Belfast Detailed Assessment Part A

Air Quality Monitoring Report

Belfast City Council

Project number: 60652891

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Quality information

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V1	14/06/2022	Draft	TS	Tom Stenhouse	Technical Director
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V3	29/03/2023	Final	GC	Gareth Collins	Regional Director
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1. Introduction

1.1 This air quality monthly monitoring report has been prepared by AECOM on behalf of Belfast City Council (BCC) as the first part (called 'Part A' throughout) of the Local Air Quality Management (LAQM) Detailed Assessment (DA). This DA has been prepared by BCC in view of recent public health concerns around fine particulate matter ($PM_{2.5}$), with a view to determining appropriate mitigation policies and measures to reduce ambient concentrations and public exposure. Nitrogen dioxide (NO_2) and particulate matter with a diameter less than 10 microns (PM_{10}) have been included within this assessment too as the other main pollutants of concern across the city. NO_2 is also the pollutant for which BCC's Air Quality Management Areas (AQMAs) are currently declared.

1.2 This DA employs a combination of ambient monitoring and ambient dispersion modelling for PM_{10}, $PM_{2.5}$ and NO_2 in order to spatially and temporally quantify the concentrations of these pollutants across the city. The monitoring and dispersion modelling will also be required to identify the geographic location and spatial extent of any exceedances of the PM_{10}, $PM_{2.5}$ and NO_2 UK Air Quality Strategy (AQS) objectives and World Health Organisation (WHO) guideline values. The monitoring, summarised within this report (Part A), will be used to inform and verify the dispersion modelling exercise, which will form the basis of the DA's conclusion reported within Part B. This report is also designed to act as a stand-alone monitoring report, providing additional data for 2021.

1.3 Six locations were identified for sensor-based monitoring across Belfast. The site locations cover a range of pollution sources (e.g. road traffic, airport, urban background), to characterise these different types of emissions within the dispersion modelling as well as providing additional monitoring data within Belfast City Centre. The sites include two roadside sites, two urban background sites, an airport site and a site co-located with the Automatic Urban and Rural Network (AURN) Belfast Centre monitoring station (later denoted as 'ZAURN'). The co-location data has been used to derive an adjustment factor for the annual mean sensor data.

1.4 The air quality monitoring requirements and locations were agreed with BCC prior to installation and are as per the Revised Ambient Monitoring Proposal_v4.pdf.

1.5 The monitoring locations are summarised in Section 3. Monitoring commenced for the majority of the sites on 2nd July 2021 and ran, as managed by AECOM, for a period of nine months up until the end of March 2022. The data was then managed by BCC until the end of the purchased period on 13th May 2022. Thereafter, ownership of the monitors was transferred to Belfast City Council and operation of the monitors is continuing by Belfast City Council Air Quality Officers.

1.6 The Zephyr monitoring units deployed in fulfilment of the monitoring requirements of the contract were calibrated by the manufacturer prior to installation. Periodic re-calibrations are made by the manufacturer where systematic biases are present when comparing a Zephyr's data with a regional average of EU-standard reference stations for a representative environment category. Copies of the calibration certificates are presented in Appendix A.

1.7 Given the documented uncertainties associated with use of low-cost sensor technologies[1][2], current advice from the Air Quality Expert Group (AQEG) is that: *"at least for now, low-cost sensors cannot be used as direct replacements for the reference standard monitors used by Defra".* The data collected from these types of monitors should therefore be interrogated for their inherent uncertainties, and where possible compared against reference standard monitoring.

1.8 The data within this report includes both ratified (i.e. that which is considered 'real' or useable data, and not instrument fault) and scaled data (i.e. data which has been adjusted using appropriate adjustment factors). Further details on the derivation of the adjustment factors are shown in Appendix A.

[1] Air Quality Expert Group (2022), AQEG advice on the use of 'low-cost' pollution sensors, available at: https://uk-air.defra.gov.uk/research/aqeg/pollution-sensors.php
[2] Defra (2022) FAQ 140 – Low Cost Sensors, available at: https://laqm.defra.gov.uk/faqs/faq140/

2. Legislation

2.1 The Clean Air for Europe (CAFÉ) programme consolidated and replaced (with the exception of the 4th Daughter Directive) preceding EU directives with a single legal act, the Ambient Air Quality and Cleaner Air for Europe Directive 2008/50/EC ('EC Air Quality Framework Directive')[3]. This directive is transcribed in Northern Ireland (NI) by the Air Quality Standards (AQS) Regulations (Northern Ireland) 2010[4].

2.2 EU legislation which applied directly or indirectly to the UK before 11.00 p.m. on 31st December 2020 has been retained in UK law as a form of domestic legislation known as 'retained EU legislation'. This is set out in sections 2 and 3 of the European Union (Withdrawal) Act 2018 (c.16)[5]. Section 4 of the 2018 Act ensures that any remaining EU rights and obligations, including directly effective rights within EU treaties, continue to be recognised and available in domestic law after exit. An amendment to the Air Quality Standards regulations brought forward through the Environment (Miscellaneous Amendments) (EU Exit) Regulations 2020[6] lowered the $PM_{2.5}$ limit at a similar time.

2.3 These regulations place a duty on NI government departments to monitor levels of air pollutants specified in the Air Quality Directives and ensure compliance with limit values for these pollutants[7]. The Air Quality Regulations (NI) 2010[4] prescribe the relevant authorities and set out the air quality objectives to be achieved, and cover aspects of air quality management areas (AQMAs) and action plans.

2.4 This report fulfils the Review and Assessment requirements of the LAQM process as set out in the Environment (Northern Ireland) Order 2002 Part III[8], the Air Quality Strategy for England, Scotland, Wales and Northern Ireland 2007[9] and the latest relevant Policy[10] and Technical[11] Guidance documents.

Air Quality Objectives and Guidelines

2.5 The measured pollutant concentrations can be compared against the following AQS objectives and World Health Organisation (WHO) guidelines as shown in Table 2-1. The WHO guidelines are not legally binding standards, but exceedance of the air quality guideline (AQG) level is associated with important risks to public health. Interim targets are provided by the WHO to guide reductions towards achieving AQG levels.

2.6 The measured pollutant concentrations can be compared against the following UK AQS objectives and WHO guidelines as shown in Table 2-1.

[3] Council for European Communities, "Ambient air quality and cleaner air for Europe Directive, 2008/50/EC," 2008.
[4] H.M. Government (2010) The Air Quality Standards Regulations (Northern Ireland) 2010, https://www.legislation.gov.uk/nisr/2010/188/contents/made
[5] H.M. Government (2018) European Union (Withdrawal) Act 2018, Available at: https://www.legislation.gov.uk/ukpga/2018/16/contents/enacted
[6] H.M. Government (2020) Environment (Miscellaneous Amendments) (EU Exit) Regulations 2020, Available at: https://www.legislation.gov.uk/uksi/2020/1313/regulation/2/made
[7] https://www.daera-ni.gov.uk/articles/air-quality-monitoring-policy-and-legislation
[8] H.M. Government (2002) The Environment (Northern Ireland) Order 2002, Available at: https://www.legislation.gov.uk/nisi/2002/3153/contents
[9] Department for Environment, Food and Rural Affairs in partnership with the Scottish Executive, Welsh Assembly Government and Department of the Environment Northern Ireland (2007) The Air Quality Strategy for England, Scotland, Wales and Northern Ireland, Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/69336/pb12654-air-quality-strategy-vol1-070712.pdf
[10] DoENI (2010) Local Air Quality Management Policy Guidance – LAQM PGNI (09), Available at: https://www.airqualityni.co.uk/assets/documents/3100729_laqm_policy_guidance_final_version_may_2010_1_.pdf
[11] Defra (2022) Local Air Quality Management Technical Guidance (TG22), Available at: https://laqm.defra.gov.uk/wp-content/uploads/2022/08/LAQM-TG22-August-22-v1.0.pdf

Table 2-1 Air Quality Objectives and Guidelines

Pollutant	Averaging Period	AQS Objective (µg/m^3)	Not to be Exceeded More Than	WHO Guideline (µg/m^3)*	Not to be Exceeded More Than
Nitrogen dioxide (NO_2)	Annual	40	N/A	10	N/A
	1-hour	200	18 hours (99.79th percentile)	N/A	N/A
	Daily	N/A	N/A	25	3 days (99th Percentile)
Particulate matter (PM_{10})	Annual	40	N/A	15	N/A
	Daily	50	35 days (90.4th percentile)	45	3 days (99th Percentile)
Particulate matter ($PM_{2.5}$)	Annual	20	N/A	5	N/A
	Daily	N/A	N/A	15	3 days (99th Percentile)

BCC Local Air Quality Management

2.7 In 2004, BCC completed its first review and assessment of ambient air quality for the city in accordance with the provisions of the government's LAQM technical guidance documents and identified four areas of 'poor' air quality, which were subsequently declared as AQMAs. The AQMAs were declared for a combination of exceedances of annual, 24-hour and 1-hour mean objectives for NO_2 and particulate matter (PM_{10}). These AQMAs remain in place today following annual review of air quality concentrations for almost the last two decades, but only for exceedances of the 1-hour and annual mean objectives for NO_2. Exceedances of the NO_2 1-hour mean objective apply only to the A12 / Westlink AQMA. Since the DA and the LAQM regime are focused on AQS objectives, any exceedances of the AQS objectives are highlighted within this report. However, comparison with WHO guidelines is also discussed for comparison.

2.8 The current AQMAs, as illustrated in Part B, are:

- M1 Motorway / A12 Westlink corridor;
- Ormeau Road from its junction with Donegall Pass to the former Belfast City boundary at Galwally;
- Cromac Street to the junction with East Bridge Street and then from East Bridge Street to the junction with the Ravenhill and Albertbridge Roads and Short Strand; and
- Upper Newtownards Road from the North Road junction to the former Belfast City boundary at the Ulster Hospital.

2.9 An Air Quality Action Plan (AQAP)[12] has recently been produced as part of BCC's statutory duties required under the LAQM framework. It outlines the actions that will be taken to improve ambient air quality in Belfast during the years 2021-2026. This AQAP supersedes the previous Action Plan, which covered the period 2015-2020. The Air Quality Action Plan 2015-2020 for the city drew upon all forms of ambient air quality and transport planning activities, including sustainable transport options as well as engineering solutions.

2.10 A review of monitoring data for Belfast indicates that there have been some recent improvements in NO_2 concentrations across the city. As a result, BCC considered in recent LAQM reporting that there may be an opportunity for revocation of the AQMAs along the Ormeau Road and Upper Newtownards Road, where monitoring data demonstrates recent sustained improvements in annual mean nitrogen dioxide concentrations, with levels consistently below the annual mean AQS objective. This DA determines whether this revocation is viable.

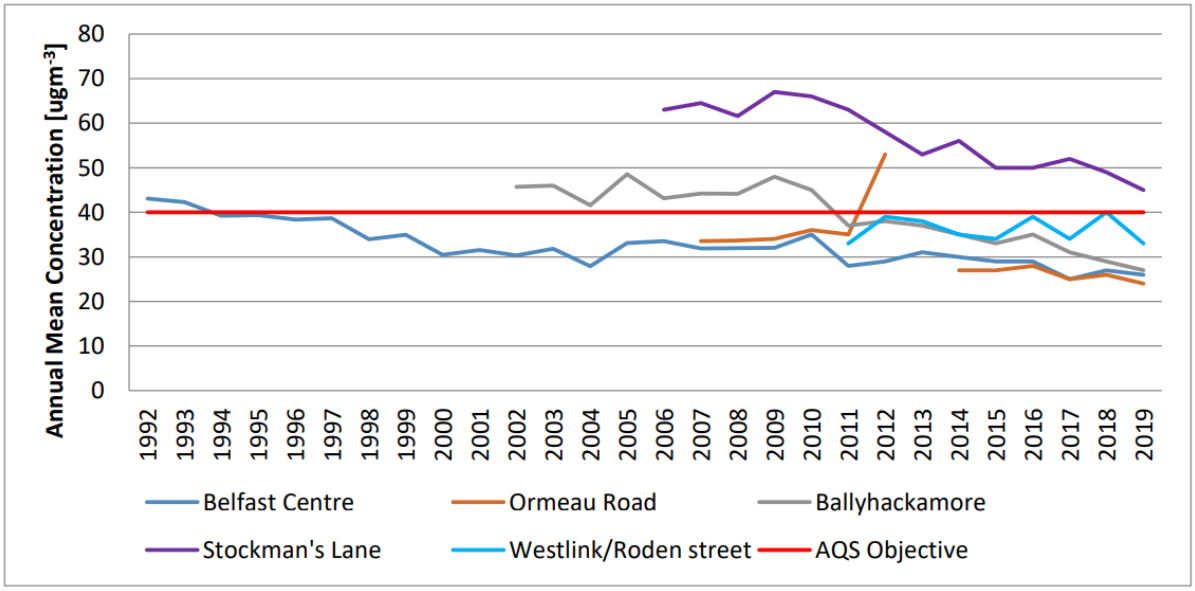
2.11 Recent trends in automatic monitoring of NO_2 have been of general decline in ambient concentrations, even before the COVID-19 pandemic which saw large reductions due to reduced transportation activity. As can be seen in Figure 2.1, only one site (Stockman's Lane, a roadside site) exceeded the annual mean NO_2 AQS objective in 2019, the year of assessment within Part B.

2.12 In addition to a summary of the actual monitored period, for the purpose of the DA it was necessary to adjust the monitored data to be representative of a 2019 annual mean, since this is the year against which the dispersion modelling supporting the DA has been verified. 2019 was selected to verify the dispersion

[12] Belfast Air Quality Action Plan (2021) https://www.belfastcity.gov.uk/documents/belfast-city-air-quality-action-plan-2021-2026

modelling as 2020 and 2021 were considered likely to have been affected by the COVID-19 pandemic and its associated lockdowns, resulting in a notable decrease in pollutant concentrations than would otherwise have been expected. However, a comparison with the AQS objective for 2021 was also undertaken based on annualised 2021 data as the monitored year. This comparison was conducted as per the methodology stated in Section 4.

Figure 2.1 Trends in Annual Mean NO_2 Concentrations Measured at Automatic Monitoring (Taken from BCC AQAP)



2.13 A summary and further analysis of non-automatic monitoring undertaken by BCC for the purpose of LAQM reporting is provided in Part B of the DA.

3. Sensor Monitoring Survey Method

Monitor Selection

3.1 A range of sensor technologies have recently emerged on the market, so there were different suitable options available to be utilised. The options were discussed with and agreed by BCC. The selected instruments, Earthsense's 'Zephyr' monitors, are small, near-reference standard air quality sensors, each weighing 1.75 – 2kg. The Zephyrs are powered wirelessly, using either a bespoke 50W solar panel, or mains power, as appropriate. One instrument is located at each site location, with additional sensor cartridges able to be installed within the unit. The sensors' performance parameters are summarised in Table 3-1.

Figure 3-1 Typical Earthsense Zephyr Monitor

Source: https://www.earthsense.co.uk/

Table 3-1 Zephyr Technical Specifications

Pollutant	Sensor Type	Range	Limit of Detection
NO_2	Electrochemical	0 to 20,000 µg/m^3	7.65 µg/m^3
PM_{10}	Optical particle counter	0 to 20,000 µg/m^3	5 µg/m^3
$PM_{2.5}$	Optical particle counter	0 to 20,000 µg/m^3	5 µg/m^3

Site Selection

3.2 Prior to the commencement of this contract, BCC already operated an extensive network of air quality monitoring sites throughout the city. The network includes four continuous monitors, as well as the Belfast Centre AURN site, and a network of diffusion tubes (55 locations in 2019). Monitoring of NO_2 is undertaken at all these sites, although $PM_{2.5}$ is monitored at the AURN site only as $PM_{2.5}$ is not currently in regulation for Northern Ireland councils' LAQM purposes. Monitoring at the AURN station is undertaken in order to

assess compliance with the 2008/50/EC Directive Average Exposure Indicator, expressed in µg/m^3 and based upon measurements in urban background locations in zones and agglomerations throughout the territory of a member state.

3.3 As previously mentioned, BCC has identified four areas of poor air quality within the city, where recorded exceedances of the UK annual and 1-hour NO_2 objective have been measured and AQMAs have been declared (Figure 3-8). The existing BCC monitoring regime provides a good coverage of NO_2 monitoring sites on roads within these AQMAs and elsewhere across the city, and are the product of many years of assessment of the most appropriate monitoring locations across the city for LAQM. Monitoring of particulate matter is undertaken at the AURN site (PM_{10} and $PM_{2.5}$) and the roadside continuous monitor on Stockman's Lane (PM_{10}).

3.4 Twelve candidate locations were identified by AECOM for their potential to enhance the monitoring regime supporting the DA, with details provided in Table 3-2.

Table 3-2 Candidate Monitoring Sites

Site	Location	Figure	Justification
N1a (Roadside)	A55, Upper Knockbreda Road		Potential site N1 is located at the corner of the main A-road(A55) and Glencregagh Rd which is near to AQMA No.4. No existing monitoring of PM_{10} or $PM_{2.5}$ undertaken in this area. Signage on lamppost could possibly obstruct monitor. Parking available across the road. Also near to Forster Green Hospital.
N1b (Roadside)	A55 St Bernard's Primary School		Alternative site to N1 similar emissions. Representing primary school. Could also locate at lamppost next to end of Wynchurch Road. Locate prior to southbound carriageway elevating
N2 (Roadside)	A20, Upper Newtownards Road		Arterial road located in AQMA No.3. No monitoring on the east side of the A20 and A55 junction. Parking available close to site.
N3 (Roadside)	106 Kings Road		Road located within AQMA No.3 along Kings Road. – No existing monitoring of PM_{10} or $PM_{2.5}$ undertaken on this stretch of the AQMA. Parking available near to site for ease of access.

Site	Location	Figure	Justification
N4a (Other)	East Twin Road		Access road near Queens Road. Site is aimed to monitor shipping emissions produced to the North. Fencing may be an alternative option although height of fencing remains an issue.
N4b (Other)	Port Health Unit		Fencing or lamppost, or even railing by emergency exit if there's a need to get it onto the Council owned site
N5 (Other)	Upper Springfield Road		Limited locations available for monitoring. Lamppost located near to Quarry for monitoring dust dispersion. Potential monitoring option dependent on the nature and activity of quarry.
N6a (Urban Background)	Lismore Street		Monitoring location based centrally in a residential area for urban background monitoring. May require further investigation on the current status of the land next to proposed location.
N6b (Urban Background)	Clara Street Playground		Inset into fencing so out of the way so less likely to be interfered with and safer. Could be mounted on either the lamp post or the fencing directly

Site	Location	Figure	Justification
N7 (Urban Background)	4 Lower Crescent		Lamppost located in a park near a residential area. May not be feasible to locate monitors here due to heritage reasons. Alternate location for the monitor is the church located at the edge of the park.
N8 (Other)	Off the A2 Sydenham By-Pass		Pollutant concentrations may be high due to airport and storage facility emissions. This location is located near access road of the main A2 road.
N9 (Roadside/ Other)	A24, near Oxford Street		Main arterial road to the east of the city centre. Located within the AQMA and above railway station. No existing monitoring of PM_{10} or $PM_{2.5}$ undertaken.
N10 (Roadside)	M1/Westlink AQMA		On New Lodge playground side of fencing – either fence or lamp post as appropriate. May be difficult to get close enough to be classed as roadside.

Site	Location	Figure	Justification
N11 (Urban Background)	Millennium Park		Can use floodlights as accessible pillars, that are out of the way. Set far enough back on road that it can be background.
N12 (Urban Background)	Hazel View, Dunmurry		Background location nearer to western boundary of city region. Addressing concerns from Councillors around landfill.

3.5 These locations were provisionally chosen taking into consideration the project objectives, existing BCC monitoring, proximity to source and suitability for model verification, nearby receptors, site accessibility and safety, and site suitability (i.e. presence of infrastructure on which to install).

3.6 The Council and other relevant stakeholders then selected five preferred sites (with the AURN co-location being the sixth) to pursue to installation based on the twelve candidate locations presented. This took into account AECOM's recommendation that the Zephyr network ideally be comprised of 2x roadside sites, 1x urban background site to consider non-road sources from a residential location, and 2x sites considering 'other' sources – i.e. airport, railway, port or quarry.

3.7 In consultation with BCC, Department for Infrastructure (DfI) and the relevant Council committee representatives, the long list of candidate monitoring locations was then refined to five preferred locations, at which installation would ideally have been pursued.

3.8 Factors influencing the five preferred locations included:

- Agreement from the port authority that the DA can utilise Zephyr monitoring run by Belfast Harbour, meaning there is no need to additionally monitor this source as part of the DA;
- Negating concerns from People and Communities Committee Members around landfill sites to the west of the city;
- Health and safety considerations;
- A preference toward background locations in order to characterise domestic $PM_{2.5}$ concentrations;
- Additional need to monitor at a location representative of a school; and
- The need to monitor within the Westlink AQMA.

3.9 Following a scoping visit by AECOM site staff and the BCC Air Quality Officer, three of the candidate locations were further refined to take account of local micro-scale siting criteria and additional safety concerns that it was not possible to ascertain via the desktop scoping exercise. These site-specific factors that resulted in changes from the initially preferred locations included:

- Denser vegetation cover than anticipated based on Google imagery at N1b;
- The split elevation of the carriageway in the vicinity of N1b/c which limited the alternative options moving north-east;
- Influence from vehicle emissions on the left turn filter lane starting at N1b;
- Heavy shading of site N6b which would reduce the reliability of the solar power supply; and
- Safety concerns around the location of N12a, wherein a police 'antisocial behaviour' monitoring sign indicated the likelihood of vandalism.

3.10 The monitoring locations eventually selected are summarised in Table 3-3 and displayed in Figure 3-8, in the context of the current AQMAs. Monitoring commenced for the majority of the Zephyr sites on 2nd July 2021 ran, as managed by AECOM, for a period of nine months up until the end of March 2022. The data were then managed by BCC until the end of the purchased period, on 13th May 2022.

Table 3-3 Site Details

Site ID	Description	Type	X	Y	Height (m)	Distance to Kerb (m)
N1	A55	Roadside	335735	370740	2.5	6
N6	Clara Street	Urban Background	336030	373469	2.5	N/A
N8	Belfast City Airport Boundary	Other Sources	337110	375535	2.5	N/A
N10	Adjacent to the Westlink	Roadside	333645	375239	4	4
N12	Mt. Eagles Glen	Urban Background	326190	369255	2.5	N/A
ZAURN (AURN co-location)	Lombard Street AURN	Urban Background	333898	374358	4	N/A

3.11 Images of each of the Zephyrs in situ are provided in Figure 3-2 to Figure 3-7.

Figure 3-2 N1 A55 Z790

Figure 3-3 N6 Clara Street Z793

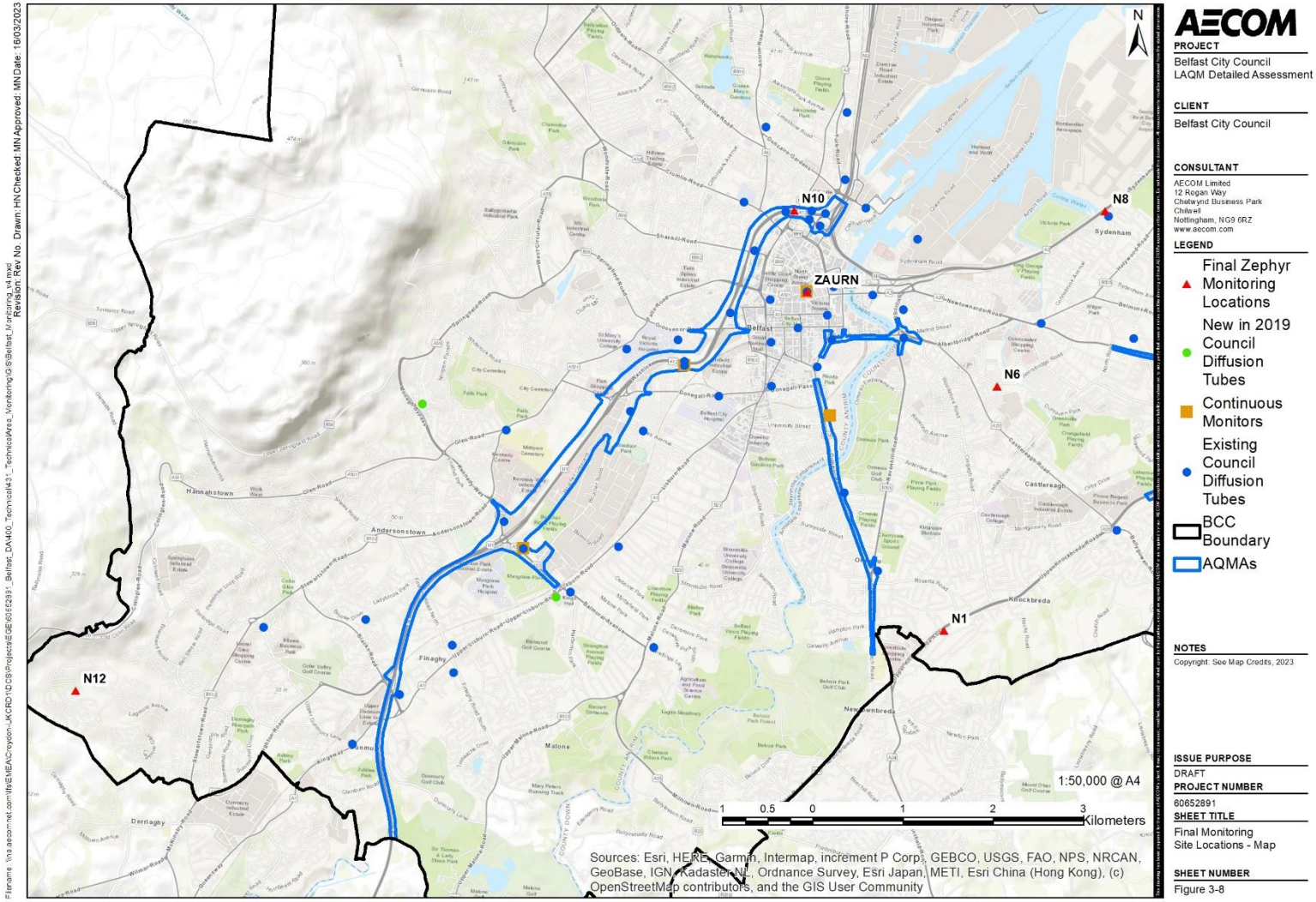
Figure 3-4 N8 Airport Boundary Z842

Figure 3-5 N10 Westlink Z748

Figure 3-6 N12 Mt Eagles Glen Z743 & 1023

Figure 3-7 ZAURN Co-Location Z787 & 799

Figure 3-8 Monitoring Site Locations – Map (c) 2022



Meteorology

3.12 Wind speeds and directions for the 2021 calendar year were gathered from the Belfast City Airport meteorological station (Station ID 3924). This site is to the south-east of the harbour. Figure 3-9 shows a wind rose for data collected at this site. The wind rose shows that the predominant wind direction is from the south-west.

3.13 2019 data (the year against which the dispersion modelling will be verified) for Belfast City Airport gives similar predominant wind speed and directions (Figure 3-10). The two years indicate a fairly consistent trend temporally across the city, and it would be expected that sites to the north of emissions sources would experience higher concentrations.

Figure 3-9 Wind Rose for 2021 Belfast City Airport Meteorological Station

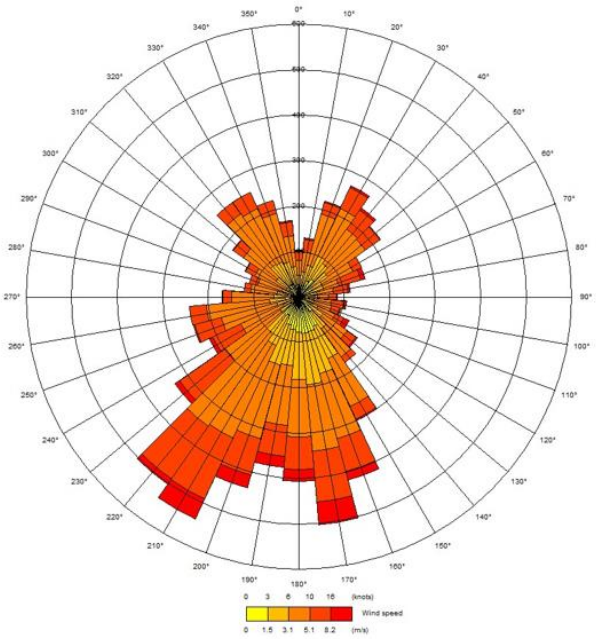
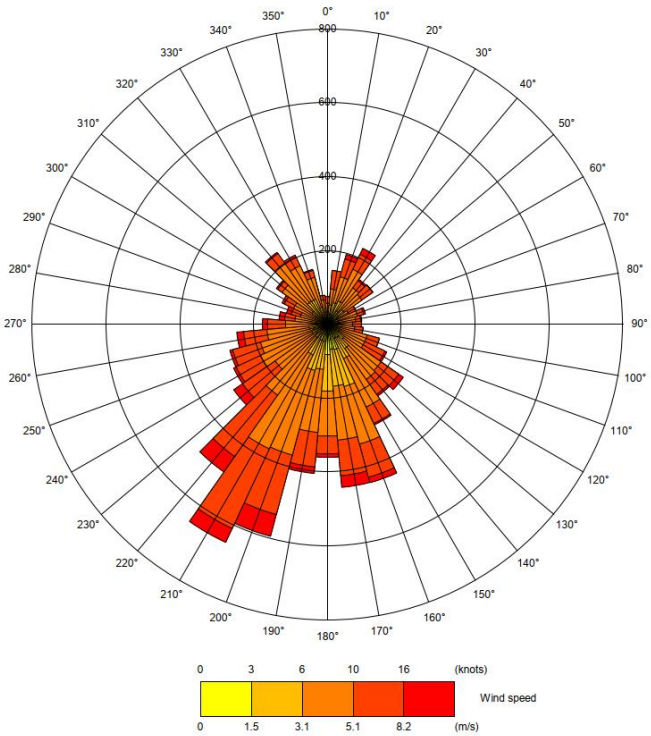


Figure 3-10 Wind Rose for 2019 Belfast City Airport Meteorological Station



4. Data Processing Method

4.1 The Zephyr monitoring units deployed in fulfilment of the monitoring requirements were calibrated by the manufacturer prior to installation. Periodic re-calibrations are made by the manufacturer where systematic biases are present when comparing a Zephyr's data with a regional average of EU-standard reference stations for a representative environment category. Copies of the calibration certificates are presented in Appendix A.

4.2 Following collection of the raw data, the provisional data (i.e. that which is considered 'real' or useable data, and not instrument fault) was collated. The data is then ratified through a process that involves removal of any negative concentrations or other spurious values. The data are interrogated in detail and based on professional judgement, data is removed from consideration that is deemed related to instrument fault and/or noise, so as not to provide a false representation of ambient concentrations. It is this data that has been reported within the monthly reports throughout the project and is referred to in this summary report as 'ratified' data.

4.3 A two-stage data scaling process has then been undertaken in the calculation of a final data mean from the ratified data. First, to account for any bias in the monitoring method, data were compared between the co-located BCC Zephyr unit and the AURN Belfast Centre monitoring station, and an adjustment factor was applied. Then, to account for any variation in sensor cartridge response between locations, a second sensor cartridge was periodically moved between each of the sites to provide a second adjustment for sensor performance. This is referred to as 'scaled' data in the report

4.4 Further details of the applied adjustments can be found in Section 4.6 onward, and Appendix A.

4.5 Data in the form of time series plots, for each pollutant and site, are provided in Appendix A.

AURN Data Scaling

4.6 To account for potential bias in the Zephyr instruments (such as a tendency to over or under predict concentrations compared to reference monitors), a comparison was made between Zephyr cartridges located alongside the AURN Belfast Centre monitoring station. A comparison of NO_2, PM_{10} and $PM_{2.5}$ hourly concentrations monitored by the "A" Zephyr cartridge at the Zephyr Belfast Centre AURN location between 13th August 2021 and 11th November 2021 was made. Scatter plots supporting these calculations can be found in Appendix A. The data are summarised in Table 4-1.

Table 4-1 AURN Data Scaling Summary

Site ID (Zephyr ID)	Period Co-located	NO_2 Intercept	NO_2 Slope	NO_2 R^2	PM_{10} Intercept	PM_{10} Slope	PM_{10} R^2	$PM_{2.5}$ Intercept	$PM_{2.5}$ Slope	$PM_{2.5}$ R^2
ZAURN (Z787)	02/07/21 – 22/11/21	2.555	1.232	0.7067	4.078	0.9572	0.5485	1.017	0.8759	0.8605

4.7 The linear regression equation for NO_2, shows a tendency for the Zephyr to under-predict NO_2 concentrations relative to the AURN station, indicated by a slope of 1.23 (i.e., greater than 1) and intercept of +2.55. The R^2 value of 0.71 indicates a positive correlation between the Zephyr measurements and the AURN data.

4.8 The linear regression equation for PM_{10}, shows a tendency for the Zephyr to under-predict PM_{10} concentrations relative to the AURN station at lower concentrations, indicated by an intercept of +4.08. At higher concentrations, the Zephyr relationship alters, hence a slope of 0.96. The plot shows considerably more scatter in the data points and an R^2 value of 0.55 indicates a weaker correlation between the Zephyr measurements and the AURN data than is the case for NO_2.

4.9 The linear regression equation for $PM_{2.5}$, shows a tendency for the Zephyr to over-predict $PM_{2.5}$ concentrations relative to the AURN station, indicated by a slope of 0.88 (i.e., less than 1) and intercept of +1.02. The R^2 value of 0.86 indicates a good positive correlation between the Zephyr measurements and the AURN data.

4.10 The regression coefficients were applied to the raw data from the "A" cartridge to calibrate the Zephyr cartridge measurements to the AURN reference station. The calibrated cartridge was then moved around the other five monitoring locations to derive the site-specific scaling factors, as described below.

Second Cartridge Data Scaling

4.11 Regression analyses were undertaken for the co-locations of the calibrated second sensor cartridge at each site as this was moved around, which were then applied to the data. A summary of the relationship and scaling data is provided in Table 4-2, with further details found in Appendix A.

4.12 Second cartridge scaling was not required for the ZAURN location because the "B" Zephyr cartridge was co-located with the reference station for the duration of the survey.

Table 4-2 Second Cartridge Data Scaling Summary

Site ID (Zephyr ID)	Period Co-located	NO_2 Intercept	NO_2 Slope	NO_2 R^2	PM_{10} Intercept	PM_{10} Slope	PM_{10} R^2	$PM_{2.5}$ Intercept	$PM_{2.5}$ Slope	$PM_{2.5}$ R^2
N1 (Z790)	24/01/22 – 17/03/22	1.328	1.105	0.9279	0.8107	0.9758	0.9545	0.1226	1.109	0.8850
N6 (Z793)	17/03/22 – 01/04/22	2.644	0.836	0.9934	2.083	0.9197	0.9664	0.201	0.949	0.9666
N8 (Z842)	01/04/22 – 13/05/22	1.873	1.026	0.9865	0.1948	0.9241	0.9915	0.02152	0.9265	0.9904
N10 (Z748)	20/12/21 – 24/01/22	2.16	0.9846	0.9866	1.179	0.916	0.9931	0.3386	0.9304	0.9931
N12 (Z1023)	22/11/21 – 20/12/21	5.199	0.774	07763	0.1607	0.8803	0.9323	1.1017	0.8198	0.8854

Annualisation and Calendar Mean Adjustment

4.13 Whilst necessary to present the ratified and scaled data as captured, for the purposes of the DA it was also necessary to adjust the data to be representative of a 2019 annual mean, since this is the year against which the dispersion modelling supporting the assessment will be verified. A 2021 annual mean has also been calculated in a similar fashion, for reporting in the BCC Progress Report, should the Council wish to do so.

4.14 Notwithstanding the uncertainties introduced by the COVID-19 pandemic (the effects of which were still affecting traffic flows and therefore concentrations at some monitoring locations during the sensor monitoring survey), adjustment of the data to previous years must take into account the general trend in pollutant concentrations, as per LAQM FAQ 139[13] and LAQM.TG(22)[14] Box 7.12.

4.15 To make this adjustment, the Roadside NO_2 Projection Factors[15] were applied to the data to compensate for the general trend of reducing concentrations over time. These factors have been calculated as the average of modelled concentrations across approximately 1,900 road links in London, and 7,000 links elsewhere, taking into account the changes in activity, and emission factors and primary NO_2 (f-NO_2).

4.16 These projection factors are location and fleet composition specific. Therefore, the location was selected as 'Rest of UK' and the fleet composition as 'HDV =<10%', The adjustment factors derived for 2021 and 2022 were 1.11 and 1.18 respectively to project back to 2019, and 1.06 to project back from 2022 to 2021[16].

4.17 Where the resultant adjusted annual mean data capture rate for the monitoring sites remained less than 75% of the year, annualisation was then used to estimate an annual average from a part year average. The technique followed to annualise the continuous monitoring data is presented in Box 7.9 of LAQM.TG(22)[14].

4.18 Annualisation is the process of estimating annual means from the extrapolation of short-term monitoring results. The methodology consists of using concentration data from nearby continuous monitoring sites to

[13] https://laqm.defra.gov.uk/faqs/faq139/
[14] Defra and the Devolved Administrations (2022) Local Air Quality Management Technical Guidance (TG22), Available at: https://laqm.defra.gov.uk/wp-content/uploads/2022/08/LAQM-TG22-August-22-v1.0.pdf
[15] https://laqm.defra.gov.uk/air-quality/air-quality-assessment/roadside-no2-projection-factors/
[16] It is noted that this methodology is designed primarily for NO_2, but in lieu of an alternative approach in the guidance, this has also been applied to PM_{10} and $PM_{2.5}$. This is considered a conservative approach, since PM concentrations are generally more stable over time that the projection factors would estimate, resulting in higher concentrations using this approach.

assist in estimating annual mean concentrations at the site(s) in question. The continuous monitoring sites used for comparison were Belfast Centre AURN (Urban Background), Belfast Stockmans Lane AURN (Urban Traffic) and Ballymena Ballykeel AURN (Urban Background).

4.19 Further details of the annualisation process are provided in Appendix A.

5. Data Summary

5.1 The monitoring period summarised in this report covers the period from 2nd July 2021 until 11th May 2022. The key statistics for the ratified data are shown in Table 5-1, with scaled data shown in Table 5-2. Data capture for each site is shown in subsequent data tables.

Table 5-1 Summary of Key Statistics – Ratified Data

Pollutant	Site	Period Mean (µg/m³)	AQS Annual Mean Objective	Number of 1-hour mean concentrations >200µg/m³	Number of 24-hour Means >50µg/m³
NO_2	AURN Belfast Centre (AURN)	22.5	40 µg/m³ annual mean 200 µg/m³ for 1 hour mean exceedances	0	N/A
	AURN co-location (ZAURN)	20.6		0 (80.3)	
	N1	15.6		0 (70.7)	
	N10	36.2		0	
	N12	9.4		0 (53.0)	
	N6	14.0		0	
	N8	18.5		0	
PM_{10}	AURN Belfast Centre (AURN)	14.3	40 µg/m³ annual mean 50 µg/m³ for 24 hour mean exceedances	N/A	4
	AURN co-location (ZAURN)	13.0			5 (26.2)
	N1	11.3			2 (24.7)
	N10	13.0			4
	N12	9.6			0 (19.9)
	N6	15.1			0
	N8	11.0			0
$PM_{2.5}$	AURN Belfast Centre (AURN)	8.4	20 µg/m³ annual mean	N/A	N/A
	AURN co-location (ZAURN)	10.8			
	N1	8.7			
	N10	10.3			
	N12	7.1			
	N6	10.8			
	N8	8.3			
Where data capture is below 85%, for short term mean objectives, 99.79th and 90.4th percentiles have been presented for NO_2 and PM_{10} respectively, in brackets.					

Table 5-2 Summary of Key Statistics – Scaled Data

Pollutant	Site	Period Mean (µg/m^3)	AQS Annual Mean Objective	Number of 1-hour mean concentrations >200µg/m^3	Number of 24-hour Means >50µg/m^3
NO_2	AURN Belfast Centre (AURN)	22.5	40 µg/m^3 annual mean 200 µg/m^3 for 1 hour mean exceedances	0	N/A
	AURN co-location (ZAURN)	25.0		0 (98.9)	
	N1	18.5		0 (80.0)	
	N10	45.7		0	
	N12	11.5		0 (80.9)	
	N6	20.6		0	
	N8	22.9		0	
PM_{10}	AURN Belfast Centre (AURN)	14.3	40 µg/m^3 annual mean 50 µg/m^3 for 24 hour mean exceedances	N/A	5
	AURN co-location (ZAURN)	13.7			2 (24.9)
	N1	14.5			3 (27.6)
	N10	16.8			6
	N12	14.8			1 (26.1)
	N6	17.9			3
	N8	15.5			3
$PM_{2.5}$	AURN Belfast Centre (AURN)	8.4	20 µg/m^3 annual mean	N/A	N/A
	AURN co-location (ZAURN)	11.6			
	N1	7.7			
	N10	10.4			
	N12	7.6			
	N6	10.8			
	N8	9.0			
Where data capture is below 85%, for short term mean objectives, 99.79th and 90.4th percentiles have been presented for NO_2 and PM_{10} respectively, in brackets.					

6. Monitoring Results

ZAURN Co-Location Site (Z787 & Z799), Lombard Street AURN

6.1 Zephyr instrument 787 (and latterly Z799) is co-located with Belfast Centre AURN site.

6.2 Incidents affecting the raw data capture at this site during its deployment are as follows:

- Instrument stabilisation on install;
- Removal of unit shortly after installation on safety grounds in early July 2021, with subsequent re-attachment with more anchorage points shortly thereafter;
- Lack of solar power between late November and early February, whilst enquiries were made to connect the unit to the AURN station's continuous power supply the sensor suffered reduced data capture;
- Interruption to the data supplied via the Earthsense portal over the Christmas period (primarily 26th and 27th December 2021) across all units; and
- A short period whilst the unit was changed, and connected to the AURN power supply on 17th February 2022.

6.3 Data processing affecting the ratified data capture at this site are as follows:

- Removal of zero concentration data.
- Removal of intermittent data collected in periods where the solar panel was not effectively charging the battery, as these data were often considered not to be representative.

6.4 Two sensor cartridges were initially installed in instrument Z787 to help derive the adjustment factors. Slot B was used for results reported at this location. The second sensor cartridge was used between August and November 2021, to derive a local calibration factor.

6.5 The mean NO_2, PM_{10} and $PM_{2.5}$ concentrations for the ratified and scaled data are shown in Table 6-1 and Table 6-2 respectively, along with numbers of exceedances of the respective objectives. Where data capture is below 85%, for short term mean objectives, 99.79th and 90.4th percentiles have been presented for NO_2 and PM_{10} respectively, in brackets.

Table 6-1 ZAURN Co-Location Z787 & Z799 (Slot B) Air Quality Monitoring Results – Ratified Data

Site	Statistic	NO_2	PM_{10}	$PM_{2.5}$
AURN Co-location Z787 (ZAURN)	Period Mean (µg/m^3)	20.6	13.0	10.8
	Number of 1-hour mean NO_2 concentrations > objective value of 200 µg/m^3	0 (80.3)	-	-
	Number of 24-hour mean PM_{10} concentrations > objective value of 50 µg/m^3	-	5 (26.2)	-
	Raw Data Capture (%)	75.3	75.6	75.7
	Ratified Data Capture (%)	67.9	71.7	71.6

Table 6-2 ZAURN Co-Location Z787 & Z99 (Slot B) Air Quality Monitoring Results – Scaled Data

Site	Statistic	NO_2	PM_{10}	$PM_{2.5}$
AURN Co-location Z787 (ZAURN)	Period Mean (µg/m^3)	25.0	13.7	11.6
	Number of 1-hour mean NO_2 concentrations > objective value of 200 µg/m^3	0 (98.9)	-	-
	Number of 24-hour mean PM_{10} concentrations > objective value of 50 µg/m^3	-	2 (24.9)	-
	Raw Data Capture (%)	75.3	75.6	75.7
	Scaled Data Capture (%)	67.9	71.7	71.6

6.6 Specific events (for scaled data) where there were exceedances of the 24-hour mean PM_{10} objective are as follows:

- 22nd March 2022 – 50.5 µg/m^3
- 26th March 2022 – 54.9 µg/m^3

6.7 These days of elevated PM_{10} concentrations coincided with a regional PM_{10} and $PM_{2.5}$ pollution episode that saw 'Moderate' to 'High' air pollution levels across most of the UK.

Roadside Sites

6.8 Zephyr instruments N1 and N10 are located at roadside (RS) locations.

N1, A55

6.9 Site N1 (Z790) is located along the A55, close to St Bernard's Primary school, but before the road becomes split level so as to capture emissions effectively from both directions of the carriageway.

6.10 The second sensor cartridge was in situ at N1 between 24th January 2022 and 17th March 2022, to derive a local calibration factor.

6.11 Incidents affecting the raw data capture at this site during its deployment are as follows:

- Instrument stabilisation on install;
- The communications and data storage on the instrument were not functional in the initial period of deployment. The supplier advised that the unit would still be collecting data, however it later became apparent that this data was irretrievable. Data capture commenced correctly on 18th August, when this issue could be resolved;
- A second issue with the replacement SD card in December 2021. Due to supply side issues, this could not be delivered by Earthsense until January 2021, affecting data capture in this period as the unit was operational but unable to store data; and
- Interruption to the data supplied via the Earthsense portal over the Christmas period (primarily 26 and 27th December 2021) across all units.

6.12 Data processing affecting the ratified data capture at this site are as follows:

- Removal of zero concentration data.

6.13 The mean NO_2, PM_{10} and $PM_{2.5}$ concentrations for the ratified and scaled data for N1 are shown in Table 6-3 and Table 6-4 respectively, along with numbers of exceedances of the respective standards. Where data capture is below 85%, for short term mean objectives, 99.79th and 90.4th percentiles have been presented for NO_2 and PM_{10} respectively, in brackets.

Table 6-3 N1 A55 RS Z790 Air Quality Monitoring Results – Ratified Data

Site	Statistic	NO_2	PM_{10}	$PM_{2.5}$
N1 A55 RS Z790	Period Mean (µg/m^3)	15.6	11.3	8.7
	Number of 1-hour mean NO_2 concentrations > objective value of 200 µg/m^3	0 (70.7)	-	-
	Number of 24-hour mean PM_{10} concentrations > objective value of 50 µg/m^3	-	2 (24.7)	-
	Raw Data Capture (%)	73.9%	73.6%	73.6%
	Ratified Data Capture (%)	73.2%	72.7%	72.6%

Table 6-4 N1 A55 RS Z790 Air Quality Monitoring Results – Scaled Data

Site	Statistic	NO_2	PM_{10}	$PM_{2.5}$
N1 A55 RS Z790	Period Mean (µg/m^3)	18.5	14.5	7.7
	Number of 1-hour mean NO_2 concentrations > objective value of 200 µg/m^3	0 (80.0)	-	-
	Number of 24-hour mean PM_{10} concentrations > objective value of 50 µg/m^3	-	3 (27.6)	-
	Raw Data Capture (%)	73.9%	73.6%	73.6%
	Scaled Data Capture (%)	73.2%	72.7%	72.6%

6.14 Specific events (for scaled data) for 24-hour mean PM_{10} are as follows:

- 22nd March 2022 – 53.1 µg/m^3
- 23rd March 2022 – 50.1 µg/m^3
- 26th March 2022 – 57.0 µg/m^3

6.15 These days of elevated PM_{10} concentrations coincided with a regional PM_{10} and $PM_{2.5}$ pollution episode that saw 'Moderate' to 'High' air pollution levels across most of the UK.

N10, Westlink

6.16 Site N10 (Z748) is within AQMA 1 and is located as near as is safe and practicable to the Westlink / M1 road, given this was identified by BCC as one of the main NO_x emission transport sources in Belfast.

6.17 The second sensor cartridge was in situ at N10 between 20th December 2021 and 24th January 2022, to derive a local calibration factor.

6.18 Incidents affecting the raw data capture at this site during its deployment are as follows:

- Instrument stabilisation on install;
- A communications fault developed just after installation, which meant the unit had to be taken down for repair between 22nd July 2021 and 3rd August 2021; and
- Interruption to the data supplied via the Earthsense portal over the Christmas period (primarily 26 and 27th December 2021) across all units.

6.19 Data processing affecting the ratified data capture at this site are as follows:

- Removal of zero concentration data.

6.20 The mean NO_2, PM_{10} and $PM_{2.5}$ concentrations for the ratified and scaled data for N10 are shown in Table 6-5 and Table 6-6 respectively, along with numbers of exceedances of the respective objectives.

Table 6-5 N10 Westlink RS Z748 Air Quality Monitoring Results – Ratified Data

Site	Statistic	NO_2	PM_{10}	$PM_{2.5}$
N10 Westlink RS Z748	Period Mean (µg/m^3)	36.2	13.0	10.3
	Number of 1-hour mean NO_2 concentrations > objective value of 200 µg/m^3	0	-	-
	Number of 24-hour mean PM_{10} concentrations > objective value of 50 µg/m^3	-	4	-
	Raw Data Capture (%)	96.7%	96.3%	96.3%
	Ratified Data Capture (%)	92.9%	92.6%	92.5%

Table 6-6 N10 Westlink RS Z748 Air Quality Monitoring Results – Scaled Data

Site	Statistic	NO_2	PM_{10}	$PM_{2.5}$
N10 Westlink RS Z748	Period Mean (µg/m^3)	45.7	16.8	10.4
	Number of 1-hour mean NO_2 concentrations > objective value of 200 µg/m^3	0	-	-
	Number of 24-hour mean PM_{10} concentrations > objective value of 50 µg/m^3	-	6	-
	Raw Data Capture (%)	96.7%	96.3%	96.3%
	Scaled Data Capture (%)	92.9%	92.6%	92.5%

6.21 Specific events (for scaled data) for 24-hour mean PM_{10} are as follows:

- 22nd November 2021 – 89.5 µg/m^3
- 21st March 2022 – 51.7 µg/m^3
- 22nd March 2022 – 58.4 µg/m^3
- 23rd March 2022 – 59.2 µg/m^3
- 25th March 2022 – 51.2 µg/m^3
- 26th March 2022 – 61.3 µg/m^3

6.22 The high PM_{10} concentrations on 22nd November 2021 may have been related to local events (e.g. fireworks, roadworks, or grounds maintenance).

6.23 The days of elevated PM_{10} concentrations during March 2022 coincided with a regional PM_{10} and $PM_{2.5}$ pollution episode that saw 'Moderate' to 'High' air pollution levels across most of the UK.

Urban Background Sites

6.24 Zephyr instruments N6 and N12 are located in urban background (UB) locations.

N6, Clara Street

6.25 Site N6 (Z793) is located on Clara Street to the east of the city, initially installed to characterise domestic particulate emissions, and give a general indication of background concentrations in this part of Belfast.

6.26 The second sensor cartridge was in situ at N6 between 17th March 2022 and 1st April 2022, to derive a local calibration factor.

6.27 Incidents affecting the raw data capture at this site during its deployment are as follows:

- Instrument stabilisation on install; and
- Interruption to the data supplied via the Earthsense portal over the Christmas period (primarily 26th and 27th December 2021) across all units.

6.28 Data processing affecting the ratified data capture at this site are as follows:

- Removal of zero concentration data.

6.29 The mean NO_2, PM_{10} and $PM_{2.5}$ concentrations for the ratified and scaled data for N6 are shown in Table 6-7 and Table 6-8 respectively, along with numbers of exceedances of the respective objectives.

Table 6-7 N6 Clara St UB Z793 Air Quality Monitoring Results – Ratified Data

Site	Statistic	NO_2	PM_{10}	$PM_{2.5}$
N6 Clara St UB Z793	Period Mean (µg/m^3)	14.0	15.1	10.8
	Number of 1-hour mean NO_2 concentrations > objective value of 200 µg/m^3	0	-	-
	Number of 24-hour mean PM_{10} concentrations > objective value of 50 µg/m^3	-	0	-
	Raw Data Capture (%)	98.8%	98.4%	98.4%
	Ratified Data Capture (%)	97.2%	98.2%	98.2%

Table 6-8 N6 Clara St UB Z793 Air Quality Monitoring Results – Scaled Data

Site	Statistic	NO_2	PM_{10}	$PM_{2.5}$
N6 Clara St UB Z793	Period Mean (µg/m^3)	20.6	17.9	10.8
	Number of 1-hour mean NO_2 concentrations > objective value of 200 µg/m^3	0	-	-
	Number of 24-hour mean PM_{10} concentrations > objective value of 50 µg/m^3	-	3	-
	Raw Data Capture (%)	98.8%	98.4%	98.4%
	Scaled Data Capture (%)	97.2%	98.2%	98.2%

6.30 Specific events (for scaled data) for 24-hour mean PM_{10} are as follows:

- 22nd March 2022 – 53.8 µg/m^3
- 23rd March 2022 – 50.5 µg/m^3
- 26th March 2022 – 52.5 µg/m^3

6.31 These days of elevated PM_{10} concentrations coincided with a regional PM_{10} and $PM_{2.5}$ pollution episode that saw 'Moderate' to 'High' air pollution levels across most of the UK.

N12, Mt. Eagles Glen

6.32 Site N12 (Z743 & latterly Z1023) is located to the south west of the city, and was intended to characterise background concentrations in this part of Belfast, as well as monitor the potential for any emissions from nearby landfill activities reaching this residential area.

6.33 The second sensor cartridge was in situ at N12 between 22nd November 2021 and 20th December 2021, to derive a local calibration factor.

6.34 Incidents affecting the raw data capture at this site during its deployment are as follows:

- Instrument stabilisation on install;
- The unit first installed developed continual communications faults from 16th September 2021. This was initially resolved on site on 21st September 2021, but the fault recurred on 29th September 2021. A replacement unit was requested to fix this, which was installed on 18th October 2021;
- A fault was identified with the replacement unit's inlet fan (affecting primarily PM data) which meant a further replacement sensor cartridge was required, installed on the 22nd November 2021;
- The unit was taken down for a period of approximately three days in December 2021, in order to recharge the battery, which was not being fully recharged by solar power in this period; and
- Interruption to the data supplied via the Earthsense portal over the Christmas period (primarily 26 and 27th December 2021) across all units.

6.35 Data processing affecting the ratified data capture at this site are as follows:

- Retrospective data deletion was necessary on identification of the fan fault in November 2021; and
- Removal of zero concentration data, and data around periods where the unit was not being charged sufficiently by the solar panel.

6.36 The mean NO_2, PM_{10} and $PM_{2.5}$ concentrations for the ratified and scaled data for N12 are shown in Table 6-9 and Table 6-10 respectively, along with numbers of exceedances of the respective standards.

Table 6-9 N12 Mt Eagles Glen UB Z743 & 1023 Air Quality Monitoring Results – Ratified Data

Site	Statistic	NO_2	PM_{10}	$PM_{2.5}$
N12 Mt Eagles Glen UB Z743 & 1023	Period Mean (µg/m^3)	9.4	9.6	7.1
	Number of 1-hour mean NO_2 concentrations > objective value of 200 µg/m^3	0 (53.0)	-	-
	Number of 24-hour mean PM_{10} concentrations > objective value of 50 µg/m^3	-	0 (19.9)	-
	Raw Data Capture (%)	80.0%	79.7%	79.7%
	Ratified Data Capture (%)	69.3%	72.2%	72.2%

Table 6-10 N12 Mt Eagles Glen UB Z743 &1023 Air Quality Monitoring Results – Scaled Data

Site	Statistic	NO_2	PM_{10}	$PM_{2.5}$
N12 Mt Eagles Glen UB Z743 & 1023	Period Mean (µg/m^3)	11.5	14.8	7.6
	Number of 1-hour mean NO_2 concentrations > objective value of 200 µg/m^3	0 (80.9)	-	-
	Number of 24-hour mean PM_{10} concentrations > objective value of 50 µg/m^3	-	1 (26.1)	-
	Raw Data Capture (%)	80.0%	79.7%	79.7%
	Scaled Data Capture (%)	69.3%	72.2%	72.2%

6.37 Specific events (for scaled data) for 24-hour mean PM_{10} are as follows:

- 22nd March 2022 – 50.1 µg/m^3

6.38 This day of elevated PM_{10} concentrations coincided with a regional PM_{10} and $PM_{2.5}$ pollution episode that saw ‘Moderate’ to ‘High’ air pollution levels across most of the UK.

N8, Airport Site, Belfast City Airport

6.39 Zephyr instrument N8 is located close to the boundary of George Best Belfast City Airport (GBBCA). It was installed to help characterise emissions from the airport, given there was less monitoring in this regard as GBBCA has previously been screened out from assessment using the criteria detailed in section 7.17 of LAQM.TG(22)[14].

6.40 That said, the NO_2 diffusion tube located at Station Road has been placed to assess NO_2 concentrations at relevant receptor (residential) locations close to the airport. This location is also indicative of NO_x emissions from the Sydenham Bypass (as could be considered to be the case for N8) and from the adjacent Belfast to Bangor train line.

6.41 At N8, the second sensor cartridge was in situ at N8 between 1st April 2022 and 13th April 2022, to derive a local calibration factor.

6.42 Incidents affecting the raw data capture at this site during its deployment are as follows:

- Instrument stabilisation on install; and
- Interruption to the data supplied via the Earthsense portal over the Christmas period (primarily 26th and 27th December 2021) across all units.

6.43 Data processing affecting the ratified data capture at this site are as follows:

- Removal of zero concentration data;
- Peak concentration events early in the instruments' deployment, reported on within the July-September 2021 monthly reports, were removed as these were considered likely to be instrument noise within the stabilisation period, given these were not repeated again through the data set as would have been expected were they related to specific emissions such as from aircraft.

6.44 The mean NO_2, PM_{10} and $PM_{2.5}$ concentrations for the monitoring period are shown in Table 6-11 and Table 6-12 respectively, along with numbers of exceedances of the respective standards.

Table 6-11 N8 Airport Other Z842 Air Quality Monitoring Results – Ratified Data

Site	Statistic	NO_2	PM_{10}	$PM_{2.5}$
N8 Airport Z842	Period Mean (µg/m^3)	18.5	11.0	8.3
	Number of 1-hour mean NO_2 concentrations > objective value of 200 µg/m^3	0	-	-
	Number of 24-hour mean PM_{10} concentrations > objective value of 50 µg/m^3	-	0	-
	Raw Data Capture (%)	99.0%	98.6%	98.6%
	Ratified Data Capture (%)	98.3%	98.6%	98.3%

Table 6-12 N8 Airport Other Z842 Air Quality Monitoring Results – Scaled Data

Site	Statistic	NO_2	PM_{10}	$PM_{2.5}$
N8 Airport Z842	Period Mean (µg/m^3)	22.9	15.5	9.0
	Number of 1-hour mean NO_2 concentrations > objective value of 200 µg/m^3	0	-	-
	Number of 24-hour mean PM_{10} concentrations > objective value of 50 µg/m^3	-	3	-
	Raw Data Capture (%)	99.0%	98.6%	98.6%
	Scaled Data Capture (%)	98.3%	98.6%	98.3%

6.45 Specific events (for scaled data) for 24-hour mean PM_{10} are as follows:

- 22nd March 2022 – 53.8 µg/m^3
- 23rd March 2022 – 52.5 µg/m^3
- 26th March 2022 – 52.4 µg/m^3

6.46 These days of elevated PM_{10} concentrations coincided with a regional PM_{10} and $PM_{2.5}$ pollution episode that saw 'Moderate' to 'High' air pollution levels across most of the UK.

Annualisation Results

6.47 The results adjusted to be representative of 2019 as per the methodology stated in Section 4 are presented below in Table 6-13.

Table 6-13 2019 Annual Mean Results

Pollutant	Site	Adjusted Annual Mean Data Capture (%)	Ratified 2019 Annualised Annual Mean µg/m^3	Ratified Number of 1-hour mean concentrations >200µg/m^3	Ratified Number of 24-hour Means >50µg/m^3	Scaled 2019 Annualised Annual Mean µg/m^3	Scaled Number of 1-hour mean concentrations >200µg/m^3	Scaled Number of 24-hour Means >50µg/m^3
NO_2	AURN Belfast Centre (AURN)	51.4	24.1	0 (92.9)	N/A	24.1	0 (92.9)	N/A
	AURN co-location (ZAURN)	58.5	24.4	0 (94.8)		29.7	0 (116.9)	
	N1	63.1	17.1	0 (83.0)		20.3	0 (93.8)	
	N10	80.1	39.8	0 (134.1)		50.3	4 (168.3)	
	N12	59.7	10.0	0 (61.8)		13.2	0 (95.6)	
	N6	83.8	15.7	0 (73.4)		23.0	0 (108.1)	
	N8	84.7	20.7	0 (90.5)		25.6	0 (109.4)	
PM_{10}	AURN Belfast Centre (AURN)	88.3	15.4	N/A	2	15.4	N/A	2
	AURN co-location (ZAURN)	61.8	14.2		9 (27.7)	12.7		7 (28.0)
	N1	62.6	12.1		6 (25.6)	15.4		6 (29.2)
	N10	79.8	14.4		7 (28.4)	18.5		9 (33.5)
	N12	62.2	10.4		1 (23.8)	16.2		3 (30.3)
	N6	84.6	16.7		6 (26.9)	19.7		7 (30.7)
	N8	85.0	12.1		5	17.2		6 (30.3)
$PM_{2.5}$	AURN Belfast Centre (AURN)	88.2	10.6	N/A	N/A	10.6	N/A	N/A
	AURN co-location (ZAURN)	61.7	12.1			13.0		
	N1	62.6	9.6			8.5		
	N10	79.7	11.4			11.5		
	N12	62.2	7.1			7.6		
	N6	84.6	11.9			11.9		
	N8	84.7	9.2			9.9		
Where data capture is below 85%, for short term mean objectives, 99.79th and 90.4th percentiles have been presented for NO_2 and PM_{10} respectively, in brackets								

6.48 The results adjusted to be representative of 2021 as per the methodology stated in Section 4 are presented below in Table 6-14.

Table 6-14 2021 Annual Mean Results

Pollutant	Site	Adjusted Annual Mean Data Capture (%)	Ratified 2021 Annualised Annual Mean µg/m³	Ratified Number of 1-hour mean concentrations >200µg/m³	Ratified Number of 24-hour Means >50µg/m³	Scaled 2021 Annualised Annual Mean µg/m³	Scaled Number of 1-hour mean concentrations >200µg/m³	Scaled Number of 24-hour Means >50µg/m³
NO_2	AURN Belfast Centre (AURN)	90.6	20.7	0	N/A	20.7	0	N/A
	AURN co-location (ZAURN)	58.5	21.5	0 (85.1)		26.2	0 (104.9)	
	N1	63.1	15.7	0 (74.4)		18.6	0 (84.2)	
	N10	80.1	36.1	0 (120.4)		45.5	0 (151.0)	
	N12	59.7	9.1	0 (55.5)		12.0	0 (85.7)	
	N6	83.8	14.0	0 (65.9)		20.6	0 (97.0)	
	N8	84.7	18.5	0 (81.2)		22.9	0 (98.2)	
PM_{10}	AURN Belfast Centre (AURN)	99.3	12.7	N/A	0	12.7	N/A	0
	AURN co-location (ZAURN)	61.8	13.1		8 (26.0)	13.7		4 (25.7)
	N1	62.6	11.3		4 (23.0)	14.4		4 (26.1)
	N10	79.8	13.4		4 (24.6)	17.3		8 (29.1)
	N12	62.2	9.7		1 (20.9)	15.0		2 (25.4)
	N6	84.6	15.5		3 (24.4)	18.3		6 (28.2)
	N8	85.0	11.2		2	15.9		5 (27.2)
$PM_{2.5}$	AURN Belfast Centre (AURN)	99.3	7.4	N/A	N/A	7.4	N/A	N/A
	AURN co-location (ZAURN)	61.7	10.6			12.1		
	N1	62.6	8.8			7.8		
	N10	79.7	10.6			10.7		
	N12	62.2	7.0			7.5		
	N6	84.6	11.0			11.0		
	N8	84.7	8.5			9.2		

Where data capture is below 85%, for short term mean objectives, 99.79th and 90.4th percentiles have been presented for NO_2 and PM_{10} respectively, in brackets

Short-Term NO_2 WHO Air Quality Guideline

The 24-hour mean NO_2 WHO AQG is set as the 99th percentile of daily average NO_2 concentrations not to exceed 25 µg/m³. To assess monitored concentrations in Belfast against the short-term WHO AQGs, data was downloaded from the Air Quality Northern Ireland website[17] for the Council's network of continuous monitoring stations. The relevant statistics were also calculated for the Zephyr sensors based on the scaled, annualised data for 2019 and 2021.

Table 6-15 shows the 99th percentile of daily mean NO_2 concentrations at the automatic monitoring sites for 2019 to 2021, inclusive. The results indicate that the 24-hour mean NO_2 WHO AQG was exceeded at all monitoring

[17] https://www.airqualityni.co.uk/

sites in all years. The highest concentrations were, as expected, recorded at the busiest roadside sites (i.e. Stockman's Lane, Westlink Roden Street). However, even at the Belfast Centre Urban Background monitoring station in Lombard Street, NO_2 concentrations were calculated to be above the WHO AQG.

Table 6-15 99th Percentile of Daily Mean NO_2 Concentrations at BCC Automatic Monitoring Stations

Monitoring Site	Site Type	99th Percentile of 24-hour Mean NO_2 (µg/m^3)		
		2019	2020	2021
Belfast Centre	Urban Background	53	45	56
Belfast Newtownards Road	Roadside	64	50	48
Belfast Ormeau Road	Roadside	49	44	44
Belfast Stockman's Lane	Roadside	81	68	66
Belfast Westlink Roden Street	Roadside	76	63	64

Table 6-16 shows the 99th percentile of daily mean NO_2 concentrations calculated from the scaled and annualised Zephyr monitoring sites for 2019 and 2021. Consistent with the results from the automatic monitoring network stations, the Zephyr results indicate that the 24-hour mean NO_2 WHO AQG was exceeded at all monitoring sites in both years. The highest NO_2 concentrations were measured at N10 (Westlink) but elevated concentrations in excess of the WHO AQG were also monitored at urban background locations.

The results presented in Table 6-15 and Table 6-16 would suggest that the 24-hour mean NO_2 WHO AQG is likely to be exceeded across much of the Council's administrative area, particularly in the city centre area and near busy roads.

Table 6-16 99th Percentile of Daily Mean NO_2 Concentrations at Zephyr Monitoring Locations

Monitoring Site	Site Type	99th Percentile of 24-hour Mean NO_2 (µg/m^3)	
		2019	2021
N1 A55	Roadside	82	74
N10 Westlink	Roadside	99	92
N6 Clara Street	Urban Background	81	73
N12 Mt Eagles Glen	Urban Background	83	74
N8 Airport	Other Sources	81	73
ZAURN	Urban Background	82	74

7. Part A Conclusions

Monitoring Survey

7.1 As with any monitoring survey, there are strengths and weaknesses to the approach and hence data collected. These can be broadly summarised as follows:

7.2 Strengths of the Survey:

- A good variation in coverage both spatially and by site type has been achieved in a cost-effective manner, as compared to reference standard monitoring.
- The air quality baseline for portions of the city that have previously had monitoring discontinued due to screening out the need for assessment has now been updated with this recent monitoring study. This monitoring has largely confirmed the Council's existing understanding of air quality in Belfast, re-enforcing the conclusions of previous LAQM assessments.
- The units were not vandalised, damaged or removed unexpectedly over the course of the survey, showing that they can be securely deployed in the city and are relatively robust.
- A regime to ratify and scale the data has now been established, that can be applied moving forward should the Council wish to continue with the monitoring longer term.

7.3 Limitations of the Survey:

- Data capture has been limited by two primary factors, namely the reliability of the sensors themselves, and the availability of solar power.
- Sensor technology is still an emerging market, with no type-approval or certification regime yet in place. Therefore, there are inherently uncertainties associated with the data as compared to reference standard monitoring, especially when comparing to calendar annual means not explicitly monitored. It should be noted that the Zephyr monitor used in this study has recently been approved as compliant with MCERTS Performance Standards as an Indicative Ambient Particulate Monitor.

Monitoring Data

7.4 Overall, there were no exceedances of the statutory AQS objectives, with the exception of the scaled N10 data, which monitored NO_2 concentrations in excess of 40 µg/m^3 across all means (period, 2019 and 2021) when scaled. It is important to note that this site is located immediately adjacent to the Westlink, so when adjusting for distance it is likely that this would result in this site not exceeding at a location of relevant exposure. This does highlight the likely need to retain AQMA 1.

7.5 24-hour mean PM_{10} concentrations monitored in excess of 50 µg/m^3 were generally related to a regional pollution event in late March 2022, related to the importation of Saharan dust across the UK. The one exception is an event adjacent to N10 in November 2021, which may have been related to local events (e.g. fireworks, roadworks, or grounds maintenance).

7.6 Regarding comparison with the WHO guidelines, for NO_2, the annual mean guideline was exceeded at all sites, based on 2019 and 2021 scaled annualised means. Analysis of data from the Council's network of automatic air quality monitoring stations showed that the 24-hour mean WHO AQG for NO_2 was exceeded at all five stations in 2019 to 2021, inclusive. Similar results were found for the Zephyr monitors with exceedances of the 24-hour mean WHO AQG for NO_2 at all monitoring locations based on scaled and annualised data for both 2019 and 2021. The highest NO_2 concentrations were recorded at N10 Westlink, but even urban background locations displayed concentrations in excess of the WHO AQG value. These results would suggest that the 24-hour mean NO_2 WHO AQG is likely to be exceeded across much of the Council's administrative area, particularly in the city centre area and near busy roads.

7.7 The PM_{10} annual mean guideline was exceeded at N6, N8 and N10 for the scaled 2021 period. Based on the annualised 2019 results, the PM_{10} annual mean guideline was exceeded at all Zephyr monitoring locations, except the Lombard Street AURN co-location site. Exceedances of the 24-hour mean guideline

occur across all means. For $PM_{2.5}$, the annual mean guideline was exceeded at all sites for both the 2019 and 2021 results.

7.8 The data will latterly be applied for the verification of the dispersion modelling supporting the DA, and should serve to improve the performance of the model, and therefore improve confidence in the assessment's conclusions, particularly for $PM_{2.5}$.

7.9 It is recommended that the scaled data are applied when using the monitored data moving forward. That said, the scaling period means that when comparing against previous calendar means, there is additional uncertainty when applying this method, which needs to be kept in mind when drawing conclusions from the data.

7.10 The performance of the Zephyr sensors varied by pollutant. The tendency was for the Zephyr to under predict both NO_2 and PM_{10}, and over predict $PM_{2.5}$. The strength of the correlation between the Zephyr and reference standard monitoring also varied. $PM_{2.5}$ showed the strongest correlation, followed by NO_2 and finally PM_{10}. It is understood that the Zephyrs were set up by Earthsense to optimise their performance for $PM_{2.5}$, which was potentially to the detriment of PM_{10} analysis.

7.11 The scaling applied to the data improves confidence in the data in the period means, but is perhaps less robust when adjusting to previous calendar means, given the co-locations occurred within discrete time series that may not be applicable to historic data. This would be integral to calculating a 2022 annual mean.

7.12 The following conclusions can be drawn from the monitored concentrations themselves, summarised on a site by site basis.

ZAURN, Lombard Street AURN

7.13 The ratified period mean data indicates that the site would be compliant with all AQS objectives, as would be expected of a background site. The WHO annual mean guidelines for NO_2 and $PM_{2.5}$ were exceeded; the WHO PM_{10} annual mean guideline was met.

7.14 The scaled period mean data indicates that the site would be compliant with all AQS objectives, as would be expected of a background site. The WHO annual mean guidelines for NO_2 and $PM_{2.5}$ were exceeded; the WHO PM_{10} annual mean guideline was met. Scaling of the data elevated all pollutant concentrations for this sensor.

7.15 The 2019 equivalent annualised data indicates that the site would be compliant with all AQS objectives, as would be expected of a background site. The WHO annual mean guidelines for NO_2 and $PM_{2.5}$ were exceeded; the WHO PM_{10} annual mean guideline was met. Correlation with the AURN reference standard was greater in the ratified data, although the PM_{10} concentrations measured by the AURN reference monitor did exceed the annual mean guideline in 2019. Scaling of the data elevated all pollutant concentrations for this sensor.

7.16 The 2021 equivalent annualised data indicates that the site would be compliant with all AQS objectives, as would be expected of a background site. The WHO annual mean guidelines for NO_2 and $PM_{2.5}$ were exceeded; the WHO PM_{10} annual mean guideline was met. Correlation with the AURN reference standard was greater in the ratified data. Scaling of the data elevated NO_2 and $PM_{2.5}$ concentrations, and reduced PM_{10} concentrations. There was a reduction in the 2021 annual means, versus the 2019 equivalent data.

7.17 The co-located site showed generally a good agreement with the AURN data. For the 2019 concentrations, marginal underestimates of PM_{10} concentrations were monitored; marginal overestimates of NO_2 and $PM_{2.5}$ concentrations were recorded. For the 2021 concentrations, marginal overestimates of pollutant concentrations were recorded.

N1, A55

7.18 The ratified period mean data indicates that the site would be compliant with all AQS objectives. The WHO annual mean guidelines for NO_2 and $PM_{2.5}$ were exceeded; the WHO PM_{10} annual mean guideline was met.

7.19 The scaled period mean data indicates that the site would be compliant with all AQS objectives. The WHO annual mean guidelines for NO_2 and $PM_{2.5}$ were exceeded; the WHO PM_{10} annual mean guideline was met. Scaling of the data elevated NO_2 and PM_{10}, but reduced $PM_{2.5}$ concentrations.

7.20 The 2019 equivalent annualised data indicates that in 2019, the site would be compliant with all AQS objectives. The WHO annual mean guidelines for NO_2, PM_{10} and $PM_{2.5}$ were exceeded. Scaling of the data elevated NO_2 and PM_{10} concentrations, and reduced $PM_{2.5}$ concentrations.

7.21 The 2021 equivalent annualised data indicates that in 2021, the site would be compliant with all AQS objectives. The WHO annual mean guidelines for NO_2 and $PM_{2.5}$ were exceeded; the WHO PM_{10} annual mean guideline was met. Scaling of the data elevated NO_2 and PM_{10} concentrations, and reduced $PM_{2.5}$ concentrations. There was a reduction in the 2021 annual means, versus the 2019 equivalent data.

7.22 N1 is classified as a roadside site, but pollutant concentrations monitored reflect a site performing more like an urban background location. The area is fairly open, which would indicate an effective dispersal of the emissions from road traffic in this location, and a strong fall off in concentrations with distance from the road.

N6, Clara Street

7.23 The ratified period mean data indicates that that the site would be compliant with all AQS objectives, as would be expected of a background site. The WHO annual mean guidelines for NO_2, PM_{10} and $PM_{2.5}$ were exceeded.

7.24 The scaled period mean data indicates that that the site would be compliant with all AQS objectives, as would be expected of a background site. The WHO annual mean guidelines for NO_2, PM_{10} and $PM_{2.5}$ were exceeded. Scaling of the data elevated all pollutant concentrations (though marginally for $PM_{2.5}$).

7.25 The 2019 equivalent annualised data indicates that in 2019, the site would be compliant with all AQS objectives. The WHO annual mean guidelines for NO_2, PM_{10} and $PM_{2.5}$ were exceeded. Scaling of the data elevated all pollutant concentrations.

7.26 The 2021 equivalent annualised data indicates that in 2021, the site would be compliant with all AQS objectives. The WHO annual mean guidelines for NO_2, PM_{10} and $PM_{2.5}$ were exceeded. Scaling of the data elevated all pollutant concentrations (though marginally for $PM_{2.5}$). There was a reduction in the 2021 annual means, versus the 2019 equivalent data.

7.27 Generally, N6 displayed some elevated PM concentrations versus some other sites, which given the site is a background site is slightly unusual. This location saw some of the highest annual mean PM concentrations.

N8, Belfast City Airport

7.28 The ratified period mean data indicates that the site would be compliant with all AQS objectives. The WHO annual mean guidelines for NO_2 and $PM_{2.5}$ were exceeded; the WHO PM_{10} annual mean guideline was met.

7.29 The scaled period mean data indicates that the site would be compliant with all AQS objectives. The WHO annual mean guidelines for NO_2, PM_{10} and $PM_{2.5}$ were exceeded.

7.30 The 2019 equivalent annualised data indicates that in 2019, the site would have been compliant with all AQS objectives in both ratified and scaled means. The WHO annual mean guidelines for NO_2 and $PM_{2.5}$ were exceeded; the WHO PM_{10} annual mean guideline was met using the ratified data but exceeded for the scaled data. Scaling of the data elevated all pollutant concentrations.

7.31 The 2021 equivalent annualised data indicates that in 2021, the site would have been compliant with all AQS objectives in both ratified and scaled means. The WHO annual mean guidelines for NO_2 and $PM_{2.5}$ were exceeded; the WHO PM_{10} annual mean guideline was met using the ratified data but exceeded for the scaled data. Scaling of the data elevated all pollutant concentrations. There is a reduction in the 2021 annual means, versus the 2019 equivalent data.

7.32 Peak concentration events early in the instruments' deployment, reported on within the July-September 2021 monthly reports, were removed as these were considered likely to be instrument noise within the stabilisation period, given these were not repeated again through the data set as would have been expected were they related to specific emissions such as from aircraft.

N10, Westlink

7.33 The ratified period mean data indicates that the site would be compliant with all AQS objectives. The WHO annual mean guidelines for NO_2 and $PM_{2.5}$ were exceeded; the WHO PM_{10} annual mean guideline was met.

7.34 The scaled period mean data indicates that the site would be compliant with all AQS objectives except the annual mean NO_2 objective (though likely not to be exceeding post distance correction). The WHO annual mean guidelines for NO_2, PM_{10} and $PM_{2.5}$ were exceeded. Scaling of the data elevated all pollutant concentrations.

7.35 The 2019 equivalent annualised data indicates that in 2019, the site would have been compliant with all AQS objectives except the NO_2 annual mean objective, which was exceeded at the site in the scaled data (though likely not to be exceeding post distance correction). The WHO annual mean guidelines for NO_2, PM_{10} (only for the scaled data) and $PM_{2.5}$ were exceeded. Scaling of the data elevated all pollutants.

7.36 The 2021 equivalent annualised data indicates that the site would have been compliant with all AQS objectives except the NO_2 annual mean objective, which was exceeded at the site in the scaled data (though likely not to be exceeding post distance correction). The WHO annual mean guidelines for NO_2, PM_{10} (only for the scaled data) and $PM_{2.5}$ were exceeded. Scaling of the data elevated all pollutant concentrations. There is a reduction in the 2021 annual means, versus the 2019 equivalent data.

7.37 As expected, the Westlink corridor is the location at which the highest concentrations of NO_2 have been monitored, as this is within an AQMA.

N12, Mt. Eagles Glen

7.38 The ratified period mean data indicates that the site would be compliant with all AQS objectives. The WHO annual mean guideline for $PM_{2.5}$ was exceeded; the WHO NO_2 and PM_{10} annual mean guidelines were met.

7.39 The scaled period mean data indicates that the site would be compliant with all AQS objectives. The WHO annual mean guidelines for NO_2 and $PM_{2.5}$ were exceeded; the WHO PM_{10} annual mean guideline was met. Scaling of the data elevated all pollutants.

7.40 The 2019 equivalent annualised data indicates that in 2019, the site would have been compliant with all AQS objectives in both ratified and scaled means. The WHO NO_2 and PM_{10} annual mean guidelines were met for the ratified data, but were exceeded for the scaled data. The WHO $PM_{2.5}$ annual mean guidelines were exceeded for ratified and scaled data. Scaling of the data elevated all pollutant concentrations.

7.41 The 2021 equivalent annualised data indicates that in 2021, the site would have been compliant with all AQS objectives in both ratified and scaled means. The WHO NO_2 annual mean guideline was met for the ratified data, but was exceeded for the scaled data. The WHO PM_{10} annual mean guideline was met for ratified and scaled data. The WHO $PM_{2.5}$ annual mean guidelines were exceeded for ratified and scaled data. Scaling of the data elevated all pollutant concentrations. There is a reduction in the 2021 annual means, versus the 2019 equivalent data.

7.42 At N12, there appears to be limited impact of the nearby landfill site on the monitored pollutants, with concentrations being the lowest monitored across the entire survey.

Recommendations

7.43 The following recommendations are made for the continuation of the monitoring regime by BCC, and to inform Part B of the DA:

- The monitoring has indicated that there is not presently the need to declare a new AQMA for any area of previously unidentified elevated concentrations.
- Based on the uncertainties inherent to the monitoring method, BCC should continue the Zephyr / AURN co-location for QA/QC purposes. It is likely to be necessary to re-locate a second cartridge with the AURN site for a period, and re-commence moving the second cartridge around between sites, given the time now elapsed since the initial co-location.
- BCC may also wish to consider co-locating the Zephyrs with NO_2 diffusion tubes, as a relatively low cost way of building in a second data quality check.

- A review of the monitoring sites is recommended, possibly revisiting the candidate sites not previously taken forward. The Council may now wish to characterise other sources (e.g. rail, or specific point sources). N6 also monitored some elevated PM concentrations versus other sites, so it may be worthwhile increasing monitoring in this vicinity to see if this is a localised effect.
- It is likely to be prudent to enhance the roadside monitoring, as the Zephyrs have confirmed that roadside NO_2 can still be considered the principal concern with regard to exceedance of statutory objectives, as per site N10. N1 has also not performed as would be expected of a roadside site, so could either be re-located or reclassified.
- As per manufacturer specification, it will be necessary to consider the replacement of sensor cartridges in July 2023, and for these to be replaced with newly calibrated cartridges due to length of exposure.
- If the monitoring survey is intended to be continued over a much longer duration for continued LAQM compliance monitoring, it is recommended that options are explored to connect each of the Zephyrs to continuous power. Some of the units suffered from a lack of solar power, especially in winter with fewer hours of sunlight.

Appendix A Data, QA/QC & Calibration Certificates

A.1 Data Plots

7.44 The graphs below display the ratified data collected over the monitoring survey. The monitored results are provided per site, per pollutant. The sites labelled AURN, for the avoidance of doubt, represent the Zephyr co-located with the AURN station. Both A and B cartridge data is included for this site.

NO_2 Time Series Charts

Figure A. 1 Time Series Plot of NO_2 Concentrations, Zephyr (A Slot) AURN Belfast Centre Co-Location

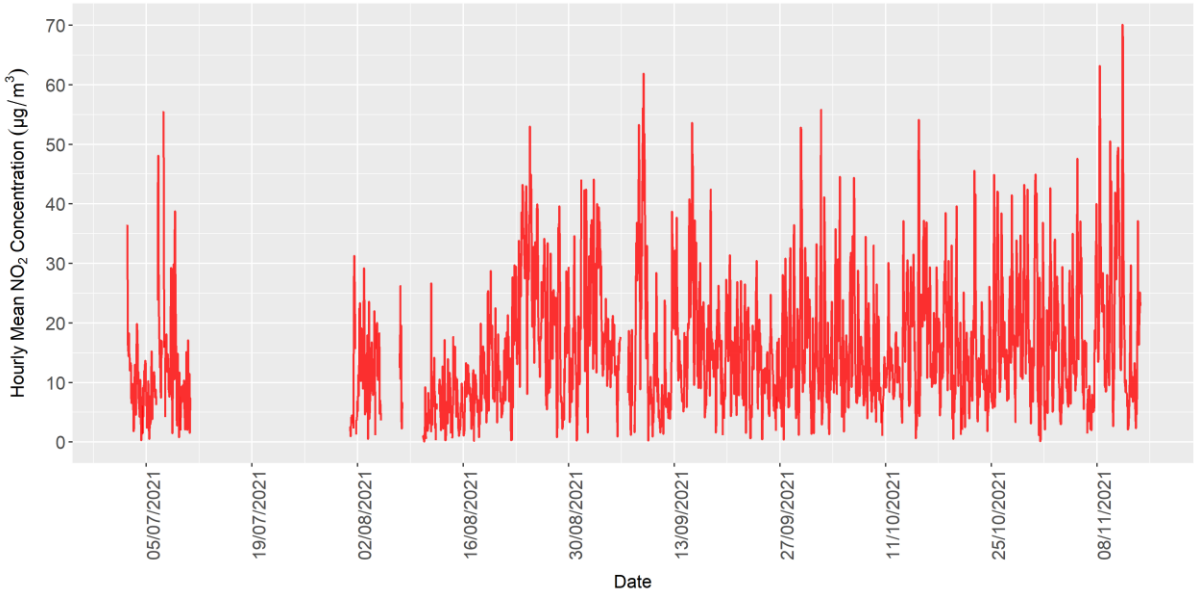


Figure A. 2 Time Series Plot of NO_2 Concentrations, Zephyr (B Slot) AURN Belfast Centre Co-Location

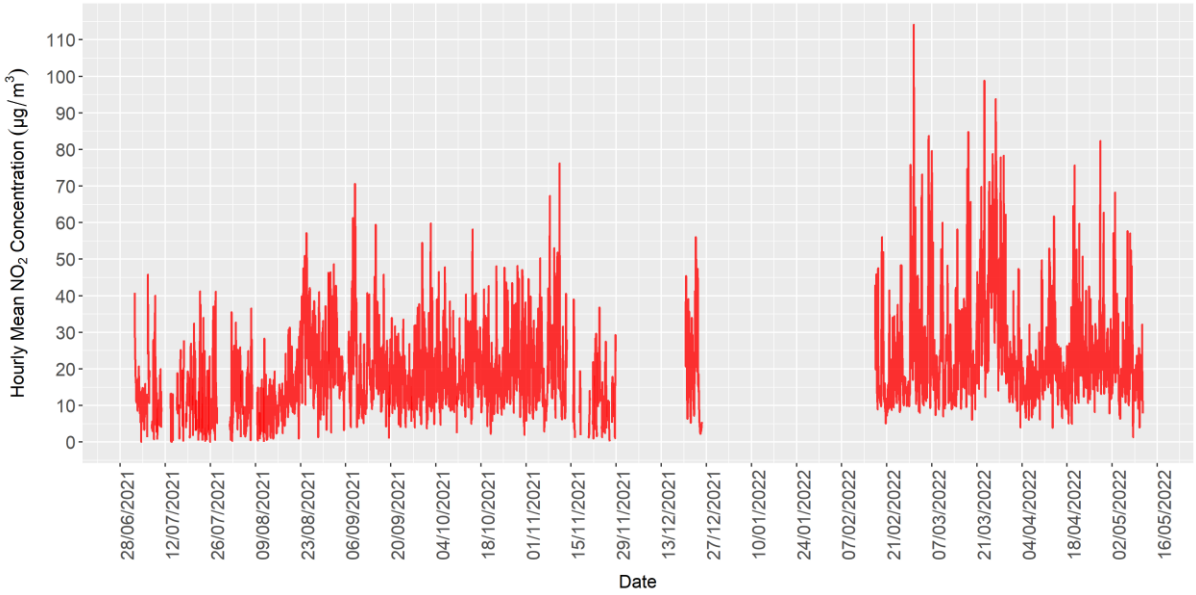


Figure A. 3 Time Series Plot of NO_2 Concentrations, Zephyr N1 A55

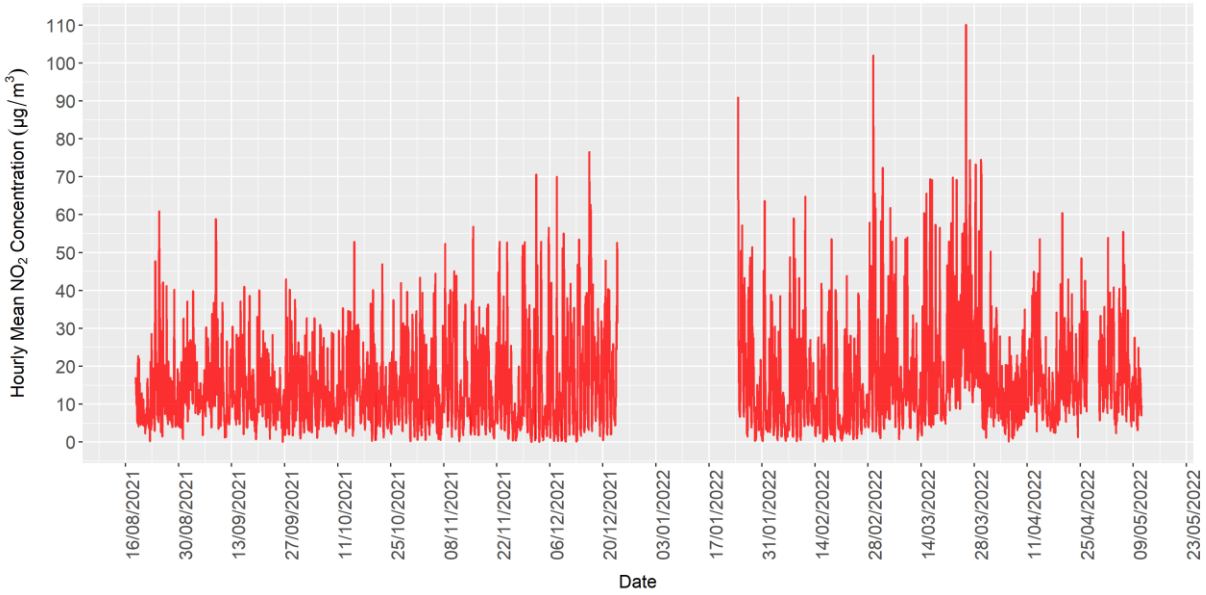


Figure A. 4 Time Series Plot of NO_2 Concentrations, Zephyr N6 Clara Street

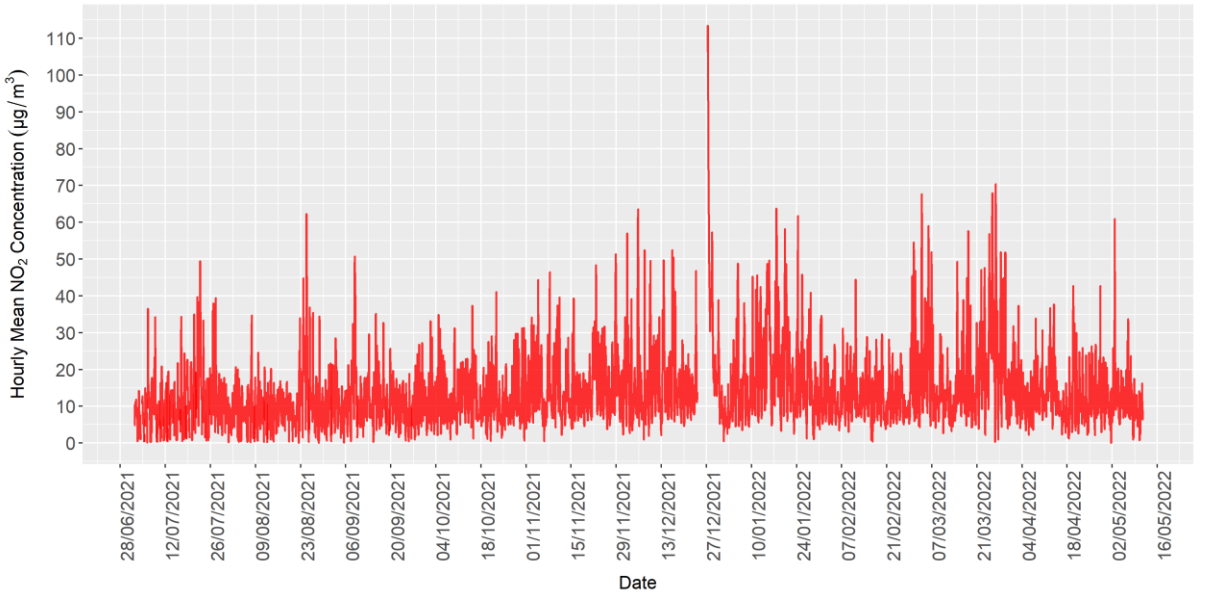


Figure A. 5 Time Series Plot of NO_2 Concentrations, Zephyr N8 Airport

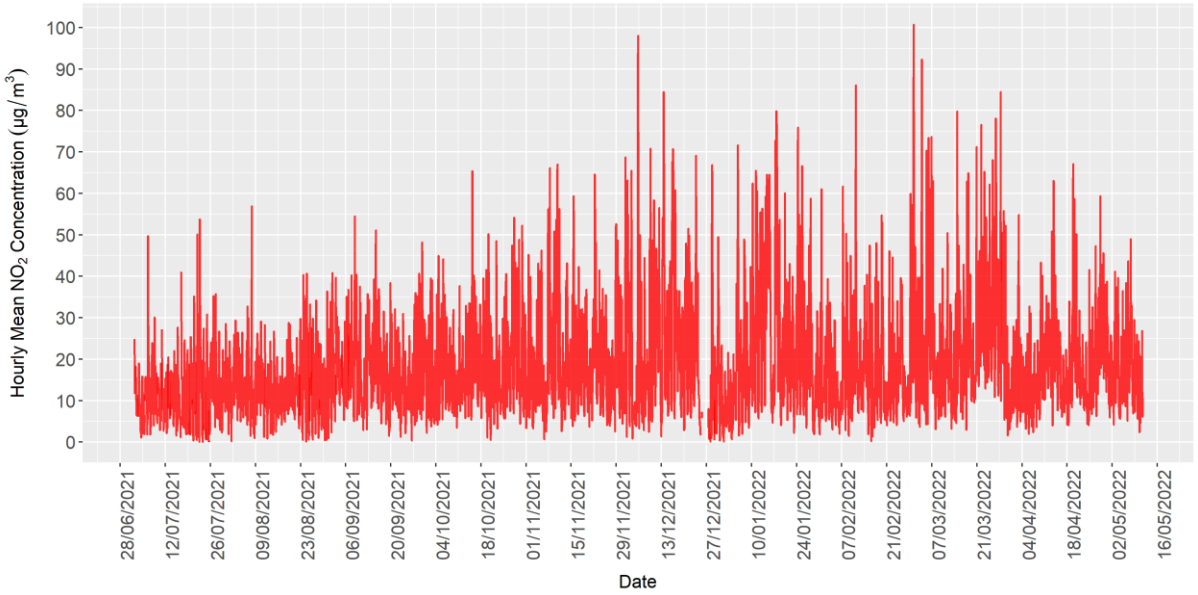


Figure A. 6 Time Series Plot of NO_2 Concentrations, Zephyr N10 Westlink

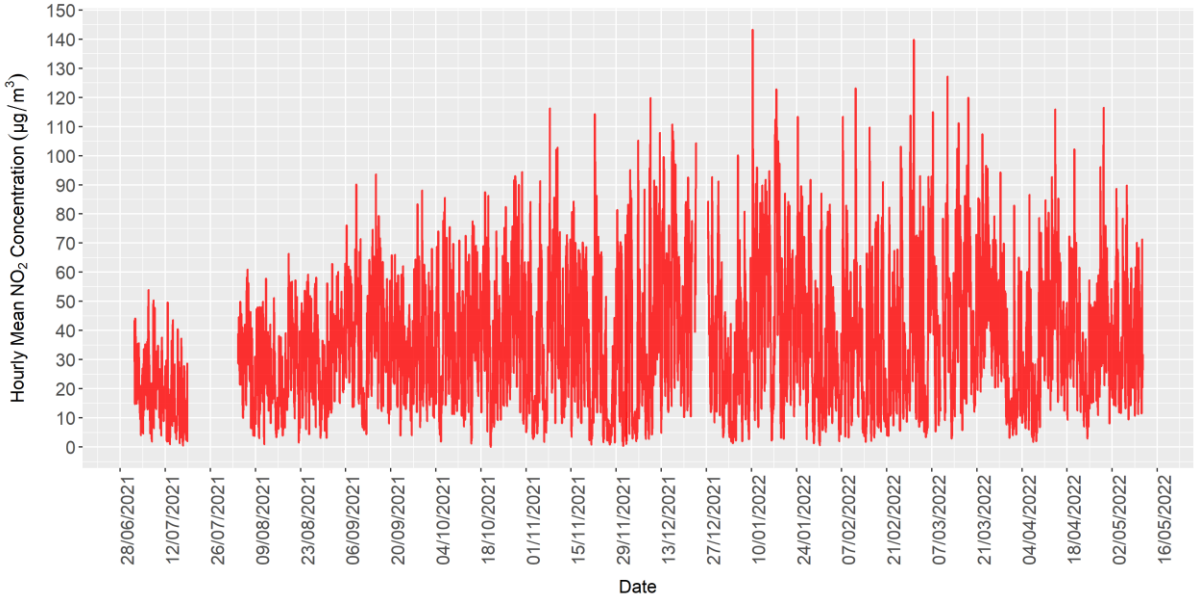
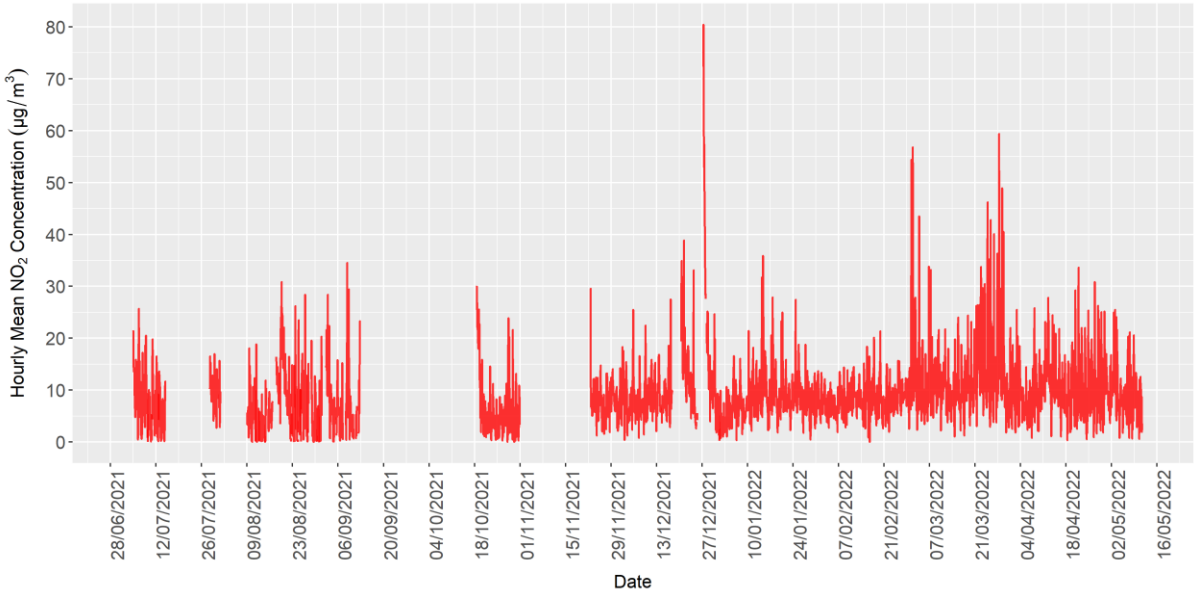


Figure A. 7 Time Series Plot of NO_2 Concentrations, Zephyr N12 Mt. Eagles Glen



PM_{10} Time Series Charts

Figure A. 8 Time Series Plot of PM_{10} Concentrations, Zephyr (A Slot) AURN Belfast Centre Co-Location

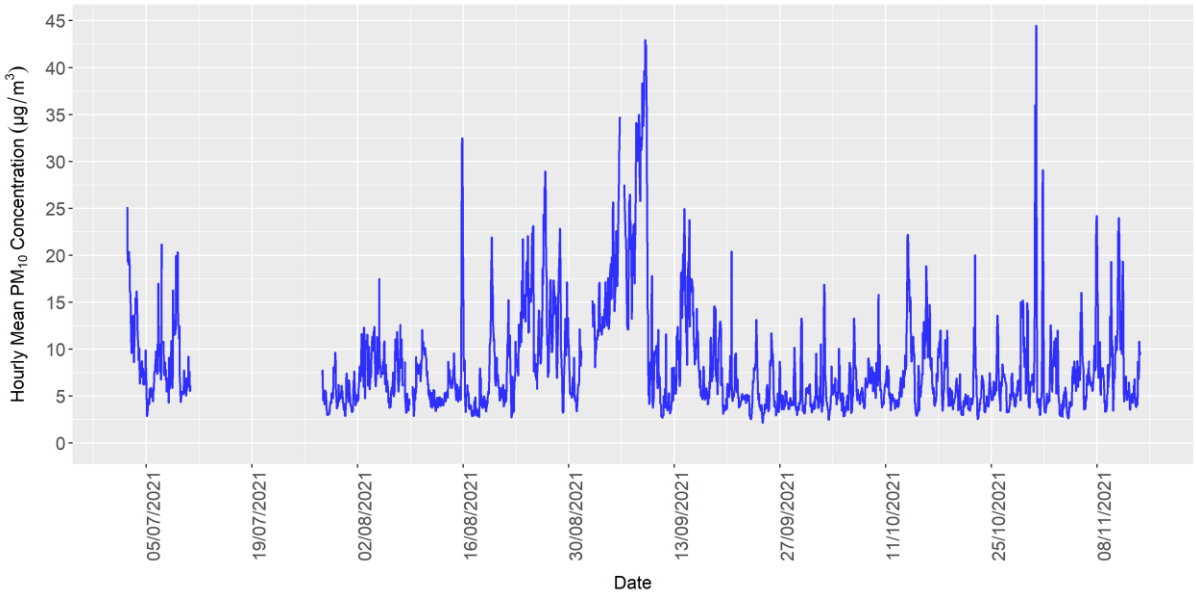


Figure A. 9 Time Series Plot of PM_{10} Concentrations, Zephyr (B Slot) AURN Belfast Centre Co-Location

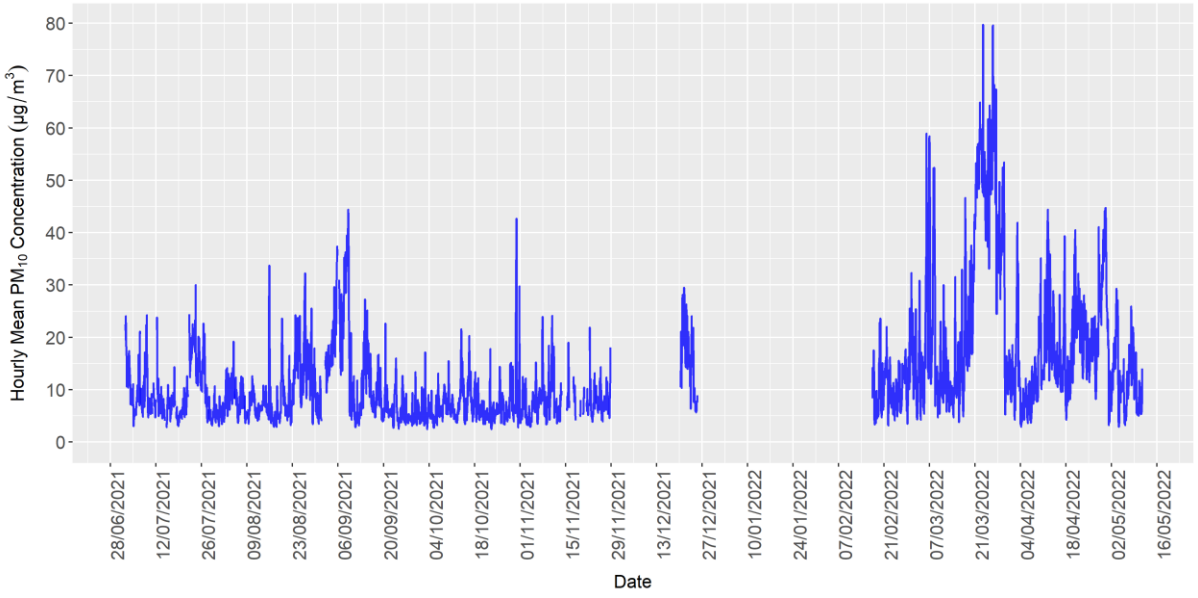


Figure A. 10 Time Series Plot of PM_{10} Concentrations, Zephyr N1 A55

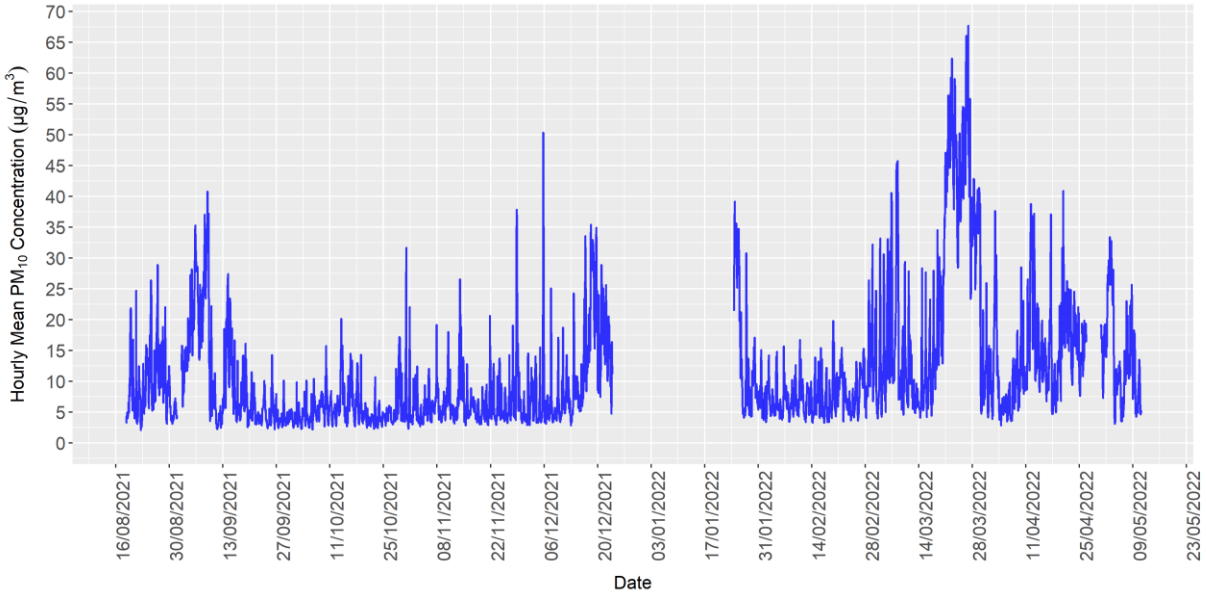


Figure A. 11 Time Series Plot of PM_{10} Concentrations, Zephyr N6 Clara Street

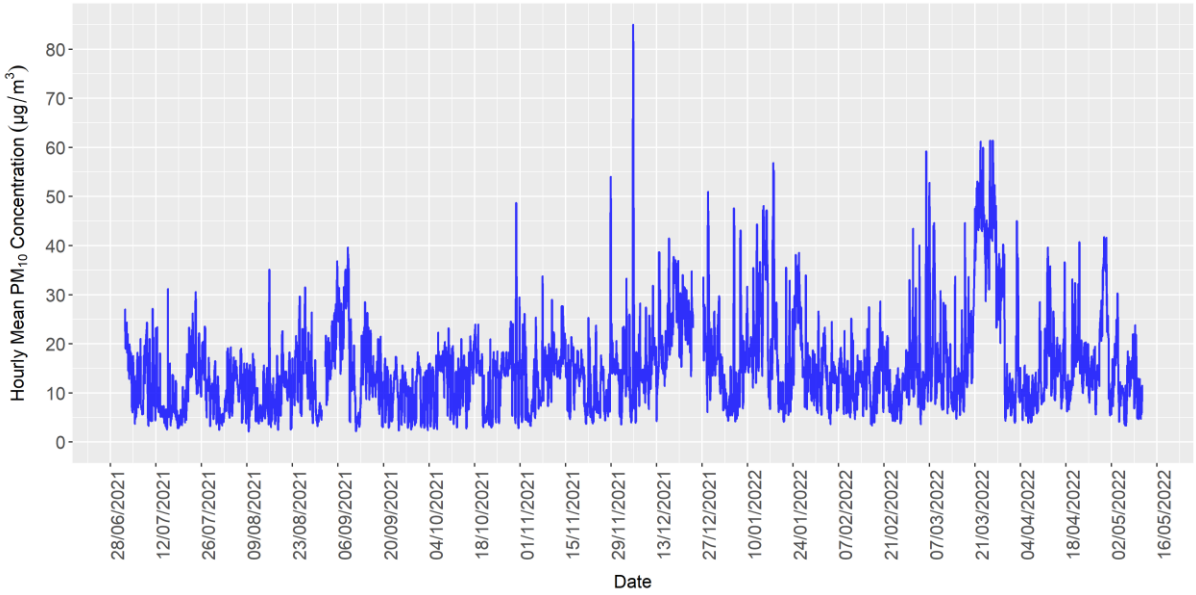


Figure A. 12 Time Series Plot of PM_{10} Concentrations, Zephyr N8 Airport

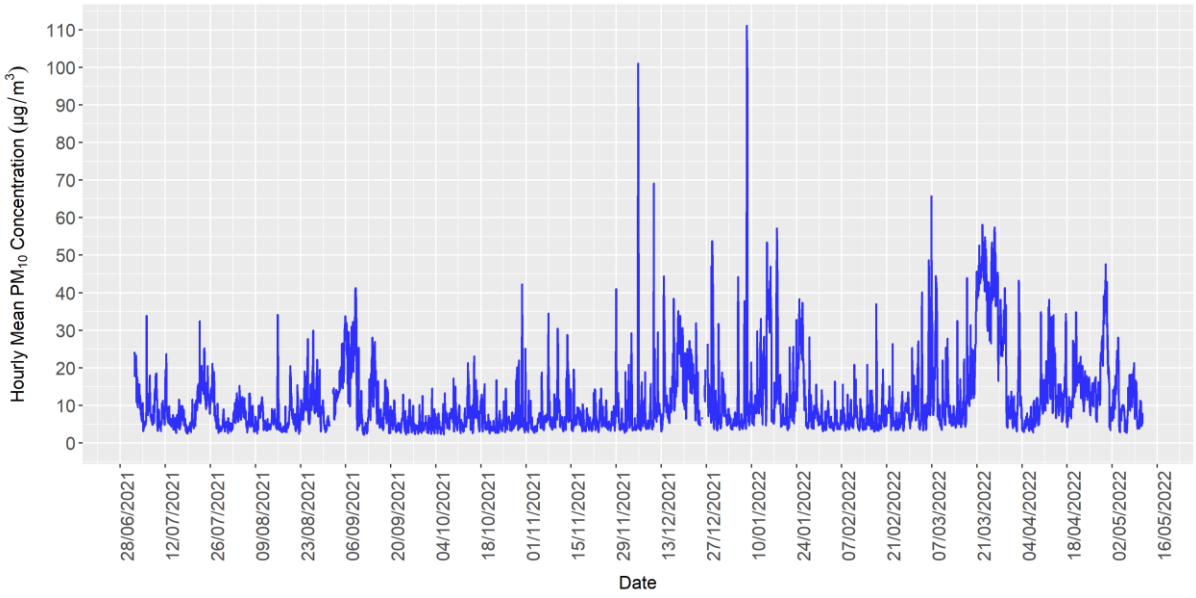


Figure A. 13 Time Series Plot of PM_{10} Concentrations, Zephyr N10 Westlink

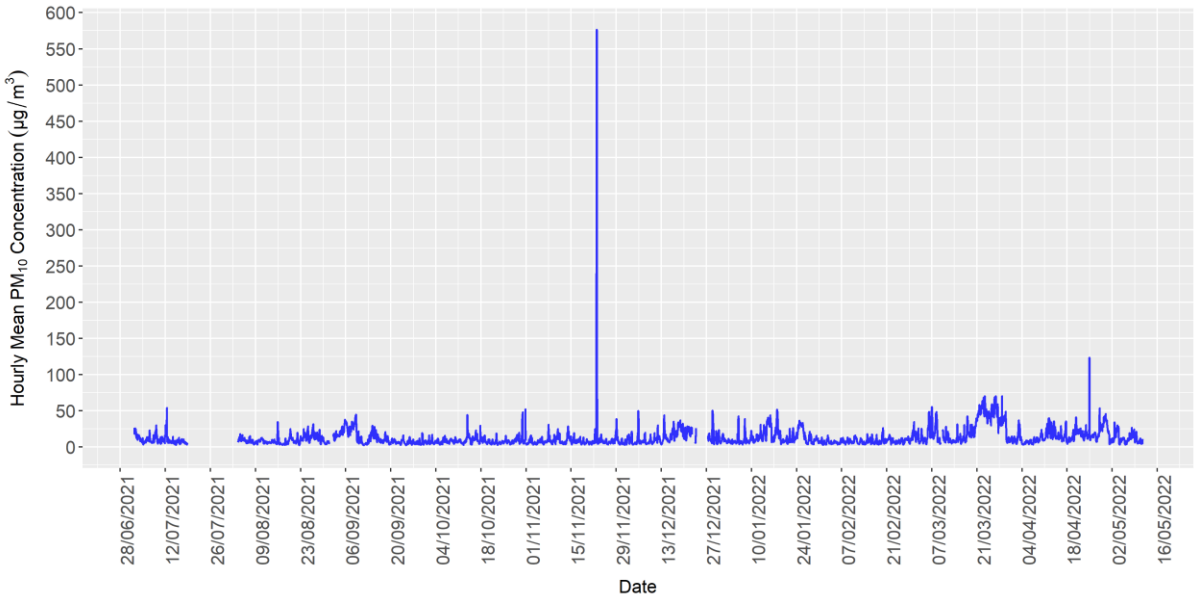
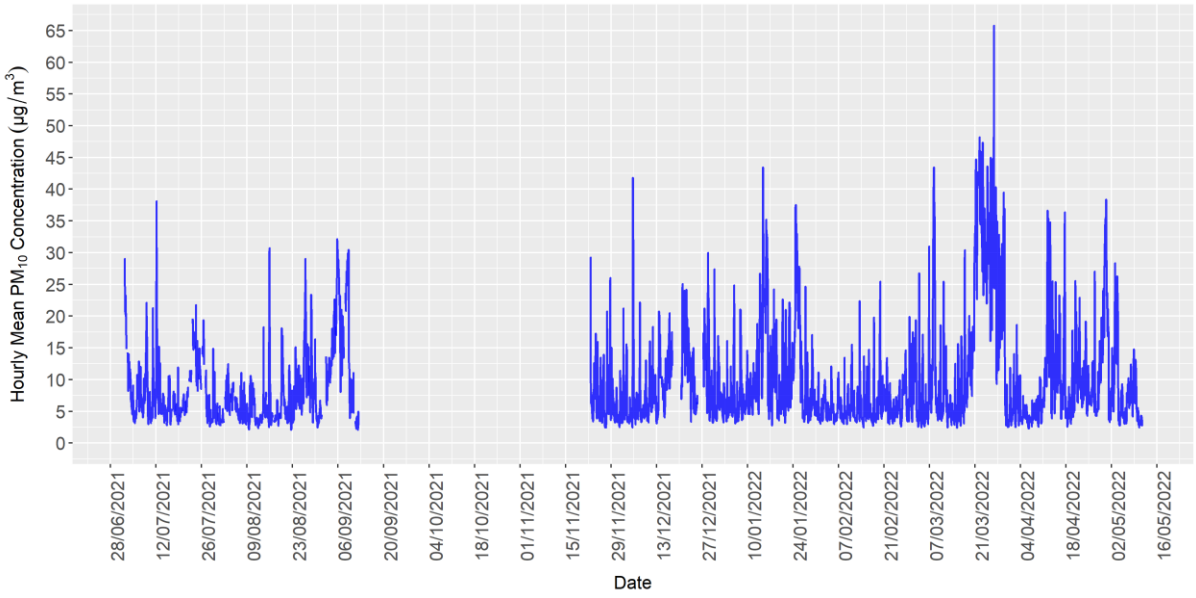


Figure A. 14 Time Series Plot of PM_{10} Concentrations, Zephyr N12 Mt. Eagles Glen



$PM_{2.5}$ Time Series Charts

Figure A. 15 Time Series Plot of $PM_{2.5}$ Concentrations, Zephyr (A Slot) AURN Belfast Centre Co-Location

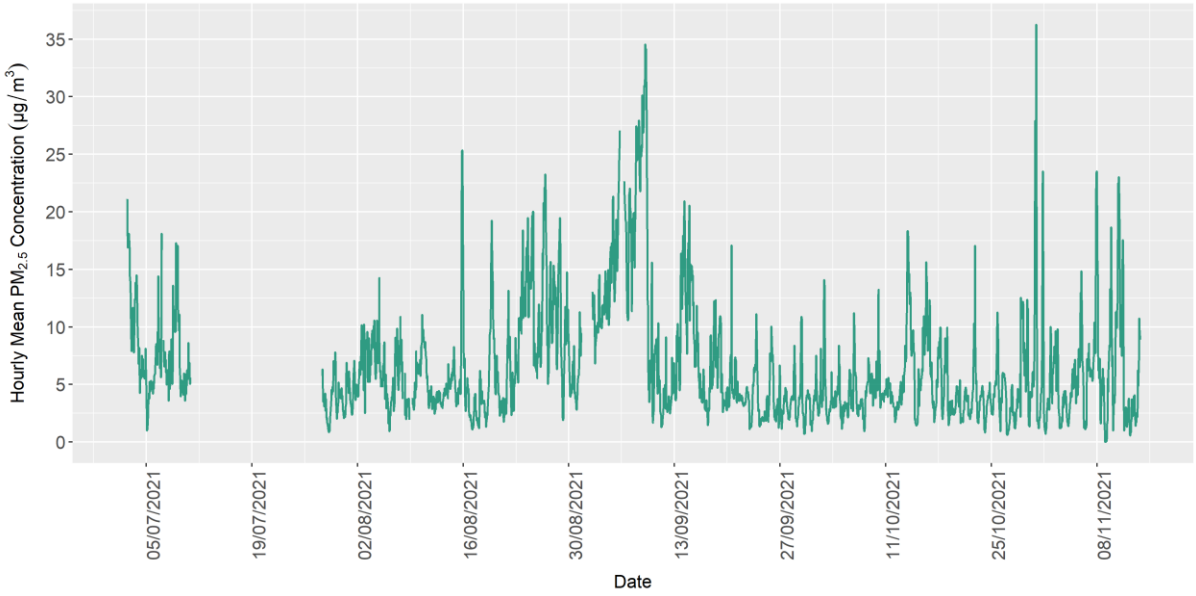


Figure A. 16 Time Series Plot of $PM_{2.5}$ Concentrations, Zephyr (B Slot) AURN Belfast Centre Co-Location

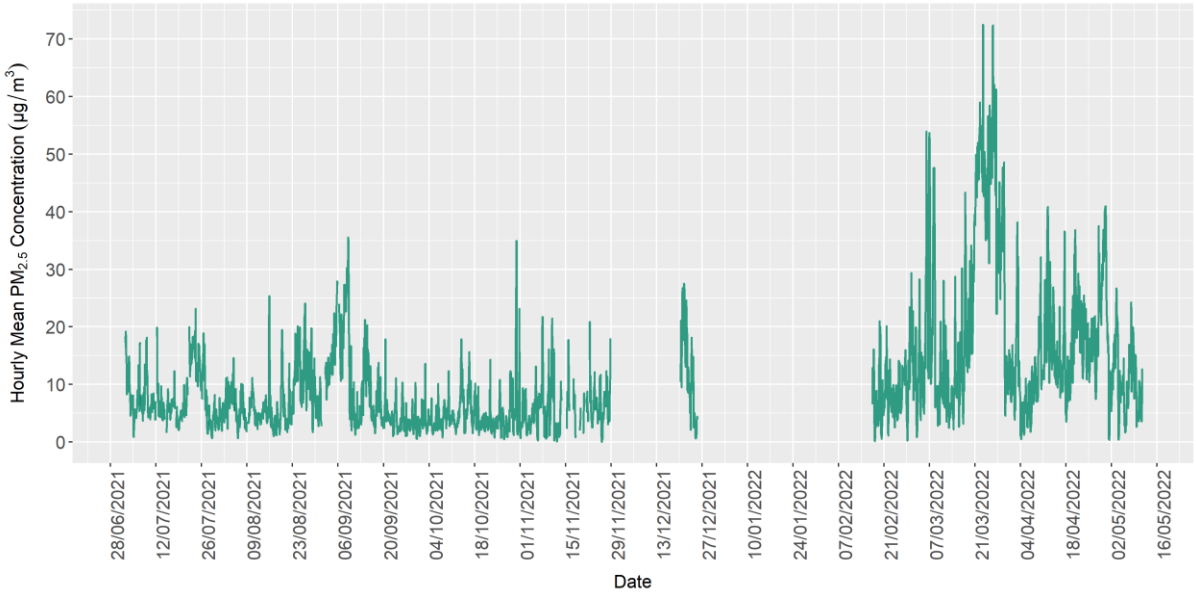


Figure A. 17 Time Series Plot of $PM_{2.5}$ Concentrations, Zephyr N1 A55

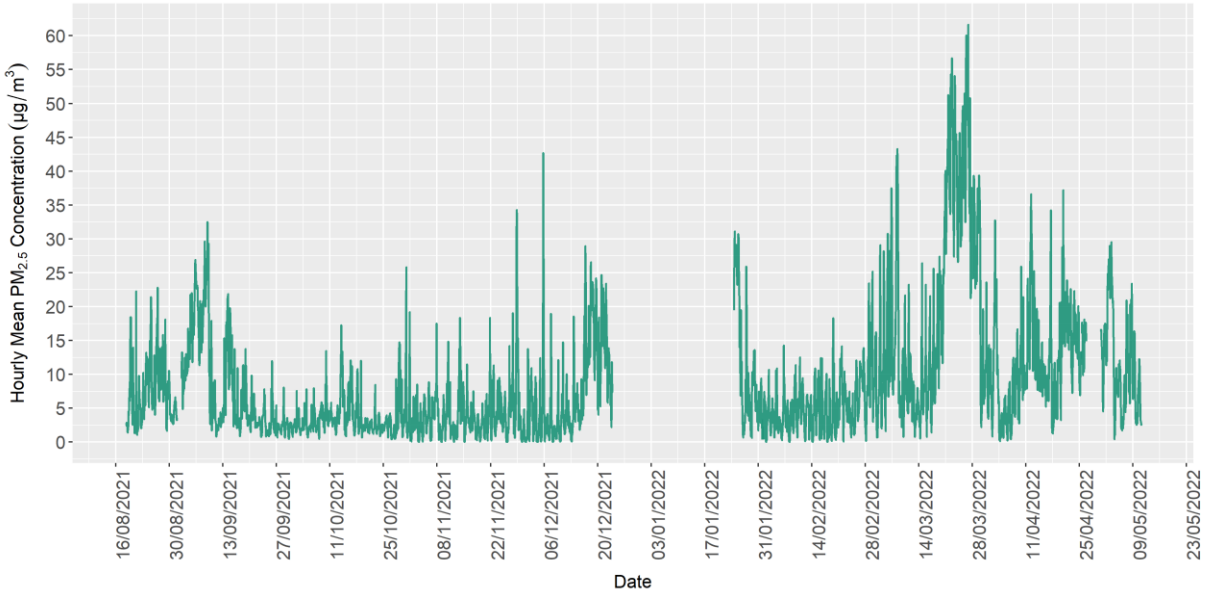


Figure A. 18 Time Series Plot of $PM_{2.5}$ Concentrations, Zephyr N6 Clara Street

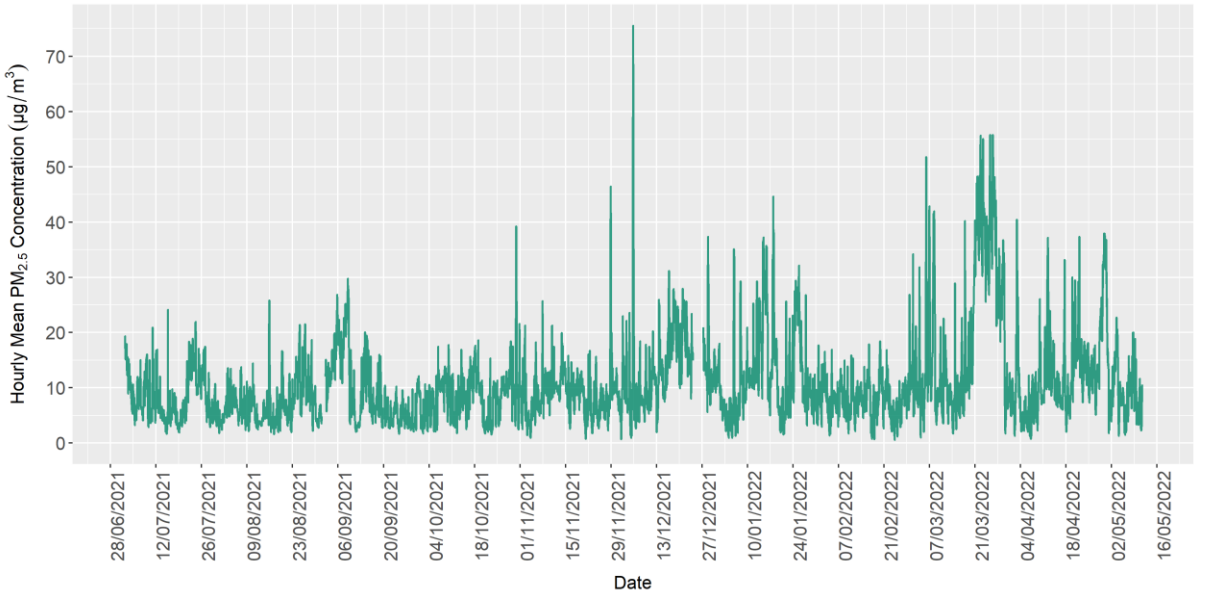


Figure A. 19 Time Series Plot of $PM_{2.5}$ Concentrations, Zephyr N8 Airport

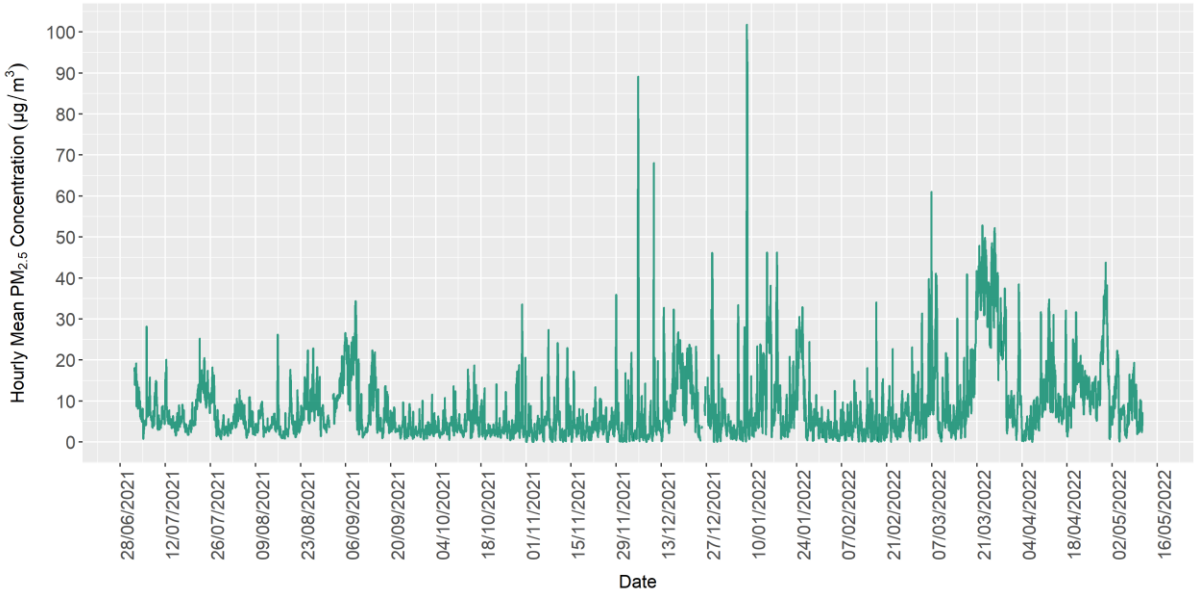


Figure A. 20 Time Series Plot of $PM_{2.5}$ Concentrations, Zephyr N10 Westlink

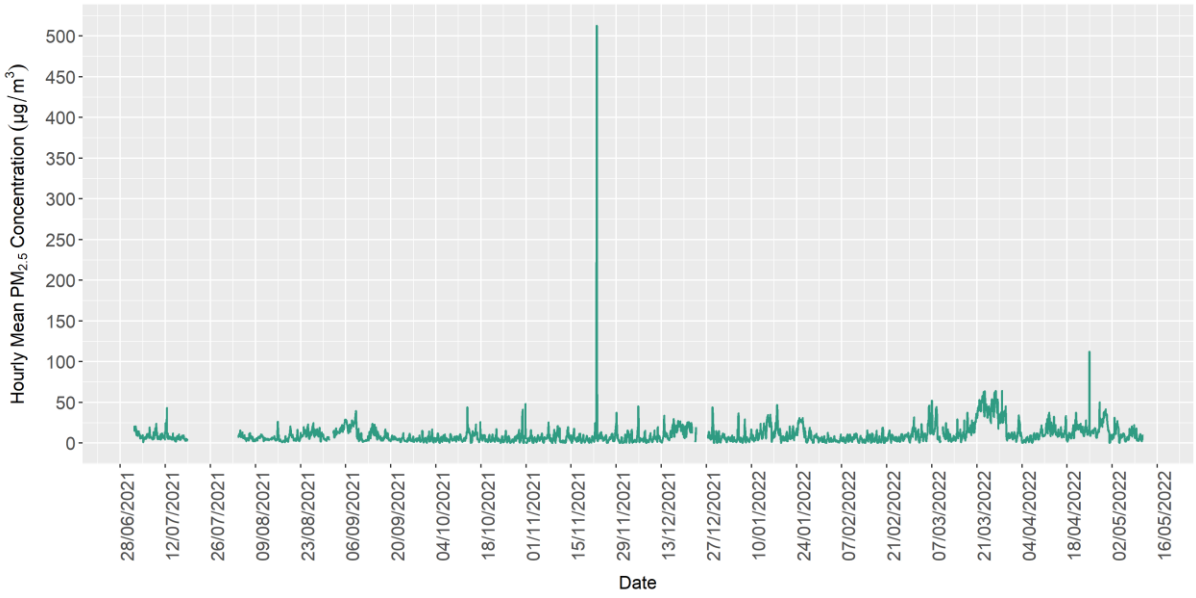
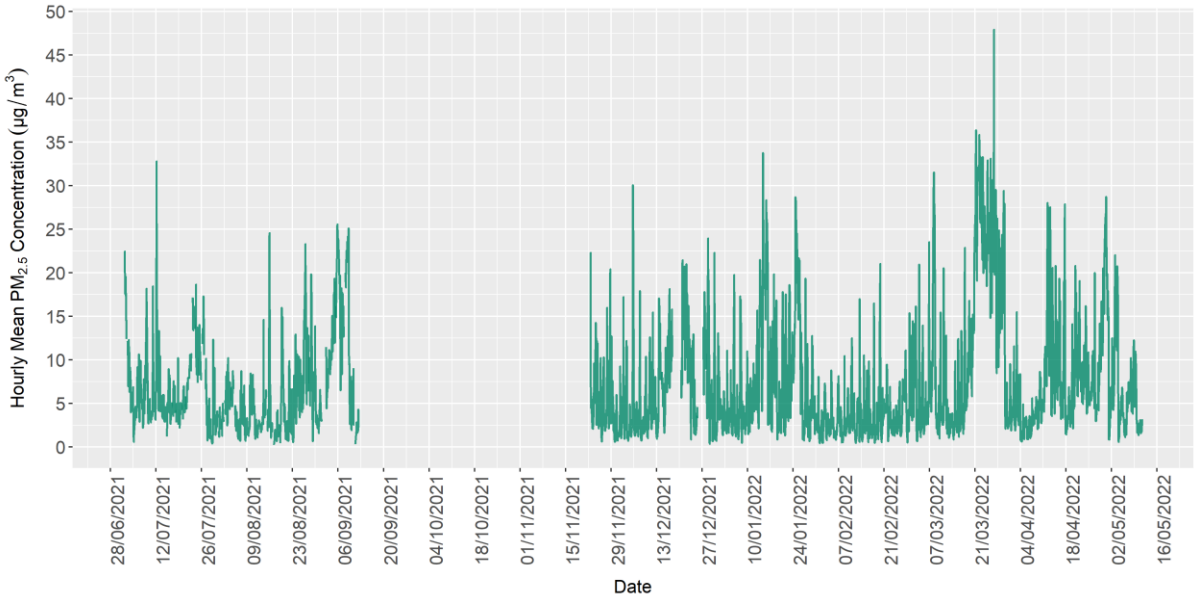


Figure A. 21 Time Series Plot of $PM_{2.5}$ Concentrations, Zephyr N12 Mt. Eagles Glen



A.2 Supplier QA/QC Procedure

7.45 Prior to the deployment of the Zephyr units, the cartridge that holds the gas and particle sensors (NO_2, PM_{10}, $PM_{2.5}$ and O_3) is calibrated with data obtained during a period of co-location at an air quality reference site. The duration of this calibration is typically one week in order to observe a representative range of concentrations and environmental conditions. Subject to performance pass criteria being met during the co-location period, the Zephyr is then deployed for use. The 'Enhanced' suite of gases not calibrated in the same way, but are validated against each other to assess agreement and remove any sensors showing anomalous readings.

7.46 Nominal in-field performance is assessed with the data collected by analysts at Earthsense. This typically involves comparative analysis with a regional average dataset from EU-standard reference analysers. Analysis carried out typically shows the calibration applied from the co-location period is appropriate, with some level of similarity in amplitude and diurnal trends measured by local EU-standard reference analysers. Shipping can occasionally cause a change to the expected signal, in which case local EU-standard reference analysers will be used to inform a new calibration. It is important to note however, that no reference gas or zero calibrations are undertaken on the sensor whilst in situ, so the data may be subject to drift without calibration.

7.47 Earthsense undertake data quality checks on their MappAir data portal, prior to the data ratification process described in this report. Calibration certificates are provided in Appendix A.

7.48 It is essential that air quality monitoring data is subject to rigorous QA/QC procedures to ensure that the reported data is accurate, reliable and fit for purpose. The QA/QC procedures applied to the Zephyr data align closely with Defra's recommended procedures, comprising an initial data validation stage followed by a more comprehensive data ratification exercise.

A.3 AECOM QA/QC Procedure

Data Validation and Ratification

7.49 Data validation is performed on an ongoing basis and consists of basic data screening to identify any potentially spurious / erroneous readings, equipment problems and malfunctions, as well as any pollution episodes or periods of high concentrations. It can also include the incorporation of any data which were initially missing due to communications failure and any updates to data scaling / processing algorithms provided by the equipment supplier. Upon completion of the data validation step, the dataset is flagged as "Provisional".

7.50 Data ratification is a detailed examination of the provisional dataset, that is typically carried out at specified intervals throughout and upon completion of a monitoring study. The process includes a review of all calibration records, servicing and maintenance records and records of any repairs. Data ratification also requires the applied professional judgement of an air quality specialist to "sense-check" the data. This includes examining the relationships between pollutants and between monitoring locations, examining spatial and temporal patterns, and the results in the context of the wider national/regional pollution climate. Upon completion of the data ratification step, the dataset is flagged as "Ratified" and at this point is considered final and not subject to further change.

Two Stage Data Scaling and Correction

7.51 For monitoring studies using low-cost sensors, it is considered good practice to carry out co-location studies of the sensors, both alongside a reference-method monitoring station (to account for any tendency of the sensors to over-read or under-read ambient pollutant concentrations) and with one another (to account for variation in the response between sensors).

7.52 One Zephyr instrument was co-located alongside the AURN Belfast Centre monitoring station from 2nd July 2021 to 11th May 2022. The Zephyr monitor uses a cartridge system with each monitor having two slots ("A" and "B"). Identical sensor cartridges were installed in each of the two slots, with the "B" cartridge remaining co-located with the AURN station throughout the entire period. The "A" cartridge was co-located with the AURN station until November 2021, to establish the relationship between this cartridge and the AURN reference station.

7.53 Thereafter, the calibrated “A” cartridge was moved around and co-located for periods of 2 to 4 weeks with each of the other Zephyr monitors in turn to determine relationships between the cartridges in use at these sites and the calibrated “A” cartridge.

AURN Co-Location and Data Scaling

7.54 One Zephyr instrument was co-located with the AURN Belfast Centre monitoring station. Data collected by the “A” cartridge of the Zephyr during the period 13th August 2021 to 11th November 2021 were compared with the corresponding measurements made by the AURN station. Scatter plots were created for NO_2, PM_{10} and $PM_{2.5}$ and linear regression lines fitted to the data. The derived regression relationships were then applied to all Zephyr monitored data across all locations to account for the deviation in measured concentrations between the Zephyr instruments and the AURN reference monitors.

7.55 Figure A. 22 shows the scatter plot for NO_2 concentrations. From the linear regression equation, the Zephyr shows a tendency to under-predict NO_2 concentrations relative to the AURN station, indicated by a slope of 1.23 (i.e., greater than 1) and intercept of +2.55. The R^2 value of 0.71 indicates a positive correlation between the Zephyr measurements and the AURN data.

7.56 Figure A. 23 shows the scatter plot for PM_{10} concentrations. From the linear regression equation, the Zephyr shows a tendency to tend to under-predict PM_{10} concentrations relative to the AURN station at lower concentrations, indicated by an intercept of +4.08. At higher concentrations, the Zephyr relationship alters, hence a slope of 0.96. The plot shows considerably more scatter in the data points and an R^2 value of 0.55 indicates a weaker correlation between the Zephyr measurements and the AURN data than is the case for NO_2.

7.57 Figure A. 24 shows the scatter plot for $PM_{2.5}$ concentrations. From the linear regression equation, the Zephyr shows a tendency to over-predict $PM_{2.5}$ concentrations relative to the AURN station, indicated by a slope of 0.88 (i.e., less than 1) and intercept of +1.02. The R^2 value of 0.86 indicates a good positive correlation between the Zephyr measurements and the AURN data.

Figure A. 22 Scatter Plot of NO_2 Concentrations, Zephyr (A Slot) Versus AURN Belfast Centre Co-Location

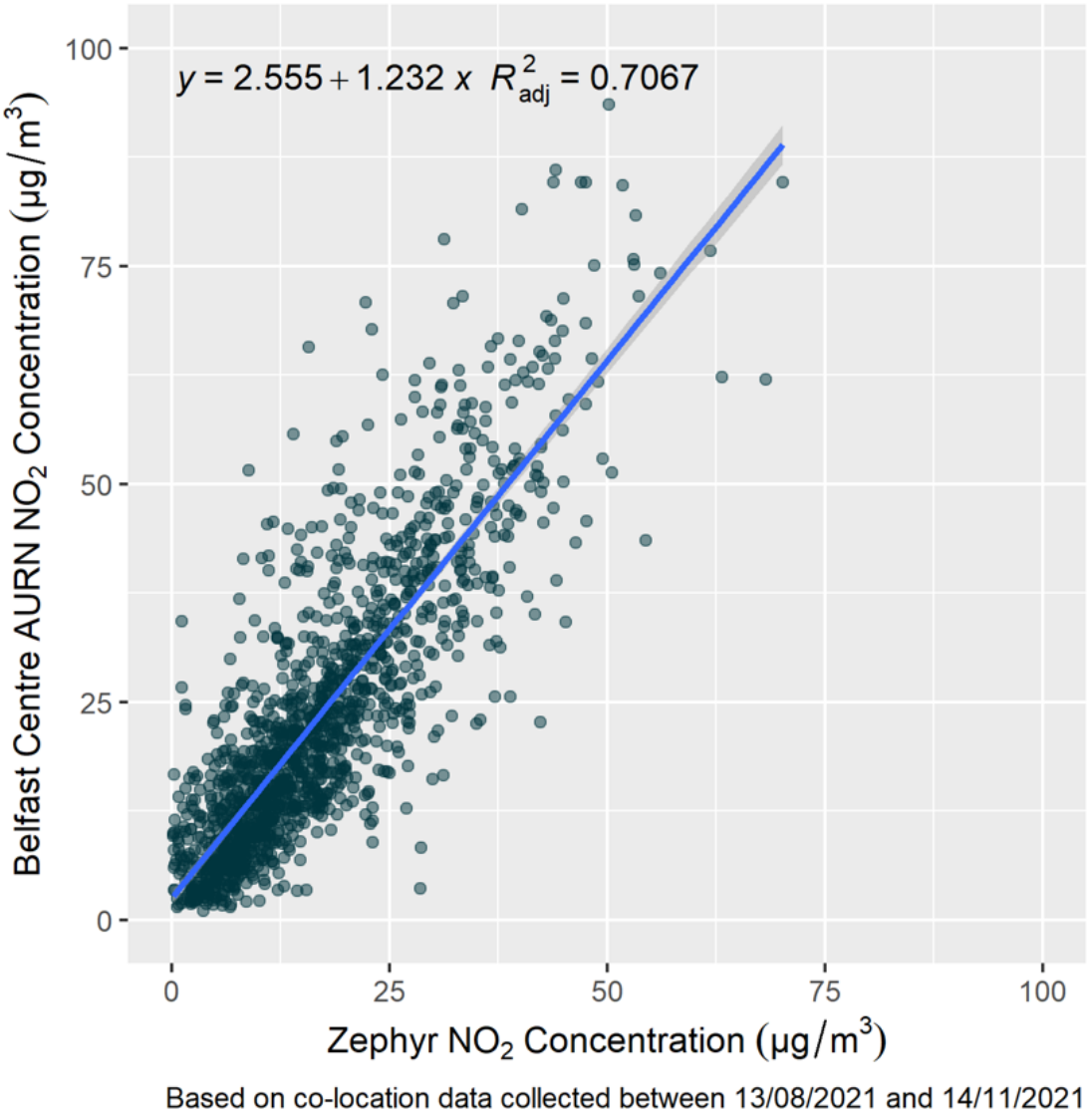


Figure A. 23 Scatter Plot of PM_{10} Concentrations, Zephyr (A Slot) Versus AURN Belfast Centre Co-Location

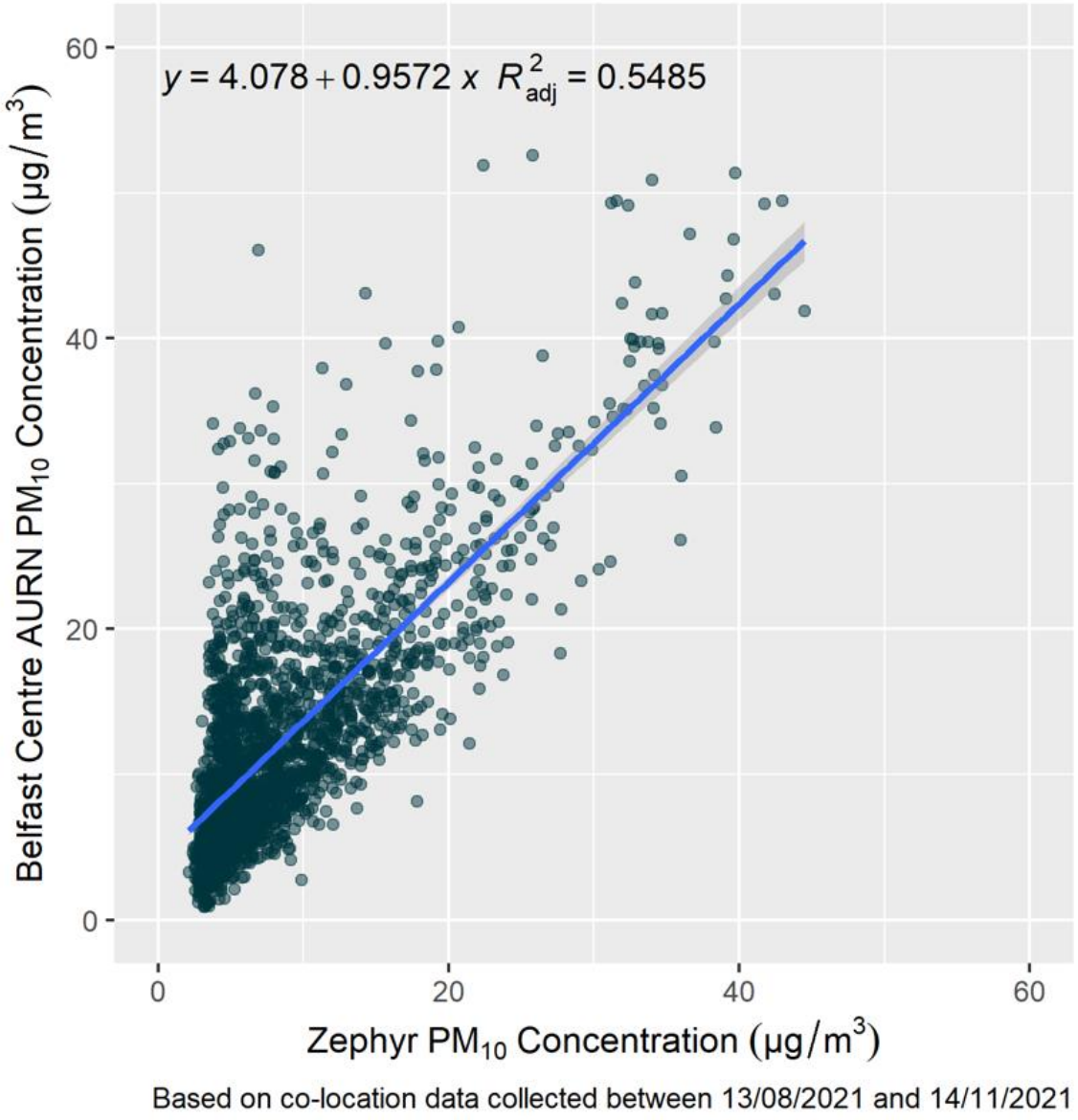
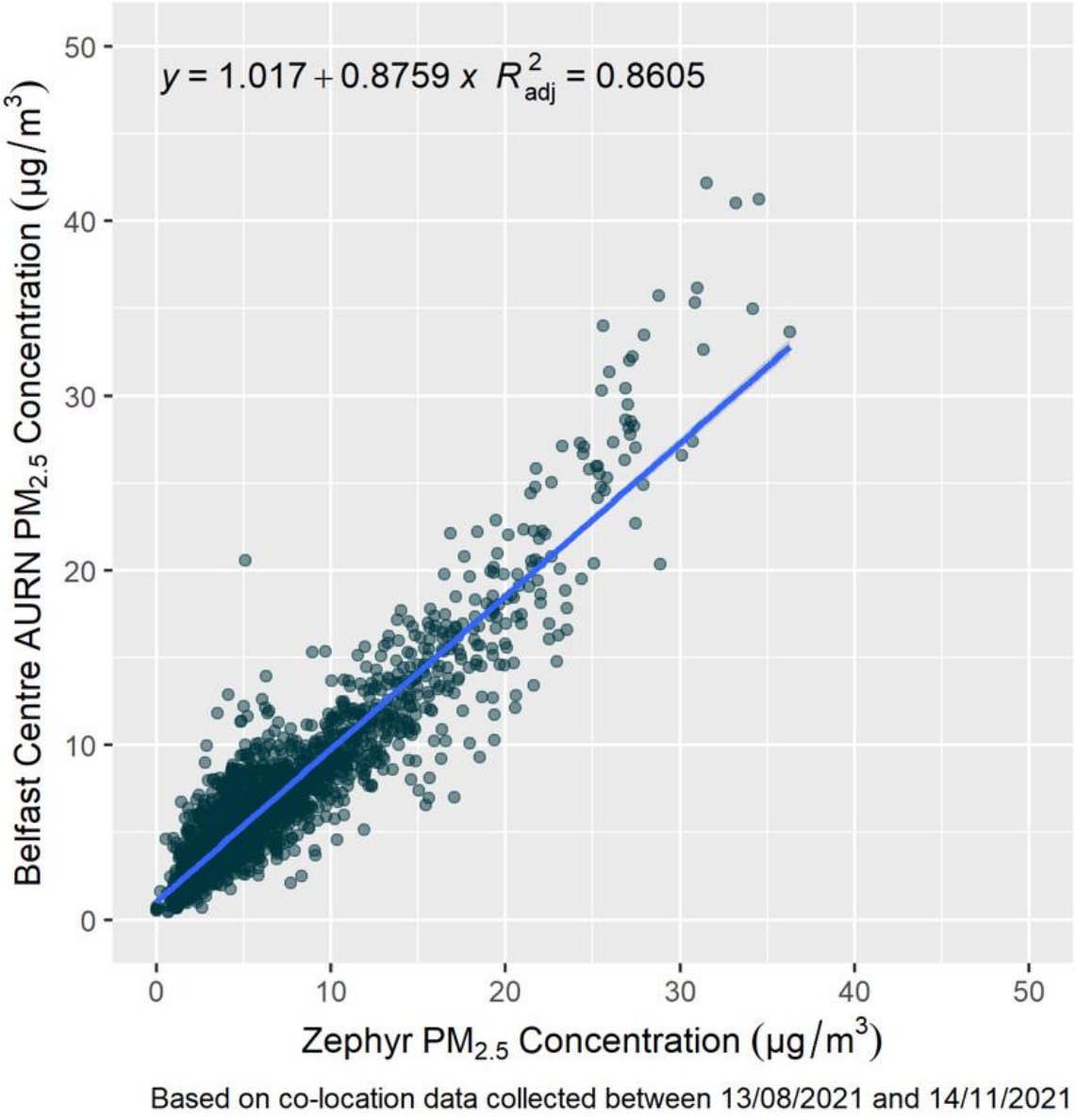


Figure A. 24 Scatter Plot of $PM_{2.5}$ Concentrations, Zephyr (A Slot) Versus AURN Belfast Centre Co-Location



Second Cartridge Co-location and Scaling

7.58 Following the completion of the co-location of the Zephyr "A" cartridge with the AURN station, the calibrated "A" cartridge was moved around the monitoring network to be co-located with each Zephyr instrument in turn. The purpose of these co-locations was to account for variations in response between Zephyr sensors.

7.59 Co-locations data were taken for periods of approximately 2 weeks (with the exception of N1, which was in situ slightly longer). The dates of the co-location data applied, by monitoring site, were as follows:

- N1: 24/01/2022 to 17/03/2022;
- N6: 17/03/2022 to 28/03/2022;
- N8: 01/04/2022 to 13/04/2022;
- N10: 28/12/2021 to 20/01/2022; and
- N12: 22/11/2021 to 17/12/2021.

7.60 As per the AURN co-location, scatter plots were created for NO_2, PM_{10} and $PM_{2.5}$ and linear regression lines fitted to the data. The derived regression relationships were then applied to all Zephyr monitored data across all locations to account for the deviation in measured concentrations between the Zephyr instruments and the AURN reference monitors.

7.61 The standard data validation and ratification QA/QC procedures were applied to the second cartridge co-location and scaling (see Data Validation and Ratification), including the exclusion of erroneous / spurious readings, periods of unusually low concentrations, and periods of equipment malfunction, such as intermittent power supply or communications issues.

7.62 Other QA/QC checks applied to the second cartridge co-locations included comparing the time series concentration data for the “A” and “B” cartridge to check temporal alignment and to check that peaks and troughs in concentrations for the co-located cartridges followed the same trend.

Scaling QA/QC

Figure A. 25 ZAURN A vs B Cartridge Co-Location NO_2

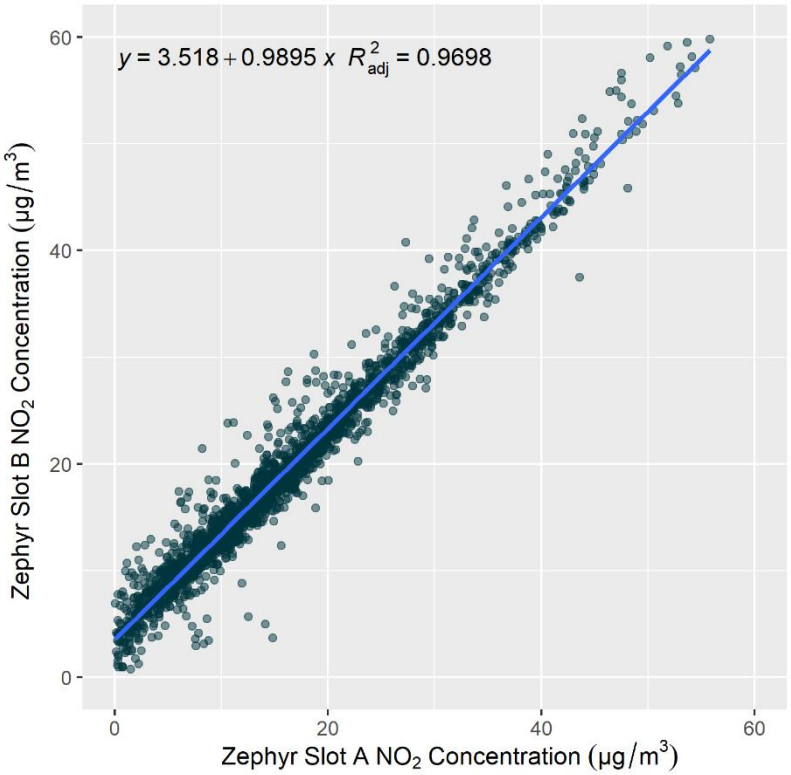


Figure A. 26 ZAURN A vs B Cartridge Co-Location PM_{10}

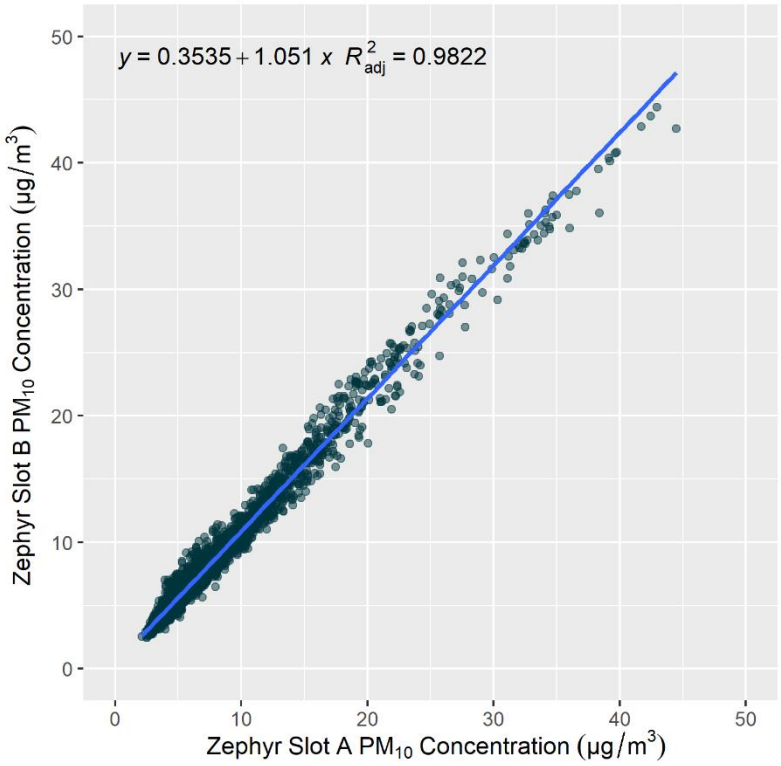


Figure A. 27 ZAURN A vs B Cartridge Co-Location $PM_{2.5}$

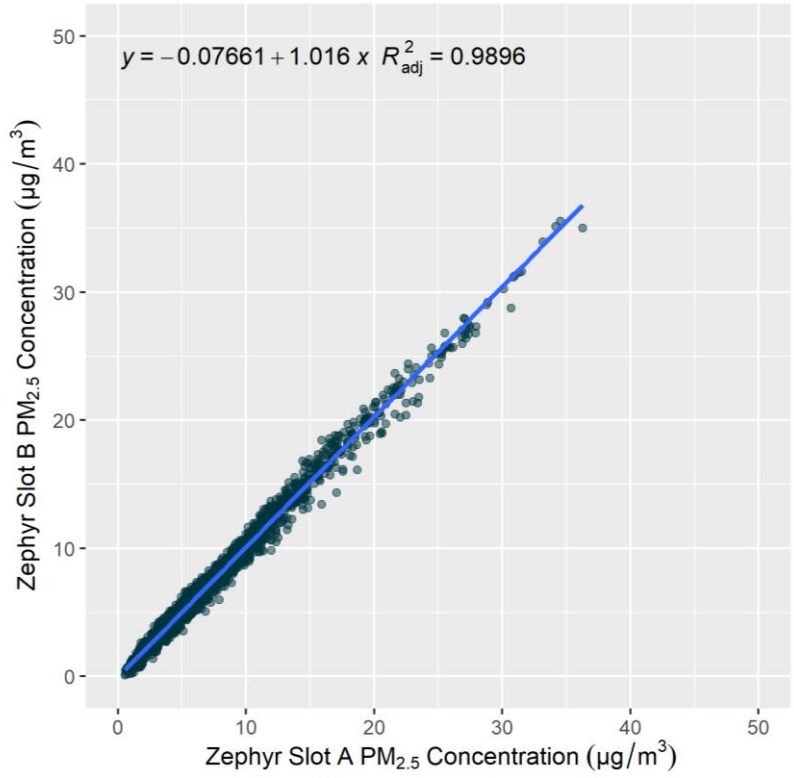


Figure A. 28 N1 A55 Cartridge Co-Location NO_2

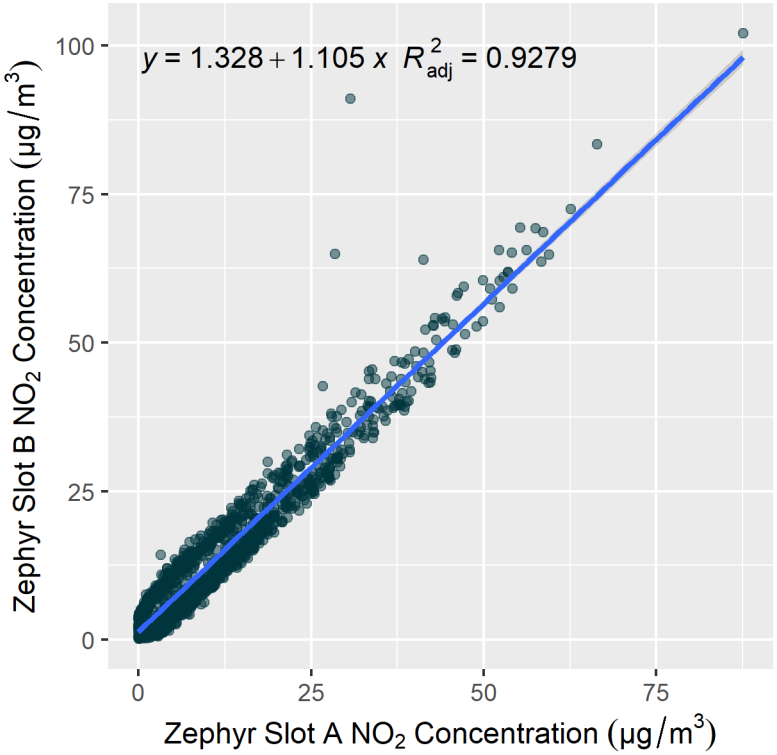


Figure A. 29 N1 A55 Cartridge Co-Location PM_{10}

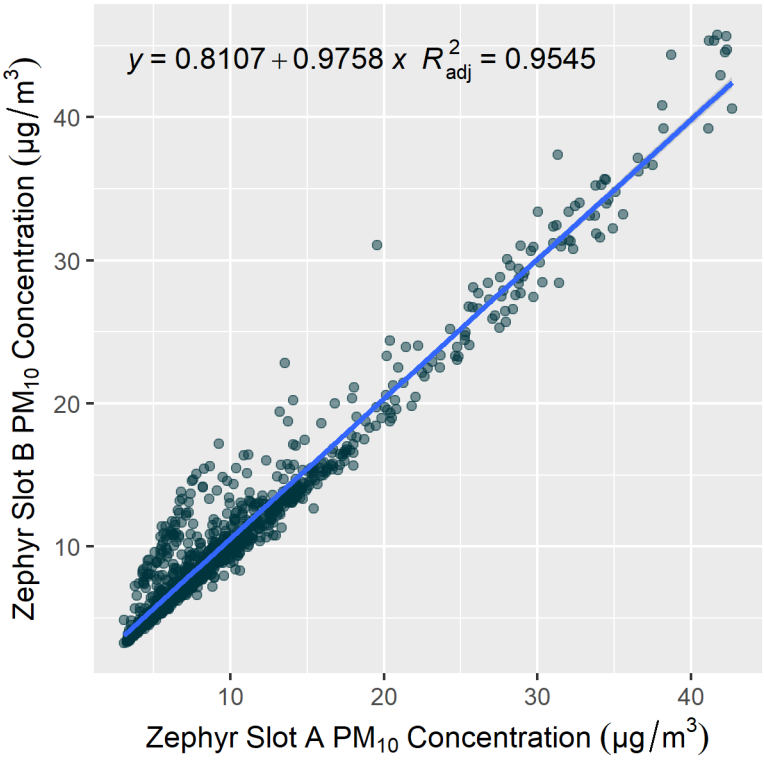


Figure A. 30 N1 A55 Cartridge Co-Location $PM_{2.5}$

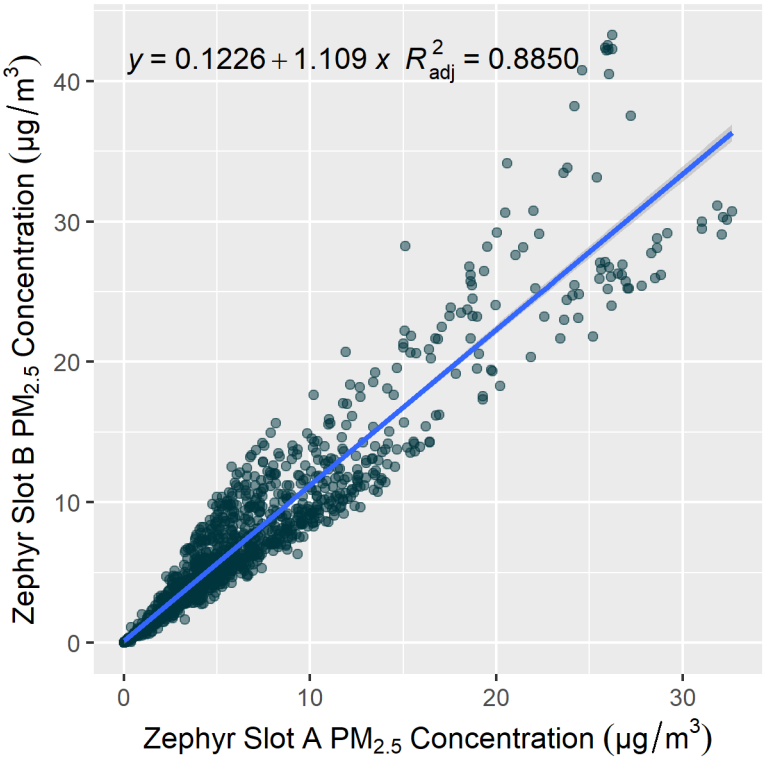


Figure A. 31 N6 Clara Street Cartridge Co-Location NO_2

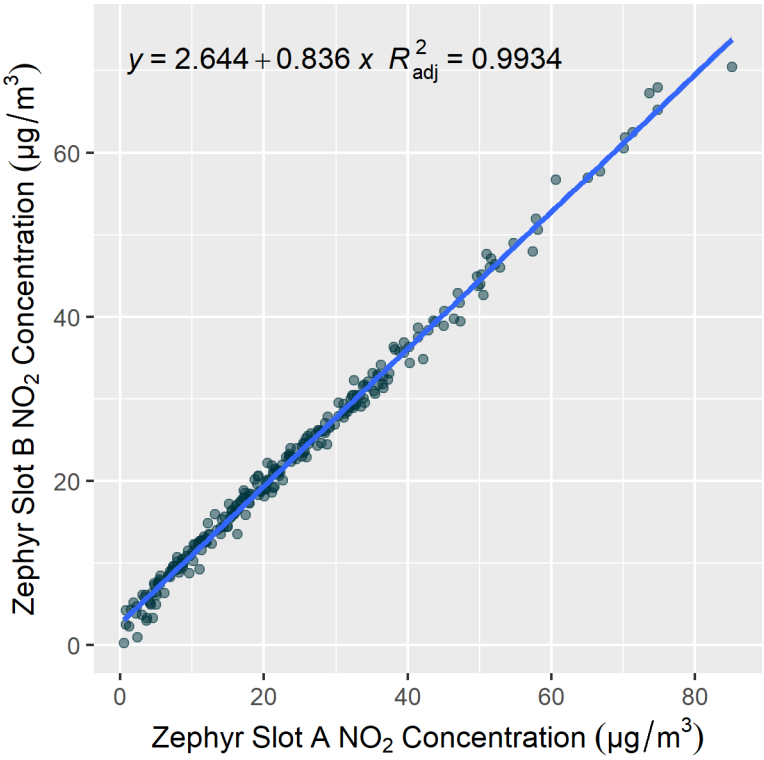


Figure A. 32 N6 Clara Street Cartridge Co-Location PM_{10}

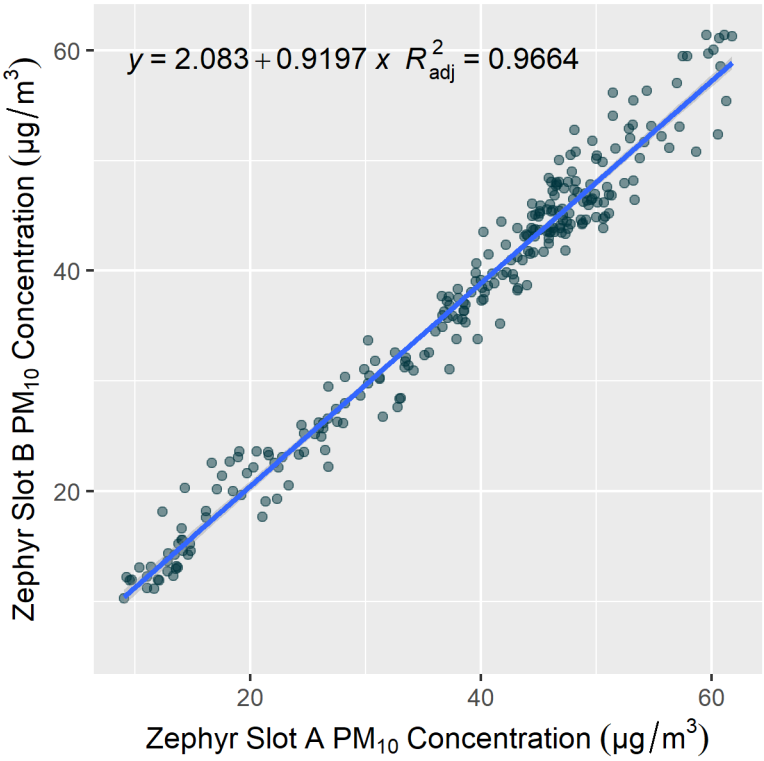


Figure A. 33 N6 Clara Street Cartridge Co-Location $PM_{2.5}$

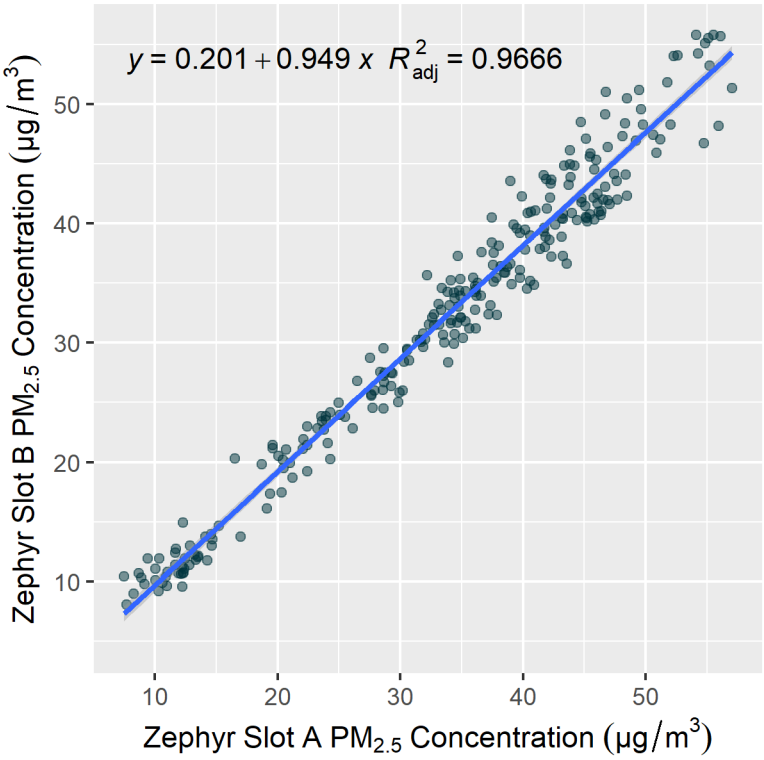


Figure A. 34 N8 Airport Cartridge Co-Location NO_2

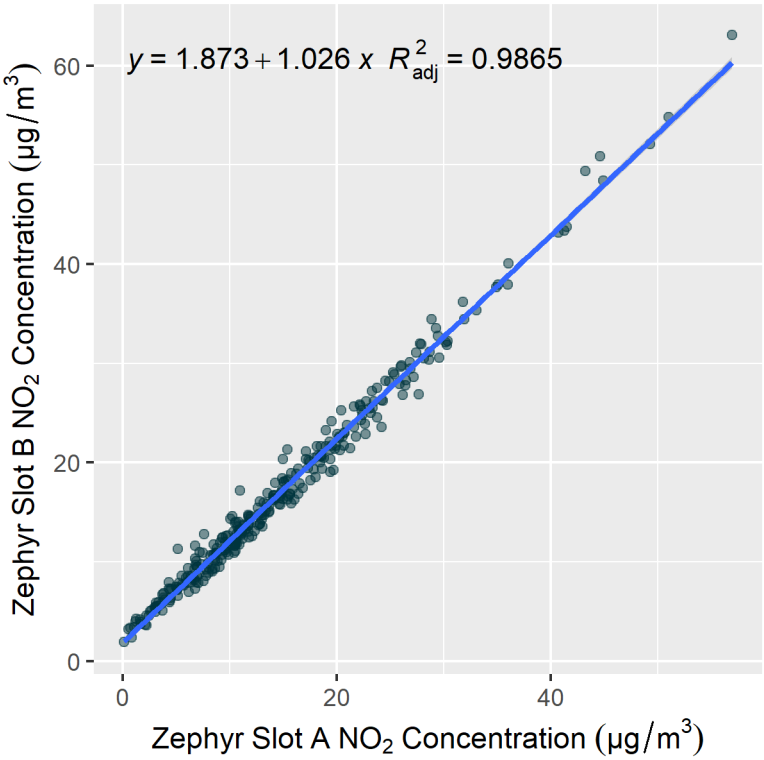


Figure A. 35 N8 Airport Cartridge Co-Location PM_{10}

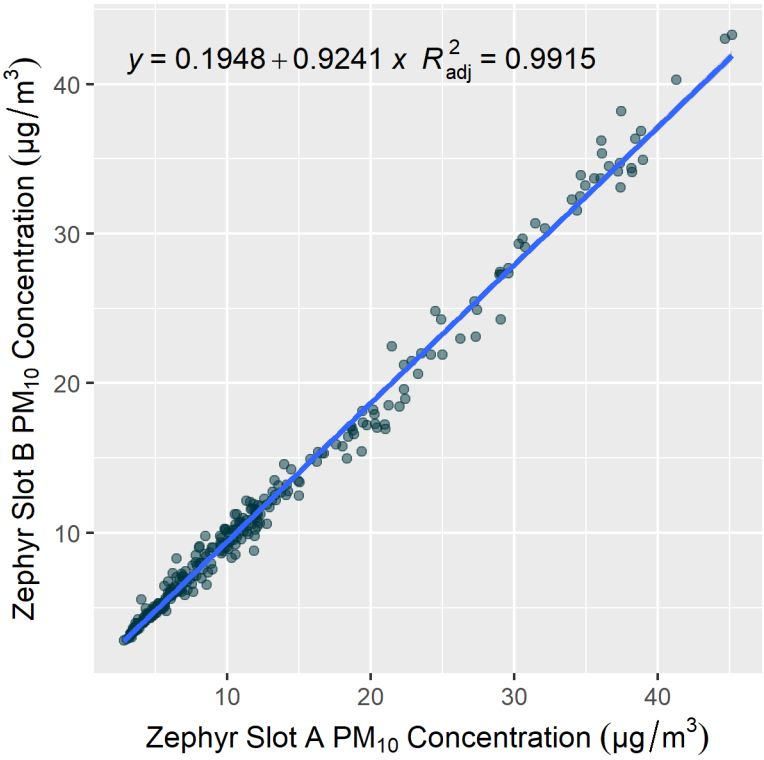


Figure A. 36 N8 Airport Cartridge Co-Location $PM_{2.5}$

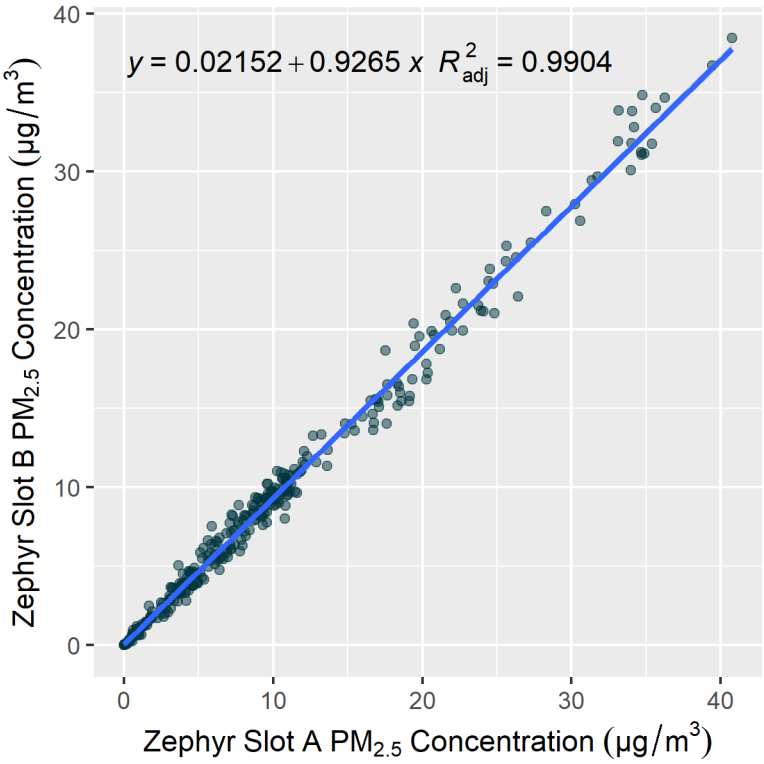


Figure A. 37 N10 Westlink Cartridge Co-Location NO_2

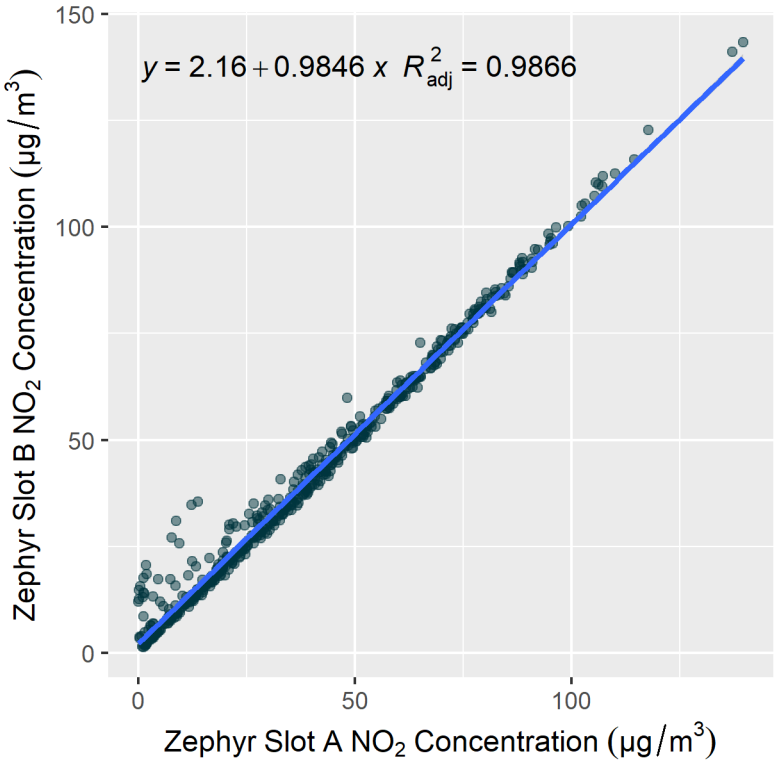


Figure A. 38 N10 Westlink Cartridge Co-Location PM_{10}

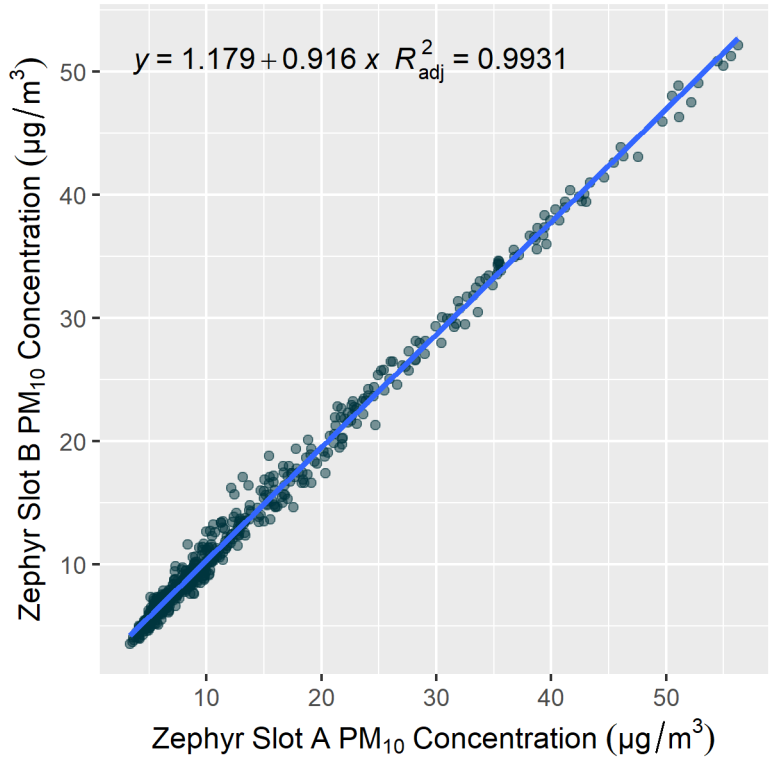


Figure A. 39 N10 Westlink Cartridge Co-Location $PM_{2.5}$

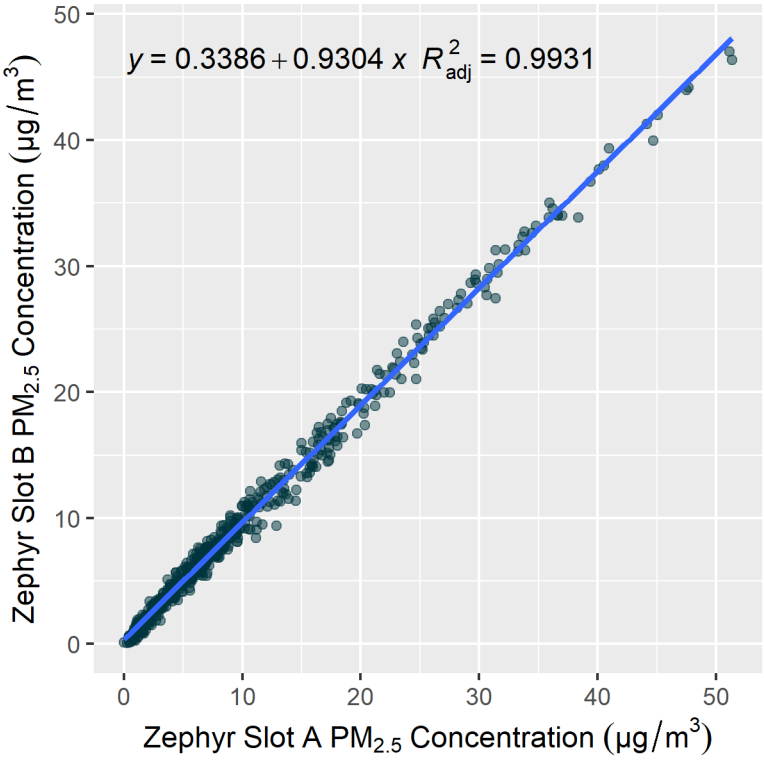


Figure A. 40 N12 Mt Eagles Glen Cartridge Co-Location NO_2

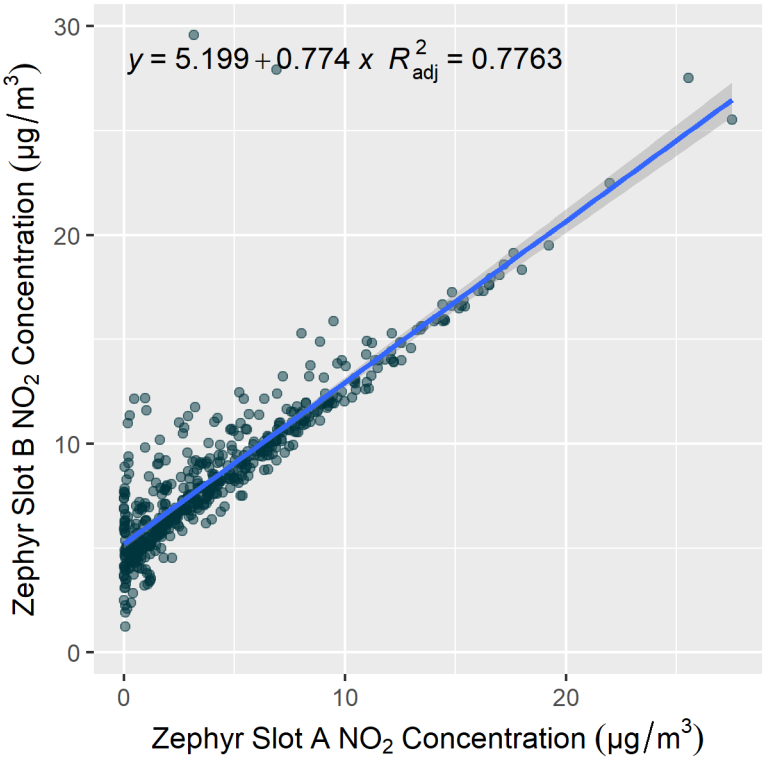


Figure A. 41 N12 Mt Eagles Glen Cartridge Co-Location PM_{10}

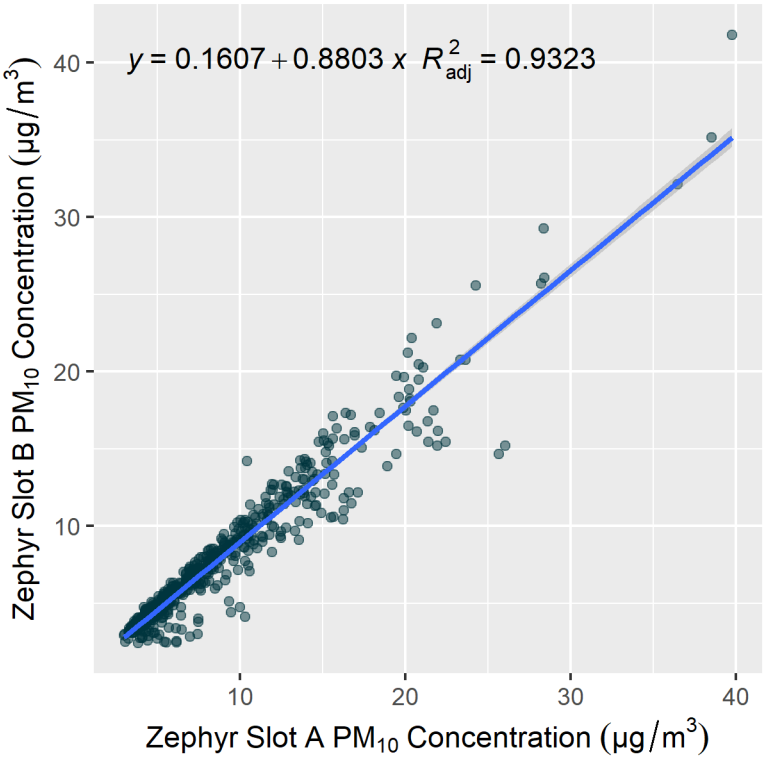
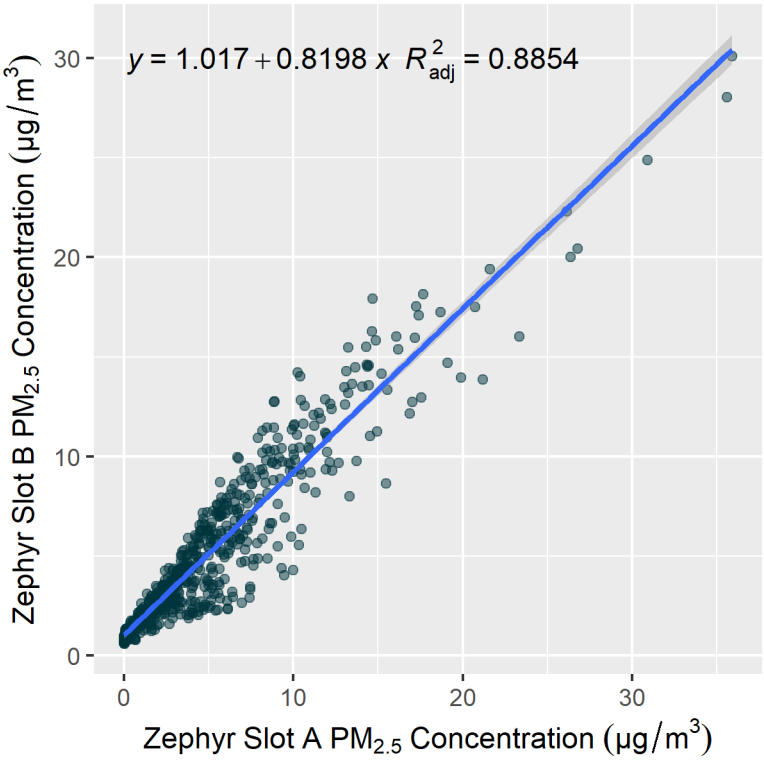


Figure A. 42 N12 Mt Eagles Glen Cartridge Co-Location $PM_{2.5}$



Annualisation Statistics

Table A. 1 2019 Equivalent Mean Annualisation Ratified Data

Site	Adjusted Calendar Annual Mean Data Capture (%)			2019 Annual Mean-Pre Annualisation µg/m^3			Annualisation Factor			2019 Annual Mean-Post Annualisation µg/m^3		
ID	NO_2	PM_{10}	$PM_{2.5}$	NO_2	PM_{10}	$PM_{2.5}$	NO_2	PM_{10}	$PM_{2.5}$	NO_2	PM_{10}	$PM_{2.5}$
N10	80.1	79.8	79.7	41.5	15.0	11.9	0.96	0.96	0.96	39.8	14.4	11.4
N12	59.7	62.2	62.2	10.8	11.0	8.3	0.92	0.94	0.86	10.0	10.4	7.1
N8	84.7	85.0	84.7	21.2	12.6	9.6	0.98	0.96	0.96	20.7	12.1	9.2
N1	63.1	62.6	62.6	17.9	13.1	10.1	0.96	0.93	0.95	17.1	12.1	9.6
N6	83.8	84.6	84.6	16.1	17.3	12.4	0.98	0.96	0.96	15.7	16.7	11.9
ZAURN	58.5	61.8	61.7	23.6	15.0	12.5	1.03	0.94	0.97	24.4	14.2	12.1
2022 / 2019 Adjustment Factor - 0.953/0.807 = 1.181; 2021 / 2019 Adjustment Factor - 0.953/0.855 = 1.115												

Table A. 2 2019 Equivalent Mean Annualisation Scaled Data

Site	Adjusted Calendar Annual Mean Data Capture (%)			2019 Annual Mean-Pre Annualisation µg/m^3			Annualisation Factor			2019 Annual Mean-Post Annualisation µg/m^3		
ID	NO_2	PM_{10}	$PM_{2.5}$	NO_2	PM_{10}	$PM_{2.5}$	NO_2	PM_{10}	$PM_{2.5}$	NO_2	PM_{10}	$PM_{2.5}$
N10	80.1	79.8	79.7	52.4	19.3	12.0	0.96	0.96	0.96	50.3	18.5	11.5
N12	56.0	62.2	62.2	14.3	17.1	8.8	0.92	0.94	0.86	13.2	16.2	7.6
N8	84.7	85.0	84.7	26.2	17.8	10.3	0.98	0.96	0.96	25.6	17.2	9.9
N1	63.1	62.6	62.6	21.3	16.6	8.9	0.96	0.93	0.95	20.3	15.4	8.5
N6	83.7	84.6	84.6	23.6	20.5	12.4	0.98	0.96	0.96	23.0	19.7	11.9
ZAURN	58.4	61.8	61.7	28.8	13.4	13.4	1.03	0.94	0.97	29.7	12.7	13.0
2022 / 2019 Adjustment Factor - 0.953/0.807 = 1.181; 2021 / 2019 Adjustment Factor - 0.953/0.855 = 1.115												

Table A. 3 2021 Equivalent Mean Annualisation Ratified Data

Site	Adjusted Calendar Annual Mean Data Capture (%)			2021 Annual Mean-Pre Annualisation µg/m^3			Annualisation Factor			2021 Annual Mean-Post Annualisation µg/m^3		
ID	NO_2	PM_{10}	$PM_{2.5}$	NO_2	PM_{10}	$PM_{2.5}$	NO_2	PM_{10}	$PM_{2.5}$	NO_2	PM_{10}	$PM_{2.5}$
N10	80.1	79.8	79.7	37.2	13.5	10.7	0.97	1.00	0.99	36.1	13.4	10.6
N12	59.7	62.2	62.2	9.7	9.9	7.4	0.94	0.98	0.95	9.1	9.7	7.0
N8	84.7	85.0	84.7	19.0	11.3	8.6	0.98	1.00	0.99	18.5	11.2	8.5
N1	63.1	62.6	62.6	16.1	11.7	9.0	0.98	0.96	0.97	15.7	11.3	8.8
N6	83.8	84.6	84.6	14.4	15.5	11.1	0.97	0.99	0.99	14.0	15.5	11.0
ZAURN	58.5	61.8	61.7	21.2	13.5	11.2	1.02	0.97	1.01	21.5	13.1	11.2
2022 / 2021 Adjustment Factor - 0.855/0.807 = 1.059												

Table A. 4 2021 Equivalent Annualisation Scaled Data

Site	Adjusted Calendar Annual Mean Data Capture (%)			2021 Annual Mean-Pre Annualisation µg/m^3			Annualisation Factor			2021 Annual Mean-Post Annualisation µg/m^3		
ID	NO_2	PM_{10}	$PM_{2.5}$	NO_2	PM_{10}	$PM_{2.5}$	NO_2	PM_{10}	$PM_{2.5}$	NO_2	PM_{10}	$PM_{2.5}$
N10	80.1	79.8	79.7	47.0	17.3	10.8	0.97	1.00	0.99	45.5	17.3	10.7
N12	56.0	62.2	62.2	12.8	15.4	7.9	0.94	0.98	0.95	12.0	15.0	7.5
N8	84.7	85.0	84.7	23.5	16.0	9.2	0.98	1.00	0.99	22.9	15.9	9.2
N1	63.1	62.6	62.6	19.1	14.9	8.0	0.98	0.96	0.97	18.6	14.4	7.8
N6	83.7	84.6	84.6	21.2	18.4	11.2	0.97	0.99	0.99	20.6	18.3	11.0
AURNB	58.4	61.8	61.7	25.8	14.1	12.0	1.02	0.97	1.01	26.2	13.7	12.1
2022 / 2021 Adjustment Factor - 0.855/0.807 = 1.059												

A.4 Calibration Certificates

Figure A. 43 Z787 Calibration Certificate

EARTHSENSE
TRUSTED AIR QUALITY INSIGHT

EarthSense Systems Ltd.

Zephyr Sensor Cartridge Calibration Certificate

Sensor Cartridge BIC1808

Calibration Summary

Location: *EarthSense manufacturing facility*
Start Date: *2021-04-26 00:00:01*
End Date: *2021-05-03 00:00:01*

Pollutant	RMSE	RMSE Pass Criteria	R^2	R^2 Pass Criteria	Status
NO2	2.98 ug/m^3	7 ug/m^3	0.82	0.75	Pass
NO	2.02 ug/m^3	8 ug/m^3	0.657	0.75	Reviewed
O3	11.94 ug/m^3	12 ug/m^3	0.952	0.75	Pass
PM2.5	4.53 ug/m^3	7 ug/m^3	0.809	0.75	Pass

Approved for customer shipment: *Isaac Mitchell*

Quality standards approval: *Dr. Roland Leigh*

Figure A. 44 Z799 Calibration Certificate

EARTHSENSE

TRUSTED AIR QUALITY INSIGHT

EarthSense Sensing Cartridge Calibration Certificate

Sensing Cartridge 1808

Calibration summary

Start Date of calibration: 2021-04-21 13:00:00

End Date of calibration: 2021-04-27 07:00:00

Location of calibration: EarthSense manufacturing facility 0 (km)

Pollutant	RMSE $\mu g\ m^{-3}$
NO_2	3.821
O_3	15.340
NO	2.889
$PM_{2.5}$	7.317
PM_{10}	9.446

Approved for customer shipment: Dr Jordan White

Quality standards approval: Dr Roland Leigh

Figure A. 45 Z790 Calibration Certificate

EARTHSENSE

TRUSTED AIR QUALITY INSIGHT

EarthSense Sensing Cartridge Calibration Certificate

Sensing Cartridge 1749

Calibration summary

Start Date of calibration: 2021-04-19 09:00:00

End Date of calibration: 2021-04-26 07:00:00

Location of calibration: EarthSense manufacturing facility 0 (km)

Pollutant	RMSE $\mu g\ m^{-3}$
NO_2	4.597
O_3	15.294
NO	2.804
$PM_{2.5}$	4.844
PM_{10}	14.692

Approved for customer shipment: Dr Jordan White

Quality standards approval: Dr Roland Leigh

Figure A. 46 Z748 Calibration Certificate

EARTHSENSE

TRUSTED AIR QUALITY INSIGHT

EarthSense Sensing Cartridge Calibration Certificate

Sensing Cartridge 1647

Calibration summary

Start Date of calibration: 2021-04-19 09:00:00

End Date of calibration: 2021-04-26 07:00:00

Location of calibration: EarthSense manufacturing facility 0 (km)

Pollutant	RMSE $\mu g\ m^{-3}$
NO_2	4.294
O_3	13.509
NO	2.745
$PM_{2.5}$	6.062
PM_{10}	11.368

Approved for customer shipment: Dr Jordan White

Quality standards approval: Dr Roland Leigh

Figure A. 47 Z793 Calibration Certificate

EARTHSENSE

TRUSTED AIR QUALITY INSIGHT

EarthSense Sensing Cartridge Calibration Certificate

Sensing Cartridge 1465

Calibration summary

Start Date of calibration: 2021-04-20 09:00:00

End Date of calibration: 2021-04-27 07:00:00

Location of calibration: EarthSense manufacturing facility 0 (km)

Pollutant	RMSE $\mu g\ m^{-3}$
NO_2	4.011
O_3	16.744
NO	1.309
$PM_{2.5}$	5.559
PM_{10}	11.465

Approved for customer shipment: Dr Jordan White

Quality standards approval: Dr Roland Leigh

Figure A. 48 Z842 Calibration Certificate

EARTHSENSE

TRUSTED AIR QUALITY INSIGHT

EarthSense Sensing Cartridge Calibration Certificate

Sensing Cartridge 1661

Calibration summary

Start Date of calibration: 2021-04-19 09:00:00

End Date of calibration: 2021-04-26 07:00:00

Location of calibration: EarthSense manufacturing facility 0 (km)

Pollutant	RMSE $\mu g\ m^{-3}$
NO_2	3.791
O_3	14.125
NO	2.130
$PM_{2.5}$	5.477
PM_{10}	12.723

Approved for customer shipment: Dr Jordan White

Quality standards approval: Dr Roland Leigh

Figure A. 49 Z743 Calibration Certificate

EARTHSENSE

TRUSTED AIR QUALITY INSIGHT

EarthSense Sensing Cartridge Calibration Certificate

Sensing Cartridge 1678

Calibration summary

Start Date of calibration: 2021-04-19 09:00:00

End Date of calibration: 2021-04-26 08:00:00

Location of calibration: EarthSense manufacturing facility 0 (km)

Pollutant	RMSE $\mu g\ m^{-3}$
NO_2	4.116
O_3	11.869
NO	2.140
$PM_{2.5}$	5.610
PM_{10}	13.463

Approved for customer shipment: Dr Jordan White

Quality standards approval: Dr Roland Leigh

Figure A. 50 Z1023 Calibration Certificate

EARTHSENSE

TRUSTED AIR QUALITY INSIGHT

EarthSense Sensing Cartridge Calibration Certificate

Sensing Cartridge 1678

Calibration summary

Start Date of calibration: 2021-04-19 09:00:00

End Date of calibration: 2021-04-26 08:00:00

Location of calibration: EarthSense manufacturing facility 0 (km)

Pollutant	RMSE $\mu g\ m^{-3}$
NO_2	4.116
O_3	11.869
NO	2.140
$PM_{2.5}$	5.610
PM_{10}	13.463

Approved for customer shipment: Dr Jordan White

Quality standards approval: Dr Roland Leigh

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