Report

Collaborative Sensor Rotation Programme: Kincardine – Forth Road Bridge Closure

Prepared for Transport Scotland
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1 Introduction

On the 4th December 2015, the Forth Road Bridge (FRB) was closed for all traffic to accommodate the immediate repair of faults discovered on the bridge structure. The FRB was reopened to cars and motorcycles on the 23rd December 2015 and fully opened to all vehicles including HGV's on 20th February 2016.

During this period of closure, several diversion routes and traffic management plans were implemented, diverting Southbound M90 traffic through Rosyth and Kincardine on the A985 and across the Kincardine Bridge to join the M9 into Edinburgh and Lothian with the northbound traffic using the reverse route. Figure 1 shows the A985 diversion route.

In early January 2016 Transport Scotland took the opportunity to deploy low cost air quality technologies to monitor the air quality adjacent to the A985 near to the town of Kincardine.

This report analyses and determines whether indicative air quality and emissions increased as a result of increased traffic volumes and the change in traffic composition on the A985 diversion route.

2 Purpose of Analysis

2.1 Air Quality Management Background

Trials with various emerging equipment suppliers to monitor in real time air quality near the trunk road network were undertaken by Transport Scotland between November 2013 and December 2015 via a Collaborative Sensor Rotation Program (CSRP).

The aim of the CSRP was to gain confidence with this new equipment in producing indicative air quality measurements and data trends while using the lower cost, reduced power and, redeployable equipment. Traffic data, and if available weather data, would also be collected at the same time to allow further analysis to be undertaken.

A review of the available equipment established that no one provider could offer a single unit that covered all relevant metrics, therefore two types of units were purchased. Transport Scotland purchased two TDC Systems HTRAC Particulate Monitors (HITRAC PM units) and two Geotech AQMesh units. These were deployed at several trunk road sites in close proximity to Air Quality Management Areas (AQMAs) and at a Defra Automatic Urban and Rural Network (AURN) site located at Townhead, Glasgow, to allow direct comparison to reference data.

Further information on the CSRP equipment and rotation exercises can be found at http://www.transport.gov.scot/environment/air-quality.

2.2 AQM – Kincardine A985

Following the FRB closure, in January 2016 Transport Scotland instructed IBI Group to install the CSRP equipment at the Longannet Roundabout to the east of Kincardine. The purpose of this was to collect air quality data, focusing on NO_2 and $PM_{2.5}$ concentrations, and analyse this with associated traffic data collected from the nearby Weigh in Motion (WiM) site at High Valleyfield on the A985. Meteorological data in the Kincardine area was also collected from an automatic weather station located on the A985.

Figure 1 shows the HGV diversion route, the location of the installed CSRP equipment, the WiM site and weather station. The diversion route shown in Figure 1 was active from 12th December 2015 to 20th February 2016.

This site was considered an ideal location to position the lower cost monitoring equipment due to the increased traffic volume from the diversion route east and westbound on the A985 and the availability of existing infrastructure to mount the equipment with minimal new infrastructure required.

Traffic data was available from the WiM site for before, during and after the FRB closure periods. The air quality monitoring equipment was installed between 15th and 29th of January and removed on 8th March, providing air quality data during the FRB closure and for two weeks after the reopening.

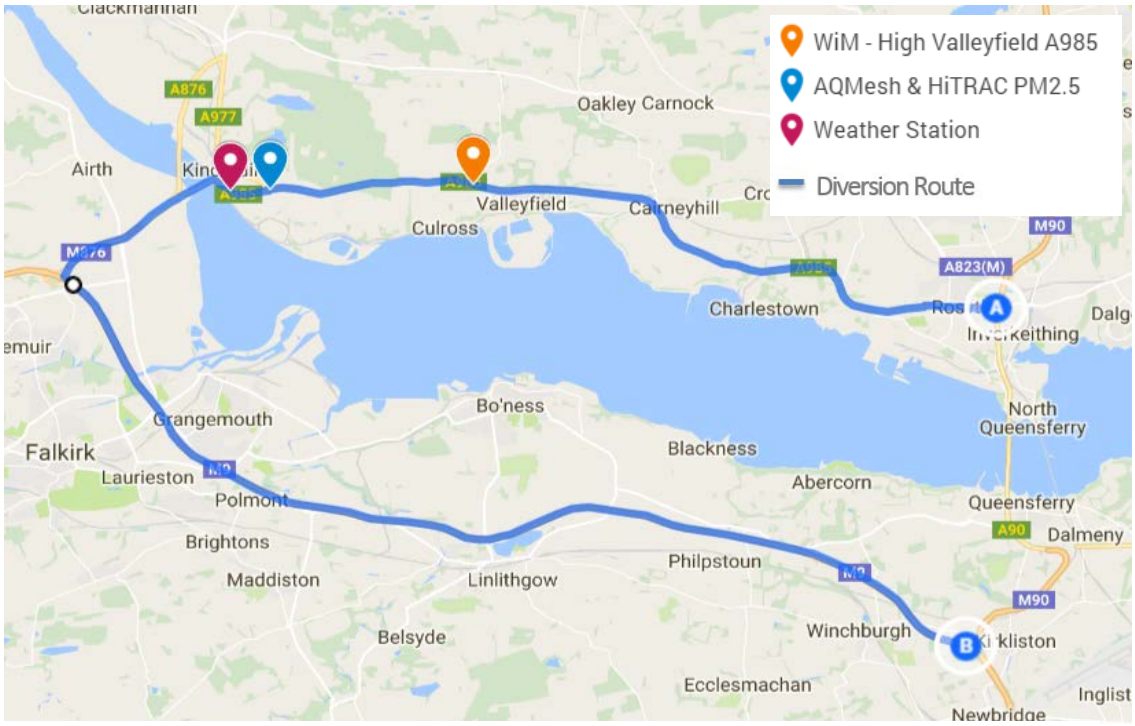

Figure 1 - WiM Site, AQM Site, Weather Station Locations with Diversion Route

2.3 FRB Closure

During the closure of the FRB several diversion routes and traffic management plans were implemented to prevent HGV access to the bridge, key dates were:

- 4th December 2015: FRB closed to all traffic
- 12th December 2015: FRB open to all vehicles excluding HGVs
- 4th – 20th February 2016: up to around 600 HGVs can access FRB from 23.00-04.00 northbound only
- 20th February 2016: FRB open to all traffic.

3 Methodology

The approach taken to delivering this report was to capture key air quality data, $PM_{2.5}$ and NO_2 concentrations, then using local meteorological data and traffic data from the A985 investigate if there was any indication of an adverse impact on the local air quality due to the A985 diversion route.

The CSRP used the Glasgow AURN site at Townhead, Glasgow, as a known reference standard to which all the low cost air quality equipment was returned to allow comparisons between the two data sets. This benchmarking allowed the CSRP equipment to be directly compared to AURN reference equipment which determined baseline readings to which correction factors could be applied.

It is acknowledged that lower cost air quality monitoring equipment cannot provide the same accuracy as calibrated reference standard equipment. The CSRP project found the lower cost equipment could be benchmarked and adjustment factors calculated to improve alignment with the reference equipment. This allowed the lower cost equipment to provide trend agreement, giving indicative pollutant concentrations. Details of the benchmarking exercise undertaken at the AURN Townhead site in Glasgow for the FRB closure are provided in section 3.2.

3.1 Data Collection and Analysis

The following section outlines the sources of air quality, traffic and meteorological data on the A985.

3.1.1 $PM_{2.5}$ HITRAC PM Data

The HITRAC PM units deployed were heated inlet nephelometers fitted with a 2.5µm sharp-cut cyclone inlet measuring $PM_{2.5}$. Data from these units was sent directly to an IBI Group server in Glasgow.

The two units were post-mounted on the A985 between 15th January and 8th March.

3.1.2 NO_2 AQMesh Data

The AQMesh units deployed during this exercise were battery operated, measuring four gases (NO, NO_2, CO and O_3) using electrochemical sensors and particulates using a light-scattering optical particle counter. Data was sent from the units to the supplier server where it was validated and algorithms were applied, the processed data was then downloaded as a csv file. As stated above only NO_2 measurements were analysed.

The two units were post-mounted on the A985 between 29th January and 8th March 2016, with valid data being collected from 1st February.

3.1.3 Traffic Data - Weigh in Motion – A985 High Valleyfield

Transport Scotland manage a traffic data collection network of roadside counters throughout the Trunk Road Network to establish traffic growth, incidents, speed, congestion and volume. As part of this network there are approximately 55 dynamic weigh in motion sites that record the standard vehicle counts and speed but also vehicle weights.

The vehicle weights can then be used along with the vehicle counts to establish the expected life of the road pavement. This also allows Transport Scotland to understand if certain classifications of vehicles are operating fully loaded and use this information in future road improvements.

Traffic Data was collected by the Transport Scotland WIM site at High Valleyfield on the A985, located approximately 3 miles east of the Longannet Roundabout, which provided individual vehicle speed, counts and classification.

3.1.4 Meteorological Data

Transport Scotland have over 200 weather stations located on the Trunk Road Network monitoring temperature, wind speed, road surface state and wind direction. Weather data is recorded and logged every 20 minutes

There is a weather station on the A985, approximately 0.5 miles west of the Longannet Roundabout.

3.1.5 AQM Equipment Performance

The air quality equipment was in the process of being prepared for servicing when the request to deploy the equipment was made and some issues were identified during the period of the closure.

The air quality monitoring equipment was installed in pairs to ensure consistent measurements but also to account for any unexpected technical failures.

The HITRAC PM units were deployed knowing that the service life of the main pump had been exceeded and unfortunately one of the units pump recorded an error during the deployment. The data from the unit with a fault was consistent with the fully functioning unit prior to the pump failure but has been excluded this from the report.

The NO_2 sensor of one AQMesh unit failed early in February 2016 so the data from this unit could not be included in the reporting.

The operational HITRAC PM and AQMesh units were returned to Townhead in Glasgow for a benchmarking exercise at a reference station and operated as expected; 3.2 Air Quality Equipment - Benchmarking details this operation further.

3.1.6 Data analysis

The WiM data was exported to Access and analysed in Excel, the weather and air quality data analysis was undertaken using Excel and R, an open-source software environment for statistical computing and graphics (see https://www.r-project.org/) using the CRAN package *openair* which contains tools specifically developed to analyse and interpret air pollution data (see http://www.openair-project.org/).

3.2 Air Quality Equipment - Benchmarking

Following the air quality data collection on the A985 the units were relocated to the AURN site at Townhead, Glasgow. The data collected at the site was used to benchmark the lower cost unit measurements against the accredited industry standard and calibrated AQM equipment housed at the AURN site.

The Townhead AURN site records hourly data, therefore the AQMesh and the HITRAC units 15 minute data was aggregated to form both hourly and daily datasets for analysis.

The equipment was collocated at the Townhead AURN site for 11 days.

3.2.1 Benchmarking – $PM_{2.5}$

The Townhead AURN site contains a TEOM-FDMS analyser. The scatterplot, Figure 2, shows there was a clear linear relationship between the actual $PM_{2.5}$ (AURN value) and HITRAC $PM_{2.5}$ with strong positive correlation.

Regression analysis provided a regression equation that could be applied to HITRAC $PM_{2.5}$ data to produce a pollutant concentration closer to the actual $PM_{2.5}$.

Corrected HITRAC $PM_{2.5}$ = 0.714×HITRAC $PM_{2.5}$ + 4.62

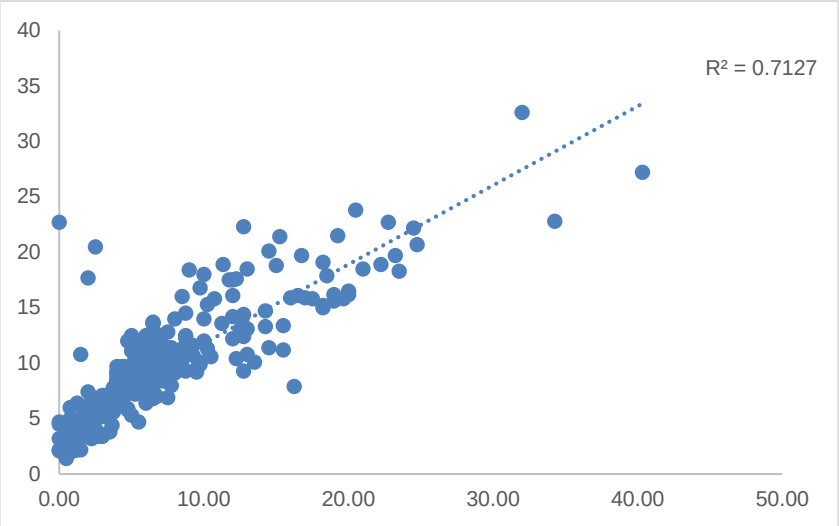

Figure 2 - AURN v HiTRAC $PM_{2.5}$ Scatterplot

Figure 3 below shows the unadjusted HITRAC $PM_{2.5}$ data compared with the AURN $PM_{2.5}$ at the Townhead site. Before correction there is reasonable time series and trend agreement between the datasets. When the correction is applied to the HITRAC figures, the resulting graph shown in Figure 4 demonstrates a more correlated set of figures between the HITRAC and AURN data. This gives a good indication that we can use this correction factor against the data collected at the Kincardine A985 site.

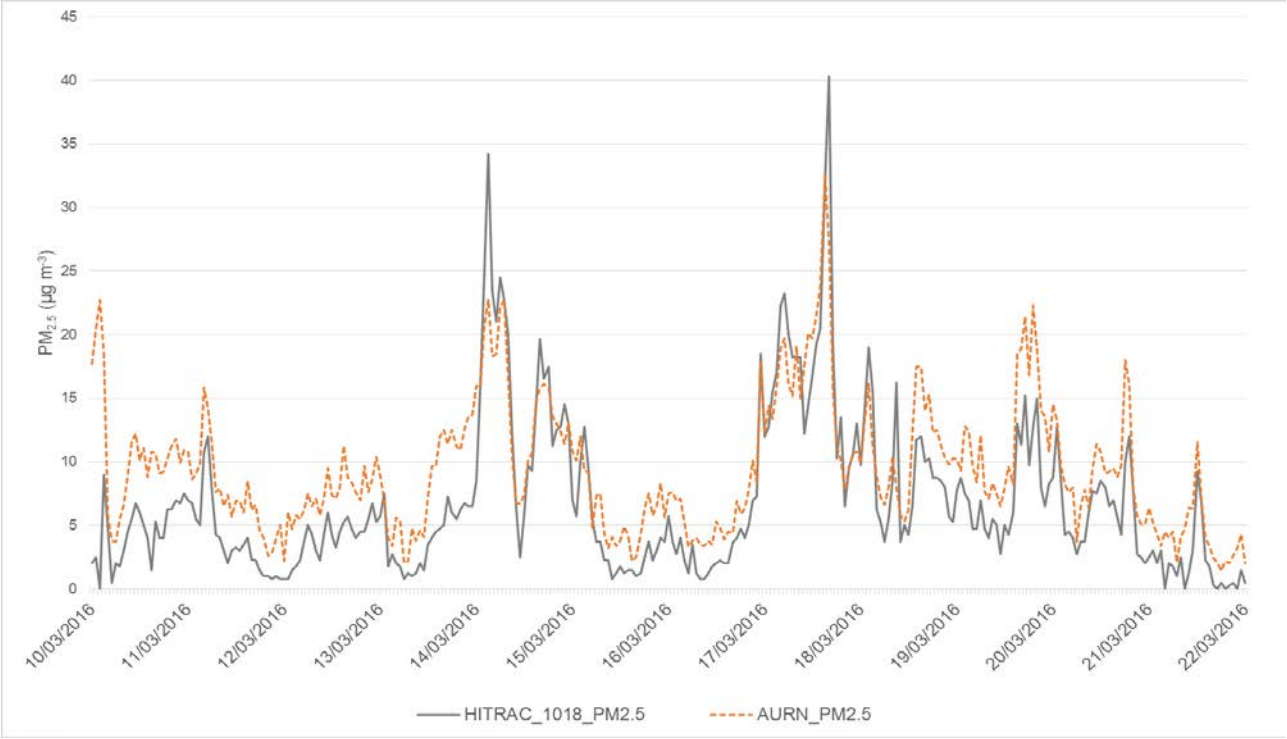

Figure 3 – Time series unadjusted HiTRAC $PM_{2.5}$ v AURN $PM_{2.5}$

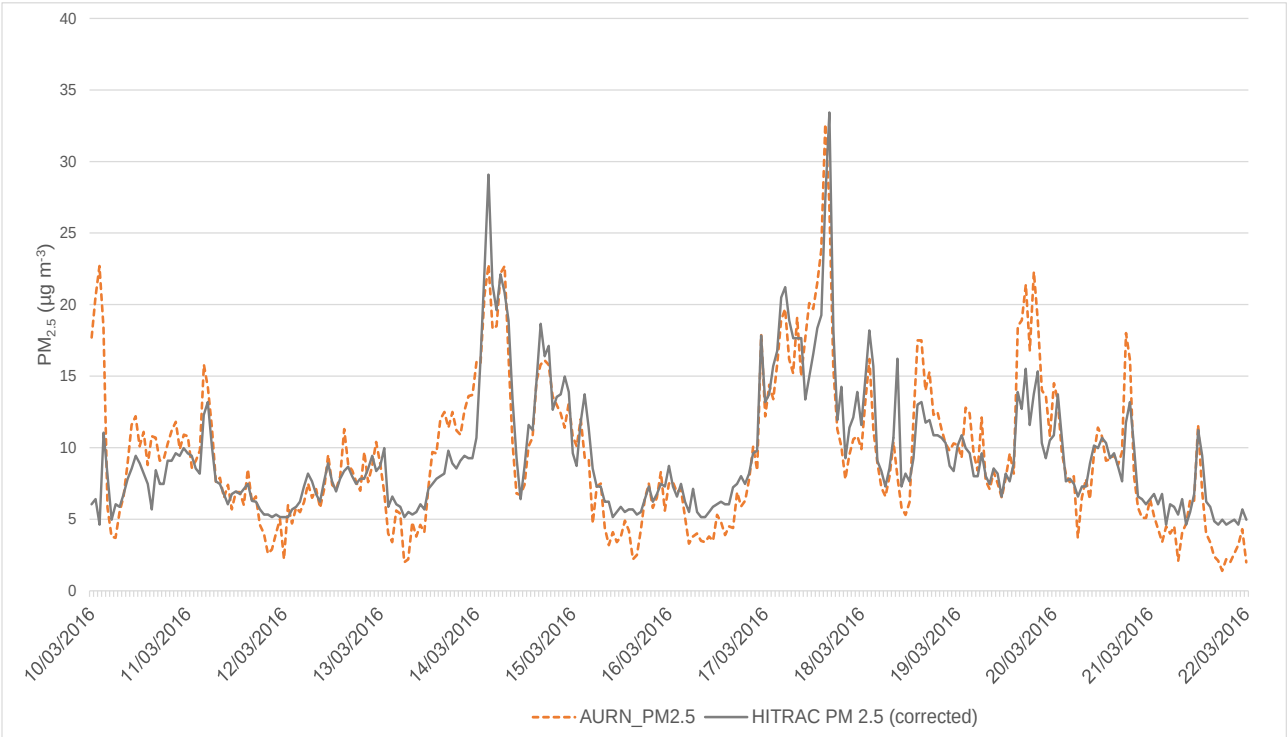

Figure 4 – Time series corrected HITRAC $PM_{2.5}$ and AURN $PM_{2.5}$

3.2.2 Benchmarking – NO_2

The AQMesh unit was relocated to the Glasgow, Townhead AURN site on the 10th March 2016 and remained in place monitoring air quality until the 22nd March 2016.

Following discussions with the manufacturer an offset was determined to the NO_2 data to show both good trending but also good measurement. This figure was -90 µg m^{-3}.

The NO_2 data below in Figure 5 shows the raw data compared to the AURN data along with the adjusted AQMesh data once the offset was applied. You can clearly distinguish a more correlated trend between the AQMesh and AURN data which demonstrates that this correction factor can be applied to the data obtained from the Kincardine AQMesh site.

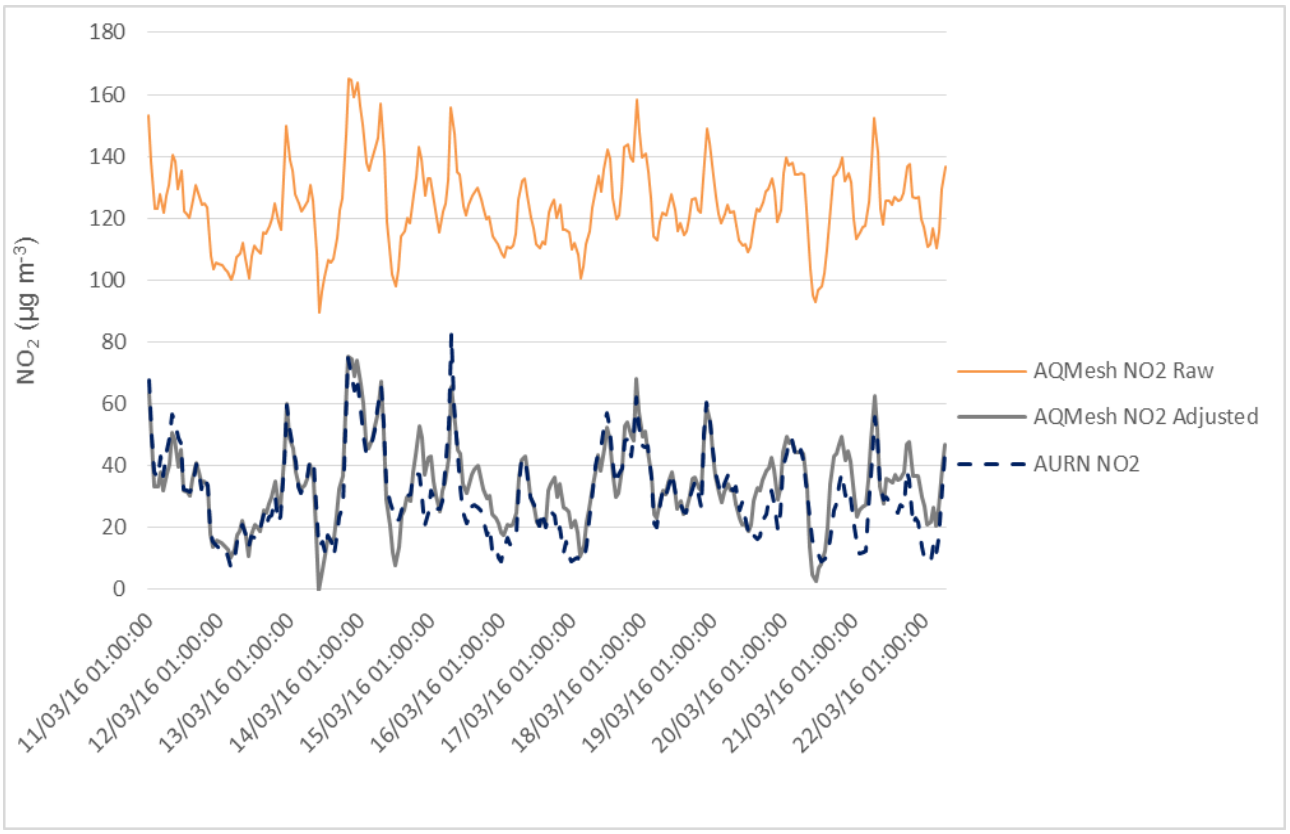

Figure 5 – Tine series AQMesh Raw v AQMesh Adjusted v AURN NO_2

4 Results, interpretation & data findings

4.1 HITRAC $PM_{2.5}$ Data

The ***Cleaner Air for Scotland: The Road to a Healthier Future*** publication from the Scottish Government states the concerns and impacts of fine Particulate Matter as;

"An increasing body of evidence suggests that fine particulate matter ($PM_{2.5}$) is the most significant fraction of particulate pollution in terms of health impacts. The WHO has set guideline PM_{10} and $PM_{2.5}$ values of 20 µg/m³ and 10 µg/m³ respectively as annual means[58]. These values are considerably more stringent than the equivalent EU and UK targets, but similar to the Scottish objectives of 18 µg/m³ and 12 µg/m³. Following the review of the Local air quality Management system (see paragraph 4.2 for more information), the Scottish Government has decided to replace the existing Scottish objectives with the WHO guideline values. Whilst this is undoubtedly a positive step, the approach will create challenges, with respect to the transboundary impacts on $PM_{2.5}$ in particular."

Further information can be found at: http://www.gov.scot/Resource/0048/00488493.pdf

With these guidelines in mind it is important to gauge whether the diversion route had a significant impact on $PM_{2.5}$ values and what impact this may have on future diversions in relation to the FRB.

The corrected data showed a much improved trend agreement with the AURN data as displayed in Figure 6. A reduction in the magnitude of variation between data points was clearly visible however some variation was evident between 10th March 2016 and 22nd March 2016, this is due to the difference in the gradient of the trend line between the two data sets.

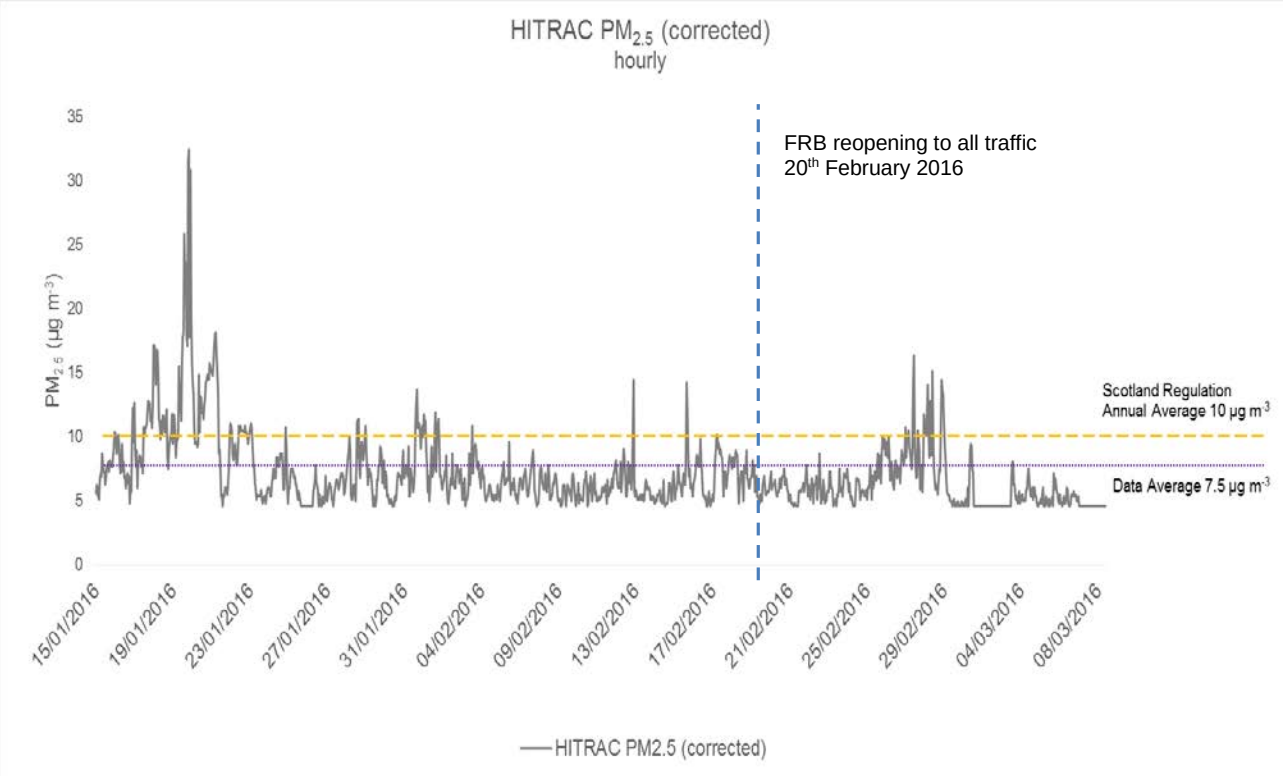

Figure 6 – Time series HiTRAC $PM_{2.5}$ corrected hourly

4.2 AQMesh NO_2 Data

Under the Scottish Governments air quality legislation of 2010, the guidelines for NO_2 annual average should not exceed 40 µg m^{-3}. As demonstrated below in Figure 7 the corrected AQMesh data average for the period between 29th January 2016 and the 8th March 2016 was 32.8 µg m^{-3} which is lower than the Scotland Regulation average by a considerable margin. Although there were a number of times when the hourly recorded data exceeded the regulated annual average, the current Scotland Regulation hourly limit is 200 µg m^{-3} and the largest amount of NO_2 recorded by the AQMesh at Kincardine was 102 µg m^{-3}.

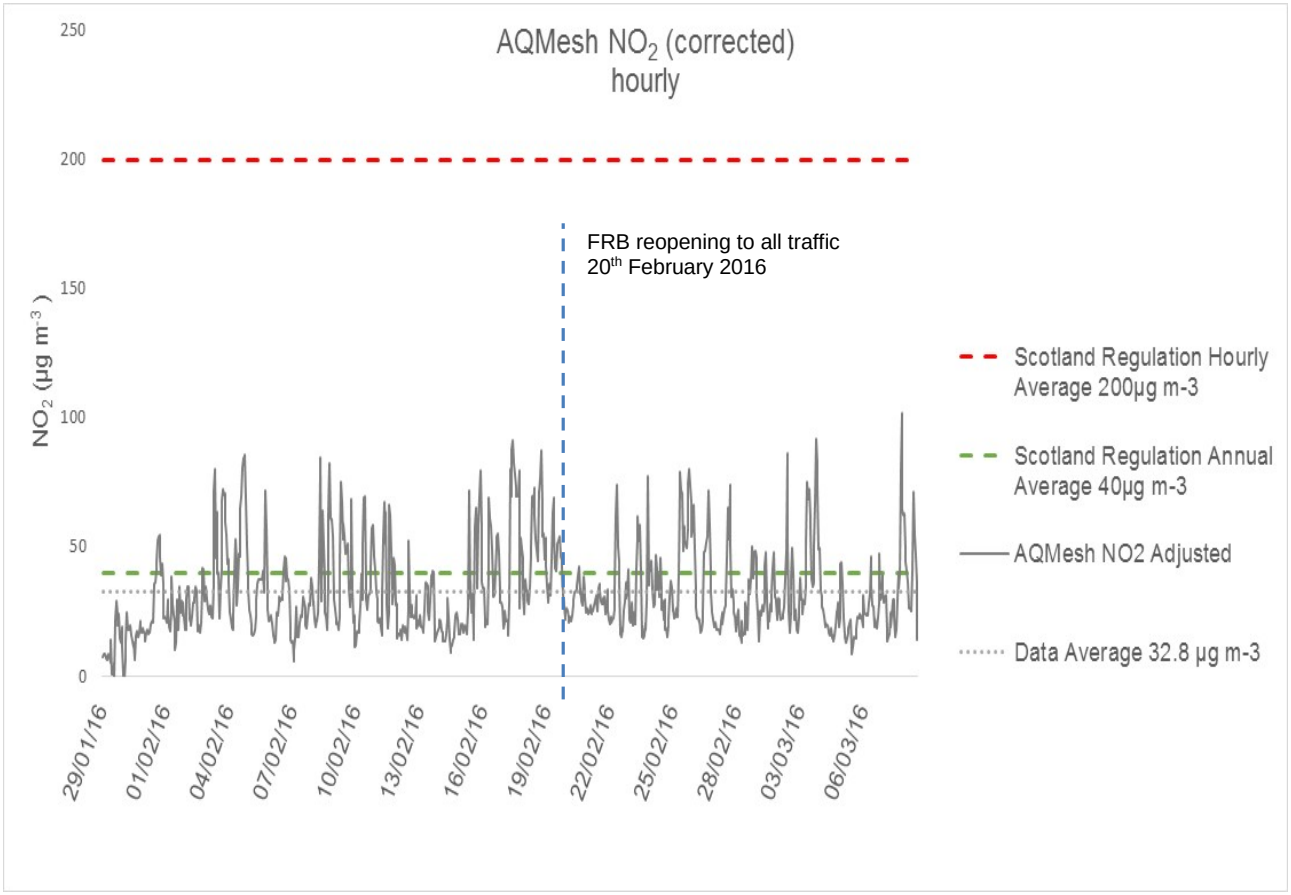

Figure 7 – Times series AQMesh NO_2 corrected hourly

4.3 Weather Data

A Traffic Scotland weather station was located 0.5 miles to the west of the equipment site on the A985. Wind speed and direction data was used assess the influence of weather conditions on the $PM_{2.5}$ and NO_2 data collected. The weather and air quality data was aggregated to hourly intervals for this analysis.

Figure 8 shows polar plots of adjusted HiTRAC $PM_{2.5}$ and AQMesh NO_2 from 29th January to 8th March 2016. The polar plot is bivariate showing the effect of wind speed and direction on pollutant concentration. For the $PM_{2.5}$ data the highest measurements were made when the wind was from the west and during periods of higher wind speeds (12 – 14 m/s) indicating the source of the highest $PM_{2.5}$ measurements were not local. The AQMesh NO_2 polar plot shows the highest measurements were made during periods of low wind speed and from the west. The higher NO_2 concentrations are likely to be attributed to traffic as the equipment was located just to the east of the Longannet Roundabout on the north of the A985.

Further historic information can be found in section 7.1 Historic AURN Data.

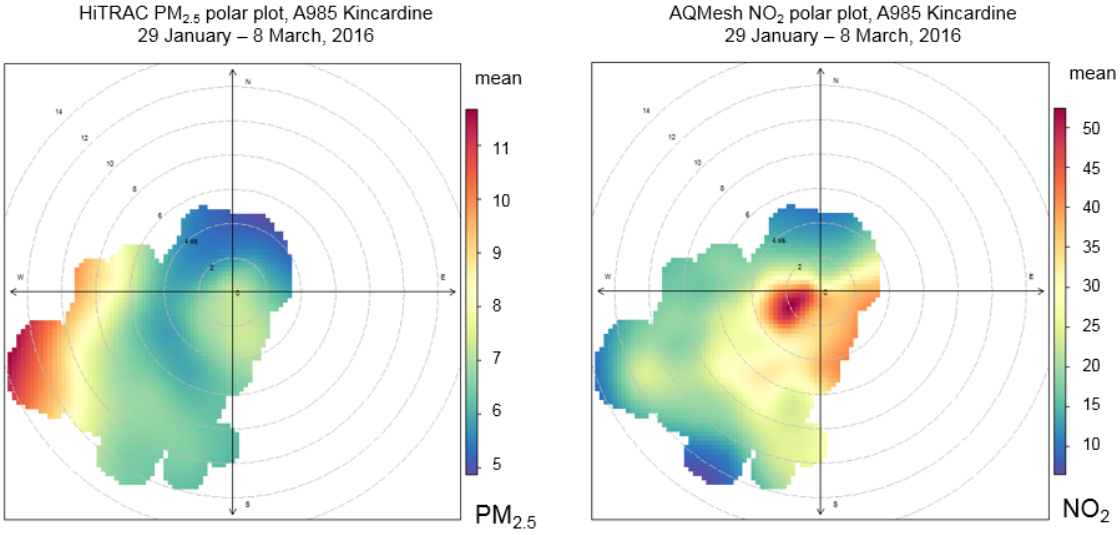

Figure 8 – Polar plots of HiTRAC $PM_{2.5}$ and AQMesh NO_2 from the A985

4.4 Traffic Data

Traffic data was recorded from the Transport Scotland Weigh in Motion site at High Valleyfield on the A985. This data was a daily traffic volume measurement which was then then grouped by EUR6 vehicle classification, motorbikes, Cars & Vans, Cars & Van + Trailers, Rigid HGV, Articulated HGV and Buses & Coaches.

The graph below, Figure 9, shows the volume of all traffic along the A985 between 15th November 2015 and 30th March 2016. There is a clear spike in traffic volume on the 3rd December 2015, coinciding with the FRB closure. There is a significant decrease in traffic volume after the 23rd December 2015 when the FRB reopened to traffic excluding HGV.

The general pattern was that HGV and commercial vehicles were impacted almost immediately by the closure of the bridge with traffic volumes on the A985 generally increasing on the 2nd February 2016. However some variations were noted particularly with Rigid Truck classifications and cars. It was noted that car travel decreased on the A985 after an initial increase with spikes in traffic volume only occurring over two weekends. The number of cars travelling along the A985 remained below the pre-closure average until almost a month after the full reopening of the FRB.

Traffic on the A985 declined significantly after the reopening to all vehicles on the FRB, 20th February 2016, for most vehicle classes a reduction in traffic was noted on the 22nd February 2016 with the only other reduction in traffic being attributed to the Christmas and New Year holidays. There was a trend for HGV's to cause a spike in traffic in between these two days with an increase in the count usually noted around the 29th December 2015 and 30th December 2015. It was also noted that vehicle counts were often higher before Christmas and New Year during the FRB closure than after.

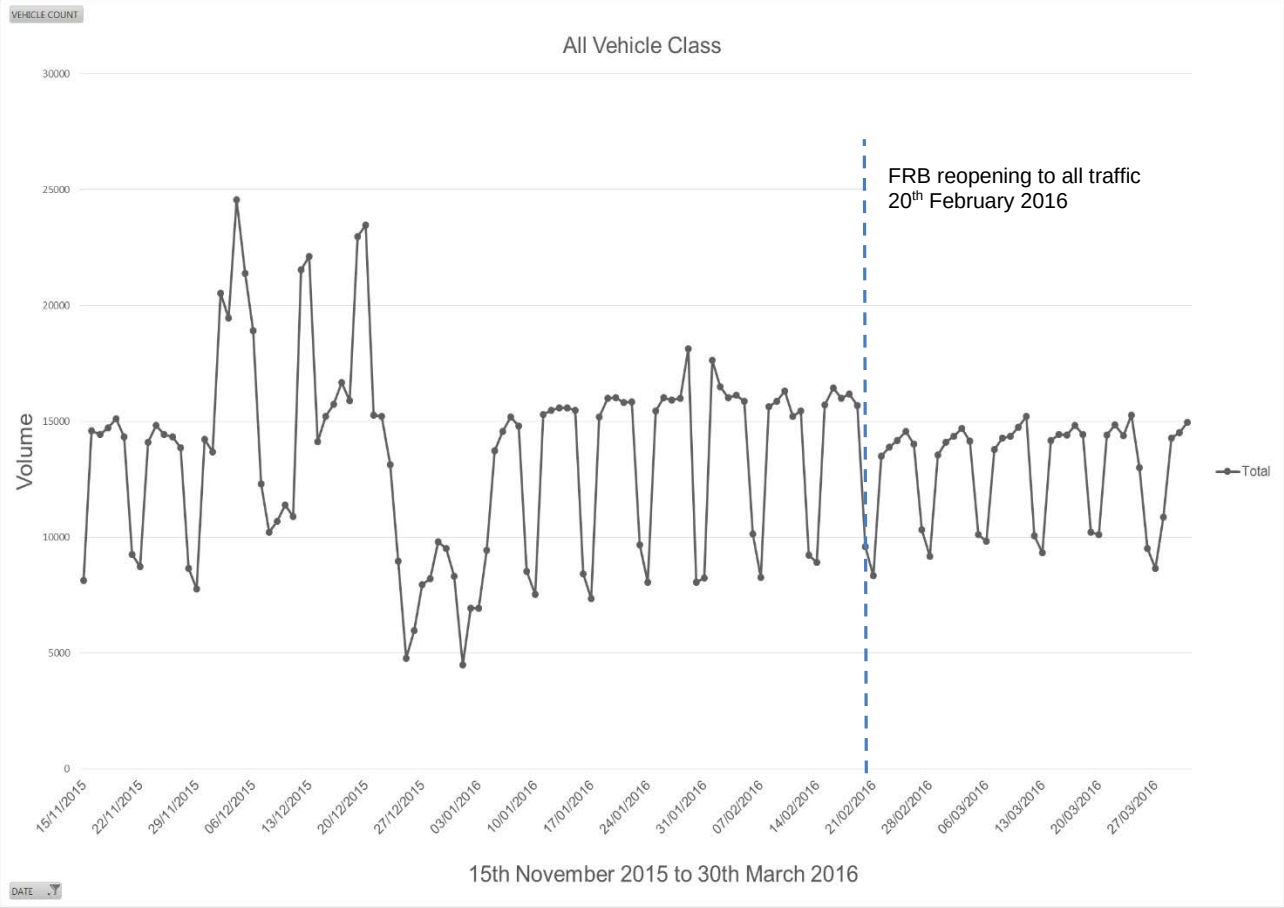

Figure 9 - Total Traffic Volume on the A985 15th November 2015 to 30th March 2016

4.5 Trends/patterns (daily/weekly)

4.5.1 Traffic Trends

Vehicle Classification: Motorcycles, Cars & Vans

- Between 15th November 2015 and 1st December 2015 prior to the FRB closure, a weekly commuter travel pattern existed on the A985 with an average daily traffic count of 10,227 motorcycles, cars and vans. (Figure 10)
- An increase in traffic was noted on Wednesday 2nd December 2015, 14750 vehicles in this class. This was followed by a weekday peak on Friday 04/12/15 of 17,980 vehicles.
- Between 7th December & 11th December 2015 and 14th December & 18th December 2015, the volume of motorcycles, cars and vans travelling along the road decreased below the pre-closure average with spikes in the count occurring during the weekend of 12th December 2015, with an average of 17,775 vehicles. A peak of 19,926 vehicles occurred on the following weekend, Sunday 20th December 2015. The decrease in midweek traffic could possibly be attributed to local commuters using other routes to avoid the increase in traffic diverted from the FRB, choosing instead to use a local knowledge of other routes to circumvent the build-up of vehicles along the A985.
- A decrease in the traffic volumes occurred on the 23rd December 2015 coinciding with the reopening of the FRB to motorcycles, cars and vans. However, as expected the volume of traffic decreased further over the Christmas and New Year holiday period.
- A rise in traffic on the road was observed after the holiday period with a gradual increase in traffic volume beginning on the 5th January 2016. An average count from the 5th to Friday 8th January 2015 of 9634 vehicles was recorded.
- From 11th January to 30th March 2016 the average number of motorcycles, cars and vans using the A985 was 10,002 vehicles. A similar trend in traffic pre FRB closure. The FRB reopened to all traffic on the 20th February 2016.

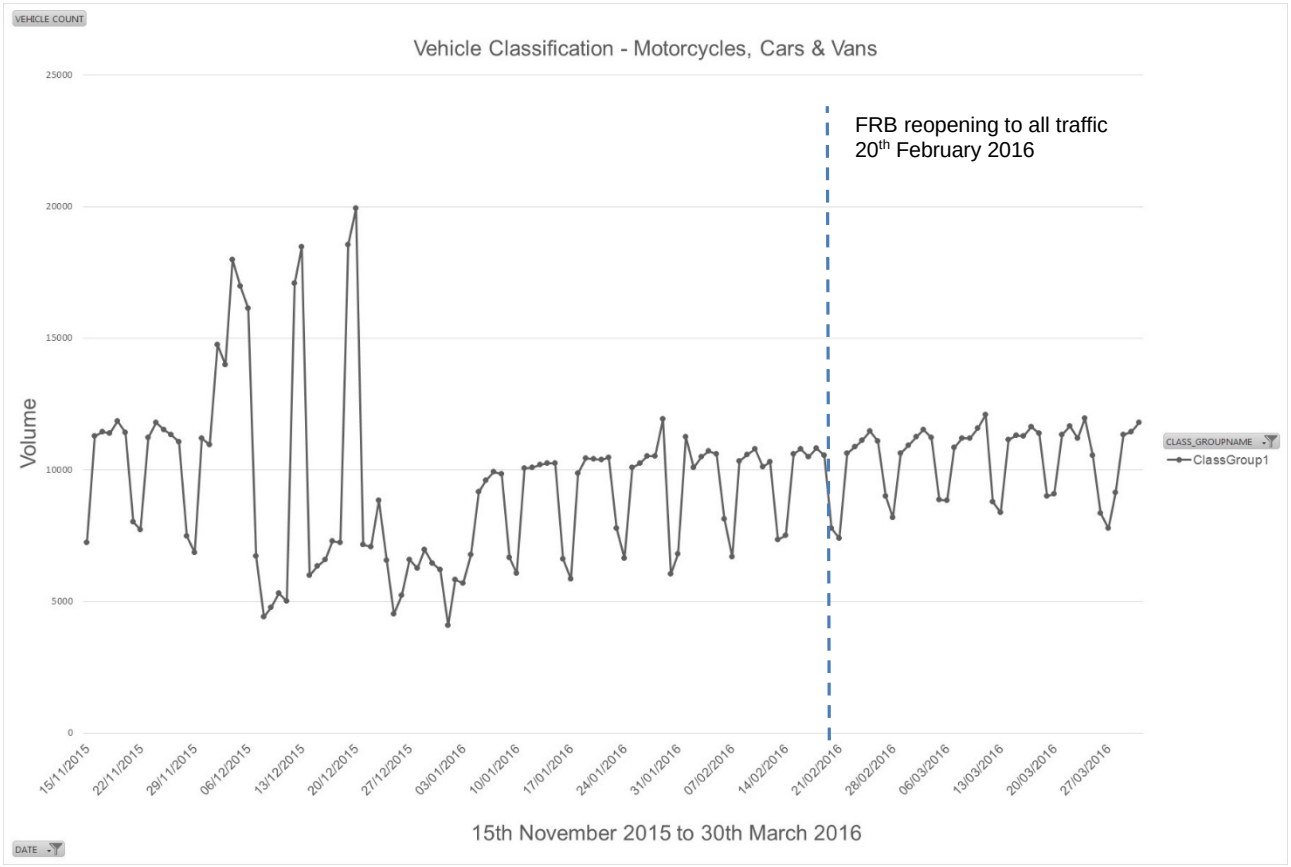

Figure 10 - Motorcycles, Cars & Vans 15th November 2015 to 30th March 2016

Vehicle Classification: 4x4, SUV & Transit Vans

- Between 15th December 2015 and 1st December 2015 prior to the FRB closure, a weekly commuter travel pattern for 4x4, SUV & Transit Vans existed on the A985 with an average daily traffic count of 1282 vehicles (Figure 11)
- An increase in traffic was noted on Wednesday 2nd December 2015, 2550 vehicles in this class followed by a weekday peak on Friday 4th December 2015 of 2851 vehicles. This increase in volume coincides with the FRB closure on 2nd December 2015.
- 6th December to 11th December 2015 a drop in the traffic count was recorded with the average count at pre closure levels of 1188 vehicles in this classification. This could be attributed to local commuters using alternative routes to avoid the increase in traffic volumes along the A985.
- The traffic volume trend increased following week, 14th December to 18th December 2015, with a midweek average of 3196 vehicles. A weekday peak count of 3528 vehicles was recorded on Thursday 17th December 2015.
- A decrease in traffic volume occurred on the 23rd December 2015 which coincided with the FRB opening to all vehicles except HGV's. With the volume decreasing further over the Christmas and New Year holiday period.
- As expected the volume of 4x4, SUV & Transit Vans increased after New Year returning to pre FRB closure levels from 5th January 2016, 1306 vehicles midweek average with a peak count of 1392 vehicles on Thursday 7th January 2016.
- From 11th January to 30th March 2016 the average number of 4x4, SUV & Transit Vans using the A985 was 1307 vehicles. A similar trend in traffic pre FRB closure. The FRB reopened to all traffic on the 20th February 2016.

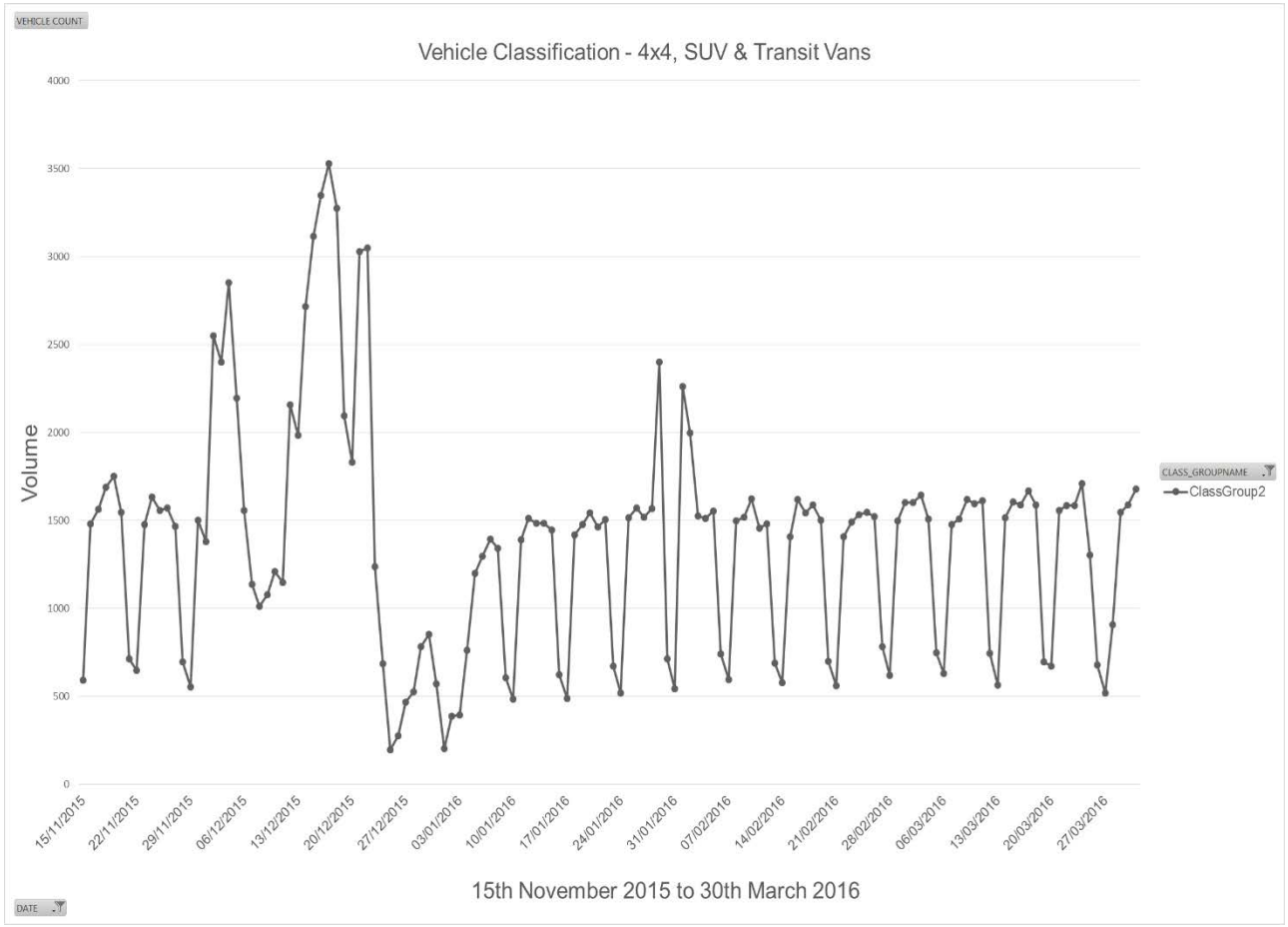

Figure 11 - 4x4, SUV & Transit Vans 15th November 2015 to 30th March 2016

Vehicle Classification: Rigid HGV's, Articulated HGV's (Class 3) & Buses/Coaches (Class 4)

- Between 15th November 2015 and 1st December 2015 prior to the FRB closure, a weekly commuter travel pattern for Rigid HGV's, Articulated HGV's & Buses/Coaches existed on the A985 with an average combined daily traffic count of 1076 vehicles (Figure 12)
- An increase in traffic was noted on Wednesday 2nd December 2015, 3112 vehicles in this class followed by a weekday peak on Friday 4th December 2015 of 3597 vehicles. This increase in volume coincides with the FRB closure to all traffic on 2nd December 2015.
- Between 7th December & 11th December 2015 a significant increase in the traffic count was recorded with the average count of 4541 vehicles in these classifications. This could be attributed to HGV's, buses and coaches only being diverted down the A985, when alternative routes were in operation for other vehicle class's.
- The traffic volume trend increased following week, 14th December to 18th December 2015, with a midweek average of 5430 vehicles. A weekday peak count of 5616 vehicles was recorded on Thursday 17th December 2015.
- A decrease in traffic volume occurred on the 23rd December 2015 with the volume decreasing further over the Christmas and New Year holiday period.
- As expected the number of Rigid HGV's, Articulated HGV's and buses/coaches increased after New Year from 5th January 2016, 3481 vehicles midweek average with a peak combined count of 3699 vehicles on Thursday 7th January 2016.
- From 11th January to 19th February 2016 the average number of HGV's, buses and coaches using the A985 was 3039 vehicles. The FRB reopened to all traffic on the 20th February 2016 and it is noted that the traffic volumes of these classifications decreased dramatically with average count between 22nd February and 30th March 2016 returning to pre FRB closure levels of 1124 vehicles.
- As demonstrated below in Figure 12, the trend lines for the class 3 & 4 vehicles are very similar and show the same relationships throughout the entire FRB closure timeline.

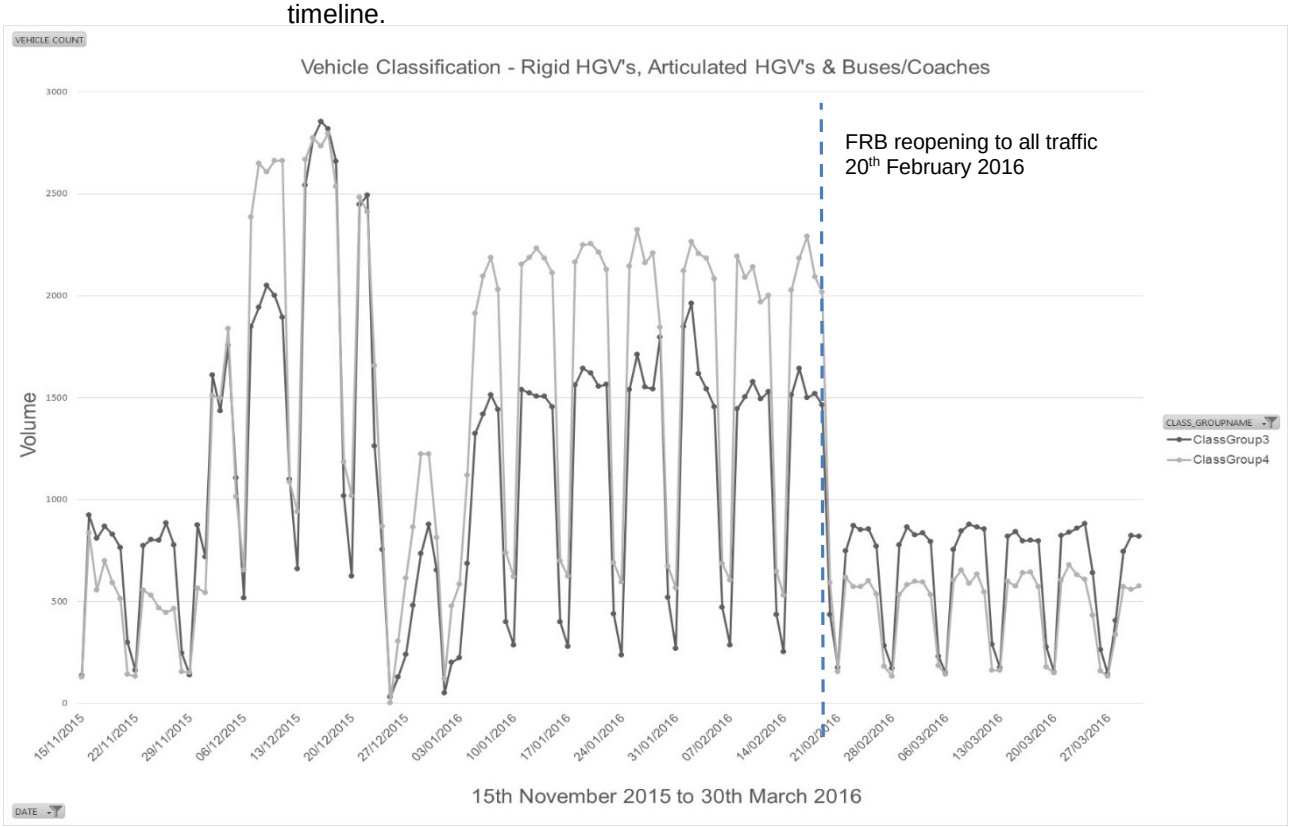

Figure 12 - Rigid HGV's, Articulated HGV's & Buses/Coaches 15th November 2015 to 30th March 2016

5 Conclusions

The CSRP air quality equipment has proven useful to better understand how air quality can change in relation to altering traffic conditions and with future hardware/software development will potentially be an additional data source to allow drivers to make informed decisions.

During the period when the air quality equipment was deployed it can be shown that at no time did the increase in traffic due to the FRB diversion impact the air quality to a level that would require further investigations to take place.

The air quality data provided by the CSRP equipment suggests that there was no significant increase in levels of NO_2 or $PM_{2.5}$ concentrations at the Longannet Roundabout for the period of the FRB closure and that no limits were exceeded at this location during the period of the bridge restrictions.

The full closure of the Forth Road Bridge was an unexpected sudden event and as such the capability to rapidly deploy air quality monitoring equipment would allow real time monitoring of air quality during future events, and in turn provide valuable information which could inform the selection and operation of alternative routes to mitigate any environmental impact.

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6 Annexes

6.1 Historic AURN Data

To further examine the data collected at the Kincardine site data from the two closest AURN sites at Rosyth and Dunfermline was downloaded from the Scottish Air Quality Website http://www.scottishairquality.co.uk. These sites are situated approximately 11.5 and 10 miles, respectively, from the Kincardine site. Both sites measure NO_2 and PM_{10}, with the Rosyth site measuring $PM_{2.5}$ from 21 July 2015.

Figure 13 and Figure 14 below show the average monthly AURN data for NO_2, PM_{10} and $PM_{2.5}$ data from the AURN sites at Rosyth and Dunfermline from January 2013 to March 2016

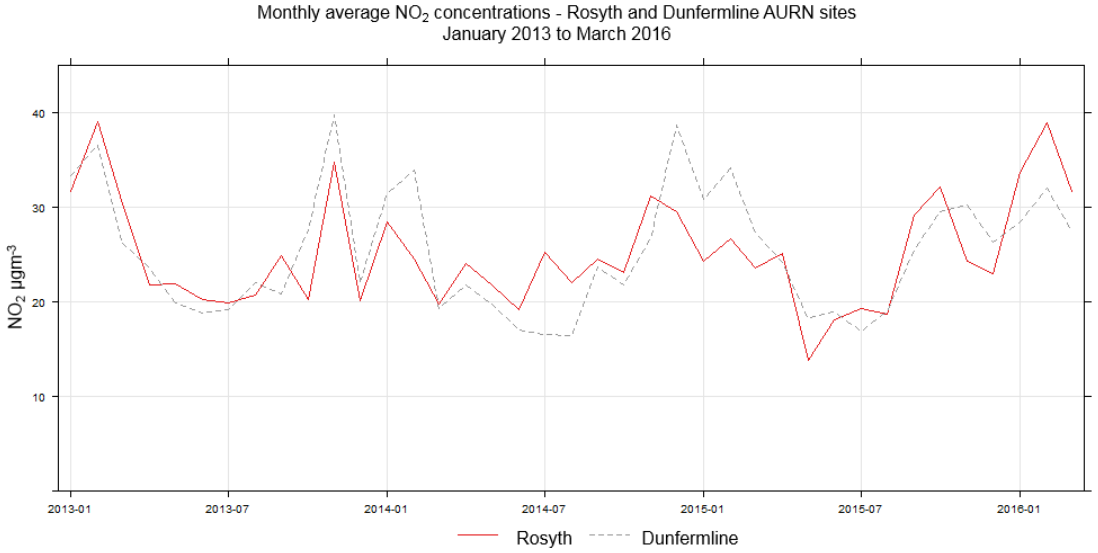

Figure 13 – Monthly NO2 average concentrations for Rosyth and Dunfermline AURN sites

The mean NO_2 for this period was 25 µgm^{-3} at both Rosyth and Dunfermline.

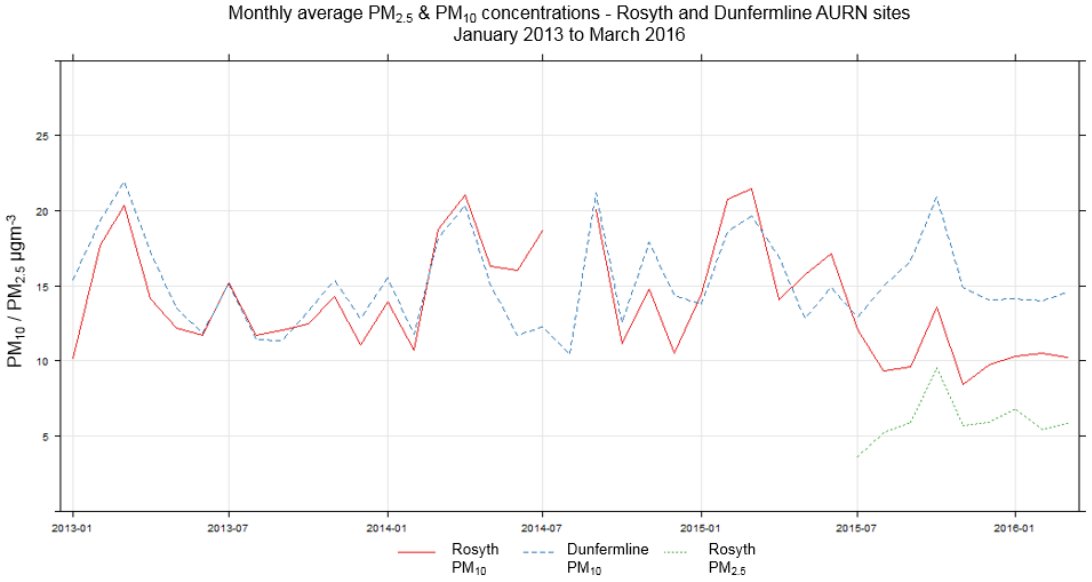

Figure 14 - Monthly PM_{10} and $PM_{2.5}$ average concentrations for Rosyth and Dunfermline AURN sites

The mean PM_{10} for this period was 13.8 µgm^{-3} at Rosyth, 15.2 µgm^{-3} at Dunfermline; and mean $PM_{2.5}$ at Rosyth was 6.2 µgm^{-3}.

Figure 15 below show the weekly average concentrations of NO_2 and $PM_{2.5}$ measured at the Kincardine site.

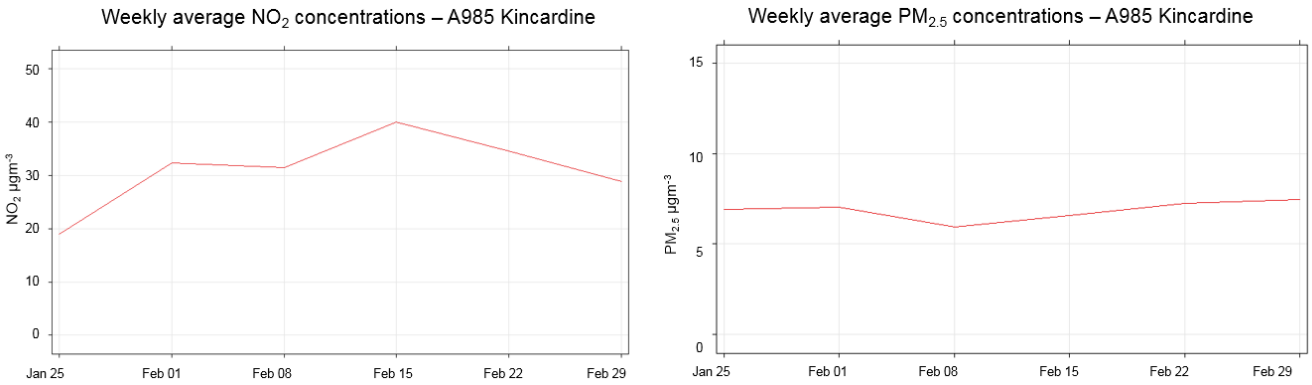

Figure 15 – Weekly NO_2 and $PM_{2.5}$ average concentrations for A985 Kincardine

The NO_2 and $PM_{2.5}$ measurements made at Kincardine were in line with the historic data averages from the past three years from Rosyth and Dunfermline AURN sites.