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Analysis of Ambient Air Quality Trends at Selected West Central Airshed Society Stations: Tomahawk and Carrot Creek

Nabila Haque[1], Mohamed Gamal El-Din[1] and Warren B. Kindzierski[1,2]
[1] Department of Civil & Environmental Engineering, University of Alberta, Edmonton, Alberta, Canada
[2] SEACOR Environmental Inc., 6940 Roper Road, Edmonton, Alberta, Canada

Abstract: This paper presents an evaluation of ambient air trends using data from two West Central Airshed Society monitoring stations in rural Alberta. Pollutants studied include O_3, NO_2, SO_2, and $PM_{2.5}$. Two approaches were examined to assess trends: (a) use of various percentiles of hourly concentration distributions from each year (50^{th} to 98^{th} percentiles), and (b) use of frequencies (number of hours) in which various benchmark concentrations were exceeded each year. Assuming these summary statistics to be linear in time, hypothesis tests (at $\alpha = 0.05$) were conducted on the best-fit lines to check whether slope of the lines was zero or not in order to indicate change. Results from these approaches clearly supported each other. At one station – Tomahawk – no statistically significant change was detected in air quality with respect to O_3 and $PM_{2.5,}$ while SO_2 and NO_2 showed statistically significant decreasing trends. At the second station – Carrot Creek – SO_2 exhibited statistically significant decreasing trends, while O_3 and NO_2 showed no change. The decreasing trends observed with SO_2 at the two stations appear to be consistent with reduced natural gas flaring and venting that has been occurring in Alberta over the same time period. The period of study over which trends were examined was short – less than a decade – and changes or lack of changes observed do not necessarily provide an indication of what may happen over the long term.

1. Introduction

Air quality issues sometimes represent challenging environmental problems currently faced by societies as more and more studies suggest impacts of atmospheric pollution on human health and environment as a whole (Desauziers, 2004). Poor air quality most notably occurs in urban areas where some (or all) of the following factors exist (Kindzierski and Scotten, 2004): numerous sources emitting air pollutants (e.g. automobile, industrial and commercial activities), meteorology (e.g. poor mixing conditions in the atmosphere), irregular topographic features, and large populations. Deterioration in air quality may be caused by compounding of these factors, e.g. emissions from a variety of sources; whether stationary (e.g.,factories, power plants, smelters, dry cleaners), or mobile (e.g., vehicles); or naturally occurring (e.g., windblown dust, volcanic eruptions). Each of these sources can emit a variety of pollutants.

These pollutants are also influenced by a number of meteorological and geographical factors in the atmosphere resulting in temporal and spatial variation in ambient concentrations. Ozone (O_3), nitrogen dioxide (NO_2), sulphur dioxide (SO_2) are known respiratory irritants and have been reported to be associated with various health effects, including pulmonary function decrements, increased hospitalization for respiratory causes, and mortality (EPA, 1999, Gold et al., 2000, Mustafa, 1994, Pope et al., 2002, Suh et al., 2000). Epidemiological studies, which rely on data from stationary ambinet monitoring sites, have reported associations between particulate matter (PM) and adverse health outcomes including cardiovascular effects (EPA, 1999, Wichmann et al., 2000).

Responding to perceptions and concerns about air quality remains a challenge and requires sound assessment. Accordingly, it is of great interest to know whether changes in air quality have occurred over time where continuous air monitoring is conducted. This information enables people to measure progress in achieving goals and to assess benefits of airshed management programs over time. It also allows people to demonstrate maintenance of air quality guidelines and standards through analysis of past air quality behavior. Finally, it can be used as a basis for developing control strategies and tracking progress towards meeting air quality guidelines and standards in areas where poor air quality exists.

Only evaluating and reporting of air monitoring data overlooks the important aspect of detecting changes in air with respect to time (i.e., trends) and hence may lack in providing a sound scientific basis required for managing and improving the environment (Bower, 1997, WCAS, 2005). Trend analysis is the process of analyzing data to identify longer-term underlying change and is often used to try predict the future based on the past data (Blanchard, 1999). In case of air, detection of temporal trends is extremely useful as the comparison of changes in pollutant emissions with changes in ambient concentrations can potentially provide information on source-to-receptor relationships and thus help in evaluating the effectiveness of emission control programs.

Weatherhead et al. (1998) discussed statistical criteria for detecting long-term linear trends in environmental data and reported that the precision of trend estimates is strongly influenced by variability and autocorrelation of the underlying noise process. According to Weatherhead et al. (1998), detectability of a trend can be summarized in two common ways: a) through precision of a trend estimate, as measured by its standard deviation, and b) number of years of data required to detect a trend of given magnitude using the trend estimate. Weatherhead et al. (1998) further concluded that it takes several (two to three) decades of high-quality data to detect long-term trends likely to occur in nature. The practical implication is that detection of trends over shorter time periods – less than a decade – does not represent long-term trends.

Air quality issues in Alberta are mostly local, both in their cause and solutions required. The West Central Airshed Society (WCAS) is an organization dedicated towards understanding the state of air quality within its airshed zone (WCAS, 2005). The WCAS operates a network of ten continuous on-line air quality monitoring stations, located throughout the zone in a manner that ensures representation of areas with industrial activity as well as remote from man-made emission sources. The present study focuses on two of the WCAS monitoring stations, Tomahawk and Carrot Creek, which largely represents rural west-central Alberta. In general, rural air quality is affected by agricultural practices such as use of fertilizers, burning wastes, and raising cattle, as well as transport of pollutants from other areas (Kelly et al., 1984, Barrie and Hoff, 1985). However, the input of anthropogenic emissions (e.g., oil and gas plants, coal fired power plants) may also influence rural air quality (Seinfeld, 1989).

The present study was performed to identify whether and the extent to which concentrations of ambient air quality parameters have changed over the short-term (between 1997 and 2004) at the selected WCAS air monitoring stations. Characteristics of O_3, SO_2, NO_2, and $PM_{2.5}$ were analyzed over time focusing on change in the “mid-to-upper-range” of the cumulative frequency distribution of hourly concentrations of these pollutants. An ultimate goal of the study was to develop and examine straightforward and easy procedures for statistical analysis of air quality data for detecting trends. The intent was to provide WCAS with these procedures to be used for on-going analysis and reporting of air quality trends in the airshed.

2. Study Area

The WCAS zone encompasses 46,000 square kilometres in west central Alberta (Figure 1). The west side of the airshed is delineated by the Alberta/British Columbia border, heavily forested and characterized by foothills and mountainous area. The east side is characterized by more gently rolling terrain with greater anthropogenic activities (e.g. gas plants and coal-fired power plants) and residential acreage developments. Further to the east of the airshed lies the Capital Region of Alberta (Edmonton and surrounding area). Two continoues air-quality monitoring stations located in the WCAS zone – Tomahawk and Carrot Creek (shown in Figure 1) – were selcted to carry out trend analysis of selcted air quality parameters.

The Tomahawk station is located ~25 km northeast of Drayton Valley near the community of Tomahawk. Land use surrounding the station is predominantly pastured and major influences are four power plants located in the Wabamun Lake area about 30 to 40 Km away (He et al., 2005). The Carrot Creek station is located ~40 km east of Edson, Alberta. Land use is characterized by pasture and local influences include three gas plants as point sources within a distance of 5 to 15 km from the station.

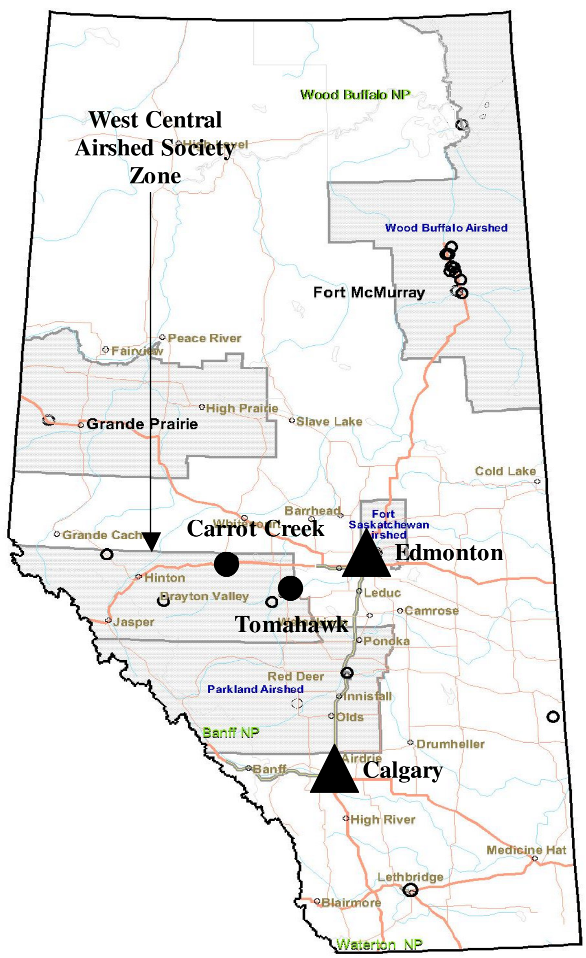

Figure 1. Province of Alberta showing West Central Airshed Society Zone and location of Tomahawk, and Carrot Creek air monitoring stations.

3. Methods

The pollutants and measurement techniques varied between the two stations during the observation periods. Data for meteorological parameters were not considered in this study. Table 1 gives the parameters, measurement techniques, and observation periods for the two stations. Hourly concentration data were obtained in electronic format from WCAS. Initially eight years of historical data – 1997 to 2004 – were requested for O_3, SO_2, and NO_2 and five years – 2000 to 2004 – for $PM_{2.5}$ and PM_{10}. Carrot Creek, however, commenced data collection in 1998 and this station does not monitor PM. A completeness criterion of 80% was used for continuous data in this study. At Tomahawk the 1999 dataset for O_3 and

SO_2; 1998 and 1999 datasets for NO_2; and 2000 dataset for $PM_{2.5}$ were not used because they failed the completeness criterion. PM_{10} had to be dropped altogether at Tomahawk due to insufficient datasets (only three of the five years had >80% completeness). Similarly, the years 1998 and 1999 were omitted for all three pollutants examined at Carrot Creek.

Table 1. Study observation sites, measuring instruments, and observation period for trend analysis (after www.wcas.ca)

Station	Parameters	Instrumentation	Observation Period
Tomahawk	Ozone (O_3)	Bendix 8002	1997-2004
	Sulphur Dioxide (SO_2)	TECO 42-CTL	1997-2004
	Nitrogen Dioxide (NO_2)	TECO 42-CTL	1998-2004
	Particulate Matter ($PM_{2.5}$/PM_{10})	TEOM (A/B) PM_{10} TEOM (A/B) $PM_{2.5}$	2000-2004
Carrot Creek	Ozone (O_3)	TECO 49-CTL	1998-2004
	Sulphur Dioxide (SO_2)	TECO 43-CTL	1998-2004
	Nitrogen Dioxide (NO_2)	TECO 42-CTL	1998-2004

Analysis of air quality is often based on average and maximum concentrations, and the frequency of exceedence of maximum concentrations above air quality criteria. However, in case of WCAS zones – where air quality is good most of the time – exceedence of maximum concentrations above air quality criteria is not a frequent occurrence. Here, assessing observed concentrations against air quality criteria is not sensitive enough to detect temporal changes. This paper examined changes in air quality, not by focusing on behavior of concentration maxima over time, but by examining "mid-to-upper-range" (50^{th} to 98^{th} percentiles) of the cumulative frequency distribution of pollutant concentrations over time, which represents a more frequently occuring air quality condition than concentration maxima.

The study adopted a methodology consisting of two approaches. The first approach consisted of trend detection using various percentiles of the hourly concentration data from each year. After screening the datasets, hourly concentration values were sorted in ascending order, ranked and plotted. From plots of each pollutant the percentile values were reordered for every 5^{th} percentile from the 50^{th} to 95^{th} percentile, and the 98^{th} percentile. This was done for every year. The percentiles were plotted for each year and trend lines were superimposed over each plot. Six percentiles – 50^{th}, 65^{th}, 80^{th}, 90^{th}, 95^{th} and 98^{th} – were selected as benchmarks to demonstrate concentrations trends (after Klemm and Lange, 1999). The second approach employed frequencies (number of hours) in which various benchmark concentrations were exceeded each year. These benchmark concentrations were determined from the initial or baseline year for which data were available for each pollutant. These frequencies were then plotted for each year and fitted with trend lines.

The main purpose of the trend test was to determine whether values of the series increased or decreased over some period of time in statistical terms (Onöz et al., 2003). The expected summary statistics in both approaches were assumed to be linear over time to facilitate their plotting as a straight line and analyzing them using simple linear regression. As a final step a hypothesis test (at $\alpha = 0.05$) was conducted for the best-fit lines to decide whether there was a statistically significant trend. The null hypothesis, $H_0:\beta = 0$ (no trend), was tested against the alternative hypothesis $H_a:\beta \neq 0$ (trend). The parametric t-test was used to test H_0. Another way of testing the null hypothesis was applied in support of the first – the F-test, i.e., using a measure of unexplained and explained variation. The F-test is comparable to the t-test for $H_0:\beta = 0$, in that they are both measures of the strength of relationship in linear regression (Harnett, 1982).

A thorough examination of data was initially carried out and erroneous data patterns were removed from each dataset. If an hourly value during any of the study periods at any of the stations was missing from the database, that specific hour was not included in the analysis. The median concentration (50^{th} percentile) was used for representing the central value for the data. As most environmental data are usually skewed to the right (i.e., most data values are low and only a few values are high), the arithmetic mean would be biased by high concentrations. Selected percentiles (50^{th}, 65^{th}, 80^{th}, 90^{th}, 95^{th}, and 98^{th}) of the hourly concentrations for each pollutant were calculated for each year and scatter plots were generated. In addition, changes in the one-hour maximum and median concentrations were observed to obtain a solid overview of the monitoring data to supplement understanding of the trend analysis.

4. Results and Discussions

4.1 Ozone

At Tomahawk the maximum one-hour average O_3 concentration observed was 97 ppb in 2002. This maximum value exceeded the one-hour Alberta ambient air guideline of 82 ppb. The second maximum was recorded in 2003 (82 ppb). There were no other exceedences recorded in the rest of the years, however other concentration maxima lay within the range of 70 to 80 ppb. The median O_3 concentration over the years ranged from 27 to 31 ppb. At Carrot Creek, the maximum one-hour average O_3 concentration was 97 ppb, also in 2002. Though no other exceedences occurred, maxima for the rest of the years lay within a very close range of 76 to 80 ppb. Median O_3 concentrations ranged from 24 ppb to 30 ppb. Lower median O_3 concentrations were mostly observed from midnight to the early morning hours and higher median levels were measured more in the afternoon at both stations. Higher O_3 levels were observed in the afternoon because of more sunlight, warmer temperatures, and more vertical mixing of the atmosphere.

Despite rather high maximum hourly concentrations, minimal variation was observed when concentrations trends (i.e. best-fit lines) for all years together were analyzed. For the period examined at Tomahawk, a minor increasing trend was visually apparent at all percentiles (Figure 2.a). However none of the six trend lines proved statistically significant at $\alpha = 0.05$; indicating that no significant change has taken place in ozone concentration during the study period. At Carrot Creek, the picture was slightly different where trend lines showed an apparent decreasing tendency (Figure 2.b). Statistically, these best-fit lines all proved insignificant ($\alpha = 0.05$). Application of the second approach (frequency of exceedence) provided identical results, for ozone – all trend lines failed to be statistically significant at both stations ($\alpha = 0.05$). This second approach supported findings of the previous approach supporting that no significant change had taken place in O_3 concentration during the study period.

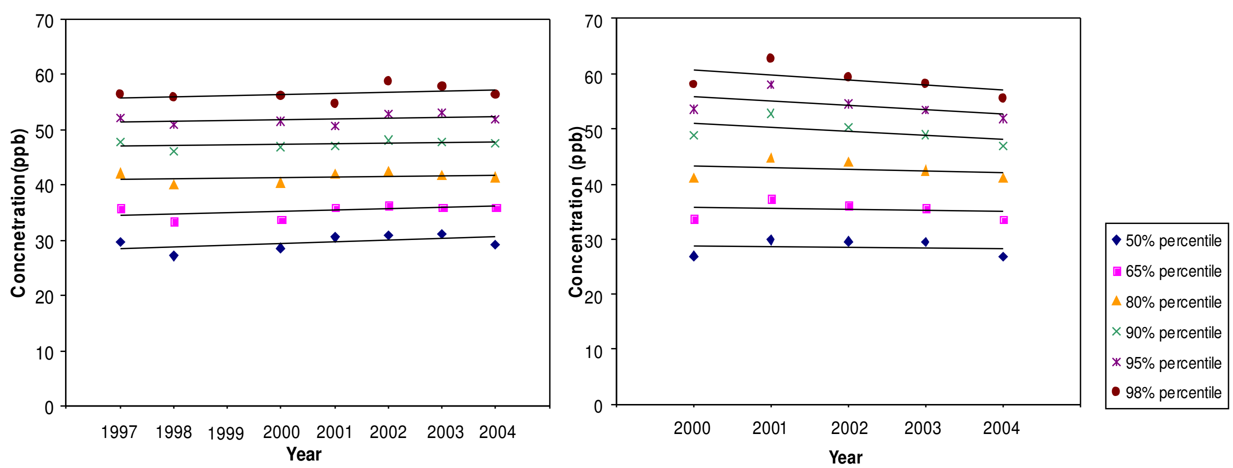

Figure 2. Concentration trends for O_3 at different percentiles: (a) Tomahawk, (b) Carrot Creek.

These findings would be expected at sites characterized as rural – where the influence of anthropogenic pollutants is not great compared to urban sites. The majority of O_3 at rural locations in west central Alberta results from natural processes (He et al., 2005). These processes include transport from the "ozone-rich" upper atmosphere and organic compounds (from vegetation) reacting with NO_x in presence of sunlight to form ozone (CASA, 2003). Also, CASA (2003) reports that O_3 concentrations approaching or exceeding the Canada-wide Standard (CWS) in several areas in the province, including Hightower Ridge, Violet

Grove and Carrot Creek, was the case only if the higher O_3 concentrations were determined to be caused by natural sources or sources outside of Alberta. Sandhu (1999) reports that, in general, O_3 formation is relatively suppressed as the meteorology is not favorable for its formation in Alberta. High temperatures and shallow mixing depths necessary for O_3 formation do not exist. This position supports observations made earlier by Peake and Fong (1990) that under climatological and meteorological conditions existing in Alberta, exceedences of hourly O_3 standards are more likely in remote areas than in cities or in areas under the direct influence of urban and industrial emissions. Therefore exceedences observed during the current study period do not signify unexpected occurrences.

The results of this study are also consistent with that observed by others. Wolff et al., (2001) reviewed trends in the concentrations of O_3 over North America and reported that in Canada (Ontario, Alberta, and British Columbia) trends of mean daily maximum one-hour O_3 concentrations at urban sites showed mixed trends with a majority of sites showing an increase from 1980 to 1993. However, Wolff et al., (2001) reported that trends appear to decrease from 1985 to 1993 or showed no significant change at the 95% level at most regionally representative sites.

4.2 Sulphur Dioxide (SO_2)

SO_2 concentrations at both stations were found to be typically low, sometimes below the detection limit. At Tomahawk, SO_2 levels were below Alberta's one-hour guideline of 170 ppb at all times (1997 to 2004). The maximum one-hour concentration was 56 ppb. Maximum concentrations in other years ranged from 23 to 52 ppb. Median SO_2 levels were quite low with 0.6 ppb as the highest (2003). A significant portion of the data was below detection limits. At Carrot Creek, maximum SO_2 levels were lower than at Tomahawk (2000 to 2004). The maximum one-hour concentration of SO_2 was 54 ppb. The median SO_2 levels were slightly higher and exhibited more variation than at Tomahawk, 0.9 ppb as the highest median in 2000.

Similar decreasing visual trends were observed at the two stations with some variations in details (Figure 3a,b). Trends at Carrot Creek appeared more defined; decreasing through all percentiles. Trends at the 65th, 80th, and 90th percentiles were found to be statistically significant at α=0.05 at Tomahawk (Figure 3a). Similar results were observed for Carrot Creek, which had statistically significant trend at the 50th, 65th, 80th and 90th percentiles. Although not shown, results from the second approach presented almost the same outcomes. In the second approach, SO_2 at Tomahawk showed observable decreasing trends at all percentiles except for the 50th percentile. Statistically significant decreasing trends (α = 0.05) were observed at the 65th, 80th, and 90th percentiles, whereas a lack of statistically significant trends was observed at higher percentiles (95th and 98th). For Carrot Creek, the findings were identical.

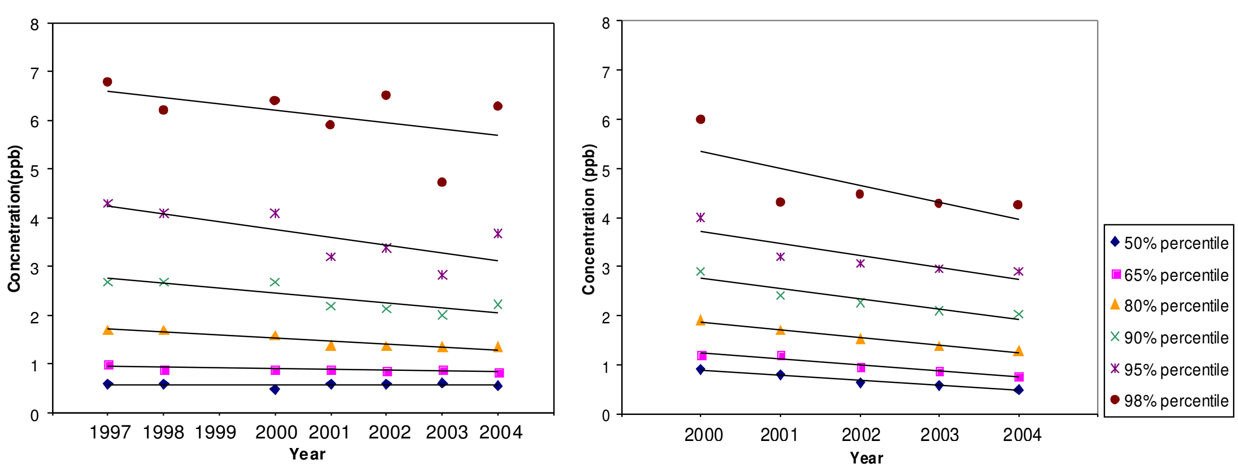

Figure 3. Concentration trends for SO_2 at different percentiles: (a) Tomahawk, (b) Carrot Creek.

In Alberta it is estimated that 51% of SO_2 emissions are produced by upstream oil and gas industries while power plants and oil sands produce about 25% and 18% of SO_2 emissions, respectively (Environment

Canada, 2000). Other sources include gas plant flares, oil refineries, pulp and paper mills and fertilizer plants. As oil and gas plants exist within range of the two stations studied, decreasing trends at both stations may be partially explained by successful efforts of the Alberta Energy and Utility Board (EUB) in requiring reduced sulphur-related flaring and venting emissions. In the year 2004 alone, EUB (2005) reported flare volumes to be 72% less than 1996 flaring baseline, and that vented volumes were 49% less than the 2000 venting baseline. These decreases compare well with decreases in SO_2 concentration observed at the stations.

4.3 Nitrogen Dioxide (NO_2)

NO_2 levels were observed to be below Alberta's one-hour guideline of 212 ppb at the monitoring locations during the study period. At Tomahawk the maximum NO_2 concentration was 58 ppb. Median NO_2 concentrations were very low and ranged from 2 to 3 ppb. At Carrot Creek maximum NO_2 levels were higher than at Tomahawk. The maximum one-hour concentration was 155 ppb. The second highest was 140 ppb. Median NO_2 levels also were higher than at Tomahawk with 6 ppb as the highest in 2003.

Slight decreasing trends were visually observed for all percentiles, among which the 65th, 80th, and 90th percentiles were statistically significant at Tomahawk (α = 0.05) (Figure 4.a). A different picture was observed at Carrot Creek (Figure 4.b). None of the trends proved to be statistically significant (α = 0.05), leading to the conclusion that no change has been taking place over the study period with respect to concentration of NO_2 at Carrot Creek. Once again, although not shown, the "frequency of exceedence" approach generated the exact same outcomes for NO_2 trends at both stations.

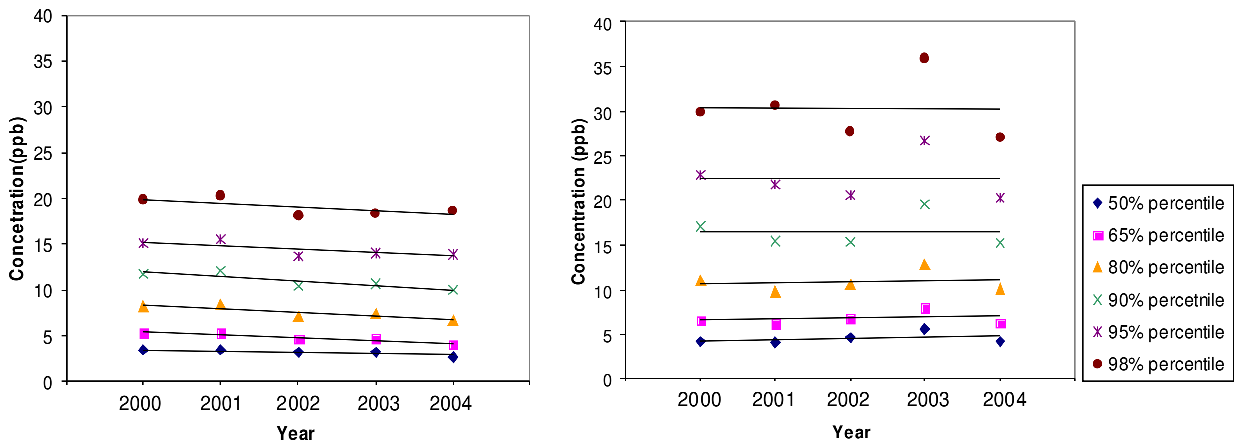

Figure 4. Concentrations trends for NO_2 at different percentiles, (a) Tomahawk, (b) Carrot Creek.

4.4 Particulate Matter ($PM_{2.5}$)

At Tomahawk, one very high concentration was recorded during the study period – 121 µg/m^3. Maximum concentrations recorded in other years were 55 µg/m^3 or less. Median concentration were <4 µg/m^3. Statistically, none of the trends proved significant for $PM_{2.5}$ (α = 0.05) (Figure 5). Although not shown, the same results were obtained from the "frequency of exceedence" approach. For the isolated high $PM_{2.5}$ concentration observed (i.e., 121 µg/m^3), an association with forest fires is suspected.

These findings support that the background concentrations at Tomahawk are low, where local anthropogenic sources are relatively few in number and small in emissions. Also, these findings are consistent with those reported by Namdeo and Bell (2005), who carried out a study at two rural locations in U.K. under the influence of anthropogenic activities. Namdeo and Bell (2005) that particulate levels were low and almost unchanged at rural sites, reflecting the prevailing background conditions.

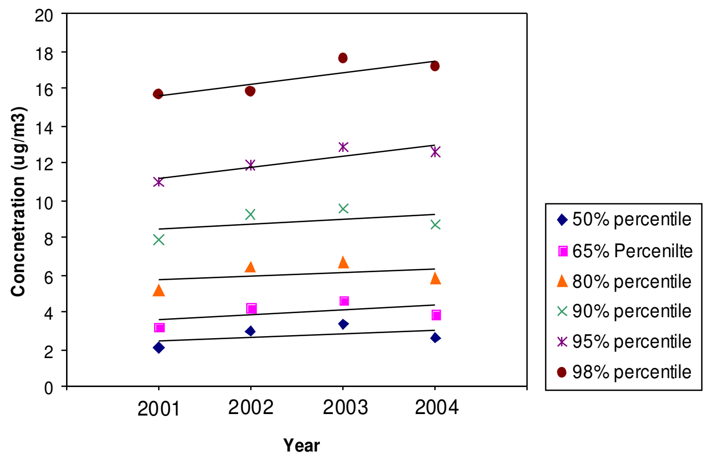

Figure 5. Concentration trends for $PM_{2.5}$ at different percentiles for Tomahawk.

5. Conclusions

Trends were analyzed on ambient air data at two rural stations in the WCAS zone using hourly concentrations for over an eight-year period. The parametric t-test and F-test were used to test the presence of a trend at a significance level of 0.05. At Tomahawk, statistically significant decreasing trends were observed for SO_2 and NO_2 at most of the percentiles examined. For O_3 and $PM_{2.5}$, none of the trends proved to be statistically significant indicating no change in air quality. For Carrot Creek, SO_2 exhibited a clear and statistically significant decreasing trend in most cases, while O_3 and NO_2 displayed no statistically significant change. As the period of study over which trends were examined was short – less than a decade – changes or lack of changes observed do not necessarily provide an indication of what may happen over the long term. Nevertheless, results obtained from both approaches (concentration trends and frequencies of exceedences) tended to support each other. Accordingly, methods examined in this study can be used as demonstrated to assess change in air quality at monitoring stations in Alberta.

6. References

Barrie, L.A. and Hoff R.M., 1985. Five years of air chemistry observations in the Canadian Arctic. *Atmospheric Environment*, 19: 1995-2010.

Blanchard, C. L., 1999, Methods of Attributing Ambient Air Pollutants to Emission Sources, *Annual Review Energy Environment*, 24: 329-65

Bower, J., 1997. Ambient Air Quality Monitoring. In R.E. Hester and R.M. Harrison (Eds.), Air Quality Management, *The Royal Society of Chemistry*, Thomas Graham House, Science Park, Milton Road, Cambridge CB4 4WF, UK, 41-65 pp.

Clean Air Strategic Alliance (CASA), 2003. Guidance document for the management of fine particulate matter and ozone in Alberta. Clean Air Strategic Alliance, Edmonton, AB. 92 pp.

Desauziers, V. 2004. Traceability of Pollutant Measurements for Ambient Air Monitoring. *Trends in Analytical Chemistry*, 23(3):252-260

Environmental Protection Agency (EPA). 1999. National Air Quality And Emissions Trend Report. US EPA, Washington, DC.

Environment Canada 2000. 2004. Criteria Air Contaminant Emissions Inventory Summaries. Pollution Data Branch, Environment Canada. Available at http://www.ec.gc.ca/pdb/ape/ape_tables/sox2000_e.cfm.

Energy and Utilities Board (EUB), 2005. Upstream Petroleum Industry Flaring and Venting Report : Industry Performance for Year Ending December 31, 2004, Alberta Energy and Utilities Board, Calgary, AB.

Gold, D.R., Litonjua, A. Schwartz, J. Lovett, E., Larson, A., Nearing, B., Allen, G., Verrier, M., Cherry, R., Verrier, R.L., 2000. Ambient Pollution and Heart Rate Variability, *Circulation*, 101: 1267-1273.

Harnett, D.L., 1982. Statistical Methods. Addison-Wesley Publishing Company, Inc. Philippines.

He, Y., Selvaraj, M., Kindzierski, W.B., and Gamal El-Din, M. 2005. Investigation of Factors Affecting Ambient O_3 Concentrations in West Central Airshed Society Zone, Alberta. Report prepared for West Central Airshed Society, Drayton Valley, Alberta. January 2005. 33 pp.

Kelly, N.A., Wolff, G.T. and Ferman, M.A., 1984. Sources and Sinks of Ozone in Rural Areas. *Atmospheric Environment*, 18: 1251-1266.

Kindzierski, W.B., and Scotten, B. 2003. Airshed Management: The Future of Ambient Air Quality Monitoring in Canada. *Canadian Civil Engineering*, 20(4): 22-24.

Klemm, O. and Lang, H., 1999. Trends of Air Pollution in the Fichtelgebirge Mountains. *Environmental Science and Pollution Research*, 6(4): 193-199.

Mustafa, M.G., 1994. Health Effects and Toxicology of Ozone and Nitrogen Dioxide, *Advances in Environmental Science and Technology*, 28: 351-404

Namdeo, A. and Bell, M.C., 2005. Characteristic and Health Implications of Fine and Coarse Particulate at Roadside, Urban Background and Rural Sites in UK. *Environment International*, 31: 565-573.

Onöz, B. and Bayazit, M. 2003. The Power Test of Statistical Tests for Trend Detection, *Turkish J. Eng.Env.Sci*, 27: 247-251.

Peake, E., and Fong, B.D., 1990. Ozone Concentrations at a Remote Mountain Site and at Two Regional Locations in Southwestern Alberta, *Atmospheric Environment*, 24A(3): 475-480.

Pope III, C.A., Burnett, R.T., Thun, M.J., Calle, E.E., Krewski, D., Ito, K., Thruston, G.D., 2002. Lung cancer, cardiopulmonary mortality and Long-term Exposure to Fine Particulate Air Pollution. *Journal of the American Medical Association* 287(9): 1132–1141.

Sandhu, H.S. 1999. Ground-level Ozone in Alberta. Science and Technology Branch, Environmental Sciences Division, Alberta Environmental Protection, Edmonton, AB.

Seinfeld, J. H., 1989. Urban Air Pollution: State of the Science. *Science*, 243: 745-763.

Suh, HH, Bahadori, T., Vallarino, J., Spengler, J.D., 2000. Criteria Air Pollutants and Toxic Air Pollutants. *Environmental Health Perspectives*, 108: 625-633

Weatherhead, E.C., Reinsel, G.C., Tiao, G.C., Meng, X.L., Choi, D., Cheang, W.K., Keller, T., Deluisi, J., Wuebbles, D.J., Kerr, J.B., Miller, A.J., Oltmans, S.J., Frederick, J.E. 1998. Factors Affecting the Detection of Trends: Statistical Considerations and Applications to Environmental Data. *Journal of Geophysical Research*, 103(D14): 17149-17162.

West Central Airshed Society (WCAS), 2005. West Central Airshed Society, Objectives. Available at: http://www.wcas.ca/objectives/overview.html (accessed on June 26th, 2005).

Wolff, G.T., Dunker, A.M., Rao, S.T., Porter, P.S.and Zubenko, I.G., 2001. Ozone Air Quality over North America: Part 1 – A Review of Reported Trends. *Journal of the Air & Waste Management Association*, 51(2): 273-82

Wichmann, H.E., and Peters, A., 2000. Epidemiological Evidence of the Effects of Ultrafine Particle Exposure. *Philosophical Transactions of the Royal Society of London Series A*, 358: 2751-2769.