles.

The vertical anemometers at the Houston site and the SF_6 tracer gas experiments confirmed the high degree of mixing. Vertical wind speeds ranging up to 2.0 mph were commonly observed. The SF_6 was released along Woodway Drive. The SF_6 concentration on T1 which was 120 ft upwind of Woodway was almost always nearly equal to the levels at T2 and T3 which were 10 ft and 95 ft downwind, respectively. The vertical SF_6 profiles at all towers were nearly flat. This high level of mixing was believed to be due to the air turbulence and updrafts created by the tall buildings near the intersection. At the College Station site, only extremely small traces of SF_6 were occasionally detected at the tower which was 135 ft upwind.

Representative vertical profiles for lead at the Houston site are shown in Figure 19 for T2. Since this tower was only 10 ft from Woodway, the largest vertical

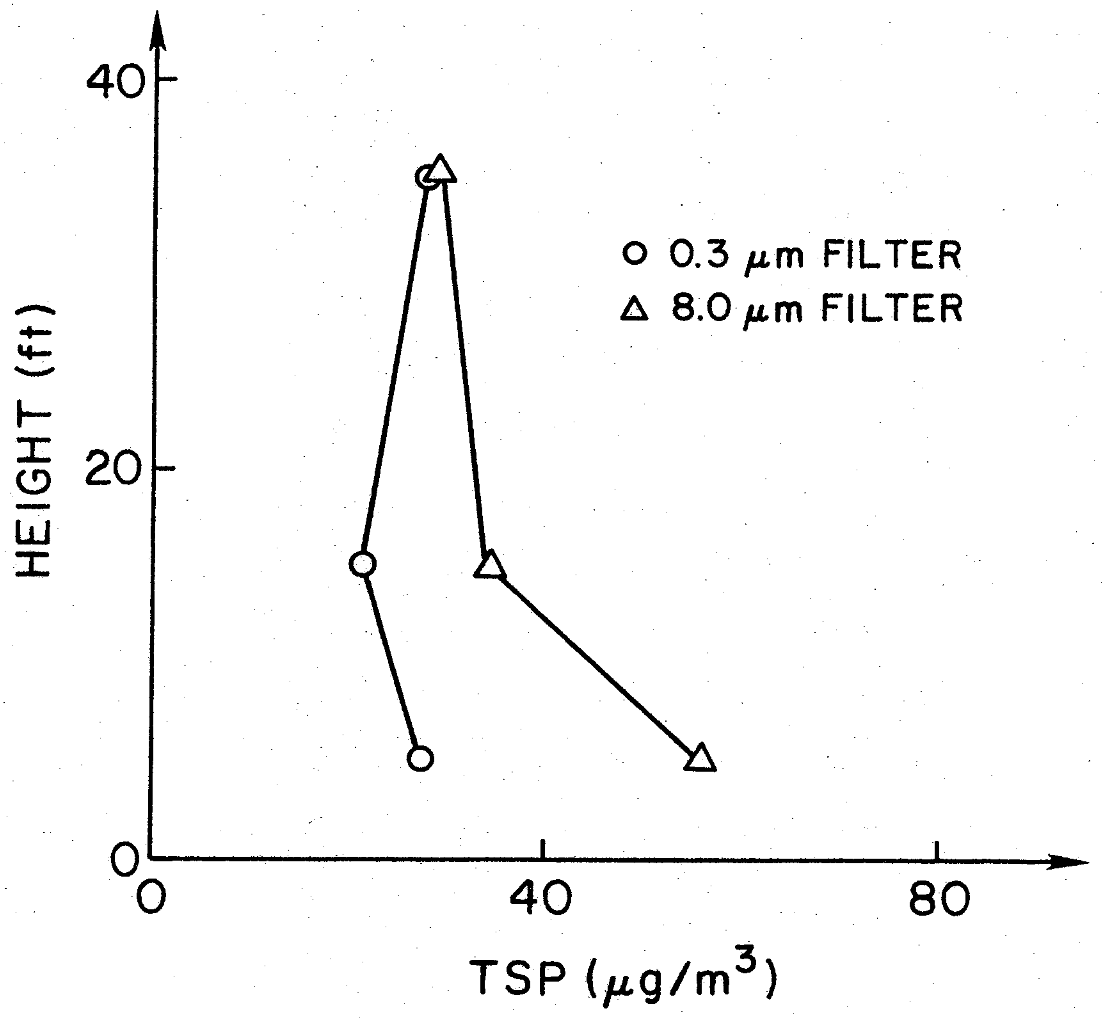


Figure 18. Vertical TSP Profiles, Houston, 10/30/81

gradients were observed there. However, due to the strong vertical mixing, these vertical gradients were quite subdued. The bromine vertical profile closely resembled the lead profile. At the College Station site, the vertical profiles upwind and downwind of Texas Avenue were very similar. The downwind values were about 20% larger than the upwind values.

Typical horizontal profiles for TSP at the Houston site are shown in Figure 20. The fine TSP was almost constant from 120 ft upwind to 95 ft downwind of Woodway. The maximum change in either the vertical or horizontal directions was only about 20%. Thus, the net effect of vehicular traffic on fine aerosols appeared to be negligible, probably due to the tremendous vertical and horizontal mixing. However, the coarse TSP, from upwind to downwind, increased by a factor of up to about four at the 5 ft height. As expected, the horizontal variation was much less at the 35 ft height. Thus, at the Houston site, the apparent net contribution of the traffic on the streets was primarily to the coarse TSP concentrations.

The horizontal lead profiles were an interesting contrast to the horizontal TSP profiles. Representative lead profiles from the Houston site are shown in Figure 21. In general, the coarse lead horizontal profiles were constant to within about 30%. On the other hand, the fine lead at the 5 ft height, downwind

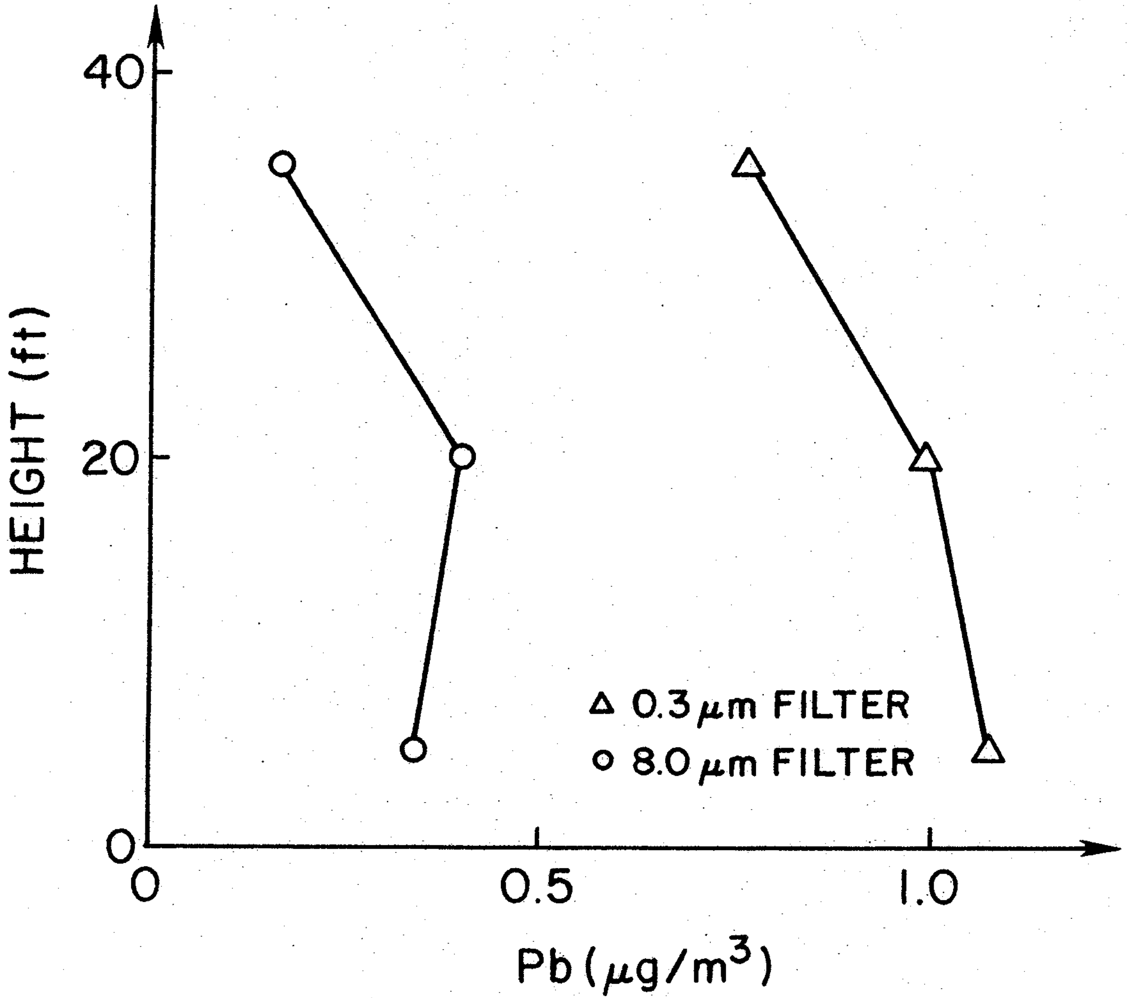


Figure 19. Vertical Pb Profiles, Houston, 9/28/81

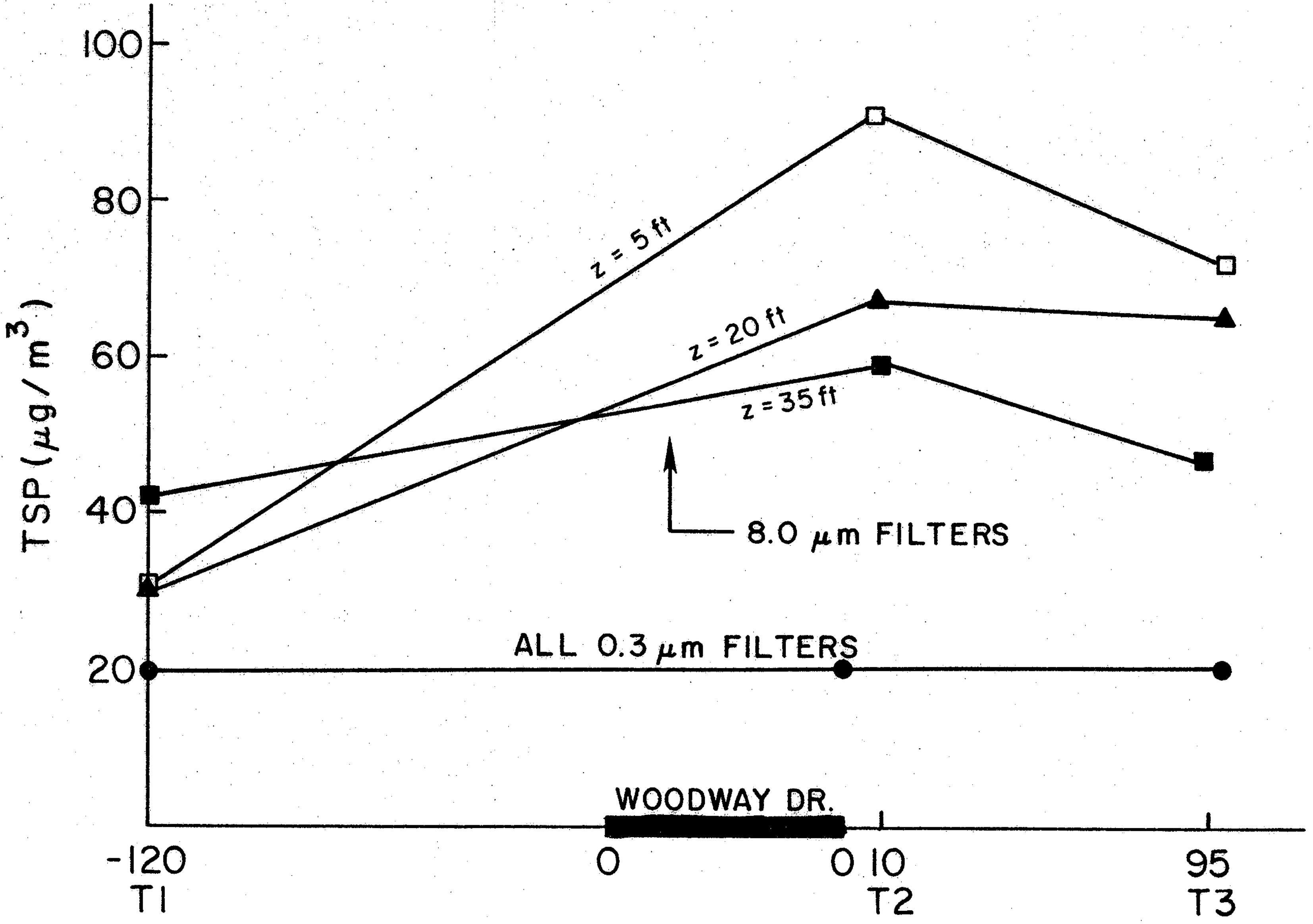
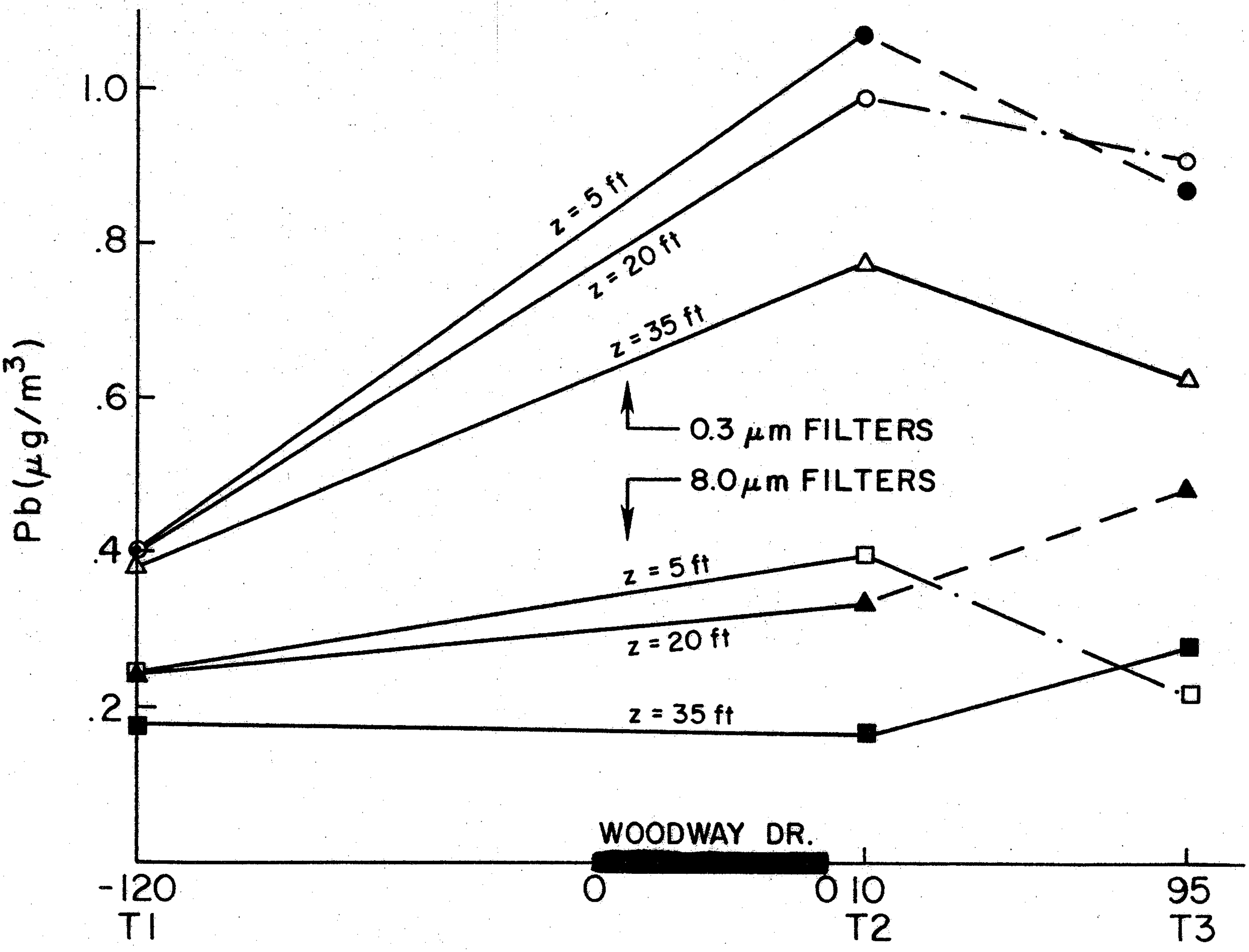


Figure 20. Horizontal TSP Profiles, Houston, 10/15/81

of Woodway was usually 2 to 5 times higher than the upwind value. In most cases the fine lead had dispersed quite well by the time it was transported to Tower 3, 95 ft downwind. At Tower 1 (upwind), the fine lead concentration was usually about equal to the coarse lead. However, downwind of Woodway the fine lead was about 2 to 4 times higher than the coarse lead. According to Friedlander (1972), vehicular emissions are the predominate source of lead. This, of course, applies to areas away from smelters and industrial users of lead. Although the lead concentrations were moderate, the vehicular traffic on Woodway was found to be a significant source of lead near the intersection.

Element Ratios: Selected element ratios from the study are presented in Table 14. The soil related and Br/Pb ratios for the coarse and fine TSP from the Houston site are compared to values calculated by Flocchini, et al. (1976) for aerosols >3.6 μm and to values for soil dust determined by Miller (1972). The values presented by Flocchini, et al. were determined from extensive aerosol sampling in the different geographic areas of California. The values reported by Miller are also based on California soils.



DISTANCE FROM WOODWAY DR. (ft)

Figure 21. Horizontal Pb Profiles, Houston, 9/28/81

Table 14
Comparison of Various Element Ratios to Literature Values

Element Ratio	Averages for Houston Data 8.0 µm	0.3 µm	Flocchini, et al. (8) avg for >3.6 µm	Miller (9) Soil Dust
Al/Si	0.23	0.59	0.28	0.41
K/Si	0.061	0.28	0.095	0.075
Ca/Si	0.97	0.51	0.20	0.075
Ti/Si	0.025	0.15	0.027	0.02
Mn/Si	0.020	0.13	0.008	0.0055
Fe/Si	0.22	0.32	0.285	0.16
Br/Pb	0.58	0.34	–	–

As can be seen from Table 14, good agreement was found between the ratios from the current study for the coarse aerosols and the ratios reported by Flocchini, et al. except for Ca and Mn. The high Ca at the Houston site was believed to be due to the large amount of building construction in the area. The ratios K/Si, Ti/Si and Fe/Si for coarse aerosols from the present work agreed closely with the soil dust ratios presented by Miller.

The Br/Pb ratio for the fine aerosols was 0.34 compared to the value of 0.33 reported by Feeney, et al. (1975) for <5 μm aerosols. Miller found no Br and only 200 ppm Pb in the soil dust. The Br/Pb from fine aerosols has been accepted (10) as a good traffic related tracer. The above Br/Pb ratio indicates that the fine aerosols at the Houston site are strongly traffic related.

Summary of Aerosol Results: Aerosol samples were collected using stacked filter units at two urban intersections in Texas. The TSP levels were generally in the range of 30-120 $\mu g/m^3$. This is equivalent to about 50-195 $\mu g/m^3$ for a high volume sampler. All samples were collected during daylight hours and usually included one rush-hour period. The contribution of the street traffic to the TSP was in the range of 10 to 60 $\mu g/m^3$.

Vertical TSP and element profiles were nearly flat at the intersection in Houston and indicated very strong vertical mixing. The high degree of mixing was also confirmed by large vertical wind speeds and by sulfur hexafluoride tracer gas experiments. Horizontal concentration profiles showed that the fine TSP was almost constant from 120 ft upwind to 95 ft downwind of the intersection. This was also probably due to the intense mixing. Horizontal fine lead profiles showed that the traffic was a significant source of fine lead.

Selected element ratios showed that the coarse aerosols were strongly soil related. A very high Ca/Si ratio of 0.97 for the coarse aerosols confirmed the large amount of construction in the area. A Br/Pb ratio of 0.34 indicated that the fine aerosols near the intersection were strongly traffic related.

Discussion of Modelling Results

The Texas A&M - College Station data were chosen as the principal basis for the modeling work. The data were found to be the most comprehensive available due to the simultaneous nature of the traffic, pollution, and meteorological measurements. Also, the data were acquired by the authors along with others in the roadway air quality group at Texas A&M and therefore were readily available and well understood. In later stages of this study, the California and Houston data became available and were utilized. Analysis of the raw data in these three data bases is described below with a discussion of the input parameters involved.

Comparison to College Station Data:

The methods by which the input parameters were specified for each of the models were made as consistent as possible to properly compare the results. The observation was made that minimizing the number and complexity of the required inputs would also be a strong advantage for a new model. For these reasons, a description of the input parameters for each model application to the Texas A&M - College Station data is given below. The inputs which were common to all models are summarized first and the input data particular to each model are discussed afterwards.

Input Conventions:

The wind speed and wind direction were required by all models, and the ambient temperature was required by all but MICRO. Stability class was also a primary requirement for all four models in question. To obtain this parameter, the average wind speed and the incoming solar radiation (as a measurement of insolation) were used in Pasquill's analysis of atmospheric stability (Pasquill, 1974).

A value of 1000 meters was used as the mixing layer height in all cases as there were no special nocturnal inversions in the College Station data base. The roughness height was determined using Myrup and Ranzieri's table of suggested surface roughness values as given in the CALINE-3 User's Guide (Benson, 1979). The input variables pertaining to the VMT mix and the operating mix (% cold starts, hot starts, etc.) were county-wide values obtained from the Texas State Department of Highways and Public Transportation (TSDPT, 1981). (These values were not required by MICRO.)

The IMM required by far the most extensive input data. The model treats each lane of traffic as a separate finite line source (or link). Consequently, the signalization for each lane (type of control, number, and length of phases, etc.) must be determined and supplied to the model. For *each* phase of the cycle, a description of *each* lane approaching the intersection must also be specified. Along with the geometry of each link, the volume, velocity into and acceleration out of the intersection must also be supplied. The acceleration data were not collected in the TAMU study, but reasonable values were estimated from the data. For the average user, obtaining reasonable estimates would be difficult. The lane capacity for each approach link must also be supplied.

The geometry of the links leaving the intersection must also be specified, but only the volume and velocity on these links need to be input in addition. The fractional volumes per lane for all links are also required and would need to be estimated by the user. However, the College Station data contained the necessary volumes by lane.

Minor modifications to the input/output routines of the IMM program were necessary to enable the simulation of all 15-minute sampling periods in one run. (The IMM is an extremely long program and repetitive compilation would have been excessively expensive.)

The MICRO program required little input due to the fact that a vast majority of the required variables are set internally to "reasonable" values. The only input data required are volume counts for the through and turning traffic on the four approach links and the type of signalization involved (type of control, number, and length of phases). The remaining variables, such as vehicle speeds, link geometry, wind speed, wind direction, receptor locations, etc., are generated internally. Minor modifications to the input/output routines allowed the actual measured values for these variables to be used and for the simulation of all the cases to be performed in one run.

The TEXIN Model required only the approach volumes and fractions turning on the four links, the number of phases and the total cycle length of the signal in addition to the common inputs. It should be noted that the other inputs required (which were common to all models) are generally those inputs required by the CALINE-3 and MOBILE-2 programs.

Statistical Comparison of Models:

The Intersection Midblock Model (IMM), the program MICRO, and the TEXIN Model were each used to simulate the 153 15-minute average sampling periods of the Texas A&M - College Station data. Scattergrams of predicted versus observed values are presented in Figures 22-24 and a comparison summary of the regressions obtained is shown in Table 15. Figure 25 presents a comparison of these regressions in graphical form. The large degree of scatter present in all of the models is due to the difficult nature of the intersection pollution problem and explains the reluctance of many highway design engineers to place much confidence in such simulations.

Examination of the statistics in Table 15 revealed that the TEXIN Model is somewhat better than the IMM and much better than MICRO for the simple signalized case under consideration. MICRO exhibited by far the worst performance of the three models. MICRO consistently underpredicted with an average error of -1.16 ppm. The slope of the regression line for MICRO was relatively flat (0.234) indicating poor

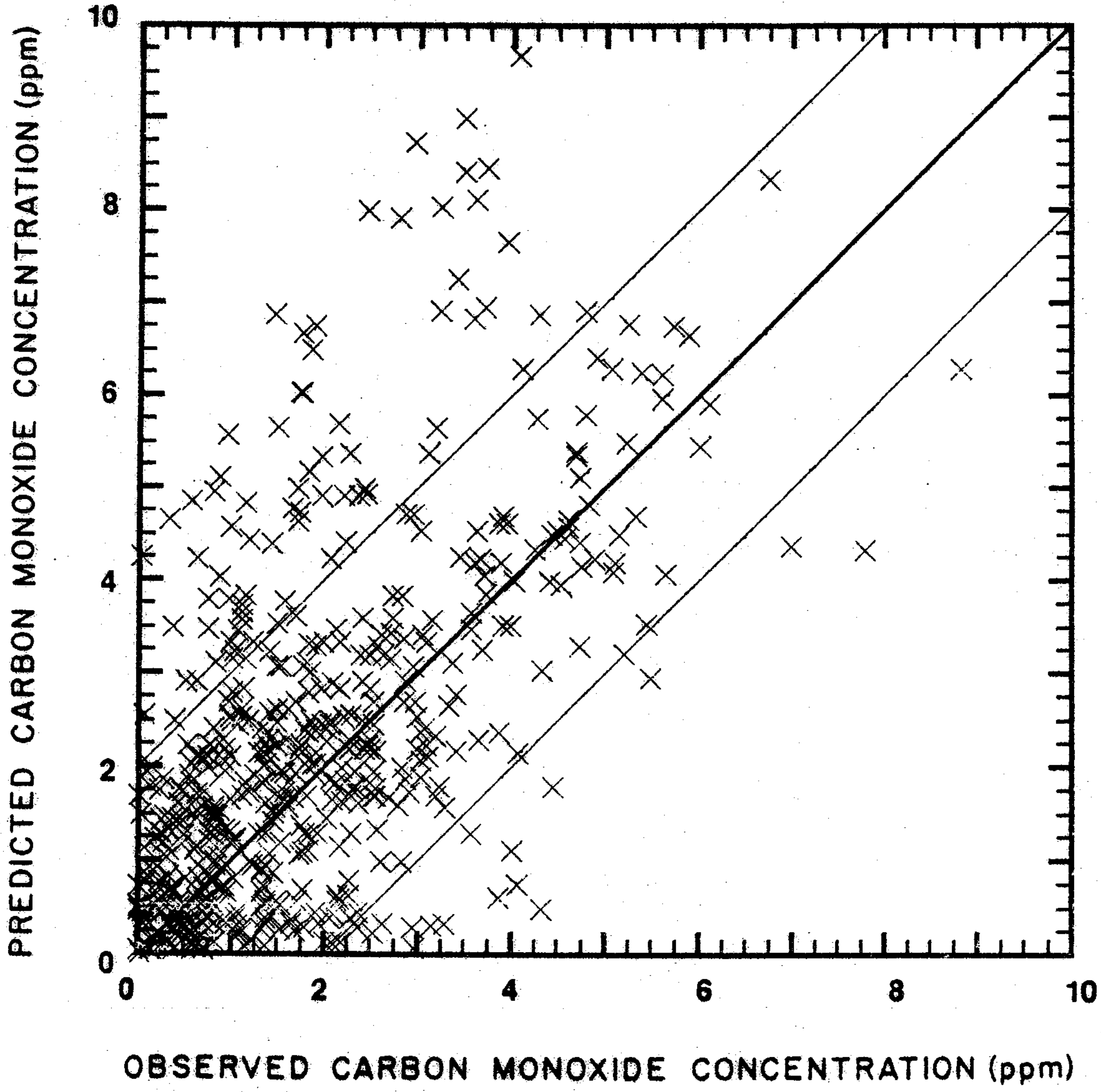


Figure 22
Scattergram of Predicted versus Observed CO
Concentrations for the IMM using the Texas
A&M-College Station Data

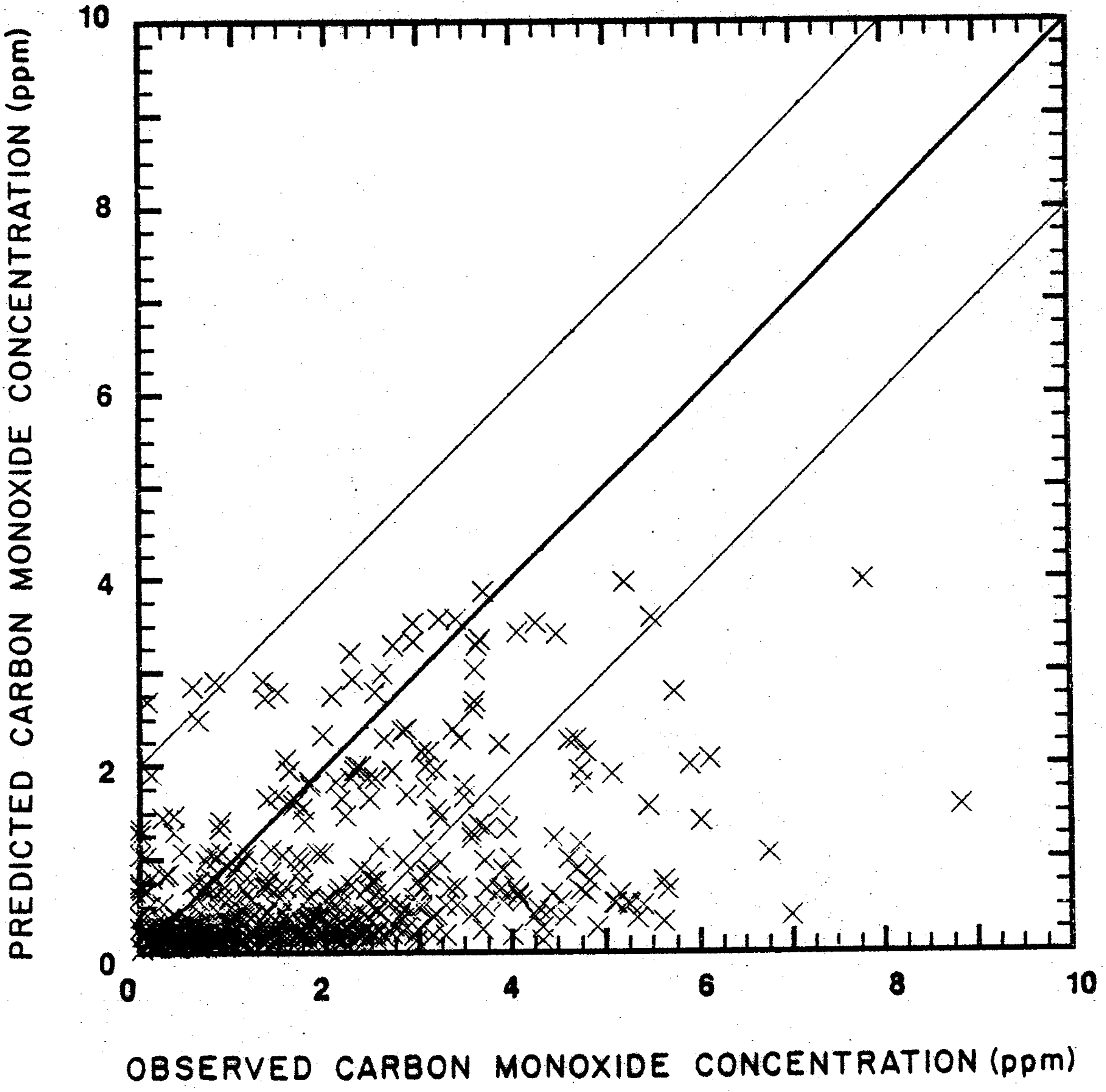


Figure E3
Scattergram of Predicted versus Observed CO
Concentrations for MICRO Using the Texas A&M-
College Station Data

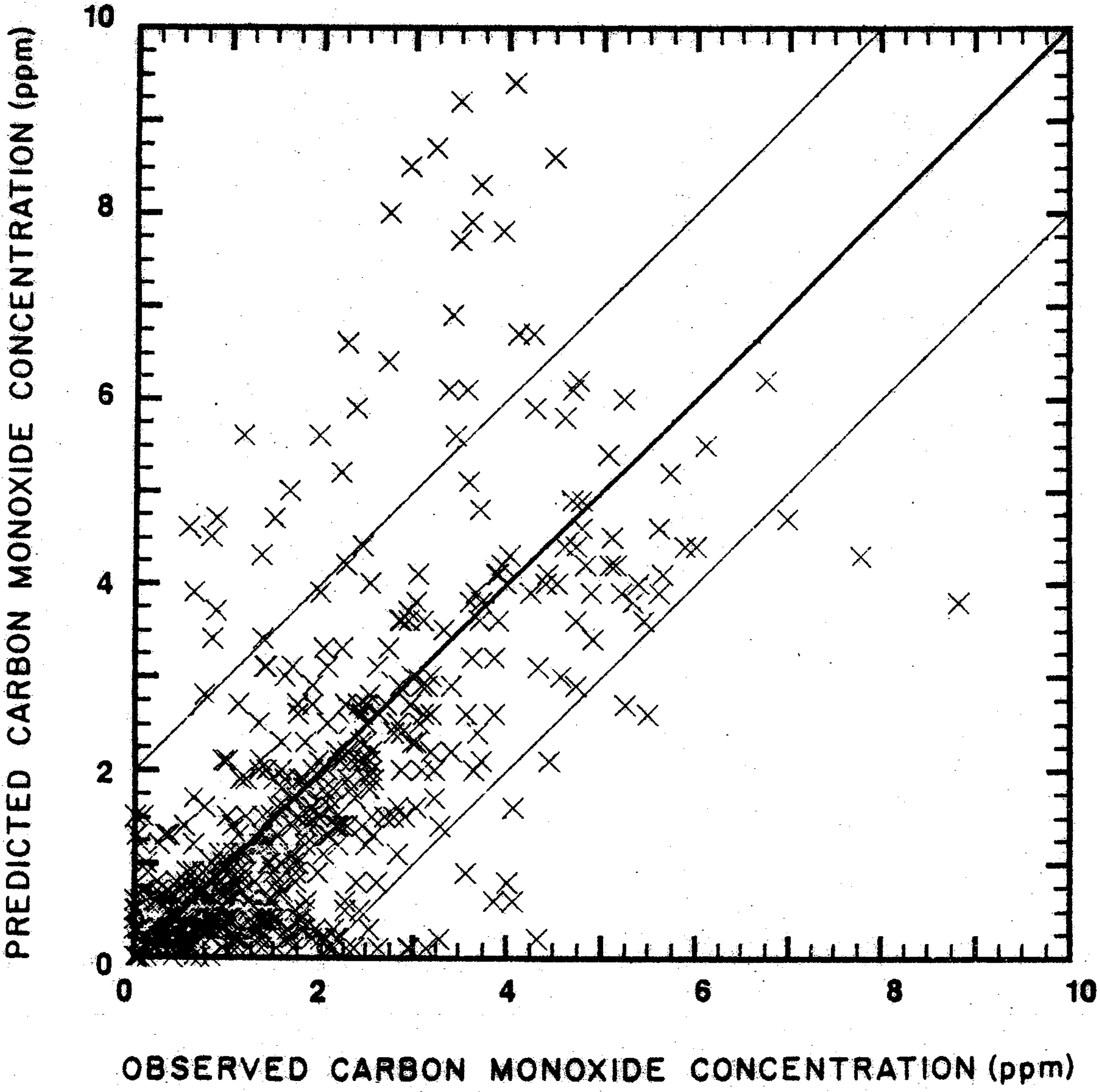


Figure 24

Scattergram of Predicted versus Observed CO Concentrations for the TEXIN Model Using the Texas A&M-College Station Data

Table 15

Statistical Results for Model Comparisons

Statistic	TEXIN	IMM	MICRO	
Slope	0.85±0.04	0.81±0.04	0.23±0.02	
Intercept (ppm)	0.14±0.09	0.80±0.10	0.26±0.05	
r^2	0.469	0.373	0.182	
Av.Sq.Er. (ppm^2)	1.80	2.67	3.12	
Avg. Error (ppm)	-0.140	0.474	-1.16	*
No. of Points:				
Total	539	539	539	
Within 2 ppm	482(89.4%)	446(82.8%)	418(77.6%)	
Within 1 ppm	380(70.5%)	327(60.7%)	277(51.4%)	
Slope	0.89±0.05			
Intercept (ppm)	1.0±0.2			
r^2	0.470			
Av.Sq.Er. (ppm^2)	4.43			
Avg. Error (ppm)	0.73			**
No. of Points:				
Total	295			
Within 2 ppm	220(75%)			
Within 1 ppm	139(47%)			
Slope	1.11±0.01			
Intercept (ppm)	-0.01±0.02			
r^2	0.495			
Av.Sq.Er. (ppm^2)	1.99			
Avg. Error (ppm)	0.084			***
No. of Points:				
Total	6164			
Within 2 ppm	5549(90.0%)			
Within 1 ppm	4851(78.7%)			

*College Station data

**Houston data

***Sacramento data

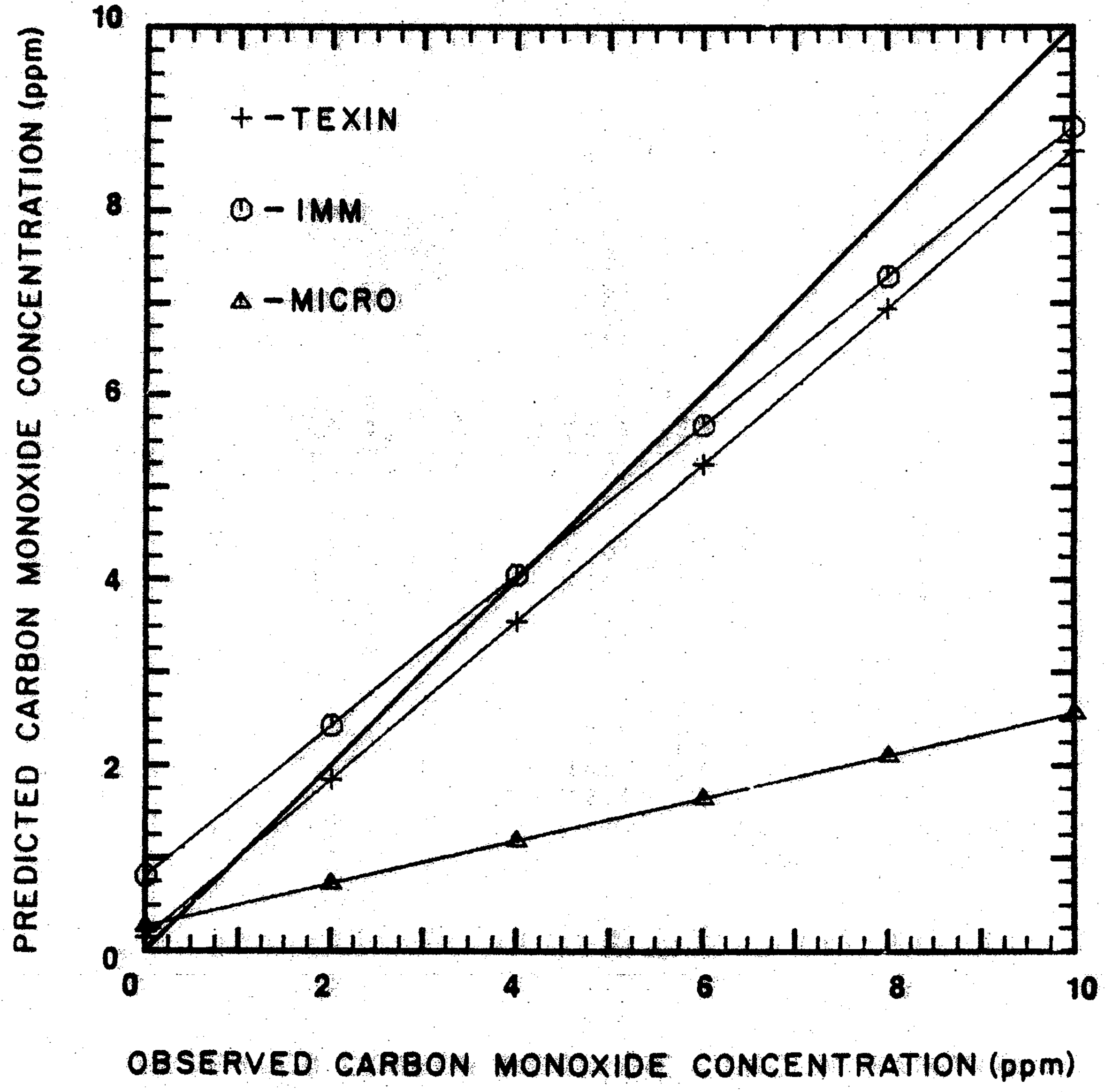


Figure 25
Regression Lines for the TEXIN Model, the
IMM and MICRO Using the Texas A&M-College
Station Data

performance.

The TEXIN Model and the IMM regression lines had similar slopes. The IMM tended to overpredict with an average error of 0.474 ppm while the TEXIN Model had a tendency to slightly underpredict (average error of -0.140 ppm). The TEXIN Model had both a higher correlation coefficient and a lower average squared error than the IMM.

As mentioned previously, the Indirect Source Guidelines were also selected for use in this study. The procedure outlined in the Guidelines is a manual procedure, and thus it was not feasible to model all 153 cases. Several 15-minute sampling periods were chosen to represent a wide spectrum of wind speeds and directions. The cases selected were accurately modelled by both the IMM and TEXIN Model. The results of these selected cases are presented in Table 16.

As can be seen from the table, the Guidelines consistently overpredicted CO concentrations by a factor of three to five for receptors at the 5 and 15 foot (1.52 and 4.57 m) levels. For receptors at the 35 foot (10.67 m) level, the Guidelines consistently underpredicted CO levels.

The major reason for the general overprediction of the Indirect Source Guidelines involves the philosophy of the guidelines. The predictions are conservative in nature due to the fact that the purpose of the

Table 16

Comparison of Indirect Source Guidelines predictions for selected Texas A&M data cases

Sampling Period	Receptor:	Tower 1			Tower 2		
	Level (ft):	5.00	15.0	35.0	5.00	15.0	35.0
03/11/80@1430	Predicted:	16.8	4.5	0.1	13.0	4.1	0.1
	Observed:	5.0	3.2	1.9	3.1	2.1	1.4
03/11/80@1445	Predicted:	21.5	6.2	0.1	17.1	5.8	0.0
	Observed:	3.9	2.3	1.5	4.5	3.3	1.6
03/11/80@1500	Predicted:	29.9	8.6	0.1	22.0	7.4	0.1
	Observed:	3.6	2.2	1.5	3.9	2.8	1.4
05/12/80@0945	Predicted:	5.8	3.2	0.1	4.9	2.9	0.1
	Observed:	1.7	0.9	0.4	1.8	1.3	1.1
05/12/80@1000	Predicted:	6.3	3.4	0.1	5.0	2.9	0.1
	Observed:	1.7	0.9	0.5	1.7	1.3	1.1
08/05/81@1430	Predicted:	12.1	4.2	0.1	12.8	4.3	0.1
	Observed:	4.7	2.8	1.4	3.0	1.4	1.7
08/05/81@1445	Predicted:	12.7	3.9	0.1	13.5	4.3	0.1
	Observed:	4.0	2.5	---	2.8	1.2	1.9
18/05/81@1412	Predicted:	18.2	4.9	0.1	12.8	4.1	0.1
	Observed:	5.6	2.6	1.5	2.7	0.9	0.7
18/05/81@1427	Predicted:	15.7	4.3	0.1	11.1	3.5	0.1
	Observed:	4.4	2.2	0.9	2.4	0.6	0.3

*Concentration in parts per million.

guidelines was to present a screening procedure for initial testing of intersections. The Guidelines thus should not be generally used as a predictive tool.

To further evaluate the performance of the TEXIN Model and IMM, the effects of wind speed and direction on the models' accuracy were analyzed. This was accomplished by stratifying the data by wind speed and wind angle. Three wind speed classes were chosen: low (0 to 2 m/s), medium (2 to 4 m/s), and high (above 4 m/s); and three wind angle classes were chosen: near-parallel (0° to 30°) to the roadway, near-forty-five degree (30° to 60°) to the roadway, and near-perpendicular (60° to 90°) to the roadway. These categories yielded nine distinct wind speed/wind angle combinations.

Scattergrams of predicted versus observed CO concentrations for the nine wind speed/wind angle categories were produced for both the IMM and the TEXIN Model. No plots were made for MICRO or the Indirect Source Guidelines due to their poor overall performances. The scattergrams for the nine categories revealed that the models' accuracy does not appear to depend upon wind angle.

For high wind speeds, at all wind angles, the models predicted best with practically all of the points falling within 2 ppm. For medium wind speeds, though, there was increased scatter with more points lying outside the 2 ppm lines; and for low wind speeds, even more points fall outside the 2 ppm lines. While both models produce increased scatter in their results as the wind speed decreases, the IMM also exhibited a tendency to overpredict for lower wind speeds with a majority of the points falling above the forty-five degree line for the low and medium wind speed classes.

Neither the TEXIN Model nor the IMM varied significantly in accuracy with respect to the receptor location. Additionally, the two models accurately predicted the CO levels for the 5 and 15 foot (1.52 and 4.67 m) level receptors. For the receptors at the 35 foot (10.67 m) level, however, the models underpredicted.

Comparison to California Data:

The TEXIN Model was the only model used to simulate the CALTRANS Sacramento data. MICRO and the Indirect Source Guidelines were not used due to their poor performance in modelling the College Station data, and the Intersection Midblock Model was not used due to the prohibitive computer cost of applying it to the large California data base of 6164 total points.

The TEXIN Model's performance for the California data was similar to that for the Texas A&M - College Station data. Statistically, the slopes of the regression lines are near unity and the intercepts are near zero for both comparisons. The regression coefficients and the average squared errors are also approximately equal for the two data bases. The percentage of points within one and two ppm are about the same for both cases. The general appearance of the two scattergrams was nearly identical.

The California simulations were also separated into the nine wind speed/wind angle combinations mentioned previously. Again, the accuracy of the TEXIN Model showed no dependence on wind angle and was best at higher wind speeds. The TEXIN Model also accurately predicted CO levels for both the 10 and 15 meter receptors at the California site in contrast to its poor performance for the 35 foot (10.67 m) receptors at the College Station site.

Late in the study, the Texas A&M - Houston data was made available for use. Only the TEXIN Model was used to simulate the Houston data for the same reasons presented previously for the California data. Although 5, 15 and 60-minute averages were available, only the 60-minute averages were utilized.

The Houston site differed from the other two sites with respect to the surrounding topography. The Houston site was surrounded by extremely tall buildings. However, the location of the buildings with respect to the intersection was such that a true street canyon situation did not exist. The results from the comparison to the Houston data differ surprisingly little from the previous two data bases, as can be seen in Table 15. The slopes, intercepts, and regression coefficients are similar for all three analyses. The average error and average squared error, however, are higher for the Houston results.

The Houston simulations were also separated into the nine wind speed/wind angle combinations. Again, the TEXIN Model accuracy showed no dependence on wind angle and the model predicted best at higher wind speeds. As with the California results, the model predicted equally well for the 5, 20, and 35 foot (1.5, 6.1, and 10.7 m) receptors. The TEXIN Model also predicted CO levels equally well for Towers 2, 3, and 4; and yet, the location of the three towers differed vastly with respect to the intersection.

Further Comparisons of Models:

One factor of particular interest not shown in Table 17 is the computer requirements for implementation of the three computer models. The programs were run on an Amdahl 470/V6/V8 computer with a Fortran H (Extended) compiler.

Table 17 gives the core space and time required to compile and execute the three models for a single simulation run. These values are for a representative run and will vary somewhat for different scenarios. As

Table 17

Computer requirements for the TEXIN Model, the IMM and MICRO (single simulation)

	TEXIN	IMM	MICRO
Compile:			
Core Space (bytes)	184 K	252 K	132 K
Time (C.P.U. sec)	5.13	7.28	1.64
Execute:			
Core space (bytes)	160 K	288 K	120 K
Time (C.P.U. sec)	0.58	6.74	0.60

can be seen from the table, the IMM requires by far the most time to execute. The ratio of the IMM's execution time to the TEXIN Model's execution time is 11.6.

This ratio increases dramatically as the number of simulations is increased. As can be seen from execution times given in Table 18, the time per simulation for IMM remains essentially constant as the number of simulations is increased, while it decreases dramatically for the TEXIN Model.

The TEXIN Model also requires considerably fewer inputs than the Intersection Midblock Model. A sample input file fo the TEXIN Model consists of eight or nine input data cards (depending on the scenario being modelled). A corresponding input file for the IMM would consist of well over 70 input data cards.

Summary of Modelling Work:

A comparison of four roadway intersection pollution models to experimental data has been presented. The models included the newly developed TEXIN Model, the Intersection Midblock Model (IMM), MICRO and the EPA's Indirect Source Guidelines. Experimental data from two intersections in Texas and one in California were used to evaluate the models. The TEXIN Model was found to give the best performance in terms of comparison to the data, ease of usage and computer run time. The IMM compared reasonably well to the data,

Table 18

Computer execution times required by the TEXIN Model and the IMM (multiple simulation runs)

	Number of Simulations			
	1	3	10	100
TEXIN:				
Total time (C.P.U. sec)	0.58	0.77	1.46	15.0
Time per simulation	0.58	0.26	0.15	0.15
IMM:				
Total time (C.P.U. sec)	6.74	21.0	63.1	----
Time per simulation	6.74	7.01	6.31	----
Ratio (IMM/TEXIN)	11.6	27.3	43.2	----

but required an order of magnitude more input information and computer time than the TEXIN Model.

MICRO underpredicted the carbon monoxide levels by a factor of 3 to 5 while the Indirect Source Guidelines overpredicted by a factor of 3 to 5. Thus, both of these models were considered unsuitable for intersection pollution analysis. The Indirect Source Guidelines were developed to serve only as a screening tool for pollution problems.

The accuracy of both the TEXIN Model and IMM was found to be independent of wind angle and receptor location. Both models performed best at high wind speeds with increased scatter at lower wind speeds.

Chapter VII

Summary and Conclusions

Air quality measurements were made at an intersection in College Station, Texas, and one in Houston, Texas. The College Station site consisted mainly of single-story residential and small businesses while the Houston site consisted primarily of multi-story buildings. Carbon monoxide and detailed meteorological measurements were made at each site. Traffic measurements were made using loop detectors. In addition, aerosol samples were collected at these sites. Several SF_6 tracer gas experiments were also conducted at each of the sites.

The one-hour carbon monoxide concentration average was usually in the range of 2 to 6 ppm and the maximum one-hour average was about 14 ppm. The maximum instantaneous values occurred at the Houston site and were about 28 to 30 ppm.

All of the instruments were interfaced to a Data General Nova 1200 minicomputer which allowed effectively simultaneous readings from all instruments. The resulting data were logged onto standard nine-track tape. Each instrument was read at rates commensurate with the frequency of the variable being monitored and at a rate such that all sampling frequencies were a power of two.

Mass balance calculations were performed on the tracer gas experiments. The detected/released ratio was found to be scattered for the College Station and Research Annex data. A study of the results showed that the scatter was most prominent for unstable atmospheric conditions. This was believed to be due to the small numbver of passes by the release vehicle during any particular sampling period. The aerosol samples showed that a maximum TSP concentration of about 140 $\mu g/m^3$ was found.

A new model to predict carbon monoxide concentrations near intersections was developed in conjunction with FHWA Project 541. The new model is called the TEXIN Model, and it incorporates the MOBILE-2 and CALINE-3 programs with a set of "short-cut" traffic and excess emission techniques. The result is an efficient program capable of estimating carbon monoxide levels near intersections given minimal geometrical, meteorological and traffic parameters. When compared to the current data in Texas and data obtained from the California Department of Transportation, the TEXIN Model was found to be slightly more accurate than the Intersection Midblock Model. The TEXIN Model used less than one tenth of the computer time required by the Intersection Midblock Model. It was also found to be much simpler to use and required only about one tenth of the input parameters needed for the Intersection

Midblock Model. Both the TEXIN and Intersection Midblock Models were found to perform equally well for all wind angles.

Recommendations for future work include the following:

1) Further analysis of the experimental data for various atmospheric stability categories needs to be performed. The detailed measurements provide a good basis for a study of the influence of the basic dispersion processes which are occurring.
2) Further tracer gas experiments with a high frequency number of passes by the release vehicle or with a continuous line source need to be performed. These are absolutely essential to further understanding of the dispersion processes.
3) The accuracy of the TEXIN Model might be improved by the use of a dispersion model superior to CALINE-3.
4) Improved techniques for modelling vehicle delay and emission are equally important in improving intersection pollution models.

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Appendix A

Particulate Data

```
09/28/81 HOUSTON SITE/WOODWAY AT S. POST OAK
08:00 START TIME
11:30 END TIME        MICROGRAMS PER M**3
8.0 UM SFU AT 21.3 LITERS PER MIN  UCD ANALYSIS
ELEM  1-H    1-L    2-H    2-M    2-L    3-H    3-M    3-L
NA     .613  1.287  1.319  1.027  1.104   .610  1.240  1.343
AL    1.142   .683   .566  1.745  1.393  1.084  2.286  3.575
SI    3.232  5.785  7.132  6.839  6.101  5.686  8.507  7.553
P      .124   .511   .391   .156   .407   .408   .169   .493
S      .423   .600   .573   .597   .497   .275   .749   .519
CL     .329   .506   .212   .331   .554   .271   .394   .341
K      .304   .334   .322   .301   .421   .223   .375   .484
CA    3.971  4.275  6.437  6.653  6.092  5.605  8.659  8.867
TI     .140   .170   .143   .140   .149   .180   .167   .179
V      .127   .156   .131   .127   .136   .136   .152   .163
CR     .120   .148   .124   .119   .129   .129   .144   .155
MN     .116   .140   .118   .115   .050   .122   .137   .148
FE    1.005  1.305  1.550  1.738  1.597  1.358  2.392  1.802
NI     .081   .098   .083   .080   .086   .086   .096   .104
CU     .076   .094   .079   .075   .082   .081   .091   .098
ZN     .053   .186   .496   .107   .071   .147   .190   .159
SE     .165   .184   .170   .157   .191   .166   .185   .203
BR     .207   .230   .213   .196   .239   .209   .231   .210
PB     .177   .244   .164   .400   .334   .277   .216   .489
TSP   34.45  29.31  55.03  61.30  51.45  52.35  68.01  63.09
```

```
09/28/81 HOUSTON SITE/WOODWAY AT S. POST OAK
08:00 START TIME
11:30 END TIME        MICROGRAMS PER M**3
0.3 UM SFU AT 21.3 LITERS PER MIN  UCD ANALYSIS
ELEM  1-H    1-L    2-H    2-M    2-L    3-H    3-M    3-L
NA     .579   .548   .617   .652   .665   .718   .491   .564
AL     .394   .372   .415   .441   .449   .285   .333   .382
SI     .524  2.168  1.801   .800  1.623  1.676   .589  1.116
P      .301   .284   .318   .337   .343   .199   .255   .291
S     3.687  2.574  3.596  4.275  3.817  3.936  3.392  4.088
CL     .157   .233   .259   .279   .274   .302   .209   .116
K      .280   .297   .456   .451   .305   .413   .248   .344
CA     .237   .263   .263   .278   .359   .277   .256   .359
TI     .124   .059   .135   .132   .070   .119   .094   .102
V      .114   .108   .120   .126   .129   .139   .097   .110
CR     .107   .101   .113   .119   .121   .131   .090   .103
MN     .069   .085   .107   .113   .116   .124   .085   .051
FE     .286   .253   .346   .423   .450   .397   .371   .402
NI     .032   .685   .039   .080   .082   .089   .061   .070
CU     .044   .063   .070   .073   .075   .080   .056   .079
ZN     .058   .054   .066   .136   .065   .094   .104   .141
SE     .165   .172   .193   .184   .188   .196   .135   .146
BR     .149   .208   .203   .221   .381   .172   .163   .175
PB     .389   .394   .777   .994  1.075   .630   .918   .876
TSP   48.55  70.02  45.19  38.70  60.63  38.26  42.73  39.60
```

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10/15/81 HOUSTON SITE/WOODWAY AT S. POST OAK
09:00 START TIME
15:45 END TIME        MICROGRAMS PER M**3
8.0 UM SFU AT 21.3 LITERS PER MIN  UCD ANALYSIS
ELEM  1-H     1-L     2-H     2-M     2-L     3-H     3-M     3-L
NA   4.955   2.577   2.354   1.555    .689   4.100   5.665   2.722
AL    .430   1.154    .935   1.017    .518   1.778   2.814   1.719
SI   3.853   2.561   4.731   5.899   3.133   4.570   9.644   6.845
P     .298    .330    .224    .218    .254    .142    .147    .081
S     .517    .228    .307    .341    .308    .304    .411    .305
CL   2.387   1.899   2.288   1.905   1.515   1.822   2.845   1.713
K     .304    .128    .302    .335    .305    .259    .418    .300
CA   2.719   1.891   3.660   4.705   4.597   3.136   7.876   6.508
TI    .106    .086    .052    .062    .070    .095    .138    .094
V     .097    .078    .075    .073    .084    .086    .110    .080
CR    .092    .074    .071    .069    .079    .082    .104    .076
MN    .088    .070    .068    .065    .076    .078    .100    .072
FE    .498    .517   1.943   1.122   1.242    .701   1.696   1.012
NI    .062    .050    .048    .046    .053    .055    .070    .051
CU    .077    .047    .045    .043    .051    .052    .067    .048
ZN    .122    .073    .065    .095    .064    .044    .076    .080
SE    .134    .110    .104    .103    .113    .109    .182    .098
BR    .168    .138    .130    .129    .087    .136    .091    .047
PB    .333    .274    .258    .256    .317    .145    .295    .188
TSP  42.53   30.01   59.33   67.56   91.54   47.39   65.82   72.07
```

```
10/15/81 HOUSTON SITE/WOODWAY AT S. POST OAK
09:00 START TIME
15:45 END TIME        MICROGRAMS PER M**3
0.3 UM SFU AT 21.3 LITERS PER MIN  UCD ANALYSIS
ELEM  1-H     1-L     2-H     2-M     2-L     3-H     3-M     3-L
NA    .339    .274    .297    .375    .351    .153    .313    .290
AL    .151    .186    .203    .173    .237    .229    .213    .100
SI    .362    .459    .253    .319    .838    .189    .272    .704
P     .176    .143    .155    .194    .181    .175    .163    .151
S    1.296   1.557   1.486   1.814   1.496   1.443   1.565   1.035
CL    .144    .117    .127    .158    .147    .143    .133    .123
K     .114    .067    .100    .051    .083    .046    .105    .098
CA    .096    .294    .104    .221    .173    .084    .117    .177
TI    .039    .046    .036    .080    .036    .054    .042    .038
V     .067    .054    .059    .073    .068    .066    .061    .057
CR    .063    .050    .027    .069    .064    .062    .058    .053
MN    .059    .048    .052    .065    .042    .059    .055    .050
FE    .034    .092    .083    .118    .121    .043    .067    .059
NI    .042    .034    .037    .047    .043    .042    .039    .036
CU    .022    .092    .034    .042    .039    .038    .019    .033
ZN    .033    .027    .030    .036    .034    .032    .031    .028
SE    .096    .081    .087    .097    .088    .084    .092    .070
BR    .115    .097    .105    .164    .318    .062    .095    .084
PB    .184    .190    .230    .792   1.037    .280    .546    .475
TSP  17.50   23.29   17.84   21.90   22.02   17.03   22.02   17.73
```

```
10/19/81 HOUSTON SITE/WOODWAY AT S. POST OAK
09:00 START TIME
17:30 END TIME        MICROGRAMS PER M**3
8.0 UM SFU AT 21.3 LITERS PER MIN  UCD ANALYSIS
ELEM  1-H     1-L     2-H     2-M     2-L     3-H     3-M     3-L
NA     .417    .559    .458    .447    .493    .555    .525    .432
AL     .802   1.616    .871   1.249   1.312    .504   1.804   1.004
SI    3.088   4.755   4.137   3.543   7.037   2.820   8.522   6.561
P      .154    .206    .170    .165    .183    .205    .192    .161
S      .121    .143    .054    .133    .100    .101    .190    .071
CL     .046    .150    .057    .075    .090    .165    .155    .129
K      .166    .265    .215    .215    .363    .301    .363    .347
CA    2.116   3.613   3.376   2.637   5.433   3.845   7.396   5.853
TI     .056    .047    .069    .062    .109    .104    .136    .095
V      .051    .068    .057    .055    .061    .068    .064    .054
CR     .049    .065    .054    .052    .058    .064    .060    .051
MN     .046    .062    .052    .049    .055    .061    .057    .049
FE     .544   1.012    .838    .609   1.335    .814   1.408    .905
NI     .033    .043    .036    .035    .039    .043    .040    .034
CU     .100    .041    .036    .033    .037    .041    .038    .035
ZN     .095    .136    .129    .074    .121    .075    .122    .080
SE     .064    .086    .076    .068    .077    .084    .080    .074
BR     .080    .108    .038    .085    .077    .106    .101    .092
PB     .158    .136    .132    .186    .406    .209    .212    .183
TSP   20.35   29.19   37.02   24.86   54.70   28.55   57.64   41.80
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10/19/81 HOUSTON SITE/WOODWAY AT S. POST OAK
09:00 START TIME
17:30 END TIME        MICROGRAMS PER M**3
0.3 UM SFU AT 21.3 LITERS PER MIN  UCD ANALYSIS
ELEM  1-H     1-L     2-H     2-M     2-L     3-H     3-M     3-L
NA     .227    .266    .286    .293    .297    .246    .212    .219
AL     .155    .323    .194    .197    .191    .168    .145    .149
SI     .152    .511    .596    .321    .518    .246    .138    .301
P      .119    .138    .148    .152    .153    .129    .111    .114
S      .288    .419    .487    .436    .445    .285    .256    .256
CL     .097    .113    .060    .125    .058    .105    .033    .093
K      .077    .077    .102    .036    .131    .059    .051    .065
CA     .164    .275    .257    .316    .318    .221    .297    .380
TI     .035    .057    .030    .039    .063    .045    .033    .026
V      .045    .052    .056    .058    .057    .049    .026    .043
CR     .042    .049    .052    .054    .054    .023    .039    .041
MN     .040    .021    .022    .051    .025    .043    .024    .032
FE     .128    .196    .194    .162    .261    .113    .133    .127
NI     .029    .033    .036    .037    .037    .031    .027    .028
CU     .058    .030    .032    .024    .028    .029    .025    .025
ZN     .023    .038    .030    .029    .052    .024    .019    .022
SE     .065    .069    .074    .097    .080    .071    .062    .060
BR     .072    .083    .098    .120    .288    .103    .075    .144
PB     .272    .393    .457    .261    .967    .234    .387    .450
TSP    9.02   12.25  999.99   13.72   14.83    8.84   11.60   11.79
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10/30/81 HOUSTON SITE/WOODWAY AT S. POST OAK
09:30 START TIME
13:45 END TIME       MICROGRAMS PER M**3
8.0 UM SFU AT 21.3 LITERS PER MIN  UCD ANALYSIS
ELEM  1-H     1-L     2-H     2-M     2-L     3-H     3-M     3-L
NA   4.026    .754   1.158   1.107   2.069   1.635   1.421    .958
AL    .501    .621    .326    .589    .964    .435    .505    .405
SI   4.485   1.846   2.552   4.519   3.567   2.334   2.891   2.990
P     .314    .305    .269    .407    .308    .301    .289    .285
S     .469    .171    .454    .537    .476    .358    .294    .327
CL   1.177    .658   1.179   1.247   1.470    .913   1.193    .939
K     .229    .080    .209    .210    .308    .241    .124    .241
CA   3.013   1.683   3.349   3.648   5.988   2.445   3.383   4.376
TI    .125    .111    .099    .147    .068    .110    .106    .043
V     .114    .101    .090    .134    .103    .100    .097    .095
CR    .108    .096    .085    .128    .097    .095    .092    .090
MN    .102    .092    .082    .121    .093    .090    .087    .087
FE    .626    .292    .626    .570    .851    .643    .531    .612
NI    .072    .064    .058    .085    .066    .064    .061    .061
CU    .068    .061    .055    .080    .063    .061    .058    .058
ZN    .063    .054    .074    .069    .067    .053    .040    .047
SE    .145    .133    .118    .171    .138    .131    .127    .120
BR    .182    .167    .063    .214    .173    .164    .159    .150
PB    .360    .330    .292    .239    .303    .324    .315    .297
TSP  53.04   56.91   29.47   33.52   54.88   26.34   49.54   45.86
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10/30/81 HOUSTON SITE/WOODWAY AT S. POST OAK
09:30 START TIME
13:45 END TIME       MICROGRAMS PER M**3
0.3 UM SFU AT 21.3 LITERS PER MIN  UCD ANALYSIS
ELEM  1-H     1-L     2-H     2-M     2-L     3-H     3-M     3-L
NA    .404    .402    .399    .391    .456    .426    .422    .501
AL    .275    .273    .271    .267    .308    .290    .163    .651
SI    .529    .474    .243    .240    .587    .250    .574    .966
P     .210    .209    .207    .204    .113    .093    .218    .095
S    3.078   3.744   3.419   2.766   3.968   3.029   3.671   3.954
CL    .171    .170    .168    .167    .192    .181    .178    .210
K     .066    .084    .113    .132    .152    .144    .098    .064
CA    .080    .086    .155    .132    .150    .138    .230    .097
TI    .087    .066    .054    .069    .050    .115    .063    .058
V     .079    .079    .078    .083    .089    .084    .082    .097
CR    .074    .074    .073    .072    .084    .033    .077    .091
MN    .071    .071    .062    .069    .045    .043    .073    .086
FE    .063    .041    .073    .061    .098    .067    .078    .057
NI    .051    .050    .050    .050    .028    .053    .053    .062
CU    .046    .046    .239    .045    .046    .049    .048    .056
ZN    .040    .040    .162    .032    .045    .042    .041    .050
SE    .111    .115    .113    .116    .121    .116    .108    .121
BR    .133    .139    .136    .140    .146    .140    .131    .146
PB    .251    .271    .387    .274    .666    .274    .377    .416
TSP  22.47   63.90   28.73   21.73   27.26   23.20   25.41   19.52
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12/16/80 COLLEGE STATION SITE/TEXAS AT JERSEY
09:00 START TIME
14:00 END TIME          MICROGRAMS PER M**3
8.0 UM SFU AT 22.0 LITERS PER MIN  UCD ANALYSIS
ELEM  1-H     1-M     1-L     2-H     2-M     2-L     4-H     4-M     4-L
NA     .729    .396    .737    .679    .709    .694    .658    .840    .780
AL    2.488    .385   2.122    .492   1.283   2.086   1.085    .450   2.541
SI    8.465    .909  10.408   3.184   5.624   8.802   5.358   2.269   8.339
P      .270    .174    .274    .254    .266    .259    .247    .311    .100
S      .218    .084    .221    .206    .214    .209    .084    .252    .233
CL     .217    .126    .103    .206    .182    .158    .198    .104    .232
K      .668    .154    .668    .334    .471    .647    .418    .099    .678
CA    3.644    .118   5.108   1.452   2.398   4.120   2.358    .321   3.785
TI     .071    .098    .143    .094    .098    .095    .037    .113    .090
V      .090    .089    .092    .086    .089    .087    .083    .103    .096
CR     .085    .084    .087    .081    .085    .082    .078    .098    .091
MN     .081    .081    .083    .077    .081    .078    .075    .093    .087
FE    1.399    .063   1.748    .652   1.119   1.350    .995    .065   1.304
NI     .057    .057    .059    .054    .057    .055    .048    .066    .061
CU     .054    .054    .055    .051    .054    .053    .050    .062    .058
ZN     .209    .046    .187    .073    .056    .058    .043    .054    .085
SE     .114    .113    .118    .110    .113    .111    .108    .127    .120
BR     .058    .142    .072    .138    .142    .139    .135    .159    .151
PB     .220    .280    .314    .274    .143    .268    .156    .315    .274
TSP   56.97   10.00   96.82   33.79   41.97   66.36   54.55   10.45   60.61
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12/16/80 COLLEGE STATION SITE/TEXAS AT JERSEY
09:00 START TIME
14:00 END TIME          MICROGRAMS PER M**3
0.3 UM SFU AT 22.0 LITERS PER MIN  UCD ANALYSIS
ELEM  1-H     1-M     1-L     2-H     2-M     2-L     4-H     4-M     4-L
NA     .314    .405    .439    .445    .443    .323    .353    .414    .365
AL     .215    .276    .336    .304    .302    .221    .242    .285    .249
SI     .474   2.544   1.101    .749   2.279    .244    .560    .256    .874
P      .165    .211    .228    .233    .231    .170    .185    .219    .191
S      .259    .197    .270    .299    .338    .238    .330    .212    .251
CL     .059    .077    .126    .191    .074    .168    .095    .117    .143
K      .120    .136    .121    .169    .149    .110    .130    .142    .304
CA     .326    .106    .774    .174    .135    .106    .265    .110    .415
TI     .046    .075    .047    .060    .039    .047    .046    .050    .063
V      .063    .080    .086    .089    .087    .064    .070    .083    .072
CR     .059    .075    .081    .083    .082    .060    .031    .078    .068
MN     .036    .071    .077    .029    .078    .057    .063    .074    .064
FE     .104    .067    .252    .072    .037    .032    .107    .070    .146
NI     .028    .051    .054    .057    .056    .041    .045    .053    .018
CU     .036    .046    .050    .052    .051    .037    .041    .048    .042
ZN     .036    .040    .043    .048    .045    .024    .036    .042    .036
SE     .081    .097    .108    .162    .133    .084    .102    .126    .104
BR     .072    .117    .283    .195    .160    .097    .093    .151    .209
PB     .375    .229    .795    .382    .314    .417    .314    .295    .636
TSP   29.39   26.82   40.45   30.91   36.52   27.88   29.85   18.79   24.85
```

Appendix B

SF_6 Standard Analysis

VERIFICATION OF SF_6 CONCENTRATION IN MATHESON CALIBRATION GAS CYLINDER

Verification of the SF_6 concentration in the gas cylinder submitted for analysis by Texas A & M was accomplished by using two separate sources of standard gas from two different vendors. A cylinder of 105 ppb SF_6 standard prepared in air was diluted to 1,2, and 4 ppb using an all stainless steel capillary dilution device designed by Radian Corporation personnel. This device prepares gas mixtures dynamically such that the mixture is never contained for any period of time thereby eliminating the permeation or condensation problems encountered in static systems.

The second calibration cylinder was obtained at a concentration of 2.02 ppb SF_6, with nitrogen used as the diluent. This was the expected concentration of the Texas A & M standard gas cylinder.

The procedure for analysis was the same for all SF_6 sources. Gas from gas cylinders or the capillary dilution device was passed through a 2 cc stainless steel sample loop. After a thorough 10-second flush of the loop and equilibration to atmospheric pressure, the gas chromatograph carrier gas was diverted to flush the contents of the loop onto the GC column by means of a 10-port Valco valve. The column and conditions for GC analysis are as follows:

Tracor 560 GC
Hewlett Packard 3380A Integrator
Column: 6' x 4 mm I.D. glass packed with 1.5% XE-60/1% H_3PO_4 on Carbopack B
Column Temperature: 50°C
Detector Temperature: 310°C
Injector Temperature: 200°C
Carrier: 5% Methane/95% Argon at 20 mL/min
SF_6 Retention Time: 2.0 minutes

Results of the analyses are presented in the attached table. The SF_6 concentration of the Texas A & M cylinder was calculated relative to the 2.02 ppb source and the 2 ppb dilution prepared from the 105 ppb source gas. The Texas A & M cylinder was determined to be 2.05 and 2.15 ppb SF_6 from the respective analyses.

RESULTS OF SF_6 VERIFICATION STUDY

(RC #225-062)

Source	Area Counts Mean ± S.D.	Number of Replicates	SF_6 Concentration (ppb)	
			Relative to 2.02 ppb Standard	Relative to 2 ppb Diluted from 105 ppb Standard
105 ppb SF_6 Cylinder	289,603 ± 2,051	3	113	118
2.02 ppb SF_6 Cylinder	5,183 ± 47	8	2.02	2.14
1 ppb SF_6 Dilution*	2,256 ± 71	4	0.88	0.92
2 ppb SF_6 Dilution*	4,899 ± 97	5	1.91	2.0
4 ppb SF_6 Dilution*	11,287 ± 594	6	4.40	4.61
Texas A & M Cylinder	5,256 ± 25	5	2.05	2.15

*Dilution from 105 ppb SF_6 bottle, using dynamic dilution device.

Appendix C

SF_6 Concentration Profiles

SF_6 Concentration Profiles College Station Site (concentrations in ppb)

			Receptor Height (ft)		
Date	Period	Tower	35	15	5
11/03/80 A.M.	1	T1	0.42	0.97	1.13
		T2	-	0.81	1.37
	3	T1	0.38	0.65	0.67
		T2	-	0.66	1.27
	5	T1	0.35	0.79	0.79
		T2	0.23	0.99	0.69
	6	T1	0.13	0.34	0.59
		T2	0.13	-	0.65
11/03/80 P.M.	4	T1	0.40	0.75	1.49
		T2	0.54	1.03	1.92
12/05/80	2	T1	0.07	0.14	0.42
		T2	0.06	0.24	0.35
	5	T1	0.06	0.13	0.16
		T2	0.07	0.13	0.45
	6	T1	0.07	0.13	0.28
		T2	0.07	0.11	0.21
12/06/80	1	T1	0.10	0.22	0.54
		T2	0.10	0.24	0.26
	3	T1	0.18	0.36	0.36
		T2	0.06	0.24	0.10
	4	T1	0.18	0.34	0.22
		T2	0.04	0.18	0.28
5/08/81	3	T1	0.14	0.50	1.26
		T2	0.21	0.48	0.51
5/13/81	5	T1	0.02	0.28	0.43
		T2	0.02	0.13	0.29
	6	T1	0.02	-	1.03
		T2	0.00	0.06	0.38
5/18/81	2	T1	0.13	0.66	1.70
		T2	-	0.48	1.34
	4	T1	0.31	0.76	1.37
		T2	-	0.38	1.06

SF_6 Concentration Profiles
Research Annex Site
(concentrations in ppb)

	Date	Period	Receptor Height (ft)					
			43	29	15	6	3	.25
Observed	7/15/81 A.M.	4	0.42	6.28	12.18	2.90	-	2.92
TXLINE			0.00	0.05	0.99	3.10	3.82	4.17
Observed		5	0.02	3.70	0.72	6.20	-	11.52
TXLINE			0.00	0.04	0.86	2.69	3.32	3.63
Observed	7/15/81 P.M.	2	0.45	2.96	0.55	2.65	-	3.82
TXLINE			0.00	0.04	0.55	2.66	3.28	3.58
Observed		3	0.13	2.54	0.56	1.80	-	4.15
TXLINE			0.00	0.04	0.85	2.65	3.26	3.57
Observed		5	0.20	4.44	1.28	2.65	-	2.73
TXLINE			0.00	0.03	0.67	2.09	2.58	2.82
Observed		6	0.10	1.90	1.71	2.13	-	3.09
TXLINE			0.00	0.03	1.03	2.99	3.65	3.96
Observed	7/17/81	1	0.22	0.24	0.40	0.74	-	2.37
TXLINE			0.00	0.02	0.50	1.57	1.94	2.12
Observed		2	0.19	0.30	0.40	1.06	-	2.89
TXLINE			0.00	0.02	0.45	1.40	1.72	1.88
Observed	7/21/81	1	0.00	0.12	0.43	2.68	-	7.84
TXLINE			0.00	0.04	0.57	1.44	1.71	1.84
Observed		3	0.00	0.02	0.41	3.05	-	10.37
TXLINE			0.00	0.03	0.49	1.31	1.57	1.70
Observed		5	0.07	0.14	0.50	4.47	-	9.97
TXLINE			0.00	0.04	0.53	1.36	1.62	1.74
Observed		6	0.02	0.02	0.77	2.95	-	9.74
TXLINE			0.00	0.02	0.33	1.04	1.28	1.40

Research Annex Site
(continued)

			Receptor Height (ft)					
	Date	Period	43	29	15	6	3	.25
Observed	7/23/81	2	0.01	0.03	0.10	0.38	-	0.30
TXLINE			0.00	0.01	0.13	0.42	0.52	0.57
Observed		3	0.03	0.05	0.17	0.32	-	0.55
TXLINE			0.00	0.01	0.12	0.39	0.48	0.52
Observed		4	0.003	0.01	0.17	0.35	-	0.44
TXLINE			0.00	0.01	0.13	0.41	0.51	0.55
Observed		5	0.003	0.005	0.03	0.27	-	0.43
TXLINE			0.00	0.01	0.12	0.37	0.45	0.49
Observed	7/24/81	1	0.12	0.19	0.18	0.63	-	0.55
TXLINE			0.08	0.30	0.90	1.42	1.55	1.61
Observed		2	0.28	0.37	2.10	1.02	-	1.35
TXLINE			0.00	0.09	0.69	1.60	1.86	1.99
Observed		3	0.24	0.44	0.85	0.72	-	1.45
TXLINE			0.00	0.03	0.63	1.75	2.11	2.28
Observed		5	0.32	0.38	2.20	0.99	-	2.05
TXLINE			0.03	0.22	0.90	1.62	1.81	1.89
Observed		6	0.18	0.25	0.40	0.85	-	0.63
TXLINE			0.00	0.10	0.83	1.95	2.28	2.44
Observed	7/27/81	1	0.07	0.23	0.57	0.92	-	1.25
TXLINE			0.00	0.08	0.69	1.61	1.88	2.01
Observed		2	0.01	0.04	0.74	1.12	-	1.55
TXLINE			0.00	0.02	0.37	1.14	1.41	1.54
Observed		3	0.02	0.03	0.17	0.77	-	1.74
TXLINE			0.00	0.06	0.36	0.74	0.85	0.90

Research Annex Site
(continued)

			Receptor Height (ft)					
	Date	Period	43	29	15	6	3	.25
Observed		1	0.24	0.26	0.225	0.58	-	1.12
TXLINE			0.01	0.11	0.53	1.01	1.14	1.20
Observed		2	0.08	0.13	0.217	0.65	-	1.50
TXLINE	7/28/81		0.00	0.08	0.48	1.01	1.16	1.23
Observed	P.M. (2)	3	0.10	0.08	0.30	0.68	-	1.05
TXLINE			0.00	0.07	0.48	1.08	1.25	1.33
Observed		5	0.12	0.12	0.34	0.82	-	1.21
TXLINE			0.02	0.13	0.55	0.98	1.10	1.15

SF_6 Concentration Profiles
Houston Site

Date	Period	Tower	Receptor Height (ft)			
			35	20	10	5
9/26/81	1	T1	2.41	-	3.55	-
		T2	4.27	4.70	-	3.41
		T3	-	3.41	-	1.66
	2	T1	3.27	-	0.99	-
		T2	6.41	4.55	-	4.34
		T3	5.55	2.55	-	2.55
	3	T1	7.77	-	-	-
		T2	4.05	8.77	-	2.91
		T3	7.12	5.91	-	2.62
	4	T1	2.20	-	1.00	-
		T2	-	-	-	-
		T3	6.20	2.87	-	2.48
	5	T1	2.52	-	3.02	-
		T2	3.70	6.62	-	2.45
		T3	5.48	7.20	-	1.59
	6	T1	5.77	-	4.62	-
		T2	6.12	6.48	-	5.12
		T3	5.48	3.91	-	1.36
10/04/81 A.M.	1	T1	0.02	-	0.10	-
		T2	0.08	11.73	-	4.50
		T3	0.02	0.79	-	2.54
	2	T1	15.35	-	8.54	-
		T2	8.54	0.18	-	0.44
		T3	15.77	13.65	-	0.63
	3	T1	4.24	-	0.02	-
		T2	1.10	0.09	-	0.36
		T3	4.24	7.80	-	0.87
	4	T1	4.40	-	13.22	-
		T2	0.07	7.59	-	0.18
		T3	1.05	0.19	-	0.39
	5	T1	0.16	-	0.69	-
		T2	0.11	19.18	-	0.36
		T3	11.73	0.59	-	1.61
	6	T1	1.18	-	0.62	-
		T2	4.29	7.78	-	0.83
		T3	22.58	5.20	-	1.50

Houston Site
(continued)

			Receptor Height (ft)			
Date	Period	Tower	35	20	10	5
10/04/81 P.M.	1	T1	7.41	-	2.61	-
		T2	19.09	24.68	-	11.30
		T3	3.40	8.99	-	2.88
	2	T1	10.57	-	3.61	-
		T2	7.90	14.47	-	12.52
		T3	4.37	4.55	-	7.05
	3	T1	4.69	-	6.26	-
		T2	4.31	47.02	-	10.23
		T3	-	7.53	-	6.32
	4	T1	0.25	-	5.34	-
		T2	7.53	19.82	-	7.65
		T3	5.37	10.27	-	7.78
	5	T1	10.33	-	4.07	-
		T2	-	-	-	-
		T3	4.61	16.41	-	5.83
	6	T1	15.68	-	2.85	-
		T2	5.34	6.68	-	5.22
		T3	11.55	8.14	-	6.56
10/13/81	1	T1	24.98	-	23.77	-
		T2	22.96	21.75	-	18.53
		T3	20.55	20.14	-	25.38
	2	T1	22.16	-	21.75	-
		T2	20.95	18.53	-	21.55
		T3	20.75	22.76	-	25.99
	3	T1	24.58	-	1.81	-
		T2	21.75	19.74	-	18.33
		T3	20.95	18.93	-	24.98
	4	T1	12.49	-	23.97	-
		T2	21.43	16.52	-	18.73
		T3	1.76	15.51	-	24.58
	5	T1	25.38	-	23.97	-
		T2	21.27	21.35	-	21.35
		T3	21.75	19.54	-	22.56
	6	T1	24.58	-	24.37	-
		T2	21.15	15.31	-	19.74
		T3	17.72	20.14	-	25.38

Houston Site
(continued)

Date	Period	Tower	Receptor Height (ft) 35	20	10	5
10/14/81	1	1	18.88	-	6.80	-
		2	8.96	5.43	-	9.77
		3	5.61	11.14	-	2.77
	2	1	16.31	-	8.86	-
		2	8.86	-	-	8.05
		3	10.57	7.27	-	3.73
	3	1	17.40	-	16.27	-
		2	10.67	-	-	10.83
		3	10.87	12.08	-	2.70
	4	1	16.52	-	22.16	-
		2	11.58	6.54	-	12.79
		3	13.59	5.94	-	11.28
	5	1	15.63	-	12.00	-
		2	11.40	7.25	-	15.91
		3	-	-	-	-
	6	1	15.71	-	16.52	-
		2	7.75	5.86	-	15.87
		3	20.90	4.79	-	2.62

Appendix D

Set A Program

Set A JCL

```
//SETA JOB (W185,001D,*45,005,JP),' HINZ  FOR TTI'
//*LEVEL           0
//*OPERATOR        ZY0358,RINGOUT
//*OPERATOR        004174,RINGIN
//*OPERATOR        TAPE ZY0358 MAY RUN  OFF END OF REEL.
//STEP2 EXEC FORTXCLG,REGION=192K
//FORT.SYSIN DD UNIT=SYSDA,DSN=WYL.JP.WFF.DATAFRT,DISP=SHR
//LKED.SYSIN DD UNIT=SYSDA,DSN=WYL.JP.WFF.DATAMAC,DISP=SHR
//GO.DUMMY DD DUMMY
//FT02F001 DD UNIT=TAPE9,VOL=SER=004174,LABEL=(07,SL,,OUT),DISP=(NEW,
//     PASS),DSN=OCT03081.CAS,DCB=(RECFM=VB,LRECL=750,BLKSIZE=18240)
//FT01F001 DD UNIT=TAPE9,VOL=SER=ZY0358,DISP=(OLD,PASS),
//       LABEL=(1,NL,,IN),DCB=(LRECL=3200,BLKSIZE=3200,RECFM=U)
//GO.SYSIN DD UNIT=SYSDA,DSN=WYL.JP.WFF.DATAIN,DISP=SHR
//STEP3 EXEC PGM=TAPEVTOC,PARM=1,REGION=100K
//PRTOUT DD SYSOUT=A
//TAPEIN DD UNIT=TAPE9,DISP=OLD,VOL=SER=004174
//*END
```

Data Set DATAFRT

```
      DOUBLE PRECISION DDNM(50)
      INTEGER*2 DATA(2000),DM(10)
      DM(1)=10
      DO 105 J=2,10
      DM(J)=0
  105 CONTINUE
      I=1
      IBD=0
      IBLK=0
      READ(5,500) NFILE
      READ(5,501) (DDNM(J),J=1,NFILE)
    1 CONTINUE
      IBLK=IBLK+1
      CALL GETR(DDNM(I),ITST,DATA,ILNG)
      IF (ITST) 2,4,3
    2 IF (ITST .EQ.-1) GO TO 6
      WRITE (6,600) ITST,DDNM(I)
      STOP
    3 IF (IBD .GT.2) GO TO 1
      IBD=IBD+1
      IBLK=IBLK-1
      BACKSPACE 1
      WRITE (6,601) IBD, DDNM(I)
      STOP
    4 IL=ILNG/2
      IBD=0
      JS=2
    5 JL=DATA(JS)
      JDM=DATA(JS+1)
      JE=JS+JL-1
      IF (JE .GT.IL) GO TO 1
      IF ( JL .GT. 135 .OR. JL .LT. 5) GO TO 7
      IF (DATA(JS+1) .LT.0 .OR. DATA(JS+1) .GT.20) GO TO 7
      IF (JDM .EQ.0 .OR.JDM .EQ.5) CALL LIST(DATA,JS+4,JE)
      WRITE (2,200) (DATA(N),N=JS,JE)
      IF (JE .EQ.IL) GO TO 1
      JS=JE+1
      GO TO 5
    6 CALL ENDQ(DDNM(I),ITST,'LEAVE')
      WRITE (6,603) DDNM(I)
      IBLK=0
      I=I+1
      WRITE (2,210)
      IF (I .GT. NFILE) STOP
      GO TO 1
    7 WRITE (6,602) IBLK,DDNM(I)
      GO TO 1
  200 FORMAT (20(100I6))
  210 FORMAT ('     8          62          23130 23130 23130 23130')
  500 FORMAT (I5)
  501 FORMAT (8(A8,2X))
  600 FORMAT (' RETRY:',I2,'  FILE:',A8)
  601 FORMAT (' READ ERROR:',I5,'     FILE:',A8)
  602 FORMAT (' *********BAD BLOCK',I3,' FILE:',2X,A8,'  *********')
  603 FORMAT ('    END OF ',A8,///)
      END
      SUBROUTINE LIST(I,JU,KU)
      INTEGER*2L(128)/0,1,2,3,55,45,46,47,22,5,37,11,12,13,14,15,16,17,
     >18,18,60,61,50,38,24,25,63,39,34,34,53,53,64,90,127,123,91,108,
     >80,125,77,93,92,78,107,96,75,97,240,241,242,243,244,245,246,247,
     >248,249,122,94,76,126,110,111,124,193,194,195,196,197,198,199,
     >200,201,209,210,211,212,213,214,215,216,217,226,227,228,229,230,
     >231,232,233,192,0,208,0,0,121,27*0,250,0,204,7/
      INTEGER*2 I(2000),C(2),IB(55)
      CALL CNVRT(ITM,I(JU-2),I(JU-1))
      IB(2)=I(JU-3)
      J=4
      IA=KU-JU+5
      IH=ITM/360000
      IM=ITM/6000-IH*60
```

```
      DO 18 I1=JU,KU
      J=J+1
      CALL DEPAK(I(I1),C)
      IF ( C(1) .GE. 128 .OR.C(2).GE. 128) GO TO 4
      IB(J)=256*L(C(1)+1)+L(C(2)+1)
      IF (C(1).NE.13) GO TO 16
      IB(J)=0
      GO TO 19
   16 IF(C(2).NE.13) GO TO 17
      IB(J)=L(C(1)+1)*256
      GO TO 19
   17 CONTINUE
   18 CONTINUE
   19 IF (J.GT.IA) J=IA
      IF (J .GT.50) J=50
      JD=J-4
      IF (ITM .EQ. 0) RETURN
      WRITE (6,600) IB(2),IH,IM,(IB(K),K=5,J)
  600 FORMAT (10X,'TYPE: ',I2,' AT ',I2,':',I2,' HOURS.',50A2)
    4 RETURN
      END
      SUBROUTINE CNVRT (I,IH,IL)
      INTEGER*2 IH,IL
      I=IL
      IF (I .LT.0) I=I+65536
      I=I+65536*IH
      RETURN
      END
      SUBROUTINE DEPAK(I,J)
      INTEGER*2 I, J(2), K(2)
      LOGICAL*1 A(4)
      EQUIVALENCE (K(1),A(1))
      K(1)=I
      K(2)=0
      A(4)=A(1)
      A(1)=A(3)
      J(1)=K(1)
      J(2)=K(2)
      RETURN
      END
```

Data Set DATAMAC

```
ESD       #    QSIO           #GETR            PUTR       %            QSI00001
ESD            ENDQ       M                                            QSI00002
TXT       #    #00##GETR ### ##1Q#-A##&A4J &## # K &#  K AU  P &#&## # QSI00003
TXT   #   #    #  4# J &## ###0A-N AU  ##A## A4# #0 # ## &#&#  #0A##00#QSI00004
TXT   #   #    #PUTR ### ##1##-A##&B#J &## ##K &#  K A#    # #U#  ## J QSI00005
TXT   Y   #    &## ###0A-N A#  ##A###    &## B## #0 # ##0A##00##ENDO ##QSI00006
TXT   /   #    # ##0D#-A##&B#N A#  ##A##&A4N AU  ##A-J &###A#N # B###A#QSI00007
TXT   #   #    # A#    &#  K#  ###0A#  # A#    &#  K#  ###0A##]##A#&# #QSI00008
TXT   &   #    &] #Q#  # &    6#   #0A%#     &   ##Q## K##  ##   #0A%# QSI00009
TXT   H   #    K #   K #    #                                          QSI00010
TXT   #   #                                                            QSI00011
TXT   8   #                                   =     0         &       FQSI00012
TXT   #   #                          #                                 QSI00013
TXT   #   #                      0          &       F                  QSI00014
TXT   #   #                                                            QSI00015
TXT   #   #    REWIND                                                  QSI00016
RLD                #  ##  ##  Q#         #  #   #                      QSI00017
END                            15741SC103 020180316                    QSI00018
```

Data Set DATAIN

```
   38
FT01F001  FT01F002  FT01F003  FT01F004  FT01F005  FT01F006
```

Appendix E

Set B and D Programs

Set BD JCL

```
//SETBD JOB (W185,001D,005,095,JP),'HINZ FOR TTI'
//*LEVEL 1
//*OPERATOR         ZY5269,RINGIN
//*OPERATOR         004175,RINGOUT
//*OPERATOR         MARK HINZ, 5-3361
//STEPB1 EXEC WATFIV,REGION=320K
//FT01F001 DD UNIT=TAPE9,VOL=SER=004175,DSN=OCT02081.CAS'
//          DISP=(OLD,PASS),LABEL=(06,SL,,IN)
//FT02F001 DD UNIT=SYSDA,DSNAME=&&SMISRT,SPACE=(CYL,(30,10)),
//          DISP=(NEW,PASS),DCB=(RECFM=VB,LRECL=3700,BLKSIZE=13000)
//SYSIN DD UNIT=SYSDA,DSN=WYL.JP.WFF.SETB.SOURCE,DISP=(SHR,PASS)
/*
//STEPB2 EXEC SORTWK,REGION=128K
//SORTIN DD UNIT=SYSDA,DSN=&&SMISRT,DISP=(SHR,DELETE)
//SORTOUT DD UNIT=TAPE9,VOL=SER=ZY5269,DISP=(NEW,PASS),
//         LABEL=(5,SL),DSN=OCT02081.STB,
//         DCB=(LRECL=3700,BLKSIZE=22000,RECFM=VB)
//SYSIN DD *
//STEP1 EXEC WATFIV,REGION=320K
//FT01F001 DD UNIT=TAPE9,VOL=SER=ZY5269,DSN=OCT02081.STB,
//          DISP=9OLD,PASS),LABEL=(5,SL,,IN)
//FT02F001 DD DSN=WYL.JP.WFF.DATA1020,DISP=(SHR,PASS),UNIT=SYSDA
/SYSIN DD UNIT=SYSDA,DSN=WYL.JP.WFF.SETD.SOURCE,DISP=(SHR,PASS)
/*
//STEP2 EXEC GENREPRO,REGION=128K
//SYSUT1 DD UNIT=SYSDA,DSN=WYL.JP.DATA1020,DISP=(SHR,PASS)
//SYSUT2 DD SYSOUT=A
```

Data Set SETB.SOURCE

```
//$OPTIONS     T=(5)
C SETB MODIFIED FOR USE BY PROJECT 2250.  JCP 2/1/80
C VECTOR USED TO MOVE RECORD TYPES AROUND AS NECESSARY.
      INTEGER*2 IX(20)/1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,
     >18,19,20/
C VECTOR USED TO CONVERT ASCII TO EBCDIC
      INTEGER*2L(128)/0,1,2,3,55,45,46,47,22,5,37,11,12,13,14,15,16,17,
     >18,18,60,61,50,38,24,25,63,39,34,34,53,53,64,90,127,123,91,108,
     >80,125,77,93,92,78,107,96,75,97,240,241,242,243,244,245,246,247,
     >248,249,122,94,76,126,110,111,124,193,194,195,196,197,198,199,
     >200,201,209,210,211,212,213,214,215,216,217,226,227,228,229,230,
     >231,232,233,192,0,208,0,0,121,27*0,250,0,204,7/
C MATRIX DESCRIPTIONS
C          IN=SAMPLE INTERVAL
C          IT=CHANNEL TYPE
C          MN=MINIMUM EXPECTED VALUE
C          MX=MAXIMUM EXPECTED VALUE
C          UN=UNITY VALUE (EG. RAW VALUE/UN=1.00)
C          OF=OFFSET USED TO CHANGE 0 VOLTS TO SOME VALUE.(EG. 32 DEGREES)
C          IE=NUMBER OF RECORDS
C          IC=
C          IB=INPUT DATA VECTOR
C          NM=NAME OF THE CHANNEL INSTRUMENT.
C          C=SCRATCH AREA FOR CONVERTING ASCII TO EBCDIC
C          NTO=TYPE TO OUTPUT FOR TELETYPE MESSAGES (EITHER 0 OR 5)
C          O=OUTPUT DATA VECTOR
      INTEGER   IN(64),IT(64),MN(64),MX(64),UN(64),OF(64),
     > IE(11,64,28)/19712*0/,IC(80),IB(150),NM(3,64)
      INTEGER*2 SP0,SP1,SP2/0/,C(2)
      INTEGER*2 NTO(50)
      REAL O(150)
      IREAD=1
      IPO=1
C  THIS READ SHOULD BE NOTHING BUT ZEROS AND FIVES
      READ (5,502) (NTO(I),I=1,50)
      IF=1
      SP0=0
      SP1=1
C  THIS READ TELLS THE COMPUTER HOW MANY DAYS OF DATA ARE THERE.
      READ (5,500) N
    1 READ (5,501,END=3) I,IN(I),IT(I),MN(I),MX(I),UN(I),OF(I),
C  THIS READ GIVES PRELIMINARY CHANNEL PARMS IN CASE TYPE 1S ARE MISSING.
     >(NM(J,I),J=1,3)
      DO 2 J=1,3
      CALL DEPAK(NM(J,I),C)
    2 NM(J,I)=(256*L(C(1)+1)+L(C(2)+1))*65536
      GO TO 1
    3 DO 21 I=1,N
    4 READ (IREAD,100,END=20) IA,(IB(J),J=2,IA)
      CALL CNVRT(ITM,IB(3),IB(4))
      IF (IB(2)-1)  15,12,5
    5 IF (IB(2)-10) 10,8,6
    6 IF (IA .LT.10) GO TO 4
      IB(5)=IB(5)+1
      IN(IB(5))=IB(6)
      UN(29) =1
      DO 7 J=10,IA
      K= J-9
      IF (UN(IB(5)).EQ.0) UN(IB(5))=32000
    7 O(K)=FLOAT(IB(J)+OF(IB(5)))/FLOAT(UN(IB(5)))
      IE(11,IB(5),IF)=IE(11,IB(5),IF)+1
      WRITE (2,200) SP1,IX(IB(2)),IB(5),ITM,K,(O(J),J=1,K)
      GO TO 4
    8 CONTINUE
      J=6
      J1=1
      IA=(IA-4)/3
      DO  9 J2=1,IA
      CALL DEPAK(IB(J),C)
      IC(J1)=C(1)
      IC(J1+2)=C(2)
      CALL DEPAK(IB(J+1),C)
```

```
      IC(J1+1)=C(1)
      IC(J1+3)=C(2)
      IC(J1+4)=IB(J+2)
      IF (IC(J1+4) .GT. 99999 .OR. IC(J1+4) .LT. 0) IC(J1+4)=99999
      J=J+3
      J1=J1+5
    9 CONTINUE
      IE(10,1,IF)=IE(10,1,IF)+1
      J1=J1-1
      WRITE (2,203) SP0,IB(2),SP1,ITM,(IC(J),J=1,J1)
      GO TO 4
   10 IF (IB(2)-5)11,15,11
   11 IF (IB(2) .EQ. 9) GOTO 115
      IB(5)=IB(5)+1
      IF ( IB(5) .GT.64 .OR. IB(5) .LT. 1) GO TO 4
      WRITE (2,200) SP1,IB(2),IB(5),ITM
      IE(IX(IB(2)),IB(5),IF)=IE(IX(IB(2)),IB(5),IF)+1
      GO TO 4
  115 CALL CNVRT(ITM,IB(3),IB(4))
      CALL CNVRT(ITM1,IB(3),IB(6))
      IF (ITM1 .LE. ITM) ITM1=ITM1+65536
      ITM1=ITM1-ITM
      IE(9,IB(5),IF)=IE(9,IB(5),IF)+1
      WRITE (2,204) SP1,IB(2),IB(5),ITM,ITM1
      GOTO 4
   12 ID=5
   13 IF (ID.GE.IA) GO TO 4
      IB(ID)=IB(ID)+1
      IN(IB(ID))=IB(ID+1)
      IT(IB(ID))=IB(ID+2)
      MN(IB(ID))=IB(ID+3)
      MX(IB(ID))=IB(ID+4)
      UN(IB(ID))=IB(ID+5)
      OF(IB(ID))=IB(ID+6)
      DO 14 J=1,3
      CALL DEPAK(IB(ID+J+6),C)
   14 NM(J,IB(ID))=(256*L(C(1)+1)+L(C(2)+1))*65536
      J=IB(ID)
      ID=ID+10
      GO TO 13
   15 DO 18 J=5,IA
      CALL DEPAK(IB(J),C)
      IF ( C(1) .GE. 128 .OR.C(2).GE. 128) GO TO 4
      IB(J)=(256*L(C(1)+1)+L(C(2)+1))*65536
      IF (C(1).NE.13) GO TO 16
      IB(J)=0
      GO TO 19
   16 IF(C(2).NE.13) GO TO 17
      IB(J)=(L(C(1)+1)*256)*65536
      GO TO 19
   17 CONTINUE
   18 CONTINUE
   19 IF (J.GT.IA) J=IA
      IF (J .GT.50) J=50
      JD=J-4
      IF (ITM .EQ. 0) GO TO 4
      CALL DMRTN(IB(2),NT0,IP0)
      IF (IB(2).NE.0) GO TO 197
      DO 195 M=1,64
      IE(1,M,IF)=IE(1,M,IF)+1
      WRITE (2,204) SP1,SP2,M,SP1,IN(M),IT(M),MN(M),MX(M),UN(M),OF(M),
     >(NM(K,M),K=1,3)
  195 CONTINUE
  197 CONTINUE
      IF (IB(2).EQ.0) SP0=SP0+2
      SP1=SP0+1
      IF (IB(2).EQ.0) IF=IF+1
      IF (IB(2) .EQ. 0) WRITE (6,601)
      WRITE (6,600) IB(2),ITM,(IB(K),K=5,J)
      WRITE (2,202) SP0,IB(2),SP2,ITM,JD,(IB(K),K=5,J)
      IE(5,1,IF)=IE(5,1,IF)+1
      GO TO 4
```

```
   20 CONTINUE
   21 CONTINUE
      I1=SPO+1
      M=SPO/2+1
      DO 22 J=1,64
      IE(1,J,M)=IE(1,J,M)+1
      WRITE (2,204)I1,SP2,J,SP1,IN(J),IT(J),MN(J),MX(J),UN(J),OF(J),
     >(NM(K,J),K=1,3)
   22 CONTINUE
      WRITE (2,203) SP2,SP2,SP2,SP2,((IE(J,K,1),J=1,11),K=1,64)
      WRITE (6,602) (( IE(J,K,1),J=1,11),K=1,64)
      DO 23 I=2,SPO,2
      I1=I+1
      M=I/2+1
      WRITE (2,203) I,SP2,SP2,SP2,((IE(J,K,M),J=1,11),K=1,64)
      WRITE (6,602)((IE(J,K,M),J=1,11),K=1,64)
   23 CONTINUE
  100 FORMAT (200(10I6))
  200 FORMAT (3I5,I15,I5,2(250F10.2))
  202 FORMAT (3I5,I15,I5,100A2)
  203 FORMAT (3I5,I15, 65(11I5))
  204 FORMAT (3I5,I15,6I10,3A2)
  500 FORMAT (I5)
  501 FORMAT (10I8)
  502 FORMAT (50I1)
  600 FORMAT ('    TYPE:  ',I1,'  AT ',I10,5X,200A2)
  601 FORMAT (///)
  602 FORMAT (///,64(20X,11I5,/))
      STOP
      END
      SUBROUTINE CNVRT (I,IH,IL)
      INTEGER IH,IL
      I=IL
      IF (I .LT.0) I=I+65536
      I=I+65536*IH
      RETURN
      END
      SUBROUTINE DMRTN(I,J,K)
      INTEGER*2 J(50)
      I=J(K)
      K=K+1
      RETURN
      END
      SUBROUTINE DEPAK(I,J)
      INTEGER*2  J(2), K(2)
      LOGICAL*1 A(4)
      EQUIVALENCE (K,A)
      IF (I .LT. O) I=I+65536
      K(1)=I
      K(2)=I/256
      A(1)=A(3)
      J(1)=K(1)
      J(2)=K(2)
      RETURN
      END
//$DATA
00555555555555555555555555555555555555555555555555
    1
        1         1        10      -100      2047        20         0     16722     21060     12336
        2         1        10      -100      2047        20         0     16722     21060     12592
        3         1        10      -100      2047        20         0     16722     21060     12848
        4         1        10      -100      2047        20         0     16722     21060     13104
        5         1        10      -100      2047        20         0     16722     21060     13360
        6         1        10      -100      2047        20         0     16722     21060     13616
        7         1        10      -100      2047        20         0     16722     21060     13872
        8         1        10      -100      2047        20         0     16722     21060     14128
        9         1        10      -100      2047        20         0     16722     21060     12337
       10         1        10      -100      2047        20         0     16722     21060     12593
       11       200        11      -854       854         5         0     16726     11825     19765
       12       400        11      -854       854         5         0     16726     12576     19760
       13       600        11      -854       854         5         0     16726     12832     19760
       14       600        11      -854       854         5         0     16726     13344     19760
```

15	1500	12	0	614	20	0	16712	11825	19765
16	1500	12	0	819	20	0	16712	12576	19760
17	1500	12	0	1228	20	0	16712	12832	19760
18	1500	12	0	1638	20	0	16712	13344	19760
19	500	13	0	2047	6	0	22103	11825	19765
20	500	13	0	2047	6	0	22103	11825	19765
21	500	13	0	2047	6	854	22103	12832	19760
22	500	13	0	2047	6	58	22103	13344	19760
23	6000	14	921	1791	13	-512	19796	11825	19765
24	6000	14	921	1791	13	-512	19796	12624	19760
25	6000	14	921	1791	13	-512	19796	12880	19760
26	6000	14	921	1791	13	-512	19796	13136	19760
27	6000	15	0	2047	20	0	18514	11825	19765
28	6000	15	0	2047	20	0	18514	13088	19760
29	6000	16	0	1500	1	0	22864	16722	8270
30	3000	17	0	2047	41	0	8224	20291	18481
31	3000	17	0	2047	41	0	8224	20291	19505
32	3000	17	0	2047	41	0	8224	20291	18482
33	3000	17	0	2047	41	0	8224	20291	19506
34	3000	17	0	2047	41	0	8224	20291	18483
35	3000	17	0	2047	41	0	8224	20291	19507
36	3000	17	0	2047	41	0	8224	20291	18484
37	3000	17	0	2047	41	0	8224	20291	19508
38	3000	17	0	2047	41	0	8224	20291	18485
39	3000	17	0	2047	41	0	8224	20291	19509
40	3000	17	0	2047	41	0	8224	20291	18486
41	3000	17	0	2047	41	0	8224	20291	19510
42	0	0	0	0	0	0	0	0	0
43	0	0	0	0	0	0	0	0	0
44	0	0	0	0	0	0	0	0	0
45	0	0	0	0	0	0	0	0	0
46	0	0	0	0	0	0	0	0	0
47									
48									
49									
50									
51									
52									
53									
54									
55									
56									
57									
58									
59									
60									
61									
62									
63									
64									

Data Set SETD.SOURCE

```
C TAPEFILES, BUT THIS CAN BE CHANGED BY DELETION OF THE SECOND REWIND 1
C
C
C
C
C VARIABLE DEFINITIONS.  THESE OCCUPY A LARGE AREA OF CORE.  320K
C ARE NEEDED TO RUN WATFIVE.
      INTEGER *4 OFST,UN, ICD(20),ICE(20),IBC(20),IEC(20),ITD(6000),IAC(
     >20)
      REAL*4  BUF(9), SPD(6),D(200),COD(6000)
     >,CF(20),FCTR(20),TSP(10,150)
      INTEGER*2 IB(11,64),IN(200),ITF(75),ITTL(10,
     >150),IANM(3)
      CHARACTER*20 DATE
C
C
C
C
C THIS TELLS HOW MANY DAYS OF DATA NEED BE TAKEN.  I5.
      READ (5,5010) MA
      DO 580 MB=1,MA
C
C
C
C
C
C THERE ARE TWO CARDS FOR EACH DAY OF DATA.  THE FIRST IS THIS:A20.
C A 20 CHARACTER HEADER PRINTED ON EACH AVERAGE.
      READ (5,5020) DATE
C
C
C THE SECOND IS A CARD CARRYING THE TIME PARAMETERS.  BEGIN,INTERVAL,EN
C 3I10.  TIMES MUST BE SUPPLIED IN MINUTES.
      READ(5,5000) IBT, IAT, IET
C
C
C
      IBT=IBT*6000
      IAT=IAT*6000
      IET=IET*6000
    2 CONTINUE
C
C
C
C THIS READ READS THE A TABLE TELLING HOW MANY OF EACH TYPE RECORD
C ARE IN THIS DAYS DATA.
      READ (1,1000,END=580)(IA,I=1,4),((IB(I,J),I=1,11),J=1,64)
      CALL ITIM(IH,IX,IS,IAT)
      IF (IX .EQ. 0) IX=60
      IA=0
      DO 7 I=1,64
      DO 7 J=1,11
      IA=IB(J,I)+IA
    7 CONTINUE
      IF (IA .EQ.0) GO TO 2
      I2=IA
      IF ( IAT .NE. 0) GO TO 8
      CALL DMRD(I2)
      GO TO 580
    8 CONTINUE
      IF (IB(5,1) .EQ. 0) GO TO 20
      IA=IB(5,1)
C
C
C
C NOW THE LOG IS READ IN AND IMMEDIATLY PRINTED OUT.
      DO 10 I=1, IA
      READ(1,1010) (IC, J=1, 4), IL, (IN(J), J=1, IL)
      CALL ITIM(IH,IM,IS,IC)
      WRITE(2,200) IH, IM, IS, (IN(J), J=1, IL)
 10   CONTINUE
 20   CONTINUE
```

```
      IB(5,1)=0
      WRITE (2,210)
C
C
C
C THE FIRST TEN CHANNELS ARE RADAR CHANNELS AND AS A RESULT MUST BE
C HANDLED SEPERATLY.  THIS SECTION HANDLES THEM.
      IF (IB(10,1) .EQ. 0) GOTO 130
      ID=IB(10,1)
      DO 125 I=1,ID
      READ (1,1040) (IC,L=1,4),(ITF(L),L=1,65)
      CALL ITIM(IH,IM,IS,IC)
      L=1
      WRITE (2,220) IH,IM,IS,L,(ITF(LL),LL=1,15)
      L=2
      WRITE (2,220) IH,IM,IS,L,(ITF(LL),LL=16,30)
      L=3
      WRITE (2,220) IH,IM,IS,L,(ITF(LL),LL=31,45)
      L=4
      WRITE (2,220) IH,IM,IS,L,(ITF(LL),LL=46,60)
      L=5
      WRITE (2,220) IH,IM,IS,L,(ITF(LL),LL=61,65)
  125 CONTINUE
      WRITE (2,230)
  130 CONTINUE
C
C
C
C THIS SECTION HANDLES ALL METEROLOGICAL INSTRUMENTS.  THE WIND VANES
C HAVE THEIR OWN SPECIAL CHARACTERISTICS AND ARE ROUTED DIFFERENTLY.
C
C
C
C THE ECOLYZERS ALSO REQUIRE A DIFFERENT APPROACH.  THEY ARE HANDLED IN
C SECTION.  THEY ARE THE ONLY INSTRUMENTS WHICH HAVE A CALIBRATION FACT
C INTRODUCED.  THE METEROLOGICAL INSTRUMENTS DO NOT REQUIRE SUCH TREATM
      DO 540 I=1, 64
      READ (1,1020) (IC,IKK=1,4),INC,ITY,MIN,UN,OFST,MN,(IANM(IK),I
     >K=1,3)
      II=1
      WRITE (2,240) I  ,II,INC,ITY,MIN,UN,OFST,MN,(IANM(IK),I
     >K=1,3)
131   NCAL=0
      ITF(1)=1000000000
      IBC(1)=1000000000
      IEC(1)=1000000000
      FCTR(1)=0.0
      IF (IB(2,I) .EQ. 0) GO TO 350
      IA=IB(2,I)
      K=1
      IBC(1)=0
      DO 320 J=1, IA
      READ (1, 1030) (IC, L=1, 4)
      IF (IC .LE. IBC(K)) GO TO 320
      IBC(K)=IC
      IBC(K+1)=IC
      IEC(K)=IC+90000
      ITF(K)=IC
      FCTR(K)=0.
      K=K+1
      ITF(K)=IC
      FCTR(K)=0.
320   CONTINUE
      NCAL=K-1
      IF (NCAL .GT. IB(2,I)) NCAL=IB(2,I)
      IB(2,I)=0
      IF (IB(3,I) .EQ. 0) GO TO 350
      IA=IB(3,I)
      IF (NCAL .EQ. 0) GO TO 350
      DO 340 J=1, IA
      READ(1, 1030) (IC, L=1, 4)
      FCTR(J+1)=0.
```

```
      DO 330 L=1, NCAL
      IF (IC .GT. IBC(L) .AND. IC .LT. IEC(L)) IEC(L)=IC
      IF (IC .LT. IBC(L)) GO TO 340
  330 CONTINUE
  340 CONTINUE
      IB(3, I)=0
  350 CONTINUE
      K=1
      IA=IB(2,I)+IB(3,I)+IB(4,I)+IB(5,I)
      CALL DMRD(IA)
      IF (IB(6,I) .EQ. 0) GO TO 420
      IA=IB(6,I)
      ICD(1)=0
      DO 380 J=1, IA
      READ(1, 1030) (IC, L=1, 4)
      IF (ICD(K).GE. IC) GO TO 380
      ICD(K)=IC
      ICD(K+1)=IC
      K=K+1
  380 CONTINUE
      IB(6,I)=0
      NCD=K-1
      ICE(1)=8640000
      L=1
      IA=IB(7,I)
      IF (IA .EQ. 0) GO TO 420
      DO 410 J=1, IA
      READ(1, 1030) (IC, K=1, 4)
      IF (L .GT. NCD) GO TO 410
      LD=L
      DO 400 M=LD,NCD
      IF (IC .LT. ICD(M)) GO TO 400
      ICE(M)=IC
      L=M+1
      IF (M .GE. NCD) GO TO 410
      IF (ICD(M+1) .LT.IC)L=L+1
      ICE(M+1)=IC
      GO TO 410
  400 CONTINUE
  410 CONTINUE
      IB(7,I)=0
  420 CONTINUE
      IA=IB(6,I)+IB(7,I)+IB(8,I)
      CALL DMRD(IA)
C THE GUTS OF THE PROGRAM GO HERE
      IF (IB(9,I) .EQ. 0) GOTO 425
      IA=IB(9,I)
      DO 422 J=1,IA
      READ (1,1030) IC,IC,IC,ITM,ITM1
      CALL ITIM(IH,IM,IS,ITM)
      WRITE (2,260) IH,IM,IS,IC,ITM1
  422 CONTINUE
  425 K=1
      ITDD=0
      M=1
      IJ=1
      IF (IB(11,I) .EQ. 0) GO TO 540
      IA=IB(11,I)
      N=1
      DO 460 J=1,IA
      READ (1,1050) (IC,L=1,4),IL,(D(L),L=1,IL)
      IF (IC .LT. ITDD) GO TO 460
      ID=K+IL
      IF (ID .GT. 6000) CALL OUTPT(COD,ITD,K,ITY,I,II,INC,N,NCAL,IL)
      COD(K)=D(1)
      ITDD=IC
      ITD(K)=ITDD
      K=K+1
      DO 450 L=2,IL
      COD(K)=D(L)
  430 CONTINUE
      ITDD=ITDD+INC
```

```
      ITD(K)=ITDD
      IF (ITD(K) .GT. 8640000) GO TO 435
      IF (M .GT. IB(6,I)) GO TO 435
      IF (ITD(K) .GT. ICE(M)) M=M+1
      IF (ITD(K) .GT. ICD(M)) GO TO 430
  435 CONTINUE
      IF (ITD(K) .LT. IBC(N)) GO TO 440
      IF (IJ .GT. 1) GO TO 437
      CALL ITIM(IH,IM,IS,ITDD)
      IJ=1
  437 CONTINUE
      BUF(IJ)=D(L)
      IJ=IJ+1
      K=K-1
      IF (IJ .LT. 10) GO TO 440
  438 CONTINUE
      IJ=IJ-1
      II=7
      WRITE (2,250) IH,IM,IS,II,I,ITY,IJ,(BUF(IK),IK=1,IJ)
      IBC(N)=IBC(N)+IJ*INC
      IJ=1
      IF (IBC(N) .LT. IEC(N)) GO TO 440
      IBC(N)=10000000
      IEC(N)=10000000
      N=N+1
      IF (N .GT. NCAL) N=NCAL
  440 CONTINUE
      K=K+1
  450 CONTINUE
  460 CONTINUE
      CALL OUTPT(COD,ITD,K,ITY,I,II,INC,N,NCAL,IL)
      II=11
      K=K-1
      IF (K.EQ. 0) GO TO 545
      CALL ITIM(IH,IM,IS,ITD(1))
      WRITE (2,250) IH,IM,IS,II,I,ITY,K,(COD(IK),IK=1,K)
  545 CONTINUE
      WRITE (2,230)
  540 CONTINUE
  580 CONTINUE
      STOP
 1000 FORMAT (3I5,I15,65(11I5))
 1010 FORMAT (3I5,I15,I5,100A2)
 1020 FORMAT (3I5,I15,6I10,3A2)
 1030 FORMAT (3I5,I15,I10)
 1040 FORMAT (3I5,I15,65(11I5))
 1050 FORMAT (3I5,I15,I5,2(250F10.2))
 5000 FORMAT (3I10)
 5010 FORMAT (I5)
 5020 FORMAT (A20)
  200 FORMAT (3I2,' 05',35A2)
  210 FORMAT ('-99999 05 END OF MESSAGE SECTION')
  220 FORMAT (3I2,' 10',I3,2X,3(4I4,I6))
  230 FORMAT ('-99999 -1 -1     1')
  240 FORMAT ('000000 01',2I3,6I5,1X,3A2)
  250 FORMAT (3I2,3I3,I2,9F7.2)
  260 FORMAT (3I2,'  9',I3,I8)
      END
      SUBROUTINE DMRD(I)
      IF (I.EQ.0) RETURN
      DO 1 J=1,I
      READ (1,100) K
    1 CONTINUE
  100 FORMAT (I5)
      RETURN
      END
      SUBROUTINE ITIM(I,J,K,L)
      I=L/360000
      J=L/6000-I*60
      K=L/100-J*60-I*3600
      RETURN
      END
```

```
      SUBROUTINE OUTPT(X,I,K,IT,M,N,INC,NC,NCL,IL)
      DIMENSION X(1),I(1)
      IF (NC .LT. NCL) WRITE (2,200)
      IS=1
      IE=1
      K=K-1
    1 CONTINUE
      IF (I(IE+1) .NE. I(IE)+INC) GO TO 2
      IE=IE+1
      IF (IE .EQ. K) GO TO 3
      IF (IE-IS .LT. 8) GO TO 1
    2 CALL ITIM(IH,IM,ISS,I(IS))
      IJ=IE-IS+1
      II=11
      WRITE (2,210) IH,IM,ISS,II,M,IT,IJ,(X(ID),ID=IS,IE)
      IS=IE+1
      IE=IS
      IF (IS .LT. K) GO TO 1
    3 IJ=1
      DO 4 ID=IS,K
      X(IJ)=X(ID)
      I(IJ)=I(ID)
      IJ=IJ+1
    4 CONTINUE
      K=IJ
      RETURN
  200 FORMAT (' WARNING!   SOME CALIBRATIONS WILL BE OUT OF ORDER')
  210 FORMAT (3I2,3I3,I2,9F7.2)
      END
//$DATA
    4
MAY 1, 1976 HOUSTON ATGRADE
       0         0      100000
MAY 1, 1976 HOUSTON ATGRADE
       0         5 1
MAY 1, 1976 HOUSTON ATGRADE
       0         5 1
MAY 1, 1976 HOUSTON ATGRADE
       0         5 1
MAY 1, 1976 HOUSTON ATGRADE
       0         5 1
MAY 1, 1976 HOUSTON ATGRADE
       0         5 1
MAY 1, 1976 HOUSTON ATGRADE
       0         5 1
MAY 1, 1976 HOUSTON ATGRADE
       0         5 1
MAY 1, 1976 HOUSTON ATGRADE
       0         5 1
MAY 1, 1976 HOUSTON ATGRADE
       0         5 1
MAY 1, 1976 HOUSTON ATGRADE
       0         5 1
MAY 1, 1976 HOUSTON ATGRADE
       0         5 1
MAY 1, 1976 HOUSTON ATGRADE
       0         5 1
MAY 1, 1976 HOUSTON ATGRADE
       0         5 1
MAY 1, 1976 HOUSTON ATGRADE
       0         5 1
MAY 1, 1976 HOUSTON ATGRADE
       0         5 1
MAY 1, 1976 HOUSTON ATGRADE
       0         5 1
```

Appendix F

Aerial View of the Houston Site