Field Trial of the Aeroqual AQS 1 in Calgary, Canada

August - October 2023

Authors

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January 2024

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Introduction

A 3-month co-location trial of an Aeroqual AQS 1 at a reference monitoring station was carried out in Calgary, Alberta, Canada. The AQS 1 was configured to measure ozone (O_3), nitrogen dioxide (NO_2), and $PM_{2.5}$.

This report details the results of the trial. The AQS 1 measurements were analyzed and compared with the reference station measurements using the field test metrics defined in ASTM D8406.

The AQS 1 data has also been used to calculate the Canadian Air Quality Health Index (AQHI) for the duration of the test period and compared with that calculated by the reference station. The AQHI is a metric developed by Environment Canada and Health Canada that provides a numerical measure of air quality. It is used to communicate air quality and the risks associated with the current air quality to the public. Ozone, nitrogen dioxide and $PM_{2.5}$ are used to calculate the AQHI.

Methods

Test Site

The test site selected for the trial was operated by the Calgary Region Airshed Zone (CRAZ) agency. The test site was the Calgary Inglewood reference station, which was adjacent to the Inglewood Bird Sanctuary (latitude 51.0305, longitude -114.0093). The location of the site is shown in Figure 1 (indicated by the red box). The pollutant sources in the area included a bird sanctuary, a residential area, a busy highway (the Deerfoot Trail), and a trucking company that is immediately southeast of the station.

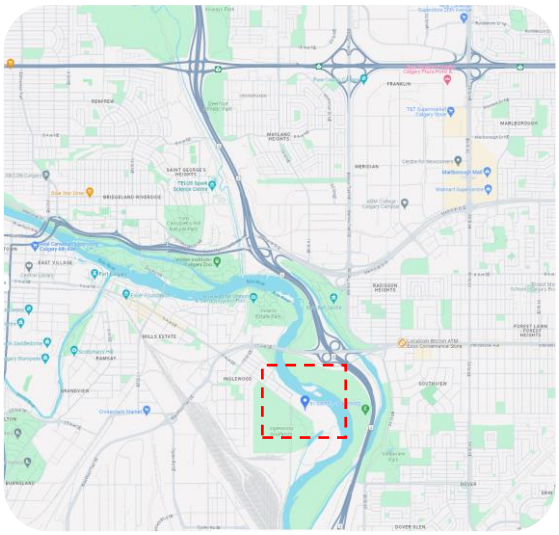

Figure 1: Location of the CRAZ Calgary Inglewood reference station.

The CRAZ reference station contained a Teledyne T640 for $PM_{2.5}$, a Thermo Scientific Model 49i Ozone Analyzer, and a Thermo Scientific Model 42i NO-NO_2-NO_x Analyzer. The reference instruments were installed inside the station's temperature-controlled shed, with their sampling inlets penetrating through the roof of the shed.

The AQS 1 (serial number 12062023-2342) was installed on the roof of the CRAZ reference station, Figure 2. The AQS 1 contained an O_3 module, a NO_2 module and nephelometer PM module with a $PM_{2.5}$ sharp cut cyclone. Further details about the Aeroqual modules can be found on the Aeroqual website (https://www.aeroqual.com/).

Data Sources

Data from the CRAZ Inglewood reference site were downloaded as hourly averaged data from the CRAZ website (https://craz.ca/monitoring/calgary-central/) for field calibration purposes, but post-trial comparative analysis was undertaken using the QA/QC data for the site from the Alberta Air Data Warehouse (https://www.alberta.ca/alberta-air-data-warehouse). Data for the AQS 1 were downloaded as hourly averaged data from Aeroqual Cloud.

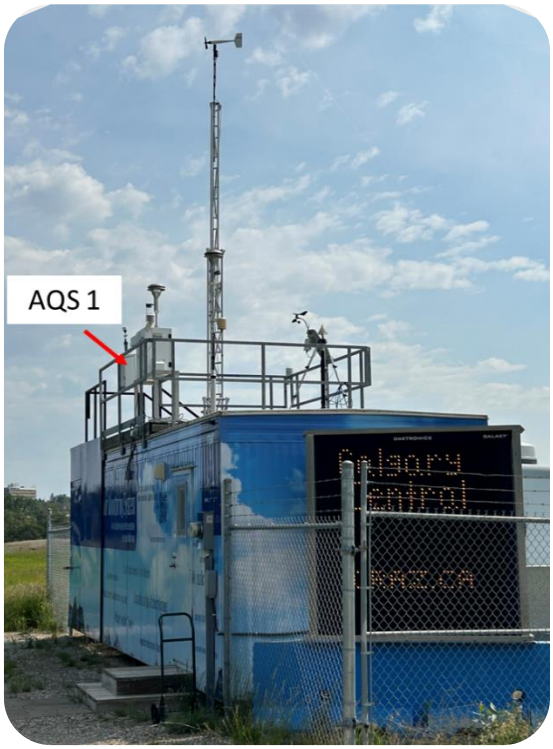

Figure 2: Calgary Inglewood reference station with AQS 1 installed on the roof.

Field Calibration

The AQS 1 was installed on June 27th, 2023. A field calibration of the AQS 1 O_3 and NO_2 modules was performed against the CRAZ reference data during the period July 13th to July 25th, 2023. CRAZ changed the reference $PM_{2.5}$ instrument from a Thermo 5030i to a Teledyne T640 on 1st August. Hence the AQS 1 $PM_{2.5}$ module was field calibrated against the CRAZ reference data for the period 1st to 8th August. New gains and offsets were calculated using a standard linear regression (Table 1) and applied on August 8th. No further changes were made for the duration of the test.

Table 1: Gains and offsets calculated for the AQS 1 using a linear regression.

AQS 1 Sensor	Old gain	Old offset	New gain	New offset
O_3	1	0	1.35	-1.1
NO_2	1	0	1.09	3.6
$PM_{2.5}$	1	0	1.39	0

Test Period

The test period ran from August 9th to October 30th, 2023. The temperature and relative humidity for this period are shown in Figure 3 and the conditions and pollutant concentration ranges are given in Table 2.

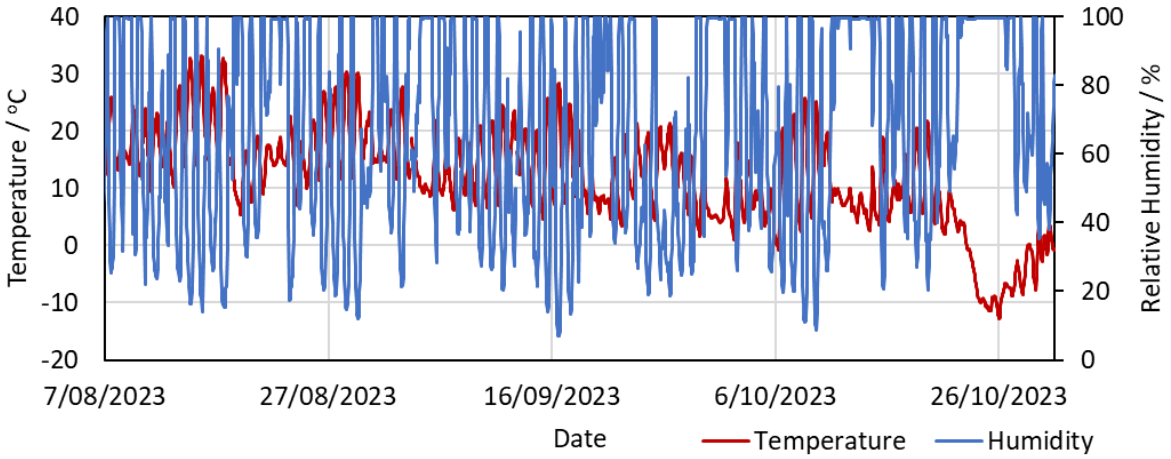

Figure 3: Relative humidity and temperature for the test period.

Table 2: Meteorological conditions and pollutant concentration ranges for the duration of the test period.

Parameter	Range
Temperature	-13 – 33 °C
Relative Humidity	7 – 99%
O_3	0 – 70 ppb
NO_2	0 – 43 ppb
$PM_{2.5}$	0 – 134 µg m^{-3}

Data Exclusions

The AQS 1 experienced a power outage from October 26th - October 27th, and therefore no AQS 1 data were recorded at this time.

Data Analysis

It was noted that the CRAZ hourly data were time-stamped as time ending whereas the Aeroqual AQS 1 hourly data were time-stamped as time beginning. Hence the AQS 1 data were adjusted to be time synchronized to the CRAZ data. Hourly averaged data for CRAZ were downloaded from the Alberta Air Data Warehouse and Aeroqual Cloud for $PM_{2.5,}$ NO_2 and O_3. The $PM_{2.5}$ data were then averaged to a 24-hour average using a midnight to midnight time period. Time series and correlation scatter plots were created for each pollutant versus the reference data. The performance of the AQS 1 versus the reference station was evaluated according to the field method defined in ASTM D8406.[1] Metrics were calculated using hourly data for O_3 and NO_2, and 24-hour data for $PM_{2.5}$. The data were also evaluated according to the EU Guidance for the Demonstration of Equivalence of Ambient Air Quality Methods[2] and the expanded relative uncertainty calculated using the equivalence calculator spreadsheet published by the European Joint Research centre[3].

The AQHI was calculated using both the AQS 1 data and the CRAZ reference data according to the method outlined in Stieb et al.[4].

Results

Ozone

Figure 4 shows the time series plots for the AQS 1 and reference ozone concentration measurements, and Figure 5 shows the scatter plot comparing the two data sets. Table 3 gives the different metrics calculated based on ASTM D8406. These results demonstrate the O_3 AQS 1 module shows good agreement with the reference data, with a strong correlation (R^2 = 0.98) and low drift (MAE = 3.0 ppb) over the co-location period. The data capture rate was 97.6% due to a power outage on 26/27th October.

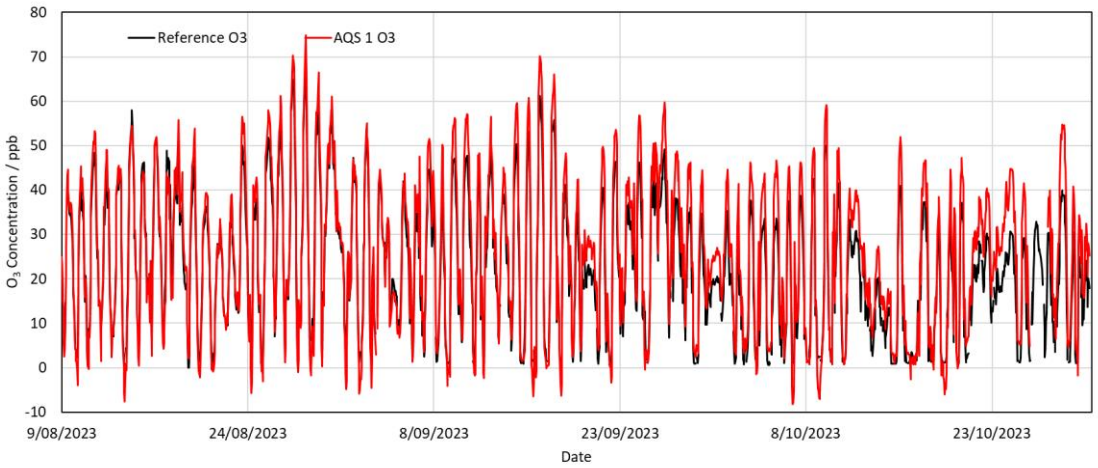

Figure 4: Hourly time series data for AQS 1 and Thermo Scientific Ozone Analyzer from August 9th to October 30th, 2023, for the Calgary Inglewood station.

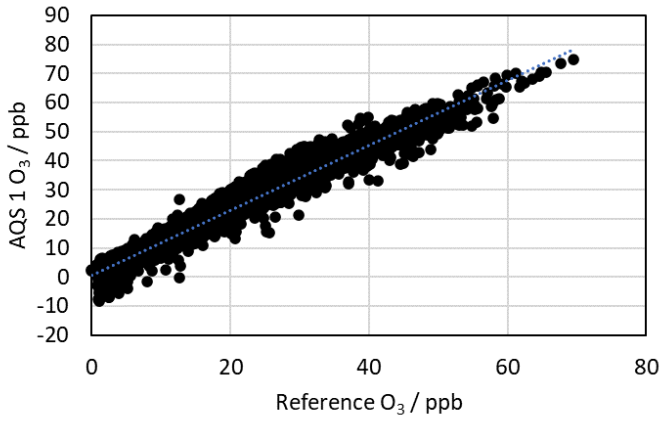

Figure 5: Scatter plot comparing hourly AQS 1 ozone module and Thermo Scientific Ozone Analyzer data for the Calgary Inglewood station from August 9th to October 30th, 2023.

Table 3: Metrics calculated for the ozone module using ASTM D8406.

Metric	Value
Data Capture Rate	97.6 %
Intercept	-1.9 ppb
Slope	1.12
R^2	0.98
MAE	3.0 ppb
RMSE	3.8 ppb

The expanded relative uncertainty between the AQS 1 instrument and the reference ozone instrument was evaluated (Figure 6) at the limit value of 76 ppb, based on the Alberta 1-hour ambient air quality objective for ozone[5]. The AQS 1 ozone exhibited an expanded relative uncertainty of 8.8% which was within the requirement of less than 15% to demonstrate equivalence to the reference method.

EQUIVALENCE TEST (CALIBRATED)		
Calibration	**0.869y + 0.124**	
u(calibration)	**0.48**	ppb
Random term	3.34	ppb
Additional uncertainty (optional)	0.00	ppb
Bias at LV	-0.20	ppb
Combined uncertainty	3.34	ppb
Expanded relative uncertainty	**8.8%**	***pass***
Ref sampler uncertainty	0.67	ppb
Limit value	76	ppb

Figure 6: Calculation of expanded relative uncertainty for the AQS 1 versus the Thermo Scientific ozone analyzer.

Nitrogen Dioxide

Figure 7 shows the time series plots for the AQS 1 and reference NO_2 measurements, and Figure 8 shows the scatter plot comparing the two data sets. Table 4 gives the calculated metrics for this dataset. Again, there is good agreement between the reference and AQS 1 data sets. The R^2 of 0.97 indicates an excellent correlation and the low MAE (1.3 ppb) shows low drift. The data capture rate was 97.6% due to a power outage on 26/27th October.

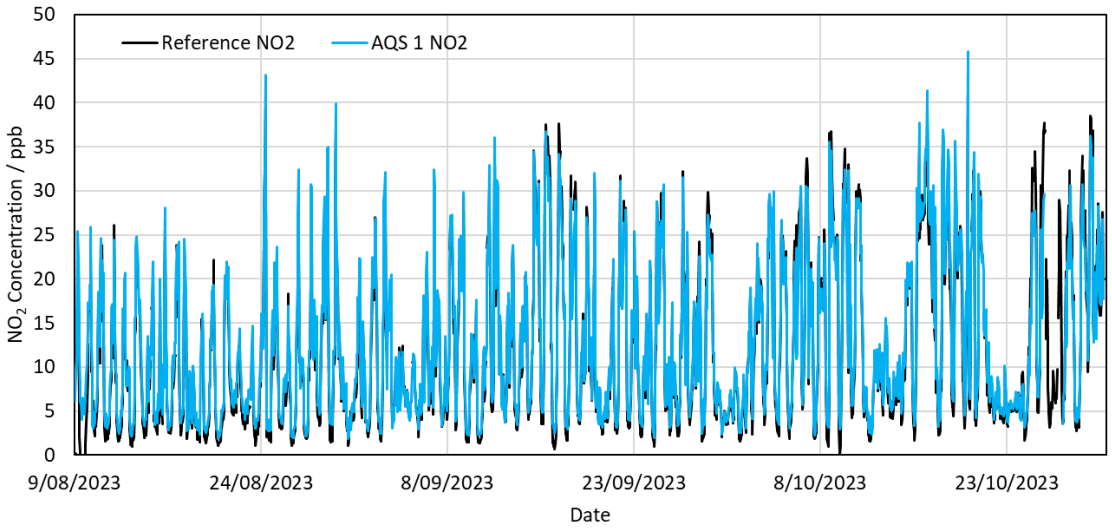

Figure 7: Hourly time series for AQS 1 and Thermo Scientific NO-NO_2-NO_x Analyzer from August 9th to October 30th, 2023, for the Calgary Inglewood station.

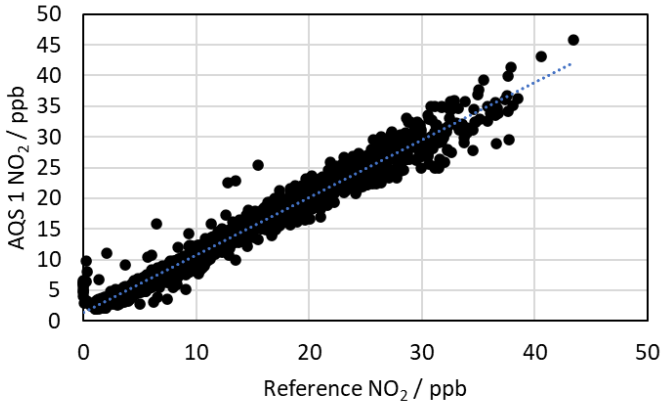

Figure 8: Scatter plot comparing hourly AQS 1 NO_2 module and Thermo Scientific NO-NO_2-NO_x Analyzer data for the Calgary Inglewood station from August 9th to October 30th, 2023.

Table 4: Metrics calculated for the NO_2 dataset based on ASTM D8406.

Metric	Value
Data Capture Rate	97.6 %
Intercept	1.32 ppb
Slope	0.96
R^2	0.97
MAE	1.3 ppb
RMSE	1.7 ppb

The expanded relative uncertainty between the AQS 1 and the reference NO_2 instrument was evaluated at the limit value of 159 ppb (Figure 9), based on the Alberta 1-hour ambient air quality objective for NO_2[5]. The AQS1 NO_2 exhibited an expanded

relative uncertainty of 1.7% which was within the requirement of less than 15% to demonstrate equivalence to the reference method.

EQUIVALENCE TEST (CALIBRATED)		
Calibration	**1.046y -1.178**	
u(calibration)	**0.56**	ppb
Random term	1.38	ppb
Additional uncertainty (optional)	0.00	ppb
Bias at LV	0.07	ppb
Combined uncertainty	1.38	ppb
Expanded relative uncertainty	**1.7%**	***pass***
Ref sampler uncertainty	0.67	ppb
Limit value	159	ppb

Figure 9: Calculation of expanded relative uncertainty for the AQS 1 versus the Thermo Scientific NO_2 analyzer.

$PM_{2.5}$

Figure 10 gives the time series and Figure 11 gives the scatterplot for the calibrated $PM_{2.5}$ AQS 1 data compared with the Teledyne T640 data over the co-location period. Table 5 gives the performance metrics calculated. The $PM_{2.5}$ module shows good agreement with the reference instrument. The R^2 of 0.98 indicates a strong correlation with the reference instrument and the low MAE (3.3 µg m^{-3}) demonstrates low drift. The data capture rate was 97.6% due to a power outage on 26/27th October.

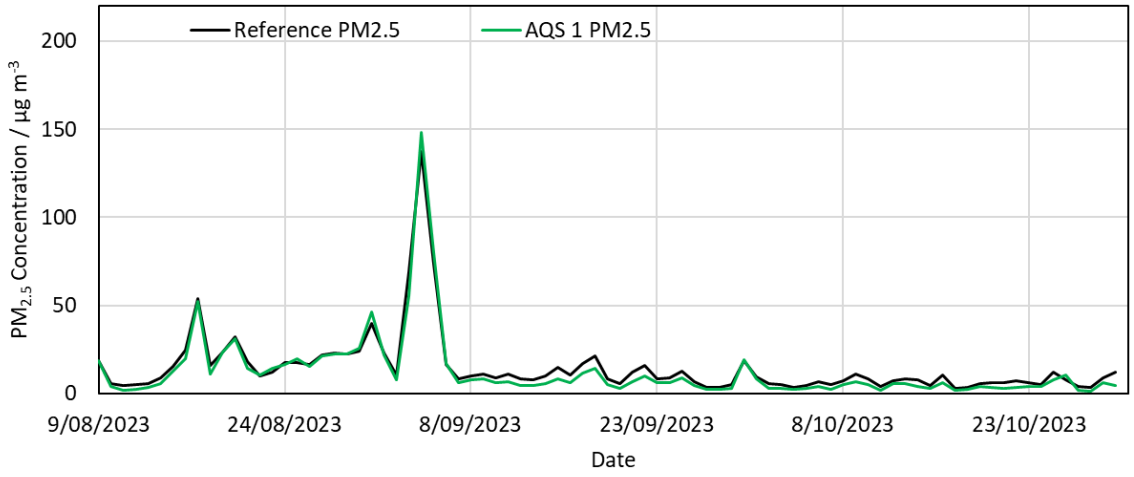

Figure 10: 24-hour time series data showing AQS 1 $PM_{2.5}$ data and the Teledyne T640 $PM_{2.5}$ data from August 9th to October 30th, 2023, for the Calgary Inglewood reference station.

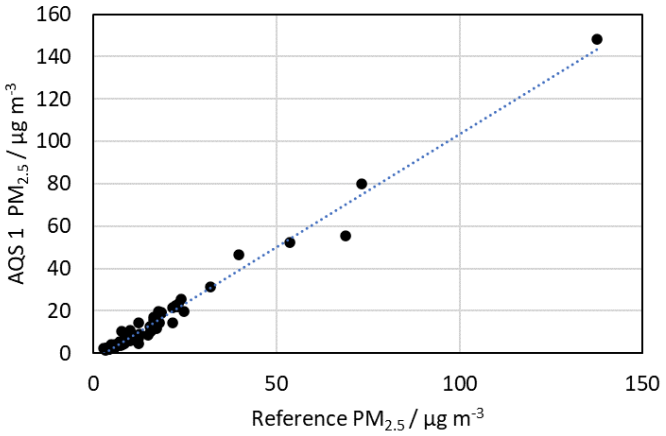

Figure 11: Scatter plot comparing the 24-hour AQS 1 $PM_{2.5}$ data and the Teledyne T640 $PM_{2.5}$ data from August 9th to October 30th, 2023, for the Calgary Inglewood reference station.

Table 5: Metrics calculated for the $PM_{2.5}$ dataset based on ASTM D8406.

Metric	Value
Data Capture Rate	97.6 %
Intercept	-3.41 µg m^{-3}
Slope	1.08
R^2	0.98
MAE	3.3 µg m^{-3}
RMSE	4.2 µg m^{-3}

The expanded relative uncertainty between the AQS 1 and the reference $PM_{2.5}$ instrument was evaluated at the limit value of 29 µg m^{-3}, the 24-hour ambient air quality objective for $PM_{2.5}$ for Alberta[5] (Figure 12). The AQS 1 exhibited an expanded relative uncertainty of 18.0% which met the requirement of less than 25% to demonstrate equivalence to the reference method.

EQUIVALENCE TEST (CALIBRATED)		
Calibration	**0.927y + 3.037**	
u(calibration)	**0.63**	µg/m³
Random term	2.61	µg/m³
Additional uncertainty (optional)	0.00	µg/m³
Bias at LV	-0.01	µg/m³
Combined uncertainty	2.61	µg/m³
Expanded relative uncertainty	**18.0%**	***pass***
Ref sampler uncertainty	0.67	µg/m³
Limit value	29	µg/m³

Figure 12: Calculation of expanded relative uncertainty for the AQS 1 versus the Teledyne T640 $PM_{2.5}$.

AQHI Calculation

The AQHI is a multipollutant health index that is used to communicate the risk of current air pollution to the community. The AQHI numerical value was calculated using both the AQS 1 data and the reference data for the Calgary Inglewood station for the duration of the test period and plotted in Figure 13. There is very strong agreement between the reference AQHI and the AQS 1 AQHI.

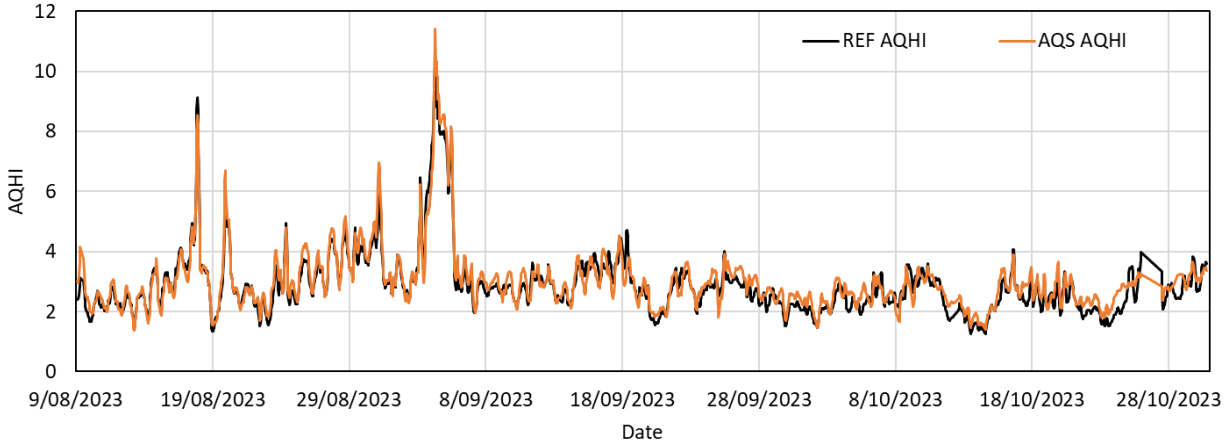

Figure 13: Hourly AQHI calculated using the AQS 1 data and the reference station data from August 9th to October 30th, 2023, for the Calgary Inglewood reference station.

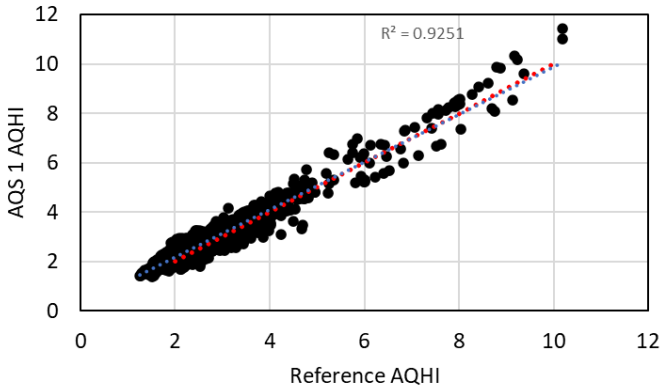

Figure 14: Scatter plot comparing the AQHI calculated using the reference data and AQHI calculated using the AQS 1 data for August 9th to October 30th, 2023, for the Calgary Inglewood reference station. The coefficient of determination is 0.9251. The blue dashed line is the fitted regression line and the red dashed line is the 1:1 line.

The calculated AQHI values were categorised as very high risk, high risk, moderate risk, and low risk, based on the Environment Canada specifications. A value of 1-3 is considered low risk, 4-6 is considered moderate risk, 7-10 is considered high risk, and 10+ is considered very high risk. The number of hours for each category calculated using the two different data sets are shown in Table 6.

Table 6: AQHI category hours calculated from AQS 1 and Reference station data.

Category	AQS 1 (hours)	CRAZ station (hours)
Low Risk	1532	1539
Moderate Risk	254	249
High Risk	39	39
Very High Risk	2	0

Conclusions

All three AQS 1 pollutant measurements were highly correlated with the CRAZ reference data for the duration of the test period. In addition, the slopes and bias of the regression lines of AQS 1 versus reference were close to 1 and 0, indicating excellent accuracy and low drift.

The ozone module showed excellent correlation with the reference analyser, with an R^2 of 0.98. The low MAE value (3.0 ppb) is indicative of low zero and span drift.

The nitrogen dioxide module showed excellent correlation with the reference analyser, with an R^2 of 0.97. The low MAE value (1.3 ppb) is indicative of low zero and span drift.

The $PM_{2.5}$ data showed excellent correlation with the reference analyser with an R^2 of 0.98 and MAE of 3.3 µg m^{-3}.

The AQHI can be reliably calculated using an Aeroqual AQS 1 configured with an O_3, NO_2 and $PM_{2.5}$ module.

The AQS 1 ozone, nitrogen dioxide and $PM_{2.5}$ expanded relative uncertainties all meet the EU reference equivalence requirement[6] at Environment Canada's pollutant limit values.

References

1. ASTM International. D8406 – 22 Standard Practice for Performance Evaluation of Ambient Outdoor Air Quality Sensors and Sensor-based Instruments for Portable and Fixed-point Measurement.

2. Guidance for the Demonstration of Equivalence of Ambient Air Monitoring Methods, EC Working Group 15, 2010.

3. https://joint-research-centre.ec.europa.eu/system/files/2016-10/aquila-rivm_pm_equivalence_v2.9.xls

4. Stieb, D. M.; Burnett, R. T.; Smith-Doiron, M.; Brion, O.; Shin, H. H.; Economou, V., A new multipollutant, no-threshold air quality health index based on short-term associations observed in daily time-series analyses. Journal of the Air & Waste Management Association 2008, 58 (3), 435-450.

5. Government of Alberta (2024). "Ambient Air Quality Objectives." from https://www.alberta.ca/ambient-air-quality-objectives.

6. Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe.