2.3.3 MOBILE5b & Part5

MOBILE5b and PART5 were used to estimate CO and $PM_{2.5}$ emissions from the Borman Expressway fleet. These models require information of fleet mix, fleet speed, fuel parameters, local policy parameters, and environmental parameters such as temperature and altitude and produce a mass emission rate in units of mass / mile. These models do not directly provide an estimate of air concentration in the local area. Mobile5 and Part5 estimate mass emission rates can be used in a dispersion model such as CALINE4 to predict local ambient air concentrations.

2.3.4 Highway Capacity Manual

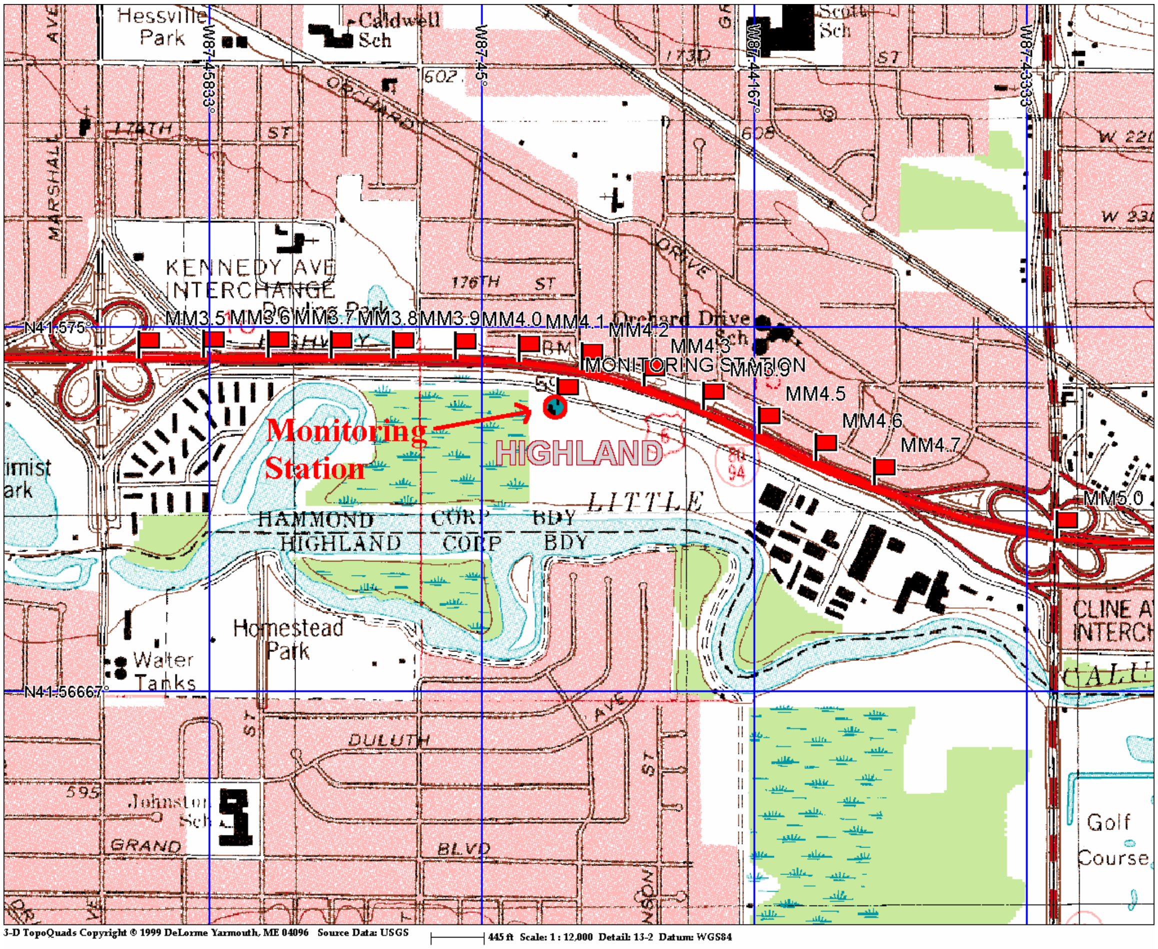
Relationships between speed and density were estimated with the guidance of the 2000 Highway Capacity Manual. The interrelationship of traffic flow, speed, and density complicates the estimation of emissions from roadways. Roadways have a finite capacity and as this capacity is approached traffic speed tends to decrease. More cars traveling a roadway produce more emissions, however, as vehicle speeds decrease while demand on the road is increasing then the emission rate from each individual vehicle may change as well. This relationship was investigated and density specific emission factor curves were estimated.

3.0 RESULTS & DISCUSSION

3.1 Background and Site Characterization

3.1.1 Bearings and Distances

Figure 3.1 is a map of the immediate vicinity of the monitoring station. Kennedy Avenue is to the west and Cline Avenue is to the east.



3-D TopoQuads Copyright © 1999 DeLorme Yarmouth, ME 04096 Source Data: USGS 445 ft Scale: 1 : 12,000 Detail: 13-2 Datum: WGS84

Figure 3.1: Monitoring Station Map Detail

Table 3.1 contains bearings and distances from the site to mile markers along the Expressway. This information was acquired from 3D Topoquads® by DeLorme. Note as the distance from the site increases the length of exposure (Distance across the Borman) increases except just beyond Cline Avenue bend are where exposure distance briefly decreases.

Table 3.1: Approximate Bearings and Distances From Monitoring Station to Borman Expressway.

Mile Marker	Bearing (degrees)	Straight line Distance To Center of Borman (miles)	To Near Side (miles)	To Far Side (miles)	Distance Across the Borman (feet)
0.5	272.2	3.65			
1	271	3.16			
1.5	271.4	2.67			
2	271.9	2.17			
2.5	272.5	1.66			
3	273.6	1.16			
3.5	276.1	0.665			
3.6	277.3	0.564	0.497	0.624	670
3.7	278.7	0.462	0.417	0.503	455
3.8	281.5	0.365	0.332	0.382	263
3.9	285	0.269	0.239	0.291	273
4	292.5	0.174	0.149	0.192	226
4.1	317.8	0.086	0.072	0.097	130
4.2	38.2	0.062	0.050	0.073	124
4.3	80.8	0.140	0.121	0.152	168
4.4	93.1	0.230	0.199	0.256	302
4.5	99	0.323	0.285	0.350	339
4.6	102.8	0.420	0.370	0.458	463
4.7	104.8	0.517	0.445	0.655	1105
5	105.2	0.816	0.455	0.885	2269
5.5	99.9	1.31	1.26	1.36	528
6	94.2	1.80			
6.5	95.8	2.30			
7	94.8	2.80			
7.5	94.1	3.30			
8	93.6	3.80			
8.5	93.2	4.30			
9	93.5	4.80			
9.5	94.2	5.29			
10	93.9	5.79			

All measurements taken off maps and are therefore approximate.

3.2 Borman Sensitivity.

Credibly associating change in local air quality with change in Borman Expressway traffic was the overriding theme of the data analysis. As previously discussed, flux was used to account for the effect of wind on concentration. The angle of exposure to the Borman expressway affects the concentration at the site as well. Figure 3.2 illustrates this effect. In this idealized example wind vectors A and B are of identical magnitude but different direction. Any volume of air associated with Vector A is exposed to the roadway segment considerably longer than a parcel of air associated with Vector B. This means that under identical traffic and environmental conditions, with exception for wind direction, the concentration measured under condition "A" would be greater than the concentration measured when winds are perpendicular to traffic flow as in condition "B".

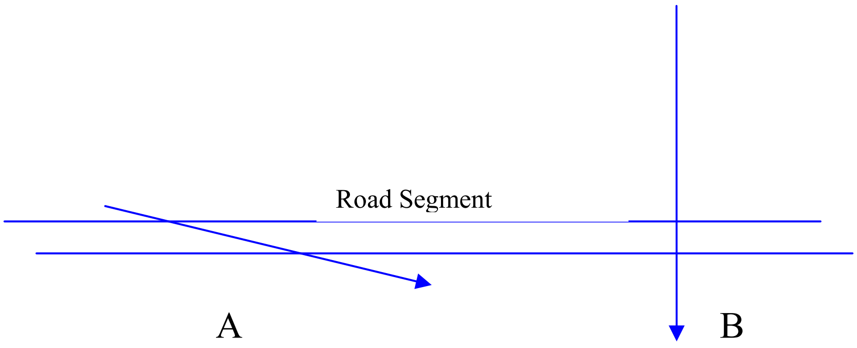
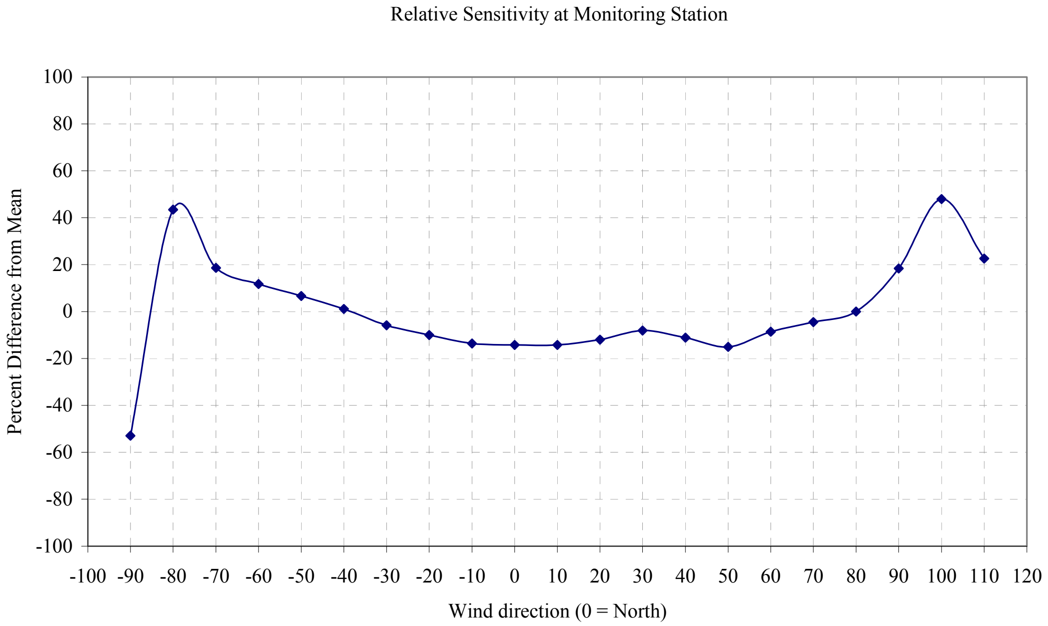


Figure 3.2: Wind Vector and Resultant Concentration

CALINE4 was used to estimate the sensitivity of the site to varying wind directions. The Borman expressway near the monitoring station was carefully plotted into the model. Special attention was paid to curves near the site. Average traffic and environmental conditions were selected and held constant with the exception of wind direction, which was varied across the region of Borman exposure. The results were normalized by comparing each value to the mean of all values and then plotted. As figure 3.3 shows the site should be very sensitive to winds from 100 degrees. The figure shows the relative magnitude of difference to be expected by change in wind direction. For example; if winds changed from -40 degrees (320 degrees) to 10 degrees and no other factors changed a 14.2% drop in concentration would be expected. This is useful because if during a traffic incident, environmental parameters changed by 100% but the change coincided with a shift in winds, environmental variation could still be attributed to the traffic incident as the wind direction alone would not produce a change of such magnitude.



Relative Sensitivity is an estimate of what the monitoring station would measure given all variables are held constant except for the wind direction. For example if a PM2.5 concentration of 10 ug/m^3 was measured when the winds were from -40 degrees (310 degrees) then under identical conditions with winds from 10 degrees a concentration of 10 + (-14.2% * 10) = 8.58 ug/m^3 would be measured. This is important to consider when interpreting incidents where the wind is shifting signifcantly during the event. The site is most sensitive to winds from around 100 degrees. The site is not symmetrically sensitive because it is located near an "S" curve where the alignment of the Borman Expressway shifts.

Figure 3.3: Sensitivity of the monitoring station to the Borman Expressway

The sensitivity graph of the monitoring station can also be used as a fingerprint of traffic effects. At any given moment traffic conditions over the Borman Expressway can vary considerably. Over a long period of time however the mean traffic conditions on any bearing from the monitoring station would gradually approach the same mean assuming the overall demand on the Borman is the same. Therefore if the Borman is substantially contributing to the local air quality it would be reasonable to expect that a trace of the sensitivity graph might be evident in data collected from the site.

Figure 3.4 is a plot of the average concentration and flux measured from Jan 1, 2001 to November 30, 2001. In general, flux is greater from northerly directions than from southerly directions. This suggests that the Borman does indeed affect the local air quality but it doesn't address the issue of other non-Borman sources such as local streets, industrial sources, etc.

The Borman Exposure region of ~270 degrees to ~110 degrees in figure 3.5 shares some features with the sensitivity graph. The carbon monoxide trace shows distinct double peaks at oblique angles to the Borman but both peaks are closer to north than was predicted in the sensitivity graph. The $PM_{2.5}$ trace doesn't show both of these humps but it does have a peak near the predicted high sensitivity area of ~100 degrees.

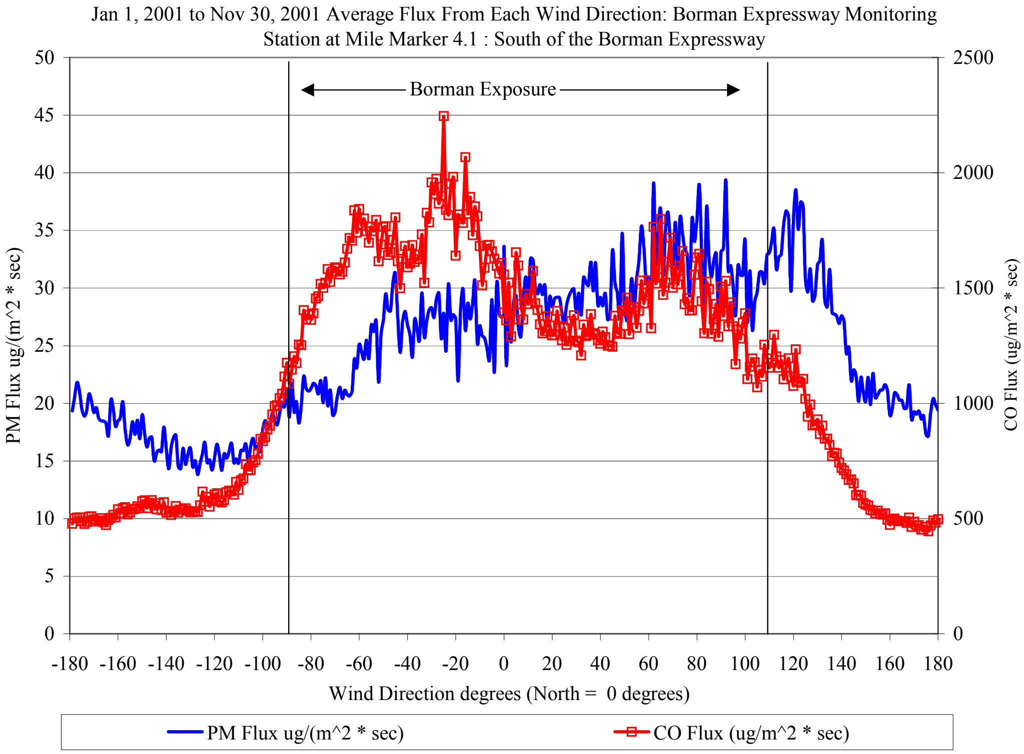


Figure 3.4: Average Flux vs. Origin Direction: January 1 2001 - November 30, 2001

Data from the Borman exposure region was normalized by calculating the difference from the mean of data in the arc from 272 degrees to 110 degrees, similar to what was done in the sensitivity graph. In figure 3.5 CO emissions appear to more closely resemble the sensitivity predictions than do the $PM_{2.5}$ measurements.

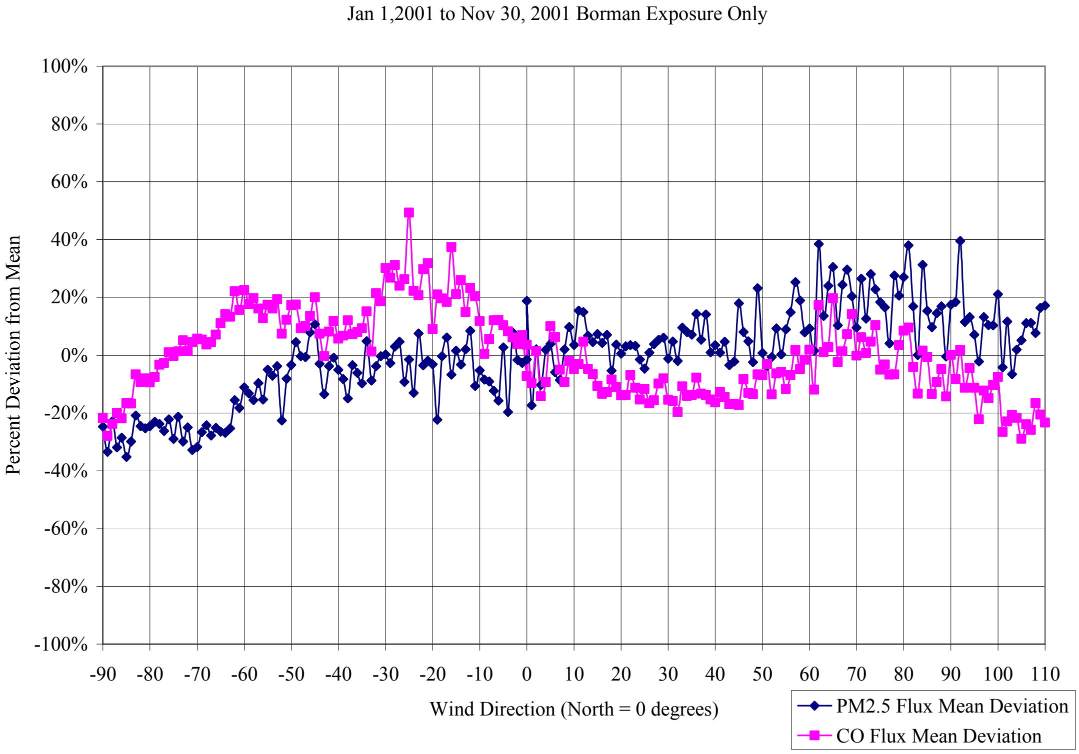


Figure 3.5: Borman Exposure Flux Deviation from Mean -90 to 110 degrees (270 to 110)

3.3 Seasonal Data and General Characterization

Given the monitoring stations location south of the Borman Expressway it is not in a location to receive the prevailing winds. As figure 3.6 shows, the prevailing winds are from the south. However, the approximately 37% of winds were from between 270 degrees to 360 degrees and between 0 degrees and 110 degrees, angles providing influence by or exposure to the Borman expressway. This exposure has been sufficient to permit substantial analysis.

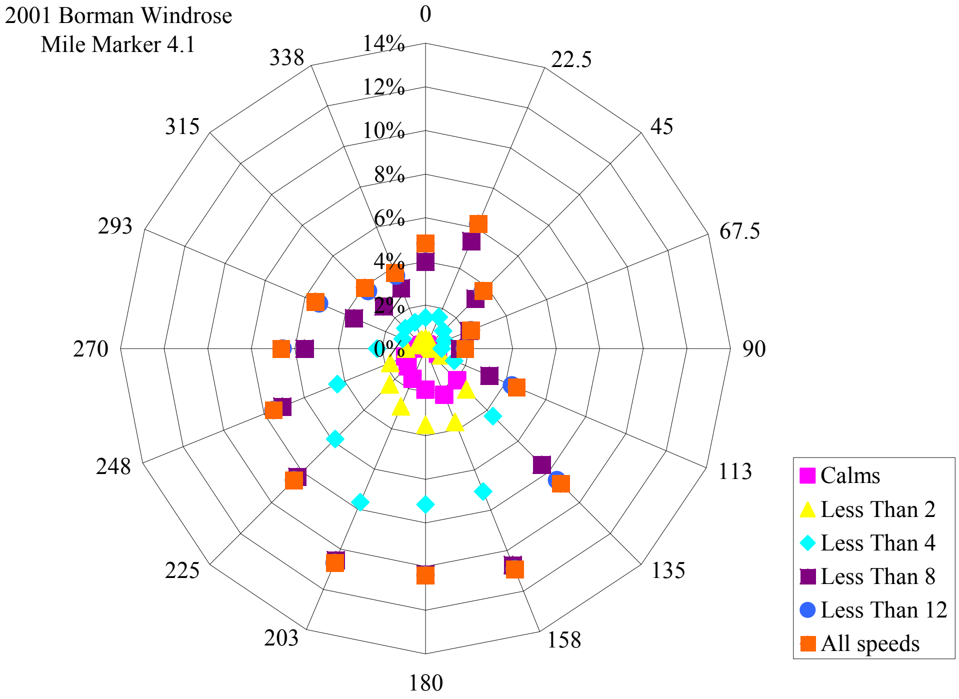


Figure 3.6: 2001 Borman Monitoring Station Wind Rose

The area near the Borman monitoring site does not routinely experience CO values near NAAQS standards of 35 PPM hourly average and 9 PPM 24 hour average. Measured $PM_{2.5}$ concentrations have been considerably closer to the standard of 15 μg/m^3 annual and 65 μg/m^3 hourly. While there is no 1-hour standard for $PM_{2.5}$ several very high hours were measured in 2000 and 2001 around Independence Day evening. These were most likely attributable to pyrotechnics and not the Borman Expressway. Table 3.2 and 3.3 summarize these measurements.

Table 3.2: Comparison of Measured Parameters to Environmental Standards

Standard	**Value**	**Borman Expressway**
1 Hour CO	35 PPM	4.2 PPM 2000, 2001 YTD
24 Hour $PM_{2.5}$	65 $\mu g/m^3$	2000 38, 36, 32 $\mu g/m^3$ 2001 44, 38, 36 $\mu g/m^3$
Yearly $PM_{2.5}$	15 $\mu g/m^3$	12.6 $\mu g/m^3$ 2000 12.2 $\mu g/m^3$ 2001

Table 3.3: Highest Hourly $PM_{2.5}$ Observations

Date	**Time**	**$PM_{2.5}$**
July 4, 00	9:00 PM	144.9 $\mu g/m^3$
July 4, 00	10:00 PM	106.5 $\mu g/m^3$
July 4, 01	9:00 PM	102.5 $\mu g/m^3$
July 4, 01	10:00 PM	135.9 $\mu g/m^3$
July 4, 01	11:00 PM	174.9 $\mu g/m^3$
July 5, 01	12:00 AM	127.4 $\mu g/m^3$

Seasonal Variation in CO and $PM_{2.5}$ is illustrated in figure 3.7. $PM_{2.5}$ concentrations are highest in late spring and into summer and appear be at their lowest in winter. Analysis of 2001-2002 winter data will continue and be included in the final report. CO concentrations do not exhibit the same obvious trend as $PM_{2.5}$. Note the apparent correlation of $PM_{2.5}$ concentration with ambient temperature.

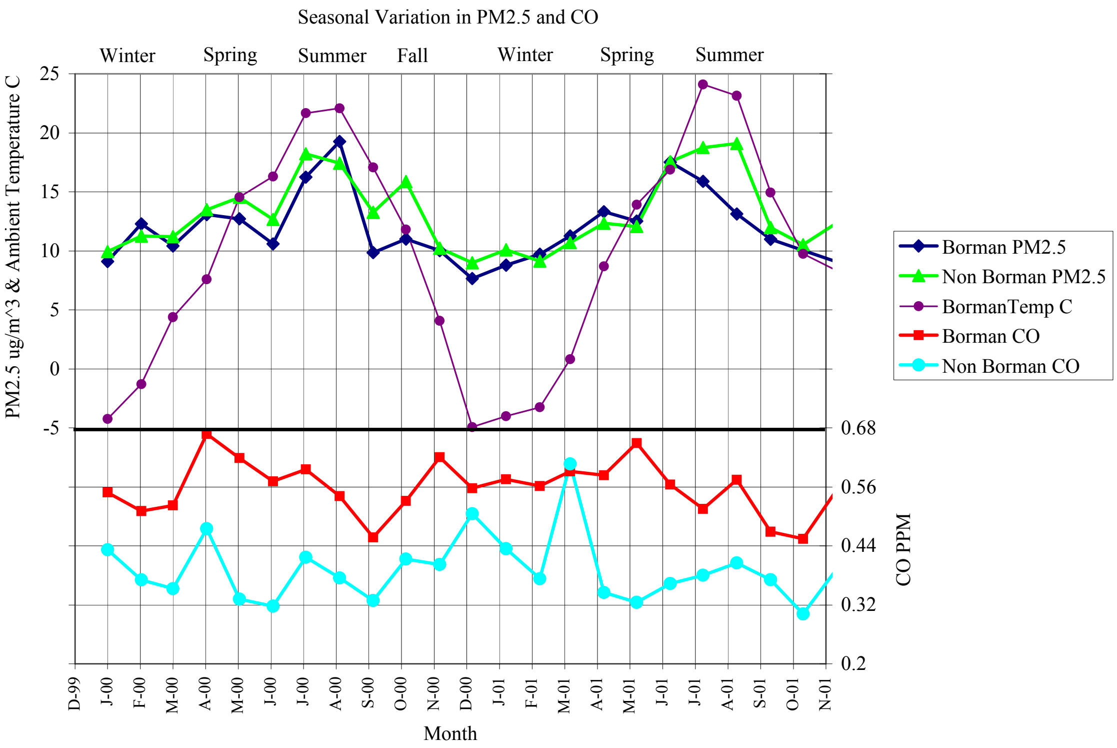


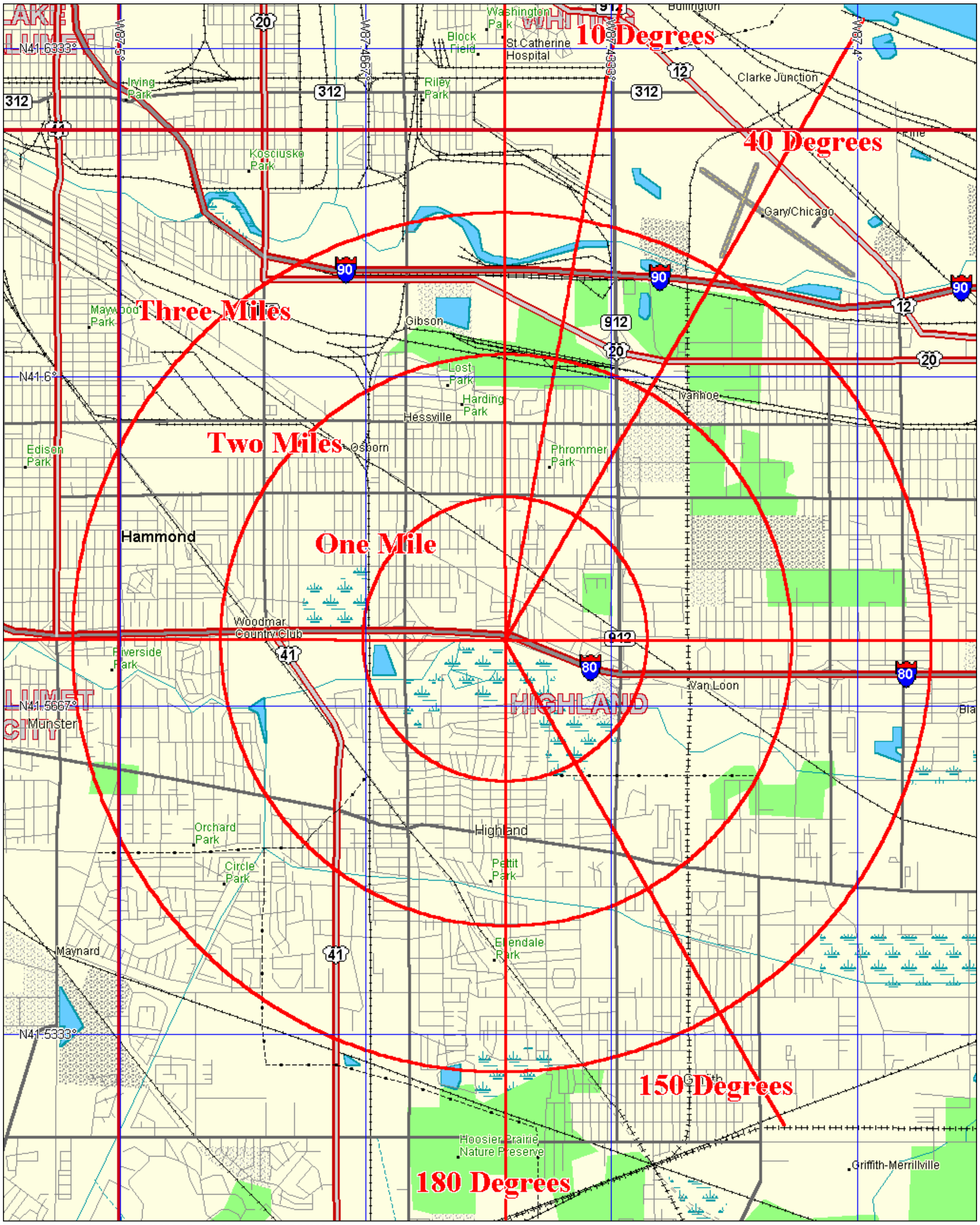
Figure 3.7: Seasonal Variations in CO and $PM_{2.5}$ Concentration

3.4 Background determination by sector analysis

It has been demonstrated that the Borman is detectable in the local air quality. However, the measurements from the northerly direction include pollutants emanating from both the Borman and from non-Borman background sources. Ambient monitoring stations in the region were not located close enough to our monitoring site to prove useful for our data needs. Placing an additional station on the northern side of the Borman was logistically and economically unfeasible so clever analytical methods had to be devised to estimate the background component of northerly measurements.

Two 30-degree sectors (10˚- 40˚ and 150˚ - 180˚), one northerly and one southerly, were selected from the Borman area for comparison and estimation of the background component. Two sectors of similar development and population should have similar background emissions. If the sectors are carefully selected to avoid inclusion of major industrial sources such as steel mills the only other substantial difference between the two sectors would be the presence or absence of the Borman Expressway. The difference in average flux measurements between the two sectors would represent the Borman portion of the local air quality.

Figure 3.8 shows the sectors chosen for inclusion in analysis. The sectors were chosen to minimize inclusion of permitted industrial sources and avoid the three large steel mills to the north and northeast. Preference was given to sectors that contained similar population density as figure 3.9 shows. Figure 3.10 provides a visual sense of the development around the Borman monitoring station. These three figures show that the sectors of 10˚- 40˚ and 150˚ - 180˚, though not perfectly identical, are similar enough to permit comparison. One of the researchers did a driving inspection of the communities in the area a verified the similarity of these sectors.



3-D TopoQuads Copyright © 1999 DeLorme Yarmouth, ME 04096

2000 ft Scale: 1 : 56,250 Detail: 11-4 Datum: WGS84

Figure 3.8: Roads and General Background Surrounding the Borman Expressway Monitoring Station

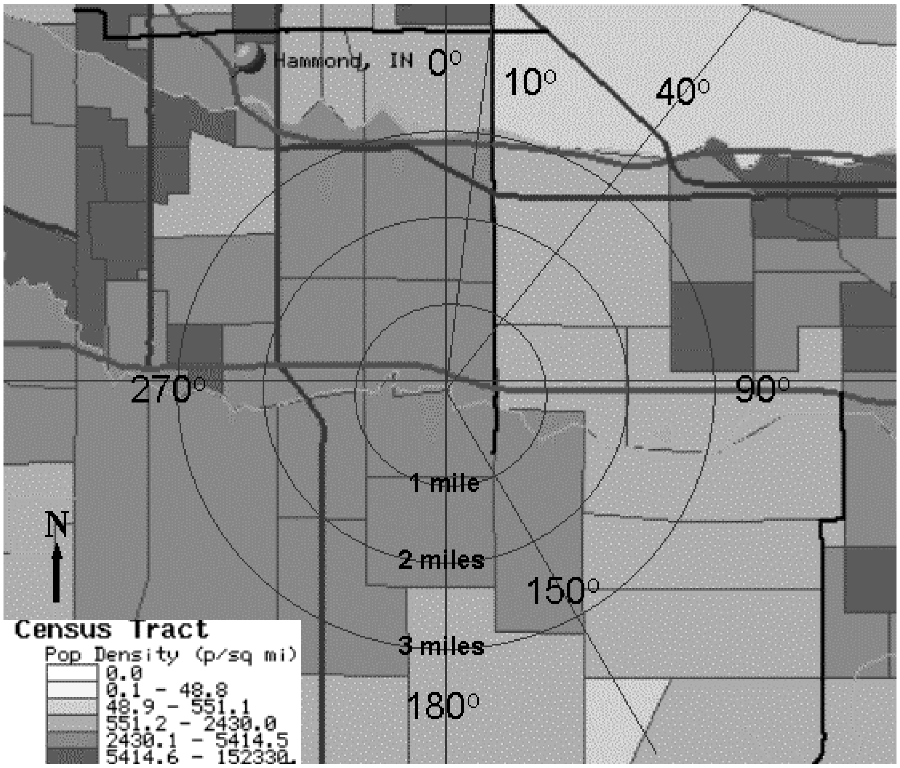


Figure 3.9: Population Density Surrounding the Monitoring Site on the Borman Expressway

(United States Census Bureau. 1990)

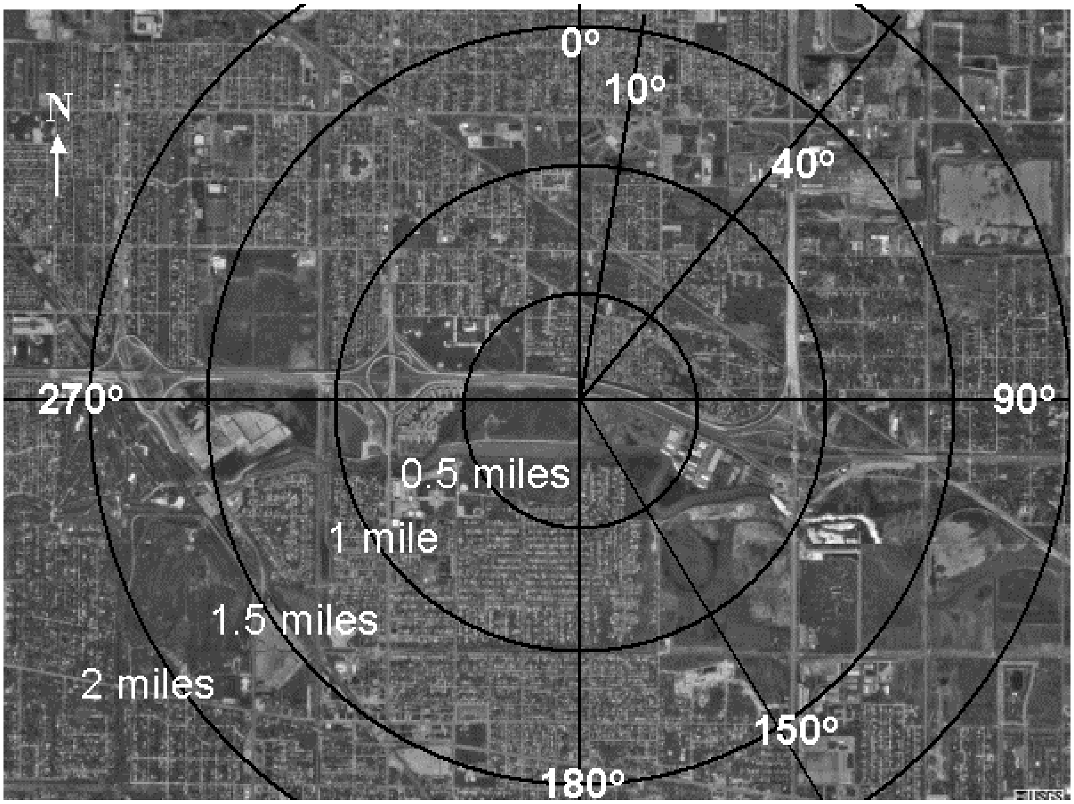


Figure 3.10: Aerial Photograph Directly Over the Monitoring Site on the Borman Expressway (Hammond, Indiana United States. From TerraServer

Average $PM_{2.5}$ and CO Flux from January 1, 2000 to November 30, 2001 originating from each arc was calculated and was plotted in figure 3.11. Carbon monoxide flux from the northern arc was greater than CO flux from the southern arc at all times. $PM_{2.5}$ flux from the south was greater than $PM_{2.5}$ flux from the north during late evening and early morning hours when traffic flow would typically be lower. This is evidence that the sectors are not absolutely identical in terms of $PM_{2.5}$ emissions. Subtracting the southerly flux from the northerly flux produces a negative flux, not possible of course. Using the remaining positive flux values would be overly conservative in estimating the portion of northern flux due to the Borman expressway.

Adjusting the difference between the northerly and southerly flux by the greatest negative difference leaves one hour where 0 percent of the local $PM_{2.5}$ is of Borman origin and the remaining hours with some portion of Borman origin. This is still conservative, because at any hour of the day there is traffic on the Borman expressway and some part of the local $PM_{2.5}$ is of Borman origin.

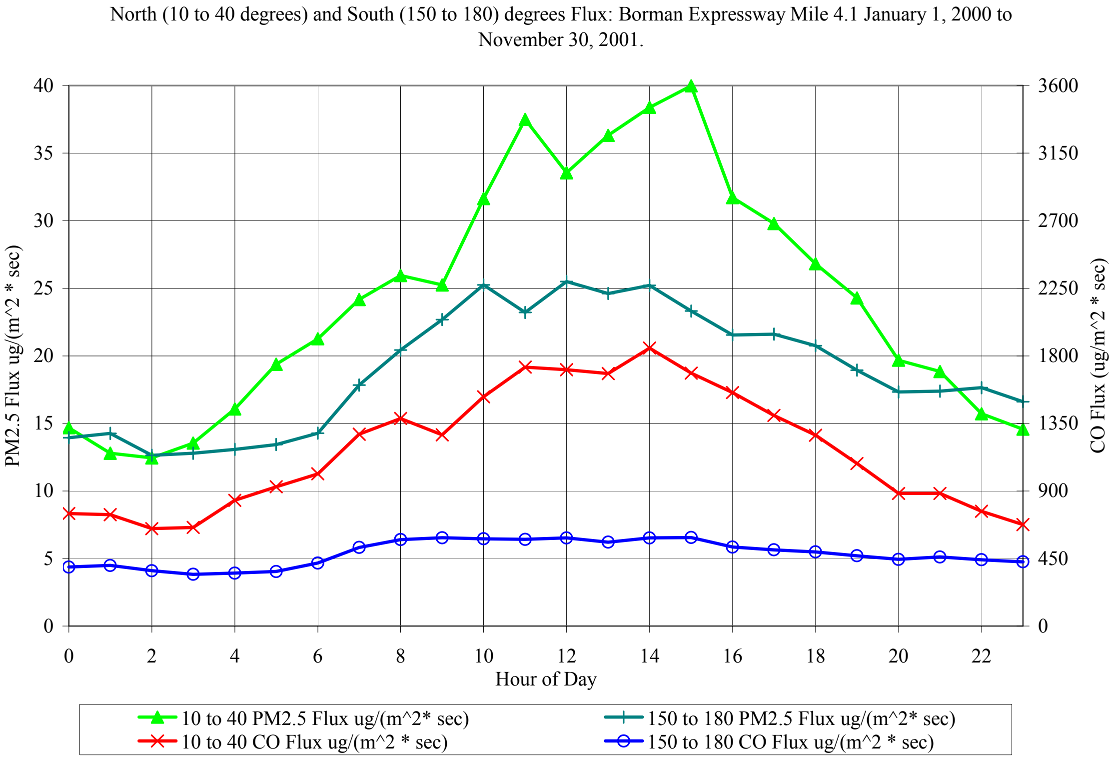


Figure 3.11: Flux Emanating from 10 to 40 and 150 to 180 degree arcs

Figure 3.12 shows the difference between the two northern and southern flux curves as well as the respective traffic flow occurring in this period. The traffic distributions are based on a sensor located just east of the Borman Expressway I-65 interchange. These values do not reflect the exact mix of vehicles along the expressway but were the best representation available of the patterns in fleet mix.

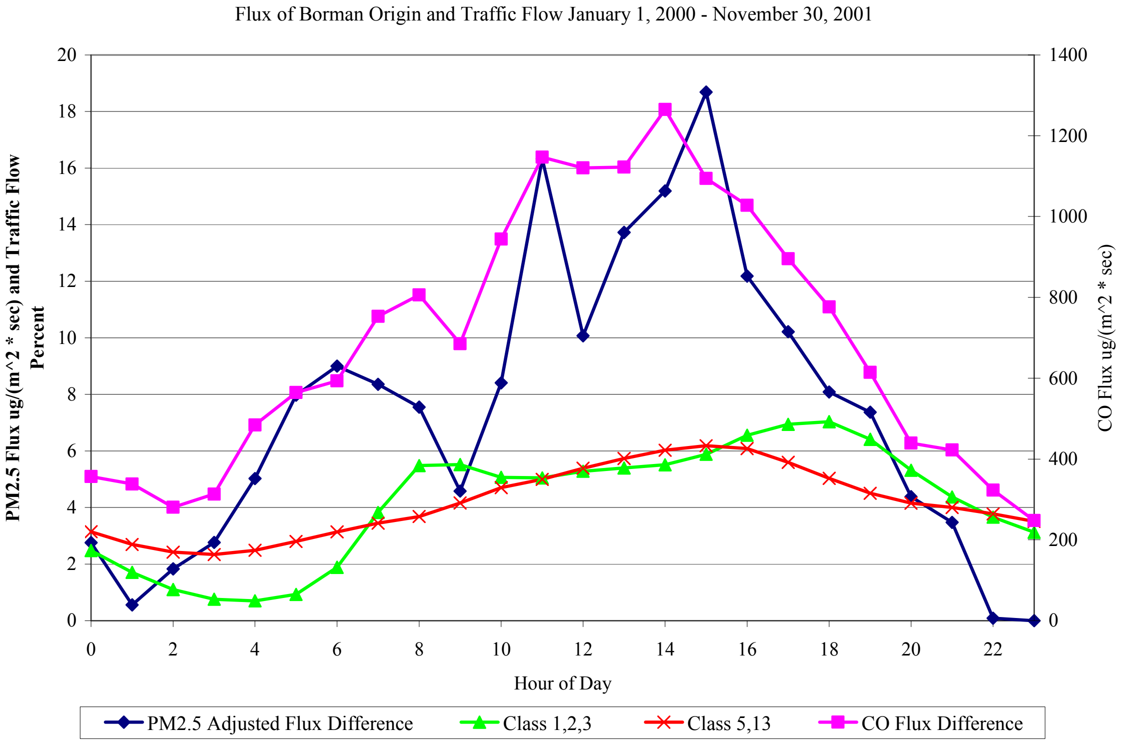


Figure 3.12: Flux of Borman Origin and Relative Traffic Flow

The difference in vehicular flow patterns is evident as is its implication in local air quality. Gasoline fueled (Class 1, 2, & 3) vehicle flow declines much more in the early morning hours as compared to diesel fueled (Class 5 & 13) vehicles. The peak in $PM_{2.5}$ at 6 am not seen in the carbon monoxide emissions is indicative of this difference in flow pattern.

Atmospheric stability and mixing height are also in a factor at this point. Figures 3.13 and 3.14 show that the atmosphere is generally most stable and mixing heights are lowest in the hours prior to dawn and therefore dispersion is generally at its minimum at this point. (Atmospheric stability is a measure of the atmosphere’s resistance or enhancement of vertical mixing. In figure 3.14 a higher numerical stability value implies a more stable atmosphere thus the atmosphere is generally most resistant to vertical mixing in the early morning hours.) This explains why the $PM_{2.5}$ peak is of substantial magnitude even though diesel fueled vehicular flow between 2:00 and 8:00 hours is 1/3 to 2/3 of the peak flow at 15:00 hours.

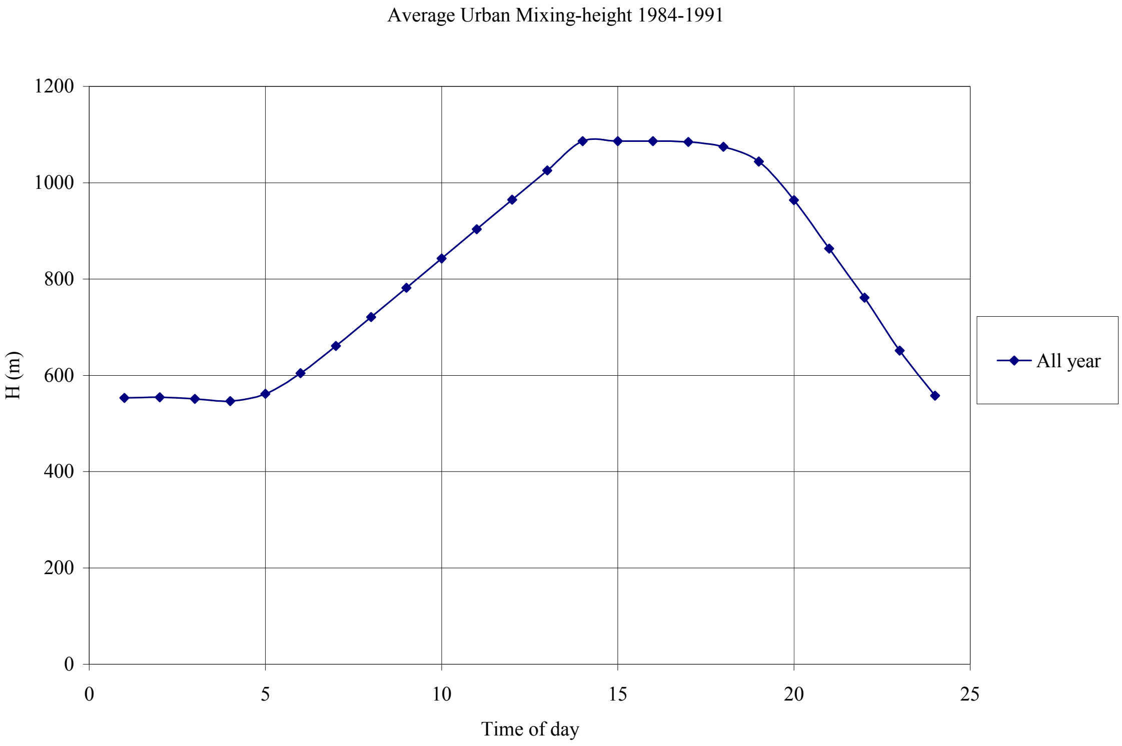


Figure 3.13: Average Urban Mixing Height. Peoria, Illinois

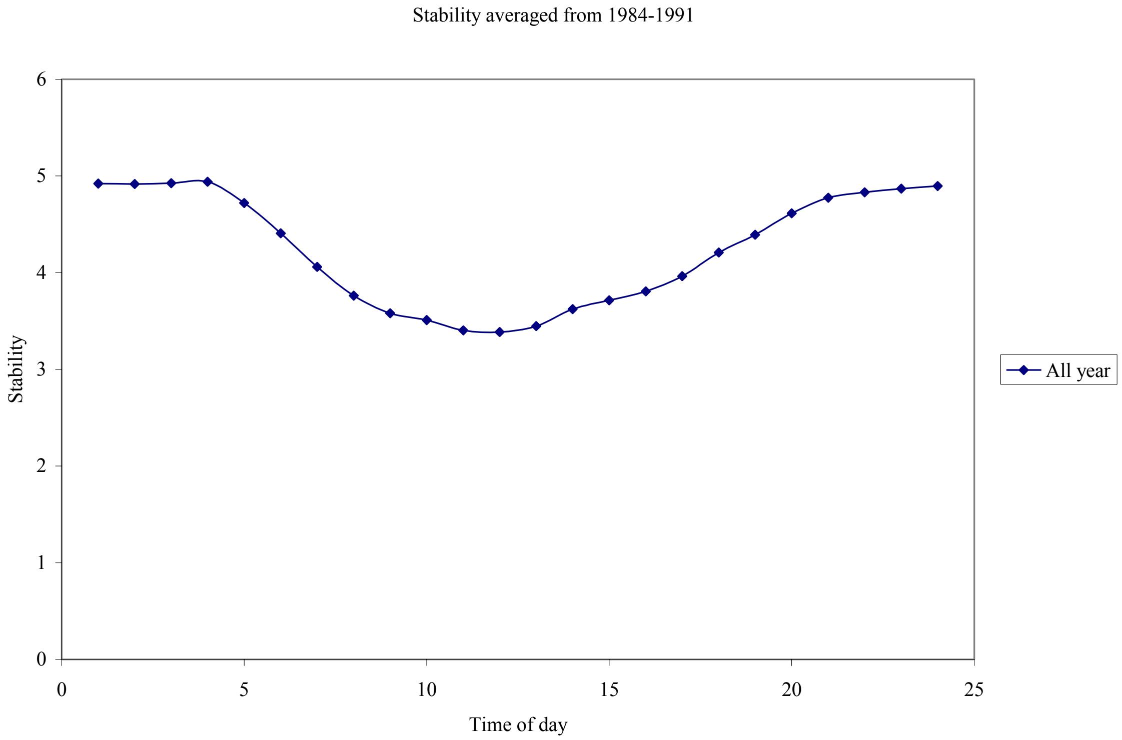


Figure 3.14: Average Atmospheric Stability: Chicago (Ohare), Illinois

An average Borman component of local air quality was calculated by dividing the difference in northern and southern flux by the northern flux. The average Borman component of the local $PM_{2.5}$ ranged from 0 to 47% with an average of 27%. The average Borman component of local CO ranged from 37% to 68% with a net average of 56% when winds were from 10 to 40 degrees (table 3.4). Obviously the Borman expressway contributes some $PM_{2.5}$ to the local air quality. The 0% value at hour 23 is an artifact of the slight difference between the northern and southern arcs, refer to figure 3.12. The values represented here are conservative in respect to this.

Table 3.4: Average Hourly Borman Component of Local Air Quality From 10 to 40 degrees. January 1, 2000 to November 30, 2001

Flux emanating from Borman Expressway 10-40 Degrees					
Hour	**$PM_{2.5}$**	**CO**	***Hour***	**$PM_{2.5}$**	**CO**
0	19%	48%	12	30%	66%
1	4%	46%	13	38%	67%
2	15%	43%	14	40%	68%
3	20%	48%	15	47%	65%
4	31%	58%	16	38%	66%
5	41%	61%	17	34%	64%
6	42%	59%	18	30%	61%
7	35%	59%	19	30%	57%
8	29%	58%	20	22%	50%
9	18%	54%	21	18%	48%
10	27%	62%	22	1%	42%
11	44%	67%	23	0%	37%

As previously shown in figure 3.3, the 10˚ - 40˚ and 150˚ - 180˚ azimuth of Borman exposure is likely to be among the least sensitive to traffic among the range of 272 to 110 degrees. Any other arc would likely have an even larger Borman Component in the local air quality.

3.5 ISCST3 background estimates

Major industrial emission sources were intentionally avoided in estimating the Borman portion of the local air quality. The area has several major sources of both $PM_{2.5}$ and CO. Figures 3.15 and 3.16 show the location of $PM_{2.5}$ and CO sources in the area.

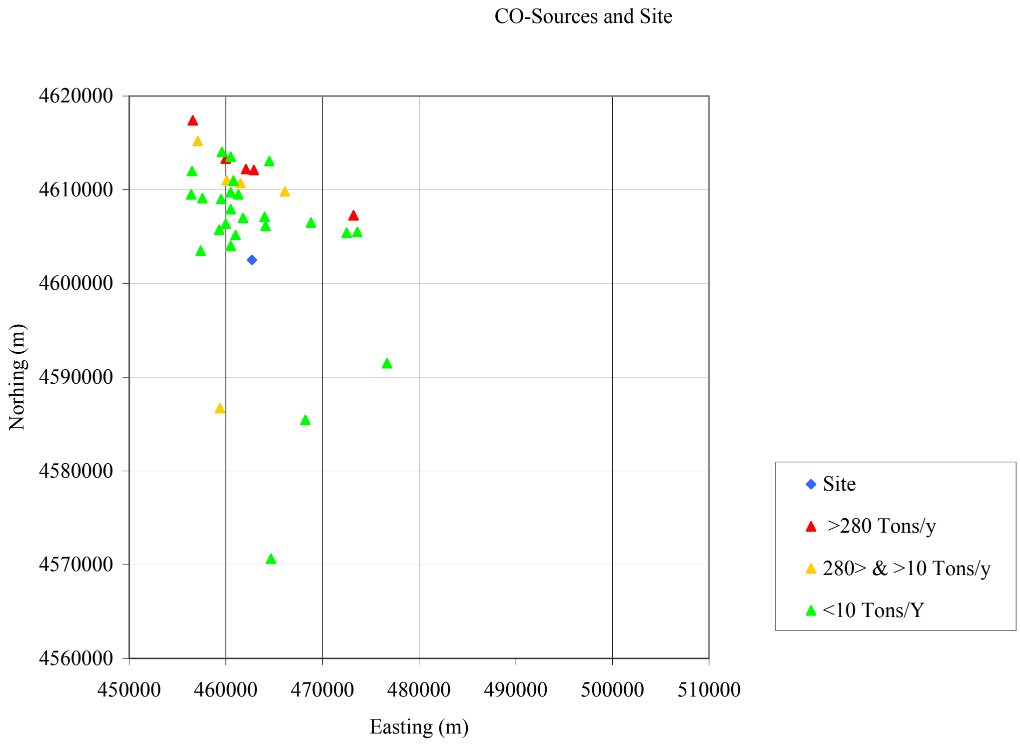


Figure 3.15: CO Sources and Monitoring Station

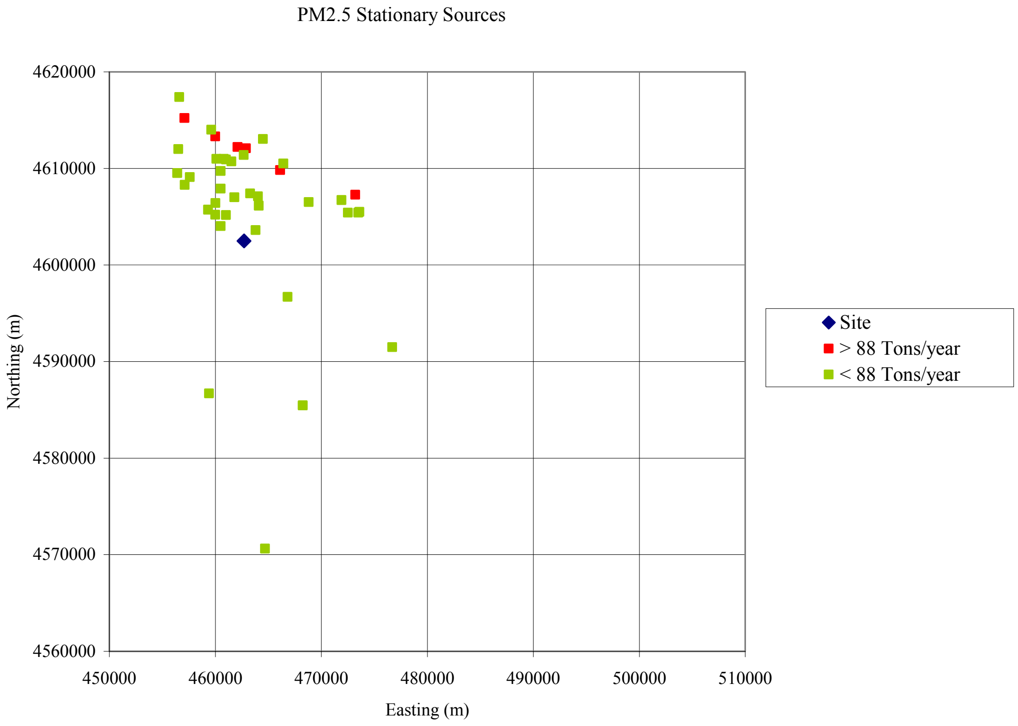


Figure 3.16: $PM_{2.5}$ Sources and Monitoring Station

As figures 3.15 and 3.16 show, measurements during wind directions from the north-northwest could be under the influence of industrial sources. The locations and emissions from these sources were entered into the EPA Industrial Source Complex model. Location data and emission data was acquired from the EPA Aerometric Information Retrieval System (AIRS). Model runs were made with meteorological and mixing height data from 1986 to 1991. From these runs meteorological data from 1984 and 1986 were found to produce the highest average CO and $PM_{2.5}$ concentrations respectively at the monitoring station. Remaining analysis was based on these years, the worst average years.

The predicted average year round concentration of $PM_{2.5}$ and CO of permitted point source origin is shown in figure 3.17. Figure 3.17 represents the average concentration predicted year round and includes winds from all directions.

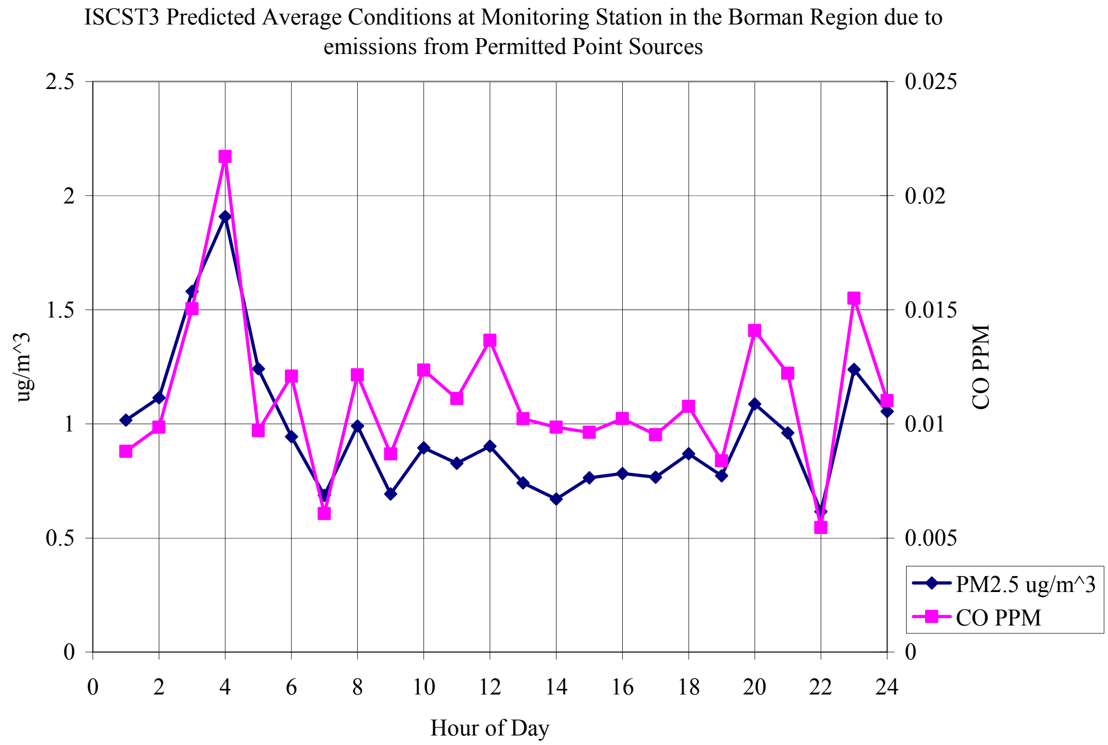


Figure 3.17: ISCST3 Predicted Average Concentrations from Permitted Point Source Origin

As figures 3.15 and 3.16 previously showed, several major industrial sources are northwest and east northeast of the monitoring station. Figure 3.18 shows the distribution of predicted $PM_{2.5}$ concentrations at Borman intersecting wind directions. Arcs of -10 to 5 degrees and 60 to 75 degrees present regions of considerable predicted $PM_{2.5}$ and must be considered cautiously when reviewing data. However, these predictions overestimate the magnitude of impact considerably as shown in figure 3.19. On first in inspection figure 3.19 suggests that most of the $PM_{2.5}$ measured in the affected arcs is of point source origin. However, if this were true then there would be a precipitous drop in the concentration measured at the site to either side of the affected arcs. This is not the case, and while point sources do contribute to the local air quality, ISCST3 overestimates the magnitude in this case. Even when compared to measured conditions observed between midnight and 5 am (when traffic flows are generally least) the predicted magnitude of impact on measured concentrations is not seen (figure 3.20). These predictions were based on emissions estimates that sometimes represent the maximum potential emissions from a source. The modeling estimate also assumes that the source was actually operating during a period where the wind was blowing toward the site. They are useful in suggesting areas that require additional attention when interpreting serial traffic – environmental events.

The percentage of observations in the arcs of -10 to 5 and 60 to 75 degrees is 6.5% and 7.4% respectively leaving 86.1% of Borman exposure relatively unaffected by $PM_{2.5}$ from permitted point sources. For CO, the percentage of predictions in the -18 to 8 degree and 55 to 76 degree range are 10.7% and 9.9% respectively, this arc includes a considerable span where concentrations would be relatively low, < 0.025 PPM (figure 3.21). Affected arcs above a 0.025 PPM threshold span include -4 to 6 degrees and 56 to 76 degrees. These arcs span 4.2% and 9.1% of predictions leaving a total of 86.7% of Borman exposure relatively unaffected by permitted point source CO emissions.

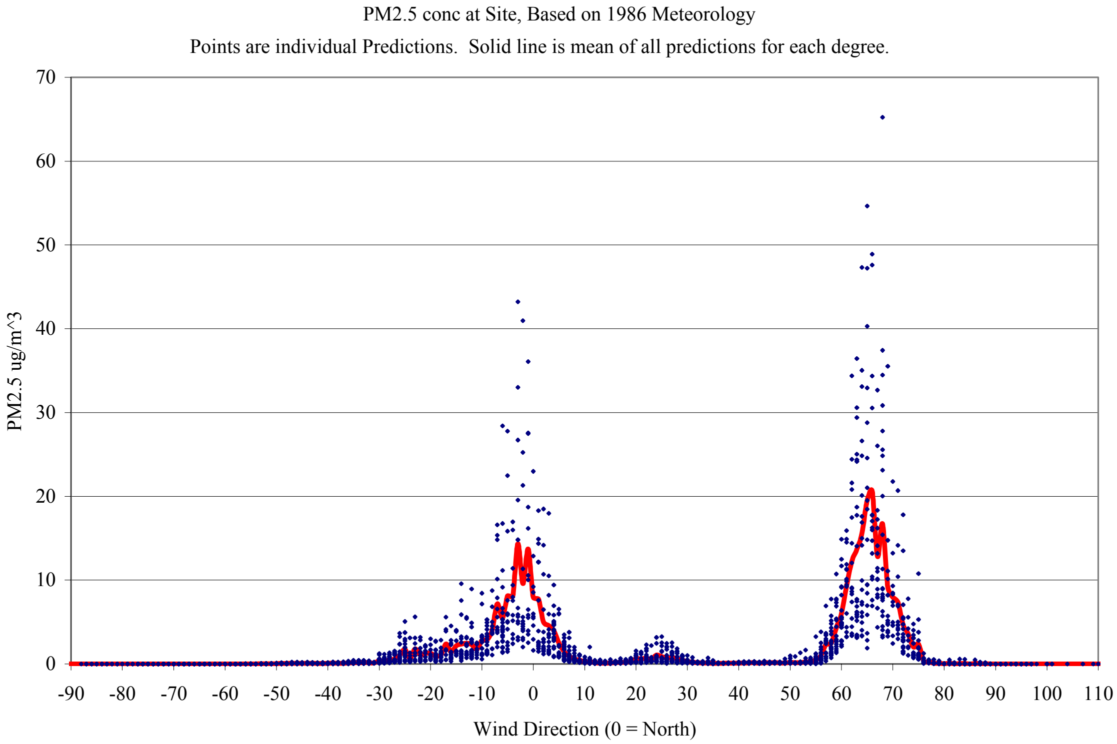


Figure 3.18: ISCST3 Predicted Average Concentrations from Permitted Point Source Origin

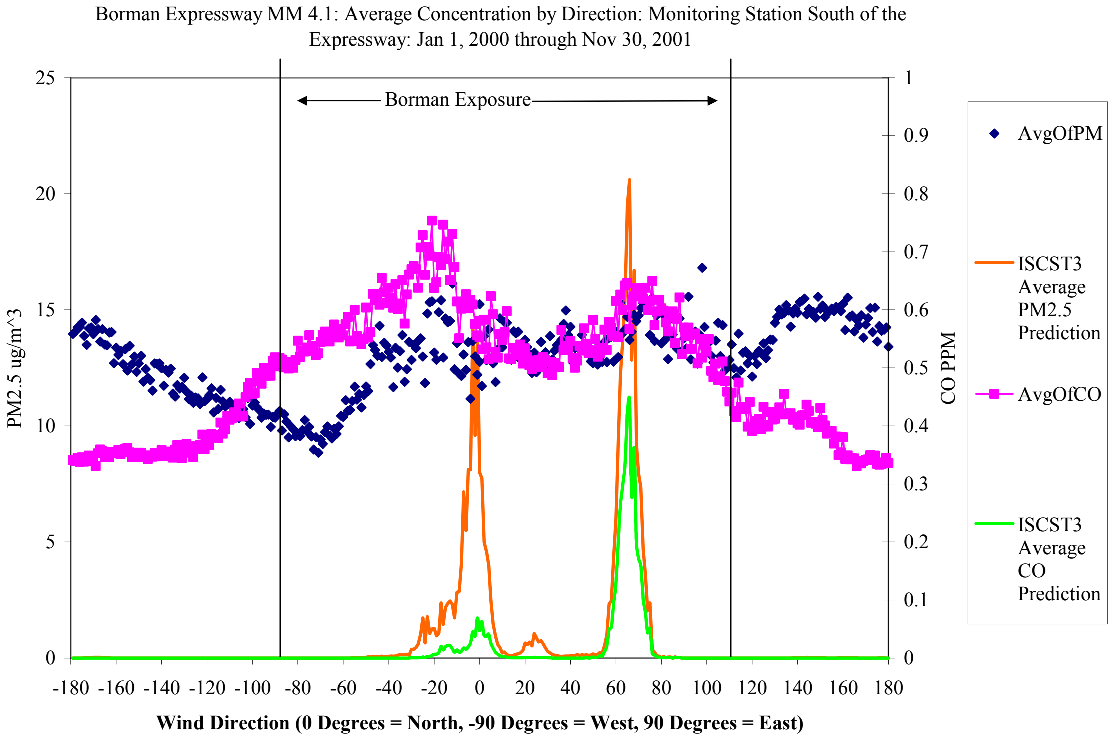


Figure 3.19: Average Measured Concentration of $PM_{2.5}$ and CO By Wind Direction: Midnight to Midnight

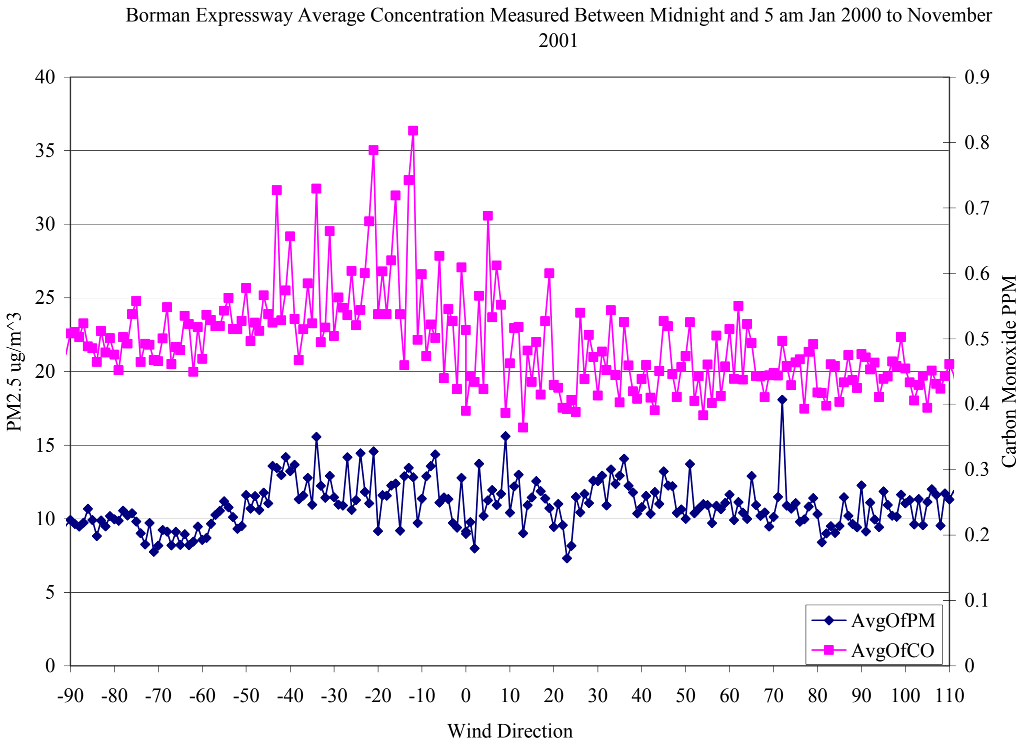


Figure 3.20: Average Measured Concentration of $PM_{2.5}$ and CO By Wind Direction Midnight to 5 am

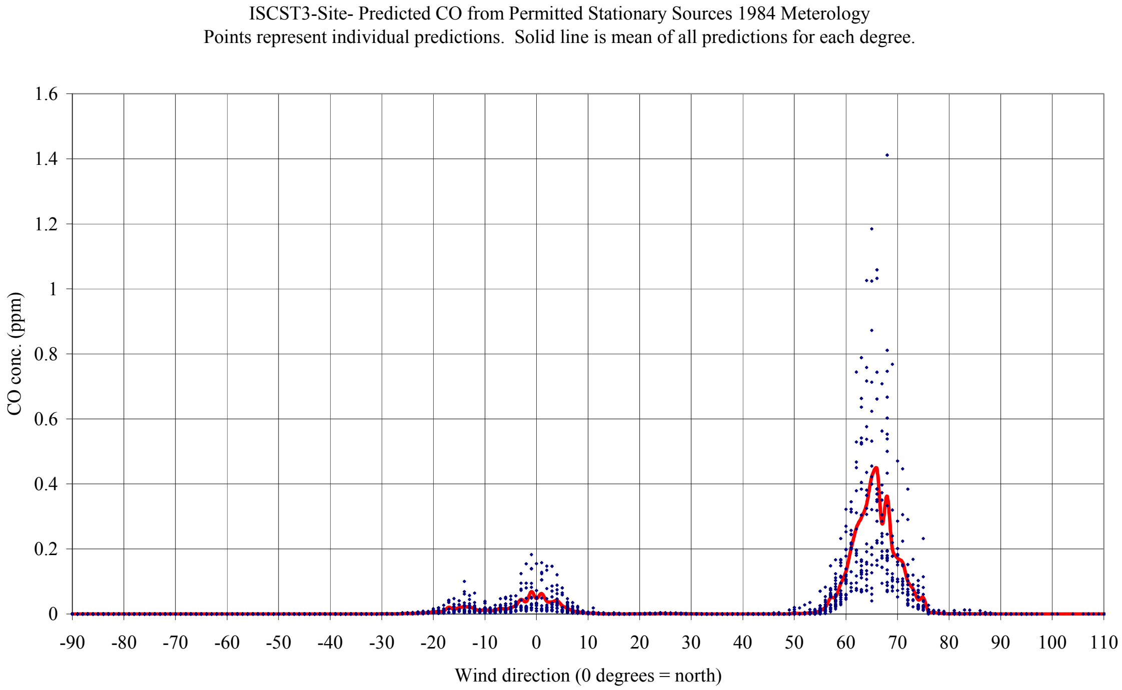


Figure 3.21: Predicted CO concentrations of Permitted Stationary Source Origin

4.0 ANALYSIS OF TRAFFIC ENVIRONMENT RELATIONSHIPS

Two general approaches can be taken in analyzing detailed data collected over a long period of time, an aggregate or a serial approach. An aggregate approach seeks correlation between groups of time and environmental conditions i.e. between 6 am and 10 am during weekdays pollutant levels are generally observed to rise. With a serial approach events are analyzed in the order that they occurred (i.e. at 5 pm on June the 5th an accident occurred and $PM_{2.5}$ concentrations rose sharply at 5:15 pm and remained elevated until the accident cleared). The former is useful in observing overall trends. The latter is useful for assessing the specific benefit of the actions of ITS components such as the Hoosier Helpers or variable message boards.