Reconstructing the Historic Database of Annual $PM_{2.5}$ Values for Kamloops, B.C. by Calculating the Offset between TEOM and BAM Measurements

prepared by

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ABSTRACT

For the 16-year period, 1998 to 2013, this report shows using three different statistical methods that the average of the $PM_{2.5}$ annual averages in Kamloops, computed using hourly values, is in the range of 8.6 – 8.8 μg/m^3 with a mean of 8.7 μg/m^3. The annual average $PM_{2.5}$ values as measured by the TEOM instrument from 1998 to 2010 were severely underestimated**.** Using a simple mean adjustment method, we find that the TEOM annual average adjustment factor ranges from 3.1 to 3.3 ug/m^3, with a mean of 3.2 μg/m^3. This adjustment factor is added to the TEOM values to create a $PM_{2.5}$ series that can be merged with the modern BAM instrument measurements. The impact of our proposed adjustment to the historic $PM_{2.5}$ data base for Kamloops is major. Adjusted values show the city has typically had annual mean values of $PM_{2.5}$ that are above the provincial guideline of 8 μg/m^3 since 1998. We can state, with 95% confidence, that the 16-year, long-term average $PM_{2.5}$ in Kamloops is over the current British Columbia Ambient Air Quality Objective value of 8 μg/m^3. It is well above the provincial goal of 6 μg/m^3.

Introduction and Overview of the Data

This study is part of a set of statistical examinations by KPHES of the $PM_{2.5}$ (airborne fine particulate) measurements that were made by the British Columbia Ministry of the Environment in Kamloops, B.C. from 1998 to 2013. The objective of this report is to examine what adjustment is required to the $PM_{2.5}$ measurements at the Brocklehurst (Kamloops) site, using the TEOM instrument between 1998 and 2010, in order to be able to combine these into a continuous data set with the measurements made at the Federal Building site using the BAM (Beta Attenuation Mass) instrument from 2011 to 2013.

In order to compare the two instruments, they should be operating over a period of at least a year and in close proximity to each other. In Kamloops this can be done because from October 1st 2010 until May 31st 2011 both a TEOM and a BAM instrument were operated together at the Brocklehurst site; however, in order to complete a full year, BAM measurements for June, July, August and September 2010 were taken from the instrument at the Federal Building and these were compared to the readings from the Brocklehurst TEOM for that same period.

$PM_{2.5}$ refers to airborne particulate matter with aerodynamic diameters equal to or less than 2.5 micrometers. Figure 1 shows the annual average $PM_{2.5}$ in $\mu g/m^3$ for the period from 1998 to 2010 from Brocklehurst **(**black line**)** as measured by TEOM (Tapered Element Oscillating Microbalance) and from 2011 to 2013 from the Federal Building (red line) as measured by the BAM (Beta Attenuation Mass) instruments.

The TEOM uses an older technology and has been replaced by the newer BAM instrument. TEOM instruments underestimate the $PM_{2.5}$ values by several $\mu g/m^3$ as has been widely documented, e.g. Environment Canada (2013).

> "As noted in the Air Quality Indicator web pages, since 2007 the tapered element oscillating microbalance (TEOM) monitors in the National Air Pollution Surveillance (NAPS) program have gradually been replaced by newer monitoring technologies (federal equivalency method [FEM]-approved instruments). Many studies conducted in Canada, the United States and other countries have found that the TEOM monitors under-report concentrations compared to the newer monitors, especially when the air contains a large proportion of semi-volatile particulate matter, which may be the case during cooler seasons when the air contains a greater proportion of ammonium nitrate and semi-volatile organic compounds." (See Environment Canada (EC) in references) (The BAM is a US EPA Federal Equivalency Method (FEM) instrument)

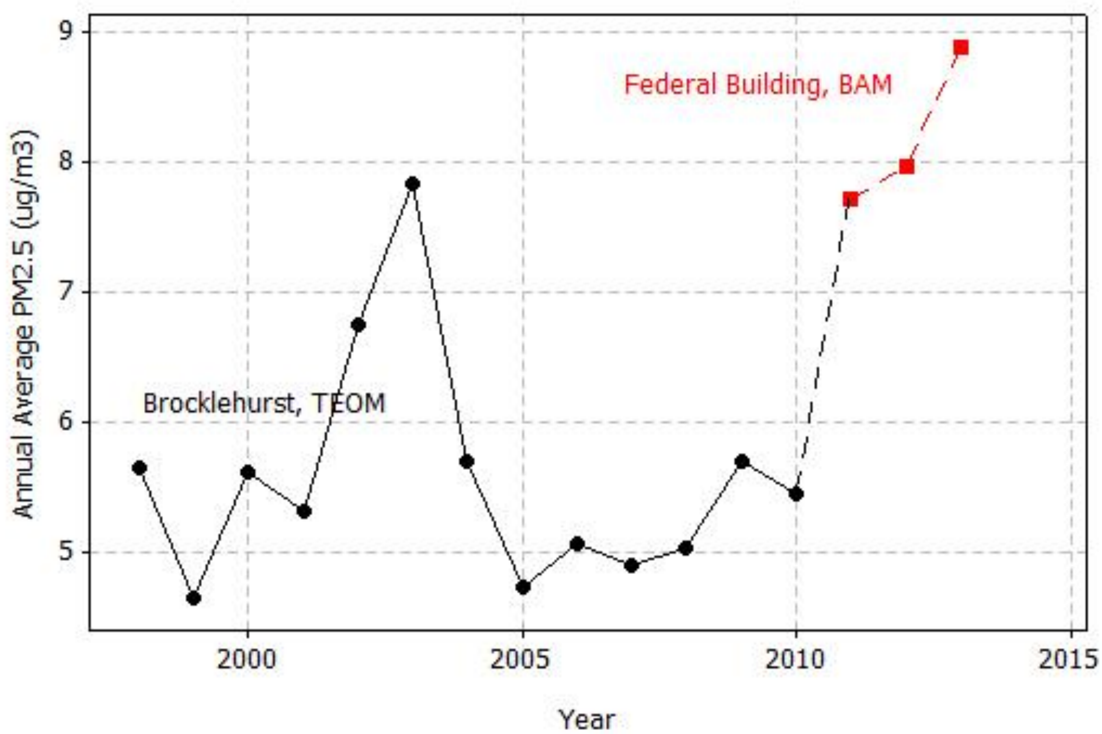

Figure 1: Annual average $PM_{2.5}$ in Kamloops, 1998-2013, as reported at present. The dotted line has been added by the authors to show what would have to be assumed if the TEOM and BAM data are both assumed correct as presently published. All calculations were done from data archived by the B.C. Ministry of the Environment. The annual averages of the $PM_{2.5}$ were calculated from hourly data.

The TEOM data from Brocklehurst will be shown below to be well below what the BAM instrument would have measured in that same period (1998 to 2010). The 2013 annual average of 8.9 $\mu g/m^3$ (BAM instrument) is higher than the 2003 annual average of 7.8 $\mu g/m^3$ (TEOM instrument), which was considered the worst year in the air quality history of Kamloops, due to the August forest fire at Strawberry Hill. The plot, if the TEOM data are not corrected, would imply there is a significant upward trend in $PM_{2.5}$ over the 16 year period. It would indicate that Kamloops air quality has been deteriorating over this period. Is this really the case or has the TEOM severely underestimated the $PM_{2.5}$ level? We find evidence that the latter is the case.

The Offset between the TEOM and BAM Instruments

There are two options open to those concerned about $PM_{2.5}$ values in Kamloops. Either the values from 1998 to 2010 are accepted as reported, in which case there is a massive increase in $PM_{2.5}$ from 2005 to 2013 or, as is well documented in the literature, the TEOM instrument values from 1998 to 2010 need to be corrected.

If the $PM_{2.5}$ annual average is constant with time, as some postulate, then the jump from 2010 to 2011 should be roughly the amount of the offset from the TEOM to the BAM readings. This would be approximately + 3 $\mu g/m^3$.

It is important to note that the BAM data are considered the best we have, or the US EPA and the Canadian federal and provincial governments would not have changed from the TEOM instrument; therefore, it is legitimate to adjust the historical TEOM data to correspond to modern BAM measurements, not the other way around. The error in the TEOM measurements is related to factors such as humidity and will vary from season to season and from location to location.

In the **2012** B.C. air quality report, one frequently asked question is related to this change in the way $PM_{2.5}$ is monitored. Here is that question and its answer:

What is being changed in the way we monitor $PM_{2.5}$, and why?

> "B.C. has brought in new air quality monitors to monitor $PM_{2.5}$ in real time. The old monitors heat the air sample to remove moisture. Heating the air causes part of the sample to evaporate, which results in a lower $PM_{2.5}$ measurement. The new monitors provide a more complete measure of $PM_{2.5}$ by accounting for the particulate matter that wasn't being measured by the older instruments due to evaporation."

And on the next inquiry: "Does this mean that $PM_{2.5}$ measurements will increase with the new monitors and, if so, by how much?" the following answer is provided.

> "Testing to date suggests that $PM_{2.5}$ measurements may increase with the new monitors, but the amount will vary from site to site, depending on the type of particulate matter present and the local temperature. The largest differences are expected in colder areas of B.C. where wood smoke is prevalent. These differences will be better understood with the ongoing collection of more data."

Looking at the Environment Canada (EC) data base for all the instruments in the country (Environment Canada, 2013), EC has determined that the Canada-wide mean PM2.5 was underestimated by about 3 $\mu g/m^3$ in the year 2000 and by around 1.5 $\mu g/m^3$ in 2011. That was for a mix of TEOM and BAM instruments and the difference decreased with time because more BAM instruments were operational in each succeeding year across the country.

For any one city like Kamloops, it may be that the offset is in fact about 3 ug/m^3. This offset would apply to all years that the TEOM was used in Kamloops. A recent study in Paris (Lefranc, A. and B. Chardon, 2014) recognized the annual average $PM_{2.5}$ as measured by the TEOM was too low and used an adjustment to raise it by 4 $\mu g/m^3$.

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Therefore, once we calculate a specific value of the measurement offset for Kamloops, we can add this value onto each of the Brocklehurst TEOM averages for years 1998 to 2010. This adjustment will tell us what the data would have been if the BAM instrument had been in operation for all those years.

Once the TEOM values are adjusted to match current BAM measurements, the revised values will show whether in fact we have had problems meeting the provincial 8 μg/m^3 guideline for a long time (1998 to 2013) in Kamloops. It is then also a long enough period to look at what trend, if any, might be present in the data.

Comparison Period for TEOM and BAM Instruments

We have data from October 1st 2010 until May 31st 2011 from BC MOE when both a TEOM and a BAM instruments were operated together at the Brocklehurst site. For the period June, July, August and September 2010, BAM measurements were taken from the instrument at the Federal Building and these were compared relative to the readings from the Brocklehurst TEOM for that same period. It was necessary to include the summer months in the calculation of the offset required to the annually averaged TEOM data as the difference between the BAM and TEOM is lower during the summer period than it is in the winter period.

The BAM recorded an annual average of 9.0 μg/m^3 during this period from June 2010 to May 2011 (Table 1), while the TEOM recorded an annual average of 5.7 μg/m^3 . The period included the August 2010 forest fires. The average of the difference between the BAM and TEOM values for the entire period June 1st 2010 to May 31st 2011 gives 3.2 μg/m^3 (Table 2). A 95% confidence band is constructed for the difference based on hourly values and it ranges from 3.09 to 3.34.

Table 1: Summary of Statistics for the two instruments from June 1st 2010 – May 31st 2011

Monitor	N	N*	Mean	St Dev	SE Mean	Median	Maximum
BAM	8426	322	9.01	12.75	0.139	6.0	185
TEOM	8563	185	5.66	11.94	0.129	3.4	283

Notes for Table 1: Descriptive statistics for the hourly values. $PM_{2.5}$ hourly values are in μg/m^3. N* is the number of missing hourly values in the BC MOE data for the time period.

Table 2: Summary of Statistics for the difference in $PM_{2.5}$ from the two stations

	N	Mean	St Dev	SE Mean	95% CI	t-test μ=3	p-value	Median
Difference	8257	3.22	5.63	0.062	(3.09, 3.34)	3.48	0.000	3.00

Notes: The difference is computed with 8257 hourly pairs of observations and averaged. In the text it is, therefore, stated as 3.2, not 3.35 as implied by the difference in the mean TEOM and BAM numbers from Table 1. The difference in individual paired values ranged from -147 to +102 μg/m^3.

Table 3 shows the patterns of the monthly averages for the BAM and TEOM measurements. Recall that for June to September 2010 the BAM instrument is at the Federal Building, while the TEOM is from Brocklehurst. Even though there is some distance (7 km) between the two stations, comparisons can still be done as the correlation between the TEOM and BAM measurements of $PM_{2.5}$ during this period is very high at 0.90 (p-value 0.0001) using the hourly values**.** From June 1st 2010 to September 31st 2010 the BAM recorded an average value of 10.95 and the TEOM 7.89 μg/m^3 for a difference of 3.06.

Note that the BAM monthly average is always higher than the corresponding $PM_{2.5}$ monthly TEOM average. The difference is highest during the months of November, December, January and February, while for the rest of the year the difference ranges from 0.74 to 3.24 μg/m^3. The mean monthly differences derived from the hourly values (BAM less TEOM measurement) are in Table 3.

Table 3: Monthly averages (μg/m^3) from TEOM and BAM

	TEOM	BAM	Difference
Jun-10	2.35	4.72	2.36
Jul-10	6.38	9.58	3.20
Aug-10	21.71	22.44	0.74
Sep-10	11.66	14.76	3.10
Oct-10	5.41	7.50	2.09
Nov-10	6.49	10.50	4.00
Dec-10	4.17	8.04	3.87
Jan-11	5.40	10.52	5.12
Feb-11	5.33	9.31	3.99
Mar-11	3.32	6.55	3.24
Apr-11	3.55	6.33	2.78
May-11	3.17	6.23	3.06

Note: see the text for an explanation of the sampling periods and sampling sites.

Adjustment Methodologies

This study calculated the adjustment using three separate approaches. The first approach “the simple mean adjustment approach”, adjusts the TEOM by the average difference between the two instruments. The second approach uses a seasonal regression approach. This approach fits the “best” linear line between the BAM and TEOM available data during the warm and cold seasons. The relationship between the BAM and TEOM measurements is different during the warm relative to the cold season and the seasonal regression accounts for this phenomenon. Once the relationship is estimated, its function is used to adjust the TEOM data. The third approach uses seasonal quantile regressions. The aim of a quantile approach is to estimate the relationship between the median (or other quantiles) of the BAM variable and the TEOM variable. The advantage of using quantile regression analysis is that the estimated relationship is not influenced by extreme outliers such as forest fire observations. We discuss the latter approaches in more detail in the appendix. Here, we present the simple approach.

Simple mean adjustment approach

The simple approach is to add a 3.2 μg/m^3 increase to the TEOM annual average measurements. The increase is the one calculated in this report (Table 1). A 95 percent confidence band is between 3.1 and 3.3 μg/m^3. This band is slightly above the value of 3 μg/m^3 we estimate was used by Environment Canada to adjust years when $PM_{2.5}$ measurements were made across Canada using TEOM instruments (Environment Canada, 2013).

When this adjustment is made to the TEOM measurements in Kamloops (Figure 2) one sees that the city has had average annual values of $PM_{2.5}$ that are near or above the provincial guideline of 8 $\mu g/m^3$ since 1998. A note of caution for the annual average figures of 1998 and 1999: there are about 40 consecutive missing days in each year, which could bias the TEOM reported annual value by an unknown amount in these years. We note this bias but have not examined the impact of the missing data for this report.

The 2003 annual average adjusted $PM_{2.5}$ was approximately11 $\mu g/m^3$. This is the year of the Strawberry Hill fires on the north edge of Kamloops (http://www.city.kamloops.bc.ca/environment/pdfs/12-AirshedBackgroundDoc.pdf). The 2003 adjusted annual average $PM_{2.5}$ exceeded even the Canadian annual average guideline of 10 $\mu g/m^3$ and was well above the BC guideline of 8 $\mu g/m^3$. The original data shown in yellow on Figure 2 are calculated directly from measurements reported in the BC MOE data base. In a future report, we will examine the impact of forest fires on annual average values as measured by the TEOM instrument.

The red line in Figure 2 shows the annual average $PM_{2.5}$ at the Federal Building station. These values are very similar to those shown in the KPHE June 2014 brochure. In that brochure, 24-hour average values were used to compute the annual average, while in this report, hourly values are used resulting in small rounding differences. The analysis procedure was discussed by Tsigaris and Schemenauer (2014). The adjusted $PM_{2.5}$ values show that the 2013 annual average appears at the upper end of the 16-year band of measurements, with the exception of years 2002 and 2003. The previous report (Tsigaris and Schemenauer, 2014) showed that the annual mean $PM_{2.5}$ value for 2013 exceeded the B.C. guideline level of 8 $\mu g/m^3$ at the 95% confidence level. It also showed that annual mean and median values in 2013 were statistically significant higher than both 2012 and 2011 at the 95% confidence interval.

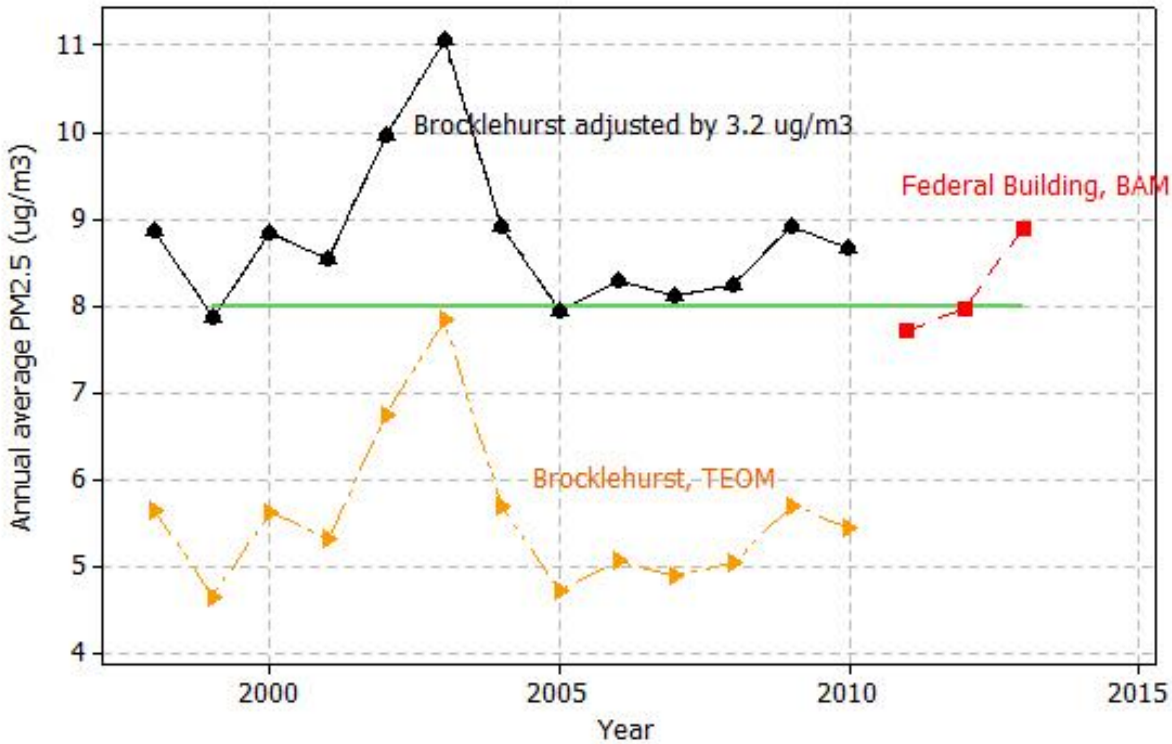

Figure 2: Annual average $PM_{2.5}$ values for Kamloops. The black line shows the measured TEOM values adjusted by the offset factor calculated in this report. The green line is the BC MOE provincial guideline value of 8 $\mu g/m^3$.

The values in yellow are calculated directly from the unadjusted BC MOE data base and were obtained using the old TEOM instrument at the Kamloops Brocklehurst site. The values in black are the adjusted values, as calculated in this report, to show what the measurements would likely be had the modern BAM instrument been in use during the entire period of record. The red dots are the measurements for 2011, 2012 and 2013 using the BAM instrument at the Federal Building in Kamloops. The BC guideline value for maximum desirable annual average $PM_{2.5}$ is shown for reference (green line).

A simplified version of Figure 2 is given in Figure 3. It shows the annual average $PM_{2.5}$ in Kamloops with the TEOM measurements adjusted by 3.2 and combined with the Federal Building annual averages.

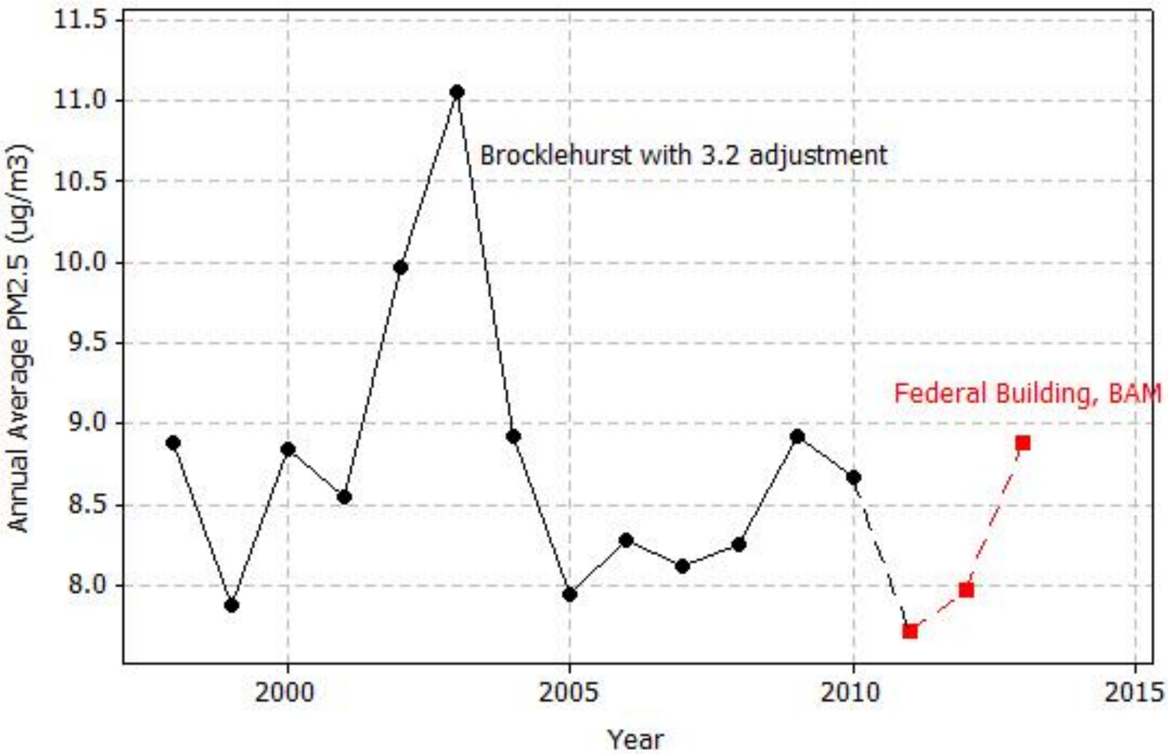

Figure 3: Kamloops annual average PM2.5 adjusted as per the text (black line). Recent $PM_{2.5}$ values unadjusted (red line).

Table 4 shows that the average $PM_{2.5}$ over the 16-year period (1998 to 2013) is 8.7 μg/m^3, with a standard error of the annual mean at 0.21. A 95 percent confidence band of the overall average ranges from 8.22 to 9.13. Hence, over the 16 year period we can reject the null hypothesis that the average of the annual mean average $PM_{2.5}$ is 8 μg/m^3 at the 5 percent level of significance (i.e. 95 percent confidence). Figure 4 shows the histogram of the frequency of the annual averages including both the adjusted TEOM and unadjusted BAM (recent) values.

Table 4: Summary of Statistics for the annual $PM_{2.5}$ from 1998 to 2013

	N	Mean	St Dev	SE Mean	95% CI	t-test μ=8	p-value	Median
Annual PM2.5	16	8.68	0.85	0.21	(8.22, 9.13)	3.18	0.006	8.61

Notes: Descriptive statistics for the annual average values. $PM_{2.5}$ hourly values in μg/m^3 .

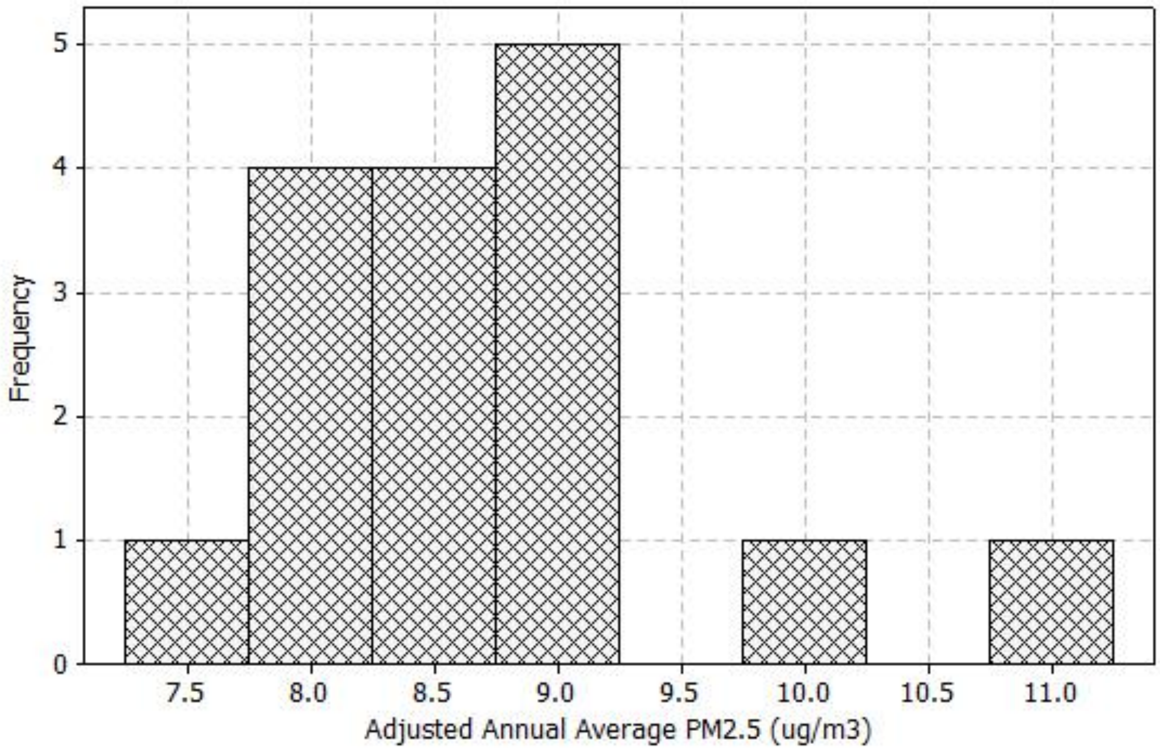

Figure 4: Histogram showing the frequency of annual mean $PM_{2.5}$ values in Kamloops, for the years 1998 to 2013, after the adjustment calculated in this report for the years 1998 to 2010.

Alternative approaches to the calculation of a $PM_{2.5}$ offset between the TEOM and BAM instruments, where the data in the warm and cold seasons are fitted with regression lines that are used to adjust the TEOM data are explored in the appendix to this report. The simple approach discussed above is within the regression band shown in the appendix and hence the simple approach follows closely the regression results in adjusting the TEOM average annual figures.

Conclusions

In order to look at the historical data for measurements of fine particulate matter ($PM_{2.5}$) in the air in Kamloops, it is necessary to reconcile the measurements made with the older TEOM instrument to those presently being made with the BAM instrument in Kamloops. The BAM is acknowledged in Canada, the USA and in Europe as producing more accurate measurements of $PM_{2.5}$.

Adjustments to the TEOM data are being made world-wide and in this report we present the first published calculations of the offset between the two instruments for the data collected in Kamloops. Three different approaches to determining the offset were examined, an averaging approach and two regression approaches. The results were very similar, although the regression approaches generated a slightly higher offset. We chose to illustrate the offset from the averaging calculation in the main body of the paper and leave the more advanced approaches to the appendix. As noted in the text, there are two interpretations open to those concerned about $PM_{2.5}$ values in Kamloops. Either the TEOM values from 1998 to 2010 are accepted as reported, in which case there is a substantial increase in $PM_{2.5}$ from 2005 to 2013 or, as is well documented in the literature, the TEOM instrument values from 1998 to 2010 have to be corrected.

It was found in this report, using the simple method, that it is necessary to increase the annual average values of $PM_{2.5}$ by 3.2 $\mu g/m^3$ so that the TEOM values agree with what the modern BAM instrument would have measured. This adjustment results in the annual averages for all 16 years being near or above the B.C. guideline value of 8 $\mu g/m^3$. The calculated overall mean for the 16 years, using the simple adjustment method, is 8.7 $\mu g/m^3$ and we can say at the 95% confidence level that the long-term mean $PM_{2.5}$ value in Kamloops is above the B.C. guideline value of 8 $\mu g/m^3$, with each of the three approaches. The average values for the individual years were in the band from 7.6 to 11 $\mu g/m^3$.

We conclude that Kamloops average concentrations of fine particulate matter in the air, over the period of record 1998 to 2013, exceeded the standard set by the Province of British Columbia for the protection of the population. The impacts this may have had on the health of the people of Kamloops should be addressed.

Acknowledgement

We would like to acknowledge a reviewer at Thompson Rivers University who carefully examined the statistical data and conclusions presented in this report.

Source for the Data

The measurements were made by the British Columbia Ministry of the Environment, who also did the quality assurance and quality control of the measurements.

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Appendix follows on the next page.

Appendix

Regression approach

In this appendix we estimate seasonal linear regressions to adjust the TEOM data as has been done in many U.S. and Canadian studies. Seasonal linear regressions yield conditional predictions (expectations) of the BAM measurement that are based on the observed TEOM measurement for that hour of the year. The cooler season for the Kamloops comparison data is from November 1st 2010 to February 28th 2011. The warmer season in Kamloops is from June 1st 2010 to October 31st 2010 and again from March 1st 2011 to May 31st 2011. Figure A1 below shows a scatter plot for the cold season, Figure A2 shows a scatter plot for the warm season including three extremely high values arising from the August 2010 forest fires, while Figure A3 excludes the three observations. Note that, in this case only, all three figures have used the 24 hour average values and not the hourly values for illustrative purposes.

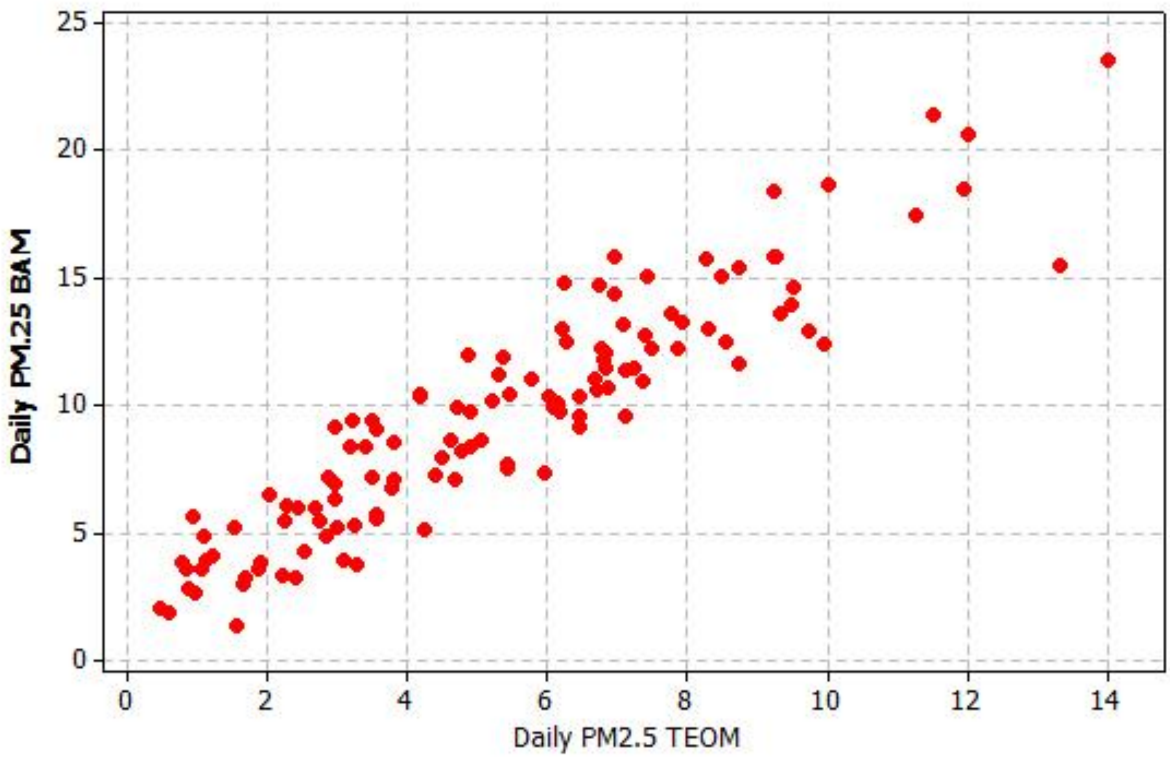
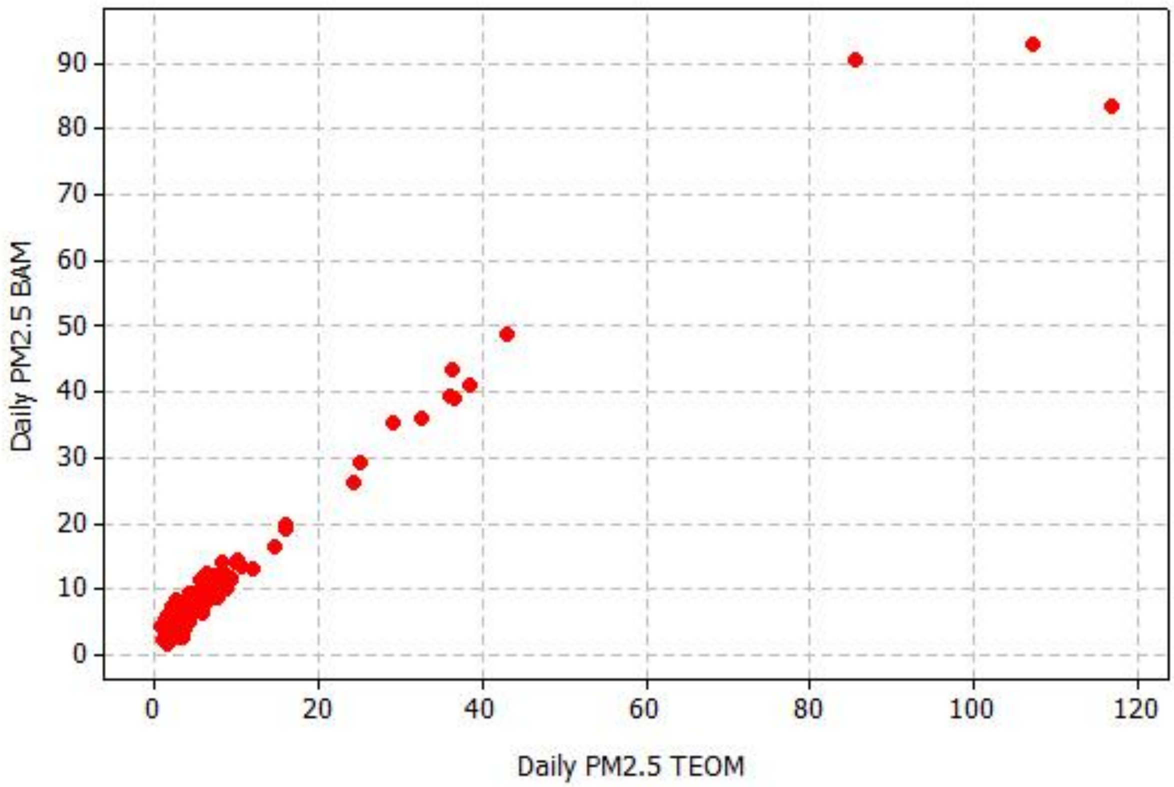


Figure A1: Cold season – based on the 24 hour average $PM_{2.5}$ values from November 1st 2010 to February 28th 2011



FigureA2: Warm season – based on the 24 hour average $PM_{2.5}$ values from June 1st 2010 to October 31st 2011 and from March 1st 2011 to May 31st 2011. Three high values from forest fire days are included.

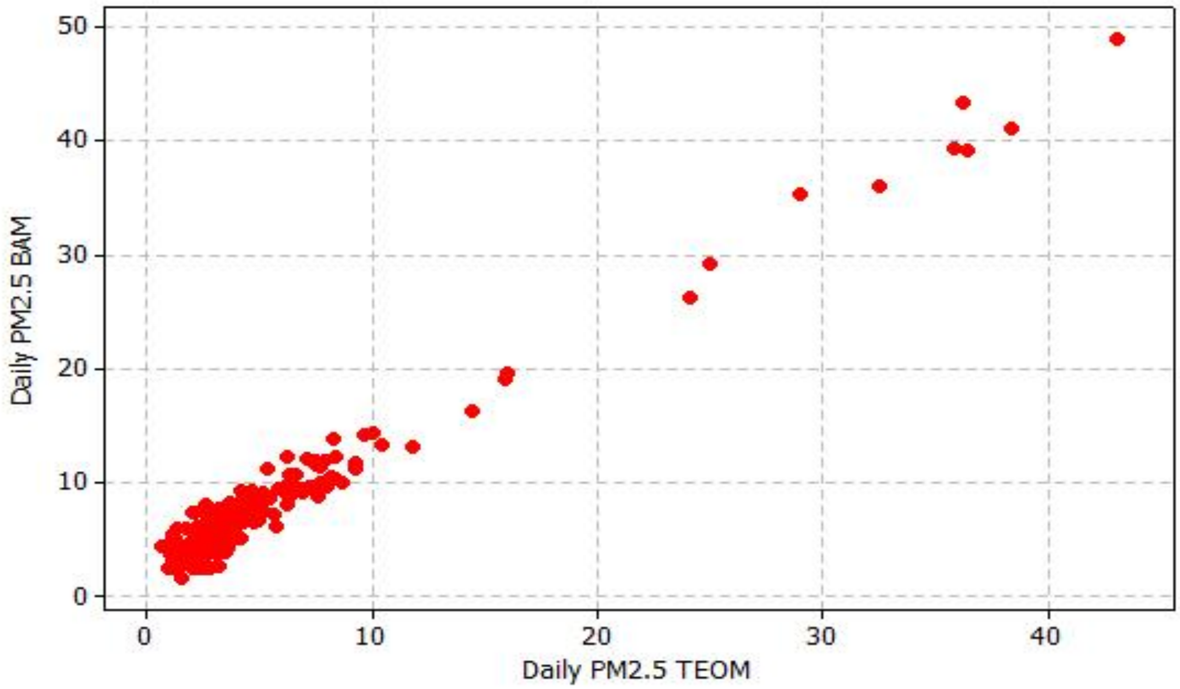


Figure A3: Warm season – based on the 24 hour average $PM_{2.5}$ values from June 1st 2010 to October 31st 2011 and from March 1st 2011 to May 31st 2011 excluding August 19-21st observations.

The forest fires in August 2010 are included in the warm period and they have a big influence on the estimated coefficients. Due to this outlier effect, we ran a separate regression without the August 19 to 21st 2010 $PM_{2.5}$ hourly values.

Once the linear relationship between TEOM and BAM is estimated we then use the estimated coefficients to forecast backwards the equivalent hourly BAM values. We do this back forecasting for all the previous years' recorded TEOM values. We then average these equivalent hourly $PM_{2.5}$ values based on the predicted BAM values to get an estimate of the annual average $PM_{2.5}$. These would be the predicted $PM_{2.5}$ annual average in the previous years had the BAM been installed from 1998 and onwards. Given that regressions with an intercept term pass through the sample means, we expect the new annual adjustments from these methods to be fluctuating around the unconditional 3.2 $\mu g/m^3$ adjustment.

Table A1 provides the results of the regression analysis. All coefficients are statistically significant at the 1% level of significance. The adjusted R-Square indicates a very good fit of the TEOM data to the BAM data.

The intercept term shows the estimated BAM $PM_{2.5}$ value when TEOM reports a $PM_{2.5}$ zero value. For example, if the TEOM reported a zero $PM_{2.5}$ hourly value then the estimated BAM is 2.65 $\mu g/m^3$ during the cold period and 3.47 during the warm period with forest fires. The slope indicates direction. When the TEOM measurements increase, the BAM measurements also increase and vice versa on average. The slope shows how the BAM is expected to change given a unit change in the TEOM. A slope that is higher than one indicates that a one unit change in the TEOM is expected to lead to a more than a one unit BAM recording. This appears to happen in the cold season. In the warm period the BAM change will be smaller given a one unit change in the TEOM measurement. In the warm season the BAM will change by less than a unit for every unit change in TEOM. When the slope coefficient is less than one there is a cut-off value. The cut-off value represents the value where the TEOM and BAM are equal. Below this cut-off value TEOM underestimates and above this value the TEOM overestimates.

The results indicate that during the cold season, the TEOM is underestimating BAM values. During the warm period the TEOM underestimates for low $PM_{2.5}$ values and overestimates for high $PM_{2.5}$values. During the warm period the slope is less than one. For the warm period including the intense forest fires period, the cut-off TEOM value is 25.3. The TEOM underestimates for values below 25.3 and overestimates for values above 25.3. The TEOM underestimates for values below 90.3 and overestimates for higher values when the forest fires are excluded.

Excluding the forest fire hourly observations reduces the intercept term of the warm period considerably from 3.49 to 2.98 and increases the slope from 0.86 to 0.97 $\mu g/m^3$.

Table A1: Seasonal linear regression results, TEOM to BAM

Period of study	Number of days	Intercept	Slope	Adjusted R-Square	Standard error of regression
Cold period	2852	2.65 (0.094)	1.30 (0.014)	0.763	3.22
Warm period with forest fires	5405	3.47 (0.089)	0.863 (0.006)	0.809	6.09
Warm period without forest fires	4786	2.98 (0.077)	0.967 (0.008)	0.723	4.76

Note: the values in the parentheses are the standard errors of the estimated coefficients. Forest fires excluded were the hours from the three days of highly elevated observations observed on August 19th to 21st 2010.

Table A2 reports the regression coefficients from the Canada wide study conducted in 2013 for TEOM to SHARP (FEM) monitors as reported in the Environment Canada (2013) based on two studies conducted by Dann (2012, 2013). The slope coefficients are similar to those in Kamloops but the intercept terms are lower in the Canada wide study of a switch from TEOM to SHARP relative to the Kamloops switch from TEOM to BAM. A summary of other studies can be accessed at: http://www.ec.gc.ca/indicateurs-indicators/default.asp?lang=En&n=BA9D8D27-1&offset=5&toc=show#fnb1

Table A2: Regression coefficients from Canada wide study

TEOM to SHARP Monitors		Intercept	Slope
Canada (2013)			
	Cold period	1.35	1.49
	Warm period	1.37	0.92

Note: Adapted from Environment Canada, 2013 table 18 page 21: Data Sources and Methods for the Air Quality Indicators.

Quantile Regression Approach

We also ran quantile regression analysis for values taken over the warm and cold period. Simple linear regression estimates the conditional mean of the BAM measurements, conditional on the values of the TEOM instrument. Quantile regression aims at estimating the conditional median (or other quantiles) of the BAM variable. The advantage of using quantile regression analysis is that the estimated relationship is not influenced by extreme outliers such as forest fire observations. It also allows one to see the conditional response of the measures of central tendency that go beyond the conditional means. Table A3 reports the quantile linear regressions results for the median (i.e., quantile of 0.5)

Table A3: Quantile linear regression results, TEOM to BAM

Period of study	Number of days	Intercept	Slope	Adjusted R-Square	Standard error of regression
Cold period	2852	2.253 (0.111)	1.34 (0.021)	0.523	3.23
Warm period with forest fires	5405	2.785 (0.079)	0.935 (0.019)	0.413	6.19
Warm period without forest fires	5349	2.91 (0.094)	0.903 (0.026)	0.351	4.80

Note: the values in the parentheses are the standard errors of the estimated coefficients. Forest fires excluded were the hourly data for the three days of highly elevated observations observed on August 19th to 21st 2010.

The quantile approach shows the median BAM is expected to change by more than one unit for a unit change in TEOM during the cold period. As in the linear regression, the impact on BAM from a change in TEOM is bigger in the cold season than in the warm period. The quantile approach, as expected, yields similar estimated coefficients with the linear regression for the cold period as there are no significant outliers in the cold period. It also yields similar results with the linear regression when the forest fires observations are excluded from the regression in terms of the estimated coefficients. Contrary to the warm period linear regression model, the quantile approach shows that the estimated coefficients are stable with forest fires included or without forest fires.

Predictions from the different approaches

We predicted the annual average $PM_{2.5}$ for the period 1998-2013 using the linear regression with and without the forest fires included, using the simple approach as discussed in the main text and using the quantile approach. Table A4 gives the predicted annual average $PM_{2.5}$. Linear regression, with forest fires included during the warm period, is reported as regression adj. 1. The regression analysis without the forest fires is labelled regression adj. 2. The simple approach and quantile regression predictions are also shown. The lower and upper bounds of the estimated BAM adjustment of the regression adj. 1 is shown as well. These are constructed by adding (upper bound) and subtracting (lower bound) 1.967 times the standard errors of the estimated coefficients. The last three years show the values estimated from the Federal building BAM instruments.

The quantile predictions are below the regression and simple adjustment. They are closer to the lower bound of the regression adj. 1. This is to be expected as the quantile regression predicts the conditional median and not the mean value. The regression adj. 1 adjusts the TEOM by a larger amount, an average of about 0.1 $\mu g/m^3$, relative to the simple adjustment.

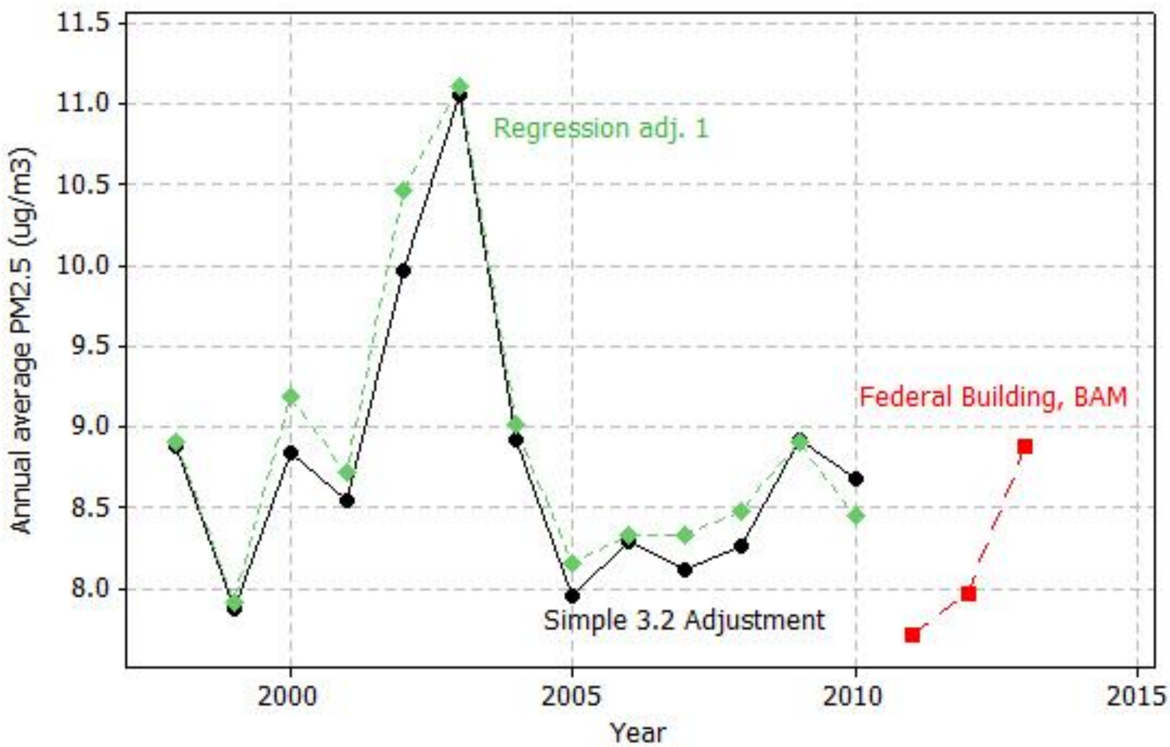
The overall average over the 16 year period with the regression adj 1 is 8.78 $\mu g/m^3$ while with the 3.2 $\mu g/m^3$ adjustment, the overall average over the 16 year period, is 8.68 $\mu g/m^3$. Using the regression adj 2 the overall average over the 16 year period is 8.72 $\mu g/m^3$.

The average over the 16 year period with the lower bound regression adj. 1 is 8.56 $\mu g/m^3$ and the upper bound regression adjustment is 9.00 $\mu g/m^3$. Hence with the regression analysis we can be 95 percent confident that the overall average of the annual averages is within the 8.56 and 9.00 $\mu g/m^3$ range. The simple approach gives a 95 percent confidence range that is from 8.22 to 9.13 $\mu g/m^3$. The more advanced regression analysis gives a narrower range to that of the simple method approach. Most of the values from the simple approach fall within the confidence interval of the regression analysis.

Table A4: Adjusted BAM values (μg/m^3) for Kamloops: 1998 - 2010

Year	Low bound adj. 1	Regression adj. 1	Regression adj. 2	Simple adj.	Quantile Regression	Upper bound adj 1
1998	8.63	8.90	8.85	8.87	8.65	9.17
1999	7.66	7.92	7.81	7.87	7.59	8.17
2000	8.90	9.18	9.08	8.84	8.90	9.46
2001	8.44	8.71	8.63	8.54	8.43	8.99
2002	10.15	10.46	10.38	9.96	10.23	10.76
2003	10.80	11.11	11.13	11.05	10.98	11.42
2004	8.73	9.01	8.94	8.92	8.75	9.28
2005	7.88	8.15	8.03	7.95	7.82	8.41
2006	8.07	8.33	8.24	8.28	8.04	8.59
2007	8.06	8.33	8.22	8.12	8.01	8.60
2008	8.21	8.48	8.37	8.25	8.17	8.75
2009	8.63	8.91	8.85	8.92	8.66	9.18
2010	8.27	8.45	8.41	8.67	8.26	8.63
2011	7.71	7.71	7.71	7.71	7.71	7.71
2012	7.97	7.97	7.97	7.97	7.97	7.97
2013	8.88	8.88	8.88	8.88	8.88	8.88
Avg	8.56	8.78	8.72	8.68	8.57	9.00

Figure A2 shows the regression adj. 1 and the simple adjustment. As stated above the seasonal regression approach adjustment is bigger than the simple approach by an average difference of approximately 0.1 μg/m^3 but both annual averages are highly correlated.



FigureA2: Regression approach and simple adjustment

Table A5 provides a summary of the four alternative approaches for the 1998 to 2013 period. All four methods yield very similar results. The mean of the annual average $PM_{2.5}$ ranges from 8.6 to 8.8 μg/m^3. The median ranges from 8.4 to 8.6 μg/m^3. In all cases, the test rejects the hypothesis that the overall average of the annual average $PM_{2.5}$ is equal to the B.C. guidelines of 8 μg/m^3.

Table A5: Summary of four alternative statistical approaches: 1998 - 2013

Statistical measure	Regression adj. 1	Regression adj. 2	Simple 3.2 adj	Quantile Regression
Mean $PM_{2.5}$	8.78	8.72	8.68	8.57
Median $PM_{2.5}$	8.60	8.52	8.61	8.35
Standard deviation	0.90	0.91	0.85	0.91
Standard error of mean	0.22	0.23	0.21	0.23
95% confidence interval	(8.30-9.26)	(8.24-9.21)	(8.22-9.13)	(8.08-9.05)
t-test: μ=8	3.48	3.16	3.18	2.50
p-values	0.003	0.006	0.006	0.024

Note: $PM_{2.5}$ values are in μg/m^3.