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INTERIM REPORT

CHARACTERIZATION OF URBAN AND RURAL INHALABLE PARTICULATE

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by

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TABLE OF CONTENTS

Page

ABSTRACT 1

INTRODUCTION 3

EXPERIMENTAL METHODS 5

Sampler Locations 5

Sampling Methods 8

Supporting Data 9

RESULTS 10

Rural Data 10

Urban Data 12

DISCUSSION 18

Rural Comparison of Standard and Size-Selective Hivol Data 18

Urban Upwind-Downwind Differences 21

High Urban TSP Concentrations 22

SUMMARY AND CONCLUSIONS 24

ACKNOWLEDGEMENTS 25

REFERENCES 27

CHARACTERIZATION OF URBAN AND RURAL INHALABLE PARTICULATES

Donald F. Gatz

INTERIM REPORT

TO THE ILLINOIS INSTITUTE OF NATURAL RESOURCES

for the period

16 October 1980 to 30 June 1981

ABSTRACT

This report documents results of a 10-month first phase of a study to characterize urban and rural particulate matter. The three main purposes of the study are 1) to assess the effects of street sweeping on urban air quality, 2) to measure and compare total and inhalable mass concentrations in a rural area, and 3) to determine the sources of urban and rural particulate matter and their relative contributions to total airborne mass, in and near Champaign-Urbana, Illinois.

Preliminary results on the comparison of standard and size-selective high-volume samplers in a rural area indicate that inhalable particles make up about 70% of the total mass. This is in good agreement with a previous measurement in the literature.

To determine the effects of street sweeping on urban particle concentrations, three standard high volume samplers were operated near a four lane road in a commercial area, and another sampler was operated in a residential area of Champaign, Illinois. Preliminary results for a period when streets were being swept show that street-related sources increase the total airborne particle mass about 20% from upwind to downwind when the wind has a component perpendicular to the street. These results will be compared with others obtained during a period without street sweeping to determine the effects of the street sweeping on air quality.

Comparison of some very high particle concentrations that we observed in Champaign with Illinois EPA measurements at several central Illinois sites on the same day suggests that the high concentrations were caused by distant, as opposed to local, sources, aided by gusty winds.

1 INTRODUCTION

Provisions of the Clean Air Act enacted in 1977 require states to revise their State Implementation Plans (SIPs) for all areas that have not attained National Ambient Air Quality Standards (NAAQS). The Illinois SIP for Total Suspended Particulates (TSP) was conditionally approved by the U.S. Environmental Protection Agency (USEPA) with certain minor deficiencies. One of the reasons for the conditional approval of the Illinois TSP SIP was inadequate documentation of the impacts and effects of various controls on non-traditional fugitive sources of TSP. Examples of these sources include reentrained road dust, wind erosion from agricultural lands, and unpaved road emissions. This and similar studies have been designed to correct those deficiencies and will be submitted to the USEPA as part of the SIP for that purpose. The results of these studies will be used by the Illinois Environmental Protection Agency (IEPA) to define further the estimated impacts of non-traditional fugitive dust sources on TSP non-attainment areas throughout the state. They will also be used to refine the control strategies which may need to be applied to various non-traditional fugitive dust sources.

The Clean Air Act, as most recently amended (1977), emphasizes that health aspects should be considered very strongly when assessing effects of air pollutants. This has caused a concern that the standard high volume (hivol) sampler does not provide a sample of particles in the limited size range important for assessing health effects. Thus, the standard hivols may soon need to be replaced with samplers that measure concentrations of particles within the specific size range known to be capable of reaching the lungs through inhalation. Several such devices are under consideration. One is the two-stage virtual impactor (dichotomous sampler), which collects particles in two size ranges: less than about 2.5μm and 2.5 to 15μm , aerodynamic diameter. Others include size-selective inlets for the standard hivols.. These devices limit the particles collected to those smaller than some cutoff diameter, such as 15μm . In this report, we shall consider inhalable particles to be those less than or equal to 15μm aerodynamic diameter.

In October, 1980, the Illinois Institute of Natural Resources funded the Illinois State Water Survey for a 10-month first phase of a study to characterize urban and rural particulate matter. This is a report of progress on that study through 30 June 1981.

The purposes of the study are:

1. To assess the effects of street sweeping on urban air quality, by comparing hivol and dichotomous sampler measurements in urban areas in the presence and absence of regular street sweeping,

2. To measure rural TSP concentrations and compare results from:

1. a standard hivol,

2. a hivol with a size-selective inlet, and

3. a dichotomous sampler

operated in a rural area having intensive agricultural activity, and

3. To determine the sources of airborne particulate matter, and their relative contributions to.TSP, in both urban and rural locations.

This study was planned so as to utilize the regular street sweeping program being conducted in Champaign, Illinois, by a research group from the Water Survey's Surface Water Section and funded by EPA as part of the Nationwide Urban Runoff Program (NURP); the Principal Investigator of this study is Michael L. Terstriep, Head of the Surface Water Section.

2 EXPERIMENTAL METHODS

2.1 SAMPLER LOCATIONS

The rural samplers are located at the Survey's Bondville Road field site, about 10 km southwest of Champaign. The site is a 3.0 hectare (7.5 acre) grassy field, surrounded by fields of corn and soybeans. Precipitation and aerosol sampling are also carried out at this site in support of our study of air pollution scavenging for the U.S. Department of Energy (DOE). This site is also a precipitation sampling site for both the DOE/EPA Multistate Atmospheric Power Production Pollutants Study (MAPPPS) network and the National Atmospheric Deposition Program (NADP).

A map of a portion of Champaign, showing the aerosol sampling sites within the NURP study basins, is shown in Figure 1. Three hivol samplers are located in the commercial "Mattis South" basin along Mattis Avenue. As shown in the figure, two samplers are located on the west side of Mattis Avenue, and one on the east side. The dichotomous sampler is located adjacent to the hivol on the east side of Mattis Avenue. An additional hivol sampler is located in a residential Champaign neighborhood; this is designated the John Street site in Figure 1.

The hivol samplers on the east and west sides of Mattis Avenue are all located 7.0 m (± 0.4 m) from the curb to minimize any effects of distance from the street on the concentrations measured by the various samplers. At the John Street site the hivol is 17.6 m north of the curb.

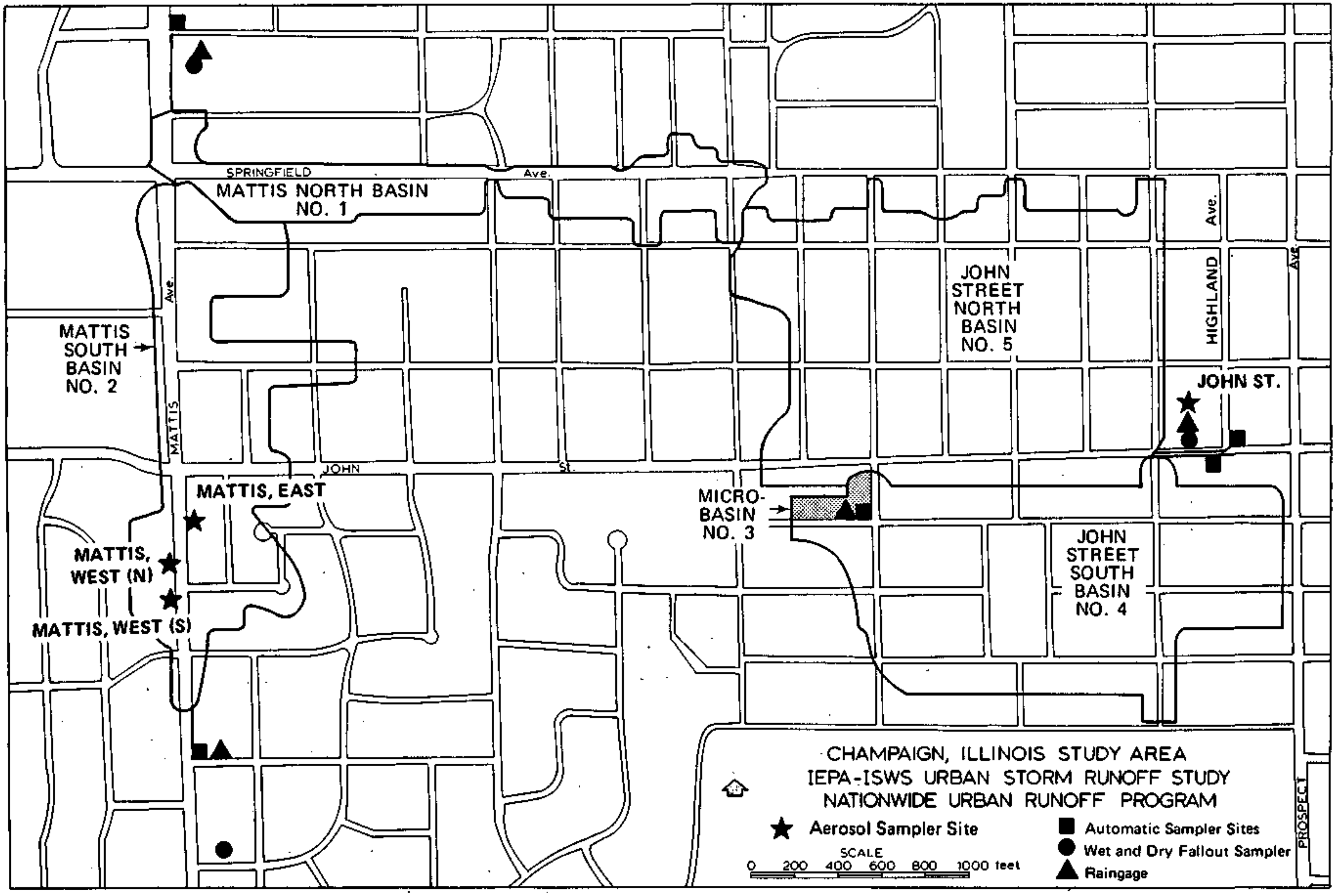

Figure 1. Partial map of Champaign, showing aerosol sampling sites and drainage basins and sampling sites of the Water Survey's project in the Nationwide Urban Runoff Program. (Modified from Terstriep et al., 1981).

2.2 SAMPLING METHODS

All the aerosol samplers were installed so that their inlets are 2 m above ground level. Thus, they conform to the standard height, i.e., between 2 and 15 m, at which hivol inlets must be placed. The urban hivol samplers are all positioned so that their inlets face the street. It is important to be consistent on this detail since there is evidence (Ortiz, 1978) that hivol sampling effectiveness varies with sampler orientation to the air flow, at least in strong winds.

As specified in our contract, IEPA provided the standard hivol samplers. These samplers were calibrated by IEPA prior to our use. Further, IEPA provides replacement pumps when the airflow falls below minimum rates. The IEPA also provides glass fiber filters for the hivol samplers, weighs the filters before and after exposure, and calculates TSP concentrations.

The urban hivol filters are changed at approximately 9:00 a.m. each Monday through Friday. This schedule provides five 24-hr duration filters each week from each sampler. The first filter of the week begins Monday morning and the last ends Saturday morning. At the rural site, hivol filters are changed on Monday, Wednesday, and Friday mornings (about 10 a.m.); here also, the filters are exposed for 24 hr.

The dichotomous sampler collects a pair (fine and coarse) of 24-hr duration filters each day of the week. Each sample begins and ends at 9:00 a.m. As suggested in the operations manual for the sampler (Spengler et al. , 1981), the instrument was carefully checked for leaks and calibrated prior to use. It was during such a leak test that damage to the filter seals, apparently caused by chewing insects, was discovered. The need for repairs to the instrument caused extensinve delays in beginning the dichotomous sampling program. Sampling was begun at the urban site described earlier during June, 1981, and has been proceeding normally, except for two samples lost due to power outages. During normal operations, the dichotomous sampler will be recalibrated every 1-2 weeks to insure accurate sample volume determinations.

2.3 SUPPORTING DATA

Several kinds of data are also being collected to aid in interpretation of the air quality data. These include meteorological data, specifically winds and precipitation, as well as information on traffic densities and the dates when the streets are swept.

Precipitation is measured at the Mattis Avenue and John Street raingage sites, as shown in Figure 1, and provided to us, along with traffic counts and dates of street sweeping, by the Water Survey NURP project mentioned earlier. Winds applicable to the rural site are measured at The University of Illinois Willard Airport, 8 km east of the rural site. Urban wind measurements are made at the Water Survey Headquarters, about 4 km east of the Mattis Avenue sites.

3 RESULTS

3.1 RURAL DATA

A comparison of particle mass concentrations measured by the standard and size-selective hivols is shown in Figure 2. The solid line represents perfect agreement between the two samplers. It is clear that the standard hivol commonly measures higher concentrations than the size-selective hivol, which excludes particles larger than 15µm aerodynamic diameter. The dashed line in Figure 2 is the least squares linear regression line fitted to the data: TSP = 1.43(IP) - 0.45. In this equation, TSP is total suspended particulate concentration, as measured by the standard hivol, and IP is the inhalable particulate concentration, as measured by the size-selective hivol. Thus, when the size-selective hivol measures an IP concentration of 75 $\mu g/m^3$, the standard hivol would measure, typically, a TSP concentration of 107 $\mu g/m^3$.

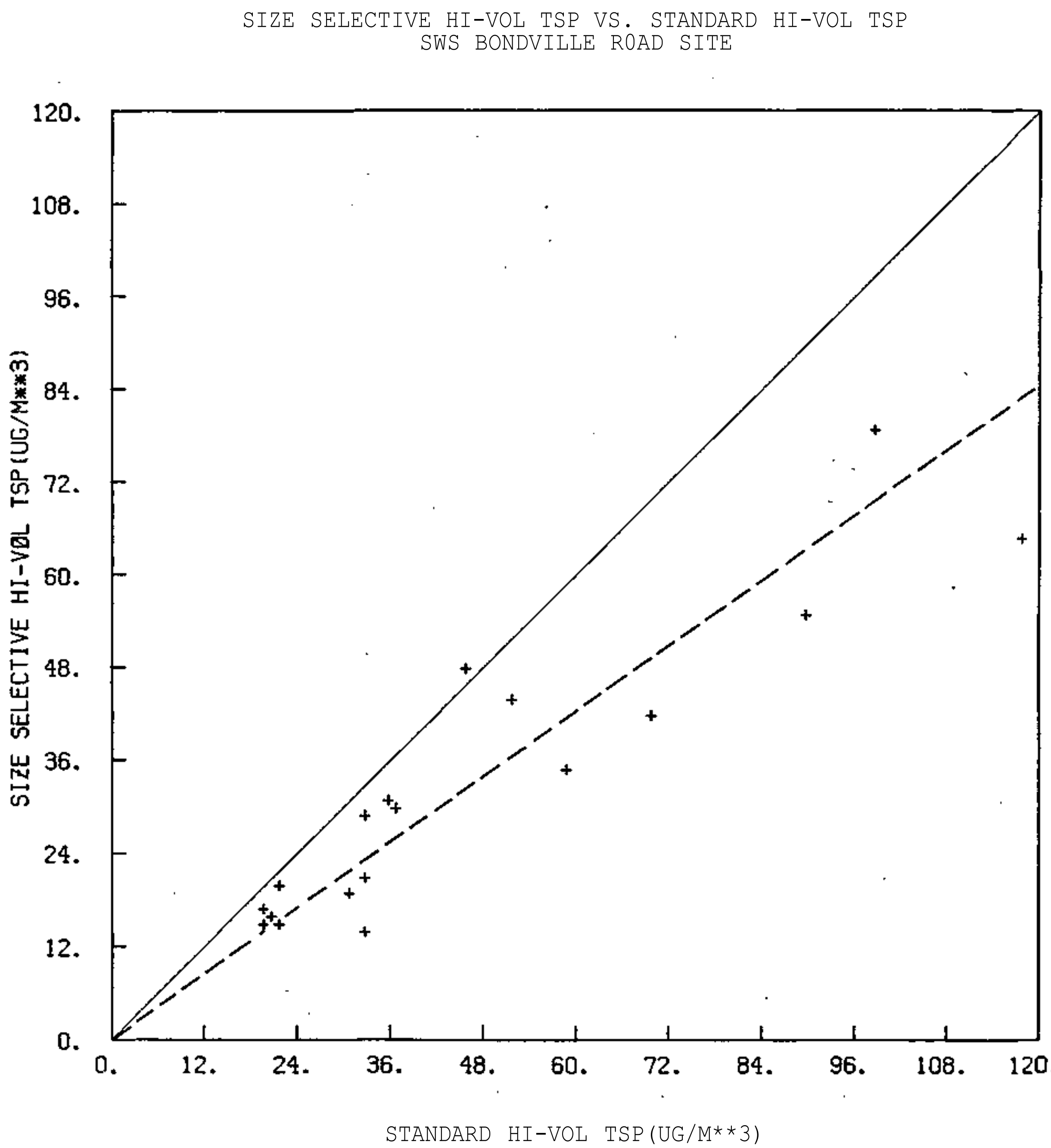

Figure 2. Comparison of rural particulate concentrations measured by standard and size-selective hivol samplers.

3.2 URBAN DATA

A summary of all available urban data is given in Figure 3. This includes TSP measurements at four sites, along with daily rainfall amount, dates of street sweeping, and wind data. Wind directions are shown by directional category. The westerly wind category (W in Figure 3) includes days when the wind blew from the 202 to 338 degree sector 75% of the hours between 6 a.m. and midnight. Wind direction was not considered relevant in the remaining hours of the sampling period because only a very small fraction of the traffic occurs then. Similarly, the easterly wind category (E) includes days when the wind blew from the 22 to 158 degree sector 75% of the hours in the same time interval. The "other" wind direction category (0) includes all other days. Mean wind speed during sample collection and daily maximum 1-minute gust speed are also shown.

A glance at the TSP data in Figure 3 reveals several interesting features. One of these is the apparent high correlation of TSP concentrations among the several sites, including the residential (John Street) site, which on most days observed the lowest TSP values. Another is the occasional occurrence of unusually high TSP concentrations, several over 100 $\mu g/m^3$ and a few over 200 $\mu g/m^3$.

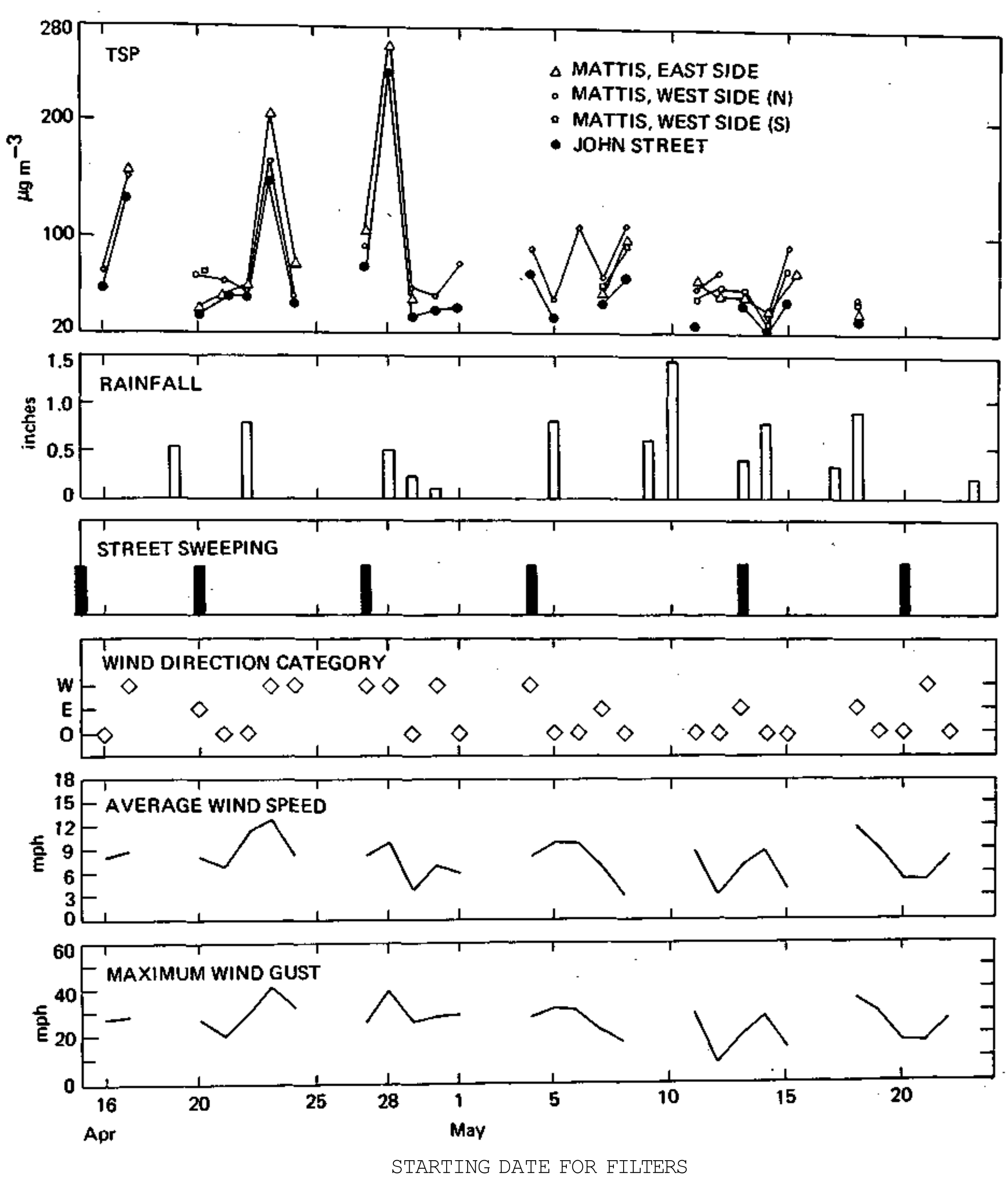

Figure 3. Summary of urban data for evaluation of effects of street sweeping on urban air quality. See text for further explanation.

Figure 3 shows that rainfall was frequent and relatively heavy during the period shown, with seven days having 1.27 cm (0.5 in.) or more. Streets were swept on a regular weekly schedule during the period.

The two highest maximum gust values, 40 and 39 mi/hr, were observed on April 23 and 28, respectively, the days when several TSP values exceeded 200 $\mu g/m^3$.

In order to assess whether street sweeping can be used to improve urban air quality, we will have to compare TSP measurements during the period when streets were being swept with similar data collected during a period when street sweeping is suspended. Such a data set is being collected, but is not now ready for analysis. We can , however, examine the data to see if roads are indeed a source of TSP in the urban area.

To examine this question, we divided the data according to the wind direction categories mentioned earlier. This was done to assess which samplers were upwind, and which downwind, when the wind direction was either easterly or westerly (i.e., having a large cross-wind component, relative to Mattis Avenue) and to identify those days when the wind was either north or south, or included both east and west winds to the extent that it would be difficult to assign upwind and downwind.

Results for the cross-street wind cases are shown in Figure 4, and those for the "other" wind category in Figure 5.

Figure 4 includes only measurements made in easterly or westerly winds, and shows a small, but clear tendency for the downwind samplers to have higher TSP values. Both upwind and downwind samplers experienced higher TSP concentrations with westerly winds. For example, the upwind means were 115 $\mu g/m^3$ for west winds and 52 $\mu g/m^3$ for east winds, a difference of 121%, relative to the east wind value. For both east and west winds, however, the downwind samplers had higher TSP values, showing that the road is a definite source of airborne particles. As before, the solid line represents perfect agreement between upwind and downwind samplers, whereas the dashed line is the least squares regression line, $U = 0.86(D) -1.47$.

The mean value, over four west wind samples, of the daily mean wind speed, was 4.2 m/sec (S.D. = 1.1 m/sec), while the corresponding value for four east wind samples was 3.8 m/sec (S.D. = 1.1 m/sec). Analogous means for the maximum gusts were 14.1 m/sec (S.D. = 3.1 m/sec) for west wind samples and 11.7 m/sec (S.D. = 3.2 m/sec) for east wind samples.

Figure 5 shows the relationship between TSP concentrations on the east and west sides of Mattis Avenue for the "other" wind category. For

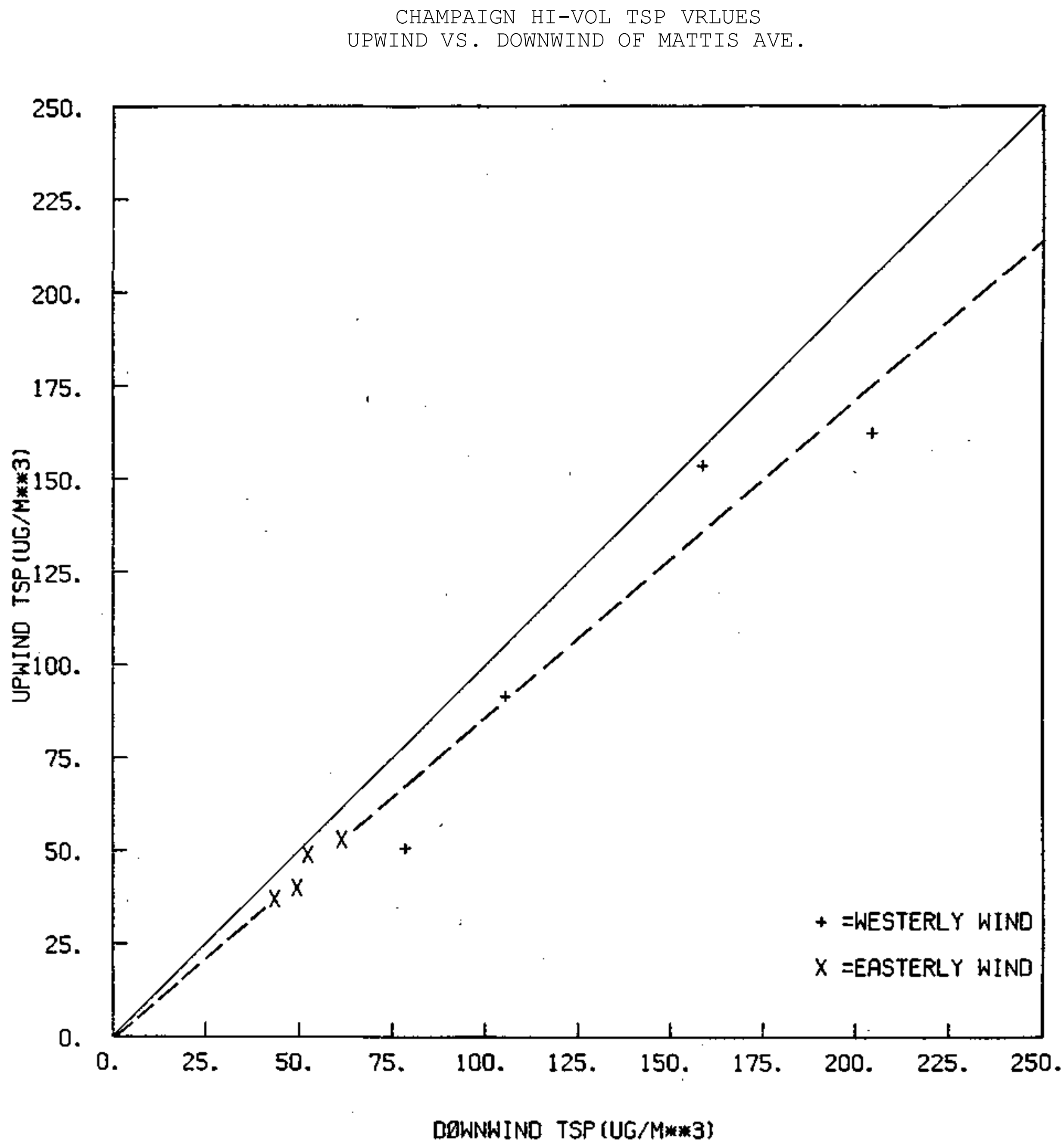

Figure 4. Comparison of TSP concentrations upwind and downwind of Mattis Avenue, for easterly and westerly wind cases.

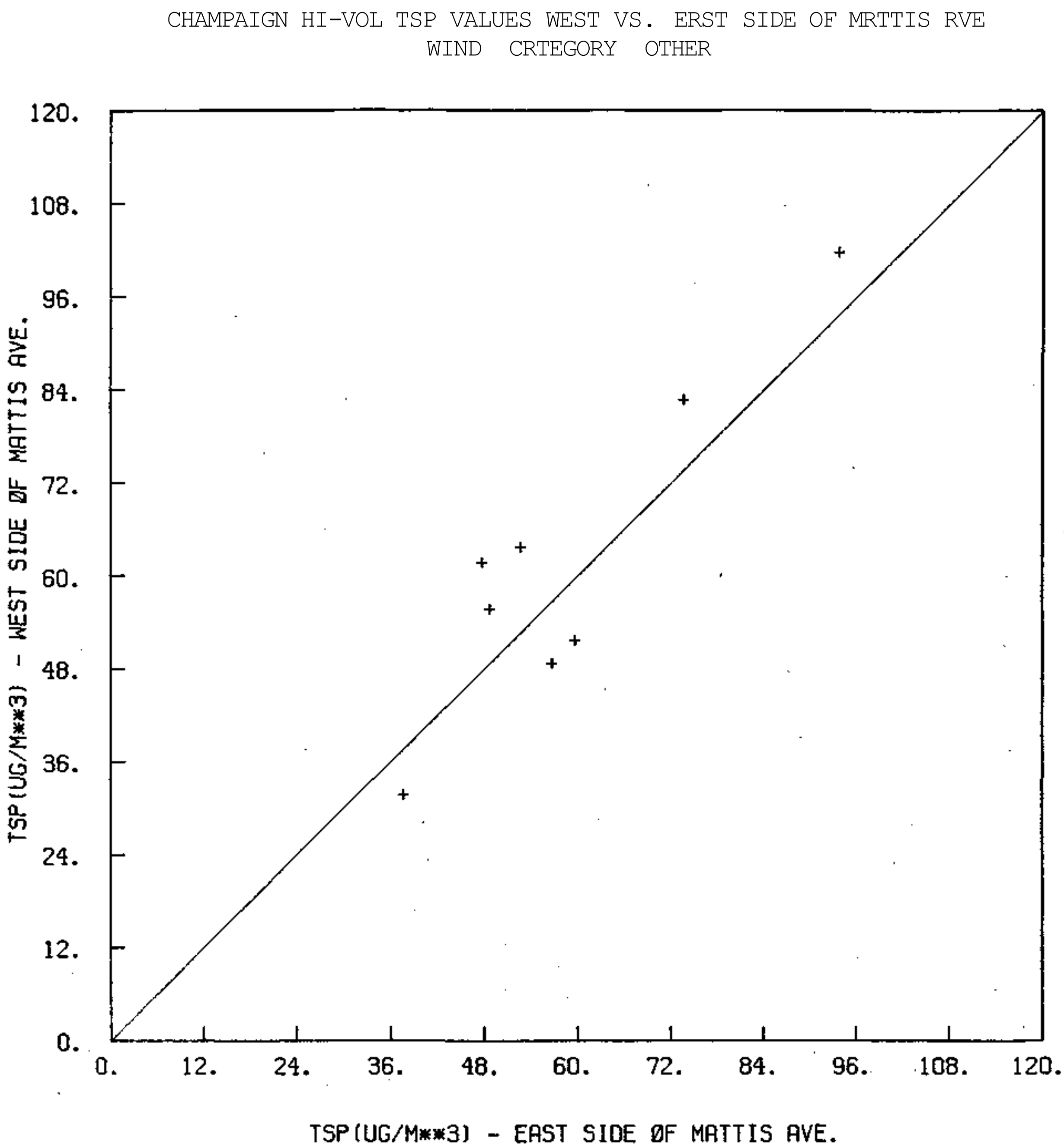

Figure 5. Same as Figure 4, but for cases where winds did not meet the criteria for the easterly or westerly categories.

these relatively few data points, there is no strong tendency for either side of the street to have higher values.

4 DISCUSSION

We emphasize that the data presented in this report represent few samples, both in absolute terms and relative to the number of samples from which the final results will be derived. Because of the preliminary nature of the data, only the major issues for which this research is being performed are discussed at this point. The results and their interpretations should, of course, be considered preliminary, and subject to change as more data are accumulated in the coming weeks and months.

4.1 RURAL COMPARISON OF STANDARD AND SIZE-SELECTIVE HIVOL DATA

Table 1 lists comparisons between TSP and IP from the literature as well as from this study. In the cases of the three previously published results, IP was measured with dichotomous samplers. However, all the samplers used had upper cutoffs of approximately 15 µm aerodynamic diameter, the same as the size-selective hivol used in this study, so comparisons are valid.

Table 1. Comparison of inhalable particle/total particle ratios in this study with literature values.

Reference	Site Locations	No. of sites	N*	IP/TSP	IP/TSP
Pace and Meyer, 1979	urban	10	**	0.5 - 0.7	
Spengler *et al*., 1980	urban	4	**		0.59 - 0.66
Kolak and Visalli, 1981	urban	4	17	0.58 - 0.64	
	rural	1	21	0.80	
This study	rural	1	18	0.70	0.73

*Approximate number of observatations per site.

**Not known

The table lists two measures of the IP/TSP ratio. The first, $\overline{IP}/\overline{TSP}$, is the ratio of the mean values of IP and TSP, while the second, $\overline{IP/TSP}$, is the mean of all the ratios computed separately for each pair of samples.

The three studies of inhalable/total ratios in urban areas all agree that the ratio lies in the range 0.5 to 0.7, whichever form of the ratio is used. Kolak and Visalli (1981) compared results at one rural site southwest of Buffalo to four urban sites in the Buffalo area, and found higher $\overline{IP}/\overline{TSP}$ values in the rural area. Since these authors measured IP with a dichotomous sampler, they were able to deduce that the urban-rural differences were probably caused by differences in the measured fine particle concentrations. These differences might represent real differences in airborne particle concentrations, but the authors note that they could have been caused by various sampling difficulties, such as artifact sulfate formation or a variation in sampling efficiency with particulate loading.

Our measurements, based on our first 18 pairs of samples, give an $\overline{IP}/\overline{TSP}$ ratio slightly smaller that Kolak and Visalli's rural value, but higher than any of the literature values for urban areas. This statement is also true for the $\overline{IP/TSP}$ ratio. Thus our preliminary results agree quite well with previous measurements in a rural area near Buffalo, New York. Kolak and Visalli used "standard" measurement techniques, but did not state the height above ground for their sampler inlets. Since the standard height for sampler inlets is 2-15 m, it is not possible to tell what height was used for the Buffalo area measurements, or how it compares to our inlet height of 2 m.

4.2 URBAN UPWIND-DOWNWIND DIFFERENCES

The data, though few, support the idea that urban paved roadways are sources of particulate matter. For all eight pairs of samples shown in Figure 4, the concentration measured downwind of the road was greater than that measured upwind. This was true for both easterly winds and westerly winds, although concentrations were always higher on both sides of the street with west winds.

The mean wind speeds for the west wind cases were about 10% higher than those for the east wind cases, and the maximum gusts averaged 20% higher for the west wind cases. These differences are in the right direction to explain the observed higher TSP values with west winds if wind-mobilized surface dust is the source of the particles. However, the magnitude of the wind speed differences (10-20%) is considerably less than the 121% difference in mean upwind TSP values. This does not rule out the possibility that the higher TSP concentrations were caused by higher or more gusty winds, since there could easily be a non-linear mechanism involved, such as a threshold velocity above which surface particles are suddenly mobilized in great numbers.

However, the possibility also exists that higher TSP concentrations were observed with west winds simply because the sampling sites are on the west side of the Champaign-Urbana urban area. Thus, with west winds soil particles from nearby rural areas have a relatively short trajectory to the samplers, whereas with east winds such particles must traverse several kilometers of urban surface before reaching the samplers. East winds could therefore be relatively depleted of particles due to dry deposition or dilution.

Using the symbols D for downwind and U for upwind, the ratio of means, $\bar{D}/\bar{U}$, was 1.19 for the eight sample pairs, while the mean ratio $\overline{D/U}$, was 1.21, with a standard error of 0.055.

4.3 HIGH URBAN TSP CONCENTRATIONS

TSP concentrations over 100 $\mu g/m^3$, which were observed on several days, at several different locations in Champaign, including a residential area, deserve a brief comment. Such concentrations are clearly unexpected in Champaign, since they far exceed the primary standard for TSP of 75 μg/m^3 annual geometric mean concentration, and since one of them exceeded 260 μg/m^3 , the value that can be exceeded no more than once per year. Champaign is currently considered to be meeting the TSP standard. The next question is then, "Were these high concentrations caused by natural or man-made sources?"

The question cannot be answered with full certainty without more extensive investigation, but the occurrence of very high values in residential areas, as well as near a heavily traveled commercial roadway, suggests that the phenomenon was widespread, and not caused by local traffic.

This explanation is supported for the April 28 case by IEPA observations in Champaign and several other sites in central Illinois. The TSP concentration measured at the IEPA Champaign site was 321 μg/m^3, and the observer noted that a "dust storm" occurred. This was the largest value observed in central Illinois, but other observations approached or exceeded 100 μg/m^3. For example, concentrations of 88 μg/m^3 were observed at a rural site near Robinson, Illinois, 109 μg/m^3 at the Decatur Naval Armory, 73 μg/m^3 at Springfield, 114 μg/m^3 at Petersburg, and 95 μg/m^3 at Effingham. No IEPA observations of TSP were made on 23 April 1981.

The likely source of these high concentrations is blowing soil dust, perhaps caused at least partially by tractors in the field for late planting or cultivating operations.

The high gusty winds that occurred on the days with high TSP may also have been at least partially responsible for mobilizing soil particles, and would have aided in bringing any particles raised by soil tilling operations into the city.

5 SUMMARY AND CONCLUSIONS

To gain information on the relationship between total particle mass concentrations and inhalable mass concentrations in a rural area, standard and size-selective hivol samplers were installed and operated at a rural 3ite near Bondville, Illinois. Premliminary results show that inhalable particles make up about 70% of the total particle mass. This is a slightly lower fraction than, but still in good agreement with, the 80% inhalable particles observed by others at a rural site southwest of Buffalo, New York.

To determine the effects of street sweeping on urban TSP concentrations, three standard hivol samplers were operated near a four lane commercial roadway, and an additional sampler was operated in a residential area of Champaign, Illinois. Preliminary results are available only for a period when streets were being swept regularly, so no conclusions can be drawn regarding effects of sweeping. However, the first eight pairs of samples collected on days when winds were predominantly perpendicular to the street clearly show that the street was a source of airborne particles. About 20% more mass per unit volume of air was present downwind of the street than upwind.

Very high TSP concentrations observed on a few days appear to have been caused by distant, as opposed to local sources, perhaps aided by gusty winds.

6 ACKNOWLEDGEMENTS

This work was possible only through the dedicated efforts of Susan Wiley, who collected most of the samples and performed the data analysis, and Bruce Komadina, who devised a convenient means of mounting the hivols and supervised their installation. Thanks are also due Randall K. Stahlhut, for programming assistance, Eberhard Brieschke, who helped with the installations, and Mr. Kenneth Porter, Mr. Lawrence Boastick, and Dr. and Mrs. Glenn Stout, who are allowing us to operate samplers on their property. The Illinois EPA, through the assistance of Mr. Arden Ahnell, Mr. Bob Hutton, and Mr. John Shrock, provides, calibrates, and maintains the standard hivols, and provides and weighs the filters. Mr. Hutton also supplied the IEPA TSP data. We also thank Mr. Michael Terstriep and Mr. Michael Bender for their cooperation in supplying data.

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