York Region Air Quality Study
2008

March 2009

Air Monitoring & Reporting Section
Environmental Monitoring and Reporting Branch
Ontario Ministry of the Environment

1. INTRODUCTION

The Ministry of the Environment initiated a study in two communities, Town of Markham and City of Vaughan, located in southern York Region to obtain quantitative information of the air quality in recognition of their large population-base. The purpose of this study was to determine if the existing ministry Air Quality Index (AQI) station located in Newmarket is representative of the heavily populated areas of southern York Region. This study also presented the opportunity to provide some indications of the new health-risk based index developed by the federal government, the Air Quality Health Index (AQHI).

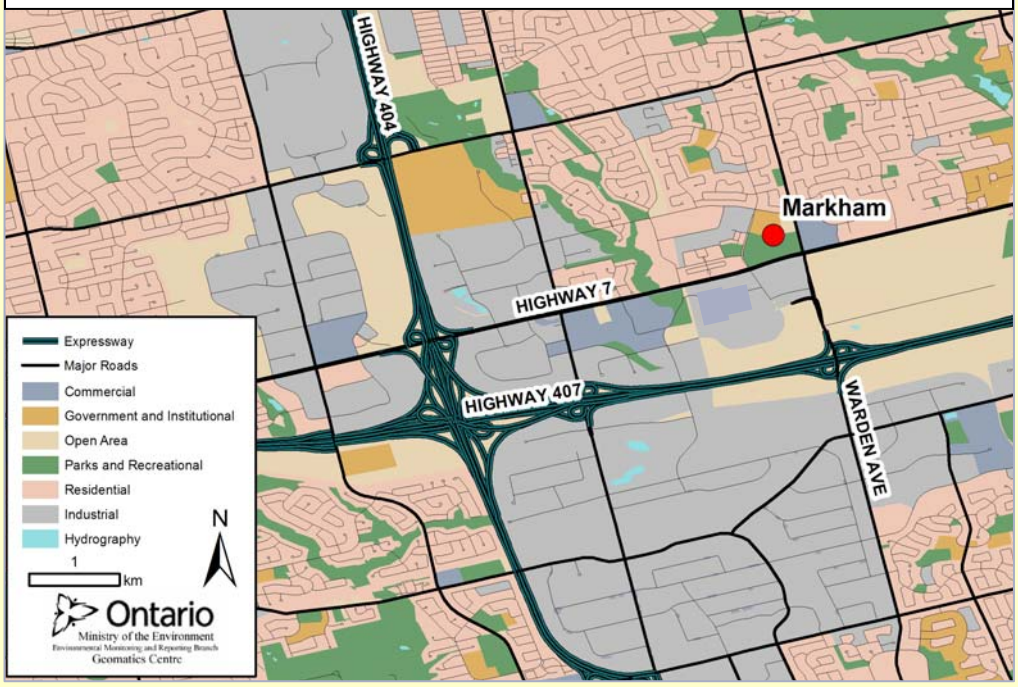
For this study, the ministry's mobile Particulate Matter Unit (PM Unit) conducted monitoring from July 23 to August 20, 2008 in the Town of Markham and from August 22 to September 22, 2008 in the City of Vaughan.

Both study site locations were selected with the assistance of the local municipalities. The study site in Markham was located in the northern parking lot of the Markham Town Center at 101 Town Centre Boulevard. The surrounding area was comprised of residential and commercial developments. Highway 7 and Highway 407 are located approximately 500 metres (m) and 2.2 kilometres (km), respectively south of the site. The study site in Vaughan was located at 2800 Rutherford Road, in the rear parking lot of the Vaughan Public Works Department. The surrounding land use was comprised of commercial and industrial areas to the south and residential areas to the north. Rutherford Road was located approximately 100 m south of the site and Highway 400 was located approximately 1.5 km west of the site. A representation of the land use in the area of the study sites is shown in **Figure 1.**

The PM Unit recorded measurements of five AQI criteria pollutants – ozone (O_3), fine particulate matter ($PM_{2.5}$), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), and carbon monoxide (CO) – which have adverse effects on human health and the environment. In addition, AQI and AQHI values were calculated from the criteria pollutant data collected at each site. Descriptions of the instrumentation used to collect these data are listed in **Appendix A.**

Data from the study sites were compared with data from nearby fixed AQI monitoring stations to determine if the data from these stations are similar to and representative of the data recorded in Markham and Vaughan. The locations of the fixed AQI monitoring stations include Newmarket, Toronto North, Toronto East and Oshawa. Locations of the study sites in relation to the fixed AQI stations are displayed in **Figure 2.**

Figure 1: Land Use Representation of Areas Surrounding the Markham and Vaughan Study Sites



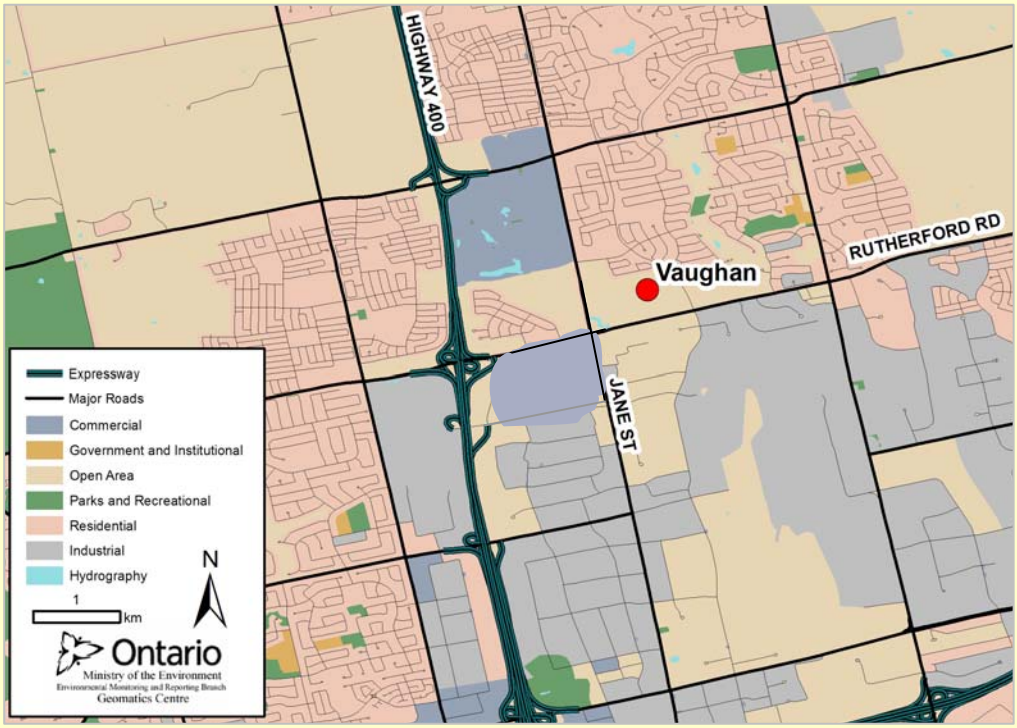
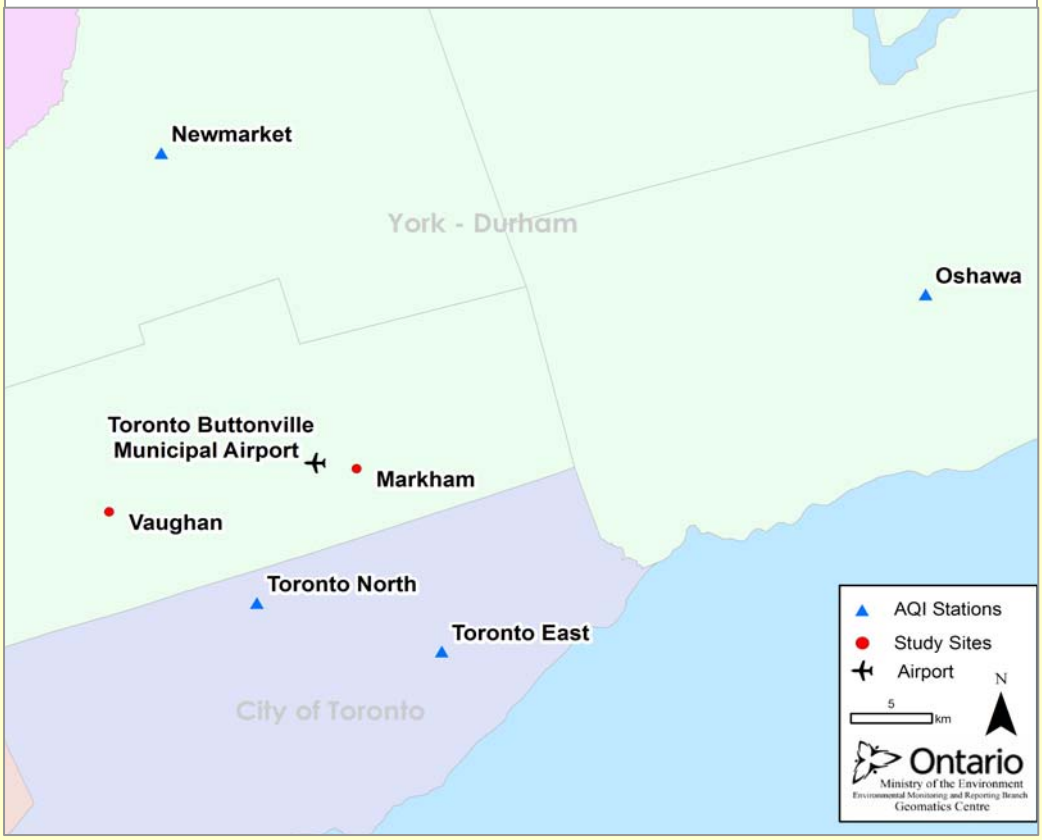


Figure 2: Mobile Air Monitoring Locations for Markham (July 23 – August 20) and Vaughan (August 22 – September 22) in Relation to the Surrounding Fixed AQI Stations



Note: Meteorological conditions during the study periods were measured at Toronto Buttonville Municipal Airport.

2.0 ANALYSIS OF DATA

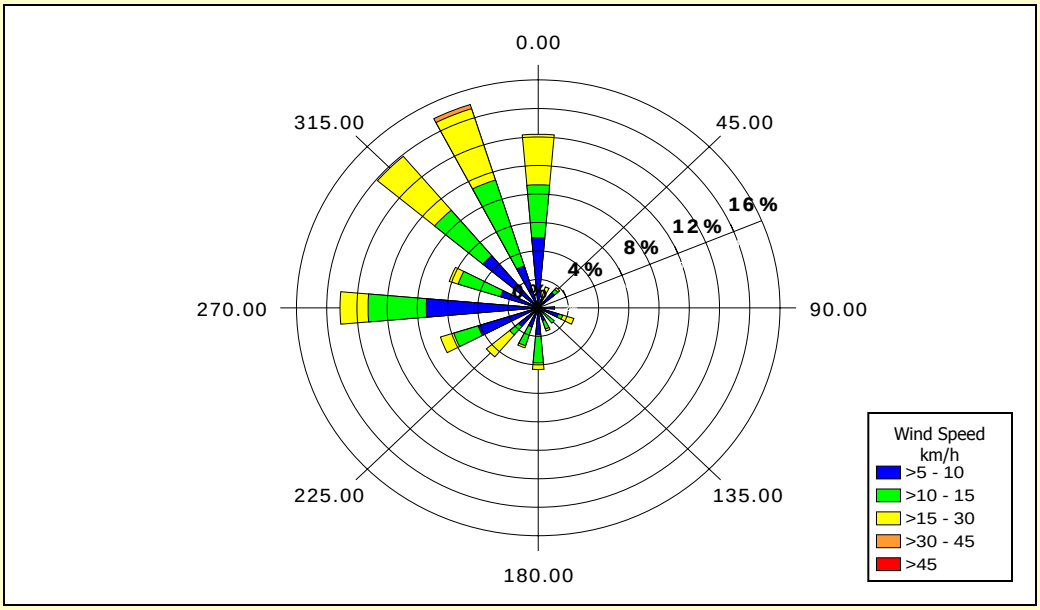
The purpose of correlation analyses is to show whether a relationship between data sets exist. As such, correlation studies were carried out for ozone, $PM_{2.5}$ and NO_2 data collected at the two study sites, Markham and Vaughan, and the surrounding fixed AQI stations in Newmarket, Toronto North, Toronto East and Oshawa. Data were collected in Markham from July 23 to August 20, 2008 and Vaughan from August 22 to September 22, 2008. The PM Unit completed 29 days of monitoring at the Markham study site and 32 monitoring days in Vaughan.

MARKHAM STUDY PERIOD: JULY 23 – AUGUST 20, 2008

Meteorology

Sky conditions, minimum and maximum temperatures, total amount of precipitation, and average wind direction and wind speed data for the study period were recorded at the Toronto Buttonville Municipal Airport, and are summarized in **Appendix B**. Cloudy skies prevailed over York Region during the Markham study from July 23 – August 20. Precipitation values recorded at the Toronto Buttonville Municipal Airport indicated ten days during the study had greater than 1 millimetre (mm) of precipitation and five days had trace levels to 1 mm. Maximum temperatures ranged from 17°C to 31°C. **Figure 3** displays a wind rose summarizing the wind speed and wind direction data during the Markham study period. The prevailing winds were blowing predominately from the north to west. During this period southerly winds were infrequent and regional influences from the City of Toronto were considered minor. Weather conditions during the Markham study period were not conducive for widespread photochemical smog production; as such, no smog advisories were issued by the Ministry for the Greater Toronto Area.

Figure 3: Wind Rose for Toronto Buttonville Municipal Airport
July 23 – August 20, 2008



Note: Calm winds (5 km/h and less) were recorded 17% of the time during the study period.

Ozone

Table 1 shows the linear correlation coefficients (r) of the daily maximum one-hour ozone concentrations recorded at the Markham study site in comparison to the daily maximum one-hour ozone concentrations measured at the surrounding fixed AQI stations. The table also includes the slopes, intercepts and coefficients of determination (r^2).

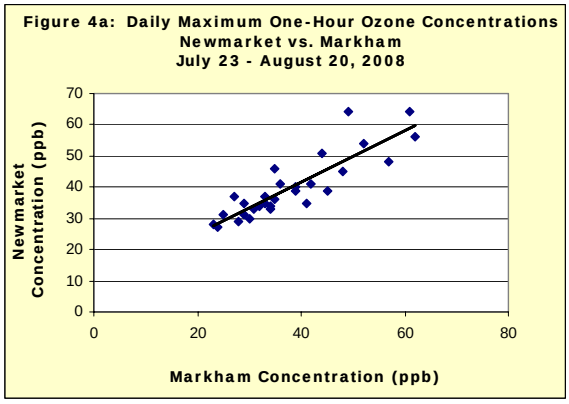
Table 1: Statistics of Daily Maximum One-Hour Ozone Concentrations between the Markham Study Site and Surrounding Fixed AQI Stations

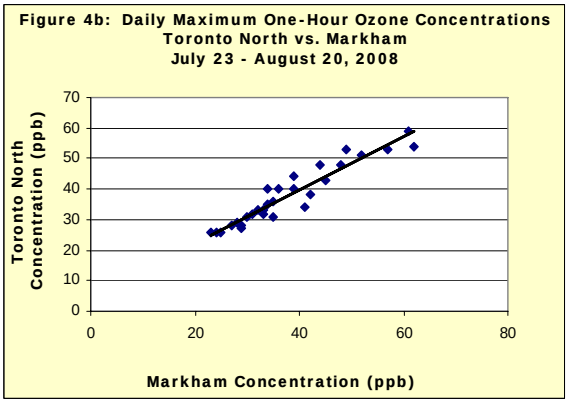
Site Location	Markham			
	Slope	Intercept	r^2	r
Newmarket	0.82	8.74	0.77	0.88
Toronto North	0.87	5.06	0.91	0.95
Toronto East	1.01	-2.54	0.87	0.93
Oshawa	1.00	2.59	0.82	0.91

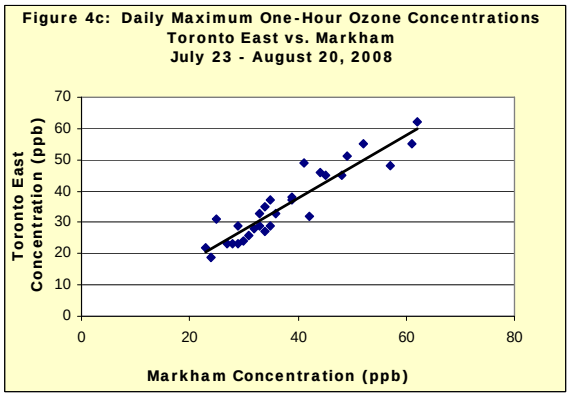
The daily maximum one-hour ozone concentrations from Markham show a high correlation with all the surrounding fixed AQI stations. Markham shows the highest correlation with Toronto North (r = 0.95), the site of closest proximity; however a very strong correlation is also noted with Newmarket, Toronto East, and Oshawa. The positive correlation coefficients close to one, slopes of the regression lines and the large coefficient of determination close to one, indicate that the ozone concentrations measured at the

surrounding fixed AQI stations, including Newmarket, are generally representative of the concentrations measured at Markham.

The scatter plots of daily maximum one-hour ozone concentrations between Markham and Newmarket, Toronto North, Toronto East, and Oshawa from July 23 – August 20, are displayed in **Figures 4a - 4d**, respectively. Data points are located close to the regression lines indicating a very strong linear relationship between the data sets.







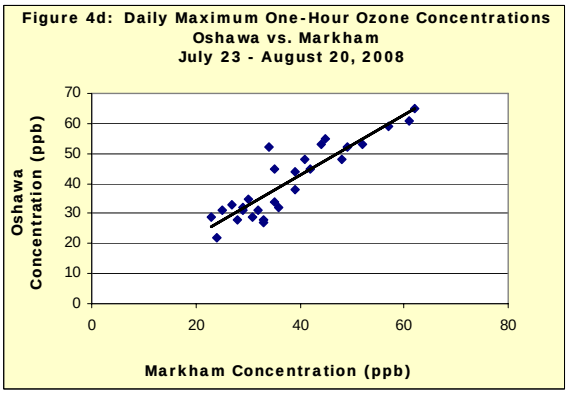


Figure 5 shows the daily maximum one-hour ozone concentrations for Markham and the surrounding fixed AQI stations for the study period. There are no significant differences between the daily maximum one-hour ozone concentrations measured at any of the sites. The one-hour Ontario Ambient Air Quality Criterion (AAQC) of 80 parts per billion (ppb) for ozone was not exceeded at any of the sites during the Markham study period.

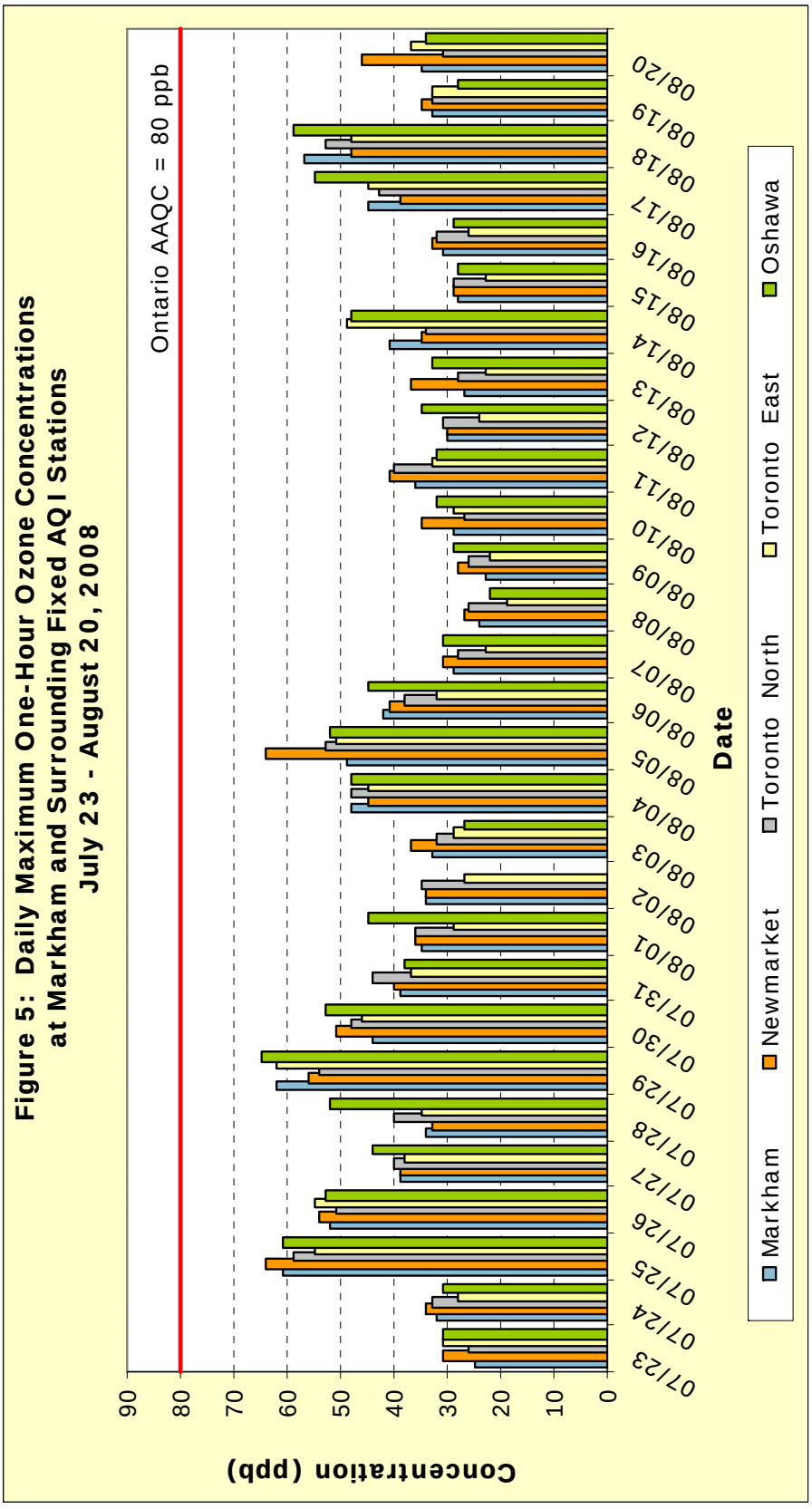
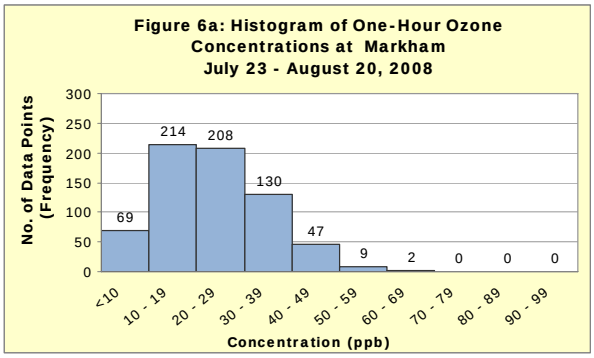
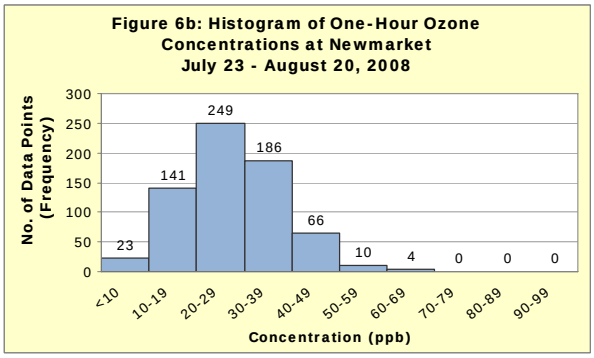
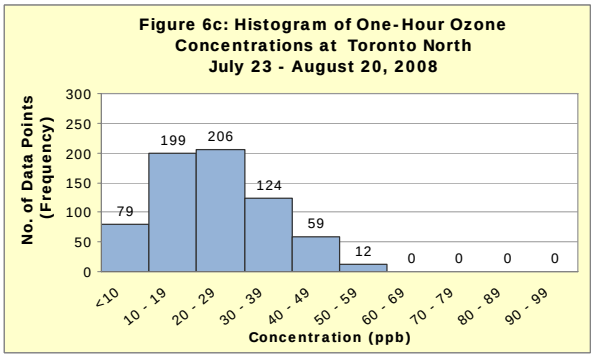


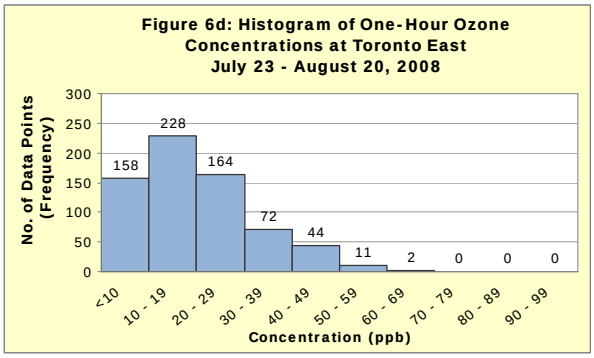
Figure 5: Daily Maximum One-Hour Ozone Concentrations
at Markham and Surrounding Fixed AQI Stations
July 23 - August 20, 2008
Ontario AAQC = 80 ppb
Concentration (ppb)
0
10
20
30
40
50
60
70
80
90
Date
07/23
07/24
07/25
07/26
07/27
07/28
07/29
07/30
07/31
08/01
08/02
08/03
08/04
08/05
08/06
08/07
08/08
08/09
08/10
08/11
08/12
08/13
08/14
08/15
08/16
08/17
08/18
08/19
08/20
Markham
Newmarket
Toronto North
Toronto East
Oshawa

Histograms of one-hour ozone concentrations measured at Markham and the surrounding fixed AQI stations during the study period are displayed in **Figures 6a - 6e**. The histograms show that Markham, Toronto North and Oshawa have a similar distribution of one-hour ozone concentrations, especially in modal classes (10 - 19 ppb) and (20 - 29 ppb). Compared to Markham, Newmarket has a lower frequency of one-hour ozone concentrations below 20 ppb and a greater frequency of one-hour ozone concentrations greater than 20 ppb, indicating slightly higher ozone levels at Newmarket.









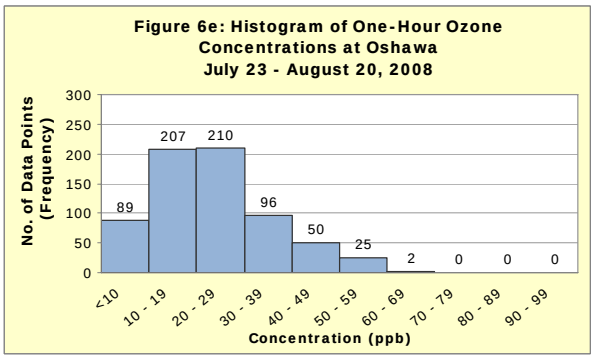
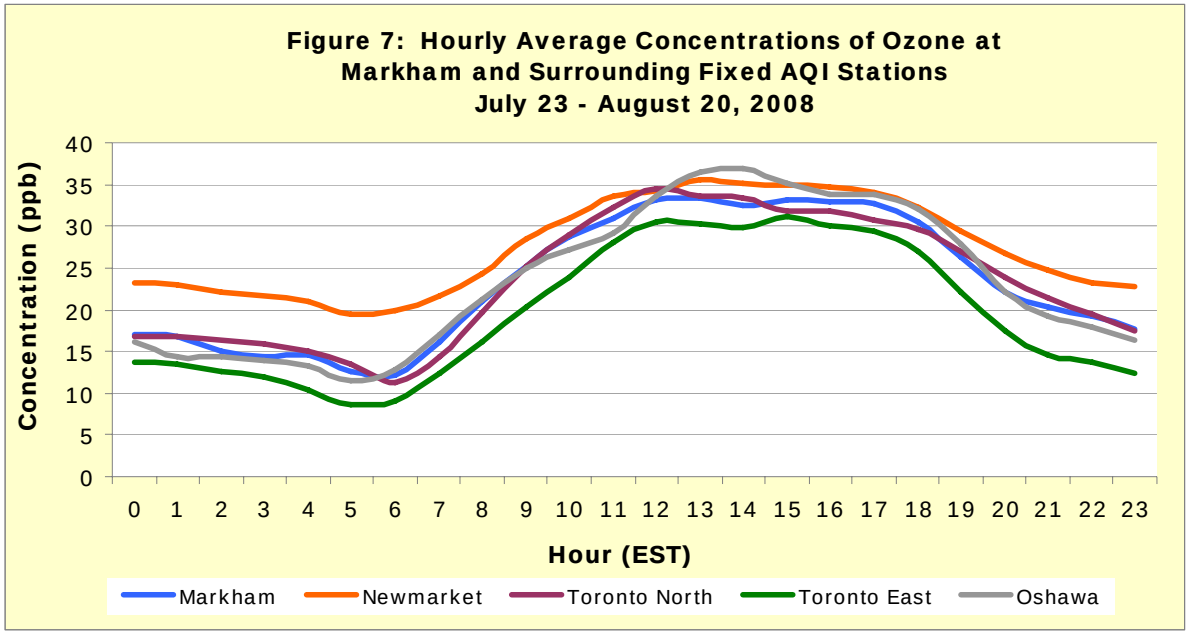


Figure 7 displays the hourly average concentration of ozone at Markham, Newmarket, Toronto North, Toronto East, and Oshawa for the entire Markham study period. There is a similar diurnal variation among the hourly average concentrations of ozone at all sites. The average concentration of ozone in the early morning is generally higher at Newmarket compared to the other sites including Markham, but peak concentrations at mid-day are similar. This suggests that local contributions of nitrogen oxides (NO_X) are greater at Markham than Newmarket, and morning ozone concentrations at Markham are lower due to the scavenging effect of nitrogen oxide (NO).



Figures 8a and **8b** further investigate this suggestion by comparing the diurnal variation of ozone and its relationship with NO_X (expressed as the sum of NO and NO_2) between Markham and Newmarket during the study period. Both sites experience an increase in NO_X concentrations during the early morning commute. The increase is mainly the result of emissions from vehicular traffic, and peaks around 06:00 Eastern Standard Time (EST). As the NO_X concentrations increase, the ozone concentrations decrease due to the reaction between NO and ozone to produce NO_2. By mid-morning, ground-level ozone starts to rise as a result of chemical reactions between volatile organic compounds (VOCs) and NO_x in the presence of sunlight. Ozone concentrations peak by mid-afternoon when the sun is still relatively intense. As the sun sets, ozone concentrations typically decrease. Both figures show similar peak ozone concentrations at the sites, however the NO_X concentrations were higher at Markham during the early morning hours, indicating a greater local traffic influence when compared to Newmarket.

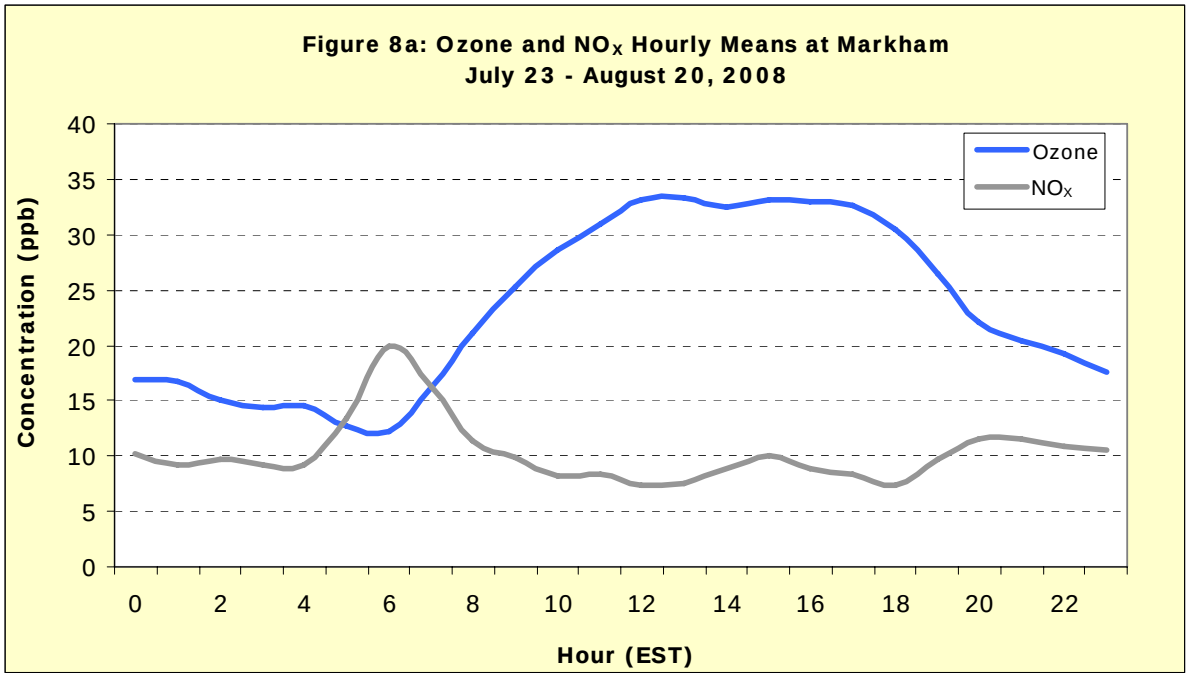


Figure 8a: Ozone and NOx Hourly Means at Markham
July 23 - August 20, 2008
Concentration (ppb)
Hour (EST)
Ozone
NOx
0
5
10
15
20
25
30
35
40
0
2
4
6
8
10
12
14
16
18
20
22

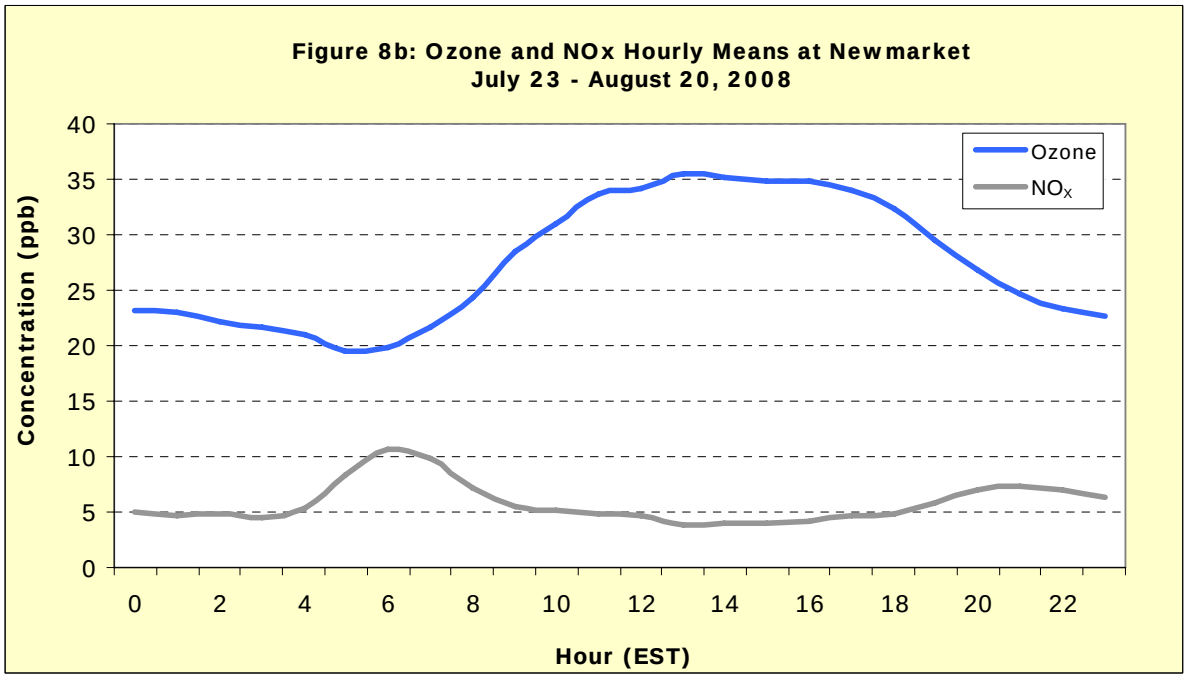


Figure 8b: Ozone and NOx Hourly Means at Newmarket
July 23 - August 20, 2008
Concentration (ppb)
Hour (EST)
Ozone
NOx
0
5
10
15
20
25
30
35
40
0
2
4
6
8
10
12
14
16
18
20
22

$PM_{2.5}$

Table 2 shows the linear correlation coefficients (r) of the daily average $PM_{2.5}$ concentrations recorded at the Markham study site in comparison to the daily average $PM_{2.5}$ concentrations measured at the surrounding fixed air monitoring stations. The table also includes the slopes, intercepts and coefficients of determination (r^2).

Table 2: Statistics of Daily Average $PM_{2.5}$ Concentrations between the Markham Study Site and Surrounding Fixed AQI Stations

Site Location	Markham			
	Slope	Intercept	r^2	r
Newmarket	0.85	-0.14	0.91	0.95
Toronto North	1.04	-0.07	0.94	0.97
Toronto East	0.87	-0.01	0.91	0.96
Oshawa	0.88	0.34	0.91	0.95

The daily average $PM_{2.5}$ concentrations from Markham show a high correlation with all the surrounding fixed AQI stations. Markham shows the highest correlation with Toronto North ($r = 0.97$), the site of closest proximity. However a very strong relationship is also noted with Newmarket, Oshawa, and Toronto East by correlation coefficient values ranging from 0.95 to 0.96. The positive correlation coefficients close to one, slopes of the regression lines, and the large coefficient of determination close to one, indicate that the concentrations measured at the surrounding fixed AQI stations are generally similar to the concentrations measured at the Markham study site.

The scatter plots of the daily average $PM_{2.5}$ concentrations between Markham and the surrounding fixed AQI stations for the study period are displayed in **Figures 9a - 9d**. Data points are located close to the regression lines indicating a strong linear relationship between the data sets.

The box plots in **Figure 10** are summary statistics of the daily average $PM_{2.5}$ concentrations measured at Markham and the surrounding fixed AQI stations during the study period. None of the daily average $PM_{2.5}$ concentrations measured during the period exceeded the 24-hour Ontario reference level of 30 micrograms per cubic metre ($\mu g/m^3$). The medians at all stations are very similar and no statistical significant difference was observed among these sites. This suggests that the $PM_{2.5}$ measurements at Markham are overall similar to those of the surrounding sites.

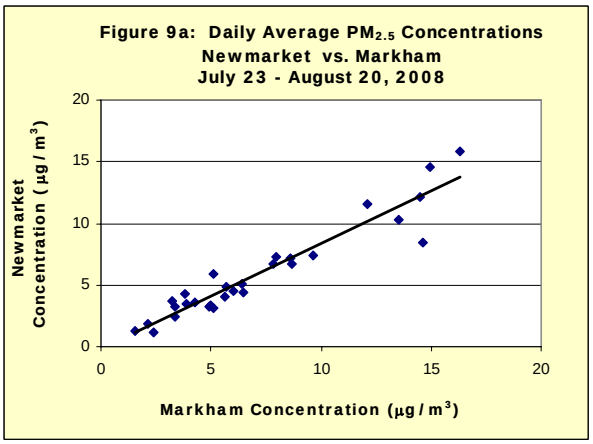


Figure 9a: Daily Average PM2.5 Concentrations
Newmarket vs. Markham
July 23 - August 20, 2008
Newmarket Concentration (µg/m3)
Markham Concentration (µg/m3)
0
5
10
15
20

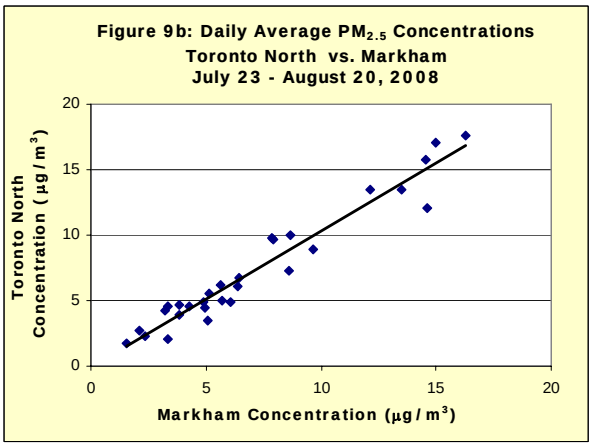


Figure 9b: Daily Average PM2.5 Concentrations
Toronto North vs. Markham
July 23 - August 20, 2008
Toronto North Concentration (µg/m3)
Markham Concentration (µg/m3)
0
5
10
15
20

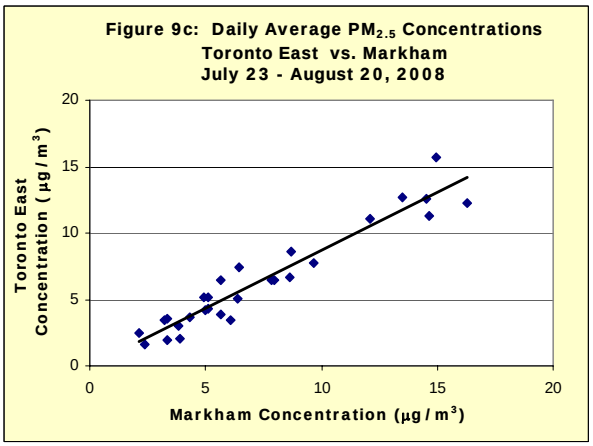


Figure 9c: Daily Average PM2.5 Concentrations
Toronto East vs. Markham
July 23 - August 20, 2008
Toronto East Concentration (µg/m3)
Markham Concentration (µg/m3)
0
5
10
15
20

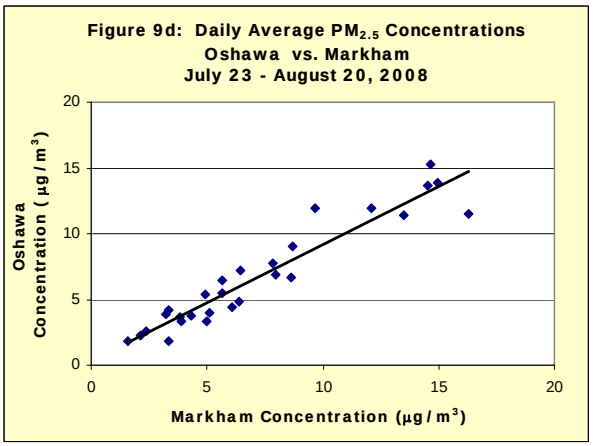


Figure 9d: Daily Average PM2.5 Concentrations
Oshawa vs. Markham
July 23 - August 20, 2008
Oshawa Concentration (µg/m3)
Markham Concentration (µg/m3)
0
5
10
15
20

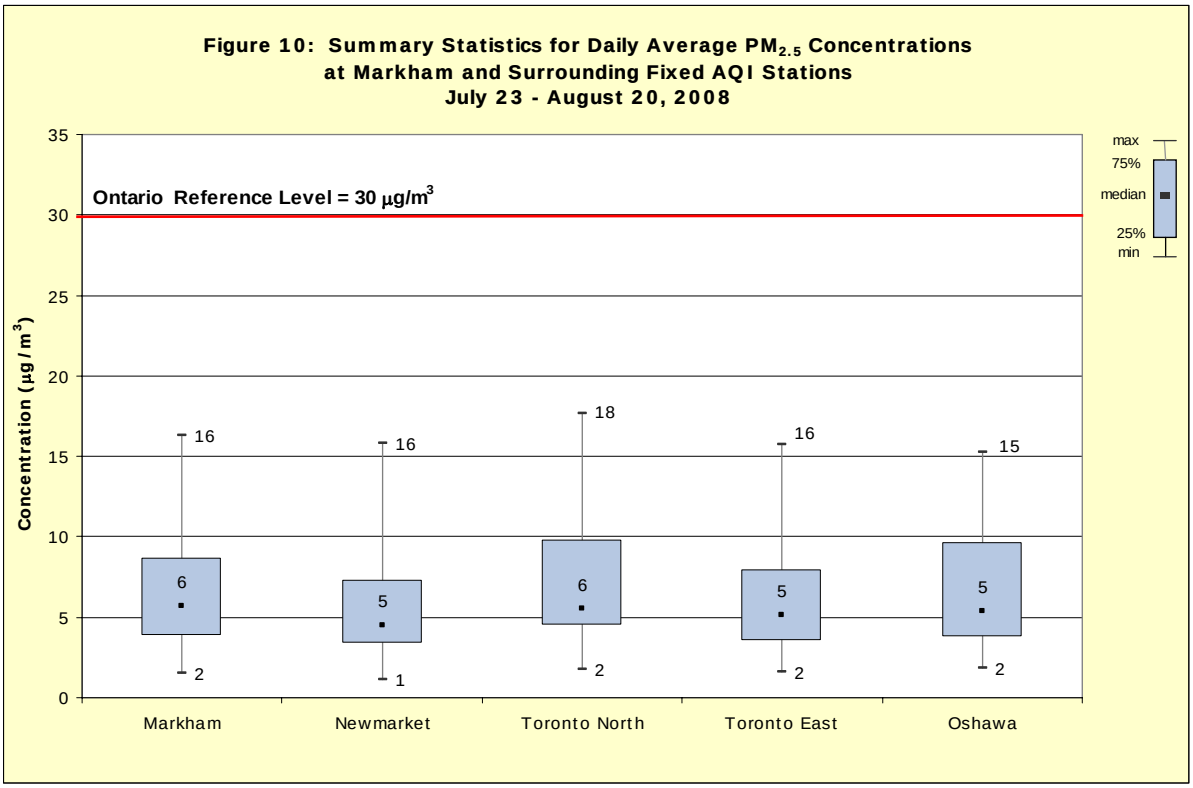


Figure 10: Summary Statistics for Daily Average PM2.5 Concentrations
at Markham and Surrounding Fixed AQI Stations
July 23 - August 20, 2008
Ontario Reference Level = 30 µg/m3
Concentration (µg/m3)
max
75%
median
25%
min
Markham
Newmarket
Toronto North
Toronto East
Oshawa
16
6
2
16
5
1
18
6
2
16
5
2
15
5
2

Nitrogen Dioxide

Table 3 shows the correlation coefficients (r) of the daily average NO_2 concentrations recorded at the Markham study site in comparison to the daily average NO_2 concentrations measured at the surrounding fixed AQI stations. The table also includes the slopes, intercepts and coefficients of determination (r^2).

Table 3: Statistics of Daily Average NO_2 Concentrations between the Markham Study Site and Surrounding Fixed AQI Stations

Site Location	Markham			
	Slope	Intercept	r^2	r
Newmarket	0.42	1.08	0.47	0.69
Toronto North	1.13	1.50	0.80	0.89
Toronto East	0.40	9.94	0.24	0.49
Oshawa	0.44	1.65	0.76	0.87

The daily average NO_2 concentrations from Markham show the highest correlation with Toronto North (r=0.89), the site of closest proximity. The correlation analysis between Markham and Newmarket indicates that a strong relationship does exist between the data sets, but it is not as strong as Toronto North or Oshawa. Local influences in NO_2, such as high traffic areas surrounding the Markham site, may be responsible for the weaker correlation coefficient between Markham and Newmarket. The scatter plots of the daily average NO_2 concentrations between Markham and the surrounding fixed AQI stations from July 23 – August 20 are displayed in **Figures 11a - 11d**.

Figure 12 shows the summary statistics for the one-hour NO_2 concentrations measured at Markham and surrounding fixed AQI stations from July 23 – August 20. All of the one-hour NO_2 concentrations measured during the study period were well below the Ontario one-hour criterion of 200 ppb. Maximum one-hour NO_2 concentrations were similar between Toronto North (37 ppb), Toronto East (33 ppb), and Markham (31 ppb). Newmarket and Oshawa recorded similar values of 23 and 21 ppb, respectively. Seventy-five per cent of all recorded values at Markham were below 10 ppb and the median was 6 ppb. Newmarket recorded the lowest one-hour NO_2 concentrations, with 75 per cent of the measured data lower than 5 ppb and a median of only 3 ppb.

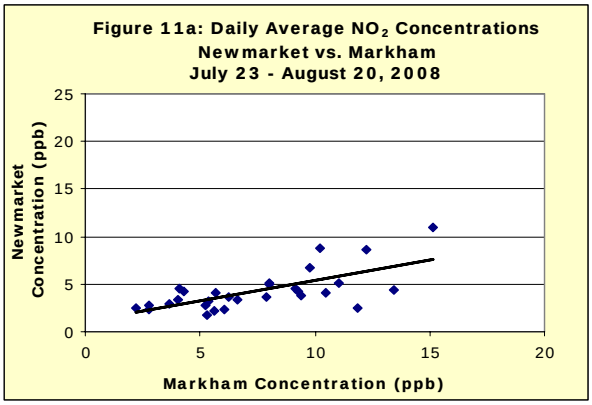


Figure 11a: Daily Average NO2 Concentrations
Newmarket vs. Markham
July 23 - August 20, 2008
Newmarket Concentration (ppb)
Markham Concentration (ppb)
0
5
10
15
20
25

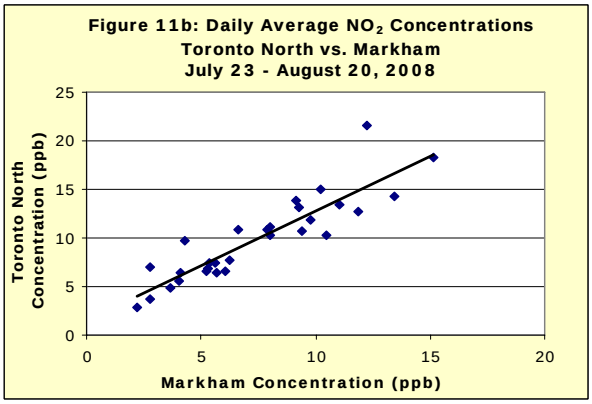


Figure 11b: Daily Average NO2 Concentrations
Toronto North vs. Markham
July 23 - August 20, 2008
Toronto North Concentration (ppb)
Markham Concentration (ppb)
0
5
10
15
20
25

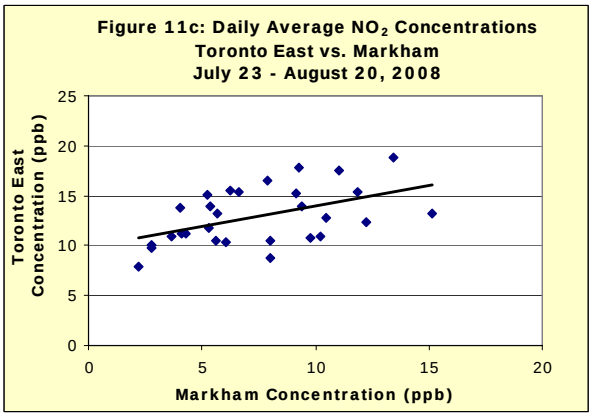


Figure 11c: Daily Average NO2 Concentrations
Toronto East vs. Markham
July 23 - August 20, 2008
Toronto East Concentration (ppb)
Markham Concentration (ppb)
0
5
10
15
20
25

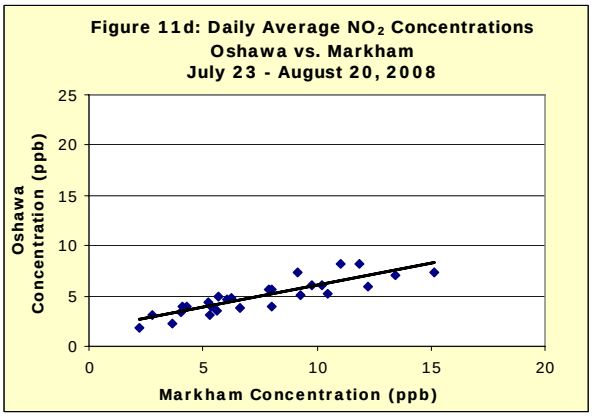


Figure 11d: Daily Average NO2 Concentrations
Oshawa vs. Markham
July 23 - August 20, 2008
Oshawa Concentration (ppb)
Markham Concentration (ppb)
0
5
10
15
20
25

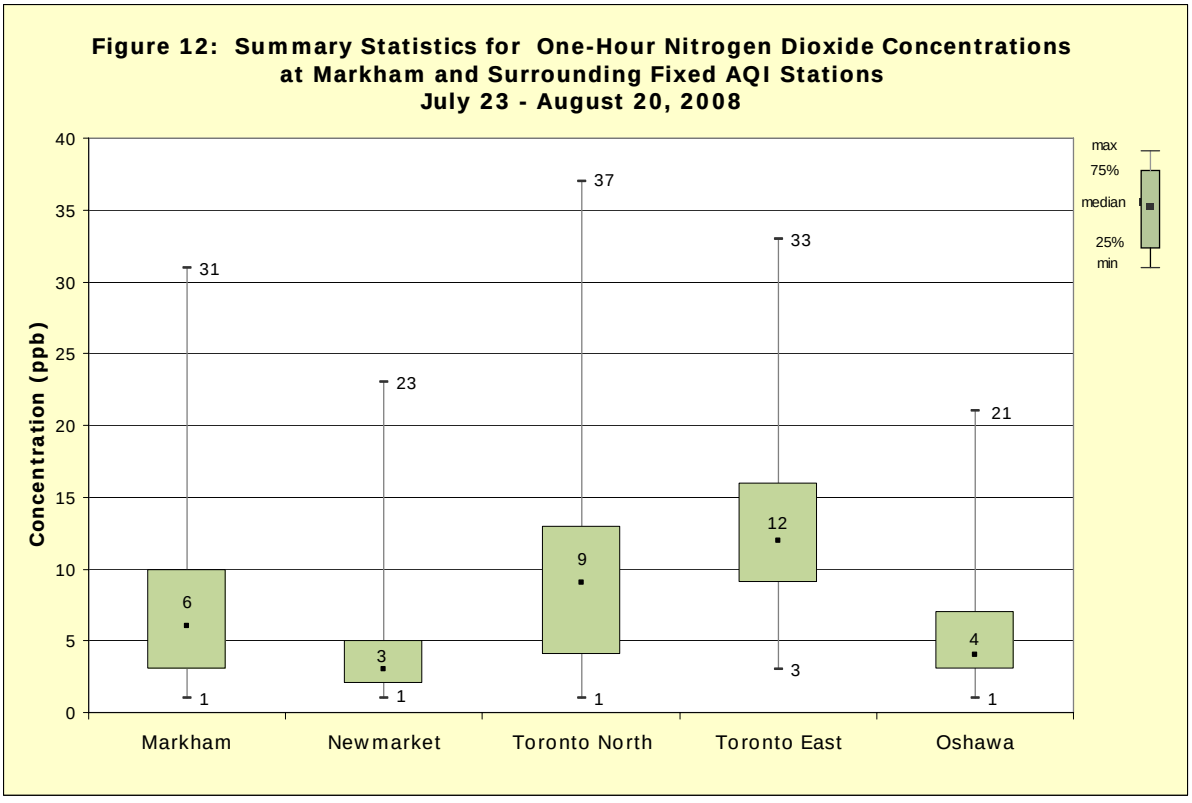


Figure 12: Summary Statistics for One-Hour Nitrogen Dioxide Concentrations
at Markham and Surrounding Fixed AQI Stations
July 23 - August 20, 2008
Concentration (ppb)
0
5
10
15
20
25
30
35
40
31
6
1
23
3
1
37
9
1
33
12
3
21
4
1
Markham
Newmarket
Toronto North
Toronto East
Oshawa
max
75%
median
25%
min

Carbon Monoxide

CO concentrations were measured at the Markham study site from July 23 – August 20. The highest one-hour concentration measured at Markham was 0.35 ppm on July 30. The highest eight-hour concentration measured at Markham was 0.26 ppm on July 31. The Ontario AAQC for one-hour and eight-hour maximum CO is 30 ppm and 13 ppm, respectively, and were not exceeded during the study period.

Sulphur Dioxide

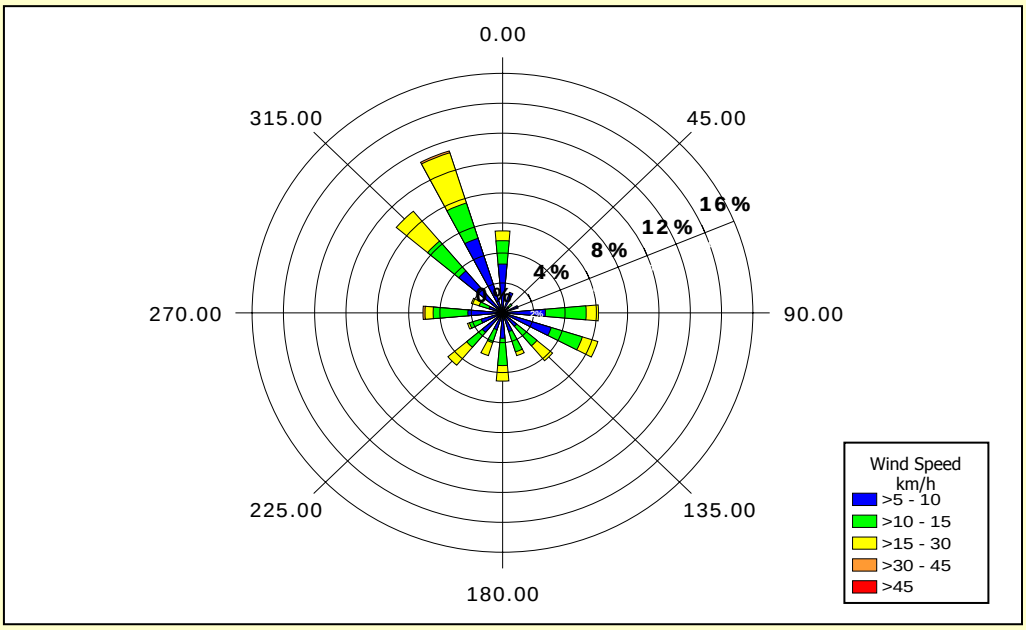
SO_2 concentrations were measured at Markham from July 23 – August 20. The highest one-hour SO_2 maximum concentration was 8 ppb, recorded on July 29. All values recorded at the Markham study site were well below the Ontario one-hour AAQC for SO_2 of 250 ppb.

VAUGHAN STUDY PERIOD: AUGUST 22 – SEPTEMBER 22, 2008

Meteorology

Sky conditions, minimum and maximum temperatures, total amount of precipitation, and average wind direction and wind speed data during the study period were recorded at the Toronto Buttonville Municipal Airport, and are summarized in **Appendix B**. A mix of cloudy and clear skies was observed in York Region from August 22 to September 22, while the PM Unit was located in Vaughan. Precipitation values recorded at the Toronto Buttonville Municipal Airport indicate eight days during the study had greater than 1 mm of precipitation and four days had trace levels to 1 mm. The prevailing winds as shown in **Figure 13**, plotted for Toronto Buttonville Municipal Airport, are considered quite variable, however southerly winds were recorded for approximately 20% of the study period. Regional influences from the City of Toronto and transboundary flow are possible with southerly winds. Maximum temperatures ranged from 16°C to 31°C. August 22 and 23 experienced ideal conditions for photochemical smog production with a maximum temperature of 28°C and southerly winds. A smog advisory was issued for York Region on August 22 - 23, and September 3, 2008.

Figure 13: Wind Rose for Toronto Buttonville Municipal Airport
August 22 – September 22, 2008



Note: Calm winds (5 km/h and less) were recorded for 28% of the time during the study period.

Ozone

Table 4 shows the linear correlation coefficients (r) of the daily maximum one-hour ozone concentrations recorded at the Vaughan study site in comparison to the daily maximum one-hour ozone concentrations measured at the surrounding fixed air monitoring stations. The table also includes the slopes, intercepts and coefficients of determination (r^2).

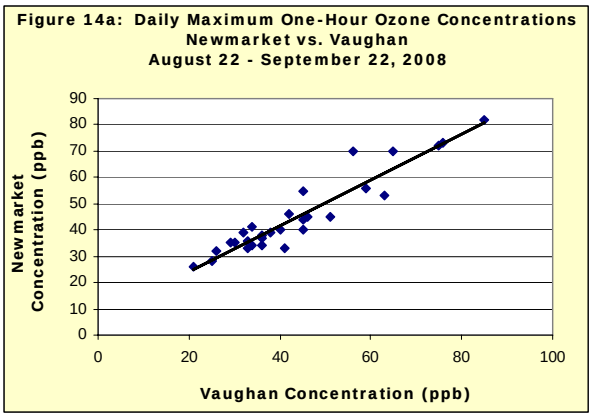
Table 4: Statistics of Daily Maximum One-Hour Ozone Concentrations between the Vaughan Study Site and Surrounding Fixed AQI Stations

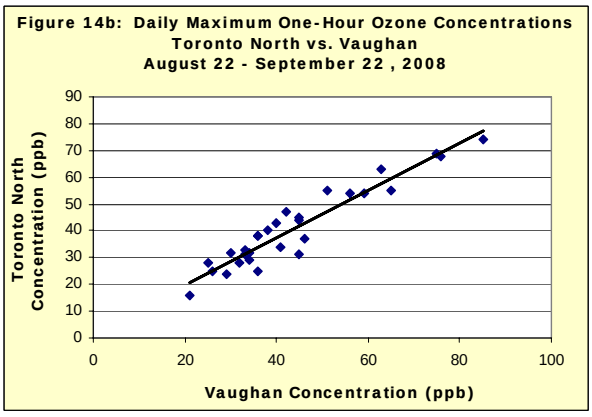
Site Location	Vaughan			
	Slope	Intercept	r^2	r
Newmarket	0.87	6.79	0.89	0.94
Toronto North	0.88	2.43	0.90	0.95
Toronto East	0.90	1.74	0.86	0.93
Oshawa	0.89	3.61	0.78	0.88

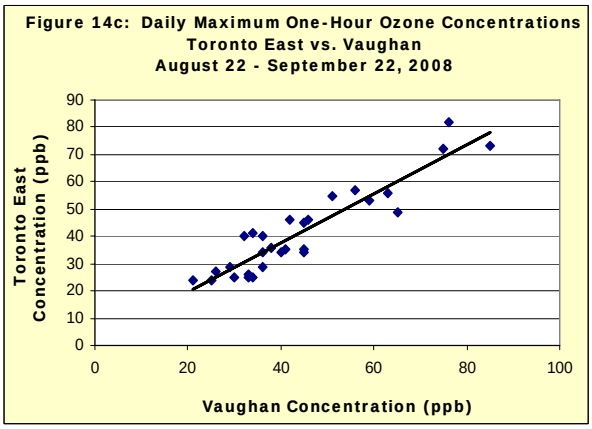
The daily maximum one-hour ozone concentrations from Vaughan show the highest correlation with Toronto North (r = 0.95), but correlation coefficients close to one are also noted between the other three sites, indicating the existence of a very strong linear relationship. The positive correlation coefficients close to one, slopes of the regression lines and the large coefficient of determination close to one, indicate that the concentrations measured at the surrounding fixed AQI stations, including Newmarket, are generally

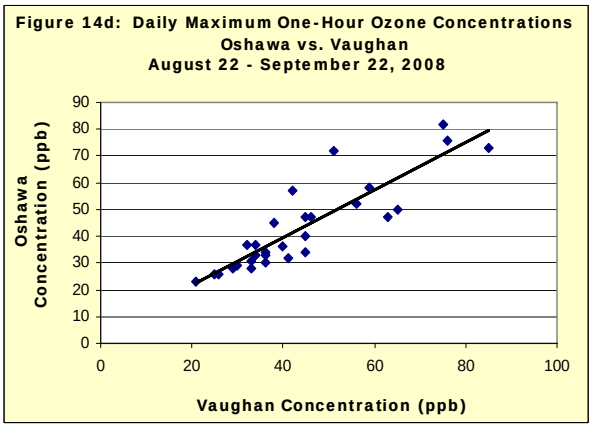
representative of the concentrations measured at Vaughan. The scatter plots of daily maximum one-hour ozone concentrations between Vaughan and surrounding fixed AQI stations from August 22 – September 22 are displayed in **Figures 14a** – **14d**. Data points are located close to the regression lines indicating a strong linear relationship between the data sets.

Figure 15 shows the daily maximum one-hour ozone concentrations for Vaughan, Newmarket, Toronto North, Toronto East, and Oshawa for the study period. There are no significant differences between the daily maximum one-hour ozone concentrations at any of the sites.









On August 22, the one-hour Ontario AAQC of 80 ppb for ozone was exceeded at Toronto East (82 ppb). Vaughan, Newmarket and Oshawa recorded maximum one-hour ozone concentrations of 73 ppb, 76 ppb, and 76 ppb, respectively. On August 23, the Ontario one-hour AAQC for ozone was exceeded at Vaughan (85 ppb) and Newmarket (82 ppb). On September 3, the only site to exceed the Ontario AAQC for one-hour ozone was the Oshawa AQI station with a concentration of 82 ppb, while Vaughan and Newmarket recorded concentrations of 75 ppb and 72 ppb, respectively. All exceedances of the one-hour Ontario AAQC for ozone occurred on smog advisory days, which is further discussed in Section 3.0.

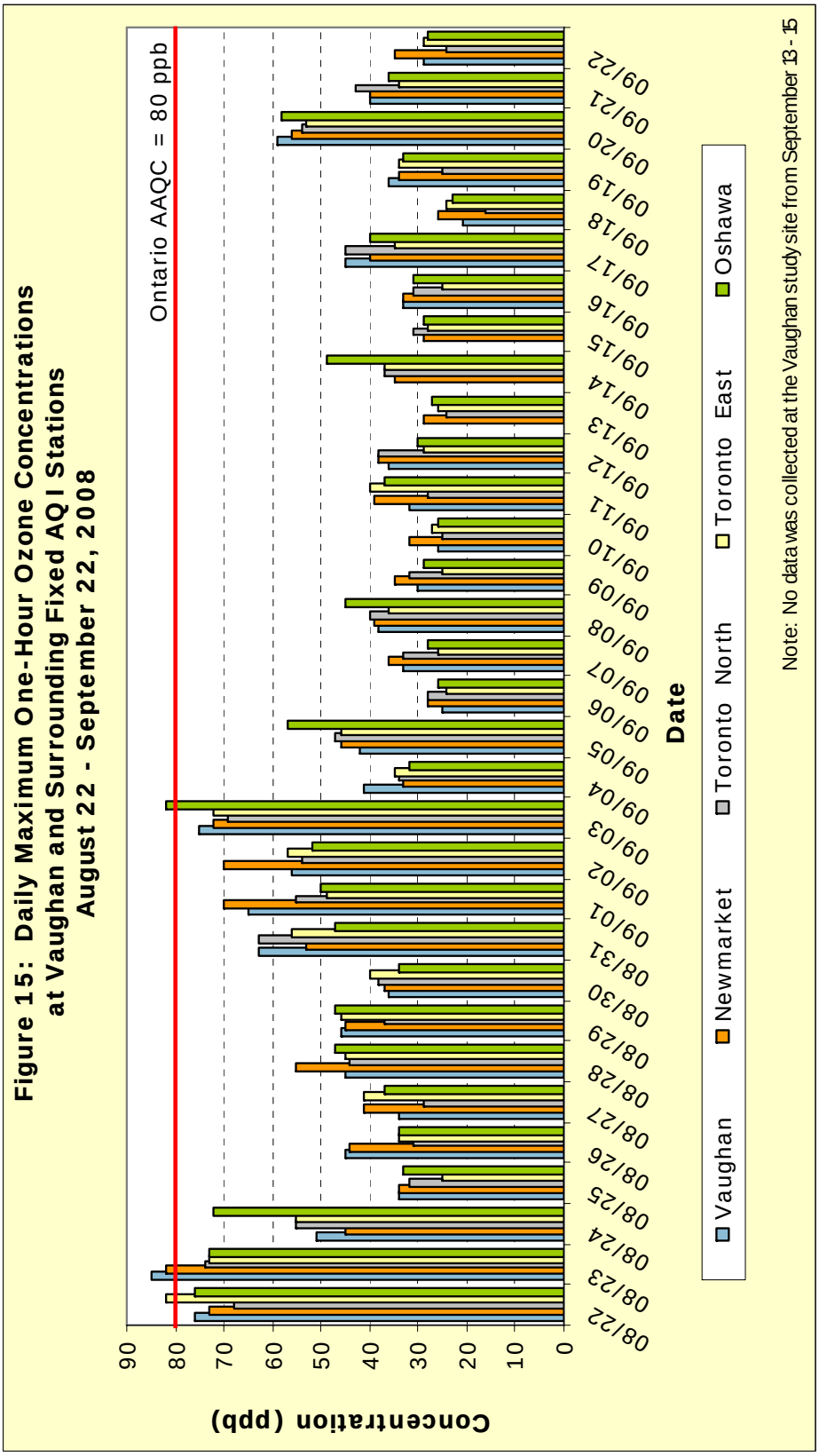
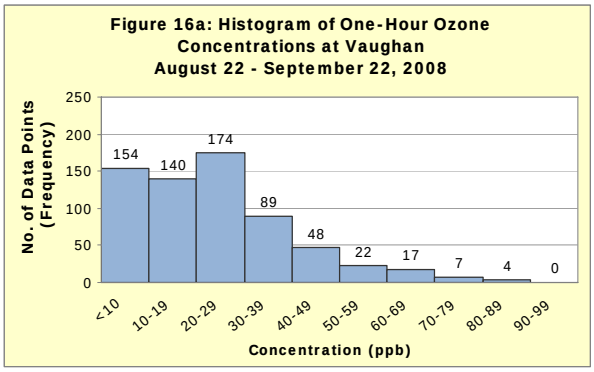
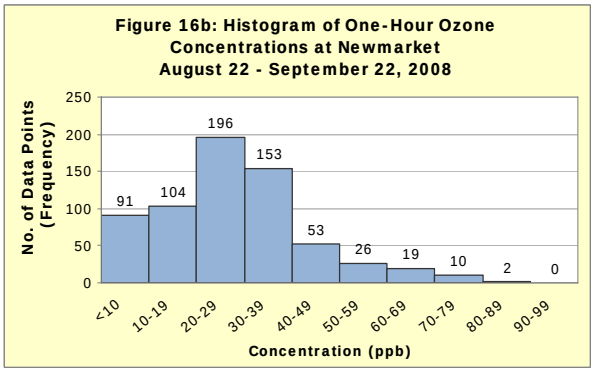


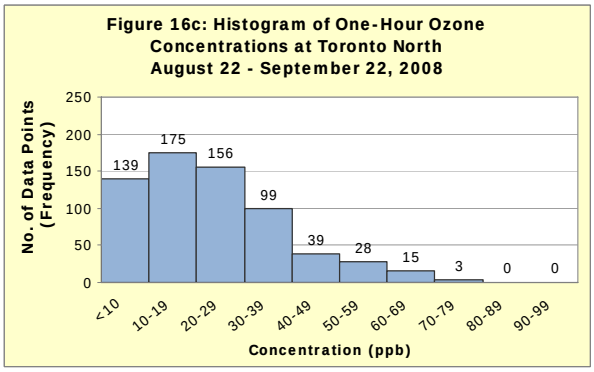
Figure 15: Daily Maximum One-Hour Ozone Concentrations at Vaughan and Surrounding Fixed AQI Stations August 22 - September 22, 2008
Ontario AAQC = 80 ppb
Concentration (ppb)
Date
Vaughan
Newmarket
Toronto North
Toronto East
Oshawa
Note: No data was collected at the Vaughan study site from September 13 - 15

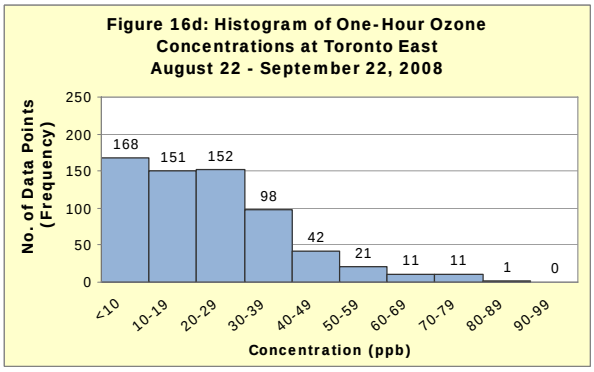
Histograms of one-hour ozone concentrations measured at Vaughan and the surrounding fixed AQI stations during the study period are displayed in **Figure 16a - 16e.** A similar distribution of one-hour ozone concentrations was seen at Vaughan, Toronto North, and Toronto East. The Newmarket AQI station was observed to have a lower frequency of one-hour ozone concentrations below 20 ppb. For example, Newmarket recorded 195 values below 20 ppb while Vaughan and Toronto North recorded 294 and 314 values, respectively.

Comparison of the one-hour ozone histograms between Vaughan and Newmarket indicate slightly higher ozone levels at Newmarket. Local influences play a role in decreasing ozone levels at the Vaughan and Toronto North sites. Areas close to urbanized centers or high traffic areas, such as Vaughan and Toronto North, experience higher levels of NO, which can react with ozone to produce NO_2 and oxygen. Areas with higher levels of NO will result in lower levels of ozone in the early morning and late evening.









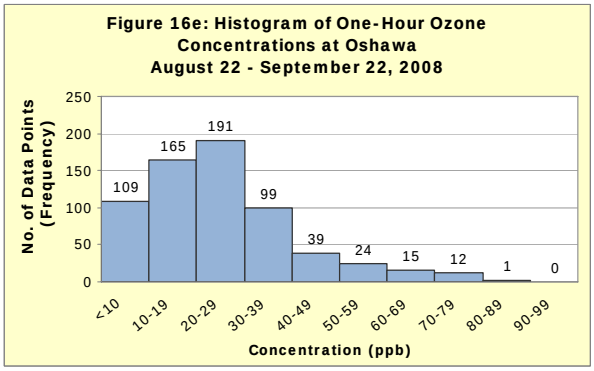
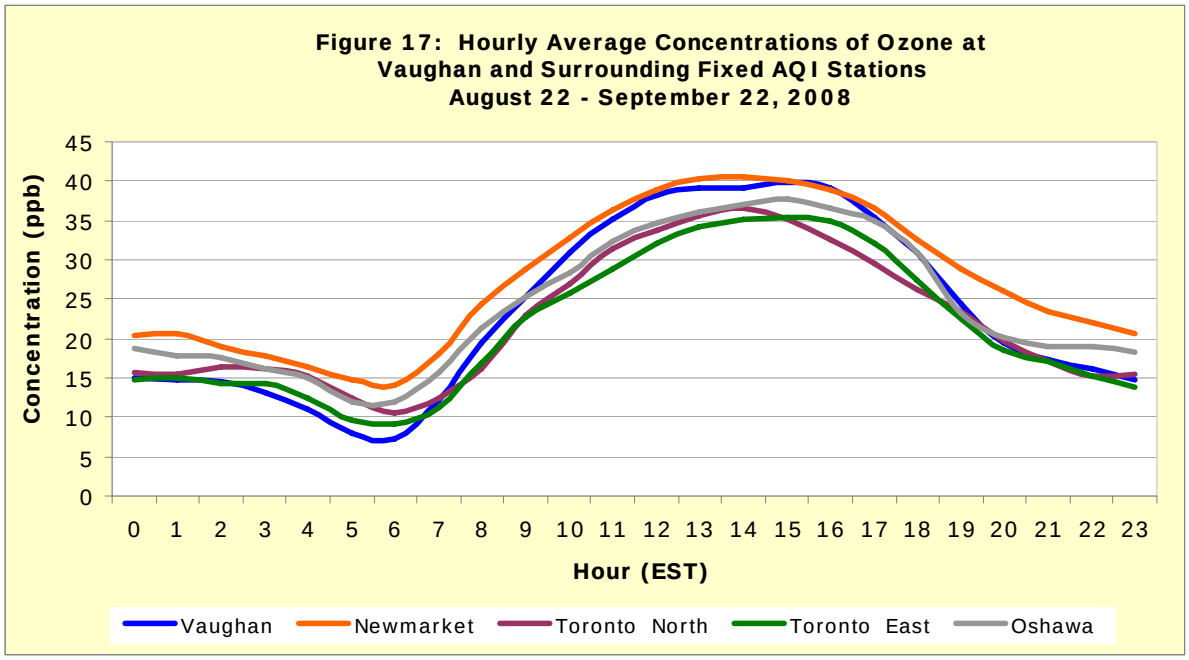


Figure 17 shows the hourly average concentration of ozone at Vaughan and the surrounding fixed AQI stations from August 22 – September 22. There is a similar variation among the hourly average concentrations of ozone at all sites. The average concentrations of ozone in the early morning and at night are generally higher at Newmarket compared to Vaughan, but peak concentrations at mid-day are similar. This suggests that local contributions of NO_X are greater at Vaughan and morning concentrations of ozone at this site are lower due to the scavenging effect of NO.



Figures 18a and **18b** further investigate this suggestion by comparing the diurnal variation of ozone and its relationship with NO_X (expressed as the sum of NO and NO_2) between Vaughan and Newmarket during the study period. Both sites experience an increase in NO_X concentrations during the early morning. The increase is mainly the result of vehicular traffic, and peaks around 06:00 EST. Both figures show similar peak ozone concentrations at Vaughan and Newmarket; however the NO_X concentrations were approximately 20 ppb higher at Vaughan during the early morning hours, indicating that higher concentrations at Vaughan are due to local NO_X sources.

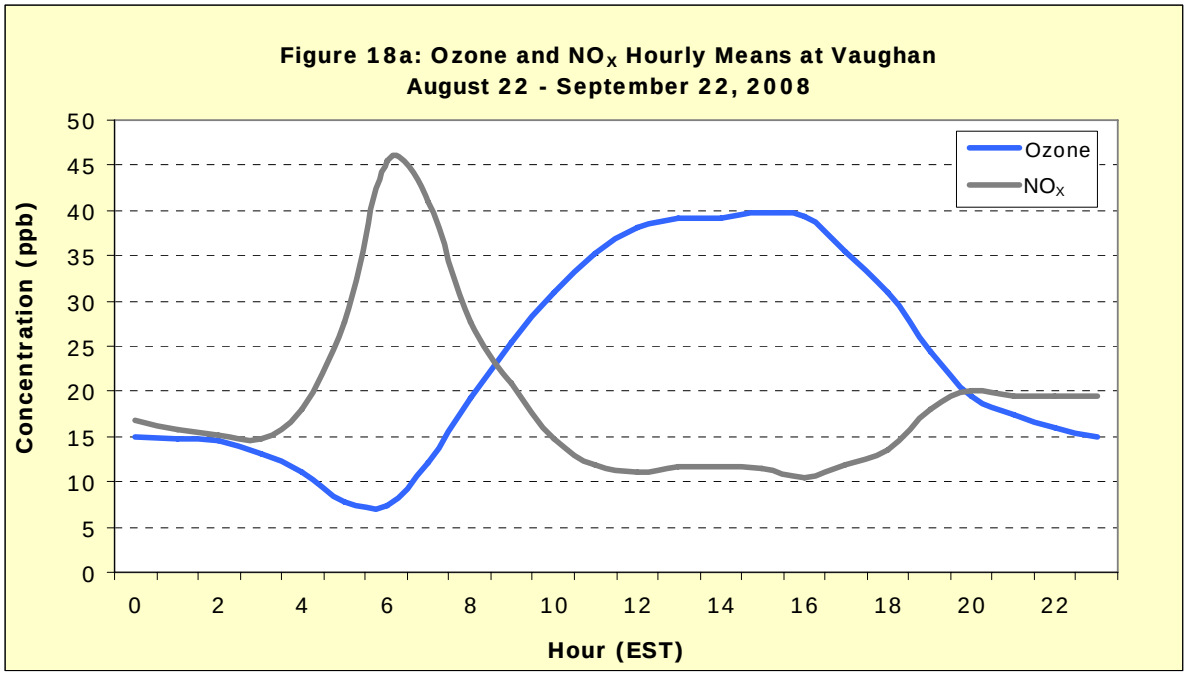


Figure 18a: Ozone and NOx Hourly Means at Vaughan
August 22 - September 22, 2008
Concentration (ppb)
50
45
40
35
30
25
20
15
10
5
0
0
2
4
6
8
10
12
14
16
18
20
22
Hour (EST)
Ozone
NOx

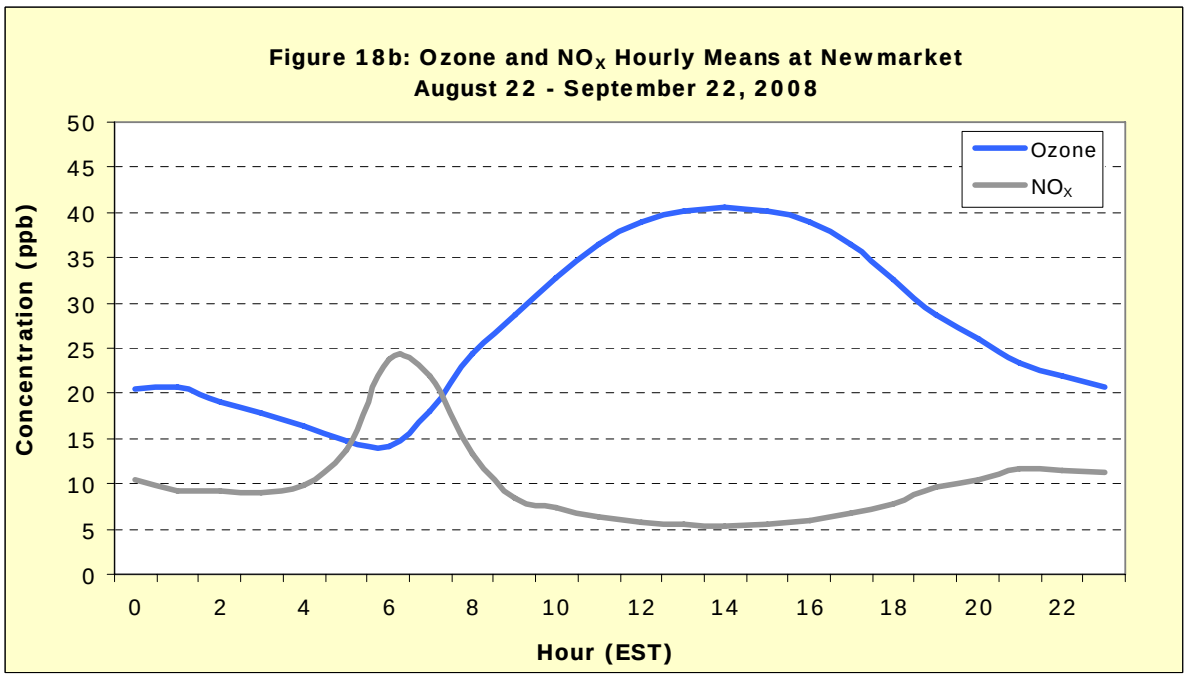


Figure 18b: Ozone and NOx Hourly Means at Newmarket
August 22 - September 22, 2008
Concentration (ppb)
50
45
40
35
30
25
20
15
10
5
0
0
2
4
6
8
10
12
14
16
18
20
22
Hour (EST)
Ozone
NOx

$PM_{2.5}$

Table 5 shows the linear correlation coefficients (r) of the daily average $PM_{2.5}$ concentrations at Vaughan in comparison to the daily average $PM_{2.5}$ concentrations measured at the surrounding fixed AQI stations. The table also includes the slopes, intercepts and coefficients of determination (r^2).

Table 5: Statistics of Daily Average $PM_{2.5}$ Concentrations between the Vaughan Study Site and Surrounding Fixed AQI Stations

Site Location	Vaughan			
	Slope	Intercept	r^2	r
Newmarket	0.88	-0.09	0.98	0.99
Toronto North	0.95	0.53	0.98	0.99
Toronto East	0.87	0.74	0.88	0.94
Oshawa	0.94	-0.18	0.92	0.96

The daily average $PM_{2.5}$ concentrations from Vaughan show a very strong linear relationship between Vaughan and the surrounding fixed AQI stations (r = 0.94 to 0.99). The positive correlation coefficients close to one, slopes of the regression lines and the large coefficient of determination close to one, indicate that the concentrations measured at the surrounding fixed AQI stations are generally similar to the concentrations measured at Vaughan.

The scatter plots of daily maximum one-hour ozone concentrations between Vaughan and the surrounding fixed AQI stations from August 22 – September 22 are displayed in **Figures 19a - 19d**. Data points are located close to the regression lines indicating a strong linear relationship between the data sets.

Figure 20 shows the summary statistics for the daily average $PM_{2.5}$ concentrations for Vaughan and the surrounding fixed AQI stations for the study period. The $PM_{2.5}$ 24-hour Ontario reference level of 30 $\mu g/m^3$ was not exceeded at any of the sites during the study period. The medians at all the stations are very similar and no statistical significant difference was observed among these sites. This suggests that measurements at Newmarket and the other fixed AQI stations are typically representative of concentrations recorded at Vaughan. The highest daily average $PM_{2.5}$ concentration of 25 $\mu g/m^3$ was recorded at Vaughan on August 23, and similar values were observed at the surrounding fixed AQI stations. A smog advisory for York Region was issued for August 22 - 23, 2008 and is further discussed in Section 3.0.

Figure 19a: Daily Average $PM_{2.5}$ Concentrations
Newmarket vs. Vaughan
August 22 - September 22, 2008

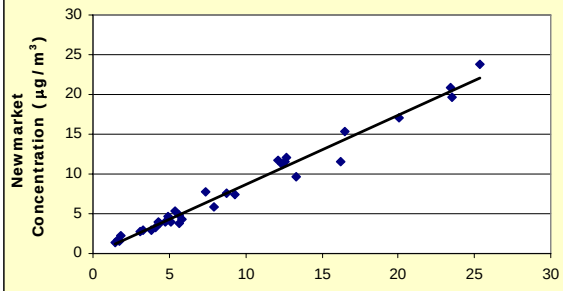


Figure 19b: Daily Average $PM_{2.5}$ Concentrations
Toronto North vs. Vaughan
August 22 - September 22, 2008

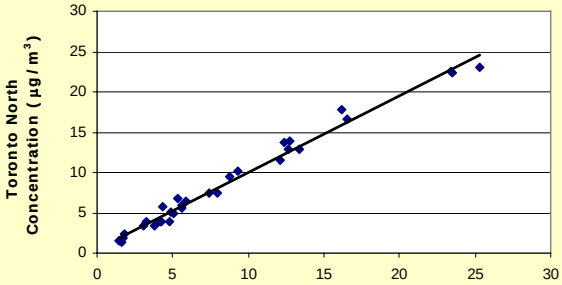


Figure 19c: Daily Average $PM_{2.5}$ Concentrations
Toronto East vs. Vaughan
August 22 - September 22, 2008

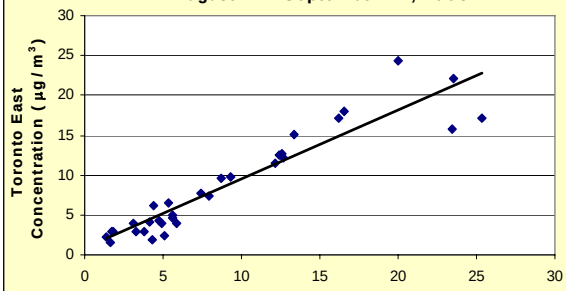


Figure 19d: Daily Average $PM_{2.5}$ Concentrations
Oshawa vs. Vaughan
August 22 - September 22, 2008

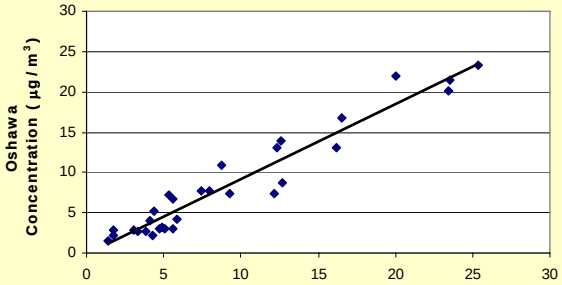
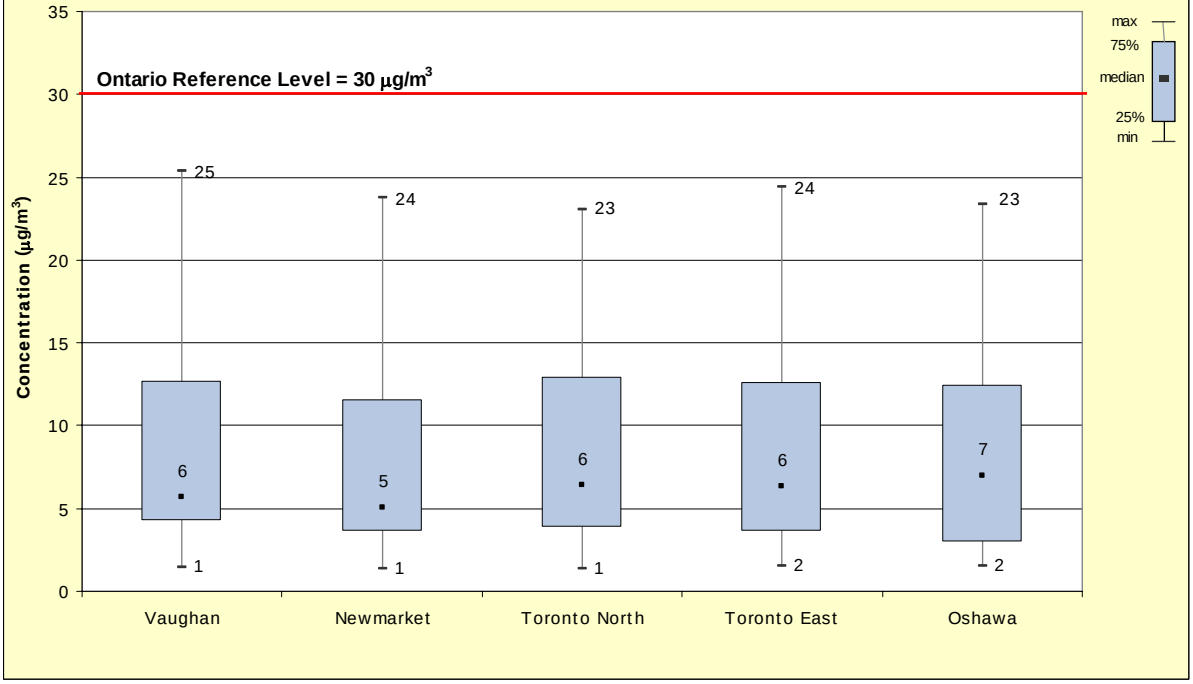


Figure 20: Summary Statistics for Daily Average $PM_{2.5}$ Concentrations at Vaughan and Surrounding Fixed AQI Stations
August 22 - September 22, 2008

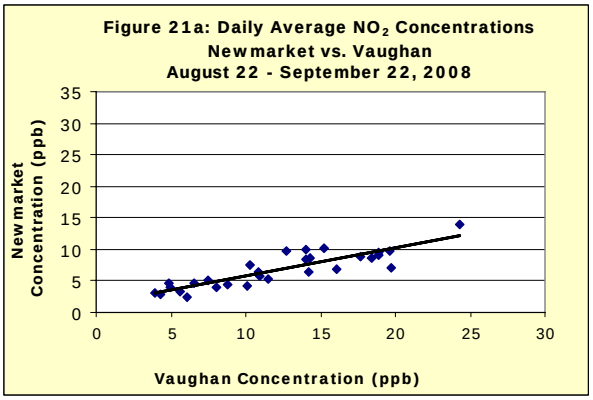


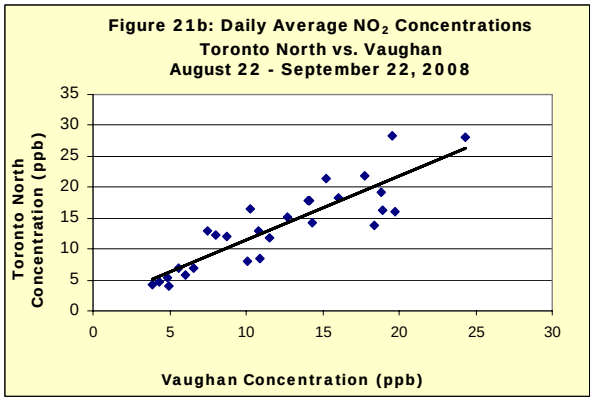
Nitrogen Dioxide

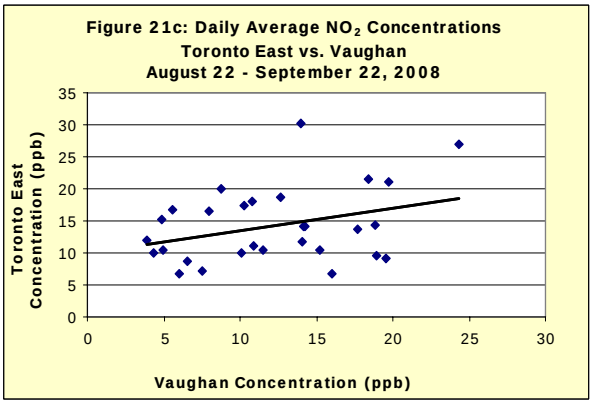
Table 6 shows the correlation coefficients (r) of the daily average NO_2 concentrations at Vaughan, in comparison to the daily average NO_2 concentrations measured at the surrounding fixed AQI stations. The table also includes the slopes, intercepts and coefficients of determination (r^2). The scatter plots of the daily average NO_2 concentrations between Vaughan and the surrounding fixed AQI stations for the study period are displayed in **Figures 21a - 21d**.

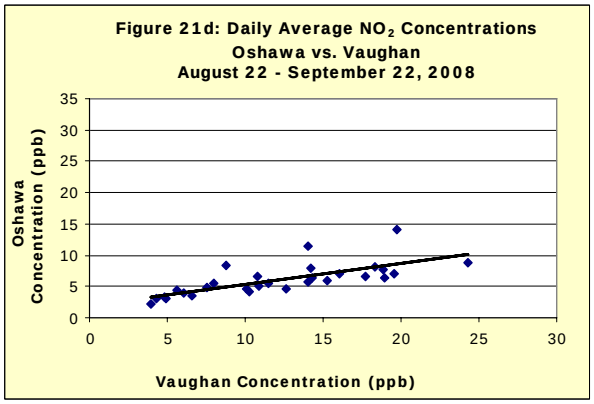
Table 6: Statistics of Daily Average NO_2 Concentrations between the Vaughan Study Site and Surrounding Fixed AQI Stations

Site Location	Vaughan			
	Slope	Intercept	r^2	r
Newmarket	0.44	1.39	0.77	0.88
Toronto North	1.04	1.10	0.77	0.88
Toronto East	0.36	9.90	0.12	0.35
Oshawa	0.33	2.09	0.51	0.71

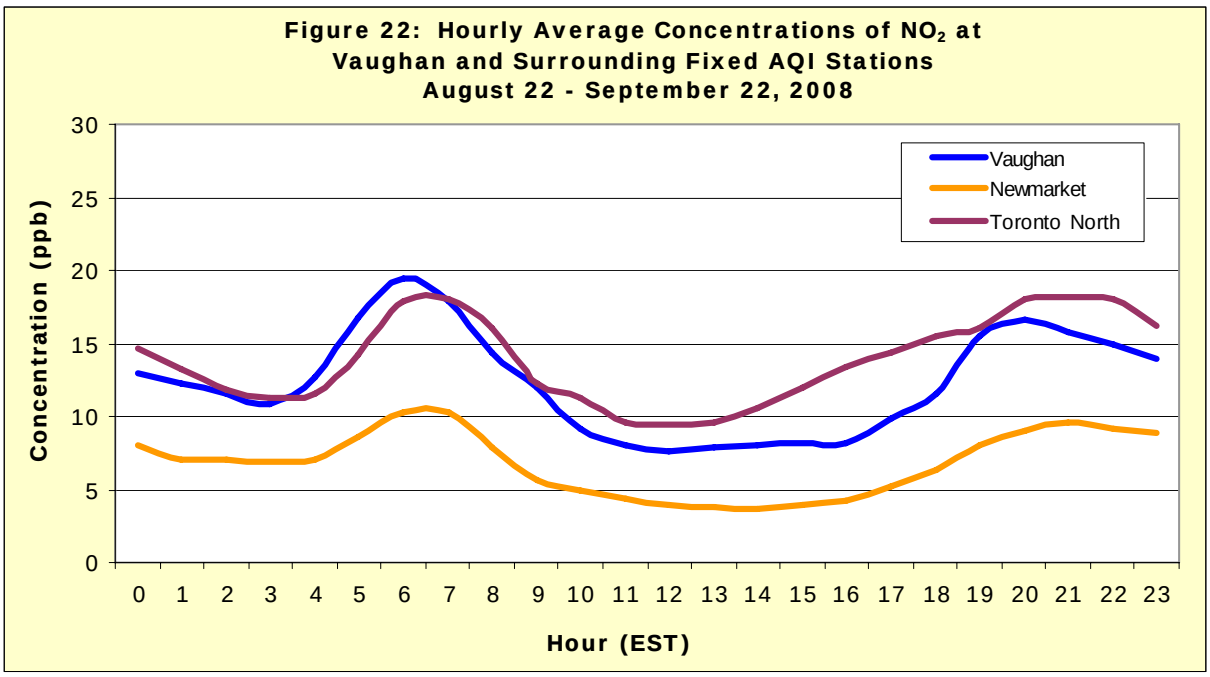






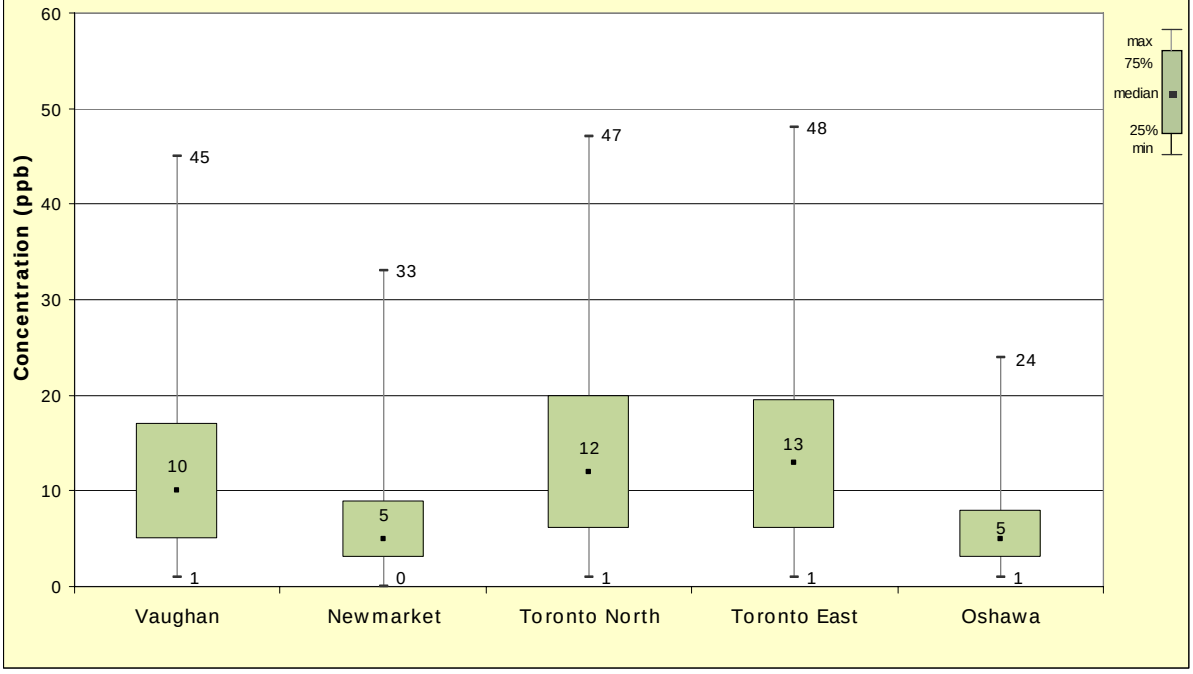


A high correlation was found between daily average NO_2 concentrations at Vaughan and Newmarket, and Vaughan and Toronto North. Both pairings have a correlation coefficient of 0.88. However, by examination of the slope of the regression lines it is noted that Vaughan and Toronto North have more of a direct comparison of values. The regression line between Vaughan and Toronto North is close to one, indicating similar values at similar times. The slope of the regression line between Vaughan and Newmarket is lower (0.44) indicating that although a similar variation in the data can be seen over time, the daily average NO_2 concentrations at Newmarket are, on average, lower than Vaughan. This is further shown in **Figure 22**, which displays a similar variation in the hourly average concentrations of NO_2 at Vaughan, Newmarket, and Toronto North, but the concentrations recorded at Newmarket are typically 5 ppb lower than levels recorded at Vaughan.



The box plots in **Figure 23** are summary statistics of the one-hour NO_2 concentrations measured at Vaughan and surrounding fixed AQI stations for August 22 – September 22. The one-hour AAQC of 200 ppb was not exceeded at any of the sites during the study period. Examination of the summary statistics show that one-hour NO_2 concentrations are higher at Vaughan than Newmarket. Values measured at Vaughan were similar to those measured at the Toronto North and Toronto East AQI sites.

Figure 23: Summary Statistics for One-Hour Nitrogen Dioxide Concentrations at Vaughan and Surrounding AQI Stations August 22 - September 22, 2008



Carbon Monoxide

CO concentrations were measured at the Vaughan study site from August 22 – September 22. The highest one-hour concentration measured at Vaughan was 0.42 ppm on September 3. The highest eight-hour concentration measured at Vaughan was 0.23 ppm on September 12. The Ontario AAQC for one-hour and eight-hour CO is 30 ppm and 13 ppm respectively. The maximum concentrations recorded during the study period were well below these levels.

Sulphur Dioxide

SO_2 concentrations were measured at Vaughan from August 22 - September 22. The highest one-hour SO_2 maximum concentration was 12 ppb, recorded on August 23 during the first day of a two-day smog advisory. The maximum concentrations recorded during this study period were well below the Ontario one-hour AAQC for SO_2 of 250 ppb.

3.0 AQI, AQHI, and SMOG EPISODES

This section examines the AQI and AQHI values recorded at the two study sites, Markham and Vaughan, and the surrounding fixed AQI stations located in Newmarket, Toronto North, Toronto East and Oshawa. Data were collected in Markham from July 23 to August 20, 2008 and Vaughan from August 22 to September 22, 2008. Smog episodes during the study periods are also discussed.

Ontario's AQI is based on six criteria pollutants that have adverse effects on human health and the environment (www.airqualityontario.com). The pollutants are: ozone, $PM_{2.5}$, NO_2, CO, SO_2, and total reduced sulphur (TRS) compounds. At the end of each hour, the concentration of each pollutant measured at each site is converted into a number ranging from zero upwards using a common scale or index. The calculated number for each pollutant is referred to as a sub-index. At a given site, the highest sub-index for any given hour becomes the AQI reading for that hour. The AQI is based on set air quality criteria, and typically ozone and $PM_{2.5}$ are the main pollutants that result in AQI values in the poor category.

The federal government (Environment Canada and Health Canada) has developed an AQHI for which pilot programs have been operational in Toronto since July 9, 2007, and the Greater Toronto Area since June 4, 2008. The index reports a "health risk" based on the cumulative risk associated with three criteria pollutants (ozone, NO_2, and $PM_{2.5}$). It utilizes a numbered scale between 1 and 10+, with 10+ being the greatest health risk. When the AQHI is calculated, a weighting factor is applied to each of the three associated pollutants, with the greatest emphasis on NO_2.

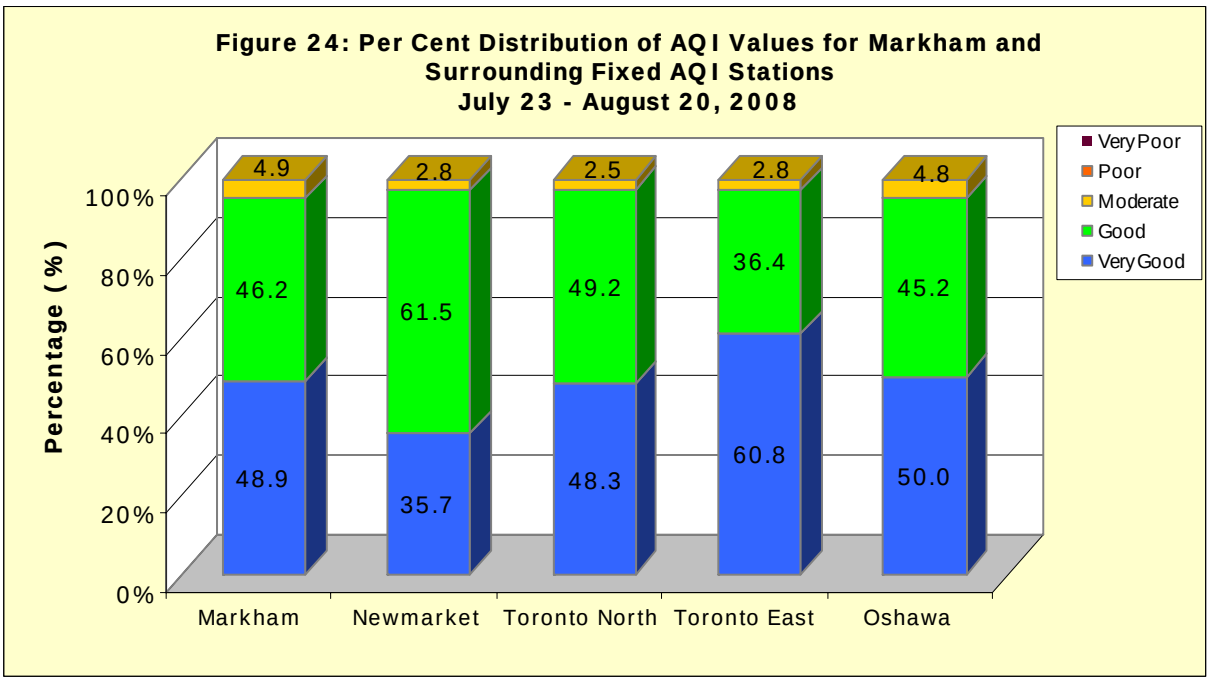
The Ontario Ministry of the Environment issues a Smog Advisory when widespread, elevated (AQI values greater than 49) and persistent smog (ozone and / or $PM_{2.5}$) levels are forecast to occur within the next 24 hours (www.airqualityontario.com), or if elevated smog conditions occur without warning and weather conditions conducive to elevated smog levels are forecast to continue for several hours.

MARKHAM STUDY PERIOD: JULY 23 – AUGUST 20, 2008

Air Quality Index

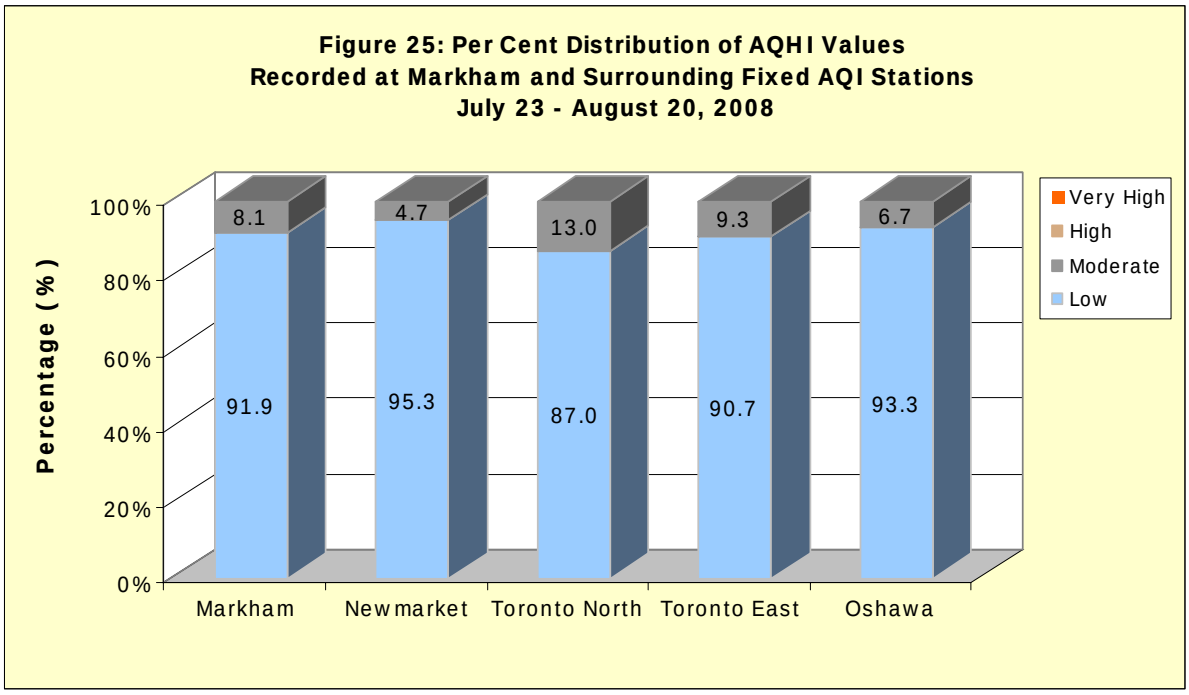
From July 23 to August 20, AQI values recorded at the Markham site ranged between very good to moderate. Approximately 49 per cent of the recorded AQI values were considered very good, 46 per cent good, and 5 per cent moderate. **Figure 24** displays the percentage of AQI values in each category recorded at Markham and surrounding fixed AQI stations. A similar distribution of values was observed at Markham, Toronto North, and Oshawa. Newmarket had the lowest percentage of AQI values within the very good range, approximately 13 per cent lower than Markham. Markham and Oshawa recorded the

highest percentage of moderate AQI values, 4.9 and 4.8 per cent, respectively, but was not significantly different from the other three sites. No poor (AQI 50 – 99) or very poor (AQI 100 and greater) values were recorded during the study period at any of the sites.



Air Quality Health Index

From July 23 to August 20, AQHI values recorded at the Markham site ranged between low and moderate health risk. **Figure 25** displays the percentage of AQHI values recorded at Markham and the surrounding fixed AQI stations in each category. Approximately 92 per cent of the AQHI values recorded at Markham were within the low risk category while the remaining 8 per cent of values fell within the moderate risk category. Similar distributions were observed at all of the surrounding sites. Toronto North recorded the highest percentage of moderate values, approximately 5 per cent higher than Markham. Variations of NO_2 between Markham and Newmarket did not result in significant variations between AQHI values. No values were recorded in the high risk category at any of the sites during the study period.



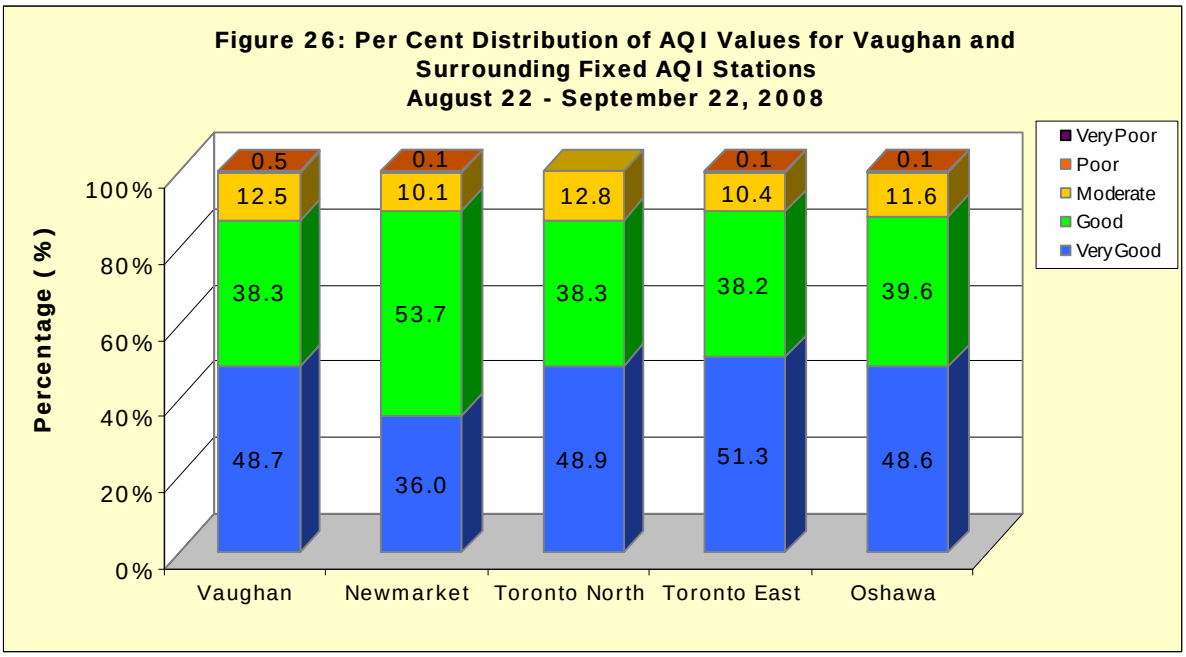
Smog Episodes

No smog advisories were issued for York Region during the study period of July 23 – August 20, 2008.

VAUGHAN STUDY PERIOD: AUGUST 22 – SEPTEMBER 22, 2008

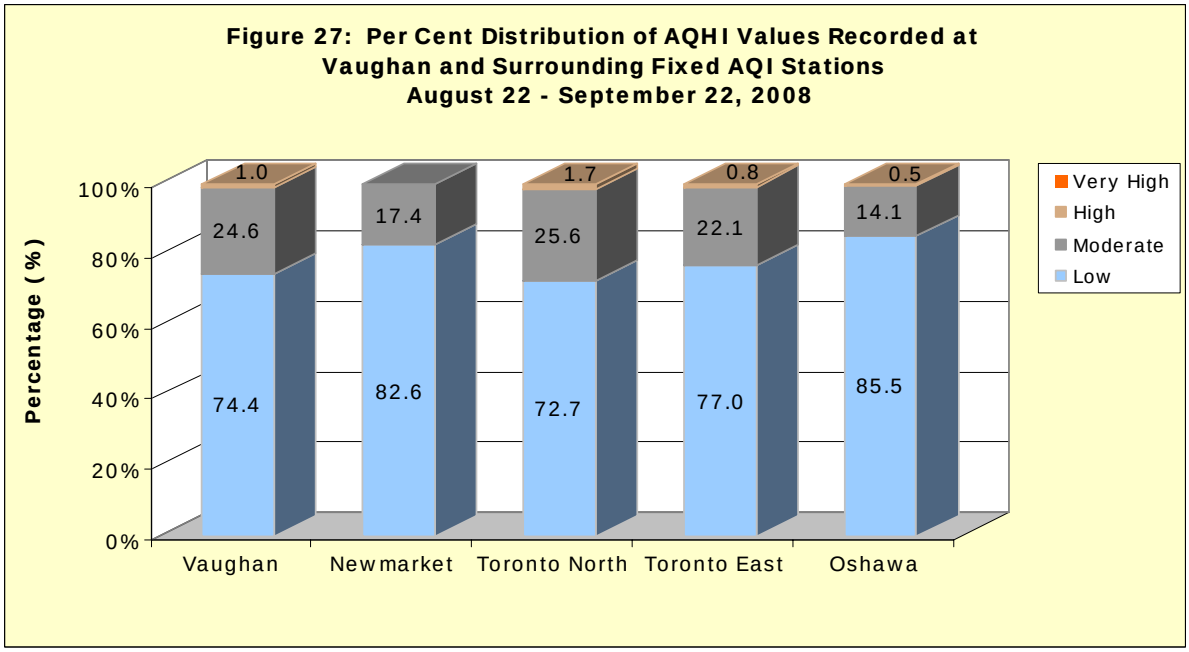
Air Quality Index

From August 22 to September 22, AQI values recorded in Vaughan ranged between very good to poor. Approximately 49 per cent of the values were considered very good, 38 per cent good, 12 per cent moderate and 0.5 per cent poor. **Figure 26** displays the percentage of AQI values in each category recorded at Vaughan and the surrounding fixed AQI stations. The greatest similarities were seen at Vaughan, Toronto North, Toronto East, and Oshawa. Newmarket recorded the lowest percentage of values in the very good category (36.0 per cent) and Toronto East recorded the highest (51.3 per cent). All stations except Toronto North recorded poor AQI values.



Air Quality Health Index

Between August 22 and September 22, the majority of AQHI values recorded at Vaughan were within the low to moderate risk categories. Approximately 74 per cent of the AQHI values recorded at Vaughan were in the low risk category, 25 per cent in the moderate risk category, and only 1 per cent of the values reached the high risk category. **Figure 27** displays the percentage of AQHI values recorded in each category at Vaughan and the surrounding fixed AQI stations.



Vaughan, Toronto North, and Toronto East have similar per cent distributions, while Newmarket and Oshawa share similar distributions. Newmarket was the only station not to reach the high risk category during the study period. High risk values of 7 were recorded at Vaughan on August 22 between 13:00 and 17:00 EST and August 23 at 15:00 EST, while Newmarket recorded an AQHI value of 6 during the same periods. All high risk AQHI values were recorded during smog advisories.

Stations located near high traffic areas generally observe greater concentrations of NO_2, and as a result report higher AQHI values than sites at a greater distance from major roadways. This suggests that the variability between AQHI values recorded at Vaughan and Newmarket are due to differences in land use surrounding the two sites. Vaughan was located in a primarily commercial area approximately 600 m east of the busy intersection of Jane and Rutherford and 1.5 km from Highway 400, whereas Newmarket is located in a primarily residential area and further north of Toronto.

Smog Episodes

During the study period, two smog advisories were issued for York Region, while the mobile PM Unit was stationed in Vaughan. The first advisory was of a two day duration, from August 22 - 23, and the second advisory lasted one day on September 3. Smog episode days here are defined as days with elevated ozone and/or fine particulate matter concentrations. Both smog advisories during the study period were due to elevated ozone concentrations.

Figure 28 displays 48-hour back trajectories of air parcels travelling into the study area at 13:00 Eastern Daylight Savings Time (EDT) on each of the episode days (August 22 – 23 and September 3). The back trajectories plotted for August 22 - 23 generally indicate a south to southwesterly air flow. Both air parcels travelled across major U.S. and Canadian cities with dominate sources of smog-causing pollutants, vehicles, heavy industry, and fossil-fuel power plants. On September 3, the back trajectory indicates a southwesterly wind flow originating in the Detroit area and travelling across Michigan and southwestern Ontario before reaching the study area. During both episode periods, trajectories show conditions conducive to the transport of pollutants from the south.

Figure 28: 48-Hour Back Trajectories at 500m Elevation Arriving in the Vicinity of Vaughan, Ontario at 13:00 EDT for Smog Episode Days occurring between June 23 – September 22, 2008

Note: The Hybrid-Single Particle Lagrangian Integrated Trajectory (HYSPLIT) model developed by the National Oceanic and Atmospheric Administration was used for this report.

Table 7 displays the daily maximum one-hour ozone concentrations and number of exceedance hours for each site on Smog Advisory days, August 22 - 23 and September 3, 2008. Examination of the daily maximum one-hour ozone concentrations indicate that variability in data measured at Vaughan and Newmarket during periods of elevated smog are similar.

Table 7: Daily Maximum One-Hour Ozone Concentrations and Number of Ozone Exceedances Recorded at Vaughan and Surrounding AQI Stations for Smog Advisory Days Issued During the Study Period

Site Location	August 22, 2008		August 23, 2008		September 3, 2008	
	Maximum 1h Ozone (ppb)	No. of Exceedances (hours)	Maximum 1h Ozone (ppb)	No. of Exceedances (hours)	Maximum 1h Ozone (ppb)	No. of Exceedances (hours)
Vaughan	76	0	85	4	75	0
Newmarket	73	0	82	2	72	0
Toronto North	68	0	74	0	69	0
Toronto East	82	1	73	0	72	0
Oshawa	76	0	73	0	82	1

Figures 29a and **29b** display the daily maximum AQI value for Vaughan and the surrounding fixed AQI stations for August 22 and 23. On August 22, Toronto East was the only station to reach the poor category with a maximum AQI value of 51. Vaughan, Newmarket and Oshawa reached the moderate category with maximum AQI values of 47, 45, and 47, respectively. On August 23, Vaughan and Newmarket recorded AQI values in the poor category. The Vaughan site reached the poor category from 13:00 to 16:00 EST and the highest maximum AQI value recorded was 53. Newmarket reached the poor category with a value of 51 at 14:00 EST. From examination of these figures; it is evident that Vaughan and Newmarket were uniformly affected by the transport of pollutants into the area during the smog advisory of August 22 – 23. On September 3, Oshawa was the only station to reach the poor AQI category, with a value of 51, while the other stations recorded AQI values ranging from 43 to 46.

Figure 29a: Daily Maximum AQI Value Recorded at Vaughan and Surrounding Fixed AQI Stations on August 22, 2008

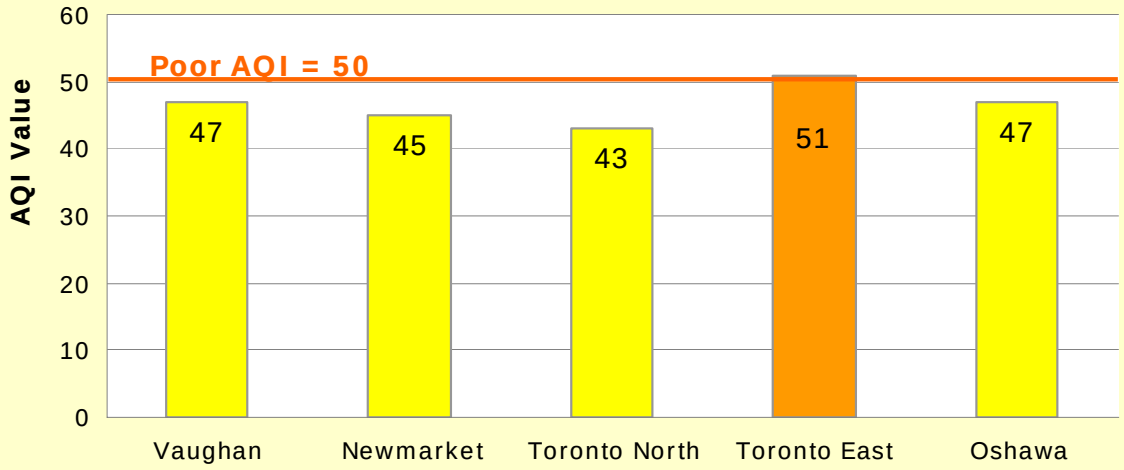
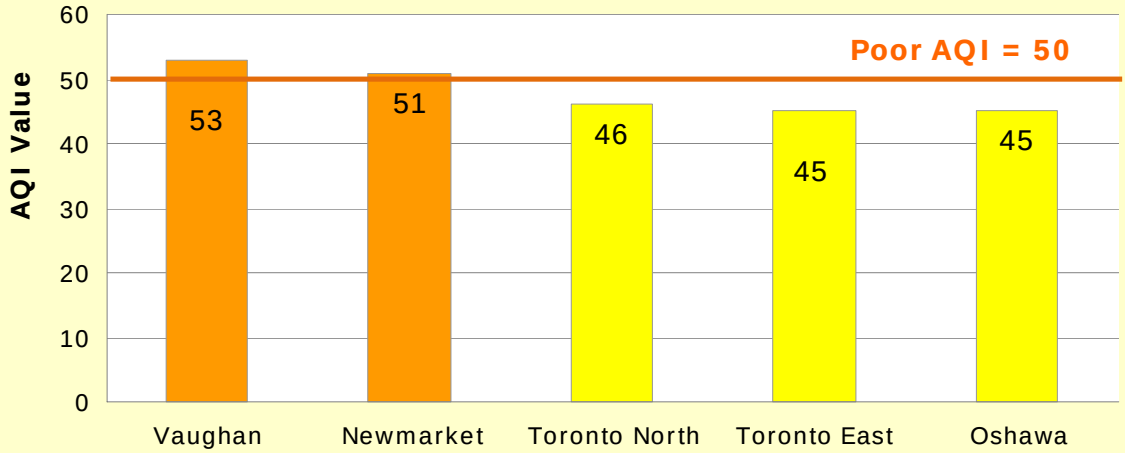


Figure 29b: Daily Maximum AQI Value Recorded at Vaughan and Surrounding Fixed AQI Stations on August 23, 2008



4.0 CONCLUSION:

The purpose of the York Region Study, conducted by the Ontario Ministry of the Environment, was to determine if the existing ministry AQI station located in Newmarket is representative of the heavily populated areas of southern York Region. The study commenced in the Town of Markham (July 23, 2008 to August 20, 2008), and concluded in the City of Vaughan (August 22 to September 22, 2008). Measurements collected from the study sites via the ministry's mobile PM Unit were compared to surrounding fixed AQI stations – Newmarket, Toronto North, Toronto East and Oshawa.

The Ontario AAQC for one-hour ozone was not exceeded at any of the sites during the Markham study period. However, the ozone criterion was exceeded during two smog episodes, August 22 - 23, 2008 and September 3, 2008 which took place within the Vaughan study period. The ozone criterion was exceeded for one hour at the Toronto East station on August 22, 2008, and for two hours at Newmarket and four hours at the Vaughan study site on August 23, 2008. Oshawa was the only site to exceed the ozone criterion during the smog episode on September 3, 2008. Generally, there are no statistically significant differences between the daily one-hour ozone maximum concentrations recorded at both study sites, Markham and Vaughan, compared to the surrounding fixed AQI stations.

The daily $PM_{2.5}$ concentrations did not exceed the 24-hour provincial reference level during the York Region Study; and the hourly NO_2, CO and SO_2 concentrations recorded in Markham and Vaughan were far below their provincial AAQC.

There was a similar distribution of AQI and AQHI values at all of the sites examined during the York Region Study. With the exception of the poor AQI and high risk AQHI values recorded during the smog episodes, the majority of the AQI and AQHI readings were within the very good to moderate AQI range and low to moderate risk AQHI categories.

Overall, the study, which took place in the Town of Markham and the City of Vaughan, concludes that measurements from the surrounding fixed AQI stations at Newmarket and Toronto North provide adequate representation of regional pollutants (ozone and $PM_{2.5}$) in the areas of southern York Region. However, for traffic-related pollutants, such as NO_2, concentrations in Markham and Vaughan were more comparable to those recorded at Toronto North.

Appendix A – Mobile Air Monitoring Equipment / Instrumentation

The mobile Particulate Matter Unit (PM Unit) is a 10-metre "Orion" coach vehicle equipped with a 17.5-kilowatt generator, a 10-metre telescopic meteorological tower for wind speed, wind direction and ambient temperature, and a wide variety of analyzers for monitoring ambient air pollutants.

This unit serves the Ministry's purposes in conducting regional air quality characterization surveys. It is capable of unattended operation and collection of data 24 hours per day, 7 days a week.

Table A1: Instrumentation Used Aboard the Particulate Matter Unit

Instrument	Pollutants Measured	Operation / Details
Chemiluminescence NO-NO_2-NO_x Analyzer (Thermo Model 42C)	Ambient NO, NO_2, NO_x 0 to 1000 ppb	Nitric Oxide (NO) reacts with ozone (O_3) to produce a characteristic luminescence with intensity linearly proportional to the NO concentration. Infrared light emissions results when electronically excited NO_2 molecules decay to lower energy states. $NO + O_3 \rightarrow NO_2 + O_2 + hv$ To measure NO_x ($NO + NO_2$), NO_2 is converted to NO.
Trace Level Pulsed Fluorescence SO_2 Analyzer (Thermo Model 43C-TL)	Ambient SO_2 0 to 100 ppb	Sulphur Dioxide (SO_2) molecules absorb ultraviolet (UV) light and become excited at one wavelength, then decay to a lower energy state emitting UV light at a different wavelength proportional to the SO_2 concentration. $SO_2 + hv_1 \rightarrow SO_2^* \rightarrow SO_2 + hv_2$
Trace Level CO Analyzer (Thermo Model 48C-TL)	Ambient CO 0 to 50 ppm	Carbon Monoxide (CO) absorbs infrared radiation at a wavelength of 4.6 microns. Since infrared absorption is a non-linear measurement technique, it is necessary for the instrument to transform the basic analyzer signal into a linear output.
Photometric Ozone Analyzer (Thermo Model 49C)	Ambient O_3 0 to 500 ppb	Ozone (O_3) molecules absorb UV light at a wavelength of 254 nm. The amount of UV light that is absorbed (intensity) is directly proportional to the ozone concentration.
TEOM Ambient $PM_{2.5}$ Monitor (R&P Model 1400AB with Sample Equilibration System)	Fine Particulate Matter ($PM_{2.5}$) 0 – 200 µg/m^3	$PM_{2.5}$ is measured gravimetrically by drawing ambient air through a Sample Equilibration System to a filter at a constant flow rate, continuously weighing the filter and calculating near real-time (10 minute) mass concentrations. The mass transducer (Tapered Element Oscillating Microbalance) detects the difference between the filter's current weight and the filter's initial weight giving the total mass of the collected particulate.

Appendix B – Meteorological Conditions Observed in York Region for July 23 – August 20 and August 22 – September 22, 2008

Table B1: Meteorological Conditions Observed at Toronto Buttonville Municipal Airport for July 23 – August 20, 2008

Date	Sky Conditions	Max Temp (°C)	Min Temp (°C)	Amount of Precipitation (mm)	Average Wind Direction & Speed (km/h)
July 23	Mostly Cloudy with Showers	17	19.3	15.4	NE - NNW / 12
July 24	Mostly Cloudy with Showers	26.2	16.2	2.9	W / 13
July 25	Mainly Clear	28.9	14.1	0.0	WSW / 11
July 26	Partly Cloudy with Showers	27.5	17.9	2.6	WSW / 11
July 27	Partly Cloudy	27.3	15.7	0.8	WSW / 12
July 28	Partly Cloudy	27.9	15	0.0	NW / 11
July 29	Mostly Cloudy	27.7	15	0.0	NNW - N - S / 8
July 30	Mostly Cloudy with Showers	26.5	17.8	10.4	E-S-SW / 9
July 31	Partly Cloudy	27.5	17.5	0.0	WNW / 10
August 1	Partly Cloudy	28.2	16.6	0.0	WNW / 10
August 2	Mostly Cloudy with Showers	25.8	16.9	3.0	NW / 13
August 3	Mainly Clear	25.5	16.2	0.0	NNW / 15
August 4	Partly Cloudy	27.2	15.1	0.0	N-W-S-E / 6
August 5	Mostly Cloudy with Showers	26.8	16.7	9.4	N - SE - WSW / 8
August 6	Partly Cloudy	28.2	17.1	0.0	NW / 15
August 7	Mostly Cloudy with Showers	24.8	15.9	1.4	W / 11
August 8	Mostly Cloudy with Showers	22.6	14.8	0.9	NW / 18
August 9	Partly Cloudy with Rain	22.7	11.6	26.5	SW / 7
August 10	Mostly Cloudy with Showers	17	11.3	4.2	S - WSW-E-NNW / 6
August 11	Partly Cloudy	24.5	13.1	0.0	NNW - NNE / 14
August 12	Partly Cloudy	24.6	13.9	0.0	NW - N / 11
August 13	Mostly Cloudy with Showers	21.9	13.5	0.6	South - North / 6
August 14	Partly Cloudy	23.6	12.4	0.0	NNW - N - SE - NW / 6.5
August 15	Partly Cloudy	24.3	13	Trace	W - N - S - NNW / 9
August 16	Partly Cloudy	26.3	13.7	0.0	W - NNW / 10
August 17	Mostly Cloudy	27.4	16.7	Trace	NW - S / 8
August 18	Mostly Cloudy with Showers	31	15.7	8.8	SSW - NW / 15
August 19	Mainly Clear	20.2	11.5	0.0	NE - NNW / 14
August 20	Mainly Clear	22.3	9.8	0.0	NNW - S / 5

Table B2: Meteorological Conditions Observed at Toronto Buttonville Municipal Airport for August 22 – September 22, 2008

Date	Sky Conditions	Max Temp (°C)	Min Temp (°C)	Amount of Precipitation (mm)	Average Wind Direction & Speed (km/h)
August 22	Mostly Cloudy	28.5	14.1	0	N - SSE / 8
August 23	Partly Cloudy	27.9	14.9	0	N - S / 8
August 24	Partly Cloudy	29.1	15.5	T	S - NNW / 10
August 25	Mainly Clear	20.6	12.4	0	NW / 16
August 26	Mainly Clear	24	8.9	0	N - E / 7
August 27	Mostly Cloudy	23.5	9.1	0	N - E / 10
August 28	Mostly Cloudy with Drizzle	23.7	15.6	2.2	ESE / 13
August 29	Mostly Cloudy with Rain	25.9	16.3	13.6	ESE - WSW / 6
August 30	Clear	27.2	14.3	0	NNW / 11
August 31	Mainly Clear	27.7	12.6	0	N - SSE / 4
September 1	Mainly Clear	27.2	12.4	0	N - S / 4
September 2	Partly Cloudy	28	11.6	0	N - S / 5
September 3	Partly Cloudy	31.4	12.4	0.2	WNW /7
September 4	Mostly Cloudy	26.4	16.8	0	NNW - ESE / 10
September 5	Mostly Cloudy	26.5	16.6	0.4	ESE - NNW / 17
September 6	Partly Cloudy with Rain	21.2	11.3	13.2	NW / 11
September 7	Mostly Cloudy with Rain	18.1	10	8.7	SW / 4
September 8	Mostly Cloudy with Rain	23.3	10.6	7.8	WSW - NW / 8
September 9	Mostly Cloudy with Rain	19.7	9.3	13.2	NW / 11
September 10	Mainly Clear	18.5	6.1	0	N - SSE / 7
September 11	Partly Cloudy	19.5	6.5	0	N - SE / 10
September 12	Cloudy with Fog	24.9	13.3	0.4	N - WSW / 7
September 13	Cloudy with Rain	22.3	17.9	26	N / 7
September 14	Cloudy with Rain	28.9	15.6	16.8	SW / 16
September 15	Mostly Cloudy with Rain	15.7	7.4	0.4	NW / 19
September 16	Partly Cloudy	19.4	5.6	0	W / 6
September 17	Clear	24.1	8.1	0	W / 11
September 18	Partly Cloudy	18.4	7.2	0	N - SE / 8
September 19	Partly Cloudy	18.2	5.8	0	N - SE / 7
September 20	Partly Cloudy	26.1	8.5	0	N - SW / 7
September 21	Partly Cloudy	18.4	7.9	0	N - E / 8
September 22	Mainly Clear	19	6.8	0	N - ESE / 5