Air Quality Changes Associated with the Atmospheric Transport of Total Suspended Particulate in and around Chicago[1]

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Abstract

An analysis is made of the wind directional effects on the atmospheric transport of total suspended particulate in and around the City of Chicago. Daily and annual estimated values in micrograms per cubic meter are reported for total suspended particulate advected into Chicago from surrounding industrial, urban, and rural areas. Using eight years of data in the analysis, estimates are given for the mean annual values of total suspended particulate advection from northwest Indiana into Chicago, Illinois. Some estimates are given for corresponding mean daily values as well.

Introduction

The City of Chicago is not likely to meet the federal standards for air quality on total suspended particulate (TSP) in 1975. Part of this problem of not meeting the U. S. Environmental Protection Agency (EPA) standards is related to the advection of particulates from surrounding areas. The purpose of this analysis is that of estimating the impact of surrounding areas on the annual, as well as the daily, mean values for TSP within the City of Chicago.

This city is surrounded by several local governmental units in addition to being adjacent to the Indiana-Illinois state line. The governmental units include Cook County, Illinois, Lake County, Indiana, as well as several nearby city governmental units in both states.

In an attempt to avoid some of the difficulties normally associated with the attainment of uniform air quality standards between local city governments and across state lines, Air Quality Control Region 067 was set up to include the City of Chicago, Cook County, Illinois as well as the counties of Lake and Porter in Indiana. Further, the Air Stagnation Advisory Region which operates in cooperation with the National Weather Service covers the same geographical areas and local governmental units. But in practice each individual city or county government must meet the EPA's air quality standards separately. Such a scheme does not consider, in a measurable way, the fact that the air quality problems in one city may not have originated within its boundaries.

Data Sources and Methods

The figures representing isopleth analysis of TSP concentration for northwest Indiana, Cook County, Illinois, and Chicago were drawn using data from a network of 82 sites. This was done in cooperation with the following nine agencies:

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1. Division of Air Pollution, State Board of Health, State of Indiana.
2. Division of Air Pollution Control, City of Gary.
3. Department of Air Quality Control, City of East Chicago.
4. Air Pollution Control Department, City of Hammond.
5. County Health Department, Lake County, Indiana.
6. County Health Department, Porter County, Indiana.
7. Division of Air Pollution Control, Michigan City, Indiana.
8. Department of Environmental Control, City of Chicago.
9. Cook County, Department of Environmental Control.

Figure 1 shows all high-volume air sampling sites used in these isopleth analyses. In contrast to the isopleth analysis, data taken solely from the Department of Environmental Control, City of Chicago, were used in the computational analysis. These data were taken approximately every three days from January, 1966, to March, 1974, on the city's official 20-site high-volume sampling network. The total of 1155 daily city-wide means were placed on a computer file along with meterological data from Midway Airport, Chicago. The data were transformed by year using a factor that reduced each year-to-year comparison of data This procedure essentially reduced each year's annual TSP mean value to 95 $\mu g/m^3$, the 1973 value (1). This transformation technique was used to eliminate the 8-year trend in the data, thus allowing single value comparisons to be made using all 8-years of data.

To determine the influence of surrounding areas on Chicago's air quality four wind directional categories were chosen: 10°-90°, 100°-160°, 170°-260°, 270°-360°. These categories were given the following respective letter codes for convenience: NE, SE, SW, and NW. The specific categories were created in an attempt to single out different advection characteristics. These directional categories are related to the best geographical fit of compass directions to pollution sources and sinks. Winds from the NE represent flow from over Lake Michigan, an essentially clean air source. Winds from the SE contain the cases that constitute advection from the industrial areas of northwestern Indiana. Winds from the SW represent advection of air into Chicago from urban areas of Cook County, as well as the heavy industrial area of South Chicago. Winds from the NW represent air advection from suburban and rural areas in Illinois outside of Chicago.

In Figure 2, the wind rose represents the 1155 days sampled and used in this study. Of course, the wind direction divisions made herein are simplifications of the real situation. Although there will be overlap among advection sources, this effect is thought to be minimal. A special wind rose or "rain rose" is shown in Figure 3. The wind "rain rose" diagrams the mean wind speed and direction on the day following the occurrence of precipitation. The wind direction category on the sampling day is compared with the average rainfall received on the day before at Midway Airport, Chcago.

The analysis for each day represented in Figures 4 through 8 was done employing all site data available using linear interpolation between points. Daily meteorological data is also given in Figures 5 through 8. The numbers given below the wind direction are mean wind and resultant wind speeds, respectively, in mph. The temperature is the average daily temperature in degrees Fahrenheit. Also, any day with over 0.10 inches of precipitation at Midway Airport, Chicago was called a wet day.

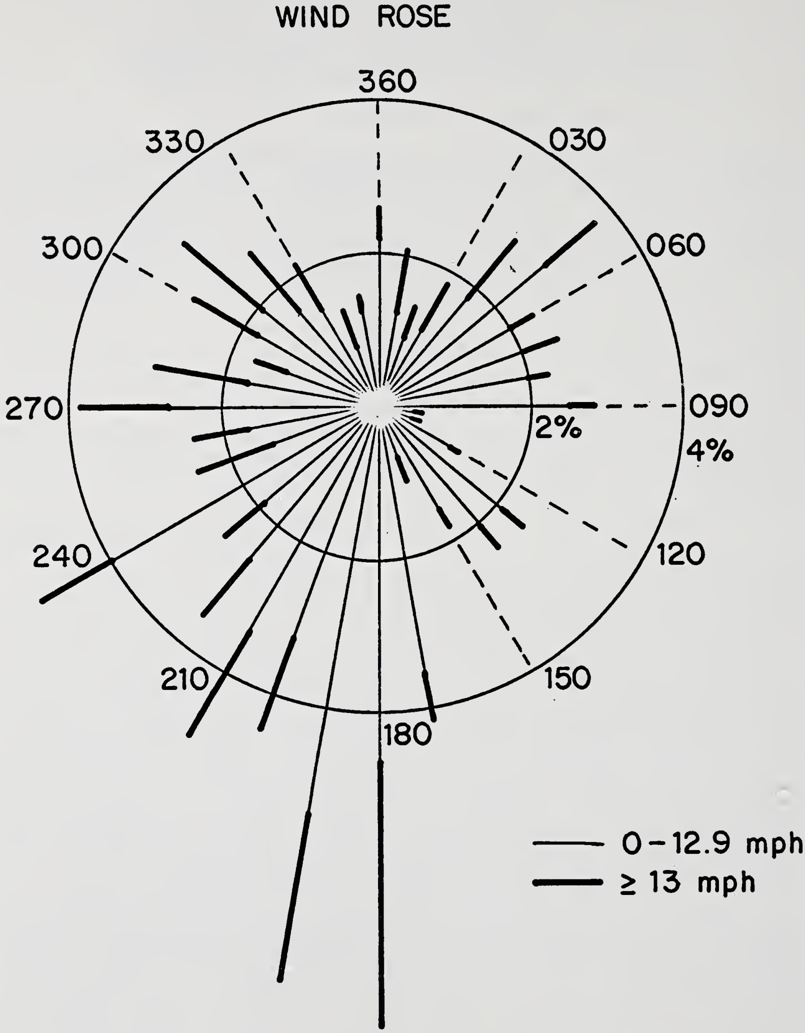

FIGURE 1. *Locations of the 83 high-volume air sampling sites.*

The problem of directional advection or atmospheric transport of particulate air pollutants seems to be related to four factors: (1) area sources of pollution in the city, (2) outside sources, (3) precipitation, and (4) air mass background quality. These factors are discussed and supporting data are reported in figures and tables.

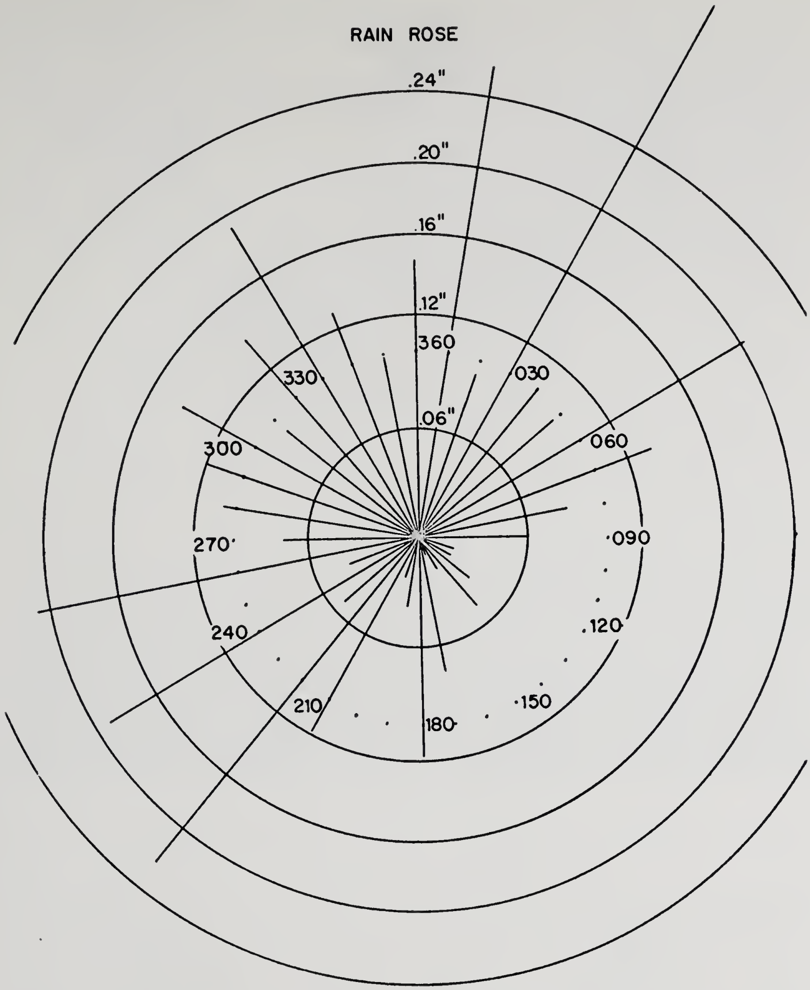

Figure 2. *Wind rose over the 8-year sampling period taken from the meteorology on the 1155 days samples at Midway Airport, Chicago.*

Discussion of Results

Figure 4 shows the 1973 mean annual isopleths of TSP loading in Chicago and the surrounding area. This figure represents only area sources and it can be seen that heavy concentration of TSP exists quasi-permanently on the eastern and southeastern sides of Chicago, and in the corner of northwestern Indiana.

Winds from the north and northwest will transport Chicago pollutants southward over the lake decreasing loading within the city as shown in Figure 5. These winds may also transport Chicago pollutants into northwest Indiana. As shown in the rain rose in Figure 3 winds

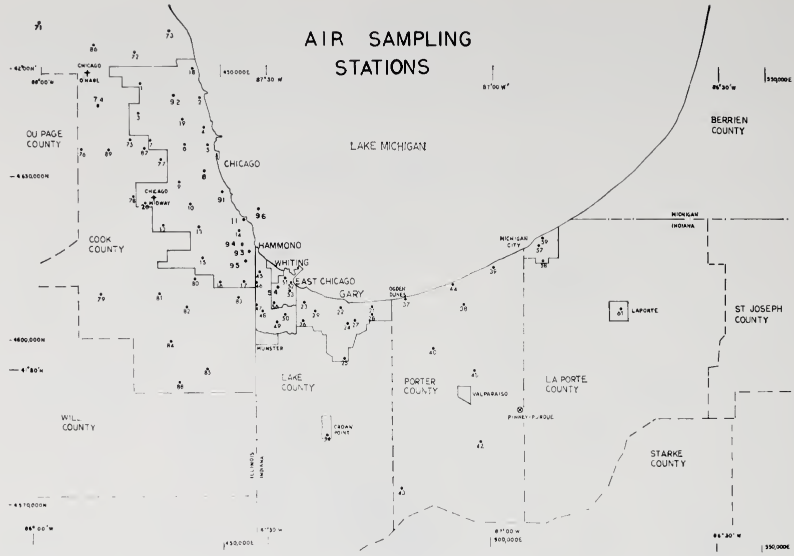

FIGURE 3. *Rain rose showing the amount of rain measured the day before the 1155 samples were taken broken down by wind direction measured on the sampling days.*

are often from the NW direction the day after a rain. This fact will have the effect of decreasing TSP due to the fact that wet ground will reduce refloatation of surface suspendable material that may account for 10-40% of TSP measurement (1). Mean TSP data reported in Table

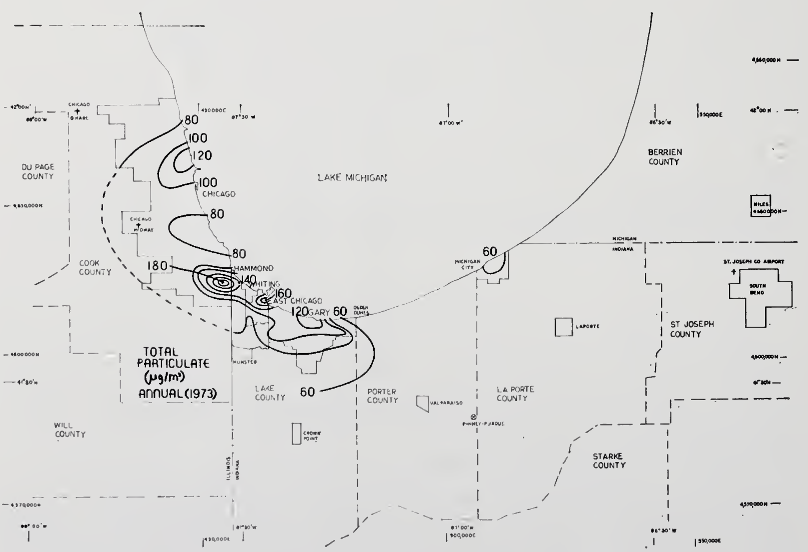

FIGURE 4. *Isopleth analysis of total suspended particulate for 1973.*

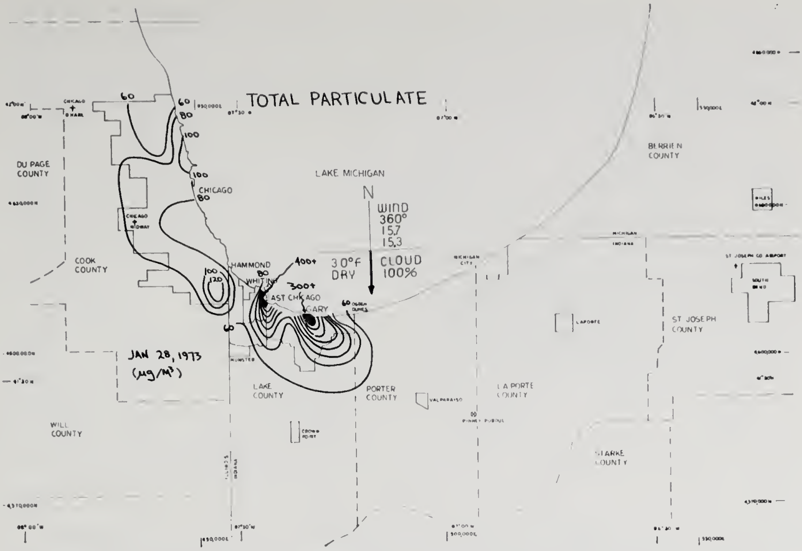

FIGURE 5. *Isopleth analysis of total suspended particulate on January 28, 1973.*

1 shows that loading from this direction is about 14% less than the 8-year annual transformed mean city-wide value of 95 $\mu g/m^3$.

Winds from the NE passing over Lake Michigan move much clean air into Chicago. Figure 6 shows the effect of transport by north-easterly winds. The centers of maximum concentration move toward the

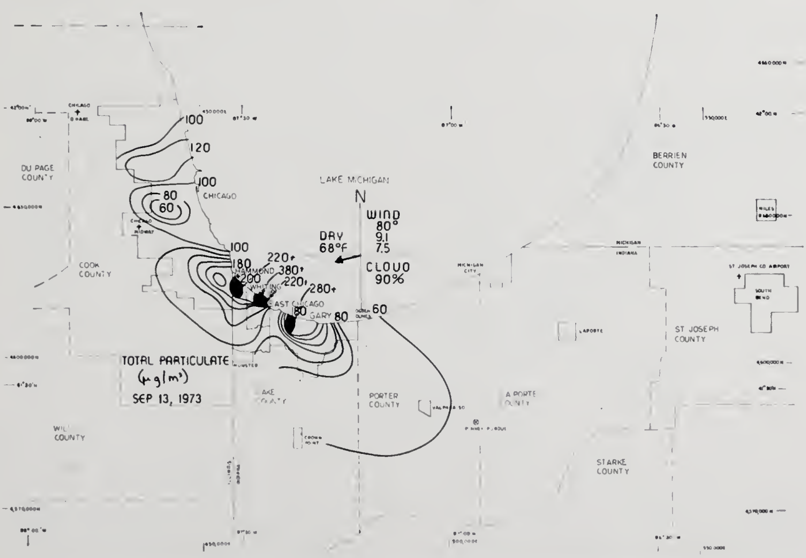

FIGURE 6. *Isopleth analysis of total suspended particulate on September 13, 1973.*

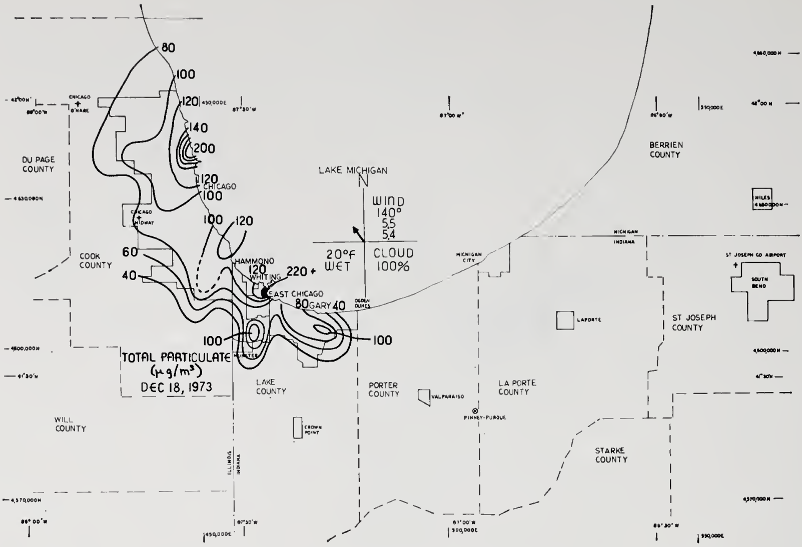

FIGURE 7. *Isopleth analysis of total suspended particulate on December 18, 1973.*

center of Chicago can be noted. Also, it may be noted that the maximum concentration of industrial pollution from Lake County, Indiana tends to drift westward.

Indiana pollution advection into Chicago is most likely when the winds are from the SE direction. Figure 7 shows that the centers of

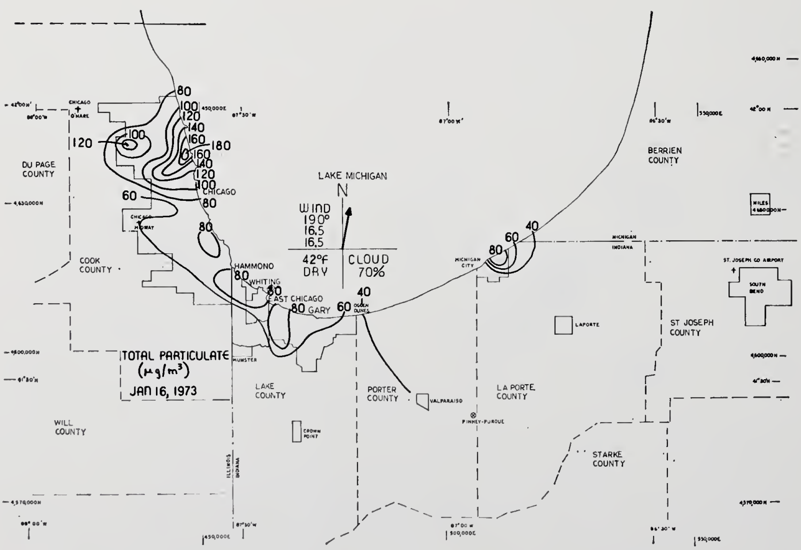

FIGURE 8. *Isopleth analysis of total suspended particulate on January 16, 1973.*

pollution concentration have considerably decreased in Lake County, Indiana, as well as in the south and east sides of Chicago. Also, increased pollution levels exist in the north side of Chicago. The extent of the Indiana pollution transport is estimated in the following paragraphs.

TABLE 1. *Characteristics of total suspended particulate (TSP) data broken down using wind direction criteria.*

24-hour av. wnd direction	City-wide average TSP Weekdays μg/m³	Weekends μg/m³	Time weighted	Percent of time wind from given direction
10°— 90° (NE)	95 ±1.4*	81 ±1.9	91	21%
100°—160° (SE)	124 ±2.0	110 ±2.8	120	10%
170°—260° (SW)	104 ±0.9	89 ±1.3	100	45%
270°—360° (NW)	87 ±1.3	69 ±1.9	82	24%

* 95% confidence interval.

Winds from the SW direction seem to transport the pollution from Lake County, Indiana to Lake Michigan. These SW winds also seem to move the pollution from the south side of Chicago to the north side (Figure 8). Much of this particulate pollution represented in Figure 8 in north Chicago may be from refloatation sources within the city. As Table 1 reveals, winds blow from the SW directional quadrant 45% of the time. This is unfortunate for much of Chicago. However, this fact is indeed fortunate for the heavy industrial areas of SE Chicago and NW Indiana. These winds transport pollution away from this area, thus, decreasing the measured TSP levels in these urban areas.

In estimating the impact of advected particulate pollution from northwest Indiana on Chicago's TSP levels, both the impact on the annual mean TSP value and the daily values need to be considered. There seem to be two possible approaches in estimating the advection from Indiana on an annual basis. First, one may assume that SE winds would have the average advection characteristics of the other three wind directions, if the industrial area of northwest Indiana were not there. Therefore, one can compute the average loading in Chicago when winds are from all but the SE, thus eliminating the Indiana advection cases. Such a value was computed at 9.1 μg/m³ from Table 1. The average loading when winds are from the SE is 120 μg/m³ (Table 1). The difference between these two values multiplied by the 10% of the time winds are from this direction results in an estimated annual increase of Chicago TSP of 2.9 μg/m³ because of pollution advection from Indiana. Secondly, one may assume that if the Indiana sources of pollution were not there, the loading from the SE direction would be the same as the TSP loading when winds are from the NW direction for cases when the wind blows from both rural and suburban areas. This assumption results in a value of increased TSP that could probably be taken as an upper limit of Indiana's total effect on Chicago TSP. Such calculations using the data in Table 1 result in an estimate of 3.8 $\mu g/m^3$ increase in the annual mean Chicago TSP value. This value represents an increase of approximately 4% of the annual total.

The impact of advection from Indiana on daily values of Chicago TSP measurement can be estimated in a similar manner. The national secondary ambient air quality standard for particulate matter measured over 24 hours states that TSP may exceed 150 $\mu g/m^3$ only once a year. From the eight years of data used in this study it was found that days when winds were from the SE accounted for 34% of the days exceeding the 150 $\mu g/m^3$ value. Winds from the SW accounted for 50% of these occurrences, which compare very closely with the 45% value that represents the fraction of time the winds are from that direction. However, since the winds are only from the SE 10% of the time, it follows that some factor associated with SE winds is causing increased loading and consequently, violations of the standard (see Table 1). The average loading of all measurements taken on days with over 150 $\mu g/m^3$ TSP and with the wind from the SE is 167 $\mu g/m^3$ (see Table 2). Based on data from Table 2, it was estimated that advection from Indiana increased these SE direction cases about 30 $\mu g/m^3$ on a daily basis. Thus, if this additional amount were subtracted from each daily TSP value from the SE direction, the percent of time that violations occurred from the SE direction would be reduced by approximately two-thirds. Consequently, it is estimated that advection from Indiana occurring when the winds are from the SE direction accounts for 20% of the yearly violations of the daily national secondary TSP standard even though the winds blow from the SE quadrant only 10% of the time on an annual mean basis.

By examining Table 1 one may determine other characteristics of the atmospheric transport of particulates in and around Chicago. As is expected (3) there is considerable difference between weekday and weekend values within each of the four directional categories. Yet, the relative differences between categories remain the same for both weekday and weekend values. It is also apparent that the SW directional winds are associated with a higher mean TSP value. That Chicago measures its own pollution a number of times as it travels from the southern industrial region to the north side of the city is one possible explanation of the elevated TSP value. Also, one may speculate that because the city extends 25 miles in the N-S direction, the winds may suspend (refloat) more exposed surface dust and dirt which is measured as TSP. Finally, the southerly winds in Chicago are often associated with the flow on the back side of a high pressure system. Such systems can give rise to air stagnation and the resulting high TSP levels due to low rates of mixing and transport of pollutants upward in the atmosphere.

Table 2 shows the analysis done using weekday values. Of the 1155 days in the 8-year analysis period 772 daily measurements occurred on weekdays and 383 on weekends. Data reported here points to the fact that differences between directional values are not very dependent on wind speed. The one major exception is between the NE winds and the three other wind directions. In this case the difference between the

TABLE 2. *20-station Chicago network, Monday-Friday mean total suspended particulate values for particular wind speed and direction criteria.*

Wind speed range (mph)	Wind direction 10°—90°		Wind direction 100°—160°		Wind direction 170°—260°		Wind direction 270°—360°	
	Average loading $\mu g/m^3$	Number of days measured	Average loading $\mu g/m^3$	Number of days measured	Average loading $\mu g/m^3$	Number of days measured	Average loading $\mu g/m^3$	Number of days measured
< 5	134	11	185	2	151	5	146	2
5- 7	113	22	135	14	127	25	105	17
7- 9	114	33	120	22	112	55	94	27
9-11	94	28	130	14	104	88	85	35
11-13	81	27	116	14	96	66	80	57
13-15	69	22	100	5	101	40	84	27
15-17	62	8	—	—	98	38	78	16
≥ 17	62	7	111	5	95	26	92	14
Total days:		158		76		343		195

NE directional category and the other three directional categories increases as the wind speed increases. This finding supports the conclusion that winds faster than an average speed of 13 mph will cause refloatation (1). Because NE wind brings in clean air from over Lake Michigan, the advected transport will dilute the pollution. Therefore, refloatation does not influence these data very much. This situation is an ideal flushing phenomenon because no refloatation will occur over Lake Michigan, the area directly upwind of the city. The main reason the other directions do not show this flushing is because the air mass that is advected into Chicago is not nearly as clean as air from over Lke Michigan. The explanation for this lies in the fact that the strong winds will refloat materials in rural and suburban areas, thus decreasing the air quality of the air advected into the city (2).

Conclusions

The degree to which particulate pollution from Indiana affects the total suspended particulate (TSP) levels in the City of Chicago has been purely a matter of speculation. This study has hopefully clarified this situation. The estimated maximum value of TSP increase due to advection from Indiana into Chicago was computed as 4%. This value represents an eight-year average. There could be deviations from this value from year to year depending upon meteorological conditions. However, it seems reasonable to conclude that advection from Indiana on a yearly basis is not the most important part of the problem. The estimation that one out of every five daily TSP violations in Chicago is due to advection from Indiana may be a more important consideration. Yet, this estimate could represent an over estimation because SE flows are often associated with increased atmospheric stability, thus higher TSP values. The chief reason is that at these times low mixing heights and small ventilation values are likely due to a synoptic high pressure system over the midwest.

Unfortunately, in this study no attempt has been made to estimate the advection of Chicago particulate pollution into Indiana and the surrounding areas. Although no data has been analyzed, some points seem clear from this study. First, that advection exists is almost a certainty. Secondly, because of the climatology (winds from NW 24% of the time), it is likely that Chicago has an impact on yearly Indiana TSP values. Extensive data needed to address this problem does not exist. However, it should be remembered that NW winds are strongly associated with precipitation occurrences which reduce the magnitude of refloatation. Furthermore, it would be difficult to use a wind directional technique in such a study because the heaviest loadings in Indiana occur during NW and W winds simply because the heaviest pollution sources in Indiana are then located upwind of many hi-volume sampler sites in Indiana as well. Thus, this possible advection direction from Chicago and Cook County into Indiana represents two distinct source areas which cannot be separated as has been done in this study for the City of Chicago.

Acknowledgements

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