One-Hour Equivalent of a 24-Hour Average Particulate Matter Standard and its Potential Application in the Index of the Quality of the Air (IQUA)

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ABSTRACT

The Alberta Index of the Quality of the Air (IQUA) is part of Alberta's air quality management system. The IQUA provides a qualitative description of air quality based on hourly concentrations of five major air quality parameters (CO, O_3, NO_X, SO_2, and coefficient of haze (COH)).

The purpose of this paper is to explore the option of incorporating a $PM_{2.5}$ standard into the Alberta IQUA. When a new parameter is incorporated into the IQUA, the resulting index should reflect the relevant air quality guidelines and standards, provide the public with a clear picture of the air quality, and retain the integrity of the IQUA. These issues are addressed in this paper via a three-part analysis. First, a one-hour equivalent of the 24-hour $PM_{2.5}$ Canada Wide Standard is identified. Second, an assessment of hypothetical exposure is performed. Finally, the potential application of a one-hour $PM_{2.5}$ concentration in the IQUA is discussed.

In the first part, daily maximum and daily average $PM_{2.5}$ data from monitors located at two locations in Alberta were used to derive the relationship between one-hour (x) and 24-hour average (y) $PM_{2.5}$ levels. The relationship was determined as $y = ax^b$, where a and b are location-specific parameters. Using this relationship, a one-hour concentration of 80 $\mu g/m^3$ was determined to be equivalent to the 24-hour CWS of 30 $\mu g/m^3$.

In the second step, the one-hour $PM_{2.5}$ concentrations of 80 $\mu g/m^3$ and 40 $\mu g/m^3$ were used as breakpoint concentrations in a hypothetical hourly exposure analysis. This analysis showed that the one-hour breakpoints could be effectively used to assist an individual in making a decision about their air quality exposure. A 24-hour $PM_{2.5}$ concentration of 18 $\mu g/m^3$ was used as a breakpoint to analyze daily exposure. This analysis showed some differences between the one-hour and 24-hour breakpoints.

Finally, an analysis was performed to determine the implications to Alberta's IQUA. Incorporating $PM_{2.5}$ into the IQUA decreased the percentage of time air quality was in the ***Good*** category from 93.6% to 90.5% in 1998 at the Edmonton Northwest station and from 99.5% to 98.1% in 1998 at the Calgary Central station. Corresponding increases in the frequency of ***Fair***

and ***Poor*** air quality are noted at these monitoring stations, when $PM_{2.5}$ is incorporated into the IQUA.

INTRODUCTION

Alberta's Index of the Quality of the Air

The Alberta Index of the Quality of the Air (IQUA) is part of Alberta's air quality management system. Developed in the late 1970's by a federal-provincial committee (Environment Canada, 1980), the IQUA provides a qualitative description of air quality based on concentrations of five major air quality parameters. Hourly concentrations of carbon monoxide, nitrogen dioxide, ozone, sulphur dioxide and the coefficient of haze (also referred to as dust and smoke) are incorporated into the IQUA using formulae based on breakpoint concentrations indicated in Table 1.

The IQUA is calculated every hour for each air quality parameter and converted to a single number, which corresponds to a description of the air quality. The parameter with the highest IQUA value for a specific hour is used as the recorded IQUA reading for that hour. An IQUA number of one to 25 indicates ***Good*** air quality; 26 to 50 is ***Fair*** air quality; 51 to 100 is ***Poor*** air quality; and a number greater than 100 indicates ***Very Poor*** air quality. For example, an index reading of 30 (***Fair***) for two individual pollutants indicates the same degree of environmental impact for each individual pollutant. The specific effects themselves, however, will vary according to the pollutant. Table 2 gives the definition for each IQUA category.

The IQUA is calculated and issued hourly by Alberta Environment for the cities of Edmonton and Calgary. The monitoring stations are automatically polled every hour and the data is loaded into a voice-based database for telephone access. Nearly 5000 phone calls are made to the automated IQUA reporting system per year in Alberta. The current air quality index is available by phoning (780) 427-7273 in Edmonton and (403) 250-2099 in Calgary.

The Need for a One-Hour Equivalent $PM_{2.5}$ Concentration

Recent evidence has shown an association between particulate matter (PM) and human health effects (Health Canada, 1999). In November 1999, CCME Ministers accepted in principle a CWS for particulate matter with an aerodynamic diameter less than 2.5 micrometres ($PM_{2.5}$). The CWS for $PM_{2.5}$, which was accepted in principle, is 30 $\mu g/m^3$, averaged over 24 hours. The Standard is to be achieved by 2010, based on the 98^{th} percentile ambient measurement annually, averaged over 3 consecutive years (CCME, 1999).

Once CCME Ministers endorse the CWS for $PM_{2.5}$, the Standard will be incorporated into Alberta's air quality management system. The $PM_{2.5}$ CWS could potentially be incorporated in to Alberta's IQUA, but more analysis needs to be done before this decision can be made. The purpose of this paper is to explore the option of incorporating a $PM_{2.5}$ standard into the IQUA.

In order for $PM_{2.5}$ to be incorporated into the IQUA, at least two issues need to be addressed. The primary issue is the averaging time of the CWS. The $PM_{2.5}$ CWS is a 24-hour average concentration. In order to incorporate $PM_{2.5}$ into IQUA, a one-hour equivalent $PM_{2.5}$ concentration must be identified. A second issue to be addressed is the use of the coefficient of haze (COH) in the IQUA. The current IQUA uses COH as an indicator for PM. This parameter would have to be replaced if $PM_{2.5}$ was to be incorporated into the Index. This issue has been raised previously, as COH has not adequately described PM levels during some ambient conditions. For example, in May and August of 1998, smoke from forest fires burning in northern Alberta was transported into the cities of Edmonton and Calgary causing $PM_{2.5}$ levels over 400 $\mu g/m^3$ (micrograms per cubic metre) as a one-hour average. ***Good*** and ***Fair*** air quality was reported by the IQUA during these forest fire smoke events. These events have highlighted the need for a particulate matter indicator other than the coefficient of haze in the IQUA.

The Use of Particulate Measurements in the IQUA for Other Jurisdictions

Currently, no jurisdictions in Canada use one-hour concentrations of PM_{10} or $PM_{2.5}$ in their respective air quality indices. Some Canadian jurisdictions use 24-hour rolling average particulate measurements from continuous monitoring instruments. Indices in the City of Montreal, British Columbia and the Greater Vancouver Regional District make use of continuous PM_{10} data from the TEOM (Tapered Element Oscillation Micro-balance) monitor. These jurisdictions use a direct linear relationship between the 24-hour rolling average concentration and the air quality index value. For example, a 24-hour rolling average PM_{10} concentration of 25 $\mu g/m^3$ corresponds to an index number of 25, and a 24-hour rolling average PM_{10} of 50 $\mu g/m^3$ has a corresponding index value of 50. Therefore, 25 $\mu g/m^3$ is the breakpoint between ***Good*** and ***Fair*** air quality and 50 $\mu g/m^3$ is the breakpoint between ***Fair*** and ***Poor*** air quality based on the 24-hour rolling PM_{10} concentration in these three jurisdictions (Personal Communication with Environment Canada, 2000).

Montreal also uses $PM_{2.5}$ in their index. The 24-hour rolling average $PM_{2.5}$ concentration of 25 $\mu g/m^3$ is used as the breakpoint between ***Fair*** and ***Poor*** air quality. Table 3 summarizes the air quality indices from jurisdictions across Canada.

ANALYSIS METHODOLOGY AND ASSUMPTIONS

When a new parameter is incorporated into the IQUA, the resulting index should reflect the relevant air quality guidelines and standards, provide the public with a clear picture of the air quality, and retain the integrity of the IQUA. Corresponding to these issues, there are three parts to this analysis: (1) the determination of a relationship between the one-hour and 24-hour $PM_{2.5}$ concentrations; (2) an assessment of the effectiveness of one-hour and 24-hour $PM_{2.5}$ breakpoints (an assessment of hypothetical exposure); and (3) the impact of the new parameter – $PM_{2.5}$ on Alberta's IQUA.

Relationship Between One-hour and 24-hour $PM_{2.5}$ Concentrations

To establish a relationship between daily and hourly PM levels, the daily maximum, the second highest, or the third highest could be used to correlate with the daily average. This study uses the daily maximum to derive the relationship based on the following considerations.

1. The selected hourly level should be representative of the levels as a whole during the day.
2. The hourly level selected should relate to the daily average in a way that clearly reflects the basis of the standard (i.e., human health considerations).
3. The IQUA should assist the public in avoiding exposures to the predetermined PM levels (indoor air quality is not considered here).
4. It is assumed that within a certain geographic location, exposures to the same hourly PM level would have similar health impacts regardless whether the daily averages are high or low (above or below the standard).
5. The IQUA should accurately reflect the quality of the air. The level of exposure to be avoided should be determined by the individual who will use the index.

Approximately two years of $PM_{2.5}$ monitoring data from Edmonton and Calgary were used. The daily mean and daily maximum $PM_{2.5}$ levels were calculated, and a regression analysis was performed between these two variables. The regression equation was used to determine a one-hour equivalent of the 24-hour $PM_{2.5}$ CWS. This one-hour equivalent was used as the breakpoint level between ***Fair*** and ***Poor*** air quality. The breakpoint level between ***Good*** and ***Fair*** air quality was selected in accordance with the current practices in other Canadian jurisdictions (BC, 2000) and was validated with the correlation between the COH and $PM_{2.5}$ levels in Edmonton and Calgary. A breakpoint between ***Poor*** and ***Very Poor*** air quality was not chosen as more data is required to determine an appropriate $PM_{2.5}$ one-hour concentration.

$PM_{2.5}$ Hypothetical Exposure Assessment

Following the establishment of a relationship between one- and 24-hour $PM_{2.5}$ data, an analysis of hypothetical exposure was performed. The purpose of such an analysis was to assess the effectiveness of the new parameter in assisting the public to avoid exposures over certain pre-determined $PM_{2.5}$ levels. Comprehensive exposure assessment on urban residents in Alberta has been carried out before by using the pNEM model developed by the US EPA (Fu, 1998). Due to the lack of indoor PM exposure data, a relatively simple exposure assessment was used to evaluate the effectiveness of the hourly $PM_{2.5}$ value in preventing exposure to the breakpoint levels.

For an urban resident living in Edmonton or Calgary, random numbers were generated to determine the time of a hypothetical call to the IQUA between the hours of 6 a.m. and 8 p.m. each day. At the time of the call, a "decision" was made based on the predetermined breakpoint levels. The two hours of data following the call were analyzed to determine if the decision to stay indoors, or to go outdoors, was correct in avoiding a pre-determined exposure level. For example, if the call was placed at 5 p.m. and the $PM_{2.5}$ level was above 40 $\mu g/m^3$ (pre-determined exposure level to be avoided), the caller would remain indoors. If the $PM_{2.5}$ level was below 40 $\mu g/m^3$, the caller would go outside for the next two hours. The goal of the caller is to avoid exposure to a predetermined $PM_{2.5}$ level by staying indoors, while maximizing the opportunity to enjoy good air quality by going outdoors when $PM_{2.5}$ levels are below the pre-determined level. For the purpose of this analysis, the term ***Good*** air quality is used to indicate levels below the predetermined $PM_{2.5}$ level, and ***Fair*** air quality is used to indicate levels above the breakpoint concentrations.

The number of hours spent outside and inside was evaluated for levels above and below the pre-determined exposure level. The following assumptions were used in this simulation:

1. the person was not under any time restraints, and can go outside at anytime of the day;
2. the time of the call was between 6 a.m. and 8 p.m., therefore exposure could occur from 7 a.m. to 10 p.m.;
3. the person made one call per day (it is recognized that a person might make additional calls if the first call resulted in a decision to stay indoors, however, more than one call is not addressed by this analysis); and
4. the error in prediction from the breakpoints can be expressed as the percentage of time a person stayed indoors when ambient PM levels are below the pre-determined exposure levels, or the percentage of time a person went outdoors when ambient PM levels are above the pre-determined exposure levels.

Two trials were conducted for each location using different sets of random numbers. It is anticipated that each set of random numbers will give a different set of results. More simulations may be needed to determine the stability of the results.

Following the hourly hypothetical exposure analysis, a second analysis was performed to compare the one-hour and 24-hour breakpoints. In this second analysis, the daily average concentrations of all "outdoor" and "indoor" scenarios were compared to the CWS level and to another pre-determined PM exposure level. For example, if a call to the IQUA was made on March 5 and the PM level was less than 40 µg/m^3 (one-hour average), March 5 is categorized as an "Outdoor" day. The concentration for March 5 was then compared to the CWS and to another 24-hour breakpoint. Using the relationship between daily and hourly $PM_{2.5}$ levels established in the first part of the analysis, the 24-hour breakpoint was determined to be 18 µg/m^3, which is the equivalent of the hourly $PM_{2.5}$ level of 40µg/m^3. This analysis assumes that the daily average $PM_{2.5}$ level represents the exposure for that day.

The Impact of $PM_{2.5}$ Breakpoints on the Alberta IQUA

In order to investigate the potential effects of incorporating a $PM_{2.5}$ standard into the Alberta IQUA, an impact analysis is carried out to provide an evaluation on this aspect. Using ambient data from Edmonton and Calgary, two sets of IQUA data were calculated with and without the application of the new $PM_{2.5}$ parameter. The impact of the new parameter is represented by the percentage change of each air quality category. The $PM_{2.5}$ levels used used as the breakpoints between ***Good***, ***Fair*** and ***Poor*** air quality are indicated in Table 4.

RESULTS AND DISCUSSION

Relationship Between One-Hour and 24-Hour $PM_{2.5}$ Concentrations

Based on the power line of best fit, the relationship between the one-hour daily maximum and 24-hour daily average $PM_{2.5}$ levels can be expressed by:

$$y = ax^b \quad (1)$$

where

y = daily mean $PM_{2.5}$ concentration
x = daily max $PM_{2.5}$ concentration
a = location specific constant
b = location specific constant.

Figure 1 and 2 depict the scatter plots and trend lines used to establish these relationships for Edmonton and Calgary. The resulting equations are:

$$y = 1.06x^{0.761} \text{ for the Edmonton Northwest station; and} \quad (2)$$

$$y = 1.06x^{0.769} \text{ for the Calgary Central station.} \quad (3)$$

A one-hour equivalent concentration of the 24-hour Canada-Wide Standard (30 µg/m^3) was calculated for the Edmonton Northwest monitoring station and the Calgary Central monitoring station using Equations 2 and 3, respectively. Based on these results, a one-hour equivalent $PM_{2.5}$ concentration of 80 μg/m^3 was selected as the breakpoint concentration between ***Fair*** and ***Poor*** air quality for calculating the IQUA from $PM_{2.5}$.

To determine the breakpoint concentration between ***Good*** and ***Fair*** air quality, the following information was considered: (1) the practices of other jurisdictions in choosing a breakpoint between ***Good*** and ***Fair*** air quality; and (2) the breakpoint between ***Good*** and ***Fair*** air quality based on the COH (the parameter which $PM_{2.5}$ would most likely replace in the IQUA).

In other jurisdictions, the breakpoint between ***Good*** and ***Fair*** air quality has been chosen as half of the number for the breakpoint between ***Fair*** and ***Poor*** air quality. Using this method, the breakpoint between ***Good*** and ***Fair*** air quality would be half of 80 μg/m^3, or 40 μg/m^3.

A COH concentration of 2.0 COH units is used in the current IQUA as the breakpoint between ***Good*** and ***Fair*** air quality (Table 2). A brief analysis was performed indicating that 2.0 COH units is approximately equivalent to 40 μg/m^3. Figure 8 and 9 show the relationship between COH and $PM_{2.5}$ at Edmonton and Calgary, respectively. (This analysis did not include COH values greater than 2.0.)

Based on these considerations, a one-hour concentration of 40 μg/m^3 was selected as the breakpoint between ***Good*** and ***Fair***. The 24-hour equivalent value of 40μg/m^3 was also established to compare the hourly and daily breakpoint values. Using the relationship between daily and hourly $PM_{2.5}$ levels established in the first part of the analysis, the 24-hour breakpoint was determined to be 18 μg/m^3. These breakpoints are estimates, and more analysis needs to be done to assess the uncertainty associated with each of the estimates.

$PM_{2.5}$ Hypothetical Exposure Assessment

The two hours following a hypothetical call to the IQUA were evaluated. In approximately two years of data, there were 29 hours above 80 μg/m^3 at the Edmonton Northwest station, and 24 hours above 80 μg/m^3 at Calgary Central station. Based on these numbers, the hypothetical exposure to ***Poor*** air quality was minimal, and the following analysis focuses on potential exposure to ***Fair*** air quality.

Table 5 lists the following information: (1) number of hours classified as "Outdoor" and "Indoor" in Edmonton and Calgary based on the one-hour $PM_{2.5}$ concentration of 40 μg/m^3; (2) the number of hours a hypothetical caller would be exposed to ***Fair*** air quality; and (3) the number of hours a hypothetical caller would miss the chance to enjoy ***Good*** air quality.

In the first random sampling of Edmonton data, 1.0% of hourly data on “Outdoor” days fell above the breakpoint of 40 μg/m^3. On days classified as “Indoor”, it was found that 52.1% of the hourly data was below the same breakpoint. This means that when the one-hour breakpoint was used as an indicator, the person may have been exposed to ***Fair*** air quality for 12 hours in approximately two years, and may have missed the chance to enjoy ***Good*** air quality 12 hours in two years. Consistent with the first trial, hourly data for the second trial showed an error of 1.6% on “Outdoor” days and 50.0% on “Indoor” days. As an example of the distribution of $PM_{2.5}$ data, Figure 3 presents the distribution of hourly data for "Outdoor" days at Edmonton for Trial 1. Figure 4 shows the distribution of hourly data for "Indoor" days at Edmonton for Trial 1.

The first random data trial for the Calgary station showed 0.9% of the hourly data on “Outdoor” days above the hourly limit of 40 μg/m^3. The analysis of this first trial revealed 50.0% of hourly values on “Indoor” days as being below the breakpoint. On days spent outdoors in the second trial, 0.5% of hourly data lay above the breakpoint of 40 μg/m^3. On "Indoor" days, 38.9% of data fell below the breakpoint.

This data may indicate an "over protection" by the breakpoint, as the caller was directed to remain indoors more often than necessary to avoid exposures to hourly $PM_{2.5}$ levels above 40 ug/m^3. However, these results are calculated assuming the person makes one call per day. It is anticipated that if the person were allowed to make two calls on an" Indoor" day, with the second call following the first, the percentage of time that ***Good*** air quality was missed would decrease.

In general, the breakpoint can be effectively used to assist an individual in making a choice about their air quality exposure. Assuming that outdoor exposure to ***Fair*** (above the breakpoint) air quality is undesired, and that exposure to ***Good*** (below the breakpoint) air quality is desired, an individual can use the breakpoint $PM_{2.5}$ level to avoid undesired air quality about 99% of the time (average of Trial #1 and #2 for Edmonton and Calgary). The hypothetical caller may miss some opportunities of enjoying ***Good*** (below the breakpoint) air quality outdoors. However, this could be reduced by a second call on the "indoor" days.

The next part of the hypothetical exposure analysis focussed on the daily averages, to evaluate the effectiveness of a daily average indicator compared to the hourly indicator. The same classification of "Indoor" and "Outdoor" days as used in the hourly analysis was used in the daily analysis. In the first Edmonton trial, daily averages for "Outdoor" days were greater than or equal to the breakpoint of 18 $\mu g/m^3$ in 19.1% of the days. Where "Indoor" days were predicted, 0.0% of daily averages were below the breakpoint. In the second trial, 19.2% of "Outdoor" days were above the breakpoint of 18 $\mu g/m^3$, and 0.0% were below, which is consistent with the first trial. Table 6 shows the number of days that the 24-hour average was a poor indicator of exposure for Edmonton and Calgary.

In the first trial with data from the Calgary station, "Outdoor" data revealed 10.1% of daily averages above 18 $\mu g/m^3$, and 0.0% of "Indoor" data below. While 10.4% of data from the second trial exceeded the breakpoint on "Outdoor" days, 0.0% of "Indoor" data fell below the breakpoint.

As an example of the distribution of daily $PM_{2.5}$ data, Figure 5 presents the distribution of daily data for "Outdoor" days at Edmonton for Trial 1. Figure 6 shows the distribution of daily data for "Indoor" days at Edmonton for Trial 1.

These results show that while a one-hour breakpoint can assist the public in avoiding undesirable PM exposure, there are measurable differences between the one-hour and 24-hour breakpoints.

The Impact of $PM_{2.5}$ on the Alberta IQUA

Based on the IQUA calculations, the impact of the one-hour $PM_{2.5}$ concentration on the IQUA is evident from the Edmonton Northwest station data in 1998. The percentage of ***Good*** air quality, based on data at this station collected from April 17 to December 31, dropped from 5801 hours (93.6%) to 5607 hours (90.5%). A corresponding increase in ***Fair*** and ***Poor*** air quality is noted during this time period. ***Fair*** air quality increased from 394 hours (6.4%) using the standard IQUA calculation method to 562 hours (9.1%) using the IQUA calculated with hourly $PM_{2.5}$ data. The number of hours of ***Poor*** air quality increased from four to 30 hours.

The IQUA calculated using $PM_{2.5}$ data at the Calgary Central station also showed increases in ***Fair*** and ***Poor*** air quality in 1998. The number of hours of ***Fair*** air quality increased from 45 to 142 hours and the number of hours of ***Poor*** air quality increased from zero to 24 hours based on the IQUA calculated using hourly $PM_{2.5}$ data.

The IQUA calculated using $PM_{2.5}$ for the Edmonton Northwest and Calgary Central stations did not show as prominent of a difference in 1999 as it did in 1998. The major difference was seen in the ***Good*** and ***Fair*** air quality categories where the number of hours of ***Fair*** air quality increased from 120 to 186 hours at the Edmonton Northwest station and from 19 to 27 hours at the Calgary Central station. ***Poor*** air quality increased from zero hours to three hours after replacing COH with $PM_{2.5}$ in the IQUA calculation for the Edmonton Northwest station. There were no hours of ***Poor*** air quality as a result of using either method based on 1999 air quality data from the Calgary Central Station. The number of hours and percentage of time in each IQUA category at both locations for 1998 and 1999, are given in Tables 7 and 8, respectively. Figure 7 shows the percent of time in each IQUA category in 1998 and 1999 based on dust and smoke and $PM_{2.5}$.

Tables 9 and 10 show air pollutant concentrations and the suggested cause for ***Poor*** air quality occurrences at the Edmonton Northwest and Calgary Central monitoring stations, respectively. As mentioned earlier, most of the ***Poor*** air quality occurrences calculated from $PM_{2.5}$ data occurred in 1998. Forest fire smoke transported into Edmonton and Calgary was the major cause for elevated $PM_{2.5}$ concentrations measured from May 5 to 7 and August 9 to 13. During these time periods, the data indicate that COH was not an adequate surrogate for particulate matter and therefore not an adequate representation of air quality.

COH values are determined by the coefficient of haze instrument that works by continuously drawing air through a filter paper. The soiling properties of the air are measured by the reduction of light transmission through the filter paper. This reduction in light transmission is reported as the coefficient of haze per 1000 linear feet of air sample (Research Appliance Company, 1971). The colour and density of the particles collected on the filter paper will influence the amount of light transmitted. It is postulated that since particulate matter from forest fires are relatively light in colour compared to particles from other sources (such as vehicular emissions), the resultant COH value may not be a true representation of the particulate concentration. In this case, $PM_{2.5}$ measured by the TEOM gives a better representation of particulate concentrations. The TEOM draws an air sample through an inlet stream that aerodynamically separates particles of a specified diameter (e.g. 2.5 μg). The air sample then passes through a filter that is attached to a tapered element in the mass transducer. This tapered element vibrates at its natural frequency. As particles are deposited onto the filter the oscillating frequency changes in proportion to the amount of mass deposited (Rupprecht & Patashnick Co., Inc. 1995).

A negative implication of calculating the IQUA using continuous $PM_{2.5}$ data in place of COH measurements, is that long-term one-hour $PM_{2.5}$ data are not available at any monitoring stations in Alberta. The earliest $PM_{2.5}$ data is available from November 1997 at the Calgary Central station. However, measurements of $PM_{2.5}$ collected as a 24-hour integration once every sixth day in accordance with the National Air Pollution Surveillance (NAPS) network may be used to estimate the long-term IQUA. Long-term 24-hour integrated measurements for $PM_{2.5}$ are available from 1984 to the present at the Alberta Environment Edmonton Central and Calgary Central monitoring stations.

Alberta Environment has plans to add continuous $PM_{2.5}$ monitoring at most of the urban sites located in Edmonton, Calgary, Fort Saskatchewan and Red Deer over the next few years. Addition of $PM_{2.5}$ monitoring at more locations will allow a more realistic approach to presenting air quality in the form of an air quality index to the public of Alberta. In addition, $PM_{2.5}$ measurements at urban monitoring stations will allow comparison with the Canada-wide Standards for $PM_{2.5}$ recently accepted in principle by the Ministers.

CONCLUSION

- It is possible to establish a relationship between one-hour and 24-hour $PM_{2.5}$ levels.
- The relationship between 24-hour daily average and one-hour daily maximum $PM_{2.5}$ levels can be expressed by:

$$y = ax^b \qquad (1)$$

  where
  y = daily mean $PM_{2.5}$ concentration
  x = daily max $PM_{2.5}$ concentration
  a = location specific constant
  b = location specific constant.

  Based on data from the Edmonton Northwest and Calgary Central monitoring stations, the constant "a" is 1.06 for both stations, and the constant "b" is 0.761 for the Edmonton Northwest station and 0.769 for the Calgary Central station. Using this formula, a one-hour equivalent concentration for the 24-hour $PM_{2.5}$ level of 30 $\mu g/m^3$ is 80 $\mu g/m^3$.
- The choice of a value of 40 $\mu g/m^3$ as a breakpoint between ***Good*** and ***Fair*** air quality categories is consistent with the current practices in other Canadian jurisdictions, where the breakpoint between ***Good*** and ***Fair*** air quality is chosen as half of the breakpoint between ***Fair*** and ***Poor*** air quality. It is also comparable with the use of COH in formulating the IQUA.
- A set of hypothetical exposure analyses indicates that the one-hour equivalents provide a more convenient index to the public than the 24-hour averages in reducing exposures to predetermined $PM_{2.5}$ levels.
- The one-hour equivalent concentrations of 40 and 80 $\mu g/m^3$ are used as breakpoint concentrations to delineate between ***Good*** and ***Fair*** air quality and ***Fair*** and ***Poor*** air quality categories, respectively. When these one-hour equivalent concentrations are used in the formulation of the ***Alberta's*** IQUA, the percentage of time air quality was in the ***Good*** category decreased from 93.6% to 90.5% in1998 at the Edmonton Northwest station and from 99.5% to 98.1% in 1998 at the Calgary Central station. Corresponding increases in the frequency of ***Fair*** air quality are noted at these monitoring stations.
- One-hour $PM_{2.5}$ concentrations are an effective indicator of air quality during forest fire smoke events. When replacing COH with $PM_{2.5}$ in the IQUA, the number of ***Poor*** air quality hours increased from zero to 23 hours at both the Edmonton Northwest and Calgary Central stations during forest fire smoke events in May and August of 1998.

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KEY WORDS

$PM_{2.5}$
Exposure
Alberta
Index
Air Quality
Canada-Wide Standards

TABLES AND FIGURES

Table 1. Breakpoint concentrations used in the calculation of the IQUA.

Air Quality Parameter	Good (0 to 25)	Fair (26 to 50)	Poor (51 to 100)	Very Poor (greater than 100)
Carbon Monoxide	concentration is less than or equal to 13 ppm	concentration is greater than 13 ppm and less than or equal to 31 ppm	concentration is greater than 31 ppm and less than or equal to 64 ppm	concentration is greater than 64 ppm
Ozone	concentration is less than or equal to 0.05 ppm	concentration is greater than 0.05 ppm and less than or equal to 0.08 ppm	concentration is greater than 0.08 ppm and less than or equal to 0.15 ppm	concentration is greater than 0.15 ppm
Sulphur Dioxide	concentration is less than or equal to 0.17 ppm	concentration is greater than 0.17 ppm and less than or equal to 0.34 ppm	concentration is greater than 0.34 ppm and less than or equal to 2.0 ppm	concentration is greater than 2.0 ppm
Nitrogen Dioxide	concentration is less than or equal to 0.11 ppm	concentration is greater than 0.11 ppm and less than or equal to 0.21 ppm	concentration is greater than 0.21 ppm and less than or equal to 0.53 ppm	concentration is greater than 0.53 ppm
Coefficient of Haze	concentration is less than or equal to 2.0 COH units	concentration is greater than 2.0 COH units and less than or equal to 4.0 COH units	concentration is greater than 4.0 COH units and less than or equal to 6.0 COH units	concentration is greater than 6.0 COH units

Table 2. Definition of Index of the Quality of the Air (IQUA) categories.

IQUA rating	Frequency in Alberta	Effects
Good	almost all the time	Desirable range: no known harmful effects to soil, water, vegetation, animals, materials, visibility or human health. The long-term goal in Canada is for air quality to be in this range all the time.
Fair	occasional	Acceptable range: adequate protection against harmful effects to soil, water, vegetation, animals, materials, visibility and human health.
Poor	very seldom	Tolerable range: not all aspects of the environment are adequately protected from possible adverse effects. Long-term control action may be necessary, depending on the frequency, duration and circumstances of the readings.
Very Poor	very rare	Intolerable range: in this range, continued high readings could pose a risk to public health.

Source: Environment Canada. 1980. Guideline for a short-term air quality index. A report by the Federal-Provincial committee on Air Pollution.

Table 3. The Use of PM Air quality indices used in jurisdictions across Canada.

Jurisdiction	Index Type
Newfoundland	no index
Nova Scotia	IQUA with no particulate
Prince Edward Island	no index
New Brunswick	IQUA with dust and smoke representing the particulate fraction
Quebec (Montreal)	IQUA with 24-hour rolling average for PM_{10} and $_{PM2.5}$
Ontario	IQUA with an independent Air Pollution Index
Manitoba	IQUA with dust and smoke representing the particulate fraction
Saskatchewan	IQUA with no particulate
Alberta	IQUA with dust and smoke representing the particulate fraction
BC	IQUA with 24-hour rolling average for PM_{10} and an independent odour index based on total reduced sulphur
GVRD	IQUA with 24-hour rolling averages for $_{PM10}$

Table 4. Breakpoint (one-hour) concentrations used to calculate the IQUA based on $PM_{2.5}$.

Air Quality Parameter	Good	Fair
$PM_{2.5}$	concentration is less than or equal to 40 µg/m^3	concentration is greater than 40 µg/m^3 and less than or equal to 80 µg/m^3

Table 5. Number of hours an incorrect prediction was made when the one-hour average PM 2.5 concentration is compared to 40 µg/m^3.

Location	Trial #	Type of Hour >40=Indoor <40=Outdoor	Total Number of Hours	Number of Hours Incorrect Prediction	Percent Hours Incorrect Prediction (%)	Result
Edmonton	1	Outdoor	1218	12	1.0	exposed to Fair air quality
Edmonton	1	Indoor	23	12	52.2	missed chance to enjoy Good air quality
Edmonton	2	Outdoor	1218	20	1.6	exposed to Fair air quality
Edmonton	2	Indoor	22	11	50.0	missed chance to enjoy Good air quality
Calgary	1	Outdoor	1446	13	0.9	exposed to Fair Air quality
Calgary	1	Indoor	6	3	50.0	missed chance to enjoy Good air quality
Calgary	2	Outdoor	1434	4	0.5	exposed to Fair Air quality
Calgary	2	Indoor	18	7	38.9	missed chance to enjoy Good air quality

Table 6. Number of hours an incorrect prediction was made when the 24-hour average PM 2.5 concentration is compared to 18 μg/m^3.

Location	Trial #	Type of Day >18=Indoor <18=Outdoor	Total Number of Days	Number of Days Incorrect Prediction	Percent Days Incorrect Prediction (%)	Result
Edmonton	1	Outdoor	609	116	19.1	exposed to Fair air quality
Edmonton	1	Indoor	13	0	0.0	missed chance to enjoy Good air quality
Edmonton	2	Outdoor	610	117	19.2	exposed to Fair air quality
Edmonton	2	Indoor	12	0	0.0	missed chance to enjoy Good air quality
Calgary	1	Outdoor	723	80	11.1	exposed to Fair Air quality
Calgary	1	Indoor	3	0	0.0	missed chance to enjoy Good air quality
Calgary	2	Outdoor	715	74	10.4	exposed to Fair Air quality
Calgary	2	Indoor	9	0	0.0	missed chance to enjoy Good air quality

Table 7. Number of hours and % of time in each IQUA category in 1998 based on COH and $PM_{2.5}$.

IQUA Category	Edmonton Northwest *				Calgary Central			
	IQUA based on COH		IQUA based on $PM_{2.5}$		IQUA based on COH		IQUA based on $PM_{2.5}$	
	# of hours	% of non-missing hours	# of hours	% of non-missing hours	# of hours	% of non-missing hours	# of hours	% of non-missing hours
Good	5801	93.58%	5607	90.45%	8715	99.49%	8594	98.11%
Fair	394	6.36%	562	9.07%	45	0.51%	142	1.62%
Poor	4	0.06%	30	0.48%	0	0.00%	24	0.27%
Missing Hours	3	n/a	3	n/a	0	n/a	0	n/a
Total Hours	6202	n/a	6202	n/a	8760	n/a	8760	n/a

* $PM_{2.5}$ monitoring began on April 17, 1998 at the Edmonton Northwest station.

n/a - not applicable.

Table 8. Number of hours and % of time in each IQUA category in 1999 based on COH and $PM_{2.5}$.

IQUA Category	Edmonton Northwest				Calgary Central			
	IQUA based on COH		IQUA based on $PM_{2.5}$		IQUA based on COH		IQUA based on $PM_{2.5}$	
	# of hours	% of non-missing hours	# of hours	% of non-missing hours	# of hours	% of non-missing hours	# of hours	% of non-missing hours
Good	8639	98.63%	8569	97.84%	8735	99.78%	8727	99.69%
Fair	120	1.37%	186	2.12%	19	0.22%	27	0.31%
Poor	0	0.00%	3	0.03%	0	0.00%	0	0.00%
Missing Hours	1	n/a	2	n/a	6	n/a	6	n/a
Total Hours	8760	n/a	8760	n/a	8760	n/a	8760	n/a

n/a - not applicable.

Table 9. ***Poor*** air quality occurrences from April 17, 1998 to December 31, 1999 at the Edmonton Northwest station.

Date	Time	COH COH units	CO ppm	NO_2 ppm	O_3 ppm	$PM_{2.5}$ ug/m^3	IQUA with Dust and Smoke	IQUA with PM2.5	Parameter Causing Poor or Very Poor IQUA
05-May-98	0700-0759	0.9	1.1	0.013	0.045	84.0	Good	Poor	$PM_{2.5}$ due to forest fire smoke
05-May-98	0800-0859	1.0	1.1	0.011	0.049	124.3	Good	Poor	$PM_{2.5}$ due to forest fire smoke
05-May-98	0900-0959	1.0	1.1	0.012	0.051	120.8	Fair	Poor	$PM_{2.5}$ due to forest fire smoke
05-May-98	1000-1059	0.9	1.2	0.011	0.049	122.0	Good	Poor	$PM_{2.5}$ due to forest fire smoke
05-May-98	1100-1159	0.5	1.0	0.011	0.048	83.3	Good	Poor	$PM_{2.5}$ due to forest fire smoke
05-May-98	1600-1659	1.2	0.8	0.021	0.038	88.3	Good	Poor	$PM_{2.5}$ due to forest fire smoke
05-May-98	1700-1759	0.9	0.8	0.013	0.047	104.0	Good	Poor	$PM_{2.5}$ due to forest fire smoke
07-May-98	2200-2259	2.1	0.9	0.016	0.045	153.3	Fair	Poor	$PM_{2.5}$ due to forest fire smoke
07-May-98	2300-2359	1.3	0.7	0.012	0.046	109.5	Good	Poor	$PM_{2.5}$ due to forest fire smoke
09-Jul-98	1600-1659	0.2	0.2	0.010	0.088	20.5	Poor	Poor	O_3 due to photochemical smog
09-Jul-98	1700-1759	0.2	0.4	0.016	0.087	22.0	Poor	Poor	O_3 due to photochemical smog
09-Aug-98	1500-1559	0.2	0.3	0.009	0.081	29.8	Poor	Poor	O_3 due to photochemical smog
09-Aug-98	1600-1659	0.1	0.2	0.008	0.081	22.0	Poor	Poor	O_3 due to photochemical smog
10-Aug-98	1200-1259	0.7	1.2	0.015	0.035	137.3	Good	Poor	$PM_{2.5}$ due to forest fire smoke
10-Aug-98	1700-1759	0.6	1.2	0.019	0.041	122.5	Good	Poor	$PM_{2.5}$ due to forest fire smoke
10-Aug-98	1100-1159	1.1	1.8	0.022	0.045	206.0	Good	Poor	$PM_{2.5}$ due to forest fire smoke
10-Aug-98	1300-1359	1.6	4.0	0.026	0.036	345.8	Good	Poor	$PM_{2.5}$ due to forest fire smoke
10-Aug-98	1400-1459	1.7	4.2	0.029	0.035	389.5	Good	Poor	$PM_{2.5}$ due to forest fire smoke
10-Aug-98	1500-1559	2.4	5.2	0.037	0.035	431.3	Fair	Poor	$PM_{2.5}$ due to forest fire smoke
10-Aug-98	1600-1659	1.8	4.5	0.029	0.042	411.3	Good	Poor	$PM_{2.5}$ due to forest fire smoke
11-Aug-98	1000-1059	1.0	1.0	0.054	0.020	92.8	Good	Poor	$PM_{2.5}$ due to forest fire smoke
11-Aug-98	1200-1259	0.9	0.7	0.028	0.056	152.3	Fair	Poor	$PM_{2.5}$ due to forest fire smoke
11-Aug-98	1300-1359	0.6	0.4	0.022	0.057	96.0	Fair	Poor	$PM_{2.5}$ due to forest fire smoke
11-Aug-98	1900-1959	1.0	1.3	0.053	0.012	85.5	Good	Poor	$PM_{2.5}$ due to forest fire smoke
11-Aug-98	1100-1159	1.1	1.0	0.027	0.052	169.3	Fair	Poor	$PM_{2.5}$ due to forest fire smoke
12-Aug-98	0100-0159	0.4	0.5	0.025	0.020	110.3	Good	Poor	$PM_{2.5}$ due to forest fire smoke
13-Aug-98	0800-0859	0.3	1.0	0.013	0.023	83.5	Good	Poor	$PM_{2.5}$ due to forest fire smoke
22-Oct-98	0800-0859	1.7	5.4	0.063	0.002	93.8	Good	Poor	$PM_{2.5}$ (cause not certain)
22-Oct-98	1800-1859	1.6	10.0	0.056	0.003	95.3	Good	Poor	$PM_{2.5}$ (cause not certain)
24-Oct-98	0800-0859	2.0	7.4	0.071	0.002	110.0	Good	Poor	$PM_{2.5}$ (cause not certain)
06-Apr-99	2000-2059	0.6	1.3	0.045	0.004	216.5	Good	Poor	$PM_{2.5}$ (cause not certain)
12-Apr-99	0800-0859	1.0	1.9	0.042	0.002	94.5	Good	Poor	$PM_{2.5}$ (cause not certain)
11-Aug-99	1400-1459	0.3	no data	0.008	0.016	88.5	Good	Poor	$PM_{2.5}$ (cause not certain)

Table 10. ***Poor*** air quality occurrences from January 1, 1998 to December 31, 1999 at the Calgary Central station.

Date	Time	COH COH units	CO ppm	NO_2 ppm	O_3 ppm	$PM_{2.5}$ ug/m^3	IQUA with Dust and Smoke	IQUA with PM2.5	Parameter Causing Poor or Very Poor IQUA
24-Jan-98	0600-0659	2.6	2.7	0.058	0.005	144.3	Fair	Poor	$PM_{2.5}$ (cause not certain)
05-May-98	0800-0859	3.3	1.8	0.035	0.026	322.8	Fair	Poor	$PM_{2.5}$ due to forest fire smoke
05-May-98	0900-0959	1.9	1.1	0.031	0.031	171.0	Good	Poor	$PM_{2.5}$ due to forest fire smoke
05-May-98	2000-2059	2.2	1.2	0.037	0.024	176.3	Fair	Poor	$PM_{2.5}$ due to forest fire smoke
05-May-98	2100-2159	3.2	1.6	0.039	0.021	270.3	Fair	Poor	$PM_{2.5}$ due to forest fire smoke
05-May-98	2200-2259	2.8	1.4	0.033	0.027	266.3	Fair	Poor	$PM_{2.5}$ due to forest fire smoke
05-May-98	2300-2359	2.3	1.2	0.029	0.025	217.0	Fair	Poor	$PM_{2.5}$ due to forest fire smoke
06-May-98	0000-0059	1.3	0.8	0.023	0.021	124.3	Good	Poor	$PM_{2.5}$ due to forest fire smoke
07-May-98	1000-1059	0.5	no data	no data	0.019	132.5	Good	Poor	$PM_{2.5}$ due to forest fire smoke
07-May-98	1400-1459	0.3	0.8	no data	no data	80.5	Good	Poor	$PM_{2.5}$ due to forest fire smoke
10-Aug-98	2100-2159	2.0	3.3	0.024	0.039	355.3	Good	Poor	$PM_{2.5}$ due to forest fire smoke
10-Aug-98	2200-2259	2.1	4.0	0.021	0.039	450.0	Fair	Poor	$PM_{2.5}$ due to forest fire smoke
10-Aug-98	2300-2359	1.7	3.3	0.017	0.038	401.3	Good	Poor	$PM_{2.5}$ due to forest fire smoke
11-Aug-98	0900-0959	1.5	1.9	0.048	0.009	93.3	Good	Poor	$PM_{2.5}$ due to forest fire smoke
11-Aug-98	1500-1559	0.6	no data	no data	0.025	81.3	Good	Poor	$PM_{2.5}$ due to forest fire smoke
11-Aug-98	0000-0059	1.5	2.8	0.015	0.036	329.8	Good	Poor	$PM_{2.5}$ due to forest fire smoke
11-Aug-98	0100-0159	1.8	3.2	0.016	0.033	403.0	Good	Poor	$PM_{2.5}$ due to forest fire smoke
11-Aug-98	0200-0259	1.8	3.1	0.019	0.028	387.5	Good	Poor	$PM_{2.5}$ due to forest fire smoke
11-Aug-98	0300-0359	1.7	3.0	0.018	0.026	383.0	Good	Poor	$PM_{2.5}$ due to forest fire smoke
11-Aug-98	0400-0459	1.5	2.5	0.027	0.019	308.8	Good	Poor	$PM_{2.5}$ due to forest fire smoke
11-Aug-98	0500-0559	1.4	2.3	0.036	0.009	250.3	Good	Poor	$PM_{2.5}$ due to forest fire smoke
11-Aug-98	0600-0659	1.6	2.6	0.042	0.003	235.0	Good	Poor	$PM_{2.5}$ due to forest fire smoke
11-Aug-98	0700-0759	1.4	2.6	0.043	0.004	210.0	Good	Poor	$PM_{2.5}$ due to forest fire smoke
11-Aug-98	0800-0859	1.8	2.9	0.050	0.004	192.8	Good	Poor	$PM_{2.5}$ due to forest fire smoke

Figure 1. Scatter plot depicting relationship between daily maximum and daily average $PM_{2.5}$ concentrations in Edmonton.

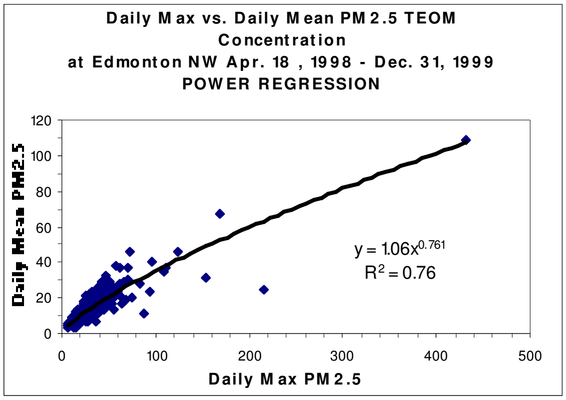

Figure 2. Scatter plot depicting relationship between daily maximum and daily average $PM_{2.5}$ concentrations in Calgary.

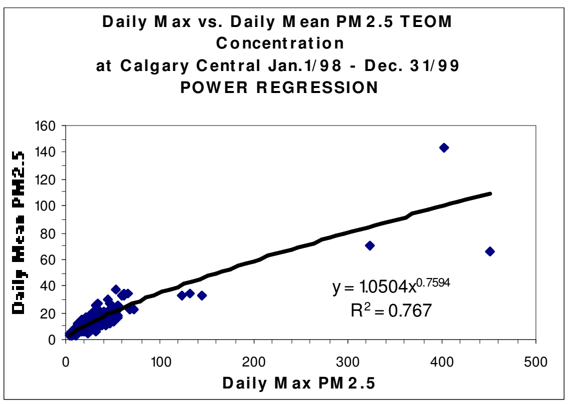

Figure 3. The distribution of hourly data for "Outdoor" days at Edmonton for Trial 1.

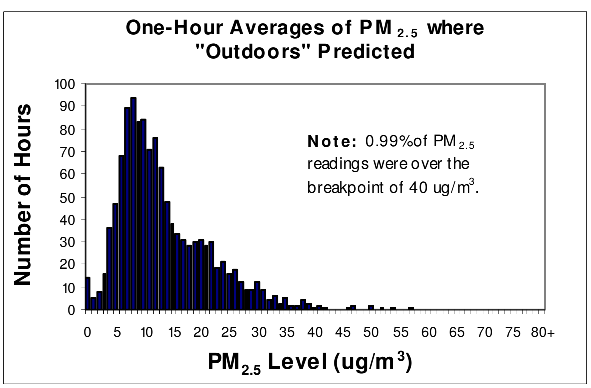

Figure 4. The distribution of hourly data for "Indoor" days at Edmonton for Trial 1.

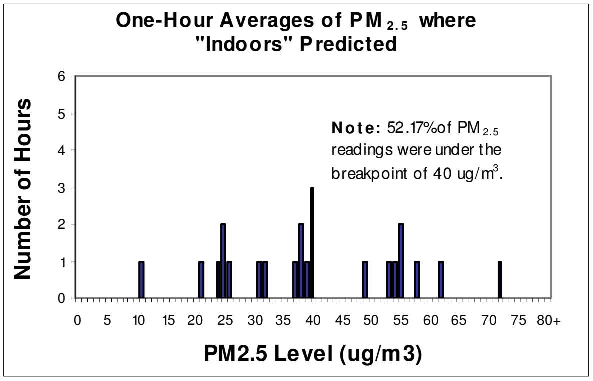

Figure 5. The distribution of daily data for "Outdoor" days at Edmonton for Trial 1.

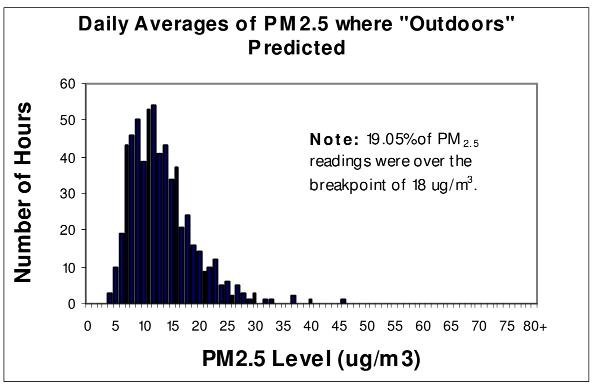

Figure 6. The distribution of daily data for "Indoor" days at Edmonton for Trial 1.

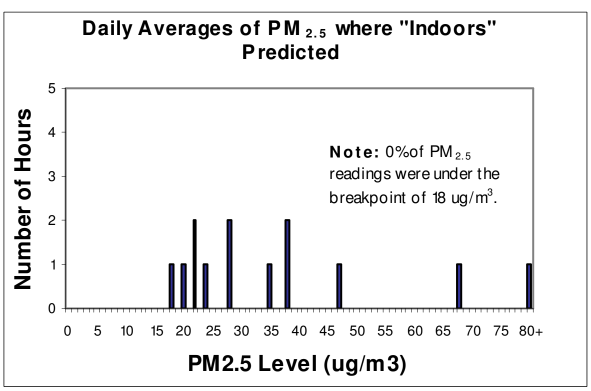

Figure 7. Percent of time in each IQUA category in 1998 and 1999 based on COH and $PM_{2.5}$.

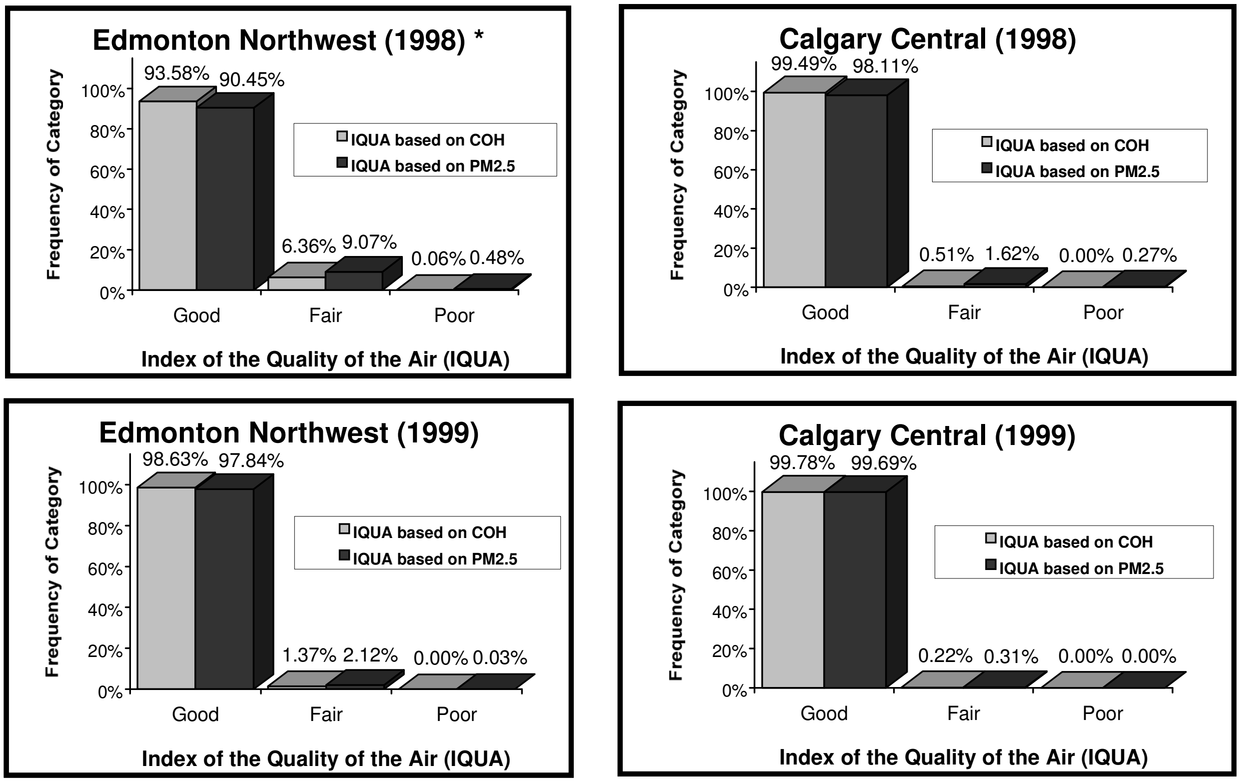

Figure 8. Scatterplot showing relationship between COH and $PM_{2.5}$ for Edmonton.

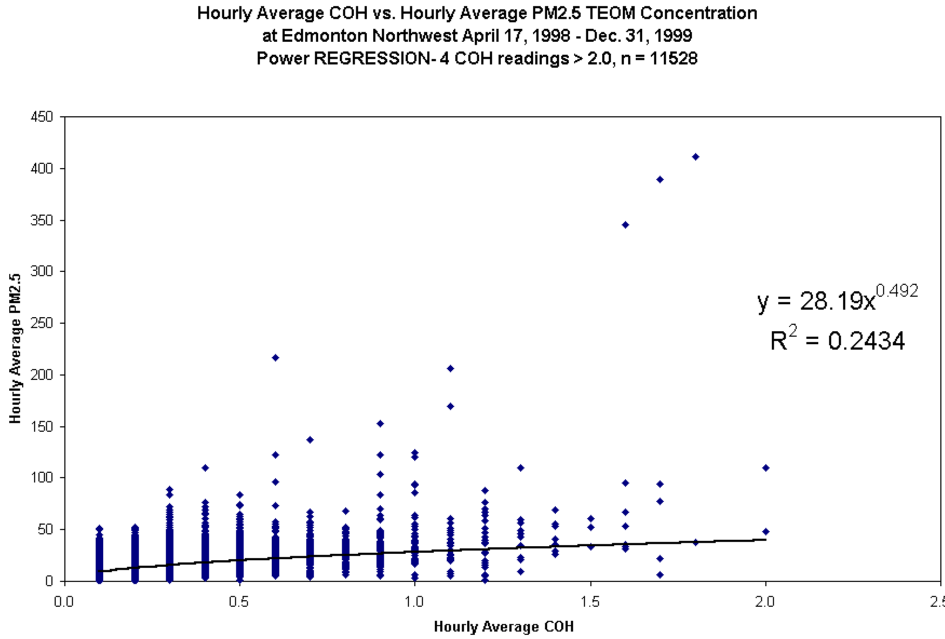

Figure 9. Scatterplot showing relationship between COH and $PM_{2.5}$ for Calgary.