Aberdeen Air Quality Modelling Pilot Project Technical Report

July 2017

Executive summary

An ADMS-Urban model was developed for the City of Aberdeen and compared to automatic and diffusion tube monitoring. Detailed traffic data, collected in 2012, were used to generate traffic emissions for each road.

Model predictions were assessed against air quality observations and showed that at most automatic monitoring locations, the model performs well (6% under-prediction at Union Street and 8% over-prediction at Market Street 2 monitoring locations). Performance against diffusion tube data was not as good. Often, model predictions for these were lower than measured values. The use of good quality data to represent background concentration was key to good model performance. Given the careful construction of the model, the availability of detailed traffic information across Aberdeen enabled predictions to be made across the city with a good level of confidence.

Model performance was found to be variable at two monitoring stations within the City (Wellington Road and King Street). Data analysis and detailed modelling of air flow in the vicinity of the monitoring stations (using Computational Fluid Dynamics) was used to investigate these issues. This work suggests that complex air flow patterns can influence measured values. Additionally, it also appears that Gaussian type models, like ADMS, cannot easily represent this complexity. In both cases, the locations chosen for the stations may not be representative of air quality conditions in the wider area.

The model sensitivities were examined including inter-annual variation, rural background data, different chemistry methods and time-varying emissions. Under-predictions occurred when rural background data with spatially varying background emissions were used. Inter-annual variation sensitivity tests found variations of approximately 10% at the Union Street and Market Street 2 monitors.

Scenarios, such as Low Emissions Zones and the impact of cleaner vehicles entering the national fleet were also modelled, with predictions suggesting that as cleaner vehicles enter the national fleet over the next 10-15 years, or if a Low Emission Zone is created, pollutant concentrations will decline. However, uncertainties are large and despite newer, cleaner vehicles entering the national fleet, this may not be enough to meet Air Quality Standards in all areas.

Throughout the report, examples of different data visualisation methods are used and demonstrated.

Since the report was written, a number of methodology changes have been made for CAFS modelling. These can be found in A9

Scope of report

To report on the methodologies used to develop an air quality model for the City of Aberdeen as part of the Aberdeen Pilot Project. The report also includes investigations and analysis of the model performance compared to air quality observations which are undertaken in the city.

List of Acronyms

AAQuIRE: Ambient Air Quality in Regional Environments
ADMS: Atmospheric Dispersion Modelling System
AERMOD: American Meteorological Society/Environmental Protection Agency Regulatory Model
ANPR: Automatic Number Plate Recognition
ArcGIS: ArcGIS is GIS software produced by ESRI
ATC: Automatic Traffic Counts
AWPR: Aberdeen Western Peripheral Route
AADF: Annual Average Daily Flow
AQMA: Air Quality Management Area
BAM: Beta Attenuation Monitor
CALINE4: California Line Source Dispersion Model (version 4)
CAFS: Cleaner Air for Scotland
CERC: Cambridge Environmental Research Consultants
CHAM: Concentration, Heat and Momentum Ltd
CFD: Computational Fluid Dynamics
COPERT: Computer Program to calculate Emissions from Road Transport
CSV: Comma Seperated Variables
DEFRA: Department for Environment, Food and Rural Affairs
DfT: Department for Transport
EMIT: Emissions Inventory Toolkit
ESRI: Environmental Systems Research Institute
FB: Fractional Bias
FDMS: Filter Dynamic Measurement System
GIS: Geographical Information Systems
HGV: Heavy Goods Vehicle
LEZ: Low Emission Zone
LGV: Light Goods Vehicle
LIDAR: Light Detection and Ranging
MATLAB: Matrix Laboratory (software produced by Mathworks)
MB: Mean Bias
MG: Geometric Mean
MISKAM: (Microscale Climatic and Dispersion Model
NAEI: National Atmospheric Emission Inventory
NGR: National Grid Reference
NetCDF: Network Common Data Form
NLEF: National Low Emission Framework
NMF: National Modelling Framework
NMSE: Normalised Mean Square Error
NO_2: Nitrogen Dioxide
NO_x: Oxides of Nitrogen
NTDS: National Traffic Data System
OGV: Other Goods Vehicle
OSPM: Operational Street Pollution Model
OSVM: Ordnance Survey Vector Map
PAN: Peroxyacyl Nitrates
PHOENICS: Parabolic, Hyberbolic or Elliptic Numercial Integration Code Series
PM_{10}: Particulate Matter <10 µm in diameter
$PM_{2.5}$: Particulate Matter <2.5 µm in diameter
SEPA: Scottish Environment Protection Agency
SIAS: Transport Planning Consultants
TEA: Triethanolamine

TEOM: Tapered Element Oscillating Microbalance (PM_{10} monitor)
USEPA: United States Environmental Protection Agency
Q-Q: Quantile-Quantile plot
VG: Geometric Variance
WinMISKAM: MISKAM software interface produced by Lohmeyer conultants

1 Introduction

Whilst we have made great strides towards tackling air pollution in Scotland over recent years, it is acknowledged that there are still areas of poor air quality in many towns and cities. The Scottish Government published the Cleaner Air for Scotland (CAFS) strategy (1) in November 2015 which sets out plans of how air quality will be improved to further protect human health and meet Scottish, UK and European legislative requirements (2). Within CAFS, there is a National Modelling Framework (NMF) and National Low Emission Framework (NLEF).

A key action in CAFS is to build air quality models for the 4 Scottish cities of Aberdeen, Dundee, Edinburgh and Glasgow which will help provide information to assist the decision making required to improve urban air quality. This includes modelling different traffic scenarios to investigate how emissions can be reduced (e.g. by reducing older emission vehicles) or using the model to investigate source attribution (e.g. what contribution each vehicle class makes to air pollution concentrations in a particular street)

The Aberdeen Pilot Study was carried out so that a better understanding of the data and software requirements for the CAFS work could be gained. Aberdeen was selected for the pilot study for the following reasons:

- It is a compact city with 6 automatic monitoring stations across the city (needed for model verification).
- The completion of the Aberdeen Western Peripheral Route (AWPR) in 2018 will provide a useful test to see how the model predictions and measurements change under a new road arrangement. The stated aims of AWPR is to reduce congestion, cut journey times, improve safety, lower pollution in the city centre and enable public transport to be developed (3)
- Good quality traffic data was available from a recent traffic data collection campaign, funded by Aberdeen City Council (Section 3.2.1).
- A previous traffic and air quality assessment was available for comparison as Aberdeen City Council had contracted AECOM to investigate proposals for a Low Emission Zone by investigating different emission scenarios using the AAQuIRE air quality modelling tool. SEPA has liaised with AECOM to consider the outcomes of their work and report, and AECOM kindly supplied the data used in their study (4).

Air Quality modelling utilises mathematical equations to simulate the dispersion of pollutants in the atmosphere to predict concentrations of air pollutants. Different types of models are available for different scales:

- Large domain models (e.g. Europe) simulate the dispersion of pollutants over long distances, however the level of emissions detail required and predicted concentrations are coarse (e.g. 5 km^2 grids). Fine details such as building geometry and street width are not included. These models include long range Lagrangian and Eulerian models.
- Urban scale models (e.g. networks of streets or cities) simulate the dispersion of pollutants from an individual street to a city. These models can include defined street geometry (road widths, building geometry etc.). CFD type models require a high level of building details and can calculate flows around these buildings, whereas Gaussian type models tend to simulate flows depending on canyon characteristics (width, height) for an entire street.

There are several key input data which are required for running a model:

- Source data: Information on the source type, location of emissions and traffic data which is used to calculate emission rates. Source location also is required such as road height (in the case of elevated roads).
- Meteorology: Required to calculate the rate and direction in which pollutants are transported, and how the pollutants are mixed and dispersed in the atmosphere. The built environment also affects the physics of dispersion such as building heights, canyon width (façade to façade distance) and roughness length.
- Background Concentrations: Pollutant concentrations which are not due to sources which are being explicitly modelled.
- Receptor Locations: Co-ordinates of specific receptor locations where predicted pollutant concentrations are of interest (e.g. roadside locations, automatic air quality monitoring locations, diffusion tube locations etc.)

1.1.1 Purpose of Report

This report details the methods which have been developed and used to build the air dispersion model for Aberdeen, a comparison of the model results with measured concentrations at air quality monitors in Aberdeen, sensitivity analysis of the model, how future scenarios can be tested and recommendations based on the methodology employed and data requirements for future CAFS work.

1.2 Air Quality Standards/Objectives

The Air Quality standards which apply in Scotland are detailed in the Air Quality Standards (Scotland) Regulations 2010 (2), and which also implement European Air Quality directives. The pollutants currently of main concern in Scotland are Nitrogen Dioxide (NO_2) and Particulate Matter (PM_{10} and $PM_{2.5}$) which are summarised in Table 1.

Table 1: Relevant Air Quality Standards and Objectives for Scotland

Pollutant	Concentration	Measured as	Percentile
Nitrogen Dioxide	40 μgm^{-3}	Annual Mean	n/a
	200 μgm^{-3} not to be exceeded more than 18 times per year	1 hourly mean	99.79th %ile
PM_{10} (Scotland)	18 μgm^{-3}	Annual Mean	n/a
	50 μgm^{-3} not to be exceeded more than 18 times per year	24 hourly mean	98.08th %ile
$PM_{2.5}$ (Scotland)	12 μgm^{-3}	Annual Mean	n/a

1.3 Air Quality Monitoring and AQMA's in Aberdeen

In Aberdeen, there are 2 types of monitoring employed, namely automatic and passive monitors. Automatic monitors provide hourly data using reference methods, passive diffusion tubes aggregate concentrations over 4 week periods.

1.3.1 Automatic Monitoring in Aberdeen

There are currently 6 automatic monitors in Aberdeen (Figure 1) which form part of the Scottish Air Quality Network (5). All monitors are located at a roadside, except for Errol Place, which is classed as an Urban Background monitor. The Union Street and Errol Place monitors also form part of the UK Automatic and Rural network (AURN) of monitors. NO_x (NO_2 and NO) and PM_{10} are monitored at all sites in Aberdeen. Errol Place, O_3 and $PM_{2.5}$ are additionally monitored at Errol Place (6).

NO_2 automatic monitors use Chemiluminescence methodology at all automatic monitoring sites.
PM_{10} automatic monitoring methods vary across the city; TEOM FDMS is used at Errol Place, Dichotomous TEOM FDMS is used at Union Street, TEOM monitors are used at Anderson Drive and Wellington Road, and BAM monitors are used at Market Street 2 and King Street

Figure 1: Automatic Air Quality Monitoring Stations in Aberdeen

Table 2, Table 3, Table 4 and Table 5 show the monitored pollutant concentrations for NO_2 and PM_{10} for all the automatic monitoring sites across Aberdeen (2009 to 2013). Further information and details on the measurement methods are available in a report published by Aberdeen City Council (5).

Table 2: Nitrogen Dioxide Annual Mean Concentrations. Breaches of 40 μg m^{-3} threshold are in bold.

μg m^{-3}	2009	2010	2011	2012	2013	2014
Union Street	**51**[a]	**58**	**44**	**53**	**48**	**46**
Market Street 2	39[a]	**44**	40	**44**	**43**	40
Wellington Road	**43**	**52**	**51**	**59**	**52**	**47**
King Street	32	29	32	29	28	27
Anderson Drive	24	27	23	30	22	25
Errol Place	26	22[a]	23	21	20[a]	21

Note: [a] Data capture less than 75%

Table 3: 99.79th percentile of Nitrogen Dioxide (Number of hours when 200 μg m^{-3} threshold is exceeded is in brackets). Breaches of 200 μg m^{-3} are in bold.

μg m^{-3}	2009	2010	2011	2012	2013	2014
Union Street	189 [a] (10)	198 (15)	168 (6)	143 (1)	135 (0)	137 (0)
Market Street 2	175 [a] (2)	156 (0)	164 (1)	161 (0)	169 (1)	145 (0)
Wellington Road	157 (0)	180 (1)	183 (4)	188 (10)	184 (6)	162 (0)
King Street	132 (0)	118 (0)	118 (0)	107 (0)	113 (0)	114 (0)
Anderson Drive	107 (0)	111 (0)	113 (0)	115 (0)	115 (0)	110 (0)
Errol Place	124 (0)	101 [a] (0)	101 (0)	105 (0)	86 [a] (0)	104 (0)

Note: [a] Data capture less than 75%

Table 4: PM_{10} Annual Mean Concentrations. Breaches of 18 μg m^{-3} are in bold.

μg m^{-3}	2009	2010	2011	2012	2013	2014
Union Street	18	18	**22**	**21**	**20**	18
Market Street 2	**24**[a]	**20**[a]	**22**	**22**	**26**	**26**
Wellington Road	**23**	**22**	**24**	**23**	**22**	**21**
King Street	17	18	**20**	**19**	**19**	**19**
Anderson Drive	15	14	16	15	15	14
Errol Place	15	13	14	12	13	14

Note: [a] Data capture less than 75%

Table 5: 98.08th percentile of the PM_{10} 24-hour mean concentrations. Breaches of 50 μg m^{-3} are in bold.

μg m^{-3}	2009	2010	2011	2012	2013	2014
Union Street	36.5	38.5	46.6	47.0	42.8	40.9
Market Street 2	**66.3** [a]	**52.3** [a]	**58.4**	**64.0**	**70.6**	**63.3**
Wellington Road	48.3	46.6	**51.0**	**52.6**	**51.0**	44.2
King Street	37.5	42.8	**53.4**	**50.1**	48.2	48.3
Anderson Drive	38.8	32.0	40.9	36.4	39.9	34.0
Errol Place	47.3	38.6	39.8	34.2	38.3	37.5

Note: [a] Data capture less than 75%

The main non-compliance issues are with the NO_2 and PM_{10} annual means, and with the PM_{10} 98.08th percentile of the 24-hourly means. However, there are known difficulties with PM_{10} measurements at 2 locations ('Market Street 2' and King Street) where BAM monitors are used. Significantly elevated concentrations during wet weather or sea mist ('haar') conditions have been found (5) at these monitors; an effect which has been noted by the Air Quality Expert Group (7). As long range transport tends to make up a significant component and local emissions a small component of overall PM_{10} concentrations, and as there are some known PM_{10} monitoring problems, NO_2 will be the main focus of the pilot project.

1.3.2 Diffusion Tube Monitoring in Aberdeen

Aberdeen City Council has a diffusion tube network across the city which provides indicative monitoring of Nitrogen Dioxide annual mean concentrations at 45 locations (5). Diffusion tubes are less expensive to use and easier to locate than automatic stations, so despite aggregated measurements with greater methodology uncertainties, diffusion tubes can provide detailed spatial information of Nitrogen Dioxide concentrations.

Limitations and uncertainties when using diffusion tubes can lead to over-reads and under-reads, though it is reported that reasons for over-reads are more difficult to eliminate (effects due to wind speed, sunlight and interfering effects of PAN) (8), whilst reasons for under-reads such as exposure periods, extraction of nitrite from grids and degradation of TEA-nitrite by light have been minimised.

Due to the uncertainties, diffusion tubes are co-located and automatic monitors to calculate a bias-adjustment factor (9); the bias adjustment factor is applied to all diffusion tubes depending on their location. Unadjusted and bias adjusted diffusion tube concentrations for Aberdeen city centre are shown in Figure 2 and Figure 3.

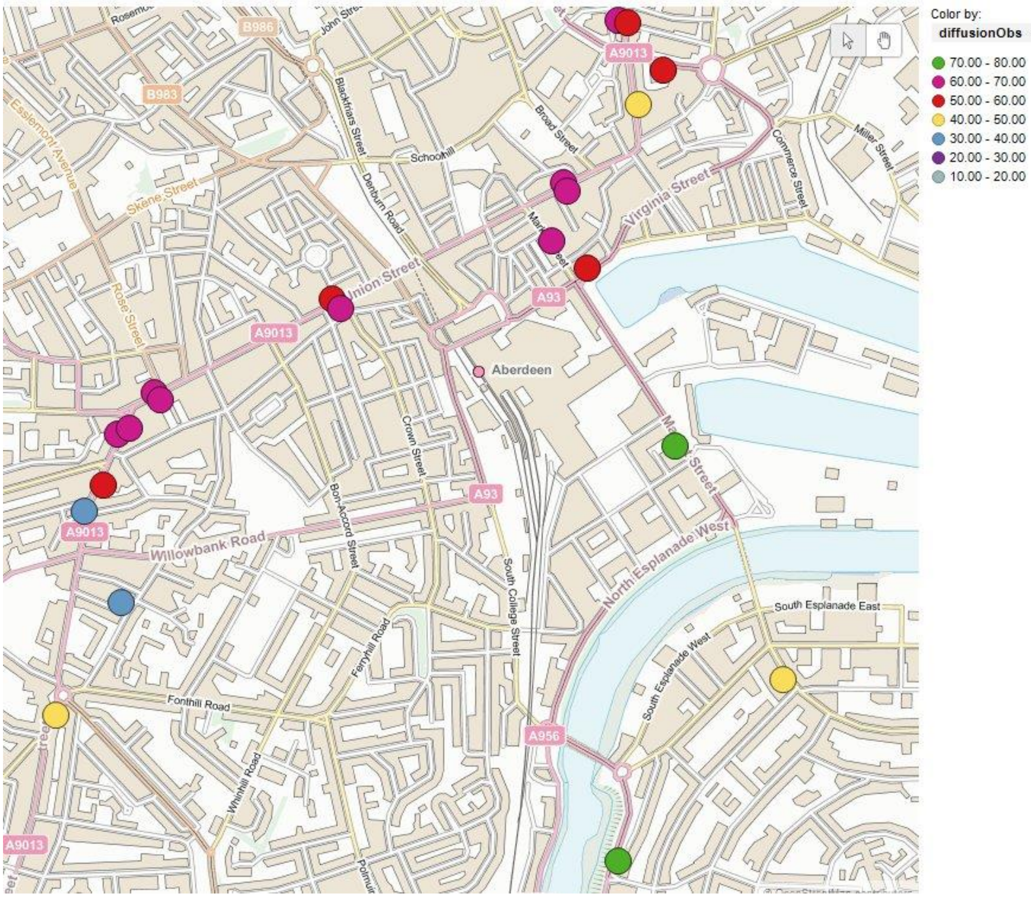


Figure 2: Map of Aberdeen city centre with diffusion tube locations coloured by unadjusted diffusion tube values for 2012 (µg m^{-3})

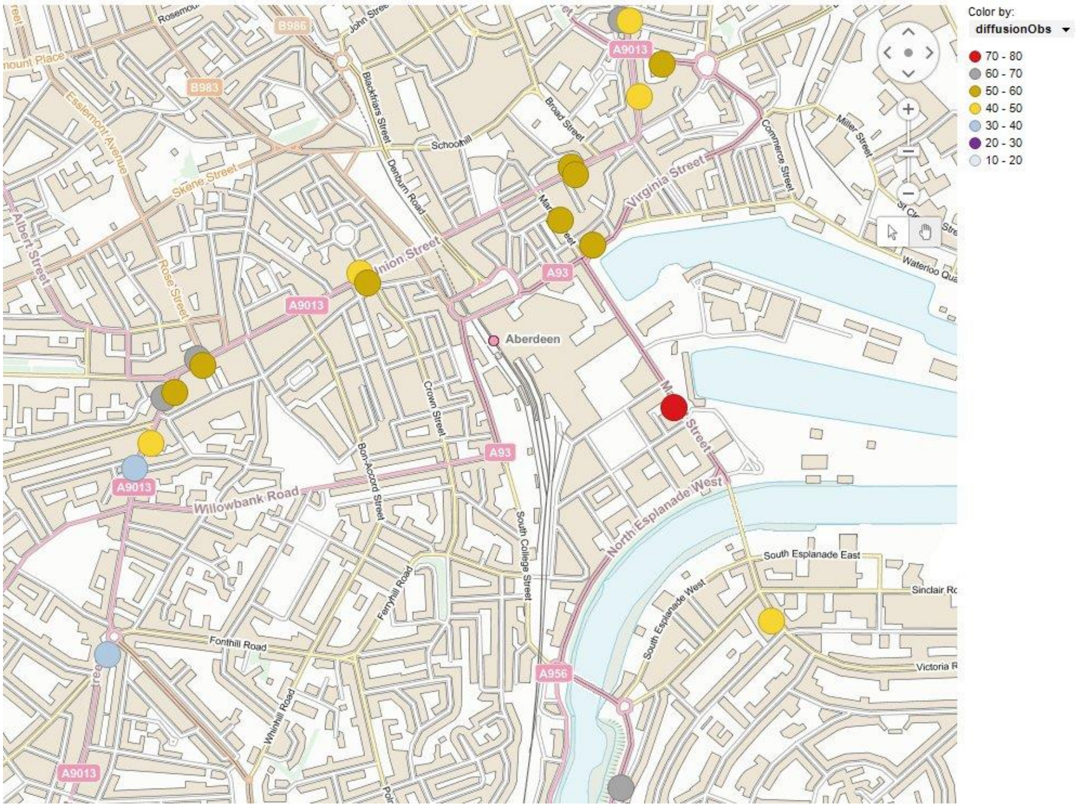


Figure 3: Map of Aberdeen city centre with diffusion tube locations coloured by bias-adjusted diffusion tube values for 2012 (µg m^{-3})

1.3.3 Air Quality Management Areas

Monitored air quality data has been used by Aberdeen City Council to designate 3 Air Quality Management Areas (AQMA's), shown in Figure 4 and Figure 5. The monitored data is essential information for model verification so that model performance can be assessed. Urban background monitoring data (Errol Place) may also be useful for including as background data in the model.

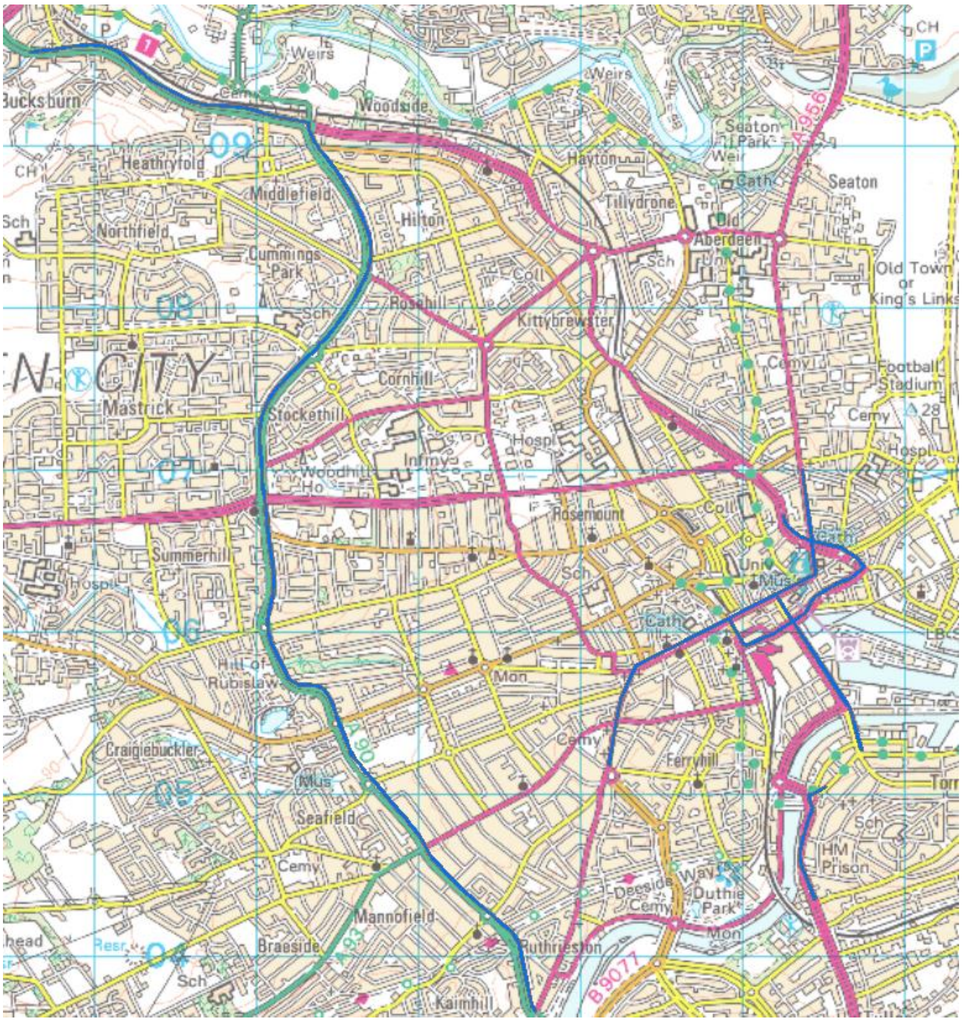


Figure 4: AQMA's in Aberdeen (blue lines)

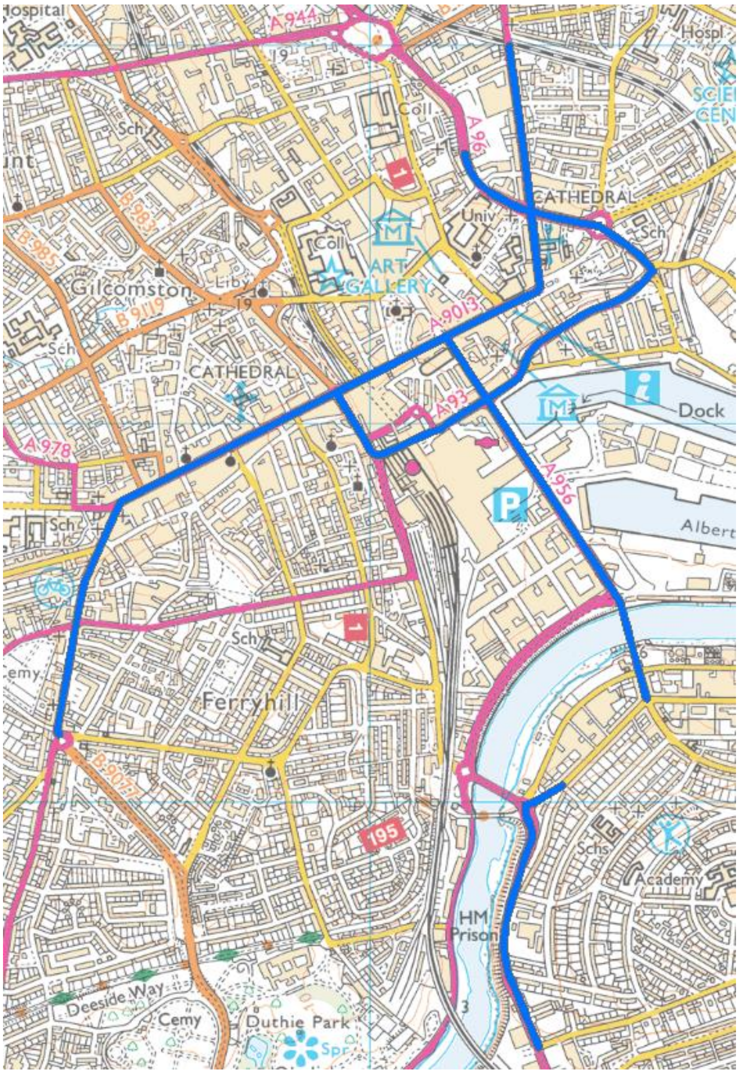


Figure 5: City Centre AQMA's in Aberdeen (blue lines)

2 Software

A number of software packages were used in this study and are outlined in more detail.

2.1 EMIT (Atmospheric Emissions Inventory Toolkit)

EMIT is a database tool developed by CERC to store and process data required in an ADMS-Urban model. EMIT calculates traffic emissions using traffic flow data and various published emission inventories (NAEI, EfT). It also has functionality to manipulate data for sensitivity tests (such as increasing traffic flows, adjusting average traffic speed etc.). EMIT can process the data into a format which ADMS-Urban requires, although it is possible to enter traffic data directly into ADMS-Urban. The advantage of using EMIT is that it is easy to manage data for multiple roads, thus reducing the risk of errors (e.g. manual inputs for ~200 roads).

In this project, the national fleet composition was used as no other data was available, although EMIT also has the ability to modify vehicle fleet compositions, which may be useful in the future studies (e.g. bespoke vehicle fleets for different cities using vehicle monitoring techniques, such as a higher percentage of diesel cars compared to the national average)

EMIT requires traffic data flows to be grouped in 3 vehicle classes (3VC) or 11 vehicle classes (11VC) (10). Details of how 3VC and 11VC categories map to each other are shown in Table 6.

Table 6: Vehicle Classes Options required by EMIT

<table>
<tr><th>3 Vehicle Classes</th><th>11 Vehicle Classes</th></tr>
<tr><td>Motorcycle</td><td>Motorcycle</td></tr>
<tr><td rowspan="3">Light</td><td>Cars</td></tr>
<tr><td>Taxis</td></tr>
<tr><td>Light Goods Vehicles (LGV’s)</td></tr>
<tr><td rowspan="7">Heavy</td><td>Buses/Coaches</td></tr>
<tr><td>2 Axle Rigid HGV’s</td></tr>
<tr><td>3 Axle Rigid HGV’s</td></tr>
<tr><td>4/5 Axle Rigid HGV’s</td></tr>
<tr><td>3/4 Axle Artic HGV’s</td></tr>
<tr><td>5 Axle Artic HGV’s</td></tr>
<tr><td>6+ Axle Artic HGV’s</td></tr>
</table>

2.2 ADMS-Urban (Atmospheric Dispersion Modelling System)

ADMS-Urban 3.4 was used in this modelling study. This model has been developed by Cambridge Environmental Research Consultants (CERC; www.cerc.co.uk), and is part of the ADMS group of air quality models. ADMS-Urban has been widely used for urban air quality modelling studies (e.g. London, Beijing, Rome etc.).
ADMS-Urban is a Gaussian Dispersion model which has been developed to model the dispersion of emissions from road sources, along with other source types (e.g. stack emissions). Although well established, and supported by peer reviewed publications, it is also important to recognise the limitations of the ADMS-Urban

model, for example, the wind direction at a source may differ from the wind direction at the weather station due to local street geometry.
ADMS-Urban has a specific road source category which has been developed for the purposes of modelling vehicle emissions. The road source category allows features specific to roads (e.g. urban street canyons), and other factors (e.g. vehicle induced turbulence) to be accounted for in the modelling.

Consideration was given to other software packages; however most UK studies use ADMS-Urban and most other European models also use a Gaussian approach. The street canyon module in ADMS-Urban is based on a Danish model, OSPM, which is commonly used in other European air quality models.

The AAQUIRE tool (used by AECOM for Aberdeen) uses the US models CALINE4 and AERMOD. AECOM report that for Aberdeen, to account for AAQUIRE under-estimation, a verification factor of 2.2 (city centre) and 2.8 (Wellington Road) were applied to the NO_x results, and a verification factor of 4 was applied to the PM_{10} results. This study uses emission factors in the Emission Factor Toolkit (v5.2), published by Defra. CALINE4 has also been shown to perform less well when compared to other air quality models, in a paper published by CERC and the USEPA (11).

2.3 ArcGIS

ArcGIS software is a commonly used Geographical Information System (GIS) software package which was required for generating, viewing and manipulating the spatial details of the road network to be modelled, such as calculating road canyon widths, the processing of NAEI background emission rasters and generation of concentration contour plots. EMIT and ADMS-Urban are designed to link to ArcGIS, to allow data (roads, concentration plots etc.) to be viewed efficiently.

2.4 MATLAB

MATLAB is a numerical programming language software package produced by Mathworks which can process and visualise large data sets. The mapping toolbox was used to process traffic data as it has the ability to write processed data in ArcGIS shapefile format (required for ADMS-Urban and EMIT).

2.5 R/Spotfire

The R package is an open source statistical package, which can quickly and efficiently carry out statistical analysis of data, and visualise these outputs in various ways. The OpenAir package within R has the ability to directly download data from the Scottish Air Quality Monitoring network host servers (hosted by AEA-Riccardo). Spotfire is a data analysis package which allows users to efficiently explore and analyse data interactively. Spotfire can also call and run R code within the package, therefore R functions such as those in OpenAir can be used within Spotfire.

2.6 Computational Fluid Dynamics (CFD)

An alternative approach to investigating the dispersion of traffic emissions is the use of CFD software, of which 2 packages have been used, PHOENICS and WinMISKAM.

2.6.1 CFD: PHOENICS

The PHOENICS CFD package, which has been developed by Concentration, Heat and Momentum Limited (CHAM; www.cham.co.uk) has been used to investigate air flow and dispersion at a smaller scale than is possible with ADMS-Urban.

PHOENICS uses a physically-based approach method, based on the numerical solution of fluid flow conservation equations which includes mass, momentum and heat. It is better suited than a Gaussian dispersion model to help understand dispersion at more detailed scales, such as in the vicinity of an individual street segment. It can take into account the effects of meteorology, moving vehicles (vehicle induced turbulence), and buildings in a simulation of dispersion whilst also considering vehicle speed, vehicle size and traffic volumes in a general way. Emissions from the vehicles can also be included and while the method remains untested against measured data at this point, it can provide a useful visualisation of tracer concentrations. During this project PHOENICS was primarily used to model complex air flow at a number of automatic monitoring locations where air quality may have been significantly affected by local building geometry.

2.6.2 CFD: WinMISKAM

WinMISKAM is software developed by Lohmeyer consulting engineers (www.lohmeyer.de) which includes MISKAM, a 3-dimensional numerical non hydrostatic flow model and a numerical Eulerian dispersion model (developed in the Institute for Atmospheric Physics at the University of Mainz). It is designed to determine pollution concentrations in built up areas, has undergone validation studies and is designed to calculate concentration annual means and percentiles (12). WinMISKAM has been used in various Low Emission studies (e.g. Bremen (13)) and, conveniently, input shapefiles of buildings and road sources which have been generated for ADMS-Urban can also be used in WinMISKAM.
WinMISKAM has been used in a few locations in Aberdeen where air quality may have been significantly affected by local building geometry.

2.7 Summary

A flow diagram of the data and software requirements needed for this work is outlined in Figure 6. This shows which data is required for each software package and how raw data is converted into data which can be used in a dispersion model. It is also highlighted which parameters can be changed for sensitivity and scenario testing.

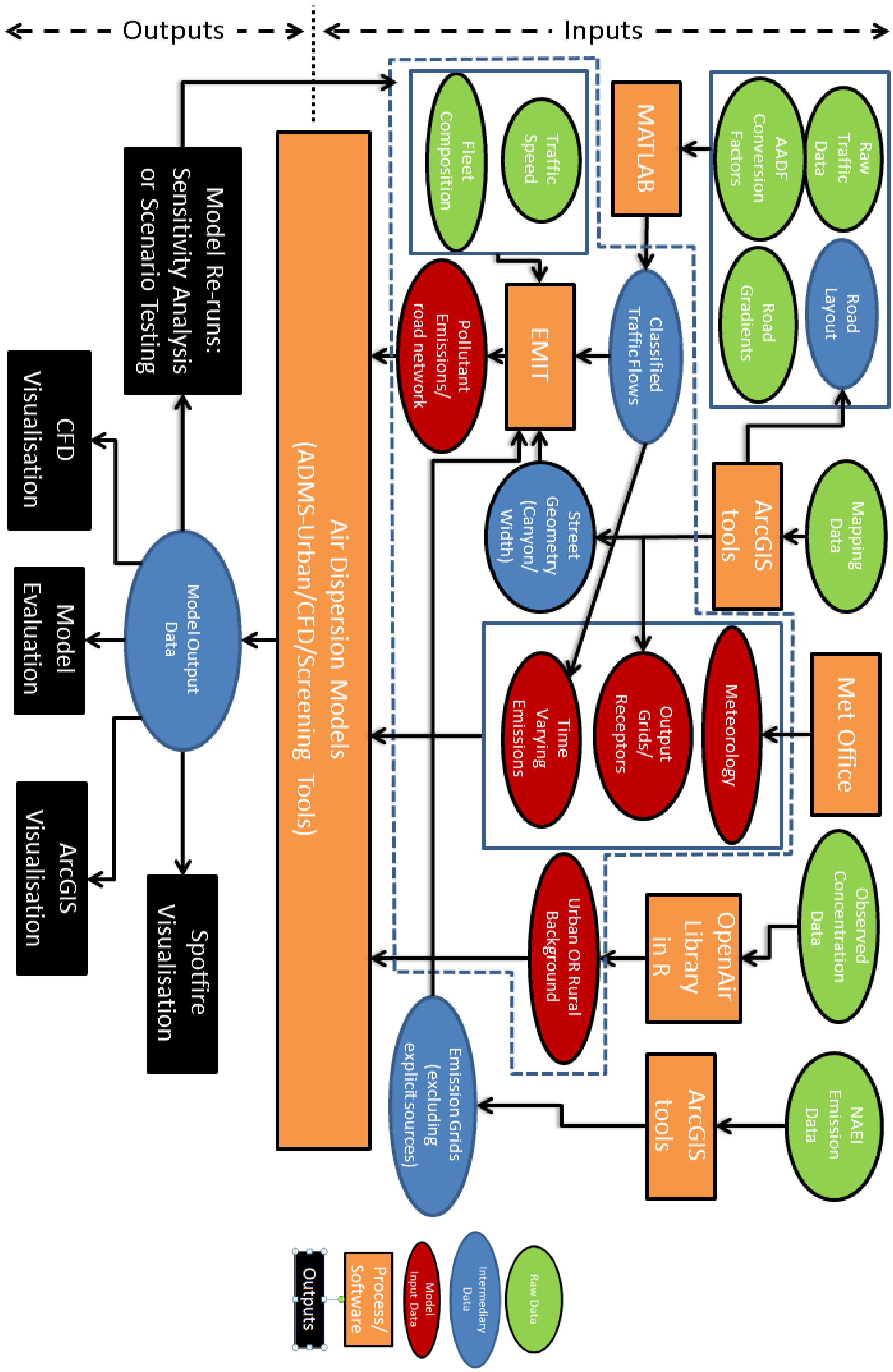


Figure 6: Flow diagram showing 'modus operandi' of the Aberdeen Pilot Project

3 Model Inputs

This section will describe how the model has been built, such as how road geometry was constructed, how traffic data was processed, how missing data was accounted for and receptor locations calculated

3.1 Road Network Layout

EMIT requires road and traffic data to be in one of three format types for import: ESRI shapefiles, MapInfo files or Comma Separated Variables (CSV) files. The ESRI shapefile format was chosen with roads represented as polylines. Each road section requires attributes to characterise each road section (explained in more detail in the sections below). It was decided that entering the data directly into ADMS-Urban did not offer the flexibility that EMIT offers for source data manipulation and sensitivity tests, and therefore this option was not considered.

The shapefile contains the polyline vertices which must be in sequential order (only 2 end points); branches or cul-de-sacs must be represented as a separate road source.

Digitised road network shapefiles are freely available from Ordnance Survey as "District Vector Maps" (14). The District Vector Maps were used as the basis for developing a road network that was suitable for ADMS model inputs; Local Vector Maps were not used as they contained more detail such as polylines to represent different carriageways on a dual carriageway road, and it was decided that representing these dual carriageways as one source was preferred for processing traffic at this stage of the project.

Figure 7: Example of Digitised Roads and modified road layout for ADMS

The District Vector Maps did require modification and simplification for use in EMIT/ADMS, such as removing roundabouts and simplifying complex junctions. This modification involved several steps:

- Removal of minor roads or roads which are not being modelled. Some polylines are very short and not easy to spot visually; they were removed by calculating polyline lengths in attribute table. Figure 7 shows the original OSVM road network in black, and the modified road network for ADMS-Urban in blue; the roads which have been removed and junction simplification can be clearly seen.
- Merge polyline road sections in District Vector Map into longer sections representing road sections to be modelled in ADMS-Urban using ArcMap shapefile editing tools.
- Simplification of junctions (removing roundabouts, complex configurations at roundabouts).
- Simplifying polylines using Douglas-Peucker algorithm (15), (16). Merging OSVM road sections results in many polyline vertices for each ADMS-Urban road section. This method removes polyline vertices so that a reduced number of vertices form a road polyline without changing the polyline shape. This can significantly reduce the model run time. Figure 8 shows the polyline vertices for an area of Aberdeen, the yellow vertices have been removed, and the red vertices retained by the algorithm. A Matlab script was written for this process which retains all other attributes.
- Modifying some polylines to follow the road centreline (where this is not already the case). This can sometimes be identified when running processes such as calculating road widths, described in more detail later.

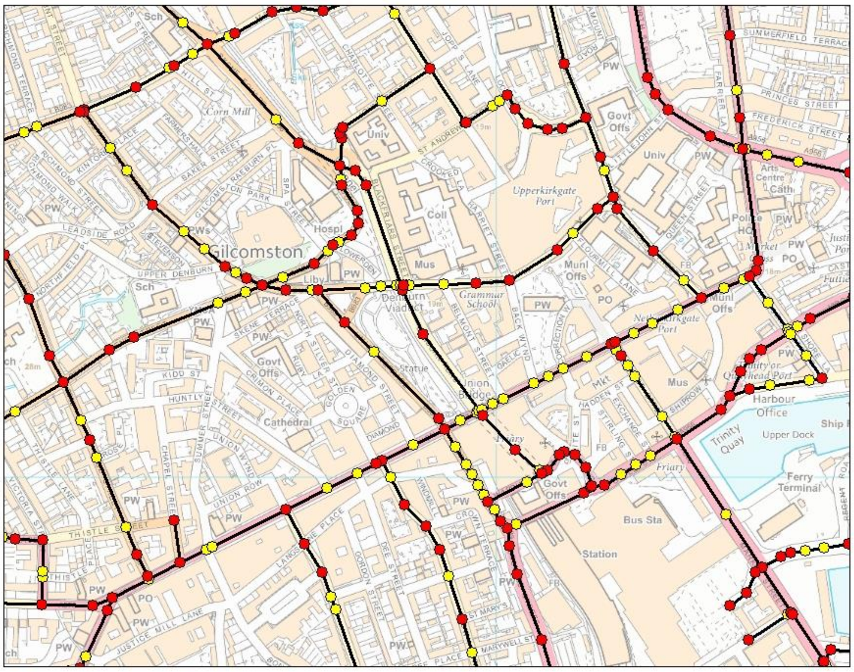


Figure 8: Road polyline vertices. Yellow vertices have been removed using the Douglas-Peucker algorithm

3.2 Traffic Data

Traffic emission rates are required for each road section in ADMS-Urban and are calculated using traffic flows and emission factors. EMIT requires traffic data to represent the Annual Average Daily Flow (AADF) for each road section.

For Aberdeen, traffic was available from 2 sources:

- Detailed traffic count from work commissioned by Aberdeen City Council and which was carried out by consultants (SIAS Ltd).
- UK Department for Transport traffic database website (17).

3.2.1 Aberdeen City Council Data

The high resolution traffic data was collected by SIAS on behalf of Aberdeen City Council to update the base data used in a traffic model (S-Paramics) (18) in October 2012.

The traffic data, which was collected by video contains:

- Measured traffic turning movements at 67 junctions in Aberdeen
- Traffic turning movements were reported in 5 minute intervals between 6am and 7pm
- Traffic data was summarised into 8 vehicle categories. Table 7 shows how the 8 vehicle classes correspond to the 11 vehicle classes required by the EMIT software when using the detailed NAEI2012 emission inventory (19).

Air pollution dispersion models require traffic flows along a road section, therefore the junction turn data required processing to calculate the AADF for the 3 and 11 vehicle categories required by EMIT.

Table 7: Traffic data categories for Aberdeen City Council data and corresponding 11 vehicle class data

<table>
<tr><th>Aberdeen City Council Data classes</th><th>11 Vehicle Classes</th></tr>
<tr><td>Motorcycle</td><td>Motorcycle</td></tr>
<tr><td rowspan="2">Cars/Taxis</td><td>Cars</td></tr>
<tr><td>Taxis</td></tr>
<tr><td>Light Goods Vehicles (LGV's)</td><td>Light Goods Vehicles (LGV's)</td></tr>
<tr><td>Private Buses/Coaches</td><td rowspan="2">Buses/Coaches</td></tr>
<tr><td>Service Buses</td></tr>
<tr><td rowspan="2">OGV1</td><td>2 Axle Rigid HGV's</td></tr>
<tr><td>3 Axle Rigid HGV's</td></tr>
<tr><td rowspan="4">OGV2</td><td>4/5 Axle Rigid HGV's</td></tr>
<tr><td>3/4 Axle Artic HGV's</td></tr>
<tr><td>5 Axle Artic HGV's</td></tr>
<tr><td>6+ Axle Artic HGV's</td></tr>
</table>

As the HGV traffic data collected in the Aberdeen dataset uses the categories OGV1 and OGV2, the vehicle numbers within these categories need to be redistributed into the detailed HGV classes required for the 11 vehicle class inventory. This was calculated using the 2012 Scottish Urban fleet composition data within EMIT (Table 8). Therefore, there may be some uncertainty of emission rates if the HGV vehicle fleet in Aberdeen is not representative of the national fleet statistics (e.g. more 3 axle rigid HGV's than the 31.5% in the national fleet statistics).

Table 8: Percentages of vehicle classed OGV1 and OGV2 in 11 Vehicle Class inventory

OGV1		OGV2	
11VC category	**Percentage**	**11VC category**	**Percentage**
2 Axle Rigid HGV's	68.5%	4/5 Axle Rigid HGV's	39.1%
		3/4 Axle Artic HGV's	2.3%
3 Axle Rigid HGV's	31.5%	5 Axle Artic HGV's	17.8%
		6+ Axle Artic HGV's	40.8%

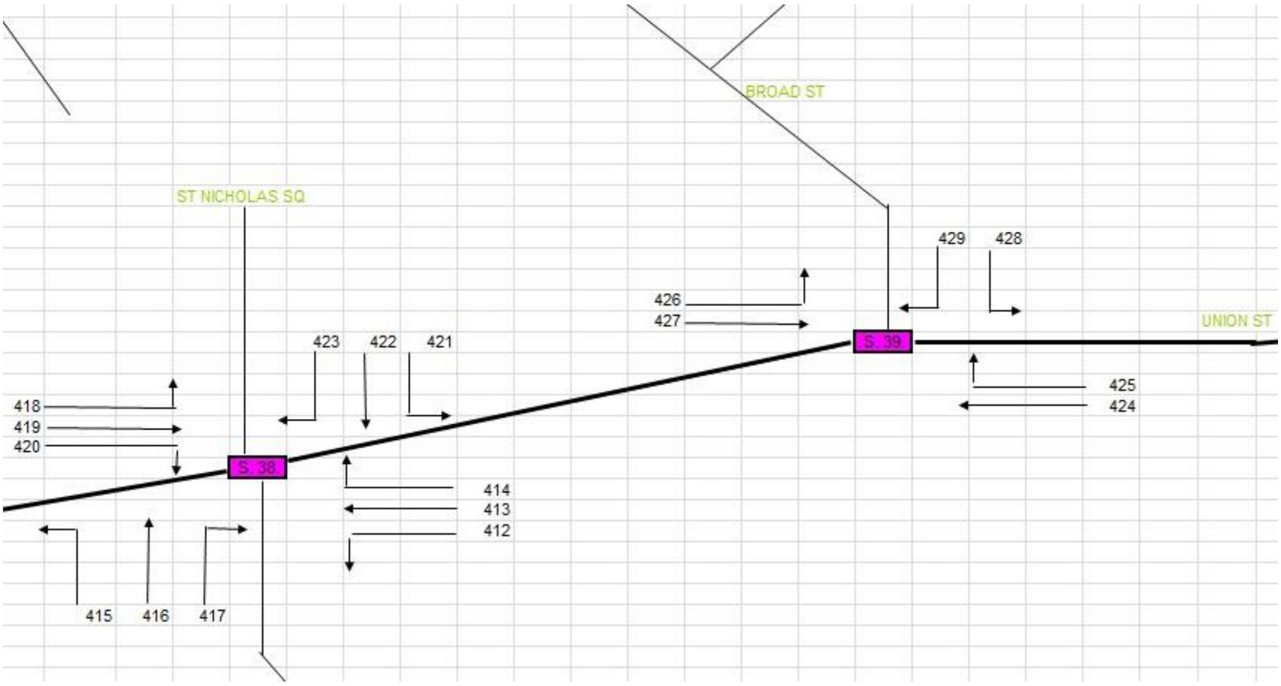


Figure 9: Labelling of Turning Movements for a section of Union Street

Each turning movement and count point has a unique ID (a sample of which is shown in Figure 9); the names of each junction were combined to name each flow section for entry into EMIT (e.g. section of Union Street in Figure 9 between S38 and S39, was named S38_39)

At the periphery of the network, where the flow was not between 2 junctions in the traffic count survey, the road section was appended with a letter (e.g. S17_A). This was repeated across Aberdeen and a road network was created as shown in Figure 11 and Figure 12.

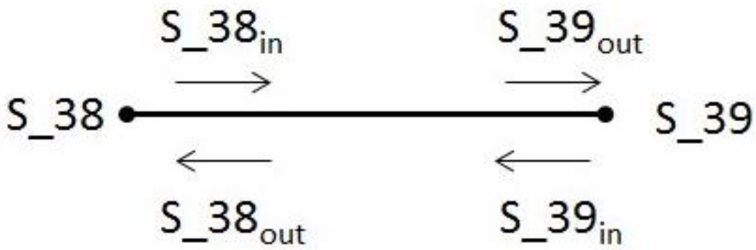


Figure 10: Simplified for of S38_39 road section

Figure 9 was simplified and represented as the schematic in Figure 10, the traffic flow for the time period can be calculated for each road section using Equation 1 to sum the flows assigned to each turning movement. This calculation was applied to all road sections in Aberdeen.

Equation 1: Flow calculation for road section S38_39

$$Flow(S38\_39) = \sum_{time} \left(\frac{(S\_38_{in} + S\_39_{out})}{2} + \frac{(S\_38_{out} + S\_39_{in})}{2} \right)$$

where $S\_38_{in} = 417 + 419 + 421$; $S\_38_{out} = 412 + 413 + 414$
$S\_39_{in} = 424 + 429$; $S\_39_{out} = 426 + 427$

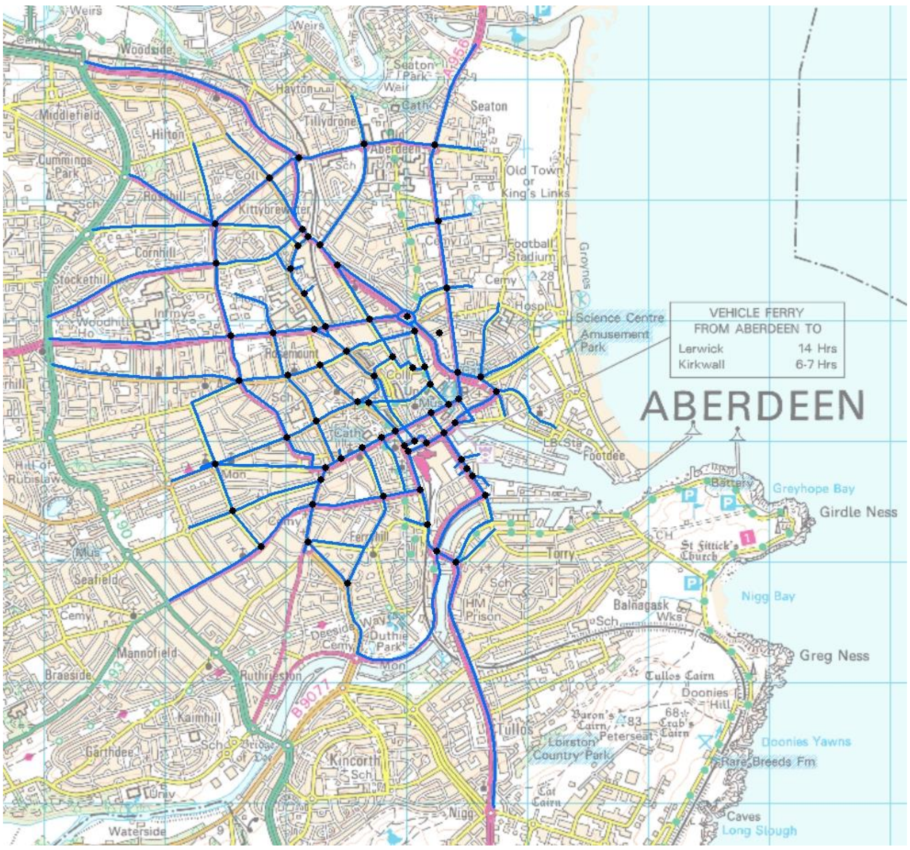


Figure 11: Aberdeen road network generated from city council traffic data. Black dots are count point locations

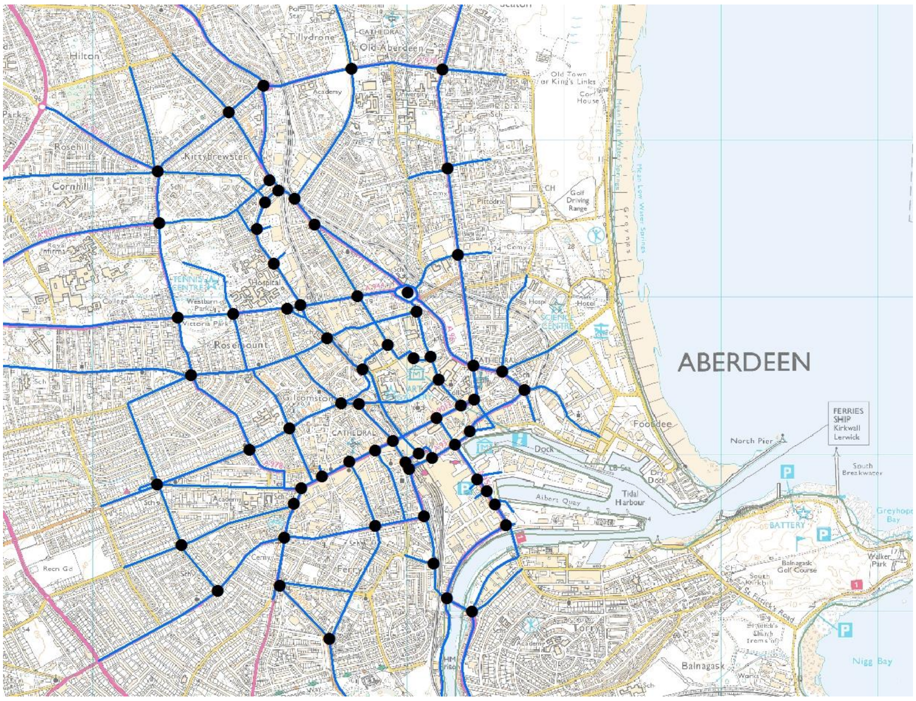


Figure 12: Aberdeen city centre road network generated from city council traffic data. Black dots are count point locations

3.2.2 AADF Conversion Factors

This calculation in Equation 1 uses data collected from 7am to 7pm, as recommended by Defra (9), and is converted to an AADF using a conversion factor. Conversion factors were available from several sources

Defra

Defra guidance recommends a conversion factor of 1.15 for roads outside of London (9)

Glasgow City Council

Glasgow City Council provided a document with conversion ratios for converting traffic counts to AADF depending on road type, month of the year (for seasonal variation ratio) and number of counting hours (i.e. 12 hours of counts) and details of how to use the factors (Equation 2).

Equation 2: Glasgow City Council AADF conversion equation

$$AADF\ Conversion\ Factor\ = \frac{1}{(Seasonal\ Variation\ Ratio\ \times Count\ Expansion\ Factor\ )}$$

Seasonal and count expansion factors were provided for 4 road types, though the explanatory note indicates that all roads are category B, with the exception of motorways (Category A). Although this document was dated 2003, Glasgow City Council advised that the factors were still valid.

When applying the Glasgow City council factors to the Aberdeen traffic data (12 hour counts collected in October), the Count Expansion Factor is 0.81 and the seasonal variation is 1.017. Using Equation 2, the AADF Conversion factor is 1.21 (20).

Automatic Traffic Counts (ATC) in Aberdeen

Automatic Traffic Counters measure traffic vehicle numbers, speeds and types (5 categories) continuously and are located throughout Aberdeen. Calculation of a conversion factor from 12 hour traffic counts (7am to 7pm) to an AADF can be made using the ATC data. It should be noted that the ATC data available is for total traffic numbers; a detailed traffic breakdown of vehicle classes from the Aberdeen ATC's was unavailable for this project.

Aberdeen City Council provided hourly ATC data of total vehicle numbers for 2 locations in Aberdeen (Union Street and Market Street), for 2011 and 2012, enabling the direct calculation of the AADF Conversion Factor (Equation 3). The AADF conversion factor is shown in Table 9 and was found to be different for Union Street and Market Street, but was the same for 2011 and 2012, indicating traffic patterns were similar over both these 2 years.

Equation 3: Calculation of AADF Conversion Factor using Automatic Traffic Counters

$$AADF\ Conversion\ Factor = \frac{ATC\ Traffic\ Flow\ (24\ hours)}{Traffic\ flow\ between\ 7am\ and\ 7pm}$$

Table 9: AADF Conversion Factors using Automatic Traffic Counters for 2011 and 2012

Street	AADF Conversion Factor	
	2011	**2012**
Market Street	1.28	1.28
Union Street	1.48	1.49

AECOM provided ATC traffic data for Union Street, along with some other locations within Aberdeen where detailed counts were taken (Wellington Road, King George VI Bridge, and Holburn Street). This data was limited to October and November 2012, though still useful for consistency checks. The calculated AADF's are given in Table 10, which shows consistency with ATC measurements for Union Street and indicates the Glasgow City Council method applied in Aberdeen gives a reasonable estimate of 1.21 for outside the city centre.

Table 10: AADF Conversion factors using Automatic Traffic Counters for October and November 2012 (provided by AECOM, except for Market Street)

Street	AADF Conversion Factor
Union Street	1.47
Wellington Road	1.19
King George VI Bridge	1.23
Holburn Street	1.30
Market Street	1.27

AADF Conversion Factors used in Aberdeen Model

After considering all 3 AADF conversion factors for the 12 hour, 7am to 7pm traffic counts described above, it was decided to use the Market Street, Union Street and Holburn Street conversion factors for these streets. As the analysis for Wellington Road and King George VI Bridge showed the AADF factor was similar to the Glasgow method of 1.21, this factor was used for all other roads (as no other data was available). Figure 13 shows the how different conversion factors were applied to different roads.

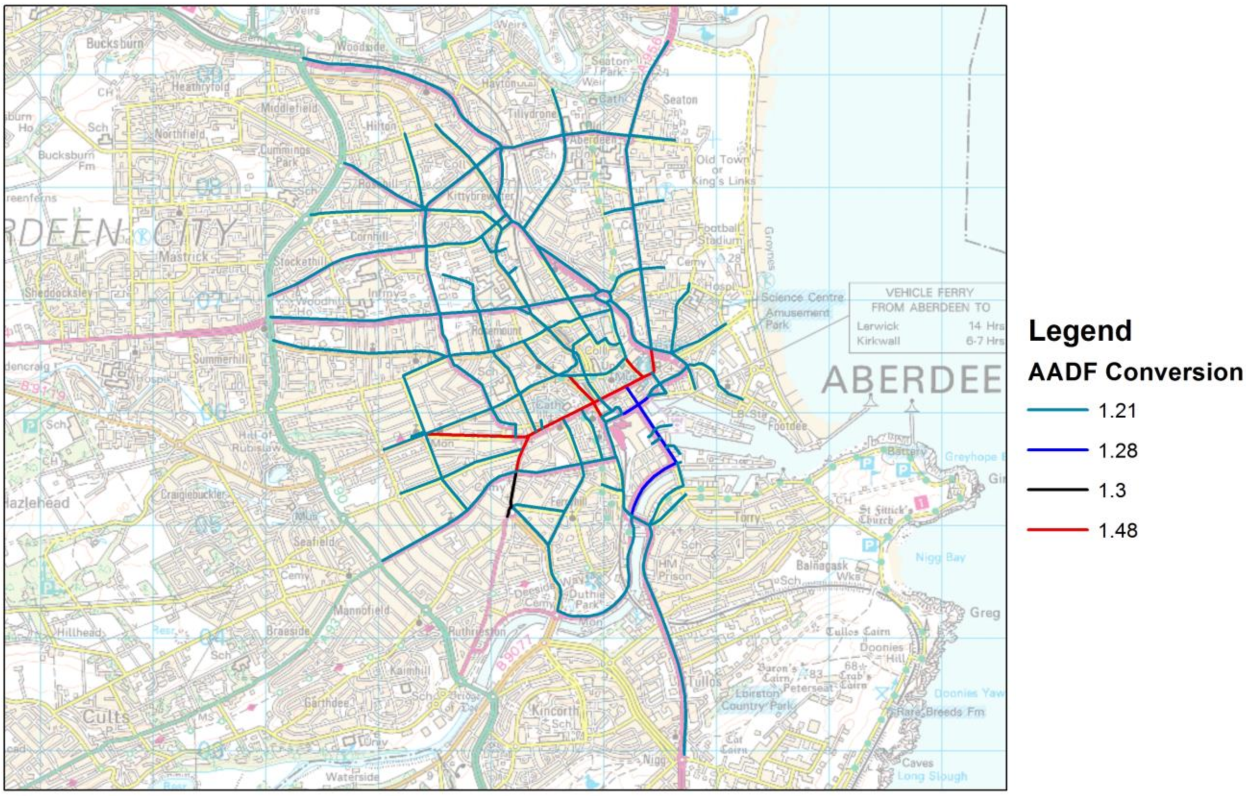


Figure 13: Conversion factors for 12 hour count to AADF for each road section

3.2.3 Department for Transport (DfT) traffic Data

The UK Department for Transport publishes traffic data (including AADF) for every Motorway and A road in Great Britain (http://www.dft.gov.uk/traffic-counts/index.php) along with information on the methodology which explains that traffic volumes are counted on a 12 hour period and an expansion factor applied to calculate the AADF. Roads may not be surveyed on an annual basis, but on a cycle of every 2, 4 or 8 years (21).

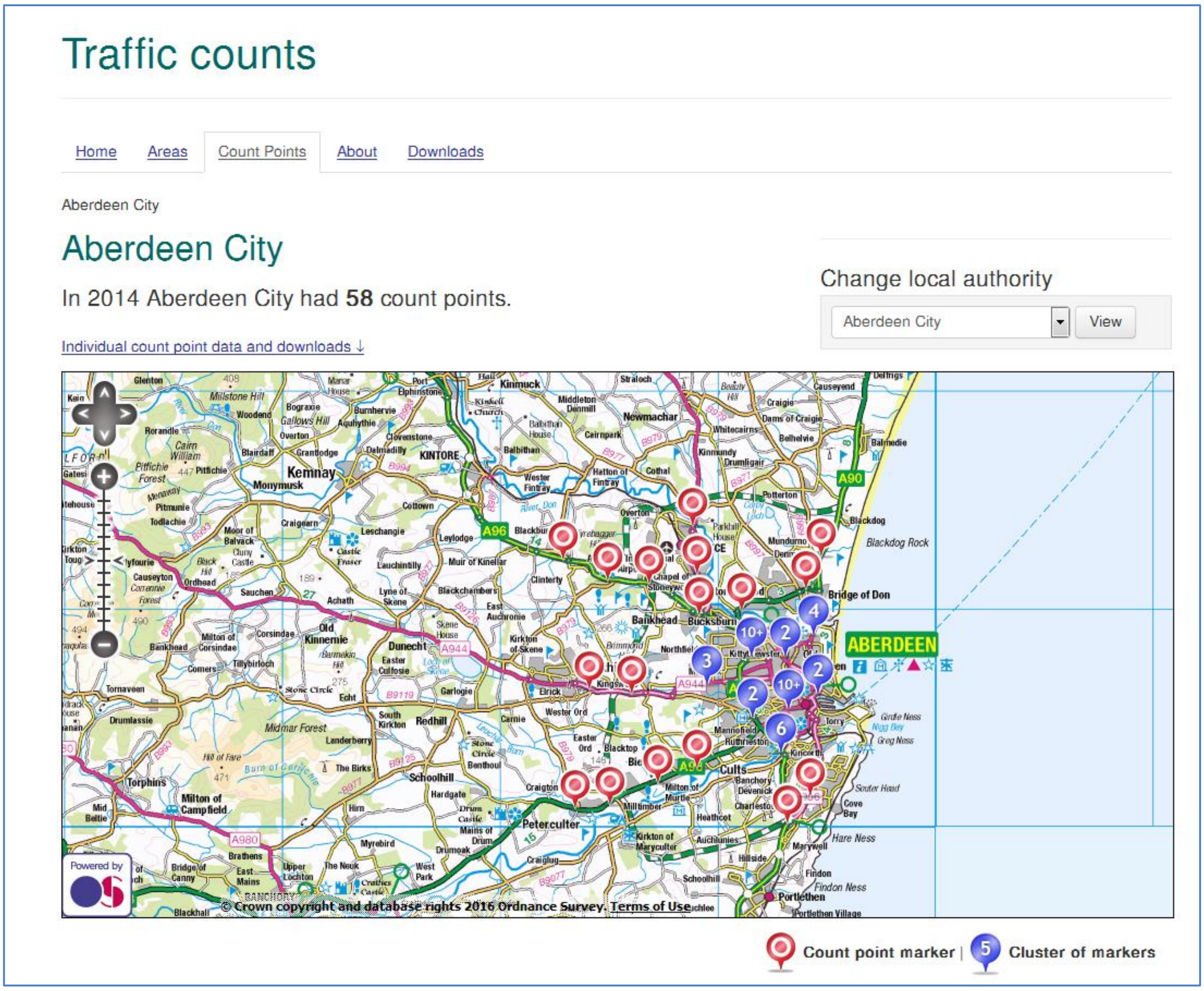


Figure 14: Screenshot from Department for Transport Traffic Count Website

Figure 14 illustrates the 58 road sections for the A roads in the Aberdeen City Council area and represent 87.8 miles (141.3 km) of road. The available traffic data are split into the following 11 vehicle categories:

- Pedal Cycles
- Motorcycles
- Cars/Taxis
- Buses/Coaches
- Light Goods Vehicles (LGV's)
- 2 Axle Rigid HGV's
- 3 Axle Rigid HGV's
- 4/5 Axle Rigid HGV's
- 3/4 Axle Artic HGV's
- 5 Axle Artic HGV's
- 6+ Axle Artic HGV's

Figure 15 and Figure 16 show the layout of roads available in the Department for Transport data for the Aberdeen City Council and Aberdeen city centre area.

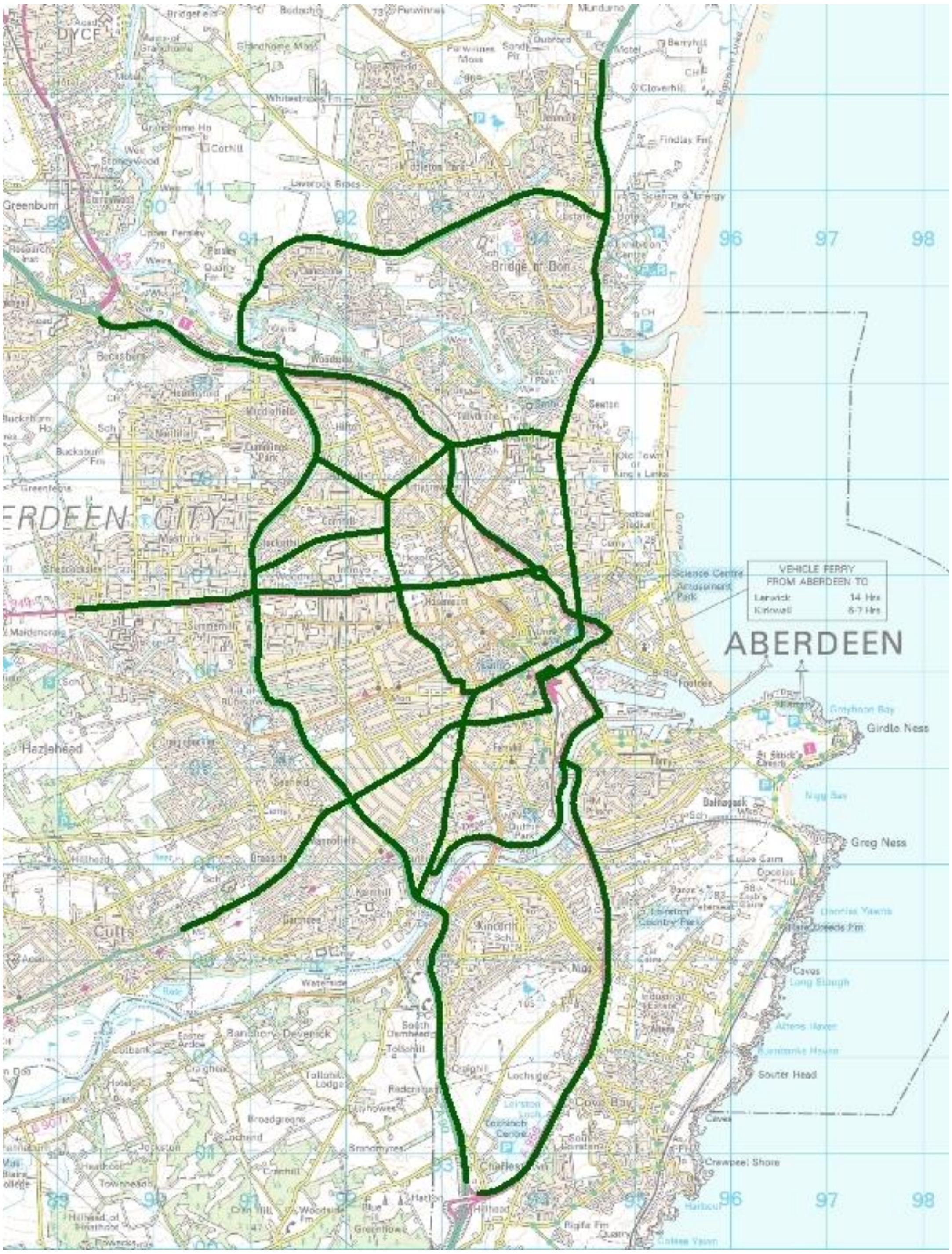


Figure 15: DfT road network for Aberdeen City Council

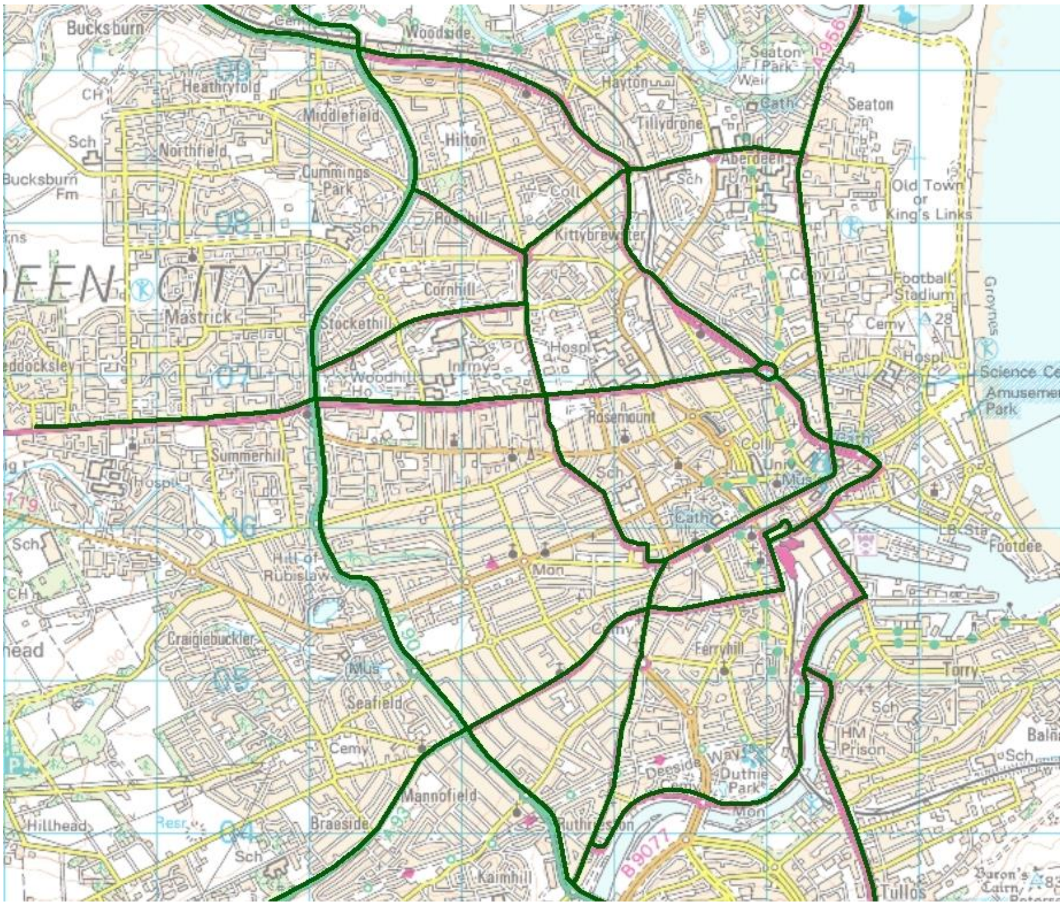


Figure 16: DfT road network for Aberdeen City Centre

3.2.4 Comparison of AADF from Aberdeen Council and DfT Data

A comparison of the Aberdeen Council traffic data (using the AADF conversion factor) with the DfT data for selected roads (Union Street, Market Street and King Street), showed that the Aberdeen Council data) reported more cars, buses and HGV's than the DfT data. Conversely the LGV traffic numbers were higher in the DfT dataset (Table 11, Table 12 and Table 13).

Table 11: Comparison of Aberdeen Council and DfT data for Union Street (Section S34_35 using AADF conversion factor of 1.48 and DfT Count Point 50866).

Vehicle Class	Motor Cycle	Car	LGV	Buses	OGV1	OGV2	All Vehicles
Aberdeen Council	150	12745	1291	2069	571	44	17501
DfT	113	9311	1404	1107	235	27	12197
% difference	-33%	-37%	8%	-87%	-143%	-63%	-43%

Table 12: Comparison of Aberdeen Council and DfT data for Market Street (Section S7_8 using AADF traffic data conversion factor of 1.28 and DfT Count Point 74313).

Vehicle Class	Motor Cycle	Car	LGV	Buses	OGV1	OGV2	All Vehicles
Aberdeen Council	213	22906	4120	760	2708	1925	32633
DfT	228	20968	4911	649	1422	1524	29700
% difference	7%	-9%	16%	-17%	-90%	-26%	-10%

Table 13: Comparison of Aberdeen Council data and DfT data for King Street (Section S99_A using AADF traffic data conversion factor of 1.21 and DfT Count Point 1041).

Vehicle Class	Motor Cycle	Car	LGV	Buses	OGV1	OGV2	All Vehicles
Aberdeen Council	111	19577	2684	751	1464	973	25562
DfT	158	17842	3171	688	664	850	23371
% difference	30%	-10%	15%	-9%	-120%	-14%	-9%

As there are some significant differences between the two datasets, and as the Aberdeen council data is based on actual traffic counts, there is a risk that the use of DfT traffic data may underestimate pollutant emissions.

3.2.5 Transport Scotland Data

Transport Scotland collects traffic count data to monitor the traffic levels on Scotland's trunk roads. There are over 1,300 automatic traffic counter sites and over 50 weigh-in-motion sites located across the network and this data is held in the Scottish Roads Traffic Database (SRTDb) which is available on the Transport Scotland website (http://www.transport.gov.scot/map-application). Currently, only data up until 2010 is available on this website because a new National Traffic Data System (NTDS) is being developed. This is designed to meet the future needs of Transport Scotland and other stakeholders, and will be launched shortly.

As the detailed traffic data for used for the Aberdeen pilot project is for 2012 and Transport Scotland data is not available for that year, Transport Scotland data was not used for this study, but is likely to be valuable for future work.

3.3 Traffic Speed

As the emission factors (discussed in paragraph 3.8) are a function of average speed, an average traffic speed value needs to be assigned to each road section. This is difficult, as average speeds can vary along each road section depending on time of day and proximity to road traffic junctions.

Allocated traffic speeds for each road section were therefore based on knowledge of speed limits and an assumption that traffic speed is lower in the city centre. Obtaining detailed information on average speeds proved difficult, though speed limit maps were found on the website (http://www.itoworld.com/map/124).
Sample traffic speed data was obtained from TomTom which included average speed for sections for Market Street, Union Street, Wellington Road and King Street covering the period 6am to 7pm for all days (Figure 17 and Figure 18).

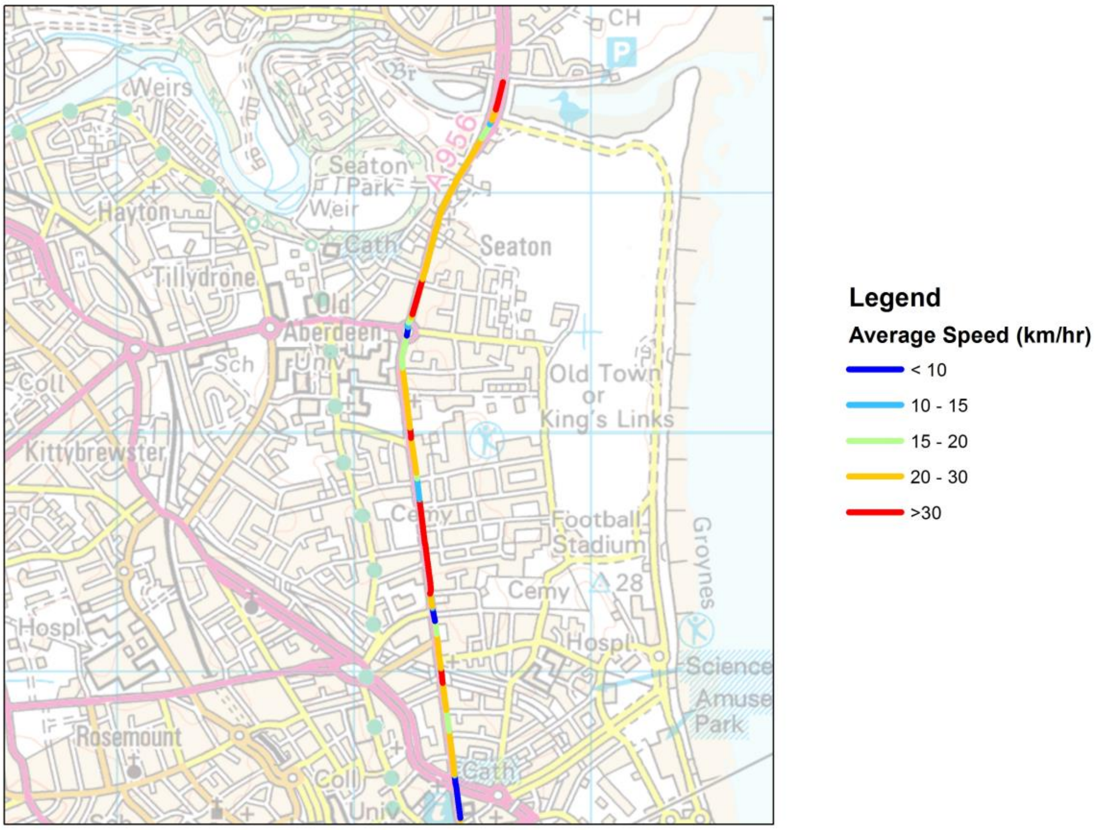


Figure 17: TomTom derived average speed data for sections of King Street, Aberdeen

After evaluating the available information, the average speed for each road section is uncertain and there are significant average speed variations within each road section to be modelled depending on the method chosen (as shown in Figure 17 and Figure 18). Given the disparity, it was decided to use model sensitivity tests to evaluate the effect of different average speeds on predicted vehicle emissions on a systematic basis. Following these sensitivity tests (Section 4.4.5), the traffic speeds in Figure 19 were selected for use in the base model run.

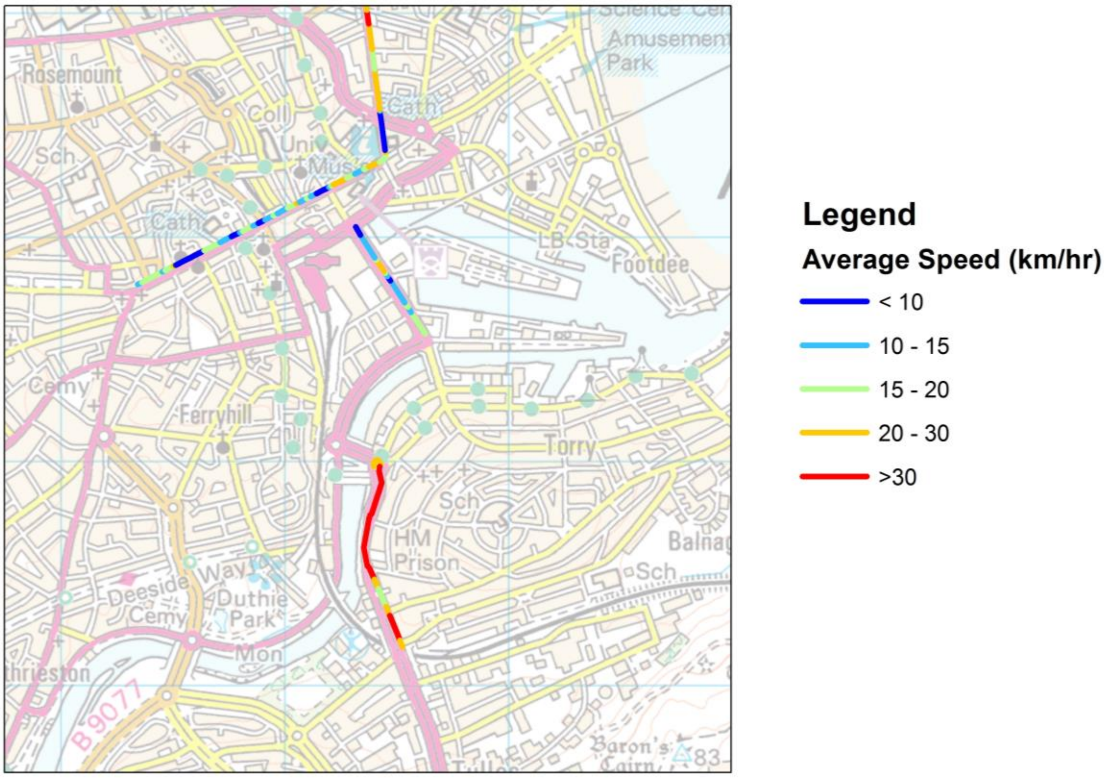


Figure 18: TomTom Derived Average Speed Data for sections of King Street, Union Street, Market Street and Wellington Road

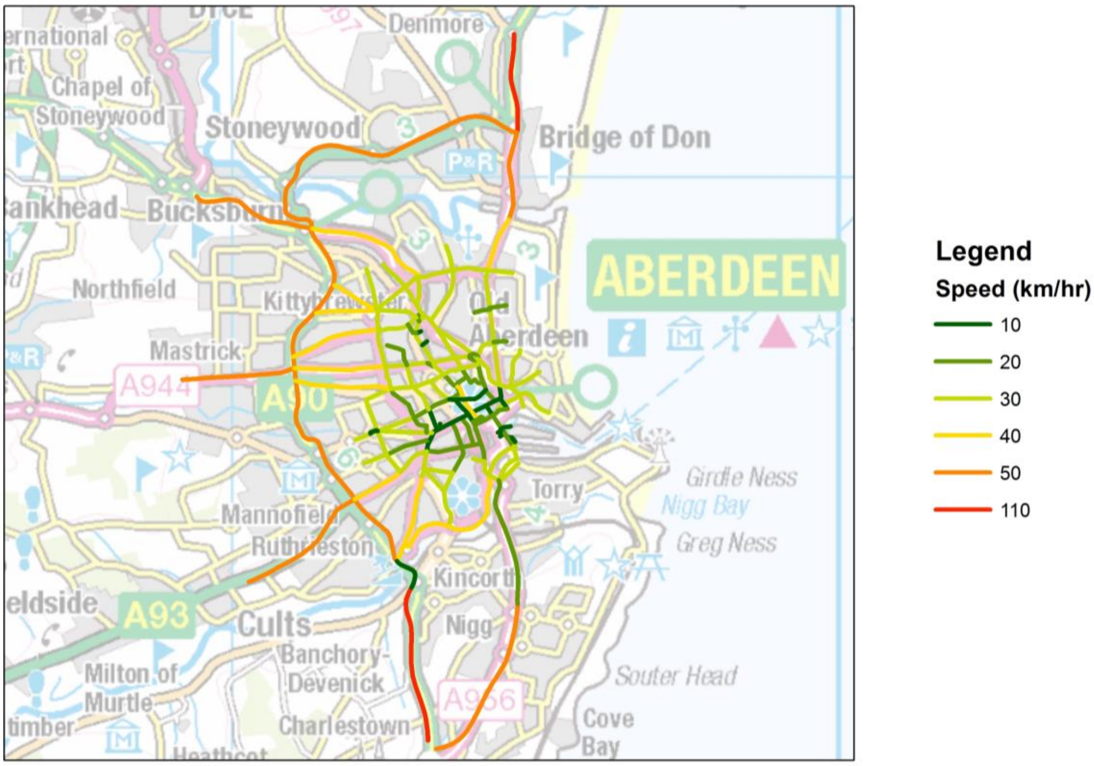


Figure 19: Traffic Speeds used in Aberdeen ADMS-Urban model for each road section

3.4 Road Widths

A key input for the dispersion calculation of road traffic emissions in ADMS-Urban is the road width. This value should be the width of the road, except where the road is classed as a canyon, in which case, the canyon width (façade to façade distance) is required.

To calculate road widths, an ArcGIS model was built utilising Mastermap data and a shapefile of road sections generated from traffic count data to be used in ADMS-Urban. The model has several stages detailed below.

1. A 100m buffer was generated around all road sections. These were dissolved from individual polygons into 1 polygon feature (Figure 20) which was then used to select polygon features in Mastermap which are in close proximity to the road sections.

2. The Mastermap 'Road Or Track' and 'Roadside' features (which represent Roads and pavements, respectively) were selected if they intersected the dissolved roads buffer generated in Step 1. Additionally, any Mastermap feature within 3m of a road section was also selected (so that bridges/shopping centres/road traffic islands were included in the selection), with the assumption that anything that is very close to the road line would form part of the road. These features were dissolved into 1 polygon feature (Figure 21).

3. Polygons representing areas which are not classified as 'Road or Track' or 'Roadside' need to be generated. To do this, a large rectangular polygon covering all of Aberdeen was generated and, the 'Erase' geoprocessing tool was used to produce an inverse of the dissolved Roads and Roadside polygon generated in Step 2. This feature is made up of many polygons, but with one ID. The 'Multipart to Singlepart' geoprocessing tool was used to explode the shapefile so that each polygon has its own unique ID as required to generate proximity statistics (Figure 22).

4. So that the influence of buildings close to road junctions is minimised for calculating proximity statistics, a feature was generated where 10 metres from each end of the road sections had been removed (Figure 22).

5. To calculate the distance between each road section and the nearest 'non-road/roadside' polygons, the representation in Figure 22 is used with the 'Generate Near Table' tool. This calculates the shortest distance between each road section and the nearest 'non-road/roadside' polygons. This tool option only considered 'non-road/roadside' polygons that were within 20m of the road polyline, and also, only for a maximum of 5 'non-road/roadside' polygon features for each road section.

6. There are now multiple (up to 5) 'Near Distance Values' for each road section representing the closest distance between the road polyline and 'non road/roadside' polygons. Using the 'Summary Statistics' tool, various statistics are generated for each road section for the range of 'Near Distance Values' for each road section (Minimum, Mean, Maximum, Range and Standard Deviation, along with the number of 'Near Distance Values' used to calculate these statistics).

7. Finally, the maximum value for each road section is doubled to calculate the road width used in ADMS-Urban (Figure 23). The maximum value is used to represent the whole road section so that for the case of canyons, any model receptor placed along the roadside will be in the ADMS-Urban canyon calculation zone.

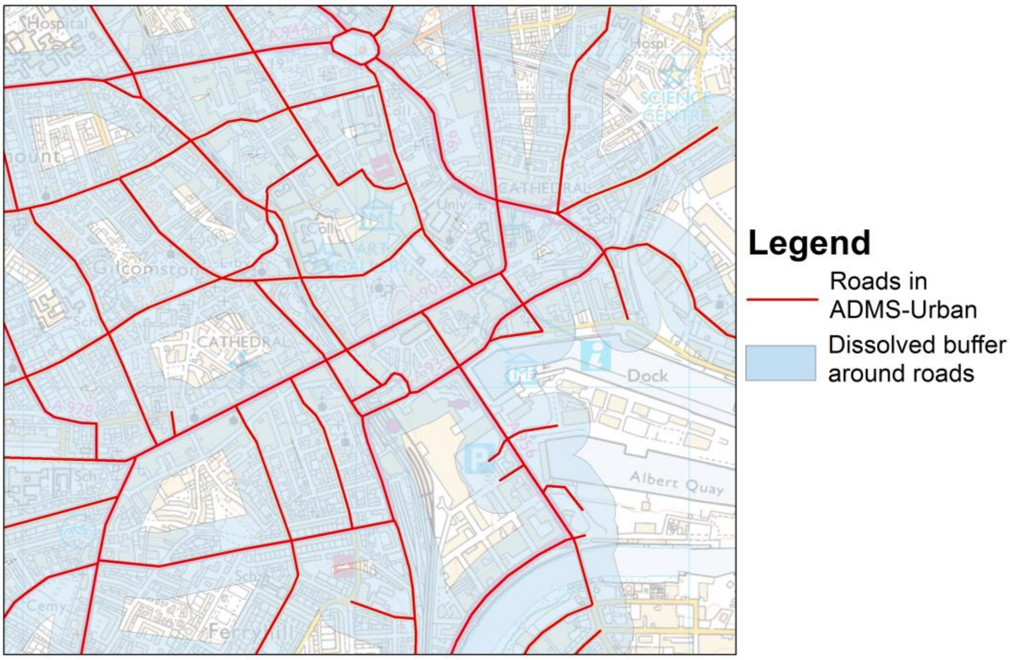


Figure 20: Road sections used in ADMS, along with the dissolved buffer which was used to select Mastermap features which were of interest

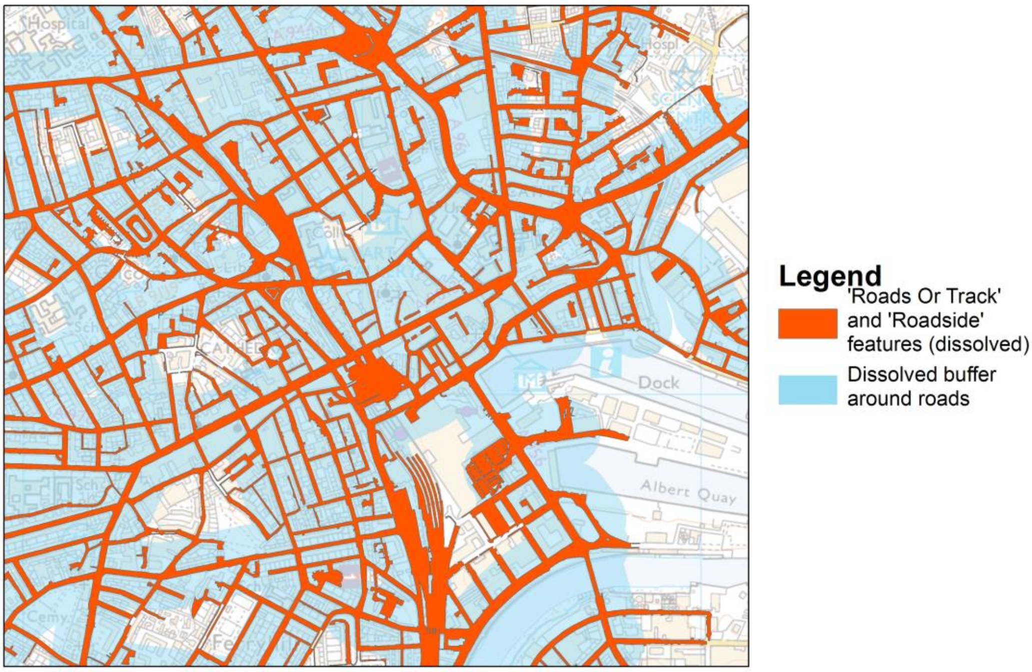


Figure 21: Dissolved 'Roads or Track' features which were selected by dissolved roads buffer

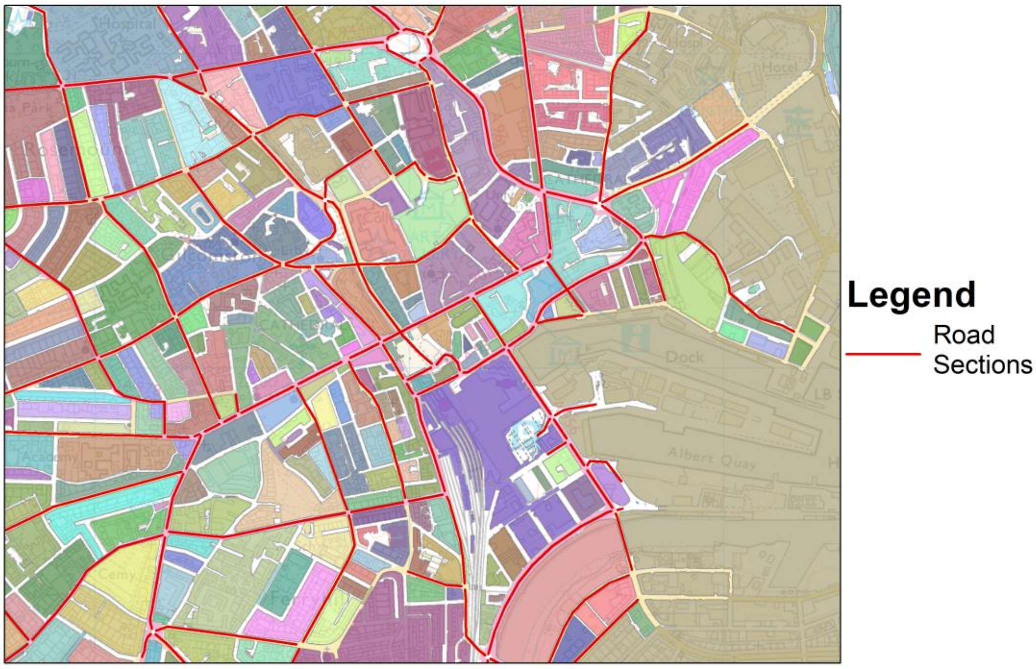


Figure 22: Trimmed ADMS road sections with polygons representing areas which are not 'Road or Track' or 'Roadside'

There are limitations associated with this method which need to be considered:

- It is assumed that roadside features such as buildings run parallel to the road along the road section, which may not always be the case.
- Modifications to remove features which are very close (within 3m) or intersect with the ADMS-Urban road sections, may affect the calculation of the Road Width.

The ADMS-Urban manual (22) recommends that for non-canyonised roads, the width should be the road width; for canyonised roads, the width should be the canyon (façade to façade) width. These calculations currently calculate a width for 'Roads and Roadside', therefore, the width values larger for some roads which are not canyons. This can be modified and refined in future model improvements.

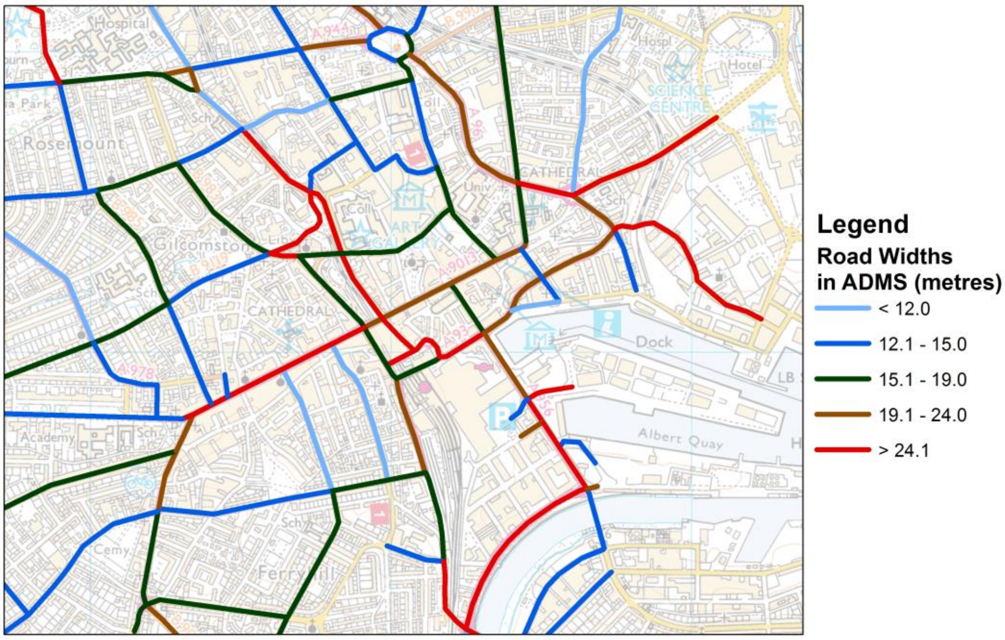


Figure 23: Road widths used in ADMS-Urban

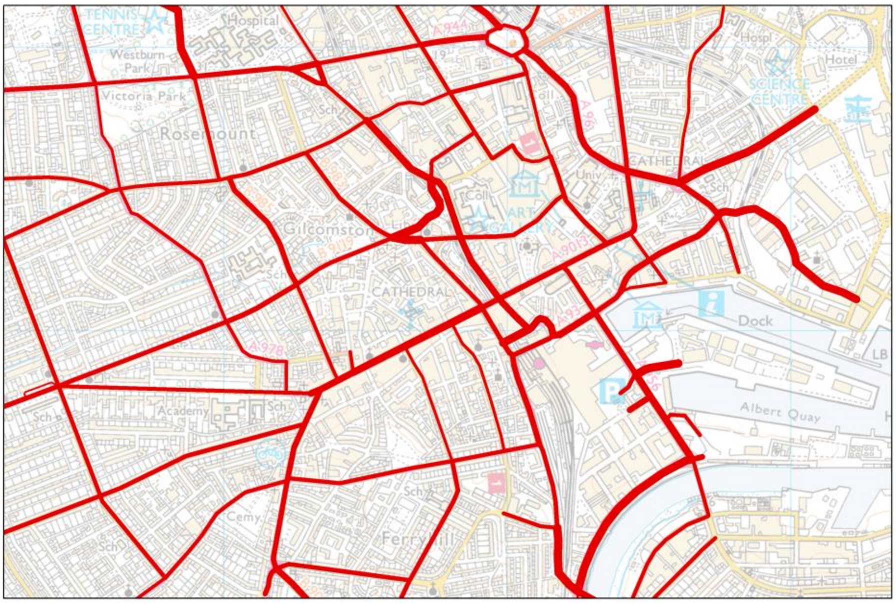


Figure 24: Road Widths used in ADMS-Urban; the width of the line is relative to the width used in the model

3.5 Canyons

The basic street canyon module in ADMS-Urban is designed to account for the dispersal of pollutants when a road section is bounded by tall buildings on both sides of the road. ADMS-Urban uses a street canyon module which is based on the Danish model, OSPM, and attempts to simulate the flow recirculation which is set up in a street canyon zone due to the effect of buildings (22). ADMS-Urban requires a canyon height to be entered for each road section, and assumes the canyon height to be the same on both sides of the road.

Calculating the canyon height for many roads proved to be a challenging, and subjective task. The limitations are listed below:

- Defining what is a canyon for modelling purposes can be subjective.
- There may be a canyon for only parts of the road section.
- Building heights may differ on each side of the road
- Where there is a canyon, the canyon height may vary along the road section.
- Calculation of building heights has limitations. Ordnance Survey building height calculations are currently not available for Aberdeen.
- Building configurations can change over time.

Despite the limitations, the aim was to approximate street canyon heights for road sections where a canyon may exist. This was carried out using GIS data and tools, along with Google Street View.

A GIS model was built to attempt to determine canyon heights for each road section, though this proved to be challenging, and manual steps were needed. The GIS model provided useful information and the steps are listed below:

1. A dissolved 20m (width) buffer was generated around the road sections. Mastermap building features which intersect with this buffer were selected (Figure 25).
2. LIDAR surface and terrain data (1 metre resolution) for each of the selected buildings was extracted, using the ‘Extract by Mask’ geoprocessing tool. The difference in LIDAR data (Surface model minus Terrain model) was calculated to estimate building heights. This method has limitations and can result in some raster cells with a negative value, some with a very large values (e.g. Trinity shopping centre which is built on steep sided slope and close to elevated road sections) or others with small values (Union Square shopping centre was built after LIDAR data was collected).
3. Using the ‘Zonal Stats’ tool, statistics (minimum, maximum, range, mean, standard deviation) for each building polygon are generated (Figure 27)
4. Building height on each side of the road is looked at separately, so as to determine whether a canyon existed. Using the ‘Spatial Join’ tool, each building is joined to a road which is within 18m. If a building is close to 2 roads, then these 2 joins will appear separately.
5. Using the ‘Summary Statistics’ tool, a range of statistics can be calculated for buildings for both sides of each road section. As there is a range of statistics for each building, there is now a range of statistics to represent all the buildings for each side of all road sections:
    a. Mean of the building mean heights
    b. Maximum of the building mean heights
    c. Minimum of the building mean heights
    d. Maximum of the building maximum heights

e. Mean of the building maximum heights
f. Minimum of the building maximum heights

6. Finally, the mean of the 2 ‘Mean of the building mean heights’ values was calculated; this value was used as the ‘CANYON’ attribute in the shapefile for use in EMIT and ADMS-Urban. The decision as to whether a canyon exists for a road section was decided manually by looking at the building layout and configuration on ArcGIS, along with Google Streetview.

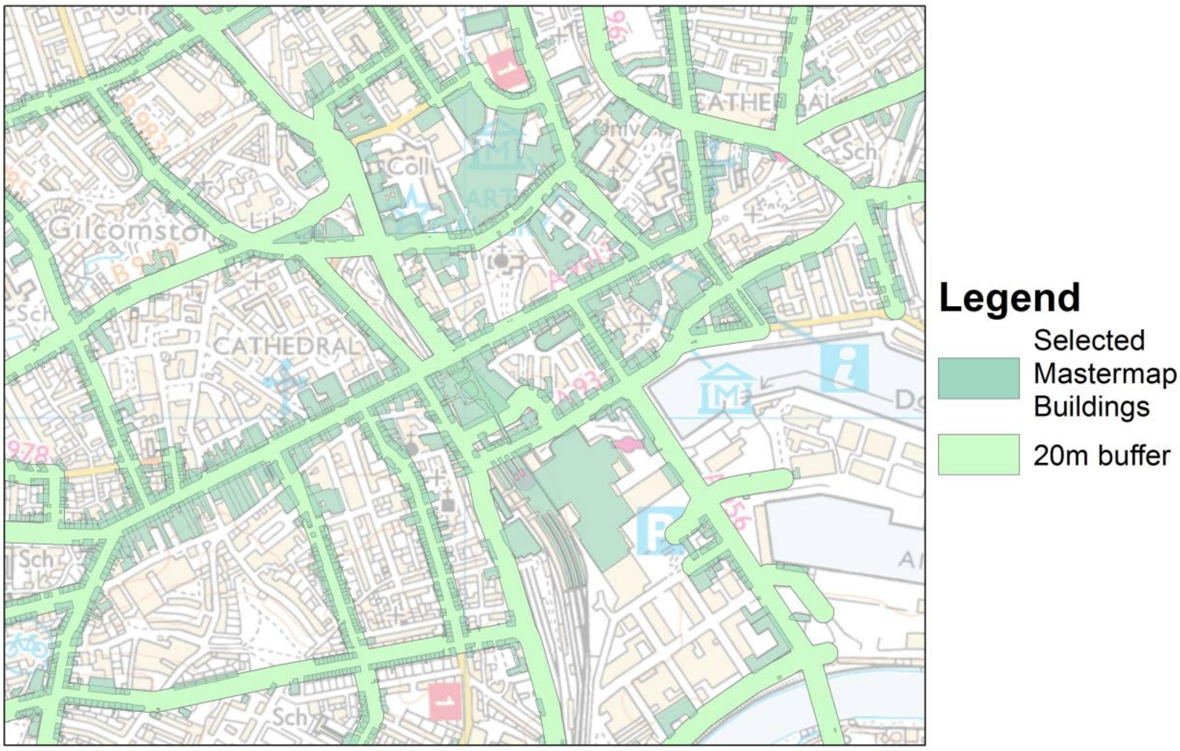


Figure 25: Dissolved roads buffer and selected buildings from Mastermap

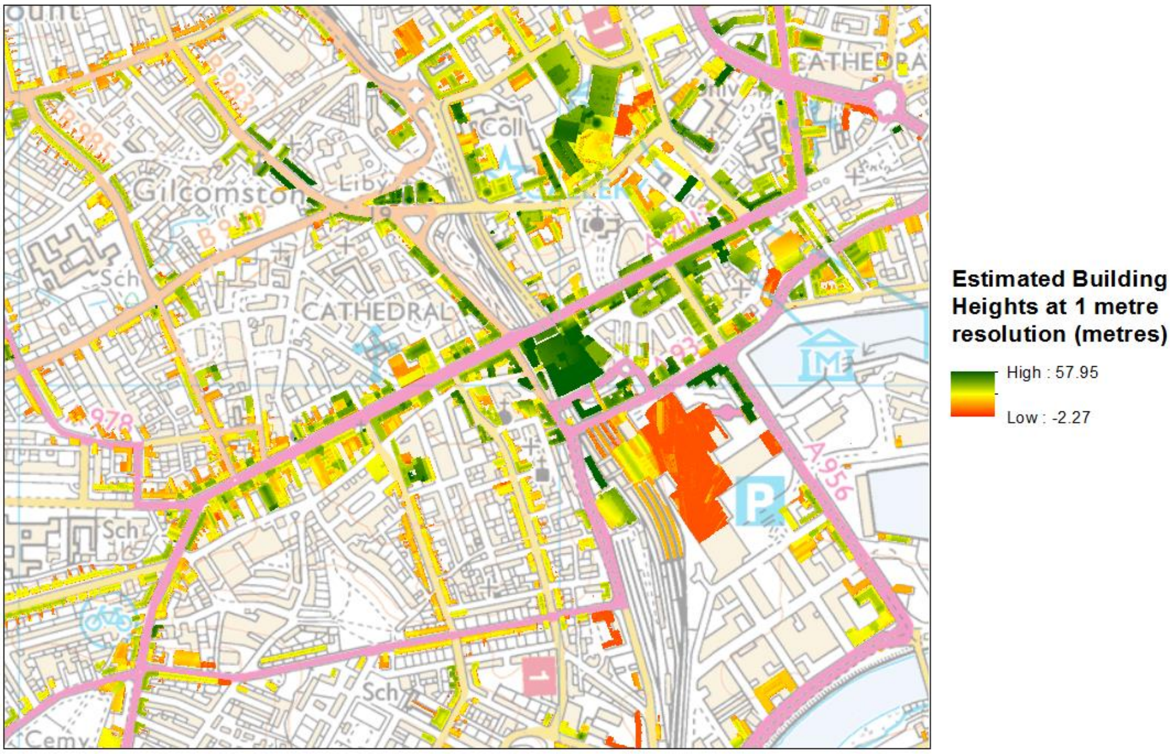


Figure 26: Estimated Building Heights at 1 metre resolution before (Difference between LIDAR surface model and terrain model)

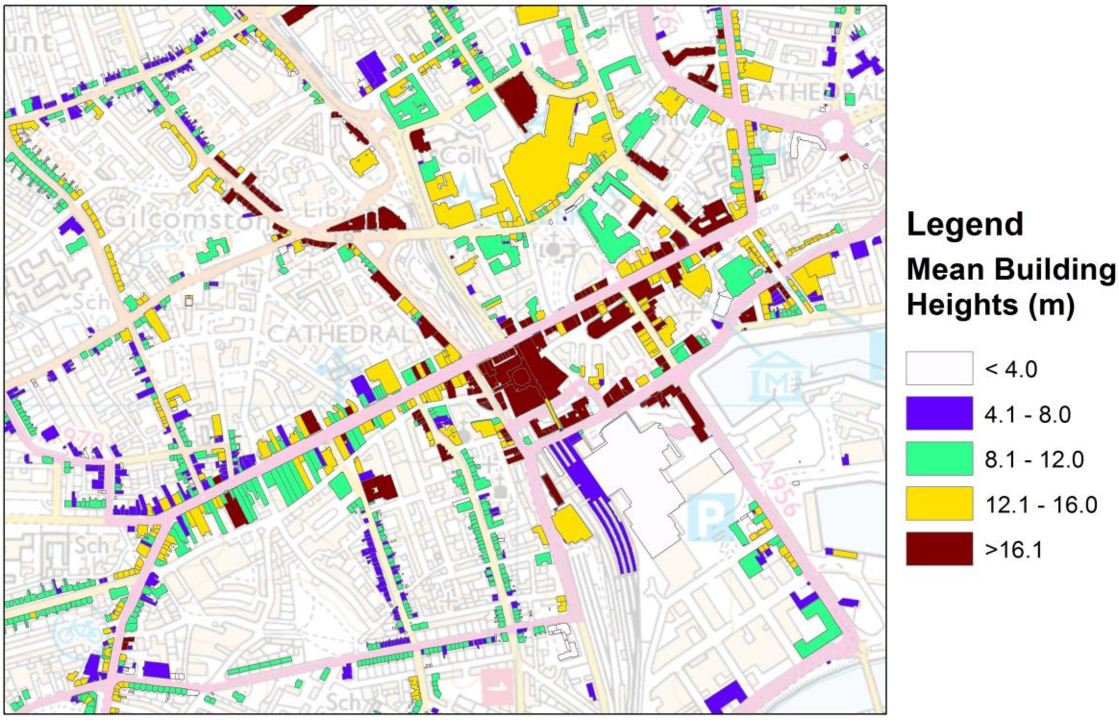


Figure 27: Mean building heights of selected buildings (metres)

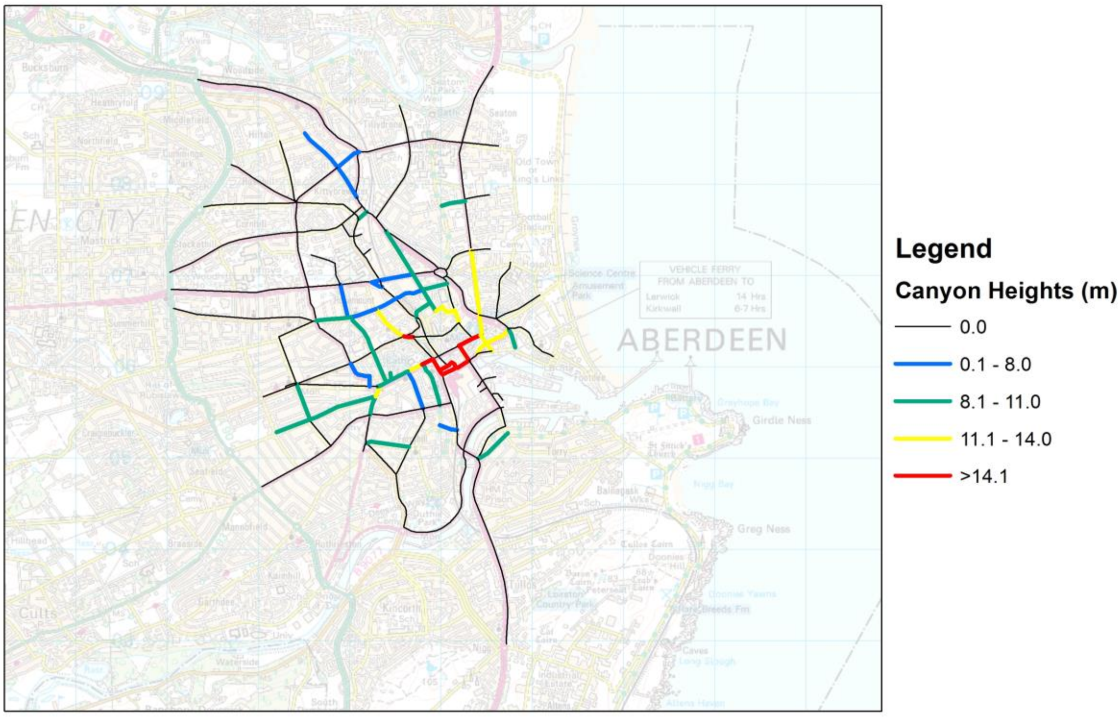


Figure 28: Canyon Heights applied to road sections in ADMS-Urban (A Height of 0m means that no canyon was applied to that street)

Despite limitations, it is thought that the values broadly represent the building and canyon heights.

3.6 Time Varying Emissions

As noted in Section 3.2, ADMS-Urban uses Annual Average Daily Flow (AADF) inputs for each road section, from which an emission rate is calculated. ADMS-Urban has an option of implementing a time-varying source, which can be used to represent the variation in traffic emissions throughout the day and week.

An example of a time-varying profile is provided by CERC (Figure 29), which shows how ADMS-Urban modifies all pollutant emissions depending on the time of day and day of the week.

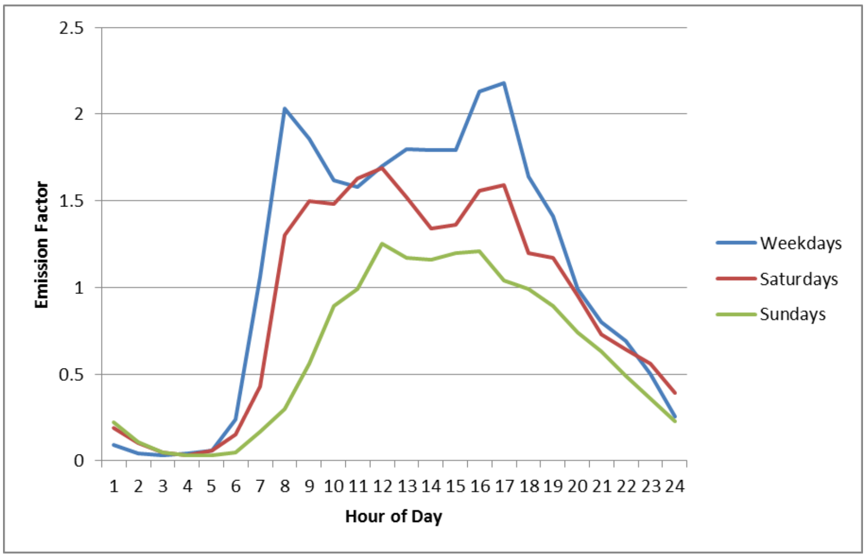


Figure 29: CERC example traffic emission diurnal cycle

Generating a bespoke diurnal cycle for Aberdeen was considered using ATC data, however, this would only provide a time-varying daily vehicle flow profile whereas ADMS-Urban requires an emissions varying cycle which considers all variables which will vary vehicle emissions (e.g. diurnal variations of speed, fleet composition etc.). It was therefore decided to use the CERC example at this stage. It may be possible to collect 'drive cycle' data which may provide useful information on emission variations for future work.

3.7 Road Gradients

Road gradients can slow traffic and will require more engine power to climb hill gradients. Conversely, less engine power is required to go downhill. This will affect vehicle emissions. DEFRA have published guidance on how to deal with road gradients (9; 23), which state road gradients which are less than 2.5% do not affect emissions for HGV's. Light vehicles are assumed to be unaffected by gradients. More recent guidance suggests that the introduction of Selective Catalytic reduction means that no compensation for gradients is required for NO_x emissions for newer (post 2014) vehicles

A GIS tool was developed to calculate average slopes on roads within Aberdeen, however, the road polylines for use in ADMS-Urban runs through some features such as traffic islands and roundabouts, which can give some unreasonable gradient values.

An assessment was made manually of the gradient at several locations across Aberdeen to assess the potential impact (although most streets in Aberdeen are flat). This shows that at Wellington Road, there would be no increase in emissions due to gradient. At other locations, emissions would increase due to the effect of gradients, for example at Market Street (between Guild Street and Union Street), bus emissions would increase by 25.5% due to the gradient, however, this would increase overall emissions by 2.7% as buses make up 10% of all traffic on this road section Table 14.

Table 14: Change in Emissions due to gradients for Buses and Articulated Vehicles at selected streets in Aberdeen (24 kph), assuming equal volumes of traffic uphill and downhill. Changes are shown for traffic class only and as a percentage of total traffic flow.

	Gradient	Increase in Emissions (vehicle class only)		Percentage of all traffic		Increase in Emissions (all traffic)	
		Buses	Artics	Buses	Artics	Buses	Artics
Wellington Road (by air quality monitor)	2.5%	0%	0%	0%	0%	0%	0%
Market Street (Guild Street to Union Street)	5.2%	25.5%	36.8%	10.5%	0.2%	2.7%	0.08%
Anderson Drive (Rubislaw)	5.9%	32%	46.2%	0.4%	2%	0.12%	0.96%
Bridge Street	4.2%	15%	22.7%	12.9%	0.18%	2.03%	0.04%

It was decided that at this stage of the project, road gradients would not be accounted for, and that we would return to it at a later stage. This may mean that for some road sections, HGV and Bus emissions may be underestimated, but this is likely to be by a few percent.

3.8 Pollutant Emissions

The CERC tool, EMIT, was used to efficiently process traffic data into a format which can be imported into ADMS-Urban with all the required parameters. EMIT can store, in database format, a large number of sources, and allows for easy manipulation of the data (e.g. change of traffic speed, adjusting traffic volume numbers by vehicle class or as a whole).

EMIT also includes emission factors for many road vehicle classes and sub-classes, along with fleet composition data for different emission inventories. More information on EMIT can be found in the User Manual (10).

It is also possible to directly enter traffic flows/vehicle numbers into ADMS-Urban, however, this is very time consuming and does not offer the flexibility which EMIT can offer.

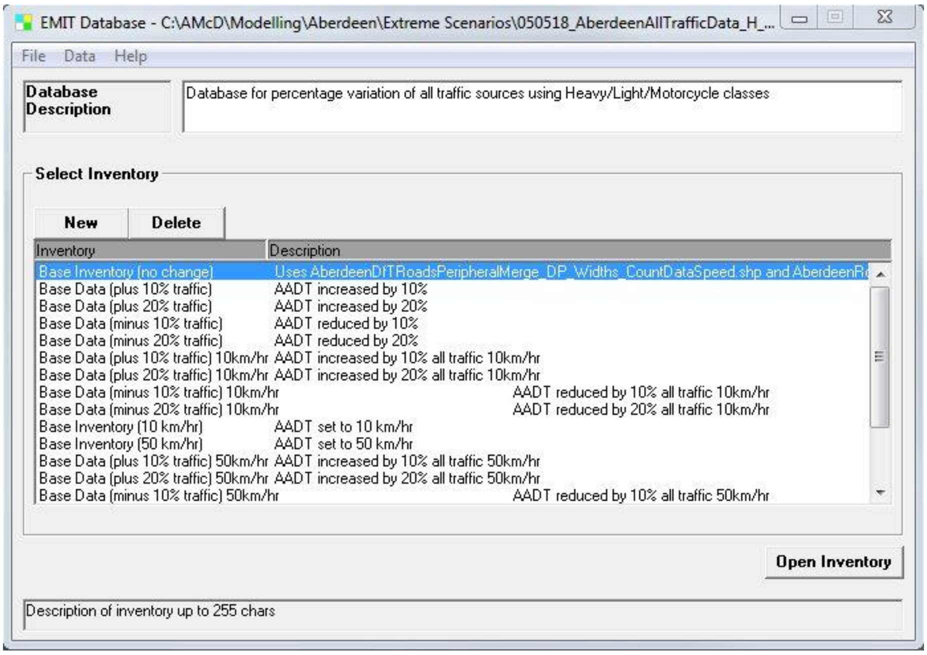


Figure 30: Example EMIT front page

3.8.1 Data for Use in EMIT

The traffic data collated in Section 3.2 was added as attributes to the shapefiles generated to represent the Road Layout (Section 3.1) using MATLAB. This included all vehicle category classes in the 11 vehicle class and 3 vehicle class categories (Table 6). Other attributes required in the shapefile are average traffic speed (Section 3.2.4), road width (Section 3.4), canyon height (Section 3.5) and road height (set to 0m for all roads in Aberdeen).

Not all of these parameters are used in emission calculations within EMIT, but are stored in the database and are included in the data format for importing into ADMS-Urban.

3.8.2 Emission Factors

Emission factors are required to calculate the emission rate for each road section. The use of emission factors is a common approach when emissions cannot be explicitly measured at source, (e.g. emissions from many vehicles or from intensive agriculture installations). Emission factors for vehicles are uncertain as they are derived from controlled laboratory tests; however there are many projects and companies developing methodology for deriving emission factors based on ‘real world’ driving.

There are a number of emission factor inventories available in EMIT, each of which is a function of Vehicle Class, Speed and Year. The emission inventories used in this project were Emission Factor Toolkit (EfT) v5.2 and National Atmospheric Emissions Inventory (NAEI) for 2012. These were the most up-to-date available during the Aberdeen pilot project, though have now been superseded by EfT v6.0.2 and NAEI2014.The published emission factors for each vehicle class are stated in units of grams per kilometre per vehicle (g/km/vehicle).

3.8.3 Emission Inventory: Emission Factor Toolkit (EfT)

The EfT has been compiled for Defra and the Devolved Administrations and is available as an Excel spreadsheet on the Defra website (24). Although the EfT Excel version has the capability to examine emissions from different source types, the EfT emission factors in EMIT use the 3 vehicle classes described in Table 6. These also are divided into sub-regions and road categories. When using the Eft inventory, the 'Scotland Urban 2012' option was selected.

More information on the EfT emission inventory and how they are implemented in EMIT can be found in Section A.2.5 of the EMIT user manual (10).

3.8.4 Emission Inventory: NAEI 2012

The NAEI 2012 emission inventory has been compiled as part of the UK NAEI, released in July 2012. NO_x and NO_2 emission factors have been calculated using the COPERT 4 tool, whilst emission factors for all other pollutants were published by the Department for Transport in 2009 (Section A.2.3 of EMIT user manual; (10)).

The 11 vehicle classes described in Table 6 are required when using this emission inventory. EMIT stores the NAEI 2012 emission factors by vehicle sub class, based on vehicle size and Euro class engine (10). For NO_2 emission factors, the 'NO_2 proportions for NO_x' for each engine type is also required (10).

A 'Route Type' needs to be selected to account for the road type (Motorway, Rural or Urban) and fleet composition (percentage of each vehicle sub-class that makes up each vehicle class). The default fleet composition is based on the national fleet, however, this is editable in EMIT. This allows the fleet to be adjusted if local fleet information is available, and also allows for modifying the fleet (e.g. removing specific sub-classes) to calculate emission factors for assessing potential future emission scenarios (Equation 4).

Equation 4: Calculation of Emission Factors from sub classes in NAEI2012 Emission Inventory

$$EF(Veh\ Class, Speed, Year) = \sum_{\substack{Veh \\ SubClasses}} EF_{SubClass}(speed) \times FleetComp(SubClass, Year)$$

where, $EF_{SubClass}$ is the Emission Factor for the vehicle sub-class
$FleetComp$ is the percentage of the vehicle sub-class which makes up the vehicle class for a particular year
EF is the emission factor for each of the 11 vehicle classes, as a function of speed

3.8.5 Emission Rates

EMIT calculates an emission rate for each road section; the emission rate units are grams per kilometre per second (g/km/s).

Equation 5: Calculation of Emission Rates from Emission Factors and AADF values for each Vehicle Class

$$Emission\ Rate = \sum_{Vehicle\ Classes} \frac{AADF(Vehicle\ Class)\ \times\ EF(Vehicle\ Class, Speed, Year)}{No.of\ Seconds\ in\ a\ Year}$$

where, $AADF$ is the Annual Average Daily Flow of a vehicle class
EF is the Emission Factor for each vehicle class (g/km/vehicle/year)

Once the emission rates are calculated in EMIT using Equation 5, the calculated emission rates and other parameters are exported to a database format, which can be imported to ADMS-Urban efficiently. Emission rates are generated for each pollutant, examples of which can be seen in Figure 31 and Figure 32

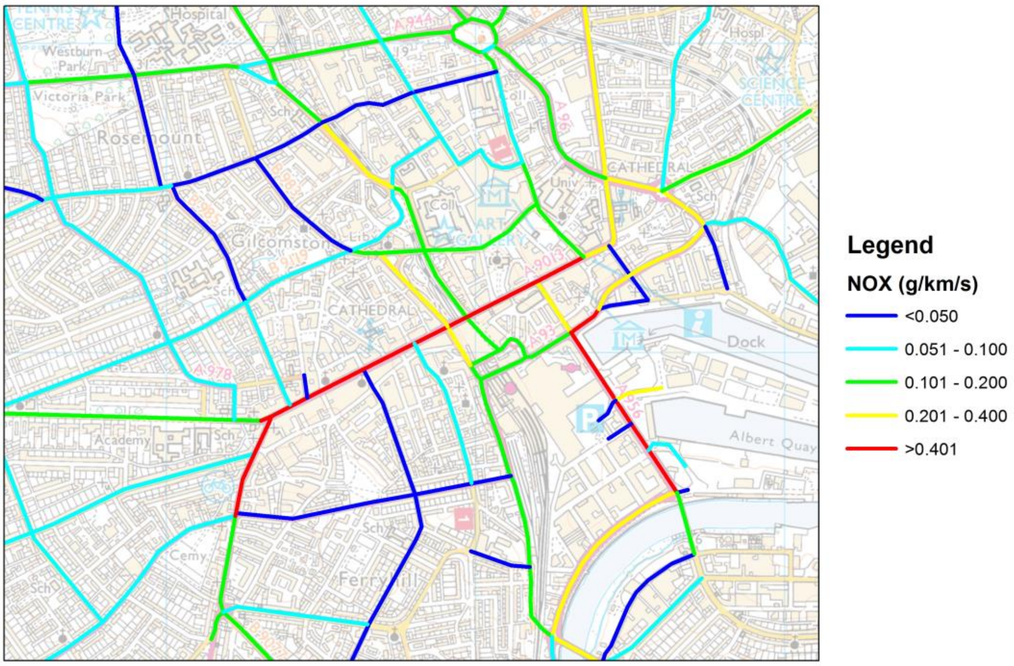


Figure 31: Example NOx Emission Rates for Aberdeen City Centre

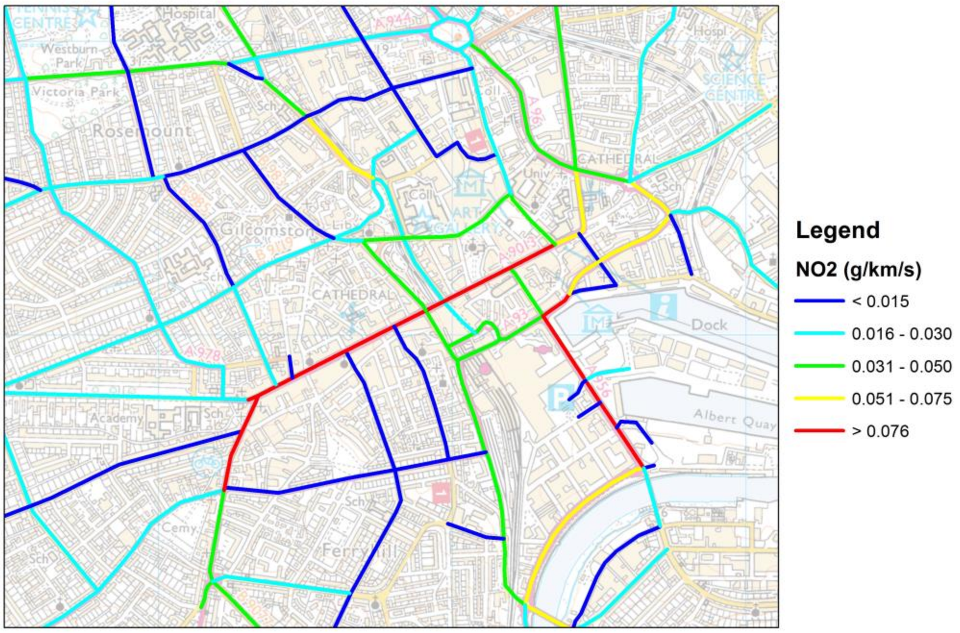


Figure 32: Example NO2 Emission Rates for Aberdeen City Centre

Various emission scenarios were generated in EMIT for ADMS-Urban runs as part of the 'Base Run' and sensitivity tests. These included:

- Varying traffic speed (e.g. average speeds for all road sections set to same speed (10-80 km/hr at 10 km/hr intervals)
- Using different emission inventories (e.g. NAEI 2012, EfT v5.2)
- Varying emission inventory year (e.g. 2012, 2015, 2020)
- Adjusting fleet compositions (e.g. remove all diesel cars, All Buses Euro 6)

The emission scenarios are described in greater detail in Sections 4 and 5, along with the results; these changes are designed to explore the sensitivity of the model when these parameters are varied, and this is different from an actual change in speed, flow etc. When an EMIT emission inventory is imported into ADMS-Urban, the emissions are classed as 'user defined'.

3.8.6 Aberdeen ANPR and Vehicle Emissions study

A study measuring vehicle emissions by remote sensing methods was carried out in Aberdeen by University of Leeds which examined vehicle emissions using remote sensing methods and ANPR (25) which reports that 85% of the total vehicle fleet in Aberdeen are Euro 4, Euro 5 or Euro 6 and 56% of the total fleet is diesel (45% of all cars are diesel).

Fleet Composition

When compared with the NAEI2012 fleet composition data for 2015 (Table 15), there are fewer diesel vehicles in the ANPR measurements than is assumed in the inventory; however 86% of cars are Euro 4 or better, compared to the inventory assumption of 81%.
Therefore, the NO_2 emissions for car vehicles may differ in Aberdeen when using a bespoke vehicle fleet than when compared to using the national fleet statistics (fewer diesels and more Euro4+ engines than inventory estimates)

ANPR data suggests the bus fleet in Aberdeen is quite old compared to the national fleet statistics, and therefore NO2 bus emissions may be underestimated (Table 16), whilst the LGV fleet in Aberdeen is close to the national fleet statistics, with a slightly higher number of diesel LGV's compared to the national fleet statistics (Table 17).

ANPR data for Other Goods Vehicle (OGV) shows that there are greater numbers of Euro 2, 3, 4 and 5, and fewer Euro 6 OGV's than the national fleet statistics suggest, which may lead to an under-estimate of OGV emissions in Aberdeen (Table 18).

Table 15: Percentage composition of Car vehicle fleet by engine type derived from ANPR study (25) and NAEI2012 (2015) fleet composition data within EMIT (10)

	ANPR			NAEI2012 (2015)		
%	Petrol	Diesel	Total	Petrol	Diesel	Total
Euro 0	0.1	0.01	0.12	0	0	0
Euro 1	0.09	0.06	0.16	0.12	0.04	0.16
Euro 2	1.4	0.21	1.6	1.4	0.33	1.7
Euro 3	8.9	3.3	12.2	10.5	6.3	16.7
Euro 4	19.5	12.1	31.6	14.9	14.7	29.6
Euro 5	23.1	27.4	50.5	18.2	25.4	43.6

Euro 6	2	1.9	3.8	3.37	4.8	8.2
Total	55.1	44.9	100	48.4	51.6	100

Table 16: Percentage composition of Bus vehicle fleet by engine type derived from ANPR study (25) and NAEI2012 (2015) fleet composition data within EMIT (10)

%	ANPR	NAEI2012 (2015)
Euro 0	0	0
Euro 1	0.49	0.43
Euro 2	15.8	5.4
Euro 3	30.4	20.5
Euro 4	26.3	15.1
Euro 5	27.4	36.1
Euro 6	0	22.4

Table 17: Percentage composition of LGV vehicle fleet by engine type derived from ANPR study (25) and NAEI2012 (2015) fleet composition data within EMIT (10)

	ANPR			NAEI2012 (2015)		
%	Petrol	Diesel	Total	Petrol	Diesel	Total
Euro 0	0.05	0.12	0.17	0	0	0
Euro 1	0	0.2	0.2	0.03	0.18	0.21
Euro 2	0.05	1.7	1.8	0.30	0.80	1.1
Euro 3	0.12	9.0	9.1	0.60	6.9	7.5
Euro 4	0	33.3	33.3	0.77	29.0	29.8
Euro 5	0.03	55.4	55.4	0.92	60.0	60.9
Euro 6	0	0	0	0.01	0.56	0.57
Total	0.25	99.7	100	2.6	97.4	100

Table 18: Percentage composition of OGV vehicle fleet by engine type derived from ANPR study (25) and NAEI2012 (2015) fleet composition data within EMIT (10)

	ANPR	NAEI2012 (2015)	
%	OGV	OGV	
		Rigid HGV	Artic HGV
Euro 0	0.19	0	0
Euro 1	0	0	0
Euro 2	6.2	0.74	0.069
Euro 3	19.1	13.7	3.1
Euro 4	19.3	12.8	6.0
Euro 5	46.9	38.6	42.0
Euro 6	8.6	34.4	48.8

Emission Factors

Only car emission factors are reported in the study. Diesel car emissions are reported as 'Year of First Registration' and this has been summarised in Table 19 to cover all years, and are therefore approximate. The emission inventory values (Table 20, Table 21) are made up of many Euro engine sub-classes and so therefore are approximate.

When comparing the emission factors, it is shown that the two values are similar. All NAEI2012 and EfT emission factors are within the measure inter-quartile range, and therefore, the emission factors used in EMIT are representative of the measured values for car vehicles.

Table 19: ANPR diesel car emission factors measured in Aberdeen (25). These are approximate values across all 'Years of first registration'.

	NO_2 (g/km)	NO_x (g/km)
Median	~0.3	~0.65
Interquartile Mean	~0.18 to ~0.5	~0.4 to ~1.2

Table 20: Approximate emission factors for diesel cars from NAEI2012 emission inventory for year 2015, based on categories R022 to R042 in EMIT (10).

	NO_2 (g/km)	NO_x (g/km)
10 km/hr	~0.45	~0.9
20 km/hr	~0.4	~0.85
40 km/hr	~0.27	~0.6

Table 21: NO_x (g/km) emission factors for diesel cars from EfTv5.2 and EfTv7.0 emission inventory for year 2015 (26).

NO_x (g/km)	v5.2	v7.0
10 km/hr	0.775	0.92
20 km/hr	0.629	0.74
40 km/hr	0.453	0.55

3.8.7 Shipping Emissions

Although they are an important component of NO_x emissions in Aberdeen, the aim of the project was to develop methods for modelling dispersion of traffic emissions. As a source term would need to be derived for these emissions, and they cannot form part of 'other background sources' due to their elevated nature, emissions from shipping was not modelled explicitly in this project, but will need to be considered if future CAFS work. However, previous work to investigate the impact of shipping on air quality in Aberdeen concludes the impact is from shipping is not significant (approximately less than 5% of total concentrations) (27)

3.9 Chemistry Scheme

There are several options in ADMS-Urban to simulate the photochemical reactions which occur between Nitrogen Oxide (NO), Nitrogen Dioxide (NO_2), Ozone (O_3) and Volatile Organic Compounds (VOC's). Sunlight is also a factor in the reaction. Therefore, it is important to consider these reactions as NO_2 concentrations may be under-predicted if only primary NO_2 emissions are considered.

3.9.1 ADMS-Urban Chemistry Reaction Scheme

The ADMS-Urban chemistry <u>reaction</u> scheme utilises a set of equations to simulate the formation and destruction of NO_2 concentrations in the atmosphere (22). The use of this model requires hourly background concentration data (Section 3.10). This scheme was used in the 'Base Run' and will be discussed in more detail in Section 4.4.2.

3.9.2 ADMS-Urban Chemistry Correlation Scheme

The ADMS-Urban <u>correlation</u> scheme uses a simplified function to estimate the NO_2 concentration for a given NO_x concentration (22). Only NO_x background data is required either as an annual mean concentration or as hourly concentrations and will be discussed in more detail in Section 4.4.2.

3.10 Background Concentrations

It is important that background concentrations are included in ADMS-Urban modelling assessments; the chemistry module within ADMS-Urban requires background concentrations and pollutants from sources which are not explicitly being modelled, but which need to be accounted for.
As ADMS-Urban calculates concentrations for each one hour time-step in isolation from other time steps (i.e. predicted pollutant concentrations are not carried forward to the next model time step), the background concentration data used can also represent concentrations from pollutants emitted in previous hours.

ADMS-Urban requires the background file to include hourly concentrations for the following pollutants:

- Nitrogen Oxides (NO_x)
- Nitrogen Dioxide (NO_2)
- Ozone (O_3)
- PM_{10}
- $PM_{2.5}$
- Sulphur Dioxide (SO_2)

However, it is important to note that background concentrations are difficult to quantify as this may vary across the city and is influenced by many factors and limitations. There are two possible approaches in ADMS-Urban: using the urban background monitor, or a rural background station with gridded NAEI emissions

3.10.1 Urban Background (Errol Place)

The Errol Place automatic air quality monitor (Figure 33) is located approximately 70m east of King Street; it is considered to be an Urban Background site as it is located on a residential side street. This is the only Urban Background monitoring location in Aberdeen. This site represents a well-mixed zone to the North-East of the city, but in ADMS-Urban, this is applied to the entire city

Hourly data for this location has been downloaded using the OpenAir library of functions in the R package. The hourly data was processed into the format required for an ADMS background file from 2008 until the most recent available year (2014).

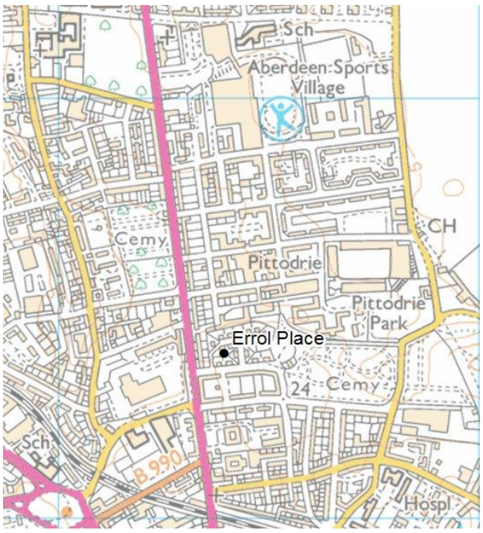


Figure 33: Errol Place Urban Background Monitoring Location

All pollutants with the exception of SO_2 are monitored at Errol Place (SO_2 is not currently monitored at any monitoring station in Aberdeen). However, given SO_2 concentrations are required for ADMS-Urban to model the formation of secondary particulates, the SO_2 concentrations value was set to 0 µg m^{-3}, as recommended in ADMS-Urban user guidance (22).

A polar plot analysis of the Errol Place average concentrations indicate that for NO_2 the highest concentrations are for south-westerly winds with low wind speeds. This may be due to a combination of local road emissions from King Street and city centre emissions which have been advected slowly towards the Errol Place. There are also significant concentrations from sources to the south of Errol Place for all wind speeds, for high wind speeds this may be due to shipping emissions, which will behave in a similar way to elevated point sources. This implies that at ground level, shipping emissions may generate similar concentrations as traffic emissions (Figure 34).

NO_x concentrations at Errol Place are highest for low wind speeds during westerly and south-westerly wind directions, which may be due to poor dispersion of city centre emissions during these conditions (Figure 35).

PM_{10} concentrations are highest for easterly winds which is likely to be due to sea salt, though there are elevated concentrations from a source to the south (Figure 36)

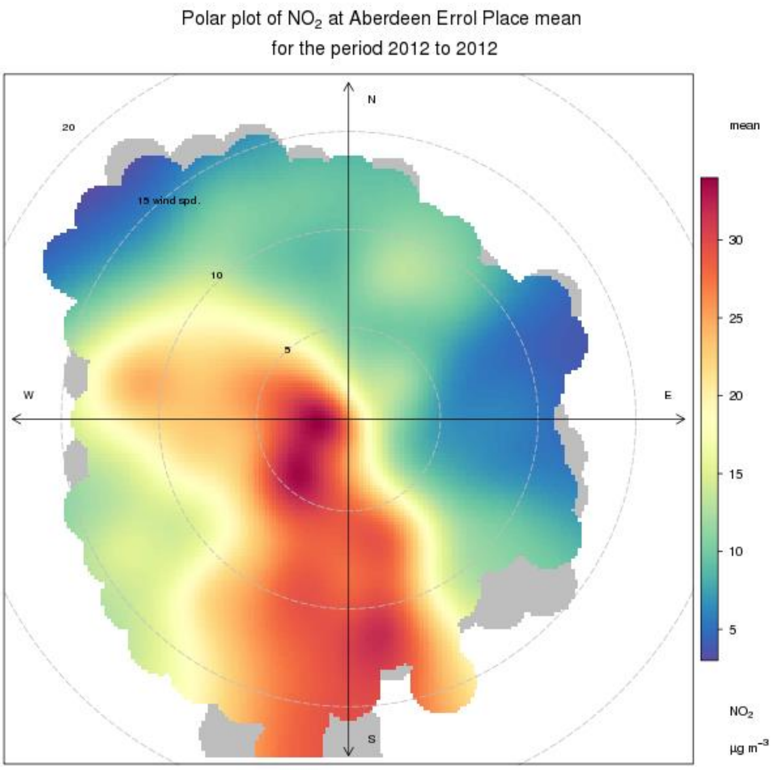


Figure 34: Aberdeen Errol Place NO_2 Polar Plot concentrations (µg m^{-3})

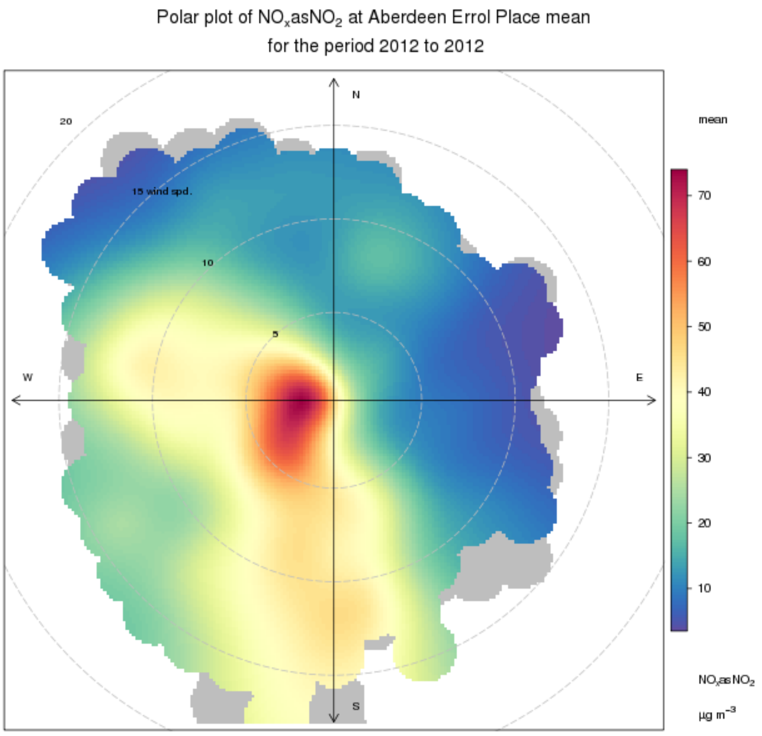


Figure 35: Aberdeen Errol Place NO_x Polar Plot concentrations (µg m^{-3})

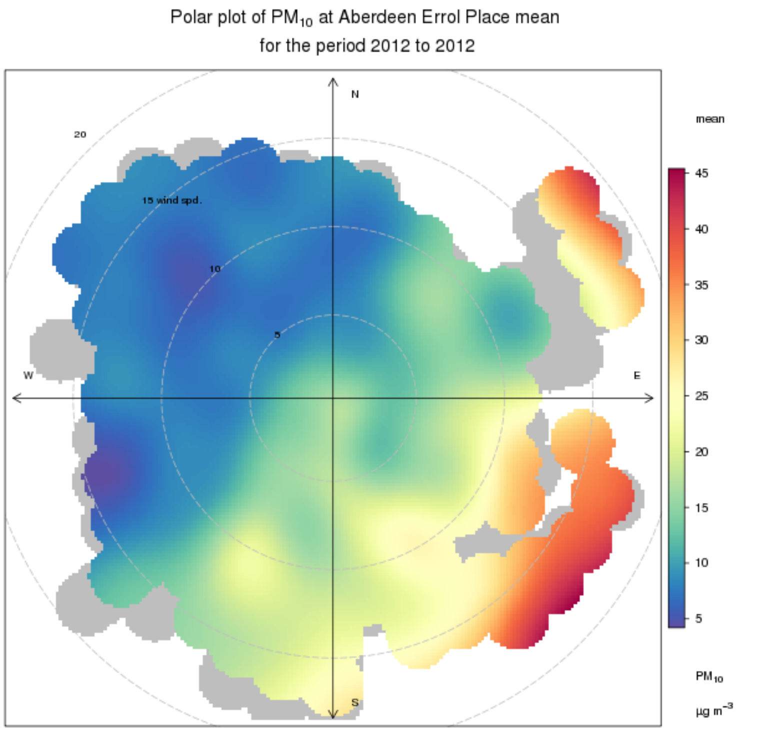


Figure 36: Aberdeen Errol Place PM_{10} Polar Plot concentrations (µg m^{-3})

Missing Data

For various reasons (equipment failure, data calibration difficulties etc.), data capture rates may be low for some years. At Errol Place, NO_2 data capture rates are low for 2010 and 2013 (Table 22).

Table 22: NO_2 capture rates at Aberdeen Errol Place

Year	Data Capture Rate (%)
2009	96.1
2010	71.6
2011	95.7
2012	93.4
2013	44.7

As the ADMS-Urban chemistry module requires background data without long data gaps, an approach was developed to fill these gaps. As using the annual mean to fill these gaps would not reflect the diurnal cycle found at an Urban background monitor, an alternative approach was developed where the diurnal cycle of the pollutant concentrations at Errol Place was calculated using the available data (i.e. the mean for each hour of the day over the year), and this data was used to fill the large data gaps.

3.10.2 Rural Background Concentrations and Gridded Area Emissions

An alternative option to using Urban Background data is to use measured Rural Background Concentrations and Gridded Area Emissions for local sources which are not being explicitly modelled. Using both these together allows local non-traffic sources to be spatially variable along with a rural background which accounts for any long range air pollution, or build ups of pollutants due to stagnant air.

Gridded Area Emissions are compiled by NAEI, along with published methodology (28), however despite being considered to be a good quality inventory, there are a number of weaknesses and limitations, such as using fuel consumption and population data to estimate emissions, which will have uncertainties (29).

The closest rural background monitoring station to Aberdeen is Bush Estate (NO_x) and Auchencorth Moss (PM_{10} and $PM_{2.5}$), both located to the south of Edinburgh.

Gridded Area Emissions are available on the NAEI website (30) for many pollutants in either CSV or Raster format. These provide emission estimates on a 1km x 1km grid resolution for different sectors (e.g. road transport, Production Processes) for many pollutants and the dispersion can be modelled in ADMS-Urban using the 'Grid Source Cells' option at a height of 0-10m. Emission estimates are also available for subsectors (e.g. Major Roads, Minor Roads etc.) in raster format, all of which can be displayed in ArcGIS (Figure 37). The NAEI assumes that within the domain shown in Figure 38, road transport emissions accounts for 41.5% of total NO_x emissions and 35.8% of total PM_{10} emissions.

As major road sources are being modelled explicitly, these were removed from the emissions inventory (the minor roads emission sector was not removed). However, as ADMS-Urban requires gridded emissions to include **all sources, including those modelled explicitly**, the road emissions for each scenario had to be aggregated and included in the grid emissions for input into ADMS-Urban. Therefore gridded emissions need to be recalculated for every road emissions scenario being modelled. ADMS-Urban then subtracts explicit modelled sources from the gridded emissions.

Due to the background emissions source height being set to 0-10m above ground level, as discussed in Section 3.8.7, shipping emissions were not included as these are emitted at a significantly greater height than 10m (Figure 38). As background gridded sources are only available for NO_x, the ADMS-Urban default value of assuming that the proportion of NO_x that is NO_2 of 12% was followed.

An advantage of using this method is that the model performance can be assessed at the location of the Errol Place automatic monitor. A disadvantage in this approach is that gridded area emissions rely on emission factors for different source types and it is less likely that the model will be able to account for emissions from previous hours which an urban background site will measure. Also, the 1km x 1km emission estimates are derived using methodology which is updated annually, and therefore are not directly comparable.

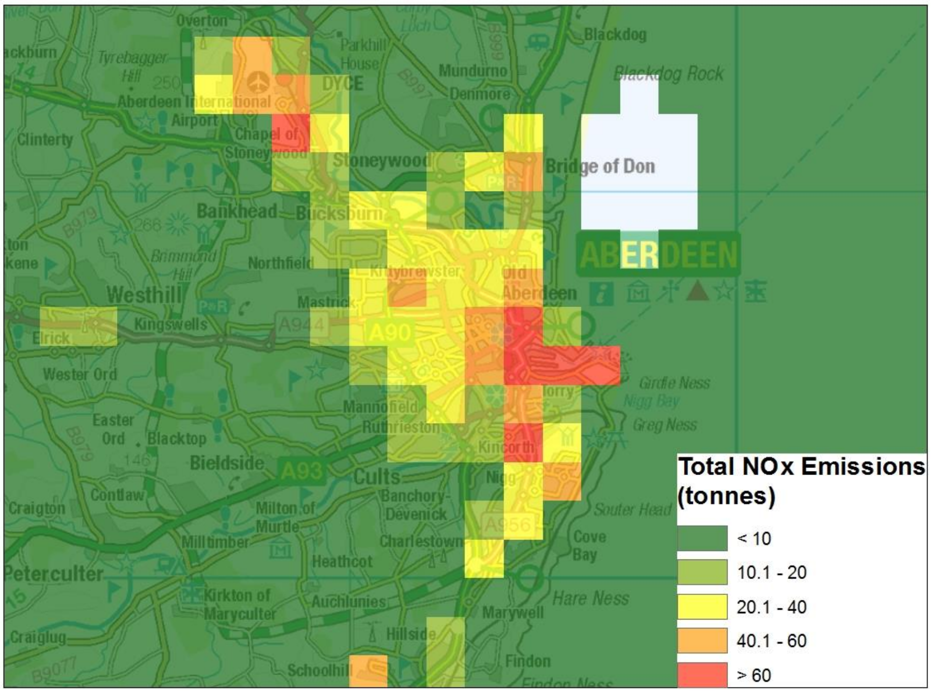


Figure 37: Total Area NO_x Emissions (2012) at 1km resolution for Aberdeen

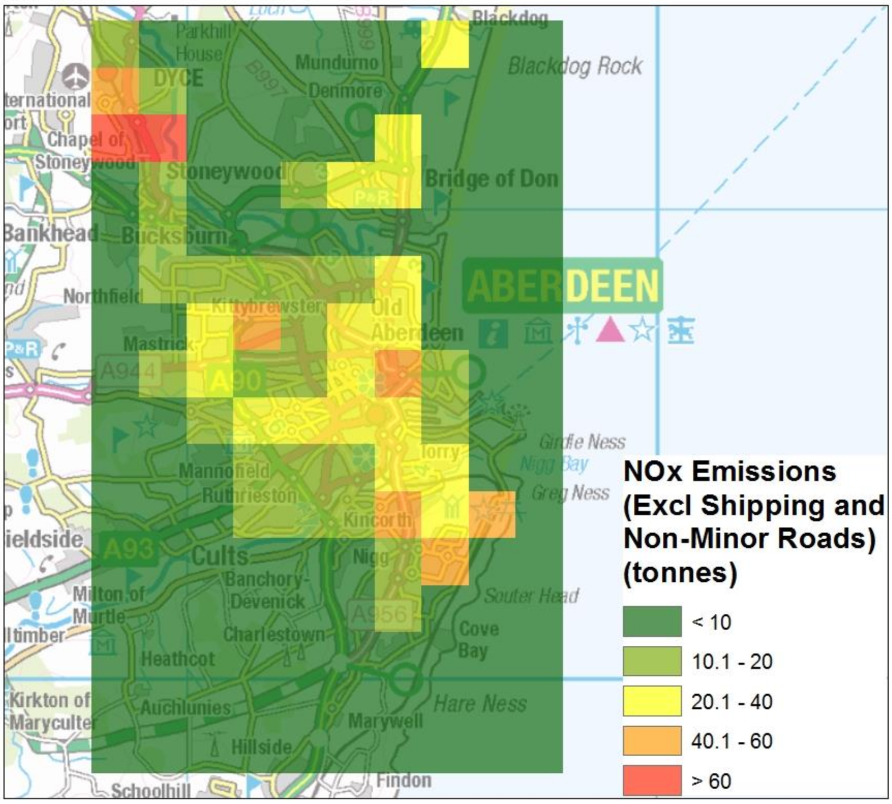


Figure 38: Total Area NO_x Emissions (2012) at 1km resolution, excluding shipping and non-minor roads

3.11 Meteorological Data

Meteorological data is an essential requirement to run ADMS-Urban (or any air quality dispersion model). SEPA obtains observed meteorological data from the UK Meteorological Office under licence.

Two weather stations were identified as being of use for this project: Dyce (Aberdeen Airport) and Inverbervie No. 2 (Figure 39), which both of which measure all meteorological conditions (e.g. wind speed, wind direction, cloud cover) required to run ADMS-Urban.

Dyce (Aberdeen Airport)

Dyce (Aberdeen Airport) weather station is located at National Grid Reference (NGR) 387695, 812695 and is approximately 9.5km from Aberdeen city centre and 8.2 km from the coast.

As it is close to Aberdeen city, it is considered to be reasonably representative of the meteorological conditions in Aberdeen; however, it may not capture the coastal effects (sea breezes etc.) which may occur in some parts of the city.

Inverbervie No 2

Inverbervie No 2 weather station is located at NGR 383879, 773416 approximately 35km south of Aberdeen and being less than 1km from the coast, is more likely to capture coastal effects (sea breezes etc.); this weather station will be useful for sensitivity tests.

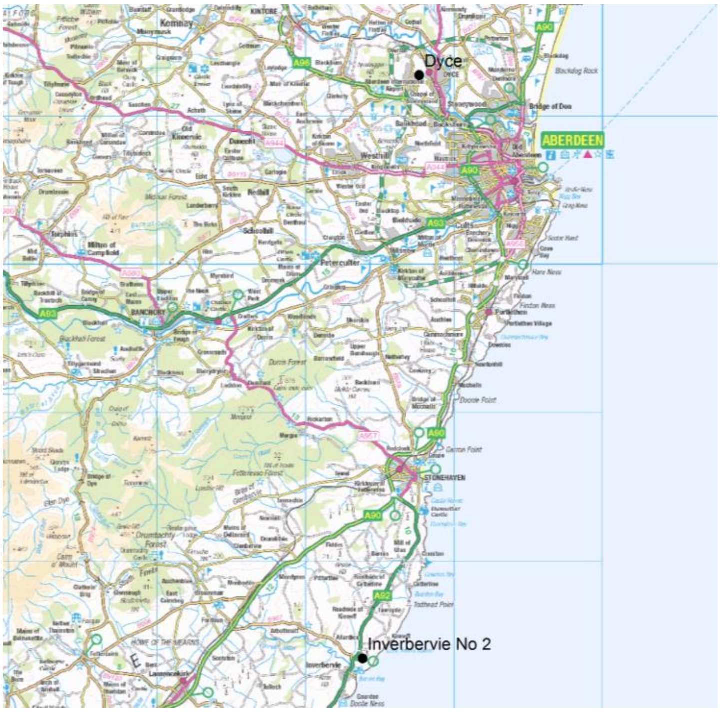


Figure 39: Locations of Dyce and Inverbervie No 2 weather stations

Within the ADMS-Urban meteorology module, parameters are required so that dispersion characteristics can be calculated using the hourly meteorological conditions (Table 23). The roughness length parameters are set to accommodate the weather stations not being located in an urban area.

Table 23: ADMS-Urban Meteorology Site Data

Parameter	Value
Latitude	57°
Dispersion Site Surface Roughness Length	0.5 m
Meteorological Measurement Site Surface Roughness Length	0.02 m
Height of Recorded Wind	10 m
Meteorological Data in sector	10°
Minimum Monin-Obukhov length	30 m

Usable Meteorological Data

It is important to assess how usable the meteorological data is for each weather station; data may not be available due to instrument errors or maintenance. When the wind speed is classed as 'calm' (less than 0.75 m s^{-1}), ADMS-Urban sets the wind speed to be 0.75 m s^{-1} and sets the wind direction to be that of the last valid hour (this is a notable difference to ADMS 5.1).

The percentage of usable meteorological data for different years at both Dyce and Inverbervie No 2 weather stations is high (Table 24).
Although for 2009, the availability of data is relatively low at Dyce, it has still been used so that a 5 year period has been covered in this work (2014 data was unavailable when starting this work), though this limitation should be noted.

Table 24: Percentage of usable meteorological data at Dyce and Inverbervie No2 for years 2009-2013

Year	Dyce	Inverbervie No 2
2009	80.9%	92.2%
2010	99.6%	88.0%
2011	99.6%	92.6%
2012	99.8%	99.8%
2013	98.5%	98.5%

3.12 Output Grids and Points

ADMS-Urban outputs predicted concentrations at specific points across the model domain.

These specific points can be presented in 2 ways:

- Regular Gridded Points: A rectangular grid with equally spaced output points within a domain. Source-oriented output points (these run parallel to the road source line) were also generated using an algorithm within ADMS-Urban, though these can vary in different model runs (22). The regular grid option is required to produce contour plots, but model run times can be long.
- Specified Points: These output points are user defined. This option cannot be used to generate contour plots, however output point locations can be fixed. The model run time is less compared to the regular grid option (though is dependent on the number of specified points).

The model can be run for one or both of these output options in the same model run. The benefit of using the regular gridded points is that exposure can be assessed over a wide area, whereas, the specified points method can assess the exposure at the same location, which allows for easy analysis over different model runs.

3.12.1 Regular Gridded Points

The selected parameters used for the Regular Gridded Points option are shown in Table 25 and can be seen graphically in Figure 40 and Figure 41. The output points are out ground level (0m), and road source-oriented grids are 'On'.

Table 25: Regular Grid Parameters for Aberdeen ADMS-Urban Model

	Minimum (m)	Maximum (m)	Number of Points
Eastings (m)	388600	396000	101
Northings (m)	800200	812600	101
Height above ground (m)	0	0	1

3.12.2 Specified Points

The Specified Points option in ADMS-Urban, allows the model user to specify the co-ordinates of output points, along with a receptor name (e.g. monitor name). To obtain model predictions along roadsides (similar to road source-oriented points) without using the Gridded Output option, a GIS model was built to generate points along the roadside:

1. Using the shapefile which represents the road sections and road width values, the Generalize tool and Densify tool are used to add vertices to each polyline at 50m intervals.
2. A buffer equal to the road width (calculated in Section 3.4) is applied to each road polyline (which has vertices at 50m intervals).
3. The 'Features Vertices to Points' geoprocessing tool is used to generate points at the vertex locations in each buffered polyline. The co-ordinates of each vertex location can then be exported to a format that can be used in the ADMS-Urban Specified Points file (Figure 42).

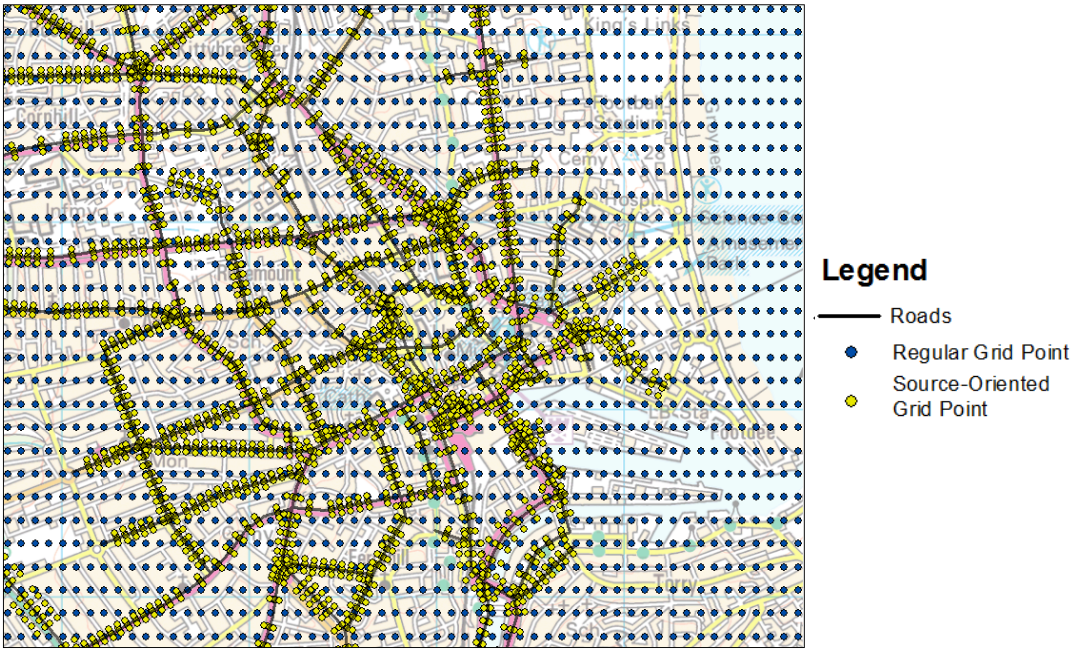


Figure 40: ADMS-Urban gridded output location points (city overview)

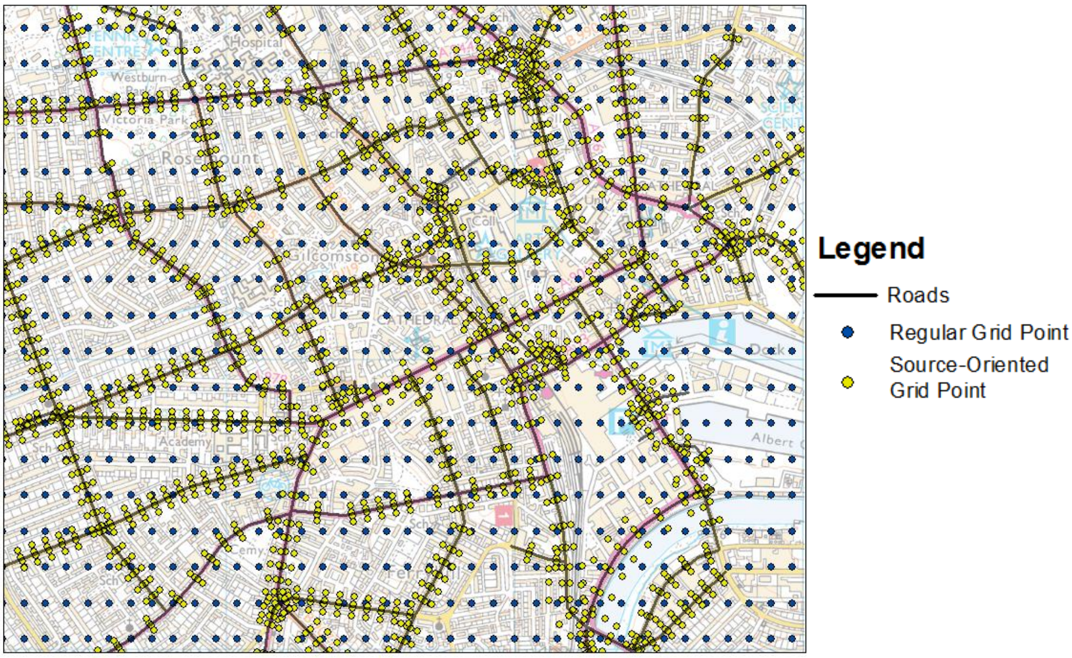


Figure 41: ADMS-Urban gridded output location points (city centre)

Specified points representing the automatic monitoring point locations, diffusion tube locations and a cross-section of the road at automatic monitoring points also were generated for the specified points file. Figure 43 shows an overview of the Specified Point locations, and Figure 44 shows the specified points close to the Union Street monitor.

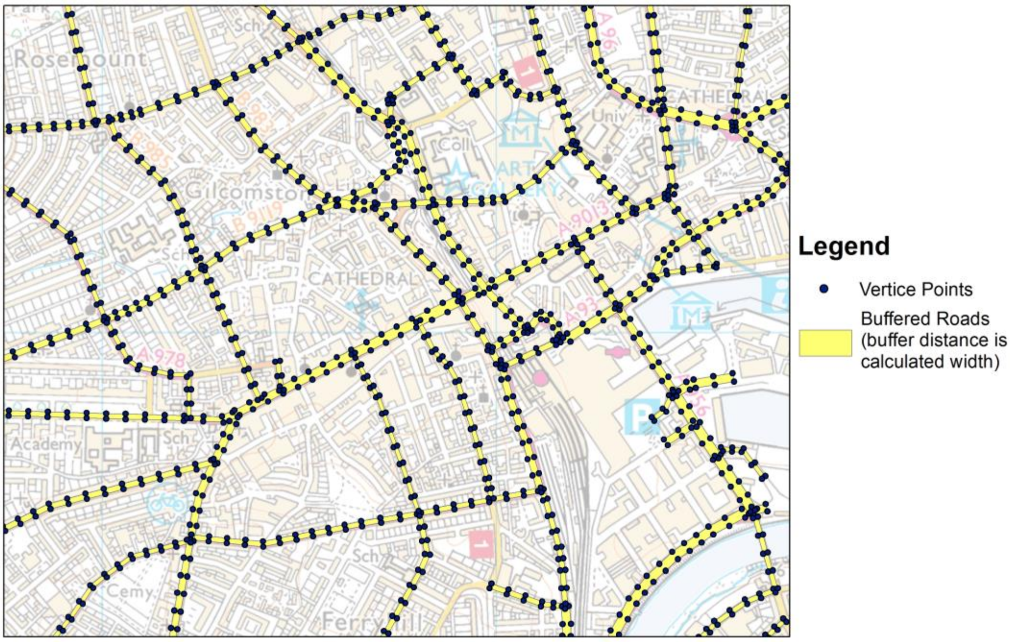


Figure 42: Vertex points generated along buffered roads. The buffer is proportional to the road width.

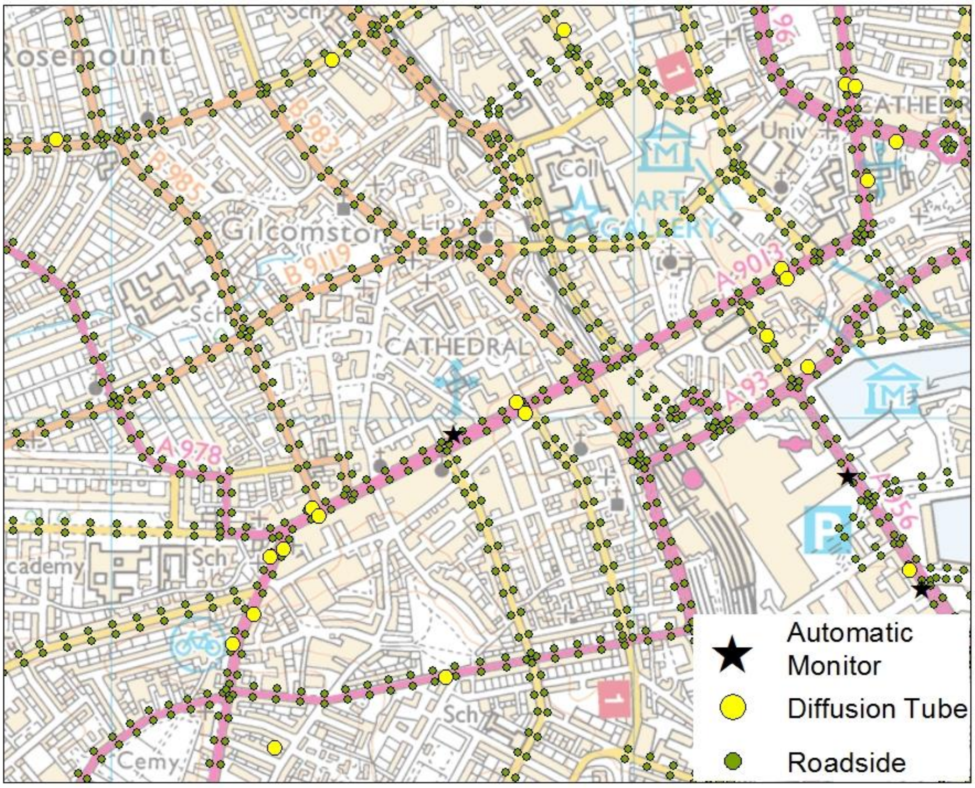


Figure 43: Specified Grid Output points (excluding cross-section points)

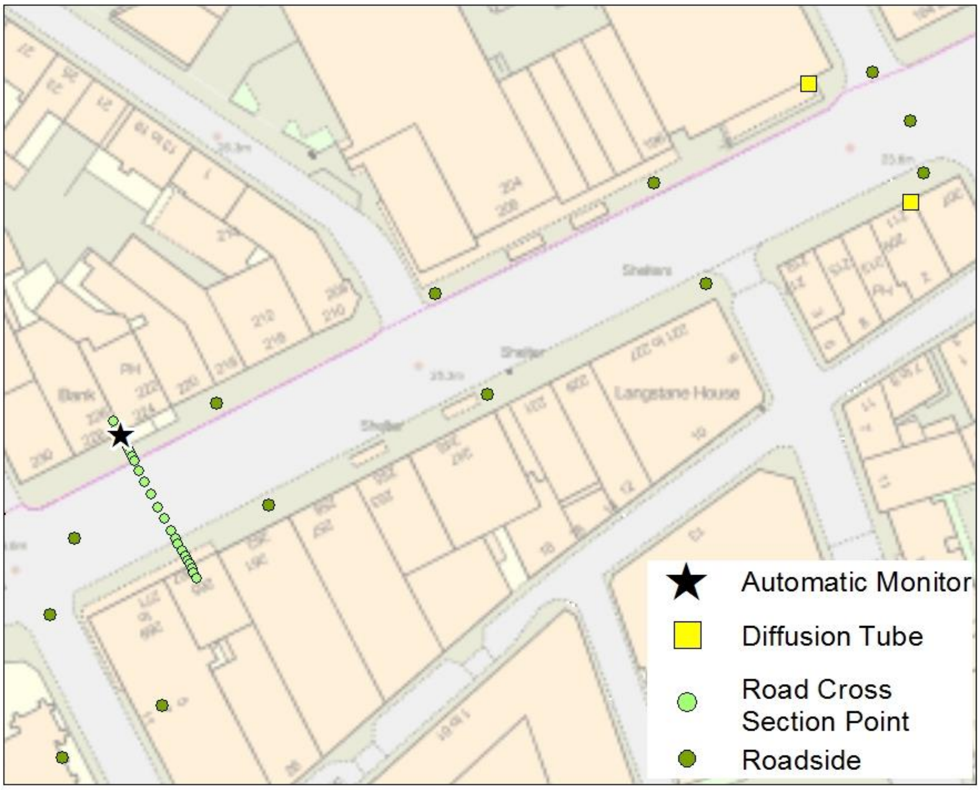


Figure 44: Specified Output points close to Union Street automatic monitor

3.13 Other Model Setup Parameters

3.13.1 Vehicle Induced Turbulence

When modelling road traffic sources, the effect of turbulence caused by the moving traffic needs to be accounted for. When road traffic is entered directly into ADMS-Urban, the vehicle induced turbulence parameters are explicitly calculated for each road section.

As emissions for the Aberdeen pilot project have been calculated using EMIT, the vehicle induced turbulence is back calculated, assuming fleet split of 95% light vehicles and 5% heavy vehicles, with a speed of 30 km/hr. This is not actually the case for all streets in Aberdeen where, based on AADF values, the number of heavy vehicles can exceed 15% of total traffic (Table 26).
An option exists in ADMS-Urban where the heavy/light vehicle split can be modified, but this is a global option and is applied to all roads. Changes to the heavy/light vehicle split were applied as a sensitivity test and are analysed in Section 4.4.6.

Table 26: Vehicle Splits at Selected Roads (based on AADF)

Road (Number)	Heavy Vehicles	Light Vehicles	% Heavy Vehicles
Market Street (S5_6)	5205	27208	16%
King Street (S99_100)	2522	13490	16%
Wellington Road (S2_C)	4295	21895	16%
Union Street (S34_35)	2685	14666	16%
Westburn Road (S74_85)	795	17123	4%
Great Northern Road (S97_A)	2108	18080	10%
North Anderson Drive (A90(7))	1935	27194	7%

3.13.2 Complex Terrain

Complex terrain effects are normally considered when gradients of greater than 1:10 exist as this can alter the air flow, however guidance suggests that in urban domains the influence of buildings is greater than terrain, and that including terrain is unnecessary (23). For the Aberdeen pilot project, terrain has not been considered as there are few significant gradients greater than 1:10 in Aberdeen.

3.13.3 NetCDF Output

ADMS-Urban has the option to output model results in NetCDF format, which stores hourly concentration predictions at each receptor location. This allows detailed statistical analysis of the model predictions which is not possible using the regular ADMS output format.

3.14 Summary: The ‘Base Run’

A ‘Base Run’ was established against which all subsequent model runs would be compared. As the detailed traffic counts available to the project were collected in 2012, this was set to be the year of the ‘Base Run’.

The Base Run was set up as follows:

- 2012 traffic emission factors from the NAEI 2012 emission inventory (11 Vehicle Classes outlined in Table 7).
- 2012 meteorological data for Dyce weather station.
- Chemistry Module ‘On’ using Errol Place urban background monitoring data for 2012

Initially, the Base Run can be tested against observed data at the automatic monitoring locations, where detailed statistical analysis and investigation of the models performance can be made. Evaluation against diffusion tube data is also required, before going onto vary inputs such as background data, choice of emission inventory, meteorological data to test how sensitive the model is to a number of parameters.

4 Model Verification and Sensitivity Tests

The Aberdeen model (using ADMS-Urban) was built in steps and verified against monitored data to assess and understand the model performance. Model performance was evaluated in several ways:

- Comparison of modelled predictions and measured concentrations at automatic monitors and diffusion tube locations
- At the automatic monitoring locations, hourly observed concentrations can be compared against modelled hourly predicted concentrations using statistical tests
- At diffusion tube monitoring locations, annual mean measured and modelled concentrations can be compared.
- Contour plots can be generated using GIS interpolation methods
- Interactive analysis using Spotfire (more information on this approach can be found in the report “Emissions Scaling Tool: Aberdeen City”)

In addition to the ‘Base Run’, various scenarios were investigated and compared against the ‘Base Run’:

- Effects of different modules (such as chemistry, diurnal cycle etc.) were assessed and compared against monitored data.
- Unit release runs (for the Spotfire scaling tool where each road has the same emission rate, and emission rates for each road can be adjusted in Spotfire)
- Changes to emissions to simulate emissions for future years
- Low emission zones

4.1 Statistical Methods for Analysis

When carrying out detailed analysis of the model results at each automatic monitoring location, statistical methods and graphs were used to assess the model performance.

Plots used are:

- Scatter Plots: Measured and observed concentration for each hour are plotted against each other
- Quantile-Quantile (Q-Q) plots: Time dependency is removed and the highest observed value is plotted against the highest modelled value, 2nd highest observed against 2nd highest modelled, and so on for all points.

Statistics can also be used to assess how the model performs against monitored data. There are many statistical parameters that can be used; work by Chang and Hanna (31) (32) suggest that model performance is good if the following statistical parameters are within certain ranges:

- **Fractional Bias (FB):** -0.3 < FB < 0.3
- **Geometric Mean Bias (MG):** 0.7< MG < 1.3
- **Normalised Mean Square Error (NMSE):** NMSE < 1.5
- **Geometric Variance (VG):** VG < 4
- **Fraction of data within a factor of 2 (FAC2):** FAC2 > 50%

Other parameters such as Mean Bias (MB) and Correlation (R) may also be a useful statistic to test of the model performance. Further work by Chang and Hanna suggests that the ranges above may need to be relaxed when modelling in an urban environment due to factors such as the effect of buildings (33).

Further information on the statistics used can be found in Appendix A8

4.2 Base Run Verification and Analysis

Initially, the Base Run (Section 3.14) was evaluated before proceeding with other sensitivity and scenario tests. This includes a detailed analysis of the model performance in estimating levels measured at each automatic monitor and at diffusion tube locations.

4.2.1 Base Run: Air Quality Standards/Objectives

Nitrogen Dioxide (NO_2)

Annual Mean

A comparison between the 'Base Run' predictions and observations at the automatic monitors shows that the model is performing well at Union Street, Market Street 2 and Anderson Drive (Table 27).
However, the model underestimates the annual mean at Wellington Road by 26%, and over-predicts the annual mean at King Street by 23%. It is important to note however, that although the annual mean is commonly used and reported, the detailed statistical analysis will provide a better understanding of the model performance.

99.79th Percentile of Hourly Mean Concentrations

A similar comparison between the 'Base Run' and observations for the 99.79th percentile of hourly means at the automatic monitors shows that the 'Base Run' tends to over-predict the 99.79th percentile at all locations, except for Wellington Road (Table 27).

Statistical Analysis

A detailed statistical analysis of model performance (Table 28) shows that the 'Base Run' model performs well given the performance statistics are all within the ranges suggested in Section 4.1. This will be analysed in more detail for each monitoring location.

Table 27: Base Model Run NO_2 Results for Air Quality Standards/Objectives (bold shows where Air Quality Standard has been exceeded)

Monitoring Point	Annual Mean (µg m^{-3})			99.79th Percentile of 1hr Means (µg m^{-3})		
	Observed	Model	Ratio	Observed	Model	Ratio
Union Street	**52.8**	**49.4**	0.94	143	163.5	1.14
Market Street 2	**44.1**	**47.6**	1.08	161	171.5	1.07
Wellington Road	**59.1**	**44**	0.74	187.8	167.6	0.89
King Street	29.2	36	1.23	107	134.3	1.26
Anderson Drive	30.4	31.4	1.03	115	121.4	1.06

Table 28: Model Statistics for NO_2 at Automatic Monitors; Base Run. (bold shows parameters which have failed tests described in Section 4.1)

Monitoring Point	MG	VG	NMSE	FB	Fac2	MB	R
Union Street	0.91	1.48	0.28	-0.06	0.75	-3.24	0.59
Market Street 2	1.11	1.63	0.42	0.1	0.72	4.69	0.55
Wellington Road	0.74	2.82	0.64	-0.27	0.68	-14.08	0.42
King Street	1.15	1.65	0.31	0.2	0.75	6.32	0.74
Anderson Drive	1.14	1.96	0.61	0.06	0.57	1.77	0.39

Nitrogen Oxides (NO_x)

Although there is no Air Quality Standard (AQS) for NO_x, it is useful to assess how the model performs for NO_x as this will provide an indication of the model performance when the non-linear elements of the chemistry are removed.

The model performs well for Union Street, Market Street 2 and Anderson Drive (Table 29) which is similar to the NO_2 results. Also, the model under-predicts for Wellington Road and over-predicts for King Street. The detailed statistical analysis shows that the model performs within the ranges outlined in Section 4.1, with the exception of Wellington Road, which fails 3 of the tests (Table 30).

Table 29: Base Model Run NOx Results

Monitoring Point	Annual Mean (µg m^{-3})		
	Observed	**Model**	**Ratio**
Union Street	136.2	133.3	0.98
Market Street 2	110.5	120.9	1.09
Wellington Road	179.5	114.3	0.72
King Street	65.7	79.9	1.22
Anderson Drive	55.8	55.7	1.0

Table 30: Model Statistics for NO_x at Automatic Monitors; Base Run. (bold shows parameters which have failed tests described in Section 4.1)

Monitoring Point	MG	VG	NMSE	FB	Fac2	MB	R
Union Street	0.97	1.77	0.53	-0.02	0.64	-2.52	0.61
Market Street 2	1.1	2.09	0.99	0.12	0.62	14.26	0.52
Wellington Road	**0.62**	**5.55**	1.26	**-0.42**	0.55	-62	0.51
King Street	1.11	2.07	0.57	0.18	0.63	13.11	0.74
Anderson Drive	1.14	2.35	1.32	0.03	0.5	1.82	0.37

Particulate Matter (PM_{10} and $PM_{2.5}$)

PM_{10} and $PM_{2.5}$ emissions were also included in the 'Base Run' and although the focus of the Aberdeen pilot project and modelling study was for NO_2, the PM_{10} results are shown for completeness (Table 31) along with model performance statistics (Table 32). These show that the model is generally under-predicting annual mean PM_{10} concentrations at all PM_{10} monitoring locations in Aberdeen.

The model is also under-predicting the 98.08th percentile of the 24 hour means with the exception of Anderson Drive where the model prediction almost matches the observations.

The statistical analysis suggests that the 'Base Run' is under-estimating at all locations (MG<1, FB<0 and MB<0). Wellington Road fails the Fractional Bias (FB) test (Section 4.1), whilst Anderson Drive is the best performing location.

$PM_{2.5}$ monitoring equipment was installed recently at Market Street 2 and Union Street. Currently, there is insufficient monitoring data available for any statistical analysis of model performance $PM_{2.5}$ analysis to be carried out.

Table 31: Base Model Run PM_{10} Results for Air Quality Standards/Objectives

Monitoring Point	Annual Mean (µg m^{-3})			98.08th Percentile of 24hr Means (µg m^{-3})		
	Observed	Model	Ratio	Observed	Model	Ratio
Union Street	21.3	16.9	0.79	47.0	37.8	0.8
Market Street 2	22.4	17.2	0.77	64.0	40.5	0.63
Wellington Road	23.3	16.9	0.73	52.6	36.4	0.69
King Street	18.6	15.9	0.85	50.1	35.4	0.70
Anderson Drive	15	14.4	0.96	36.4	36.3	1.0

Table 32: Model Statistics for PM_{10} at Automatic Monitors; Base Run. (bold shows parameters which have failed tests described in Section 4.1)

Monitoring Point	MG	VG	NMSE	FB	Fac2	MB	R
Union Street	0.75	1.32	0.24	-0.23	0.84	-4.43	0.74
Market Street 2	0.76	1.42	0.43	-0.28	0.79	-5.5	0.73
Wellington Road	0.73	1.65	0.58	**-0.32**	0.79	-6.48	0.56
King Street	0.89	1.4	0.3	-0.14	0.85	-2.44	0.72
Anderson Drive	0.9	1.56	0.22	-0.04	0.86	-0.62	0.76

4.2.2 Base Run Detailed Analysis: Union Street

The Union Street monitor is located on the north side of Union Street, just east of the junction with Union Row and Bon-Accord Street (Figure 45, Figure 46). The street is classed as a canyon. Traffic flows by this monitor indicate this route is heavily used by buses and carries around 17,500 vehicles per day (Table 33).

Figure 45: Union Street Air Quality Monitor

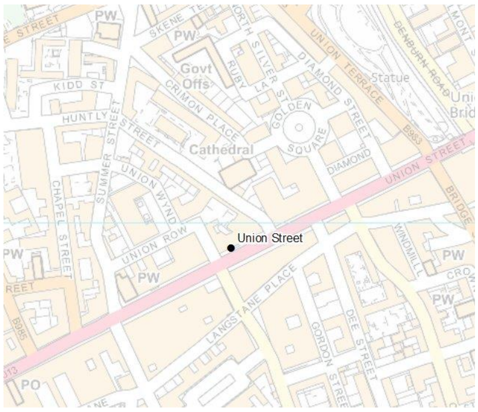


Figure 46: Map showing location of Union Street Monitor

Table 33: Annual Average Daily Flow (AADF) by the Union Street monitor (Section S34_35)

Vehicle Type	Motorcycle	Car	Bus	LGV	HGV	Total
Flow (AADF)	150	12745	2069	1921	615	17500

At the Union Street monitor, the 'Base Run' is under-predicting the NO_2 annual mean by 6%, and over-predicting the 99.79th percentile by 14% (Table 27). This shows that the model is performing reasonably well for both NO_2 Air Quality Standards/Objectives at Union Street. Although the model performs less well for the 99.79th percentile, greater uncertainties for the 99.79th percentile predictions are to be expected as peak emission scenarios can vary for many reasons such as greater than average traffic emissions or a temporary nearby source (e.g. roadworks or construction).

The 'Base Run' also performs well at the Union Street monitor for the NO_x annual mean, under-predicting it by 2% (Table 29). For the PM_{10} annual mean and 98.08th percentile of the 24 hour mean, the 'Base Run' does not perform well and is under-predicting observations by 21% and 20% respectively (Table 31).

When the NO_2 time-series is plotted over a week in November for both modelled and observed concentrations, it can be seen that there are periods when the model under-predicts and periods when it over-predicts (Figure 47, Figure 48); however over a long time period, statistics (Section 4.1) can indicate how well the model is performing overall. The short term variance could be caused by a number or reasons such as wind velocity at the monitor differing from the observation at the weather station.

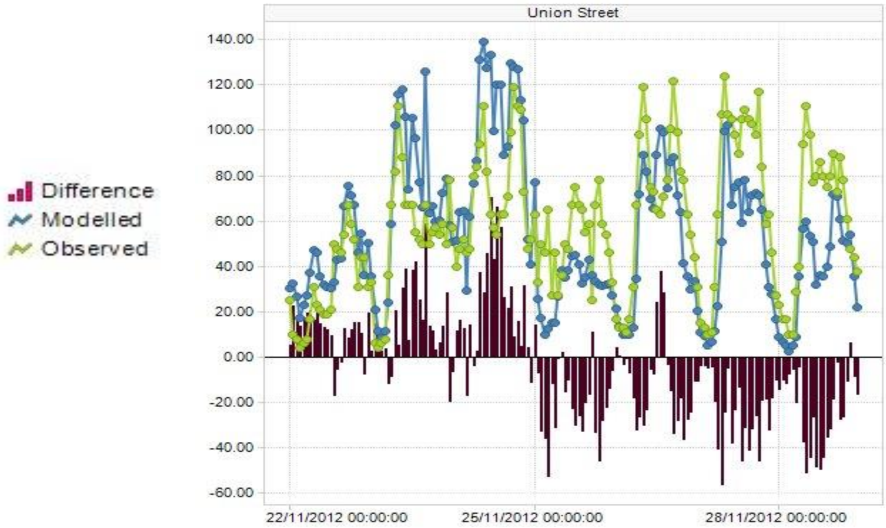


Figure 47: Example NO_2 modelled and observed time series (hourly) with difference (Units: µg m^{-3})

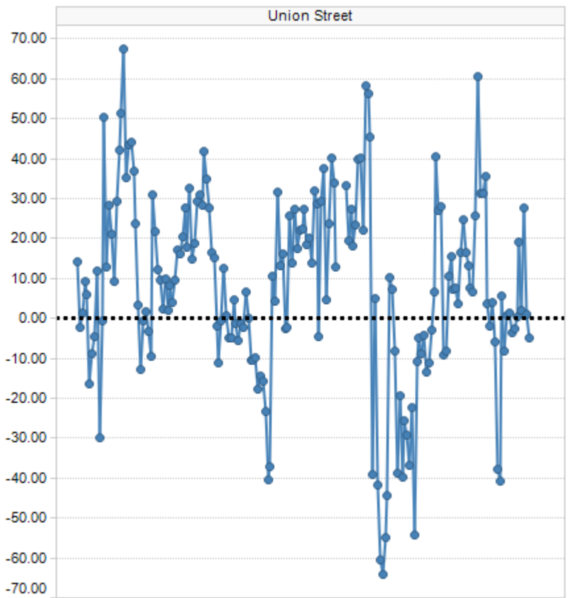


Figure 48: Example NO_2 Daily Concentration Residuals (Units: µg m^{-3})

The scatter plots (Figure 49, Figure 51 and Figure 53) for Union Street shows that there is quite a lot of variability for each hour within a year (which is to be expected). The Quantile-Quantile plots (time dependency removed), this shows that the model is performing well over the whole year (Figure 50, Figure 52 and Figure 54).

Statistical analysis (Table 34) shows at the Union Street monitor, the statistical parameters are within ranges outlined in Section 4.1, which suggest that the 'Base Run' is performing well at this location. The Fractional Bias (FB) and Mean Bias (MB) parameters indicate that the model is slightly under-predicting NO_2 and NO_x concentrations. The underestimate for PM_{10} is greater, but there are greater uncertainties when estimating PM_{10} emissions (resuspension, brake and tyre wear etc.). The correlation coefficient (R) also indicates that the model is performing well at the Union Street monitor.

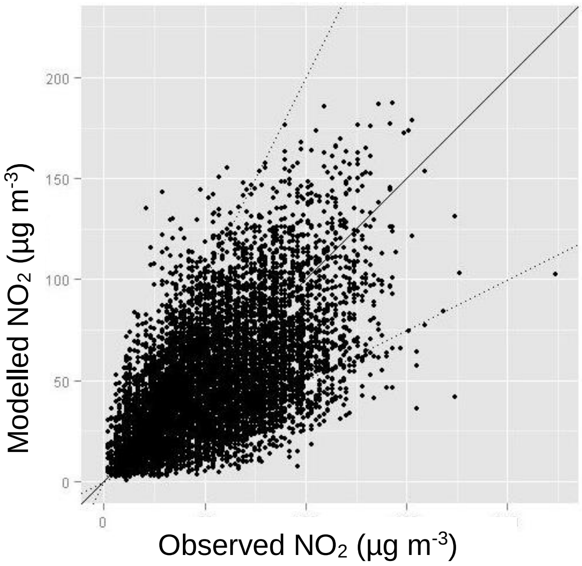


Figure 49: Union Street NO_2 Scatter Plot (Units: µg m^{-3})

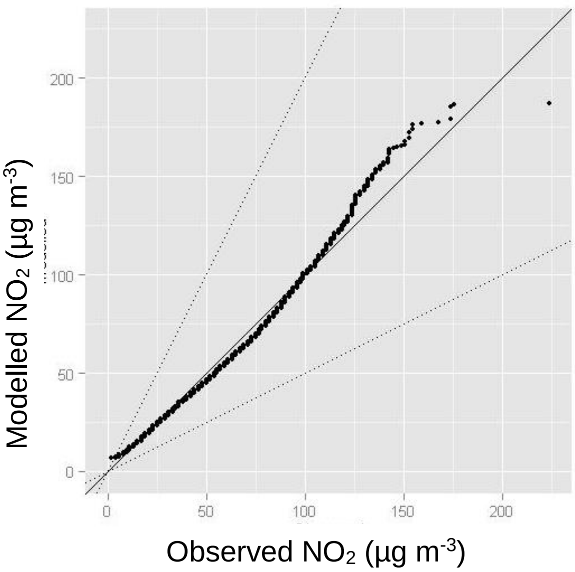


Figure 50: Union Street NO_2 Q-Q Plot (Units: µg m^{-3})

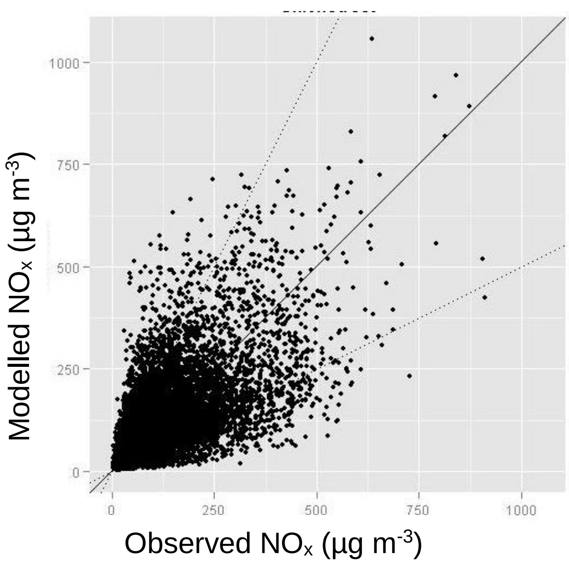


Figure 51: Union Street NO_x Scatter Plot (Units: µg m^{-3})

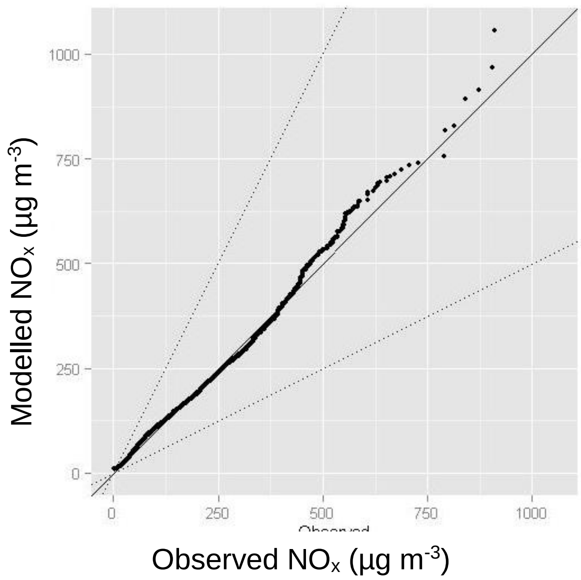


Figure 52: Union Street NO_x Q-Q Plot (Units: µg m^{-3})

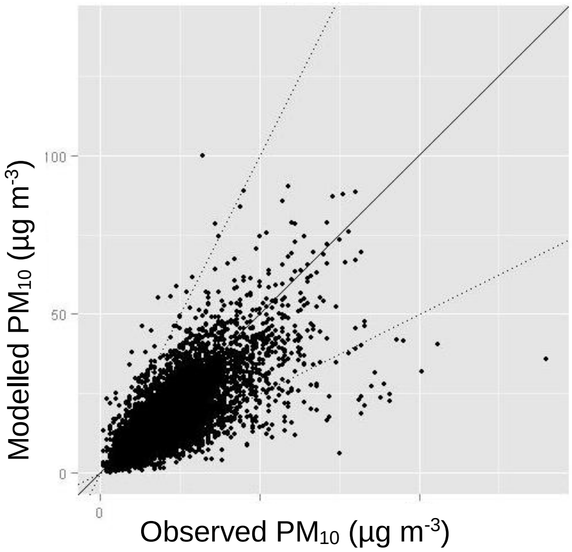


Figure 53: Union Street PM_{10} Scatter Plot (Units: $\mu g\ m^{-3}$)

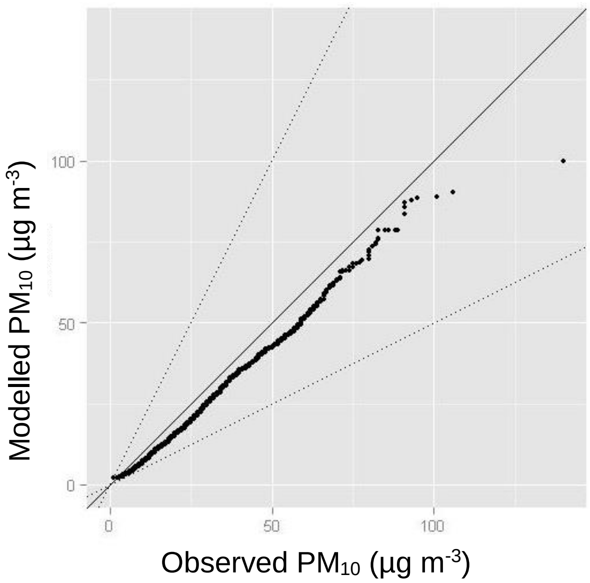


Figure 54: Union Street PM_{10} Q-Q Plot (Units: $\mu g\ m^{-3}$)

Table 34: Statistics for Base Run Model at Union Street (bold shows parameters which have failed tests described in Section 4.1)

Statistic	MG	VG	NMSE	FB	Fac2	MB	R
NO_2	0.91	1.48	0.28	-0.06	0.75	-3.24	0.59
NO_x	0.97	1.77	0.53	-0.02	0.64	-2.52	0.61
PM_{10}	0.75	1.32	0.24	-0.23	0.84	-4.43	0.74

4.2.3 Base Run Detailed Analysis: Market Street 2

The ‘Market Street 2’ monitor (which replaced the ‘Market Street’ monitor when it was removed in 2009) is located at the junction of Market Street and Poynernook Road (Figure 55, Figure 56). Although the monitor is located at the road junction, Market Street is bounded by buildings on the west side of most of the road, with few buildings on the east (harbour) side. Market Street can be considered to be 1-sided or asymmetric canyon. Unfortunately, ADMS-Urban 3.4 has no option to model asymmetric canyons, and so Market Street was modelled with no canyon. Traffic flows by this monitor indicate this is a busy route used by over 30,000 vehicles per day (Table 35)

Figure 55: 'Market Street 2' monitor looking east towards harbour

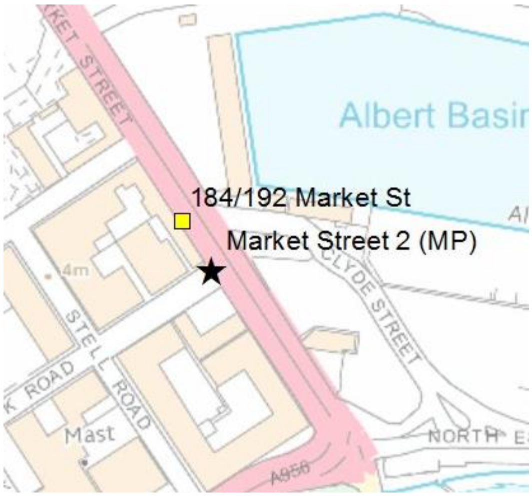


Figure 56: Map showing location of 'Market Street 2' monitor and diffusion tube at 184/192 Market Street

Table 35: Annual Average Daily Flow (AADF) by the Market Street 2 monitor (Section S6_7)

Vehicle Type	Motorcycle	Car	Bus	LGV	HGV	Total
Flow (AADF)	212	23059	759	4024	4629	32683

At the Market Street 2 monitor, the ‘Base Run’ is over-predicting the NO_2 annual mean by 8%, and the 99.79th percentile by 7% (Table 27), therefore the model is performing well within the constraints of the ADMS-Urban model for both NO_2 Air Quality Standards/Objectives at this location.

The ‘Base Run’ also performs well at the Market Street 2 monitor for the NO_x annual mean, over-predicting by 9% (Table 29). For the PM_{10} annual mean and 98.08th percentile of the 24 hour mean, the model is under-predicting by 23% and 37% respectively (Table 31).

The scatter plots for each pollutant (Figure 57, Figure 59 and Figure 61) at the Market Street 2 monitor show that for each hour there is (similar to Union Street) measureable variability for each hour within a year (which is to be expected) and there are some hours where the model over-predicts by a substantial amount.

The Quantile-Quantile plots (time dependency removed), show that the ‘Base Run’ for each pollutant is slightly over-predicting over the whole year for NO_2 and NO_x (Figure 58, Figure 60), but is still performing well. The Q-Q plot for PM_{10} (Figure 62) shows the ‘Base Run’ is under-predicting at the Market Street 2 monitor.

The performance statistics (Table 36) indicate that the ‘Base Run’ performs within the ranges outlined in Section 4.1. Interestingly, the statistics indicate the ‘Base Run’ is performing better for NO_2 than for NO_x. There appears to be more scatter in the NO_x scatter plot (Figure 59), and this is confirmed in the NMSE values (NO_2 is closer to 0).

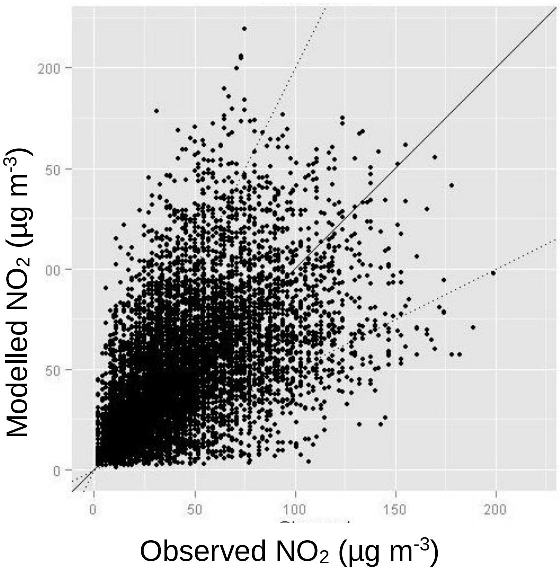


Figure 57: Market Street 2 NO_2 Scatter Plot (Units: µg m^{-3})

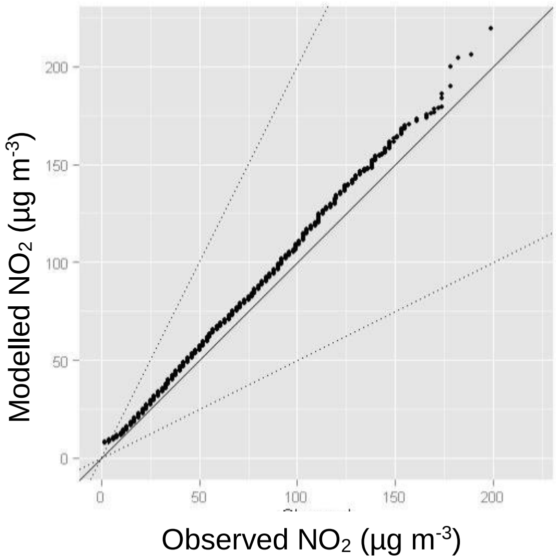


Figure 58: Market Street 2 NO_2 Q-Q Plot (Units: µg m^{-3})

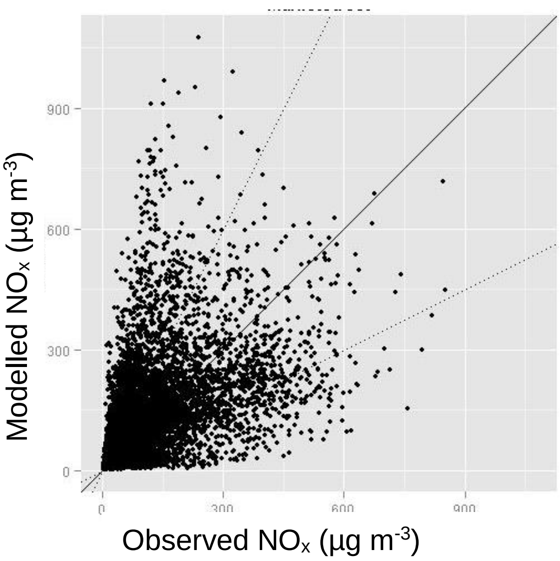


Figure 59: Market Street 2 NO_x Scatter Plot (Units: µg m^{-3})

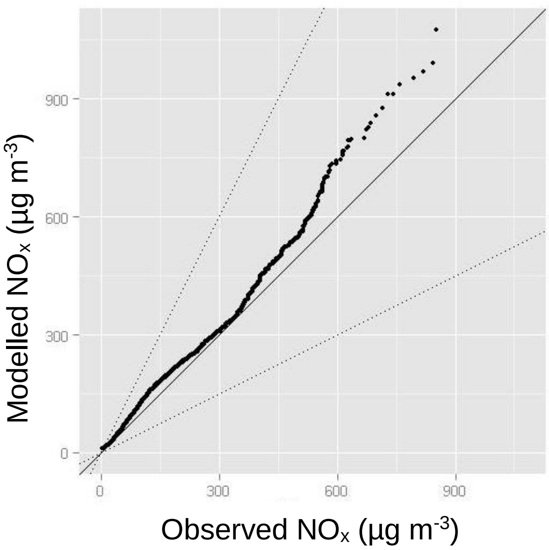


Figure 60: Market Street 2 NO_x Q-Q Plot (Units: µg m^{-3})

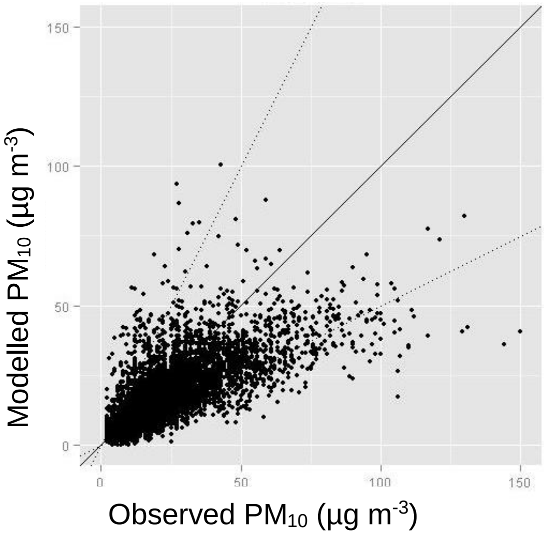


Figure 61: Market Street 2 PM_{10} Scatter Plot (Units: µg m^{-3})

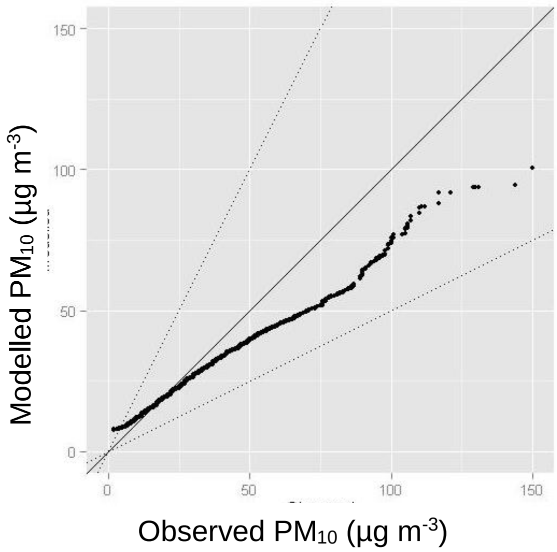


Figure 62: Market Street 2 PM_{10} Q-Q Plot (Units: µg m^{-3})

Table 36: Statistics for Base Run Model at 'Market Street 2' (bold shows parameters which have failed tests described in Section 4.1)

Pollutant	MG	VG	NMSE	FB	Fac2	MB	R
NO_2	1.11	1.63	0.42	0.1	0.72	4.69	0.55
NO_x	1.1	2.09	0.99	0.12	0.62	14.26	0.52
PM_{10}	0.76	1.42	0.43	-0.28	0.79	-5.5	0.73

Although the model may be performing well at the Market Street 2 monitor, the diffusion tube at 184/192 Market Street consistently measures concentrations which are greater than the automatic monitor (Table 37), even though the distance between the automatic monitor and diffusion tube is ~30m (Figure 56). Inter-annual variation will be discussed in more detail in Section 4.4.1, but it is found that the model under-predicts the bias-adjusted diffusion tube measurement for all years modelled by between 25% and 40% (Table 37).

Table 37: NO_2 Annual Mean Concentrations at 184/192 Market Street Diffusion Tube location (µg m^{-3})

Location	2009	2010	2011	2012	2013	2014
Diffusion Tube (unadjusted)	72	76	74	80	79	66
Diffusion Tube (bias adjusted)	64	76	64	71	70	54
Base Run Prediction	48.4	47.8	43.6	44.7	42.0	n/a

The Market Street 2 monitor is located in an open location where air flow may be less affected by buildings, whereas the diffusion tube is located next to a building in an asymmetric canyon (Figure 63). The air flow may not be conducive to good dispersion at the 184/192 Market Street, therefore higher pollutant concentrations may be found at this location. As the 'Base Run' does not account for building effects on Market Street, the model may be under-predicting pollutant concentrations along

Market Street where an asymmetric canyon exists (and other locations where asymmetric canyons exist).

Figure 63: Diffusion tubes at 184/192 Market Street

Computational Fluid Dynamics (CFD) modelling of Market Street at this location shows that for an East-North-East wind, the automatic monitor is located in a location where the wind velocity is similar to the wind velocity over the harbour (Figure 64), therefore ADMS-Urban is likely to predict representative dispersion at Market Street 2 using representative meteorological data.

However, the diffusion tube is located in an area where wind speeds are low and the wind direction is difficult to determine (possibly due to the effect of nearby buildings). Pollutant dispersion may be poor in these locations and the elevated concentration values observed at the diffusion tube may be due to the effect of buildings. Therefore a Gaussian dispersion model may under-estimate concentration values in areas where buildings exist, but where it is not possible to account for their effects.

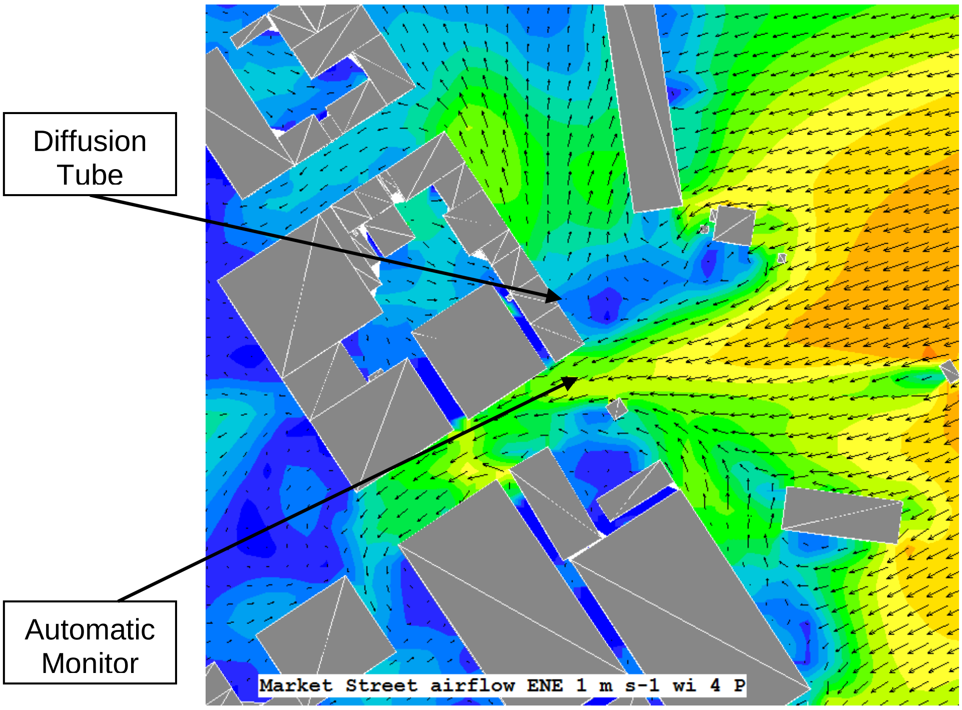


Figure 64: 'Market Street 2' CFD ground level flow field for North-East-North Wind.

4.2.4 Base Run Detailed Analysis: Wellington Road

The Wellington Road automatic monitor is located on the east side of Wellington Road, just north of Grampian Place (Figure 65, Figure 66). There are buildings located to the east (Figure 77), and Wellington Road is tree lined to the West. To the south of Grampian Place was Aberdeen prison, which was surrounded by high walls on the south side of Grampian Place, and east side of Wellington Road. Wellington Road, at this location, can be considered to be a 1-sided canyon (similar to Market Street), but as previously discussed, there is no option for accounting for the effects of an asymmetric canyon in ADMS-Urban 3.4, so Wellington Road was modelled with no canyon. This is a busy road section with a large number of LGV's and HGV's (Table 38).

Figure 65: Wellington Road Monitor looking north

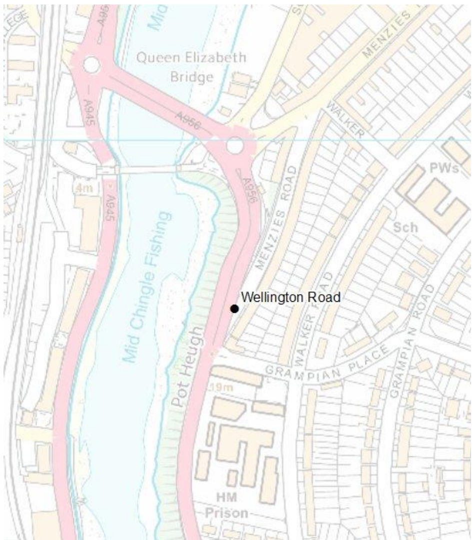


Figure 66: Map showing location of Wellington Road Monitor

Table 38: Annual Average Daily Flow (AADF) by the Wellington Road monitor (Section S2_C)

Vehicle Type	Motorcycle	Car	Bus	LGV	HGV	Total
Flow (AADF)	244	18917	433	2978	3863	26435

At the Wellington Road monitor, the 'Base Run' is under-predicting the NO_2 annual mean by 26%, and the 99.79th percentile by 11% (Table 27). The 'Base Run' is also under-predicting the NO_x annual mean by 28% (Table 29), and the PM_{10} annual mean and 98.08th percentile of the 24 hour mean, is underestimated by 27% and 31% respectively (Table 31).

The scatter plots for each pollutant (Figure 67, Figure 69 and Figure 71) at the Wellington Road monitor show that, as expected, for each hour there is quite a lot of variability for each hour over a year. It is clear that for NO_2 and NO_x there are hours when the 'Base Run' is under-predicting by a significant amount. The Q-Q plots also indicate that there is a significant under-prediction (Figure 68, Figure 70 and Figure 72) for all the pollutants.

The statistical analysis of Wellington Road (Table 39) shows that the ‘Base Run’ has failed some of the statistical tests outlined in Section 4.1. The fractional bias (FB) performs poorly overall, failing for NO_x and PM_{10}, and only just meeting the criteria for NO_2. NO_x also fails the Geometric Mean test (MG), and NO_2 and PM_{10} only just within the MG parameters in Section 4.1.

Although the ‘factor of 2’ statistic (Table 39) is comparable to other monitoring locations, the VG, FB and MG are significantly worse than other monitoring locations, suggesting that during time-steps of poor performance, the variance (under-prediction) is greater than for other locations and this has been investigated in more detail.

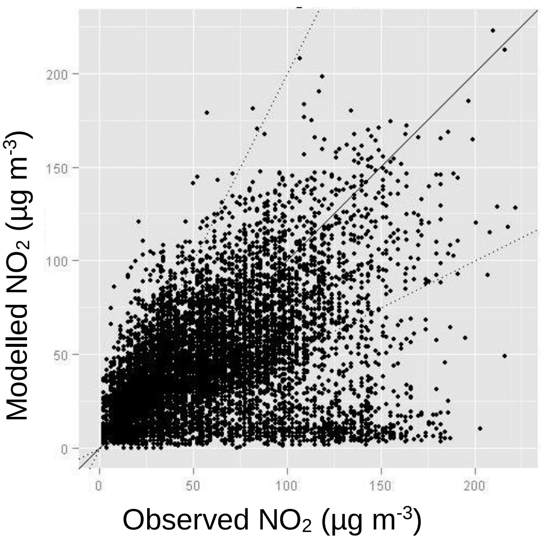


Figure 67: Wellington Road NO_2 Scatter Plot (Units: µg m^{-3})

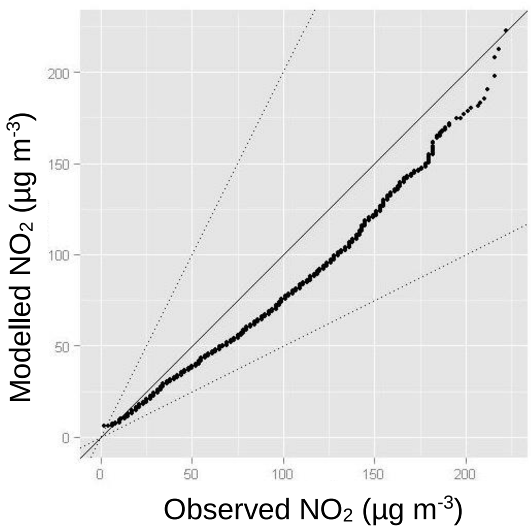


Figure 68: Wellington Road NO_2 Q-Q Plot (Units: µg m^{-3})

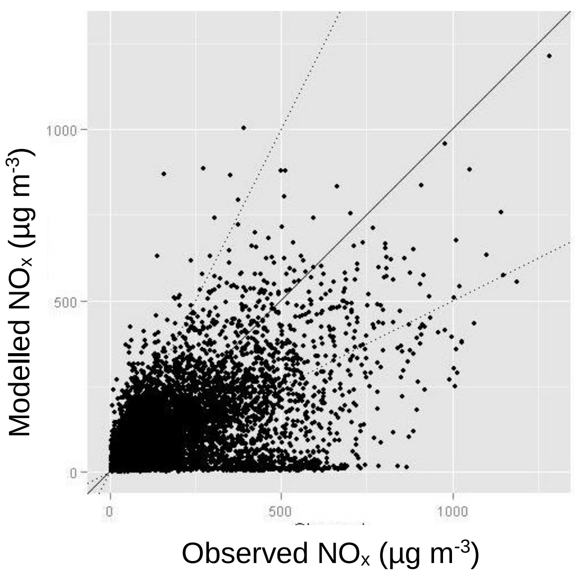


Figure 69: Wellington Road NO_x Scatter Plot (Units: µg m^{-3})

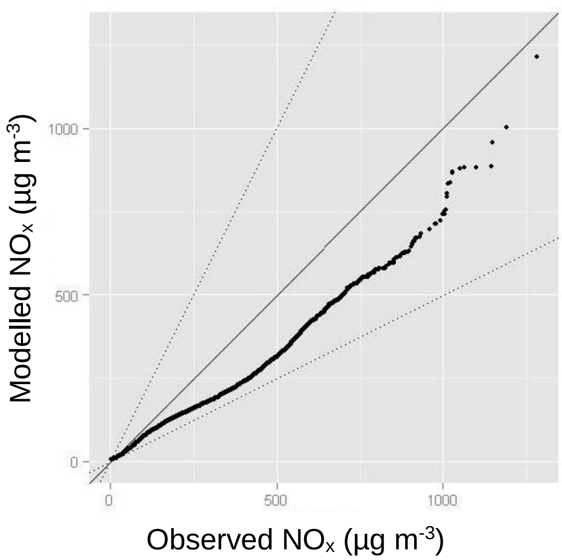


Figure 70: Wellington Road NO_x Q-Q Plot (Units: µg m^{-3})

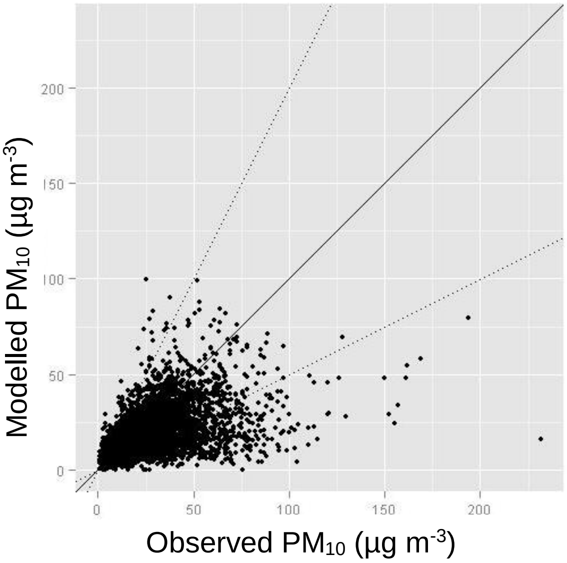


Figure 71: Wellington Road PM_{10} Scatter Plot (Units: $\mu g\ m^{-3}$)

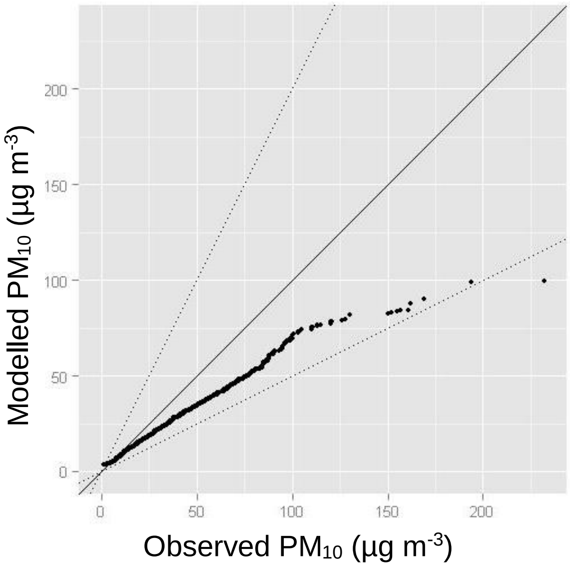


Figure 72: Wellington Road PM_{10} Q-Q Plot (Units: $\mu g\ m^{-3}$)

Table 39: Statistics for Base Run Model at Wellington Road (bold shows parameters which have failed tests described in Section 4.1)

Statistic	MG	VG	NMSE	FB	Fac2	MB	R
NO_2	0.74	2.82	0.64	-0.27	0.68	-14.08	0.42
NO_x	**0.62**	**5.55**	1.26	**-0.42**	0.55	-62	0.51
PM_{10}	0.73	1.65	0.58	**-0.32**	0.79	-6.48	0.56

A more detailed analysis of the ‘Base Run’ performance at Wellington Road was carried out using the Spotfire data analysis tool to better understand why ‘Base Run’ predictions were poor at this location. This analysis showed that there was good agreement for westerly winds (Figure 74) but poor agreement for easterly winds (Figure 73). Statistics for each wind direction show that the ‘Base Run’ performs within the ranges outlined in Section 4.1, with the exception of easterly winds (Table 40). Only 21% of model predictions were within a factor of 2 and the Geometric Variance was very large, confirming the ‘Base Run’ was performing poorly at Wellington Road when the wind direction is easterly.

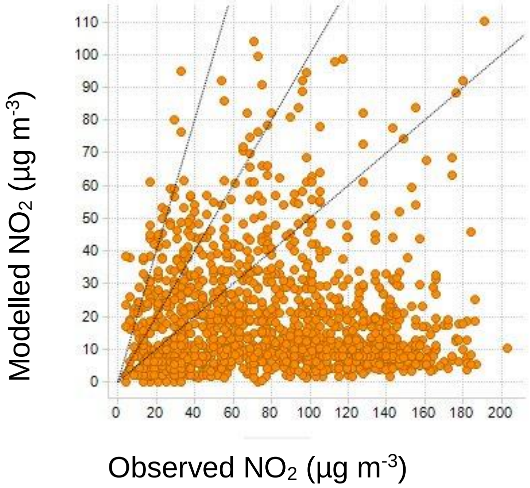


Figure 73: Wellington Road NO_2 Scatter Plot; Easterly Winds (µg m^{-3})

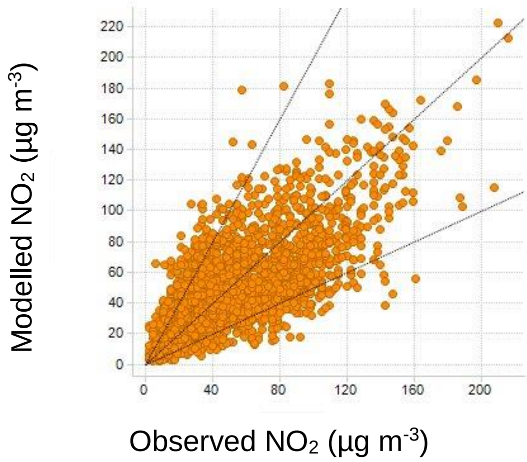


Figure 74: Wellington Road NO_2 Scatter Plot; Westerly Winds (µg m^{-3})

Table 40: NO_2 Statistic summary for different wind directions at Wellington Road (bold shows parameters which have failed tests described in Section 4.1)

Statistic	MG	VG	FB	NMSE	Fac2	MB
Easterly	**0.2**	**63.52**	**-1.23**	**3.99**	**0.21**	-61.2
Westerly	0.98	1.35	-0.08	0.26	0.77	-2.58
Northerly	0.83	1.63	-0.16	0.34	0.71	-8.78
Southerly	1.06	1.49	-0.10	0.31	0.81	-3.62

This is also confirmed in the OpenAir Polar plot for 2012 which shows that the highest concentrations occur when the wind is easterly (Figure 76). Using a tool built in Matlab for analysing ADMS-Urban hourly interpolated data (Figure 75), the highest concentrations during an easterly winds are predicted to occur to the west of Wellington Road (which is to be expected). Although there is a bus stop located close to the monitor, there are no significant sources in close proximity to the east of the Wellington Road.

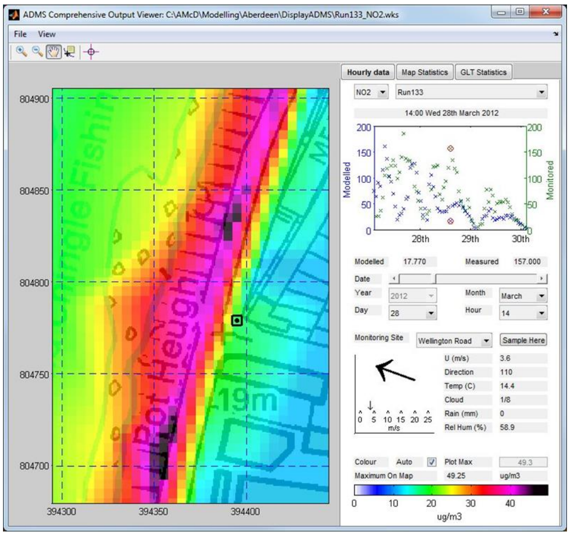


Figure 75: Example hourly interpolated model predictions for an easterly wind

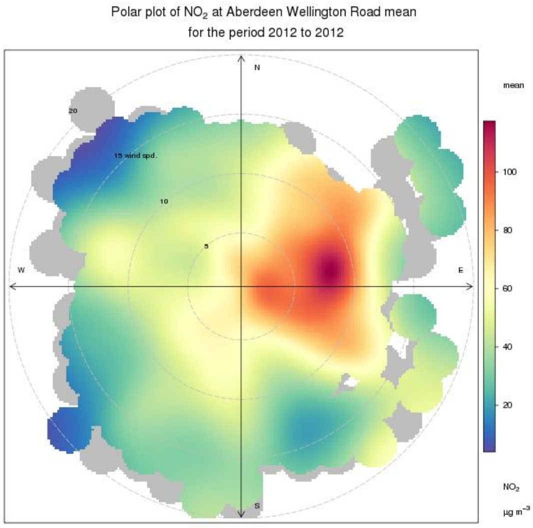


Figure 76: Polar Plot of NO_2 concentrations at Wellington Road

Figure 77: Wellington Road monitor from west, which shows proximity to buildings located to the East of the monitor.

To investigate this further, the area around the Wellington Road monitor was set-up in the Computational Fluid Dynamics (CFD) model, PHEONICS, with a tracer release to represent the road source. The CFD model predicted that during easterly winds, a recirculation zone is formed due to the building geometry and the wind direction at ground level at the monitor is westerly (Figure 78).

When the same easterly wind direction was viewed from above (Figure 79), the CFD model predicted that the air flow converges at the location where the monitor is sited and a northerly air flow is generated to the north of the monitor which will carry the pollutants towards the monitor. The tracer dispersion also shows that the pollutant concentrations may be high in the vicinity of the monitor during easterly wind events. For a westerly wind, the CFD model predicts the air flow is steady at the monitor (Figure 80), which will be similar to the flow field used by ADMS-Urban at this location.

As an alternative, the same scenario (easterly wind) was set-up in the MISKAM software package (Section 2.6.2); the predicted flow field is very similar to the flow field predicted by PHOENICS (Figure 81).

CFD output highlights the potential for local and complex air flow to influence observed Air Quality data. As discussed, this is not well represented by the simplified approach taken by ADMS-Urban. Nevertheless, the Wellington Road example shows the benefit of comparing even a simplified model to real data using a slightly deeper analysis.

In summary, the Wellington Road monitor may be in an area where, during easterly winds, concentrations are elevated. This may not be representative of wider conditions along Wellington Road. In assessing the compliance of the wider Wellington Road area with AQS it may be beneficial to collect additional high quality measurements.

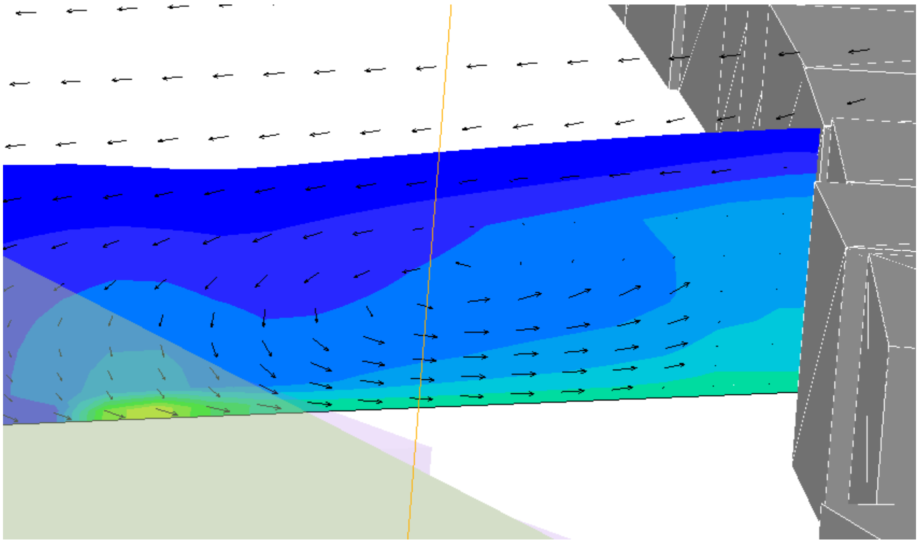


Figure 78: Wellington Road CFD flow field and tracer dispersion from road source for Easterly Wind (vertical slice)

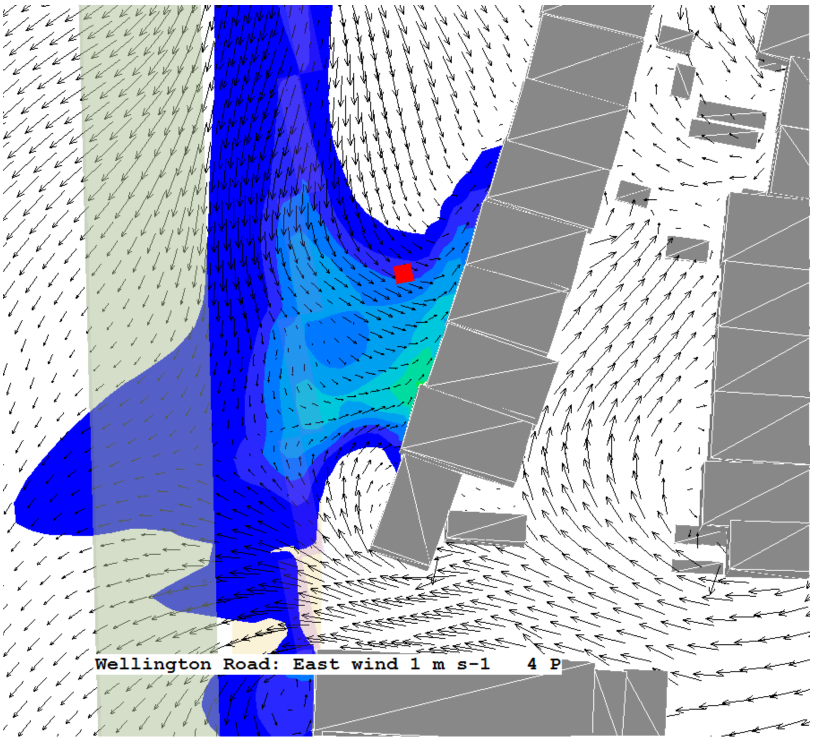


Figure 79: Wellington Road CFD ground level flow field and tracer dispersion from road source for Easterly Wind. Red marker is monitor location; brown band represents trees.

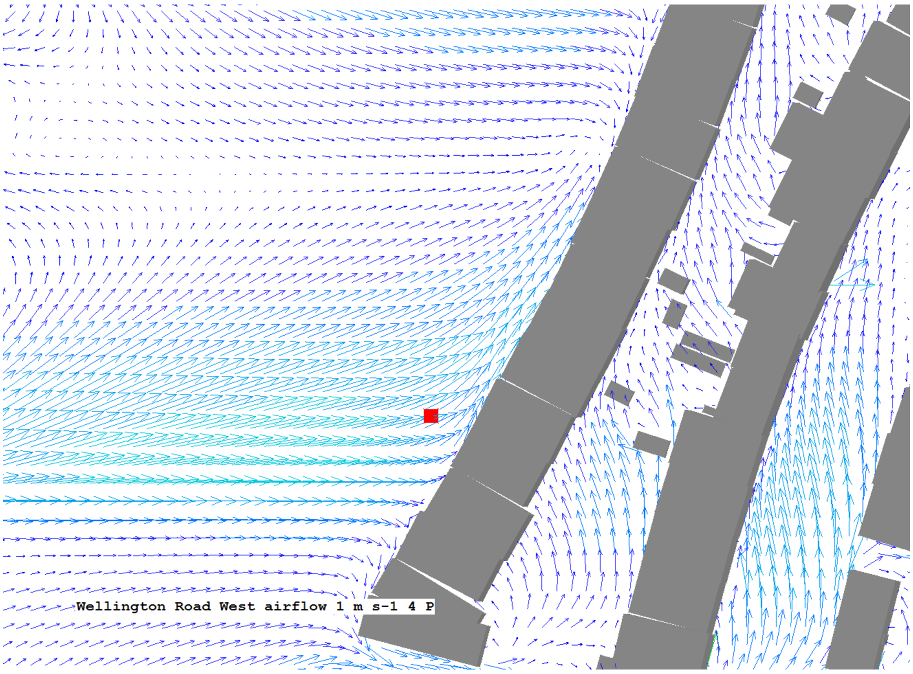


Figure 80: Wellington Road CFD ground level flow field for Westerly Wind. Red marker is monitor location.

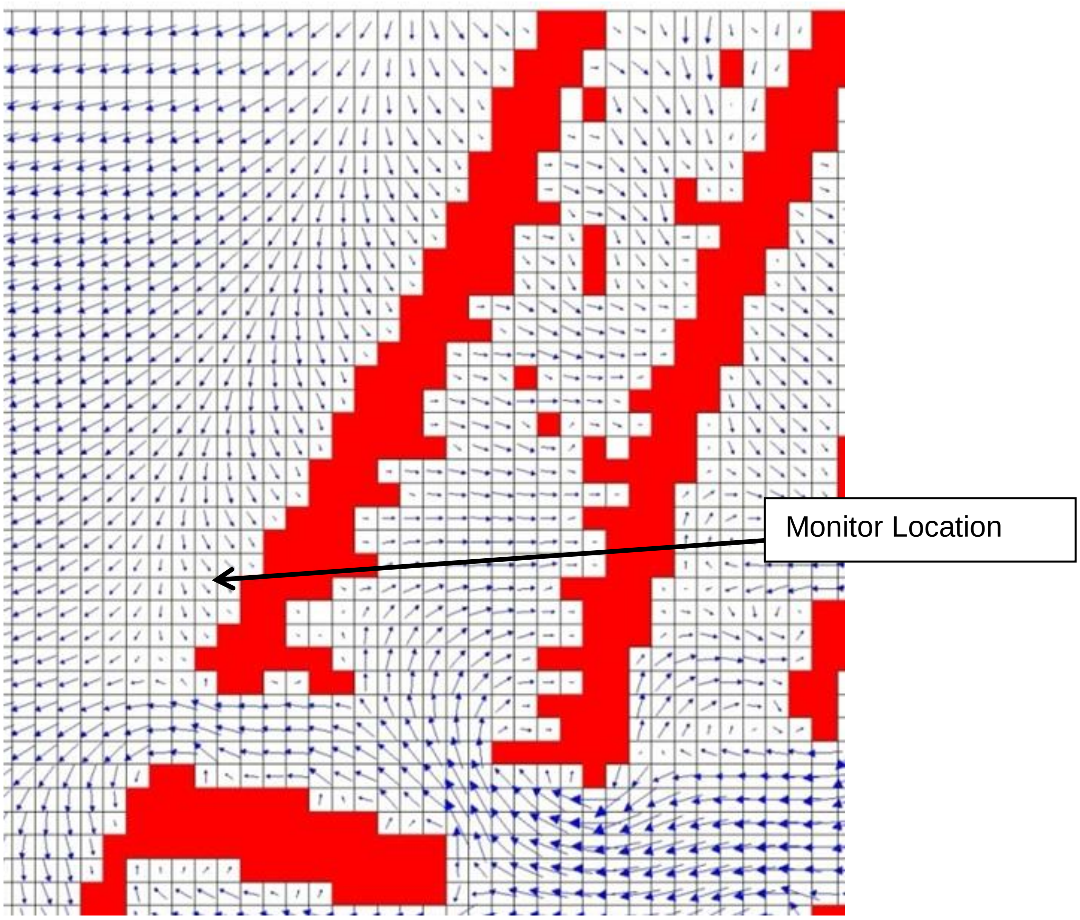


Figure 81: Wellington Road MISKAM ground level flow field for an Easterly Wind

4.2.5 Base Run Detailed Analysis: King Street

The King Street monitor is located on the east side of King Street between Harrow Road and Seaton Place (opposite to a petrol station). This section of King Street runs from the Bridge of Don to the roundabout with School Road and St Machar Drive, and is a main route into Aberdeen from the north. The nearby buildings are of a suburban nature, and although there are a few 3 storey buildings nearby, the street is not classed as a canyon. This is a busy road section for traffic as it links the city to areas north of Aberdeen and carried over 25000 vehicles per day (Table 41).

Figure 82: Map showing location of King Street monitor

Table 41: Annual Average Daily Flow (AADF) by the King Street monitor (Section S2_C)

Vehicle Type	Motorcycle	Car	Bus	LGV	HGV	Total
Flow (AADF)	111	19578	751	2685	2436	25561

At the King Street monitor, the 'Base Run' is over-predicting the NO_2 annual mean by 23%, and the 99.79th percentile by 26% (Table 27), and is also over-predicting the NO_x annual mean by 22% (Table 29).

However, the 'Base Run' is under-predicting the PM_{10} annual mean and 98.08th percentile of the 24 hour mean by 15% and 30% respectively (Table 31).

The scatter plots for each pollutant (Figure 83, Figure 85 and Figure 87) at the King Street Road monitor show that, as expected, for each hour there is quite a lot of variability for each hour over a year, though the NMSE value (Table 27) shows the amount of scatter is less than, and the R value is better than other monitors.

The Q-Q plots also indicate that the 'Base Run' is over-predicting at the King Street monitor (Figure 84, Figure 86 and Figure 88) for NO_2 and NO_x; the positive bias values in Table 42 also indicate an over-prediction for NO_2 and NO_x.

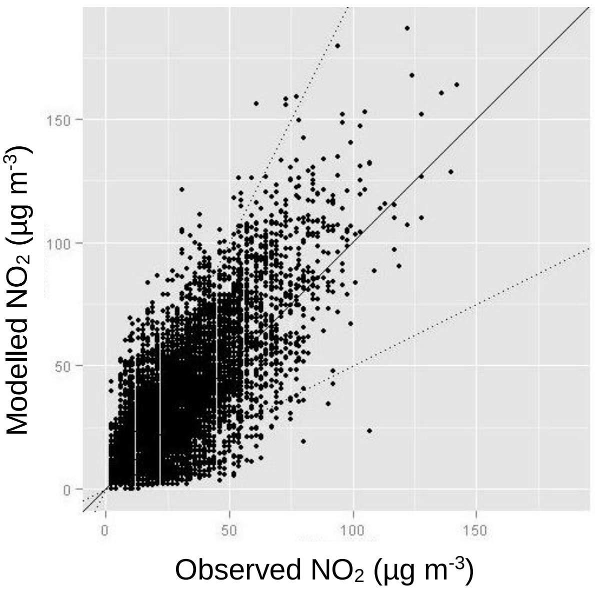


Figure 83: King Street NO_2 Scatter Plot (Units: µg m^{-3})

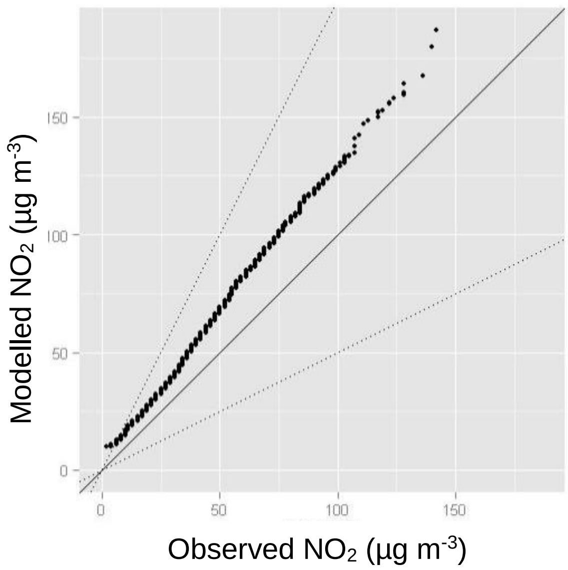


Figure 84: King Street NO_2 Q-Q Plot (Units: µg m^{-3})

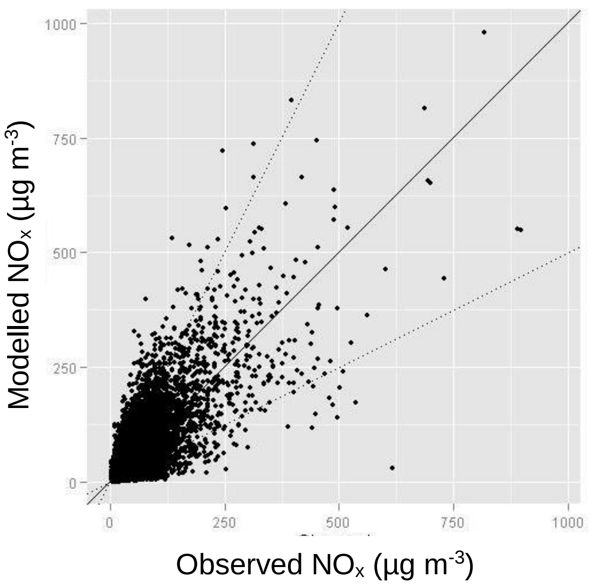


Figure 85: King Street NO_x Scatter Plot (Units: µg m^{-3})

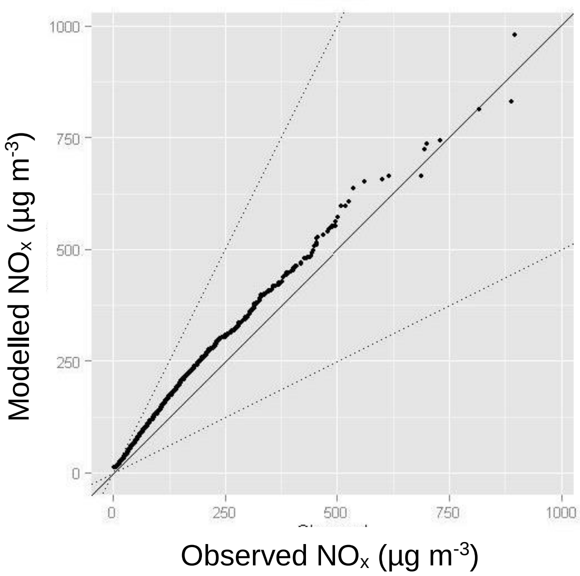


Figure 86: King Street NO_x Q-Q plot (Units: µg m^{-3})

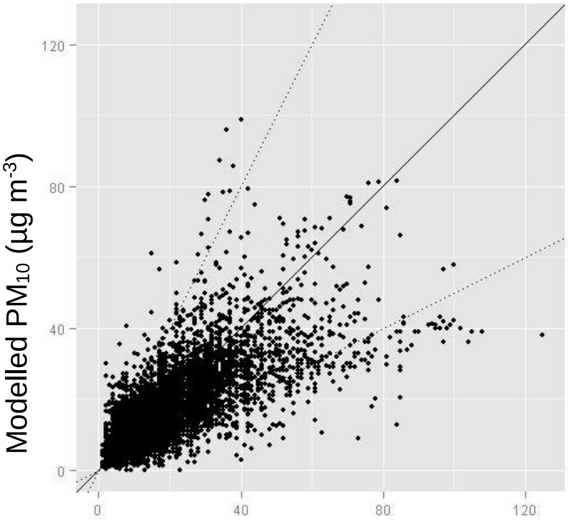


Figure 87: King Street PM_{10} Scatter Plot (Units: µg m^{-3})

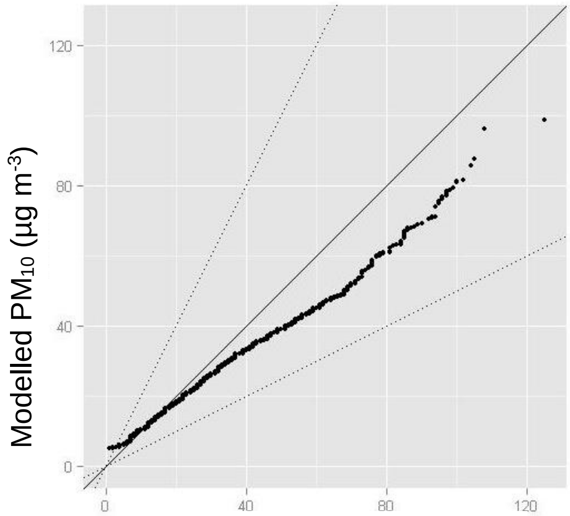


Figure 88: King Street PM_{10} Q-Q Plot (Units: µg m^{-3})

Table 42: Statistics for Base Run Model at King Street (bold shows parameters which have failed tests described in Section 4.1)

Statistic	MG	VG	NMSE	FB	Fac2	MB	R
NO_2	1.15	1.65	0.31	0.2	0.75	6.32	0.74
NO_x	1.11	2.07	0.57	0.18	0.63	13.11	0.74
PM_{10}	0.89	1.4	0.3	-0.14	0.85	-2.44	0.72

Statistical analysis of each wind direction at King Street shows that the ‘Base Run’ tends to over-predict for when the wind direction is westerly, northerly or southerly, but under-predict for easterly winds (Figure 89, Figure 90, and Table 43). Only when the wind direction is northerly are the critical statistics achieved; when the wind direction is easterly, southerly or westerly, the ‘Base Run’ falls outside the Geometric Mean Bias range outlined in Section 4.1 (Table 43). Easterly and westerly wind directions also fall outside the Fractional Bias range; for easterly winds, the ‘Base Run’ under-predicts and for westerly winds, it over-predicts.

The OpenAir polar plot for King Street (Figure 91) shows that the highest concentrations originate from the west (road side) of the monitor and high NO_2 concentrations also occur during periods of easterly winds, despite there being very few sources to the east of the monitor.

CFD modelling indicates that for easterly winds, an anti-clockwise recirculation zone is set up just to the south of the monitor. This may transport pollutants from the road towards the monitor, and could possibly account for observed concentrations which are greater than the model predictions (Figure 93 and Table 43).

For other wind directions, CFD modelling shows that for westerly and southerly wind directions, the wind speed, and therefore dispersion, is low at the monitor (Figure 92, Figure 94 and Table 43).

In a similar situation to that encountered at Wellington road, all information suggest that the King Street monitor is in an area with complex air flow and, consequently, highly variable dispersion. This goes some way to explaining the complex pattern seen in the King Street Polar Plot (Figure 91). As in the case of Wellington road additional high quality measurements along the street may be required to assess its compliance with AQS.

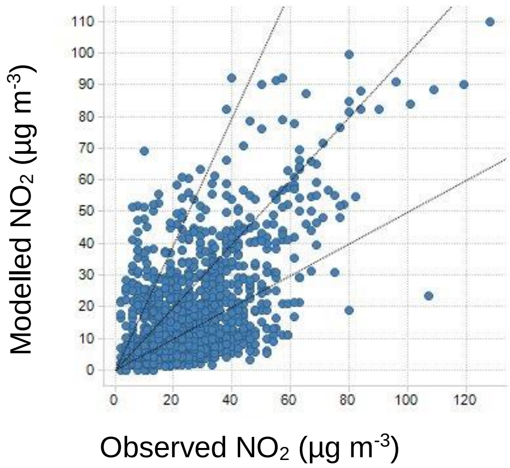


Figure 89: King Street NO_2 Scatter Plot; Easterly Winds (µg m^{-3})

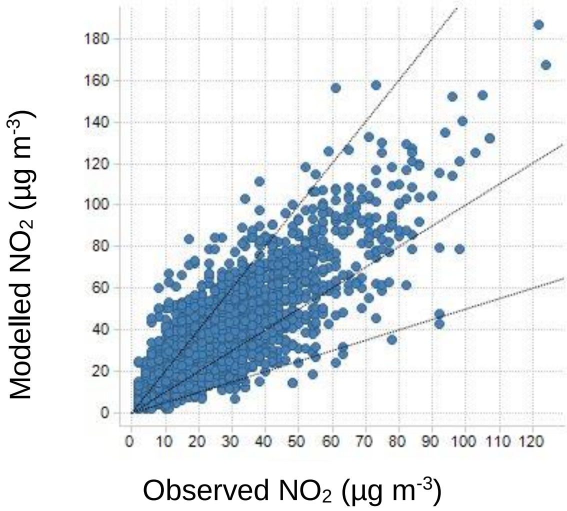


Figure 90: King Street NO_2 Scatter Plot; Westerly Winds (µg m^{-3})

Table 43: NO_2 Statistic summary for Model Performance at King Street for different wind sectors (bold shows parameters which have failed tests described in Section 4.1)

Statistic	MG	VG	NMSE	FB	Fac2	MB
Easterly	**0.57**	3.23	0.61	**-0.66**	0.52	-8
Westerly	**1.47**	1.49	0.35	**0.41**	0.71	11
Northerly	1.23	1.53	0.48	0.20	0.73	17.17
Southerly	**1.33**	1.47	0.44	0.24	0.74	17.16

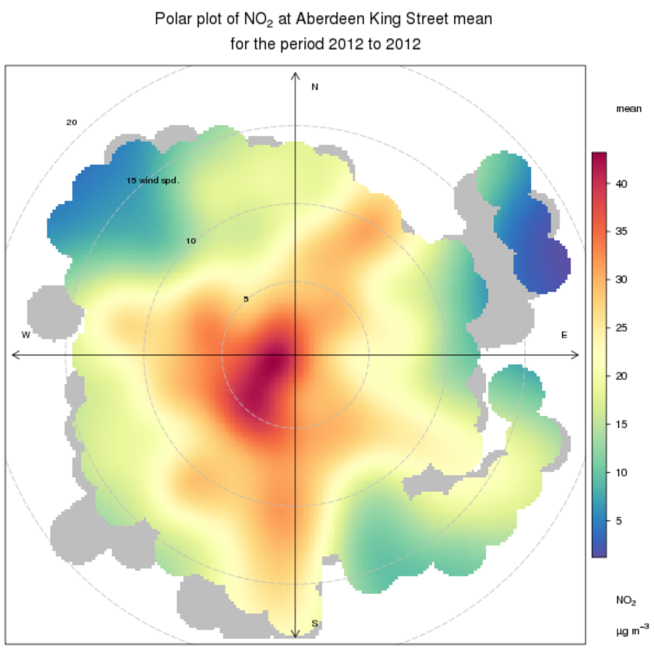


Figure 91: Polar Plot of NO2 concentrations at King Street

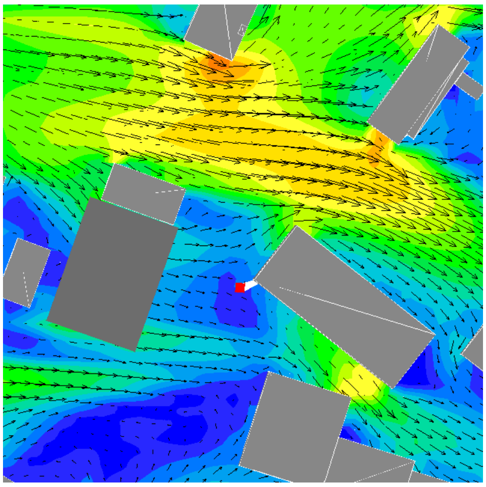


Figure 92: CFD flow field for King Street for Westerly winds. Arrow size and colour represents wind speed. (Red spot is monitor location)

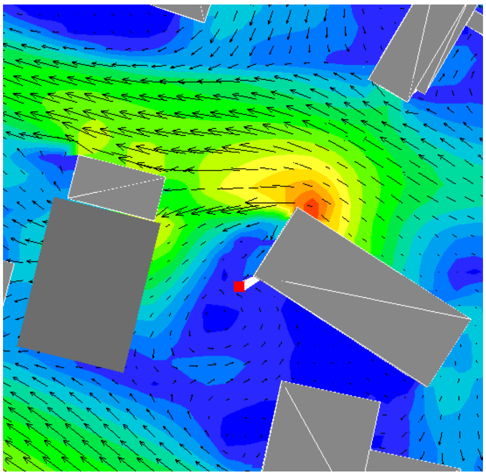


Figure 93: CFD flow field for King Street for Easterly winds. Arrow size and colour represents wind speed. (Red spot is monitor location)

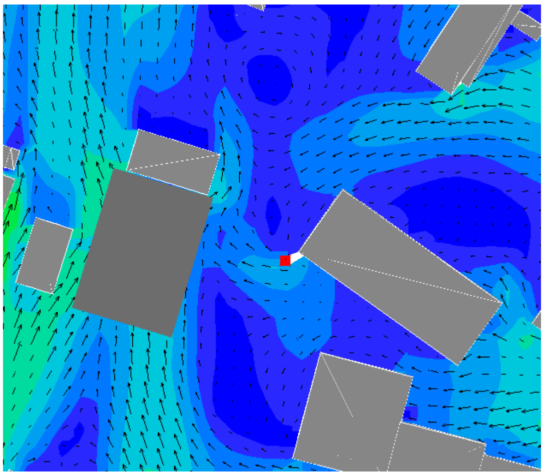


Figure 94: CFD flow field for King Street for Southerly winds. Arrow size and colour represents wind speed. (Red spot is monitor location)

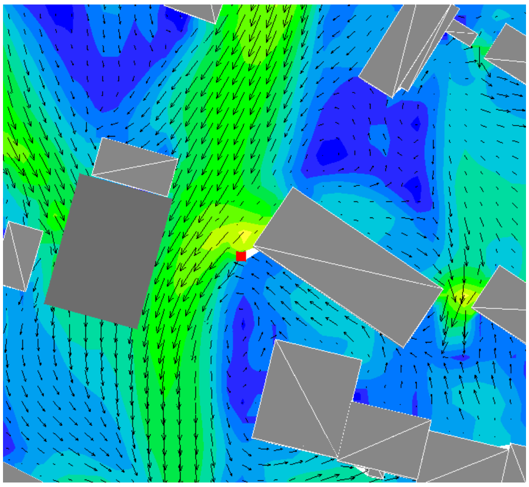


Figure 95: CFD flow field for King Street for Northerly winds. Arrow size and colour represents wind speed. (Red spot is monitor location)

4.2.6 Base Run Detailed Analysis: Anderson Drive

The Anderson Drive monitor is located on the west side of South Anderson Drive between Broomhill Road and Garthdee Roundabout (opposite Broomhill Avenue) where the road configuration changes from dual carriageway to single carriageway (Figure 96). The surrounding buildings are residential suburban, and the road is not classified as a canyon. This is a trunk road and major route for traffic travelling from north to south on the west side of the Aberdeen with around 28224 vehicles per day (Table 44).

Figure 96: Map showing location of Anderson Drive monitor

Table 44: Annual Average Daily Flow (AADF) by the Anderson Drive monitor (Section S2_C) Note: This data originates from the DfT traffic count website (17)

Vehicle Type	Motorcycle	Car	Bus	LGV	HGV	Total
Flow (AADF)	321	22855	37	3404	1607	28224

At the Anderson Drive monitor, the ‘Base Run’ is over-predicting the NO_2 annual mean by 3% and the 99.79th percentile by 6% (Table 27). The difference between the ‘Base Run’ NO_x annual mean prediction and the observed value is <1% (Table 29).

The ‘Base Run’ is under-predicting the PM_{10} annual mean by 4%, whilst difference between the ‘Base Run’ and observed values for the 98.08th percentile of the 24 hour mean is <1% (Table 31).

Despite these results suggesting the ‘Base Run’ is performing well at Anderson Drive for the Air Quality Standards/Objectives, the NO_2 and NO_x scatter and Q-Q plots suggest the performance may not be as good as initially thought.
The statistical analysis (Table 45) indicates the performance is within the ranges outlined in Section 4.1, however there is a lot of spread in the NO_2 and NO_x scatter plots, which is reflected in the NMSE statistic (only Wellington Road is worse) and there is also poor correlation. Also, only just over 50% of data points in the NO_2 and NO_x scatter plots are within a factor of 2. Performance is worse for NO_x; there appear to be many data points where under-prediction or over-prediction is large.
The Q-Q plots also show that there is an over-prediction, which is especially significant for large NO_x values.

There may be a number of reasons for this: the Errol Place background site may not be representative for the Anderson Drive monitor (they are located on different sides of the city or local air flow affect may affect the measurements). It was also found in inter-annual sensitivity tests the observed value for Anderson Drive in 2012 was significantly greater than for other years and model performance was not as good. This is discussed is more detail in Section 4.4.1.

However, the 'Base Run' does however perform well for PM_{10}, the scatter is significantly less (high R, low NMSE and high FAC2), and a fractional bias (FB) which is very close to 0.

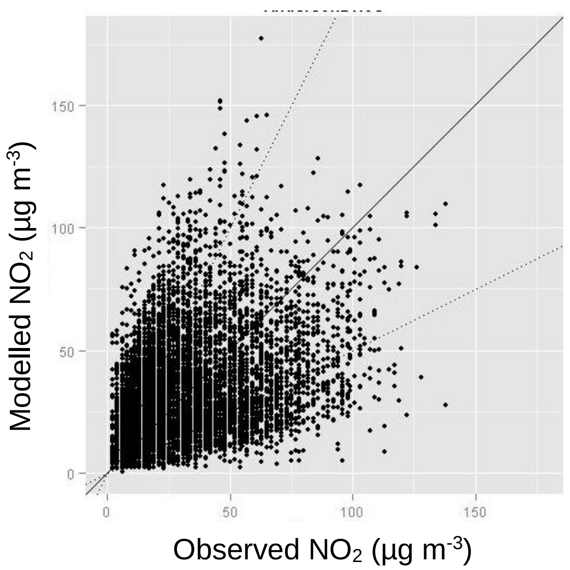


Figure 97: Anderson Drive NO_2 Scatter Plot (Units: µg m^{-3})

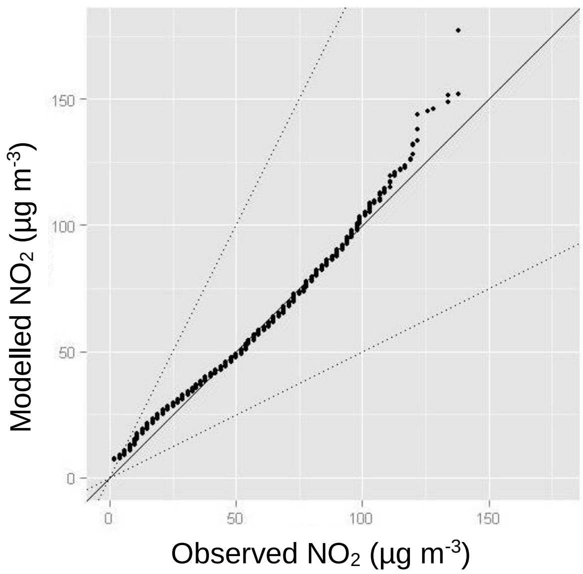


Figure 98: Anderson Drive NO_2 Q-Q Plot (Units: µg m^{-3})

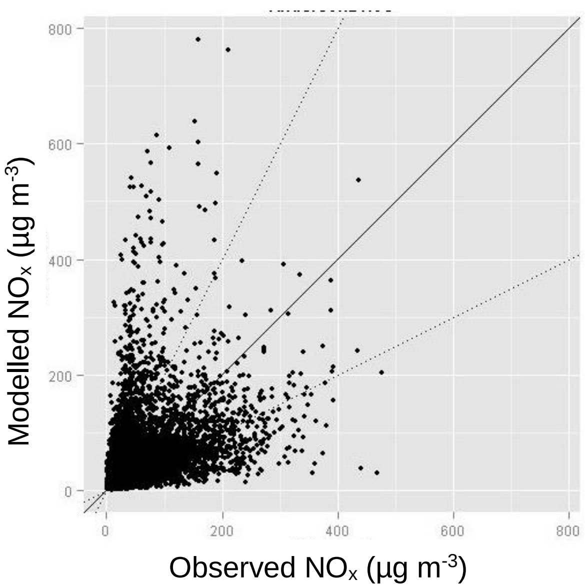


Figure 99: Anderson Drive NO_x Scatter Plot (Units: µg m^{-3})

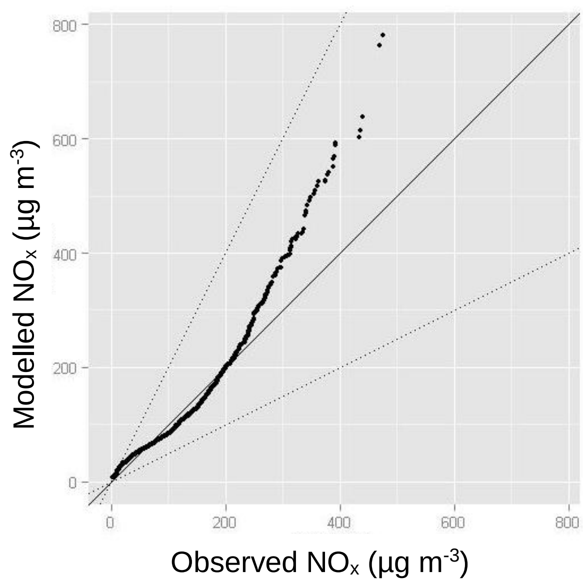


Figure 100: Anderson Drive NO_x Q-Q Plot (Units: µg m^{-3})

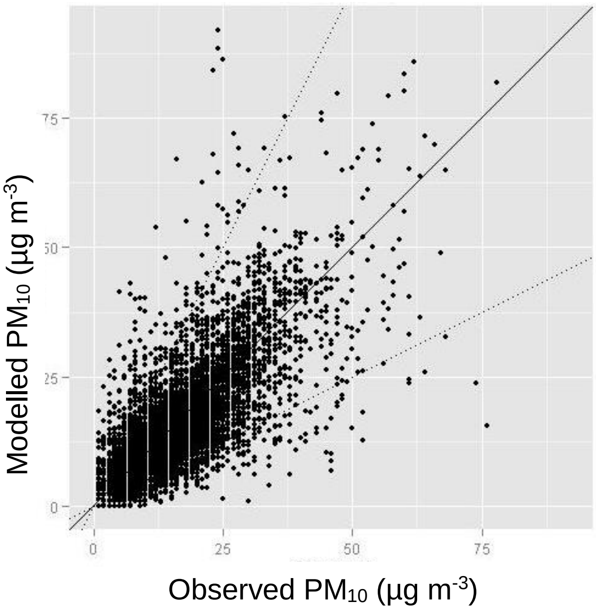


Figure 101: Anderson Drive PM_{10} Scatter Plot (Units: µg m^{-3})

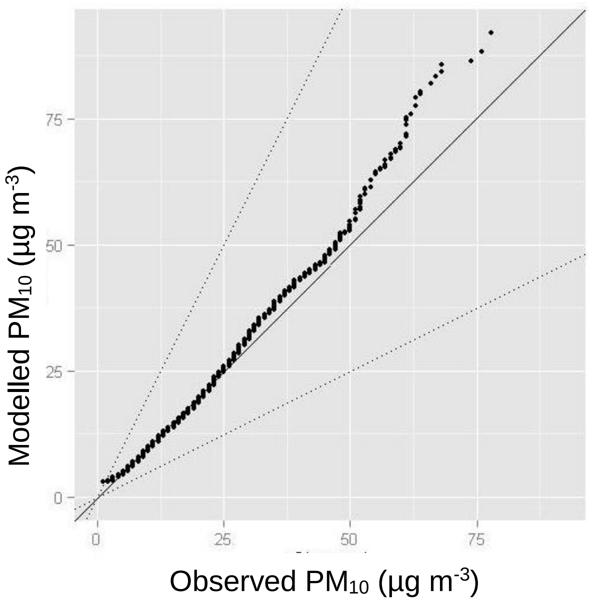


Figure 102: Anderson Drive PM_{10} Q-Q Plot (Units: µg m^{-3})

Table 45: Statistics for Base Run Model at Anderson Drive (bold shows parameters which have failed tests described in Section 4.1)

Statistic	MG	VG	NMSE	FB	Fac2	MB	R
NO_2	1.14	1.96	0.61	0.06	0.57	1.77	0.39
NO_x	1.14	2.35	1.32	0.03	0.5	1.82	0.37
PM_{10}	0.9	1.56	0.22	-0.04	0.86	-0.62	0.76

4.2.7 Diffusion Tube Results (NO_2 Annual Mean only)

The performance of the 'Base Run' can also be assessed against diffusion tube measurements (Nitrogen Dioxide annual mean only).

At the diffusion tube locations, the 'Base Run' under-predicts diffusion tube unadjusted (Figure 103) and bias-adjusted (Figure 104) NO_2 concentration at most monitoring locations, though most are within a factor of 2. This is unsurprising due to diffusion tube limitations (Section 1.3.2).

Plotting the observed/modelled ratio shows the locations where the model is under-predicting, and also, at some locations where the diffusion tubes are located closest to automatic monitors, the difference between modelled and observed concentrations can be significant (Figure 105, Figure 106)

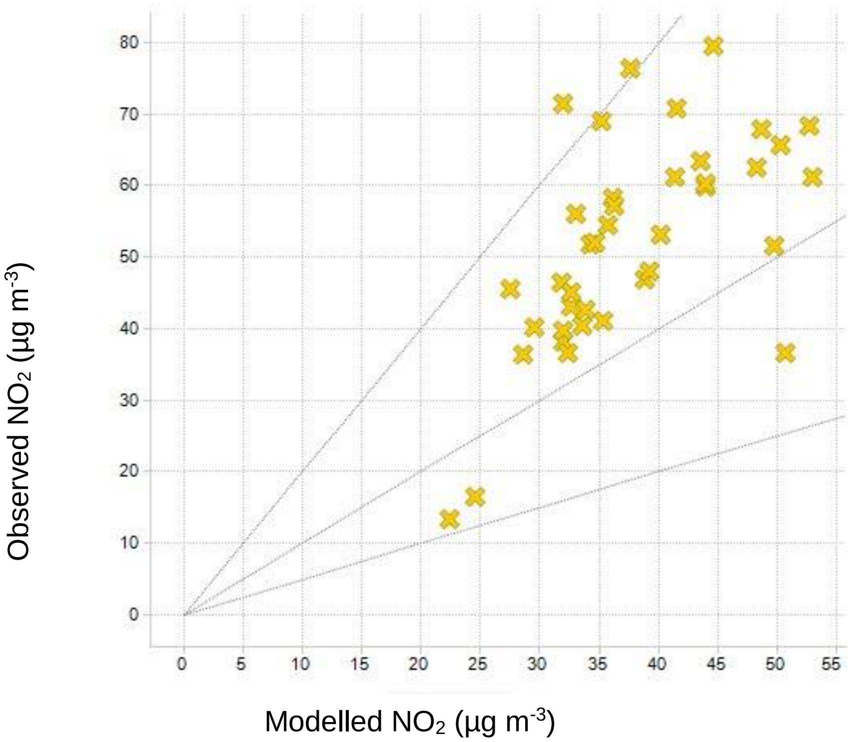


Figure 103: Observed (unadjusted) v Modelled concentrations at Diffusion tube locations (Base Run) (Units: µg m^{-3}). Note: Due to a technical reason, above 1:1 line is model underestimate)

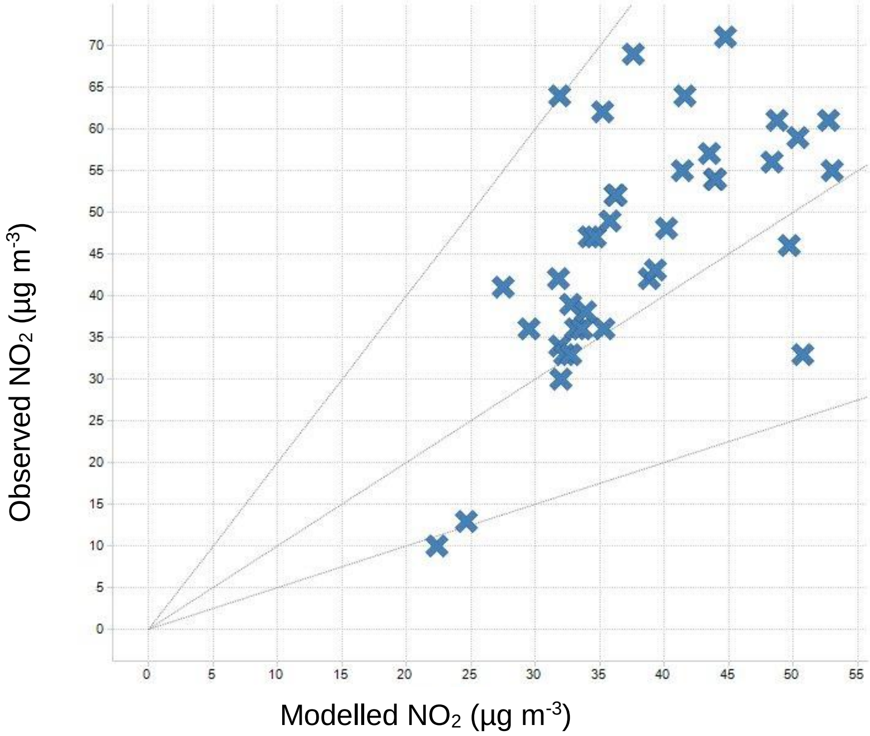


Figure 104: Observed (bias adjusted) v Modelled concentrations at Diffusion tube locations (Base Run) (Units: µg m^{-3}). Note: Due to a technical reason, above 1:1 line is model underestimate)

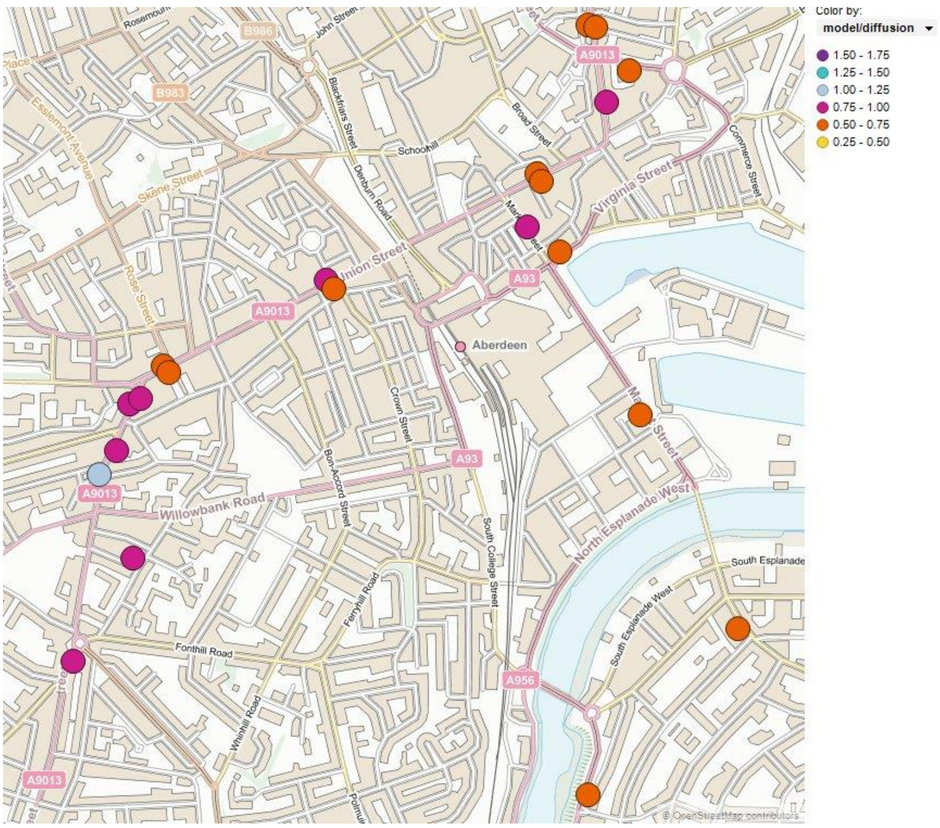


Figure 105: Map of city centre diffusion tube locations showing model/diffusion tube (unadjusted) ratios. Values <1 indicate model under-prediction, >1 indicate model over-prediction

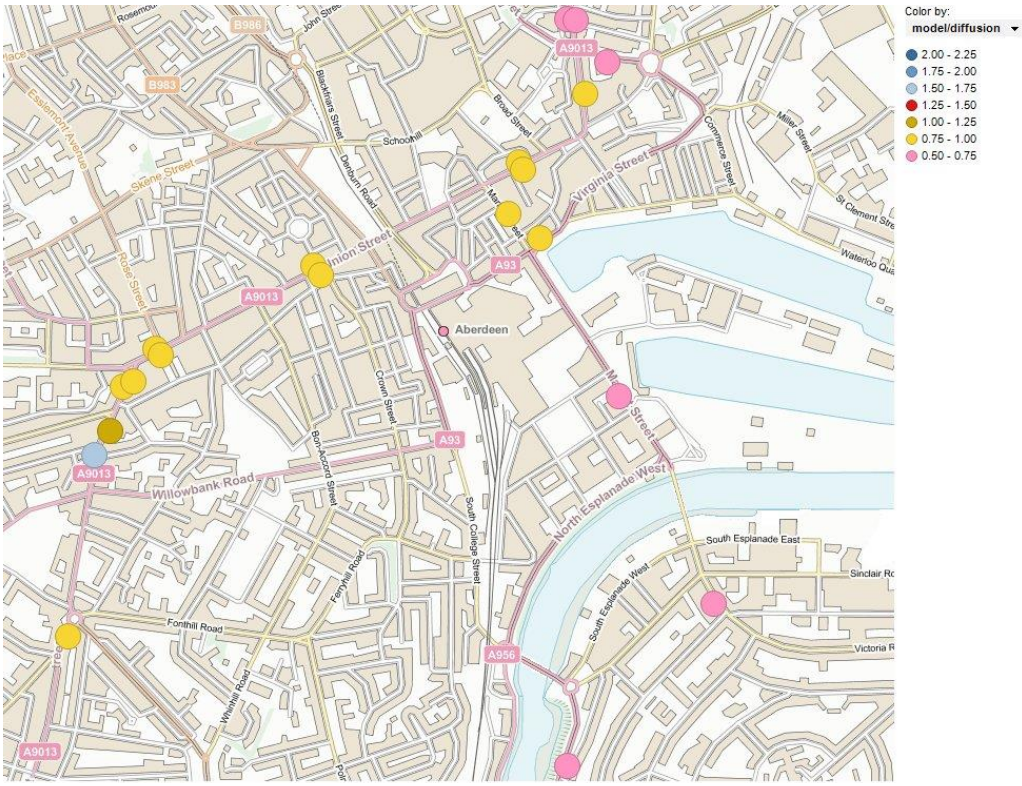


Figure 106: Map of city centre diffusion tube locations showing model/diffusion tube (bias-adjusted) ratios. Values <1 indicate model under-prediction, >1 indicate model over-prediction

4.2.8 Spatial Results

The results can also be viewed over a large area, either using GIS interpolation techniques, or by visualising the predicted concentrations at the roadside points (Section 3.12 and Figure 43).

Contour Plots

Contour Plots can be generated using the ADMS-Urban ArcGIS tool. This tool utilises the ADMS-Urban *.glt output file (Section 3.12.1); the model predictions are interpolated to visualise the concentrations over the model domain (Figure 107 to Figure 109**)**. Contour plots are useful as they provide a spatial context of the predicted concentrations and can identify the main areas of interests (e.g. city centre), or highlight specific roads where there may be air quality concerns.
The limitations of producing contour plots is that there are uncertainties associated with interpolation methods and the long model run times required to generate *.glt files for contour plots (for the ‘Base Run, the model took ~108 hours for the gridded output compared to ~19 hours for only specified points).

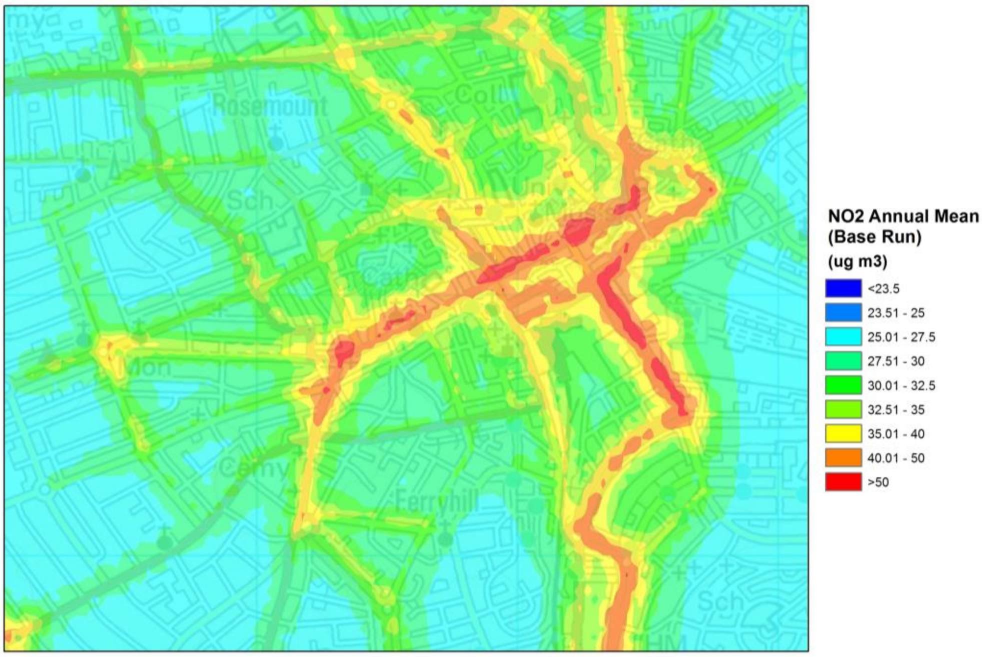


Figure 107: Predicted NO_2 Annual Mean concentration (µg m^{-3}) in Aberdeen City Centre (Base Run)

Figure 108: Predicted NO_2 Annual Mean concentration (µg m^{-3}) in Aberdeen (Base Run)

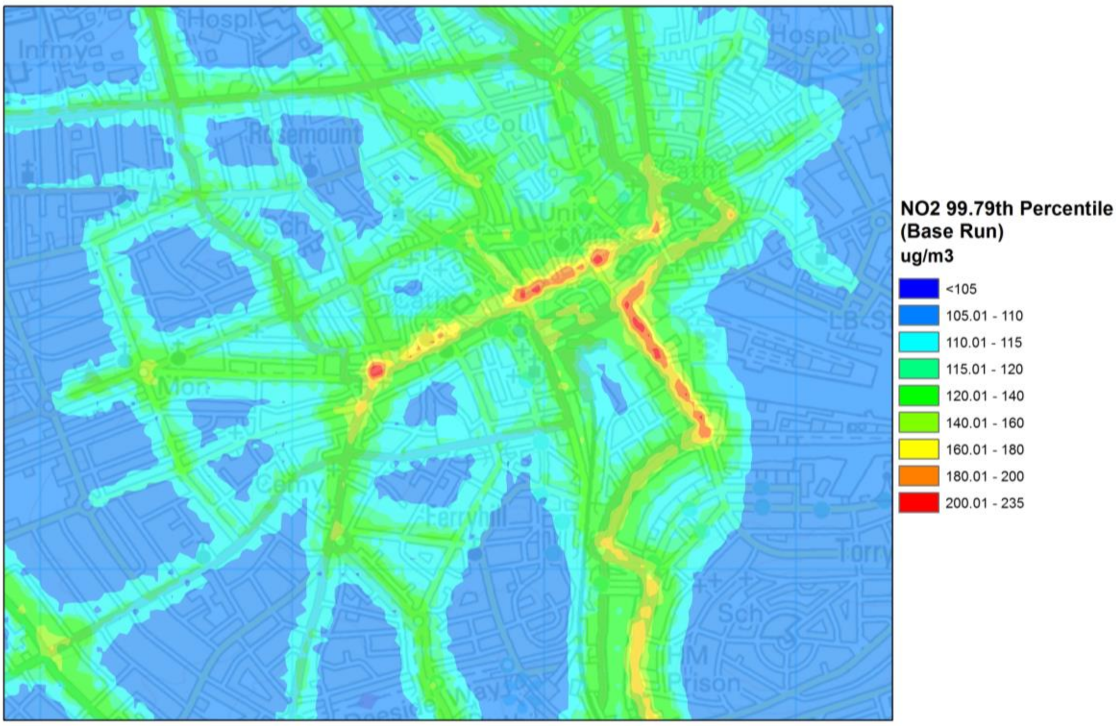


Figure 109: Predicted NO_2 99.79th percentile concentration (µg m^{-3}) in Aberdeen (Base Run)

Roadside Points Analysis

The predicted concentrations at Roadside Points can be plotted either using ArcGIS or Spotfire using *.plt files (Section 3.12.2). This allows easy comparison at specific points of model predictions and quickly identifies the locations where the model predicts compliance or failure of the air quality standards (Figure 110), and also ensures the same output grid points in each model run.

This shows that exceedances of the NO_2 annual mean are predicted along most major roads in Aberdeen, but also, where there are isolated points where exceedances are predicted (such as a road junction), this suggests that air quality exceedances may occur at these locations, and further investigation would be required.

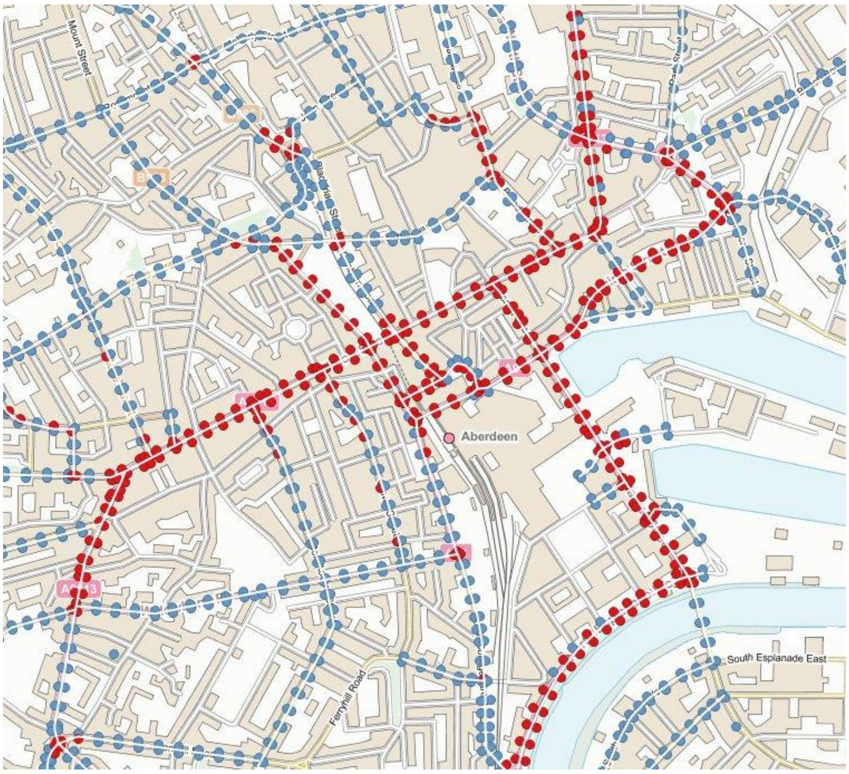


Figure 110: Roadside Points for NO_2 Annual Mean Concentrations (Base Run) (Red values are greater than 40 μg m^{-3})

4.2.9 Detailed Statistical Analysis of Base Run

A detailed statistical analysis of the Base Run was carried out as part of a Glasgow University Master of Science project (34). This used a variety of methods such as Deming Regression, Extreme Value Analysis, Functional Principal Components Analysis (PCA) and Clustering and Functional Regression to examine the model-measurement agreements in space and time.

It was found that through Functional PCA, Clustering Regression and Deming Regression that the model does not perform well at Wellington Road, but does perform well at other monitoring locations. Analysis also showed that roads appear to be the main cause of air pollution in Aberdeen, and that the model did not perform well between early April and mid-July.

As part of the statistical analysis, modelled data was compared with automatic and diffusion tube monitoring data, Figure 111 and Figure 112 show the differences when road sources are included and excluded. The differences are small, though the ADMS-Urban model tends to underestimate.

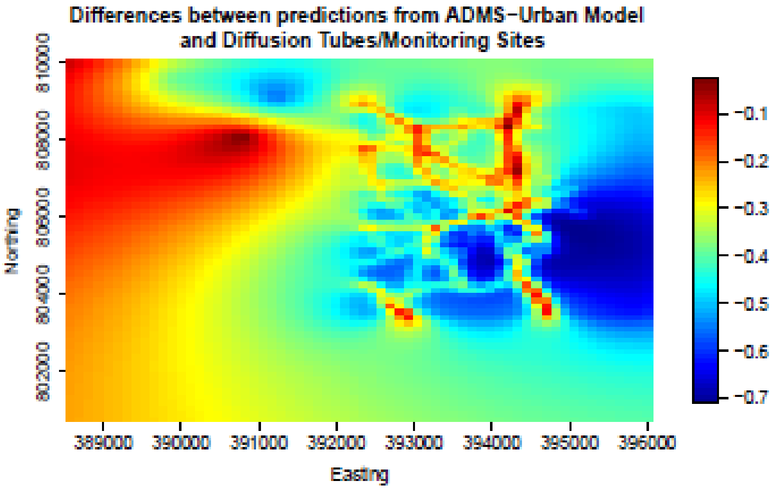


Figure 111: Map of the model measurement differences including roads (from 'Statistical Methods for Air Quality Calibration and Validation in Urban Areas' (34))

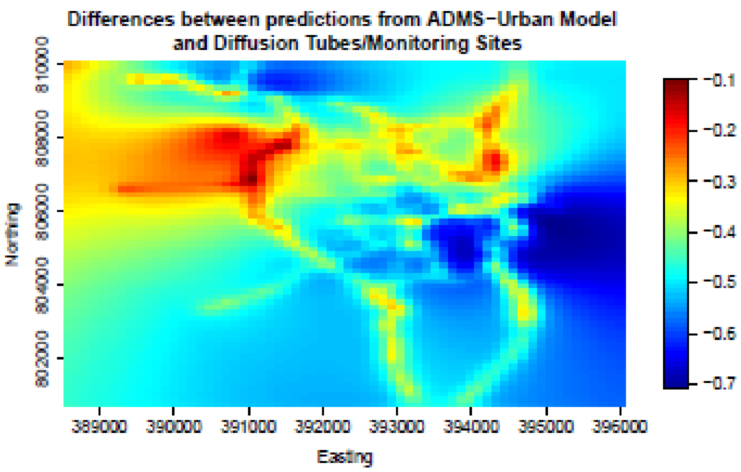


Figure 112: Map of the model measurement differences excluding roads (from 'Statistical Methods for Air Quality Calibration and Validation in Urban Areas' (34))

4.2.10 Base Run Summary

The 'Base Run' statistics show that the model is performing well against automatic monitoring data (with the exception of Wellington Road). It is important that several methods, such as using rural background data with gridded area emissions, and that sensitivity tests are carried out to assess how model results vary with different input data (e.g. meteorological data).

Overall, the 'Base Run' passes all statistical tests outlined in Section 4.1 for NO_2, and only Wellington Road fails the Geometric Variance, Geometric Mean Bias and Fractional Bias tests for NO_x. When 'Base Run' predictions area examined in more detail such as for specific wind directions, more clues on the model performance emerge, as is shown for Wellington Road, King Street and Market Street (Section 4.2.3, 4.2.4 and 4.2.5).

It is found that the 'Base Run' tends to over-predict for southerly winds at all automatic monitors (Table 46):

- Geometric Mean Bias (MG) values for southerly winds fall out of acceptable range outlined in Section 4.1 for all monitors (except Wellington Road).
- Fractional Bias values for southerly winds indicate over-predictions which only just fall within the acceptable range (except Wellington Road).

These over-predictions may be due to higher NO_2 background concentrations at Errol Place for southerly winds which may be due to the Errol Place capturing high concentrations due to city centre emissions (e.g. traffic, shipping emissions etc.).

Table 46: Bias Statistics for 'Base Run' NO2 Annual Mean for different wind directions (bold shows parameters which have failed tests described in Section 4.1)

Monitoring Point	MG				FB			
	E	N	S	W	E	N	S	W
Union Street	0.94	0.78	**1.38**	0.72	0	-0.19	0.29	-0.27
Market Street 2	0.90	1.13	**1.5**	0.89	-0.12	0.17	0.29	-0.09
Wellington Road	**0.20**	0.83	1.06	0.98	**-1.23**	-0.16	-0.10	-0.08
King Street	**0.57**	1.2	**1.35**	**1.47**	**-0.35**	0.21	0.27	**0.35**
Anderson Drive	0.84	0.82	**1.76**	1.15	-0.22	-0.15	**0.44**	0.06

The 'Base Run' also performs differently for varying stability conditions; the Fractional Bias (FB) statistics indicate that under-prediction occurs during convective conditions and over-prediction occurs during stable conditions (Table 47), though most are within the ranges outlined in Section 4.1. This may be due to the way ADMS-Urban deals with dispersion during different stability conditions.

Table 47: Bias Statistics for 'Base Run' NO_2 Annual Mean for Convective and Stable atmospheric conditions (bold shows parameters which have failed tests described in Section 4.1)

Monitoring Point	MG		FB	
	Convective	Stable	Convective	Stable
Union Street	0.82	0.98	-0.21	0.03
Market Street 2	0.91	1.24	-0.15	0.22
Wellington Road	**0.44**	0.93	**-0.68**	-0.08
King Street	0.86	1.30	-0.02	0.29
Anderson Drive	0.82	1.29	**-0.32**	0.17

4.3 Rural Background Concentrations and Gridded Area Emissions

An alternative to using the Errol Place urban background concentration data (Section 3.10.1) to represent background in ADMS-Urban is to use the published NAEI gridded area emission estimates as ADMS-Urban 'Grid Sources' along with hourly concentrations from a rural monitor (Section 3.10.2).

The model set-up is identical with the exception of background data:

- Non-major traffic emissions are generated using NAEI emission inventories and explicitly calculated aggregated road sources are included in ADMS-Urban as Gridded Area Sources.
- Hourly background data from a rural monitoring station is required, though few rural monitoring stations exist. Bush Estate (NO_2 only) and Auchencorth Moss (PM_{10} only), both of which are located to the south of Edinburgh are the closest rural monitors to Aberdeen, and are used in this study.

This approach predicts the annual mean for NO_2 and NO_x at all monitors (Table 48 and Table 49), to vary from -28% to +4% for NO_2 and -39% to +5% for NO_x at roadside monitors. The best prediction of the NO_2 annual mean is at Market Street 2 (3% over-prediction), which is closer to the annual mean than the 'Base Run' (8% over-prediction; Table 27).

Using this method, model predictions using this method are better at Market Street 2 and King Street, however are not as good at other roadside locations for NO_2 and NO_x

Model predictions are better for the 99.79th percentile, ranging from a 20% under-prediction to a 7% over-prediction.

Table 48: NO_2 Results for Air Quality Standards/Objectives using Background Area Emissions

Monitoring Point	Annual Mean (µg m^{-3})			99.79th Percentile of 1hr Means (µg m^{-3})		
	Observed	Model	Ratio	Observed	Model	Ratio
Union Street	52.8	48.3	0.91	143	150.5	1.05
Market Street 2	44.1	45.4	1.03	161	158.7	0.99
Wellington Road	59.1	42.5	0.72	187.8	155.1	0.83
King Street	29.2	30.5	1.04	107	114.4	1.07
Anderson Drive	30.4	24.2	0.80	115	100.5	0.87
Errol Place	21	26.3	1.25	105	83.7	0.80

Table 49: NOx Results using Background Area Emissions

Monitoring Point	Annual Mean (µg m^{-3})		
	Observed	Model	Ratio
Union Street	136.2	130	0.95
Market Street 2	110.5	115.6	1.05
Wellington Road	179.5	109.2	0.61
King Street	65.7	67.1	1.02
Anderson Drive	55.8	42	0.75
Errol Place	36	41.2	1.14

This method also under-predicts the PM_{10} annual mean and 98.08th percentile of the 24-hourly mean by around 35 to 45% at roadside monitors (Table 50) compared to 15-25% for the Base Run; however, as NO_2, is the main focus of this report this will not be analysed any further.

Table 50: PM_{10} Results for Air Quality Standards/Objectives using Background Area Emissions

Monitoring Point	Annual Mean (µg m^{-3})			98.08th Percentile of 24hr Means (µg m^{-3})		
	Observed	Model	Ratio	Observed	Model	Ratio
Union Street	21.3	13.4	0.63	47.0	31.1	0.66
Market Street 2	22.4	13.8	0.62	64.0	33.2	0.52
Wellington Road	23.4	13.5	0.58	52.6	30.4	0.58
King Street	18.6	11.9	0.64	50.1	28.2	0.56
Anderson Drive	15	10.2	0.68	36.4	27.4	0.75
Errol Place	12	9.7	0.81	34.2	24.9	0.73

When comparing the predictions of the Background Area Emissions approach to the ‘Base Run’, the Background Area Emission annual mean predictions for NO_2 and NO_x are slightly lower (less than 5%) for the ‘Base Run’ for city centre locations, 15% lower at King Street and 23% at Anderson Drive (Appendix A2: Table 68 and Table 69)

Comparisons of observed and predicted values indicate that there are locations where the ‘Base Run’ performs better than the Background Area Emissions approach (Union Street, Wellington Road and Anderson Drive) and vice versa for all NO_2 Air Quality Standards (Figure 113, Figure 114 and Figure 115)

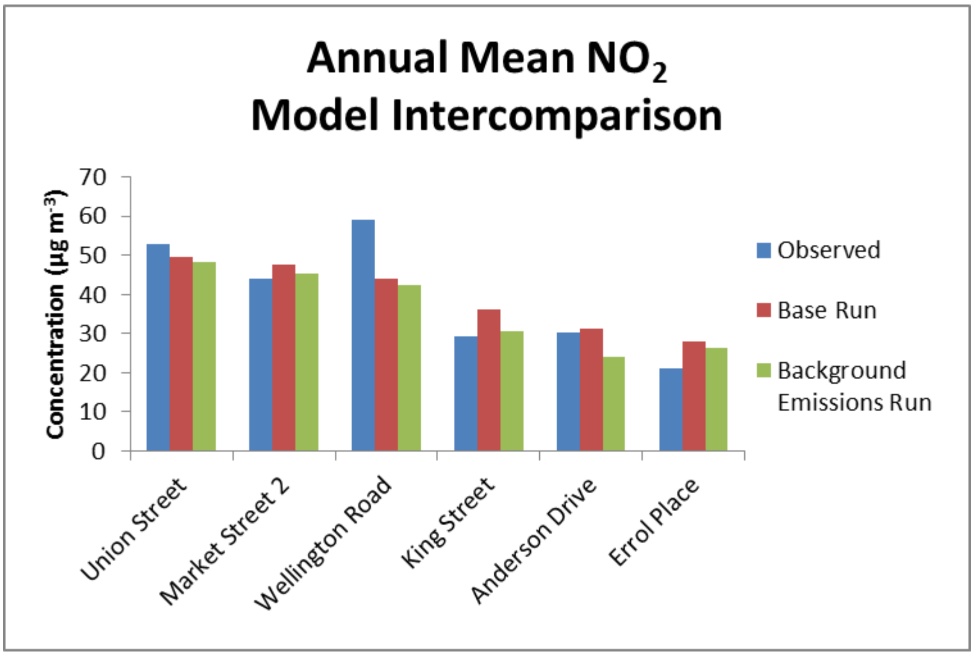


Figure 113: Annual Mean NO_2 Model Inter-comparison (Base Run/Background Area Emissions)

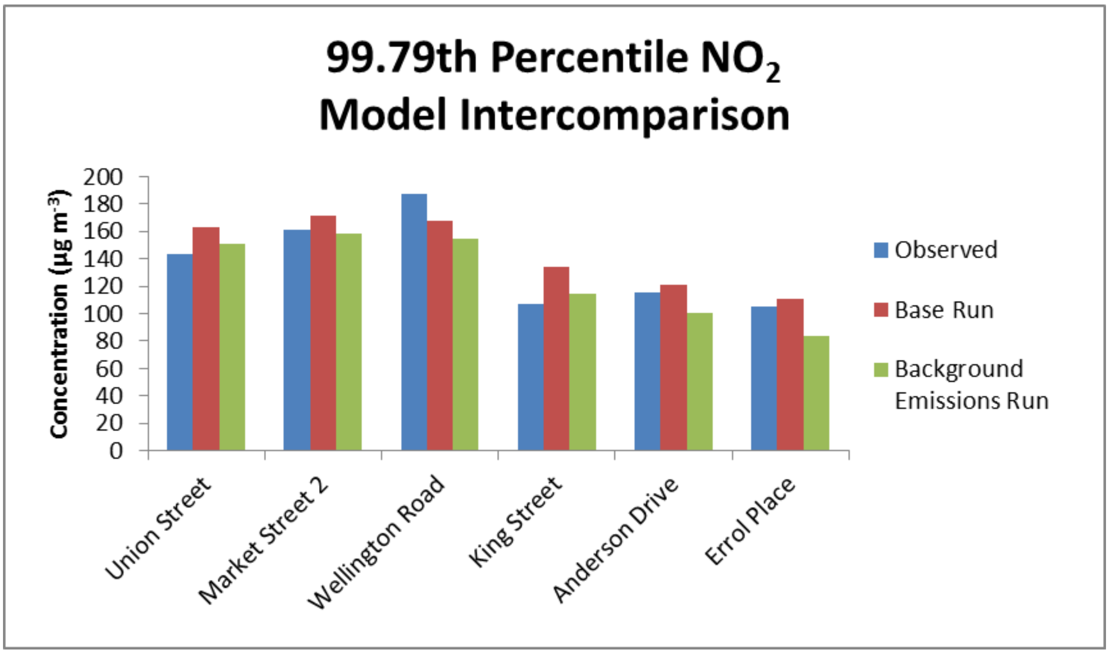


Figure 114: 99.79th Percentile NO_2 Model Inter-comparison (Base Run/ Background Area Emissions)

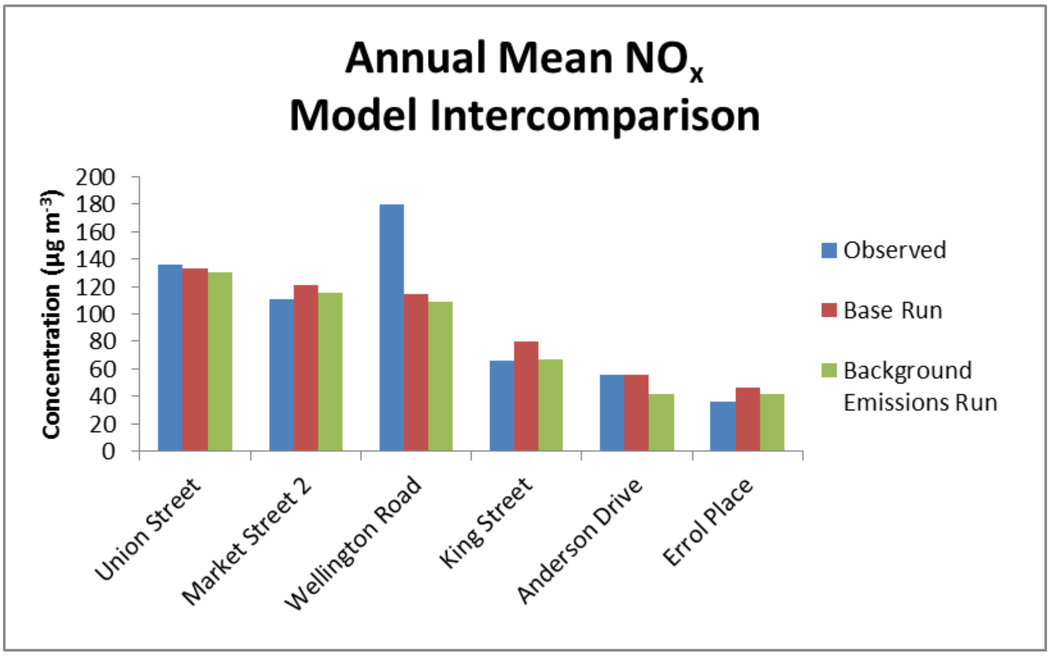


Figure 115: Annual Mean NO_x Model Inter-comparison (Base Run/ Background Area Emissions)

Selected Q-Q plots for the Background Area Emissions method (Figure 116 to Figure 125) show some differences when compared to the 'Base Run' Q-Q plots; there are broad similarities for city centre roadside monitors, and both methods look to be performing well.

At Wellington Road, both models under-predict consistently, and the plots look similar.

At King Street, although the model is making a good prediction of the annual mean, the Q-Q plots for the Background Gridded Emissions approach lose the constant gradient which is found for the Base Run; the NO_x Q-Q plot looks particularly poor. However for Anderson Drive, the NO_x Q-Q plots are poor for both scenarios.

For the Background Area Emission approach, the model performance at the Errol Place urban background monitor can be assessed (in the Base Run, Errol Place data is used as background data). At the Errol Place monitor, the model over-predicts the NO_2 annual mean by 25% and NO_x annual mean by 14%, whilst under-predicting the 99.79th percentile by 20%. This compares to Errol Place concentrations being over-predicted in the 'Base Run', which is expected as all 'Base Run' Errol Place predictions will be greater than or equal to Errol Place data.

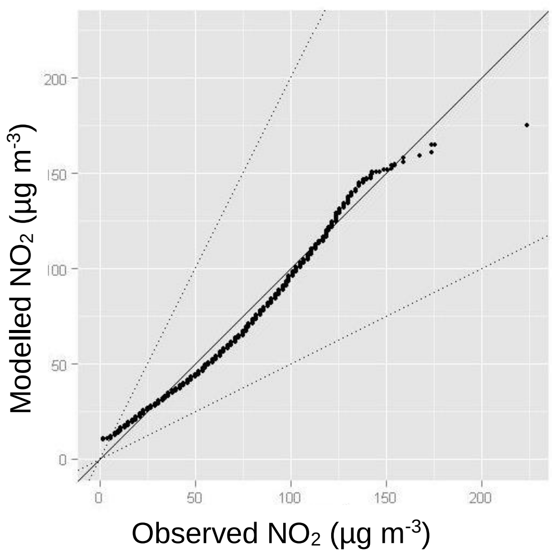


Figure 116: Union Street NO_2 Q-Q plot using Background Area Emissions (Units: µg m^{-3})

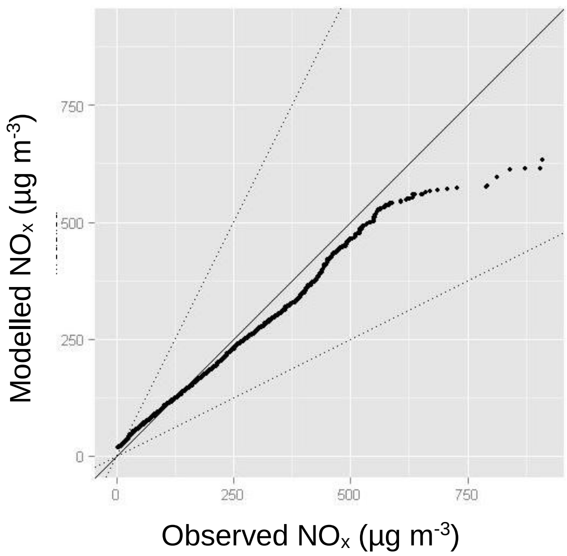


Figure 117: Union Street NO_x Q-Q plot using Background Area Emissions (Units: µg m^{-3})

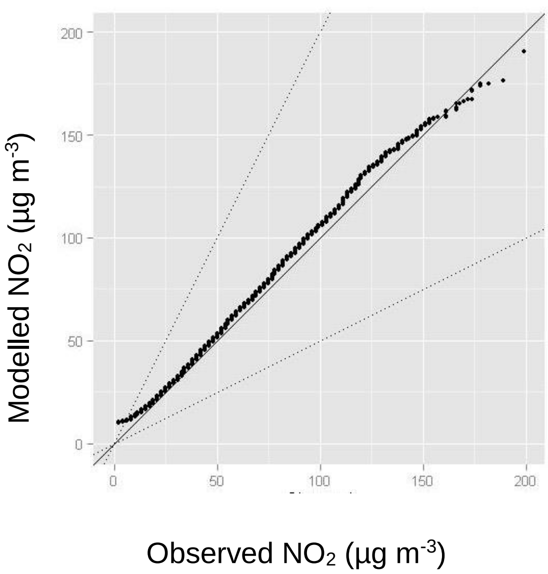


Figure 118: Market Street 2 NO_2 Q-Q plot using Background Area Emissions (Units: µg m^{-3})

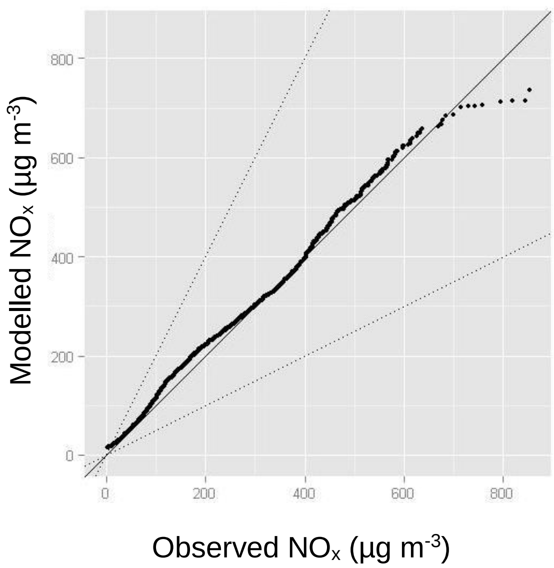


Figure 119: Market Street 2 NO_x Q-Q plot using Background Area Emissions (Units: µg m^{-3})

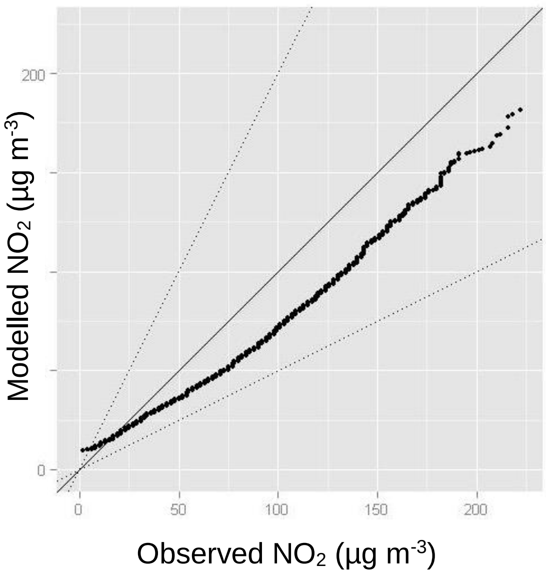


Figure 120: Wellington Road NO_2 Q-Q plot using Background Area Emissions (Units: µg m^{-3})

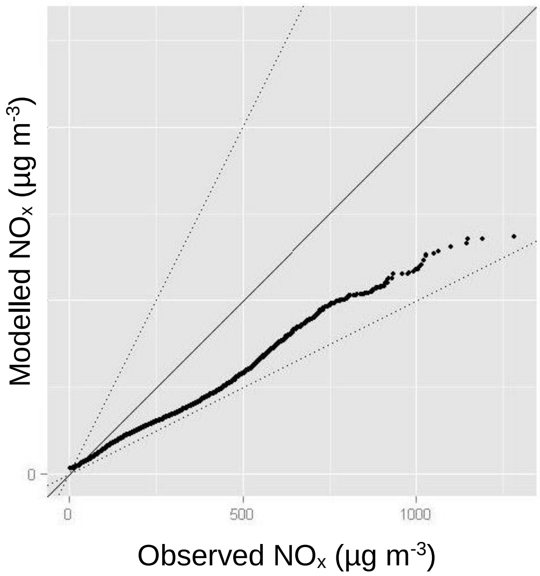


Figure 121: Wellington Road NO_x Q-Q plot using Background Area Emissions (Units: µg m^{-3})

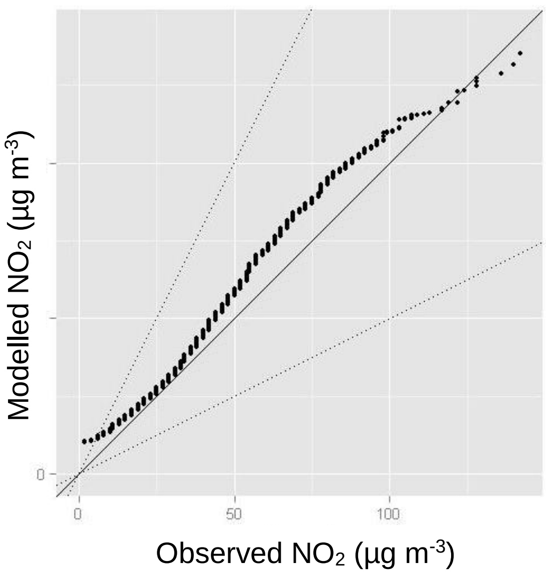


Figure 122: King Street NO_2 Q-Q plot using Background Area Emissions (Units: µg m^{-3})

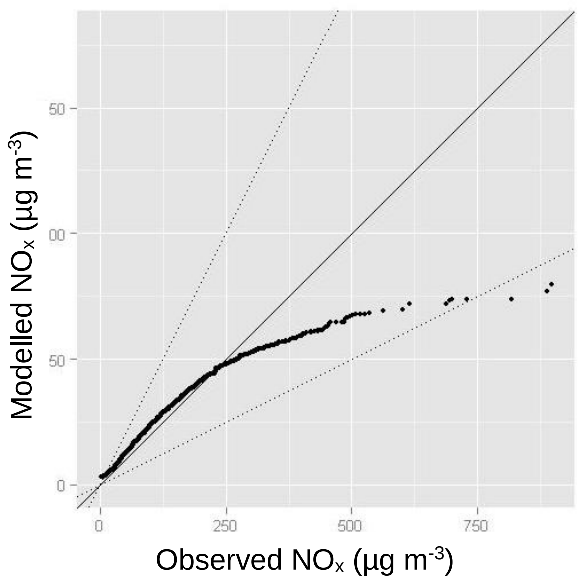


Figure 123: King Street NO_x Q-Q plot using Background Area Emissions (Units: µg m^{-3})

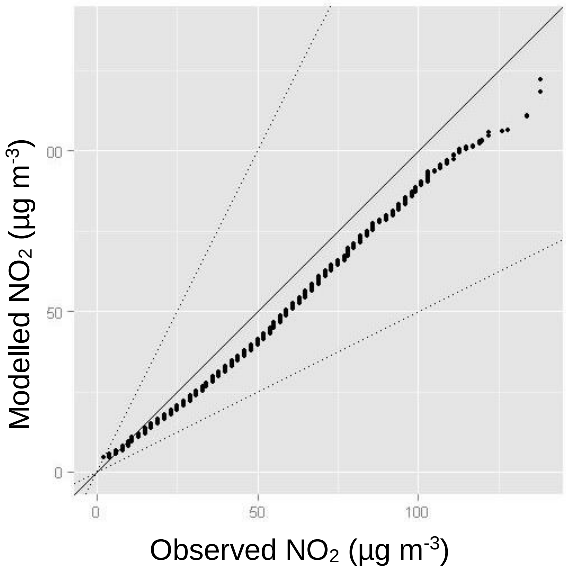


Figure 124: Anderson Drive NO_2 Q-Q plot using Background Area Emissions (Units: µg m^{-3})

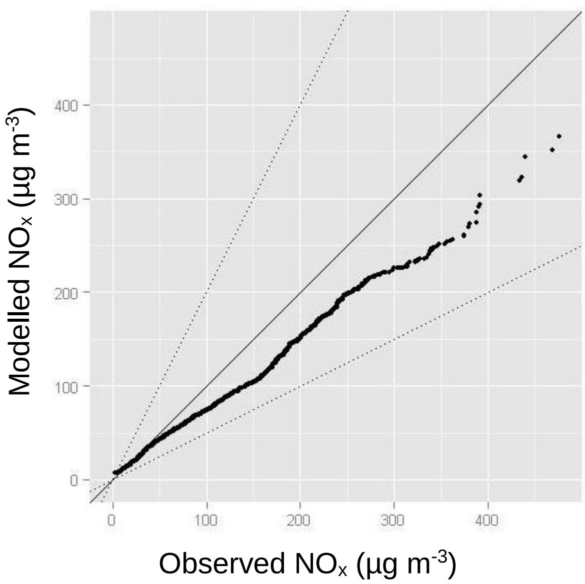


Figure 125: Anderson Drive NO_x Q-Q plot using Background Area Emissions (Units: µg m^{-3})

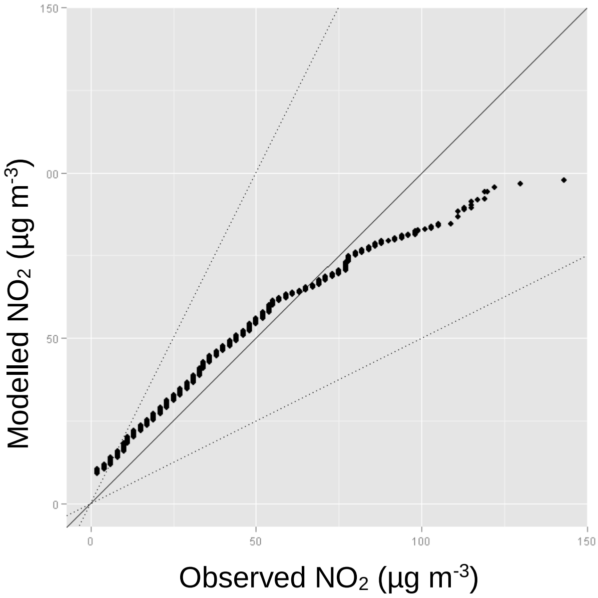


Figure 126: Errol Place NO_2 Q-Q plot using Background Area Emissions (Units: µg m^{-3})

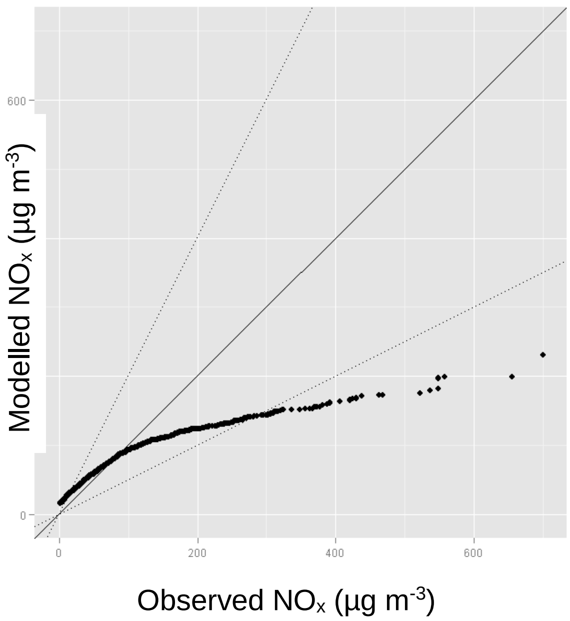


Figure 127: Errol Place NO_x Q-Q plot using Background Area Emissions (Units: µg m^{-3})

Statistical analysis suggests (Table 51, Table 52 and Table 53) that predicted concentrations using the Background Area Emissions method is similar to the 'Base Run' method at most locations. The NO_2 statistics shows that this method fails to perform within the acceptable performance range for Fractional Bias (FB) for Wellington Road ; at other locations, it is less clear as this method performs better than the Base Run for some statistical tests and the Base Run performs better for other tests (e.g. at Anderson Drive, the Fractional Bias (FB) is better in the Base Run, the correlation is better when using the Background Emissions method.

The NO_x statistical results for the Background Emissions method are also similar to the Base Run at most locations. At Wellington Road, the Geometric Mean (MG) and Fractional Bias (FB) statistical tests are not met, and Errol Place fails the 'Factor of 2' (Fac2) test.

The PM_{10} predictions are poor at all locations. The statistical tests show the Background Area Emission method performs poorly as the model fails the Geometric Bias (MG) and Fractional Bias (FB) tests at all roadside monitors. Although both methods perform poorly for PM_{10}, the Base Run performs best for this pollutant.

Table 51: Model Statistics for NO_2 at Automatic Monitors; Background Area Emissions, Rural Background. (Bold shows parameters which have failed tests described in Section 4.1)

Monitoring Point	MG	VG	NMSE	FB	Fac2	MB	R
Union Street	0.94	1.43	0.3	-0.09	0.76	-4.4	0.54
Market Street 2	1.06	1.63	0.44	0.04	0.68	2.03	0.52
Wellington Road	0.76	2.23	0.7	**-0.32**	0.63	-16.11	0.38
King Street	1.01	1.68	0.39	0.03	0.69	0.79	0.58
Anderson Drive	0.78	1.88	0.68	-0.22	0.6	-6.09	0.49
Errol Place	1.24	0.79	0.52	0.22	0.61	5.12	0.52

Table 52: Model Statistics for NO_x at Automatic Monitors; Background Area Emissions, Rural Background. (Bold shows parameters which have failed tests described in Section 4.1)

Monitoring Point	MG	VG	NMSE	FB	Fac2	MB	R
Union Street	1.06	1.69	0.57	-0.04	0.66	-5.95	0.54
Market Street 2	1.10	2.10	0.91	0.07	0.58	7.95	0.54
Wellington Road	**0.68**	3.68	1.42	**-0.47**	0.52	-68.12	0.46
King Street	1.04	2.02	0.73	0.01	0.6	0.57	0.59
Anderson Drive	0.80	2.06	1.23	-0.27	0.59	-13.13	0.47
Errol Place	1.15	0.36	1.21	0.14	**0.49**	5.36	0.49

Table 53: Model Statistics for PM_{10} at Automatic Monitors; Background Area Emissions, Rural Background. (Bold shows parameters which have failed tests described in Section 4.1)

Monitoring Point	MG	VG	NMSE	FB	Fac2	MB	R
Union Street	**0.62**	1.73	0.6	**-0.46**	0.66	-7.92	0.49
Market Street 2	**0.65**	1.99	1.03	**-0.49**	0.63	-8.87	0.42
Wellington Road	**0.6**	2.34	1.11	**-0.54**	0.61	-9.87	0.31
King Street	**0.67**	2.27	0.98	**-0.43**	0.65	-6.55	0.3
Anderson Drive	**0.65**	2.11	0.6	**-0.37**	0.64	-4.73	0.52
Errol Place	0.78	0.84	0.73	-0.25	0.67	-2.75	0.44

The Background Area Emission method also predicts the number and spatial extent of roadside locations with an Air Quality exceedance (Figure 128) is similar to the 'Base Run' (Figure 110), though there are some differences on North Esplanade West. These similarities are also seen when comparing the contour plots for the two methods for both NO_2 annual means and 99.79th percentiles (Figure 107, Figure 108, Figure 109, Figure 129, Figure 130 and Figure 131).

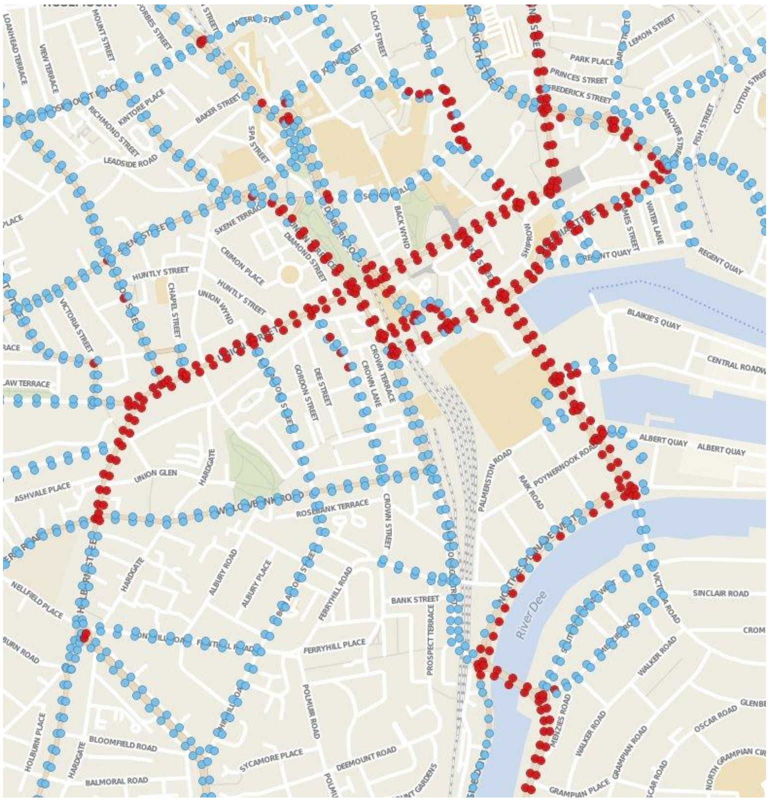


Figure 128: Roadside Points for NO2 Annual Mean Concentrations when using Background Area Emissions (Red values are greater than 40 µg m-3)

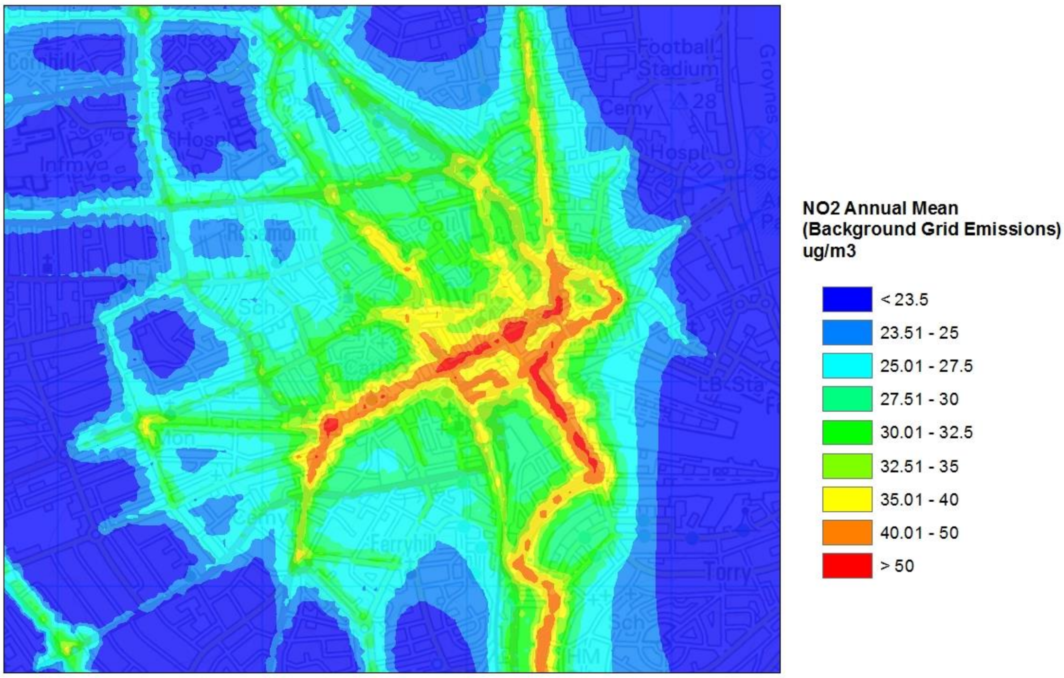


Figure 129: Predicted NO_2 Annual Mean concentration (µg m^{-3}) in Aberdeen City Centre (Background Area Emissions)

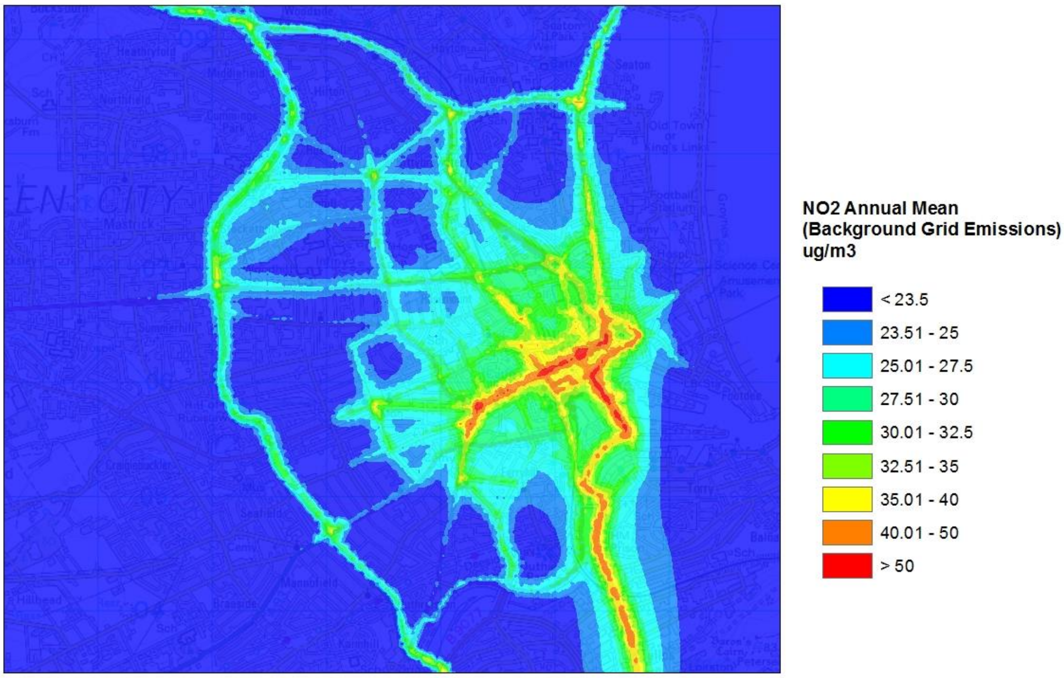


Figure 130: Predicted NO2 Annual Mean concentration (µg m-3) in Aberdeen (Background Area Emissions)

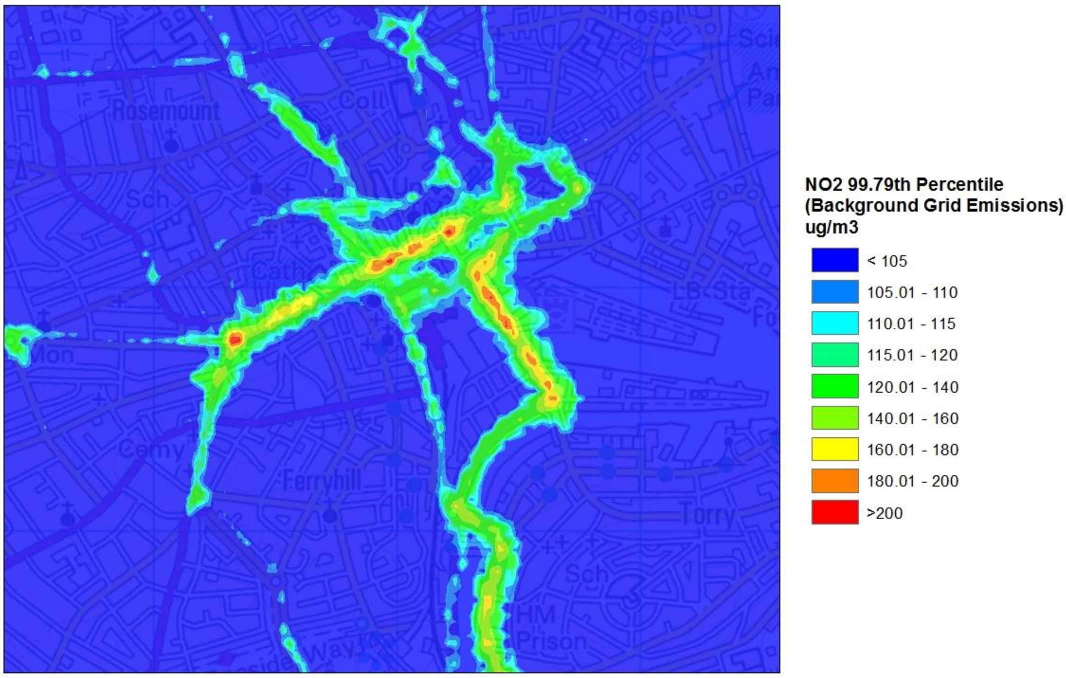


Figure 131: Predicted NO_2 99.79th percentile concentration (µg m^{-3}) in Aberdeen (Background Area Emissions)

4.3.1 Discussion of Base Run (Errol Place) and Background Area Emissions Methods

Using the two background methods have shown that there is similar model performance at most monitoring locations. At some locations (e.g. Union Street), the Base Run performance is better, whilst at other locations (e.g. King Street), the Background Emission Maps method performs better (despite the King Street monitor being close to Errol Place). Both methods over-predict at the Errol Place monitor.

The two methods have differences which offer advantages and disadvantages:

- Errol Place provides an urban environment which is not close to any significant sources, where pollutant concentrations are well mixed and may be capturing pollutant concentrations due to sources which are not included in the emissions inventory. When wind speeds are low, pollutant concentrations increase area wide and this will be reflected in the Errol Place data. Using Errol Place data may however include some double counting, however the monitor is located around 75m from the nearest busy road where pollutant levels will have dropped off.
- The Background Area Emissions method is based on emission factors for different sectors (e.g. domestic, transport, industrial etc.). As total emissions are calculated based on estimated 'activity' (Emission Factor x 'Activity'), and as there will be uncertainties in both parameters, there may be large uncertainties in estimated total emissions. Emission inventories are also several years out of date, which is an additional uncertainty, and the nearest rural monitor is located south of Edinburgh, approximately 155km from Aberdeen.

A limitation of Gaussian dispersion models is that for each model time-step, pollutant concentrations are predicted for that time step only, and there is no 'carry-over' to the next time step, and they may not be able to account for accumulation of pollutants during certain conditions (e.g. calm conditions).

The bias and variance statistics in Table 28 and Table 51 show that the Background Area emissions approaches are broadly similar, and both models generally perform well. Some statistics are better for the Base Run, whilst others are better for the Background Grid approach. For example, the statistics for King Street are generally better for the Background Grid Sources approach, with the exception of correlation.

However there is clear difference for PM_{10} predictions, where the Base Run performs better. This is likely due to PM_{10} sources which are difficult to account for such as resuspension.

4.4 Model Sensitivity Tests

To test the methods used in the Base Run, a number of sensitivity tests were carried out which varied a number of input parameters.

These include:

- Choice of ADMS-Urban chemistry scheme and relevant input data
- Time-varying emissions
- Choice of meteorological data (Different years and different weather stations)
- Choice of emission factors (inventory and year)
- Increase traffic emission factors for Background Area Emissions method

4.4.1 Inter-Annual Variation and Weather Station Sensitivity Tests

The 'Base Run' and Background Area Emissions method scenarios were each tested using different years of weather data. When modelling for different years, the hourly background pollutant data needs to match the same year as that being modelled as this can be sensitive to the wind direction for a particular hour. In all cases traffic flow numbers remain the same

Sensitivity tests were set up as 4 scenarios (Table 54):

- Meteorological conditions **only**: the weather station data and background data were varied to cover additional years at Dyce and 5 years at Inverbervie No. 2. This was applied to both the 'Base Run' (Scenario M1) and Background Area Emissions (Scenario M3).
- Meteorological conditions **and** the annual adjustments to emission rates (which may vary due to fleet composition changes), the weather station data and background data were varied to cover the additional years at Dyce and 5 years at Inverbervie No. 2 to match the year being modelled. This was applied to both the 'Base Run' (Scenario M2) and Background Area Emissions (Scenario M4). Only Background Area Emissions data for 2012 were available and so it was not possible to vary this input.

Table 54: Scenarios to test the model sensitivity to meteorological data, emission factors and background data

<table>
<tr><th>Scenario Number</th><th>Emission Inventory</th><th>Meteorological Data</th><th>Background Data</th></tr>
<tr><td>M1</td><td>2012</td><td rowspan="4">Dyce (2009-2013), Inverbervie No. 2 (2009-2013)</td><td rowspan="2">Errol Place (Year of Meteorological Data)</td></tr>
<tr><td>M2</td><td>Year of Meteorological Data</td></tr>
<tr><td>M3</td><td>2012</td><td rowspan="2">NAEI Background Area Emissions (2012); Rural Background (Year of Meteorological Data)</td></tr>
<tr><td>M4</td><td>Year of Meteorological Data</td></tr>
</table>

Scenario M1

In scenario M1, the model has been run for an additional 4 years (2009, 2010, 2011 and 2013) for Dyce meteorological conditions and 5 years for Inverbervie No. 2 meteorological conditions (2009-2013). The Errol Place background concentration data for the year modelled was used. Source emission rates were the same for all model runs (2012 emission factors), so that sensitivity due to meteorological conditions **only** could be assessed. Detailed results can be found in Appendix A3.1.

At the automatic monitoring locations, it is clear that using meteorological observations from Inverbervie No.2 weather station predicts lower concentrations than for using Dyce meteorological data (Figure 132 to Figure 137).

NO_2 annual mean

The models tend to under-predict the NO_2 annual mean at the Union Street monitor for all years and for both weather stations, though using Dyce meteorological data predicts modelled concentrations which are closer to the measured concentrations. At the Wellington Road monitor, all models are under-predicting the observed value, whilst at the King Street monitor, all models are over-predicting the observed values. At Anderson Drive and Market Street 2, some model runs over-predict and some under-predict the concentration.
Also it is noticeable that for each year modelled, predictions for each weather station data follow a similar trend. This is likely to be due to decreases in measured background concentrations at the Errol Place monitor.

99.79^{th} percentile

The models tend to under-predict the 99.79^{th} percentile, though in all cases no air quality exceedance is observed at any automatic monitor or predicted anywhere by the models. However, for this statistic, it is expected that modelling uncertainties will be greater than for the annual average statistic. The model also predicts decreasing values for this statistic through the years, perhaps due to falling peak concentrations in the Errol Place background data.

NO_x annual mean

The model predictions follow a similar pattern to the NO_2 predictions; Inverbervie No.2 meteorological conditions predict smaller concentrations than Dyce meteorological data. In the cases of Union Street, Market Street 2 and Anderson Drive, Dyce meteorological data appears to perform better than Inverbervie No.2 meteorological data, whereas Inverbervie No.2 meteorological data performs better for King Street. All models under-predict the observed value at Wellington Road. Again, it appears that there is a downward trend in predicted concentrations over the 5 year period; again likely to be due to reductions in the background concentrations at Errol Place, however there are years when predicted concentrations do increase from the previous year.

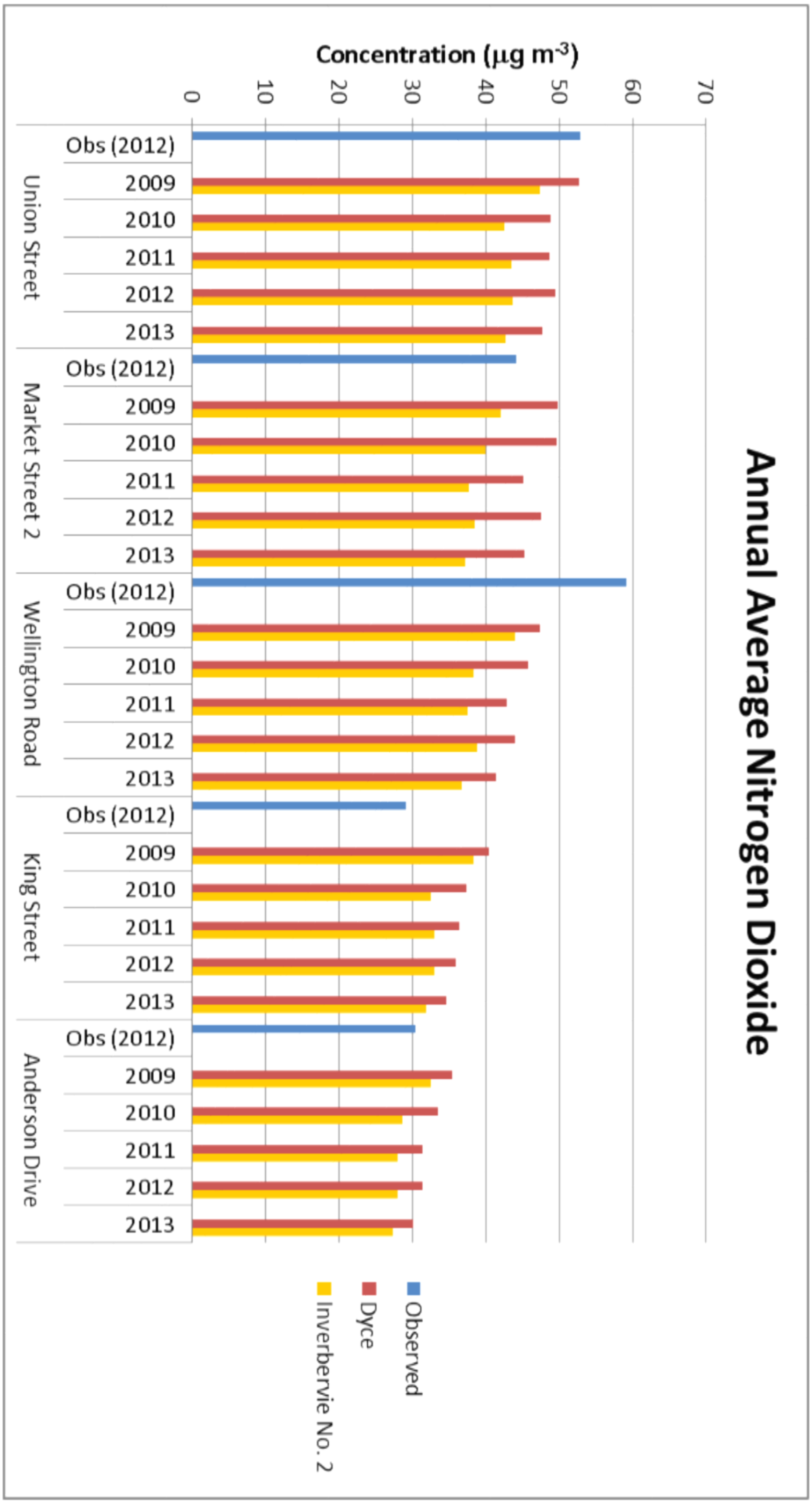
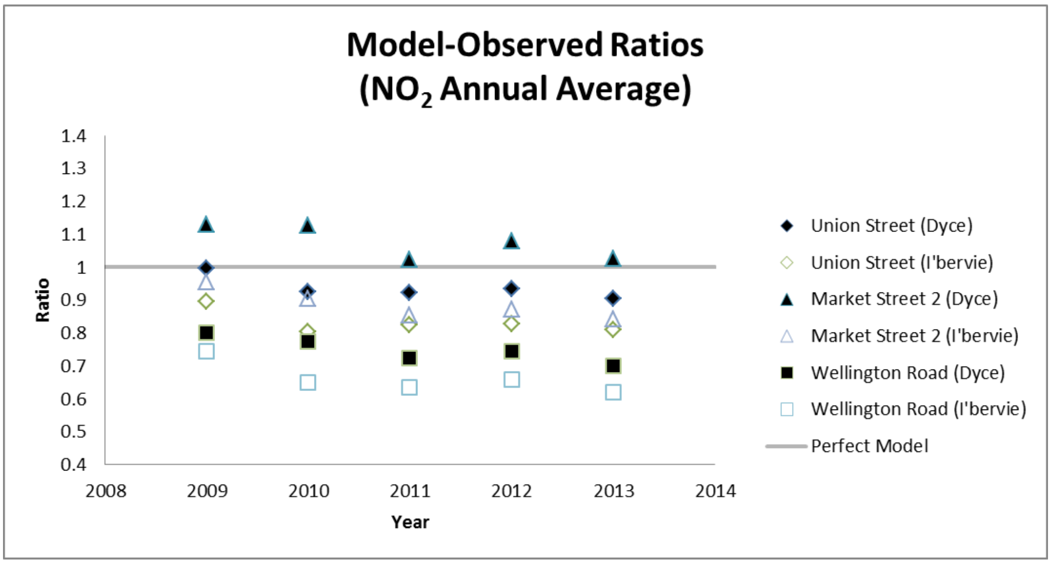


Figure 132: NO$_2$ Annual Average Concentrations for 2009 to 2013 (Meteorological files and Errol Place background files only) for Scenario M1



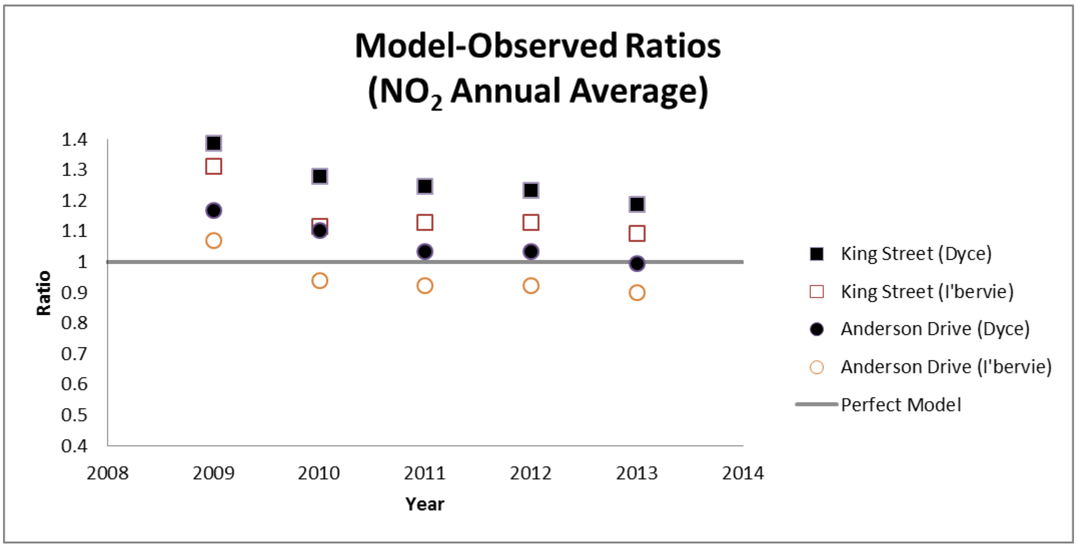


Figure 133: NO_2 Annual Average Ratios (Scenario M1)

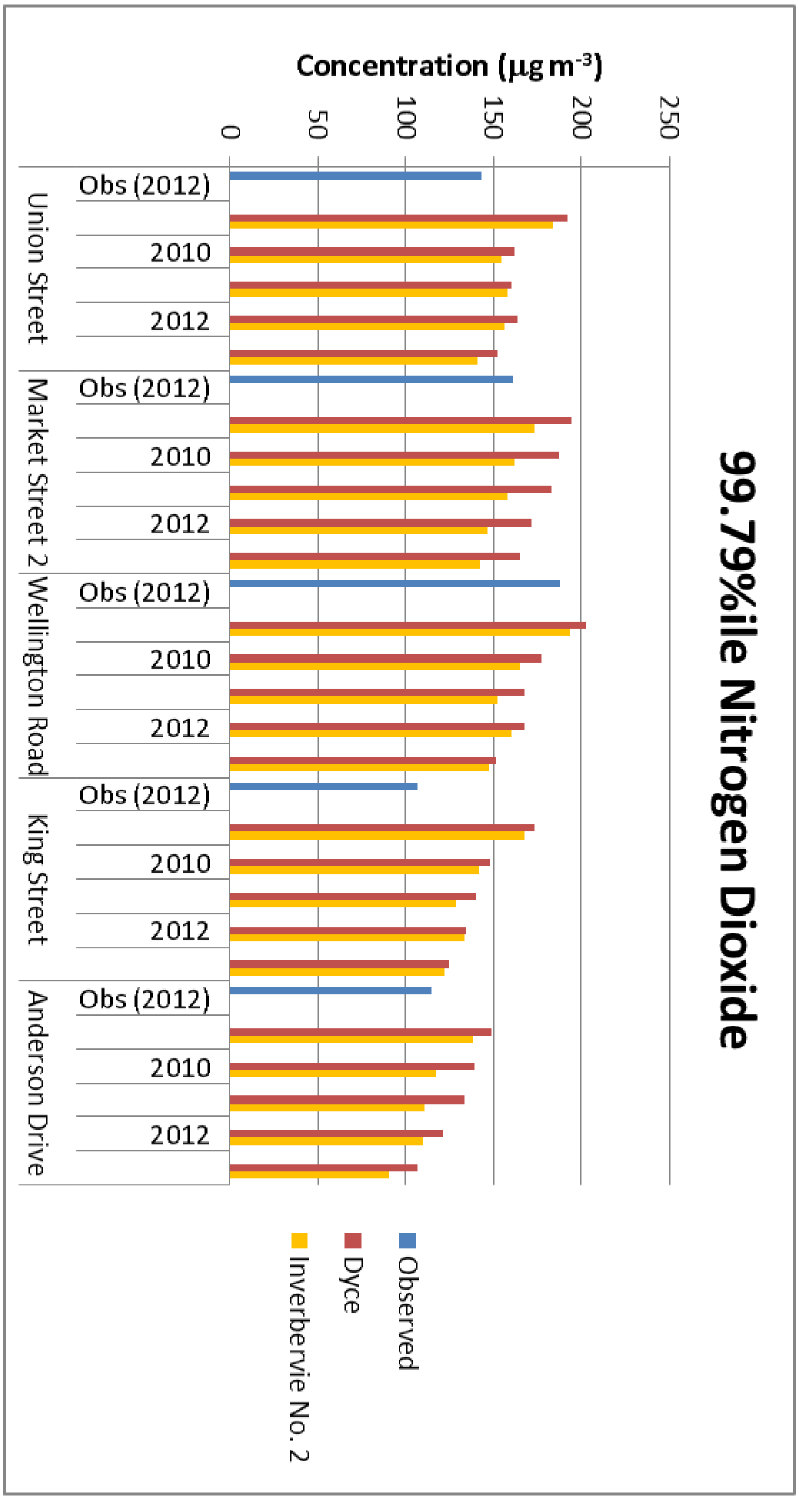
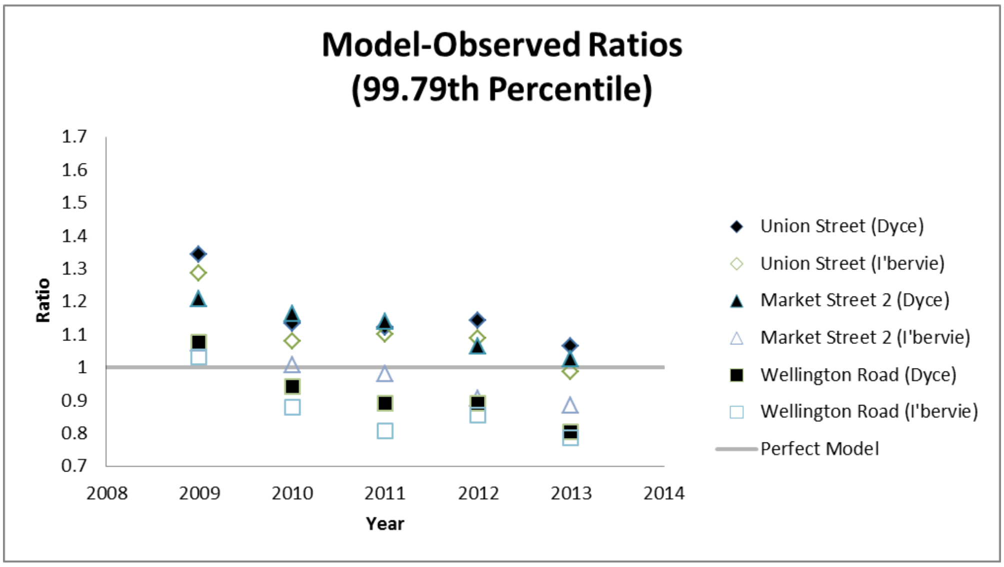


Figure 134: NO_2 99.79th Percentile Concentrations for 2009 to 2013 (Meteorological files and Errol Place background files only) for Scenario M1



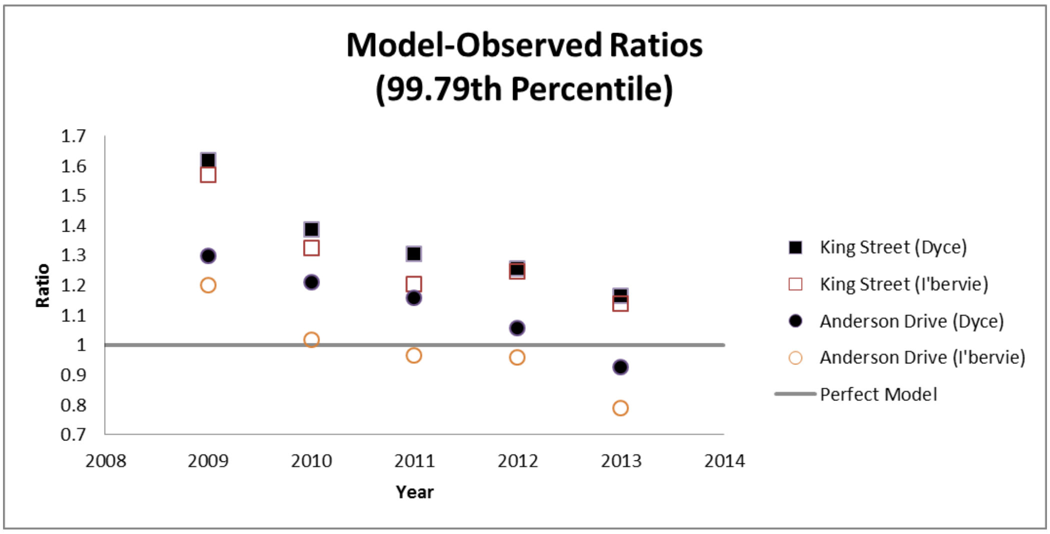


Figure 135: NO_2 99.79th %ile Ratios (Scenario M1)

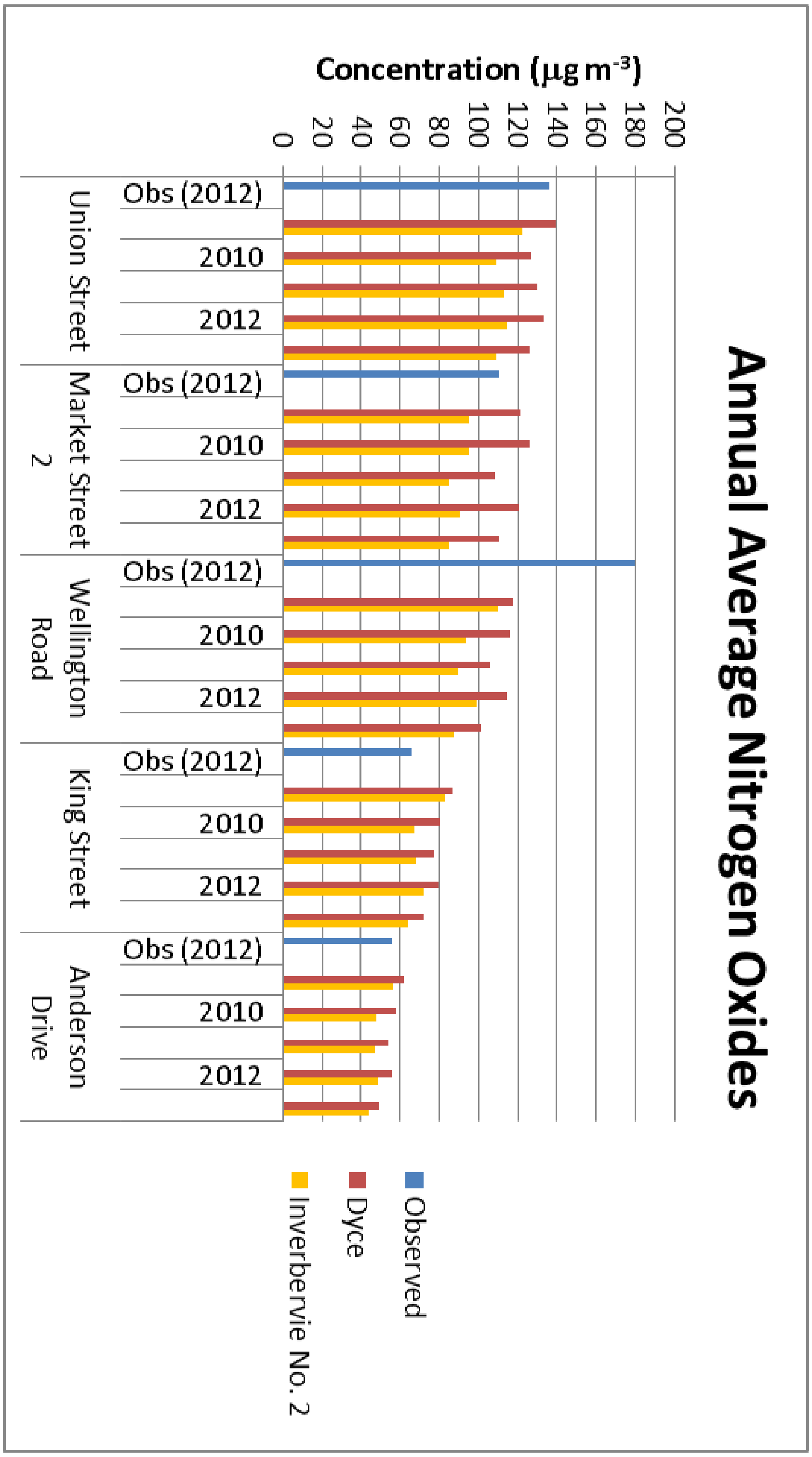
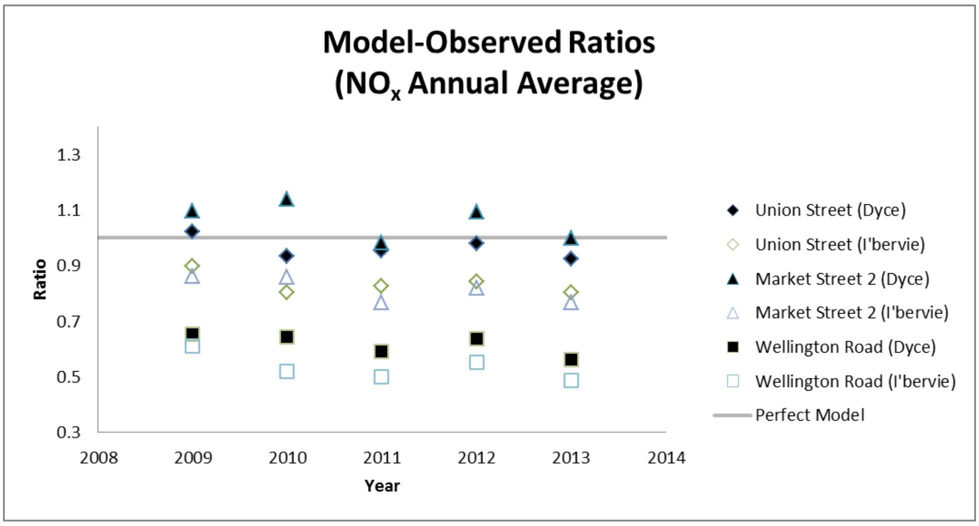


Figure 136: NO_x Annual Average Concentrations for 2009 to 2013 (Meteorological files and Errol Place background files only) for Scenario M1



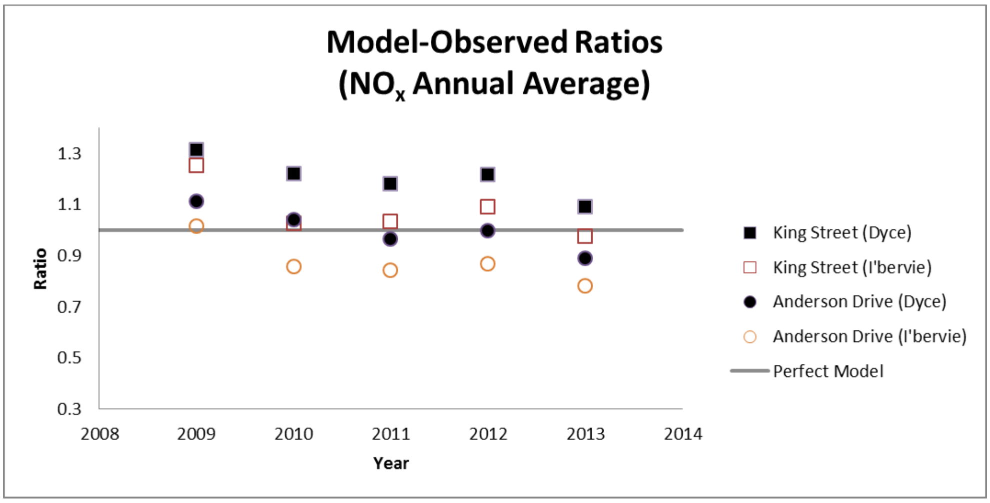


Figure 137: NO_x Annual Average Ratios (Scenario M1)

Scenario M2

Scenario M2 is the same as Scenario M1, with the exception that **road source emissions rates represent the year that is being modelled** (Section 3.8). Detailed results can be found in Appendix A3.2.

NO_2 annual mean

The models under-predict the NO_2 annual mean (Figure 138) at Union Street for 2010, 2012 and 2013, however for 2011, both meteorological data sets over-predict the observed concentration. The measured NO_2 concentration at Union Street is lower in 2011 than for other years; it is also noted that data capture at Union Street is also low in 2011 (86%) with data missing in the August to October period.
At the Market Street 2 monitor, for 2010-2013, using Dyce meteorological data over-predicts the observation whilst using Inverbervie No. 2 meteorological data under-predicts the observed concentrations. For 2009, both models over-predict at the Market Street 2 monitor, however this monitor started operating in August 2009, so data capture is low (36%).
At the Wellington Road monitor, the models under-predict concentrations for all years apart from 2009; concentrations have steadily increased since 2009 whilst model predictions have suggested a decrease in concentrations.
At the King Street and Anderson Drive monitors the models consistently over-predict (apart from at Anderson Drive in 2012 where the observed concentration is greater than for other years).

The model/observed ratio plot (Figure 139) show that the models are both under and over predicting at the automatic monitors.

Also, as before, there is also a general downward trend in predicted concentrations over time. This is likely to be due to decreases in background concentrations at Errol Place and reductions in emission rates due to assumption of newer, cleaner vehicles entering the national fleet.

99.79^{th} percentile

There is a more variability in model predictions for this air quality standard. For Union Street and Market Street 2, the models are under-predicting and over-predicting. At Wellington Road in 2009, the models are significantly over-predicting; however in more recent years, this has reversed and the models are significantly under-predicting (Figure 140).
The only location where the observed 99.79^{th} percentile is falling is at Union Street; at other locations the observed value shows no change or has increased. This is in contrast to the modelled predictions which are decreasing at all locations over time (as emissions rates decrease) and highlights a limitation that ADMS-Urban may be struggling to capture peak concentrations. However, the modelled observed ratios show that the models are both over-predicting and under-predicting (Figure 141)

NO_x annual mean

The annual average NO_x concentrations follow a similar pattern to the annual average NO_2 concentrations (Figure 142). At Union Street and Market Street 2, the model is over-predicting and under-predicting for different years. The model generally under-predicts for all years (with a few exceptions) at the Wellington Road, King Street and Anderson Drive monitors indicating that Inverbervie No. 2 predictions are performing better.
The model/observed ratios plot (Figure 143) shows that for King Street and Anderson Drive, over time, the models have changed from over-predicting to under-predicting.

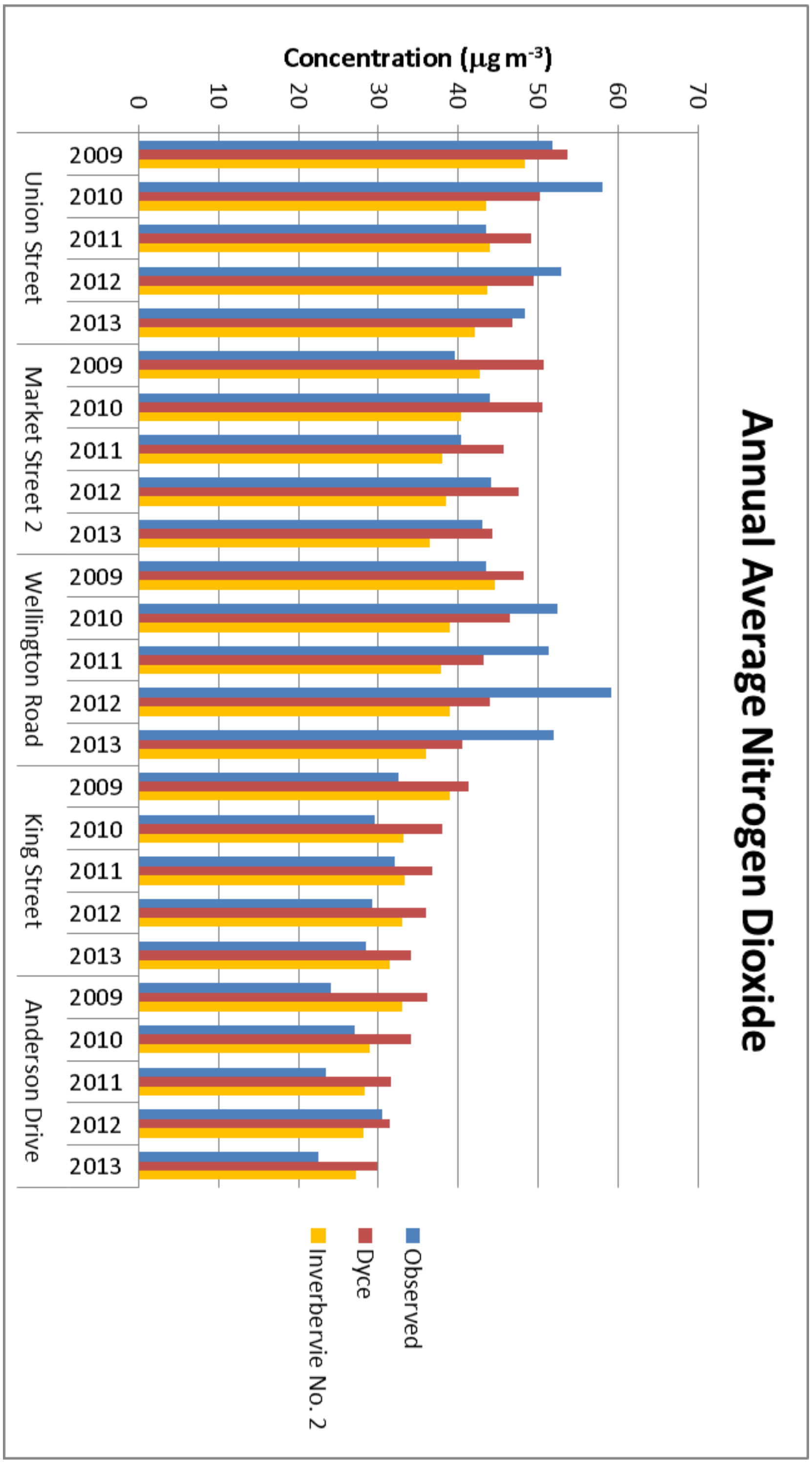
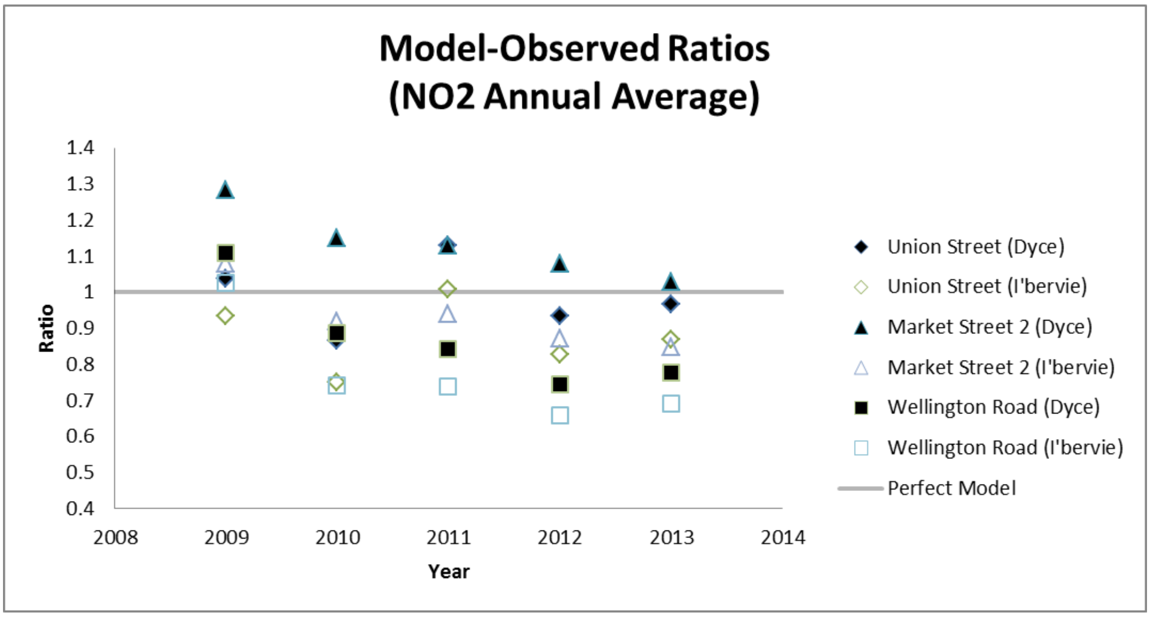


Figure 138: NO_2 Annual Average Concentrations for 2009 to 2013 (Meteorological files, Errol Place background files and Emission Factors, Scenario M2)



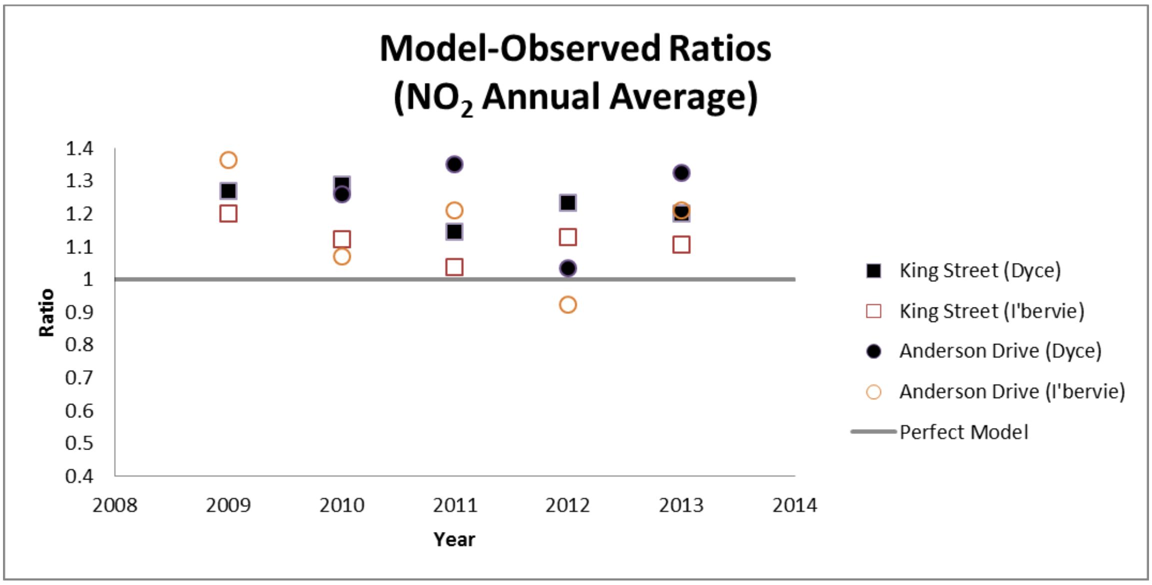


Figure 139: NO_2 Annual Average Ratios (Scenario M2)

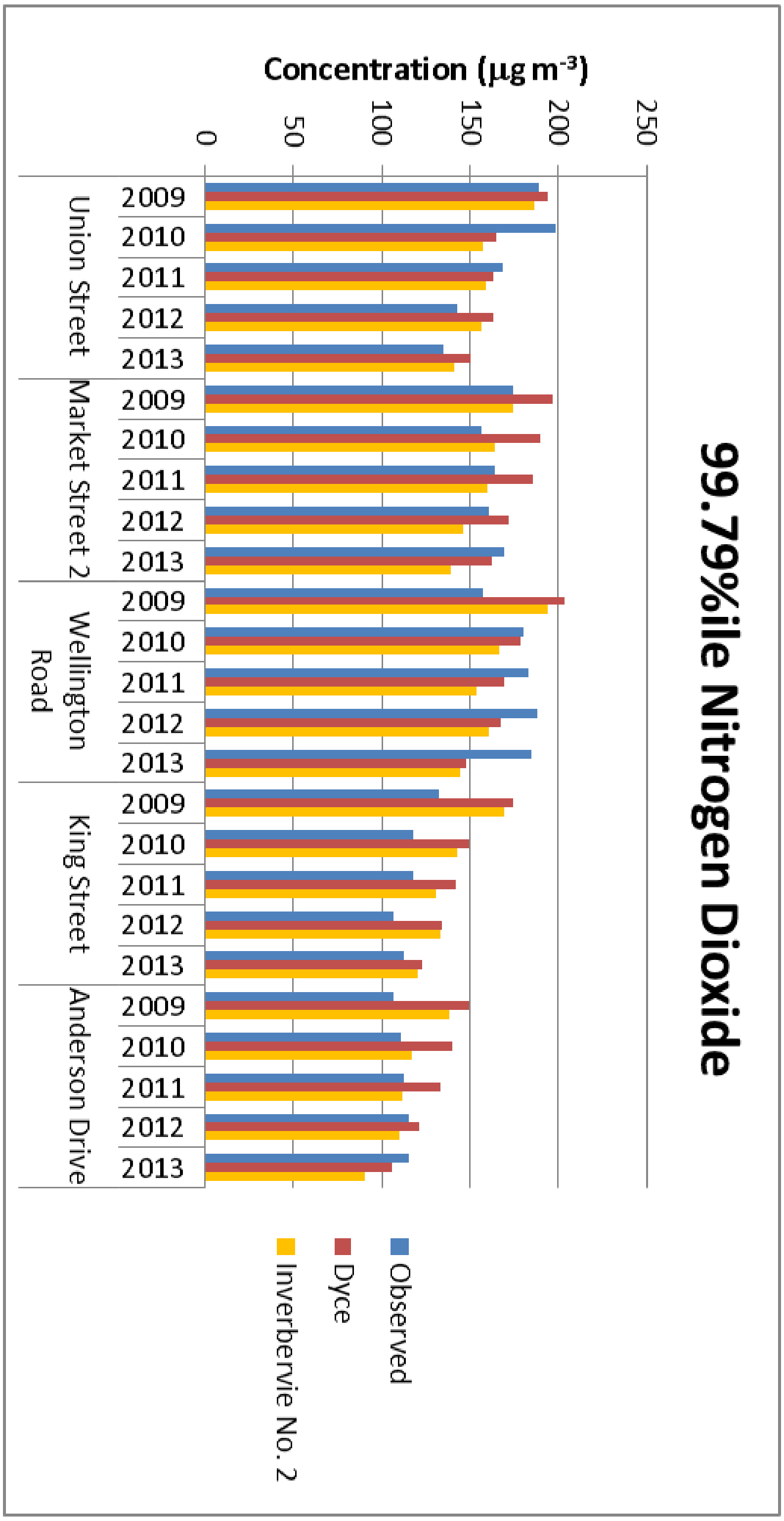
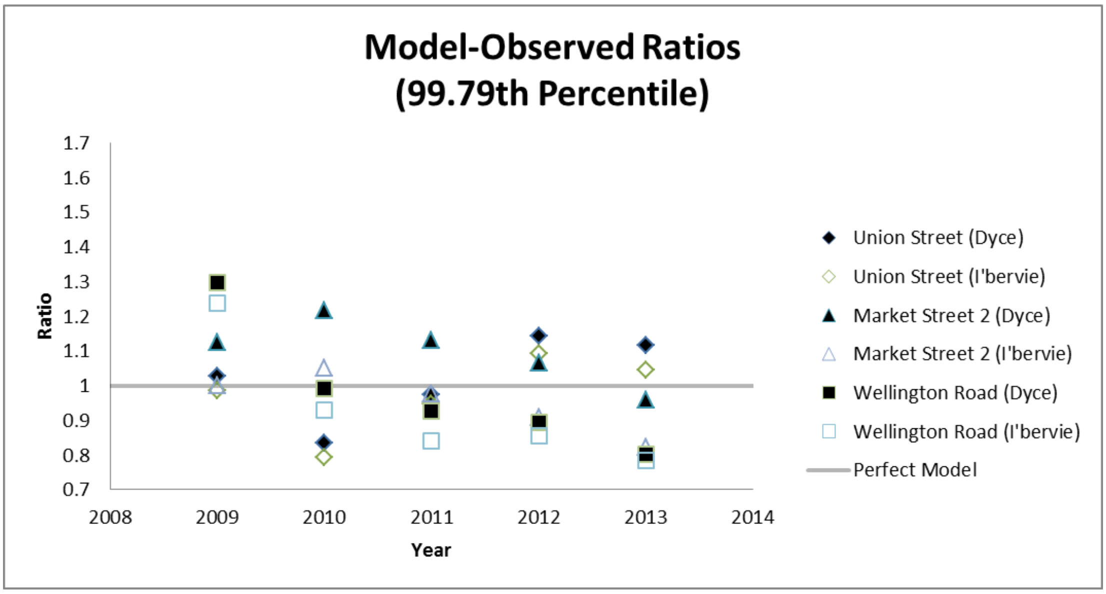


Figure 140: NO_2 99.79th %ile Concentrations for 2009 to 2013 (Meteorological files and Errol Place background files and Emission Factors, Scenario M2)



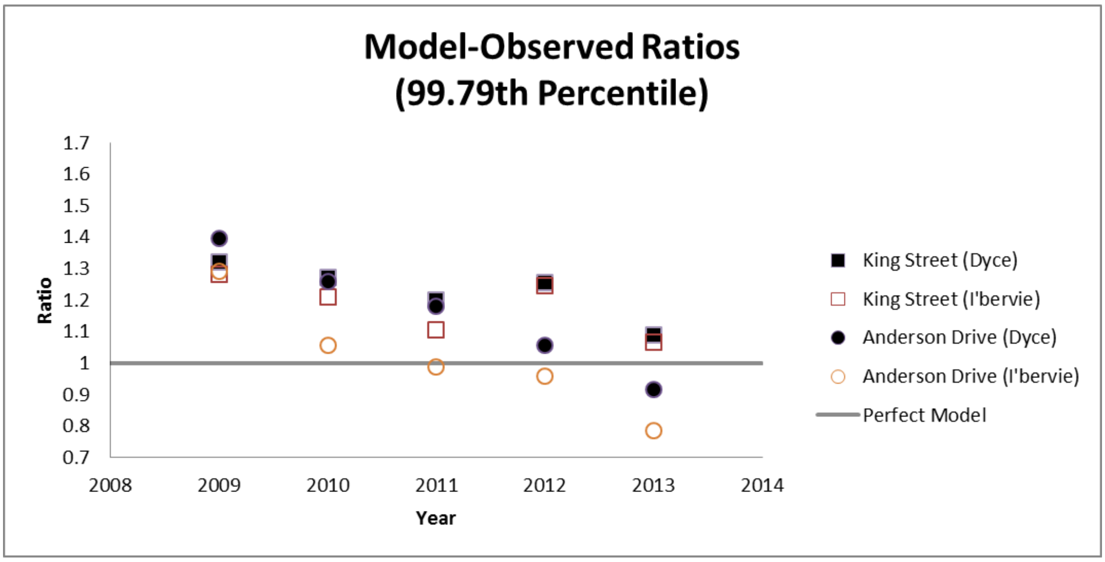


Figure 141: NO_2 99.79th %ile Ratios (Scenario M2)

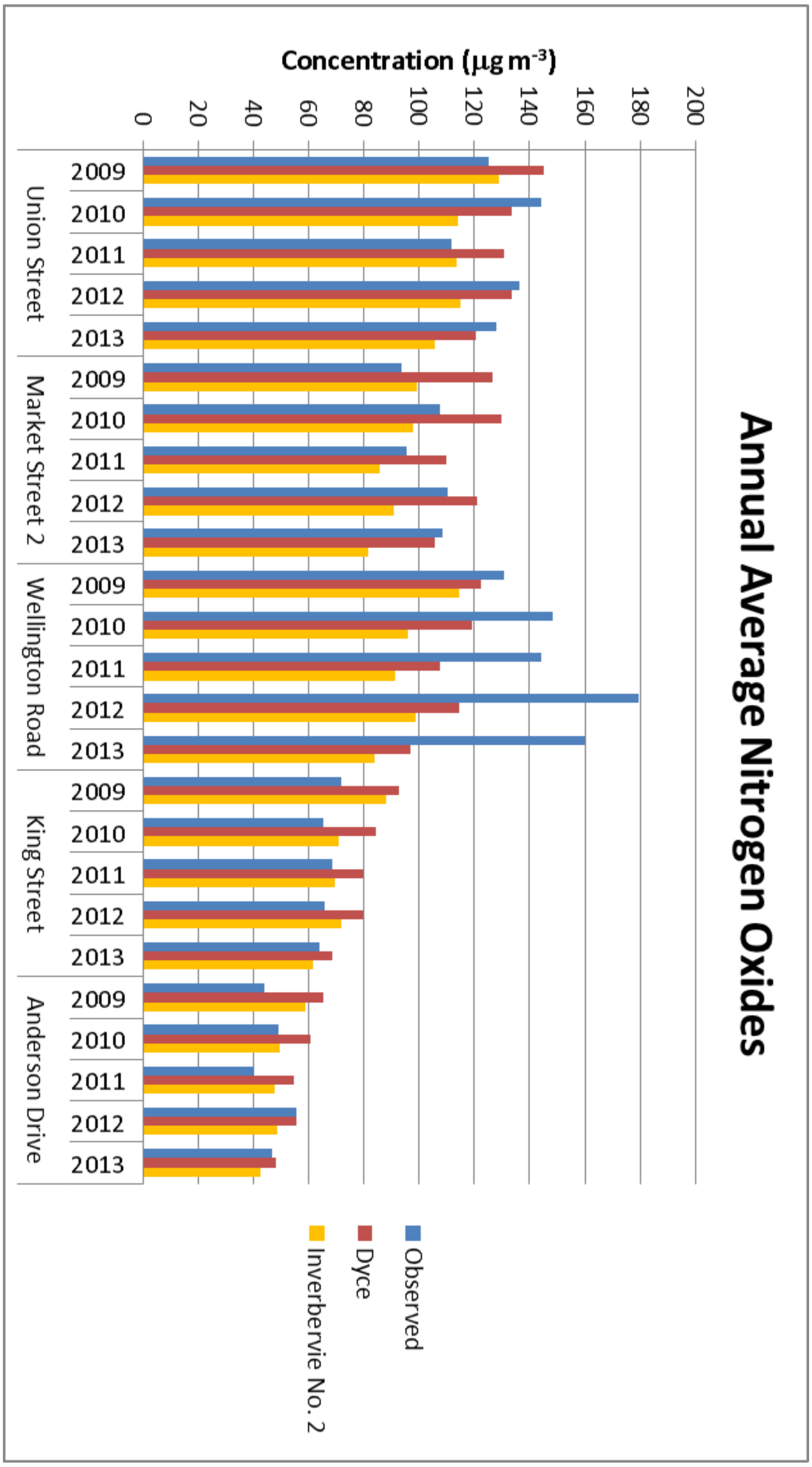


Figure 142: NO_x Annual Average Concentrations for 2009 to 2013 (meteorological files and Errol Place background files only, Scenario M2))

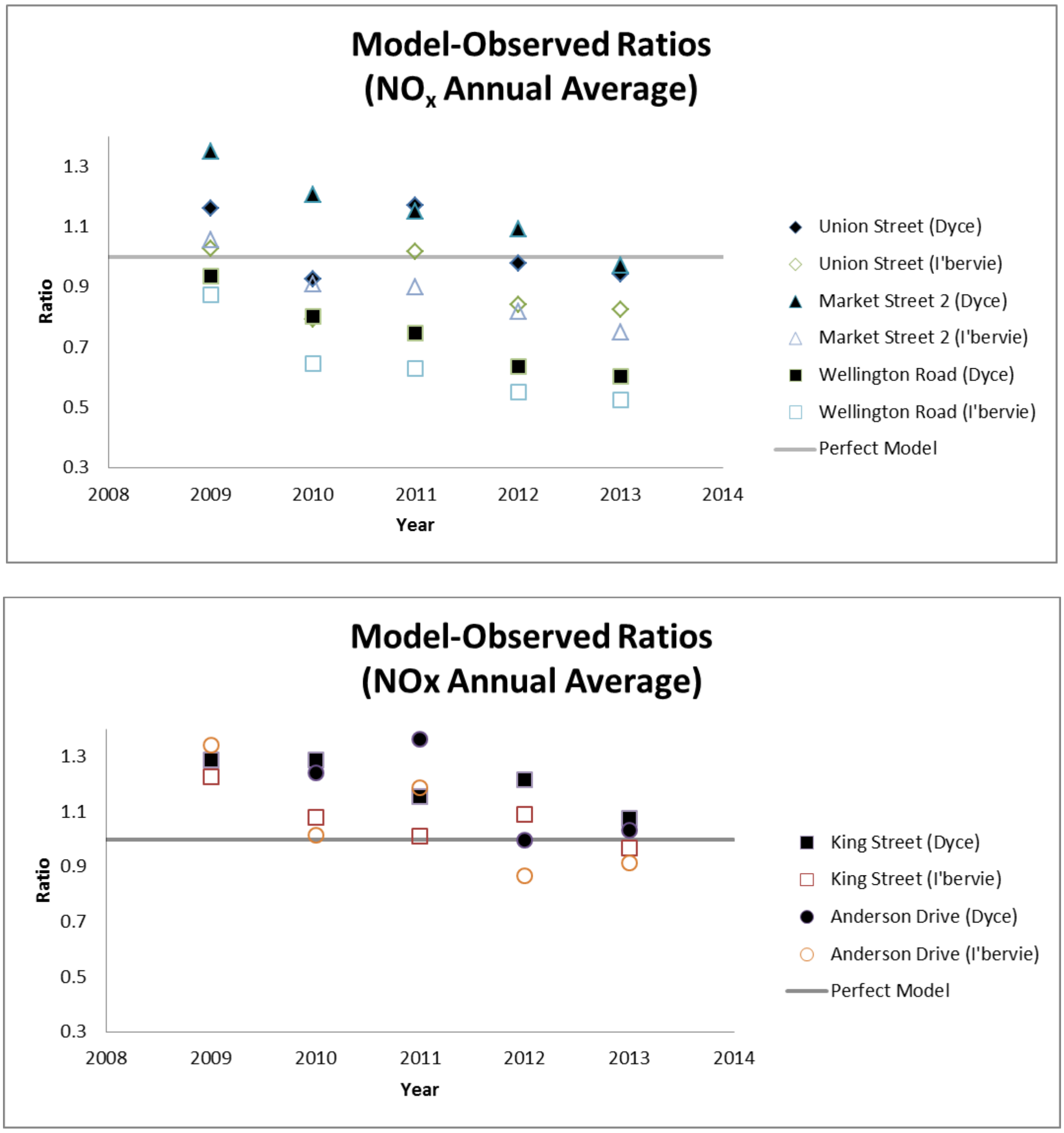


Figure 143: NO_x Annual Average Ratios (Scenario M2)

Scenario M3

Scenario M3 is similar to Scenario M1 but uses the Background Area Emissions approach (using background area emissions and rural background data for 2012 as discussed in Section 3.10.2).

The model has been run for an additional 4 years (2009, 2010, 2011 and 2013) for Dyce meteorological conditions and 5 years for Inverbervie No. 2 meteorological conditions (2009-2013). Vehicle emission rates were the same for all model runs (2012 emission factors), so that sensitivity due to meteorological conditions **only** was assessed.

For this scenario, the performance of the model at Errol Place automatic monitor can also be assessed. Detailed results can be found in Appendix A3.3.

NO_2 annual mean

Using Inverbervie No.2 meteorological conditions predicts lower concentrations than using Dyce meteorological conditions.

When analysing the specific monitoring locations, the M3 models under-predict observed NO_2 concentrations at:

- Union Street: 10-15% for Dyce data; 30-35% for Inverbervie data
- Wellington Road: 20-35% for Dyce data; 45-50% for Inverbervie data
- Anderson Drive: 12-32% for Dyce data; 40-50% for Inverbervie data

However for Market Street 2 and King Street the model performance is better:

- Market Street 2: -10% to +7% for Dyce data; -20 to -30% for Inverbervie data
- King Street: 0% to +8% for Dyce data; -12 to -32% for Inverbervie data

At Errol Place, the model over-predicts by around 25% when using Dyce data, but performs well when using Inverbervie met data. (Figure 144, Figure 145).

99.79th percentile

The models show less variance over all the years compared to scenario M1 (Figure 134, Figure 135, Figure 146, Figure 147), perhaps due to the different approach of using background data.

At the Union Street and King Street monitors, the model tends to over-predict by around 5-10%, and the decline in predicted concentrations through the years isn’t as pronounced as for Scenario M1 (Figure 134).

The model performs well at the Market Street 2 monitor (using Dyce data predicts that 4 of the 5 years modelled are within 3% of the observed concentrations). The models all slightly under-predict for Anderson Drive (5-10% using Dyce meteorological conditions), whilst at Wellington Road, the models are all under-predicting by around 15-20%.

NO_x annual mean

The NO_x concentrations (Figure 148) follow a similar pattern to the annual average NO_2 annual mean concentrations. At Wellington Road, the model under-predicts the observed NO_x concentration by around 60%, and at Anderson Drive, by around 30%.

The observed/model ratio plot (Figure 149) indicates that under-prediction exists for most model runs.

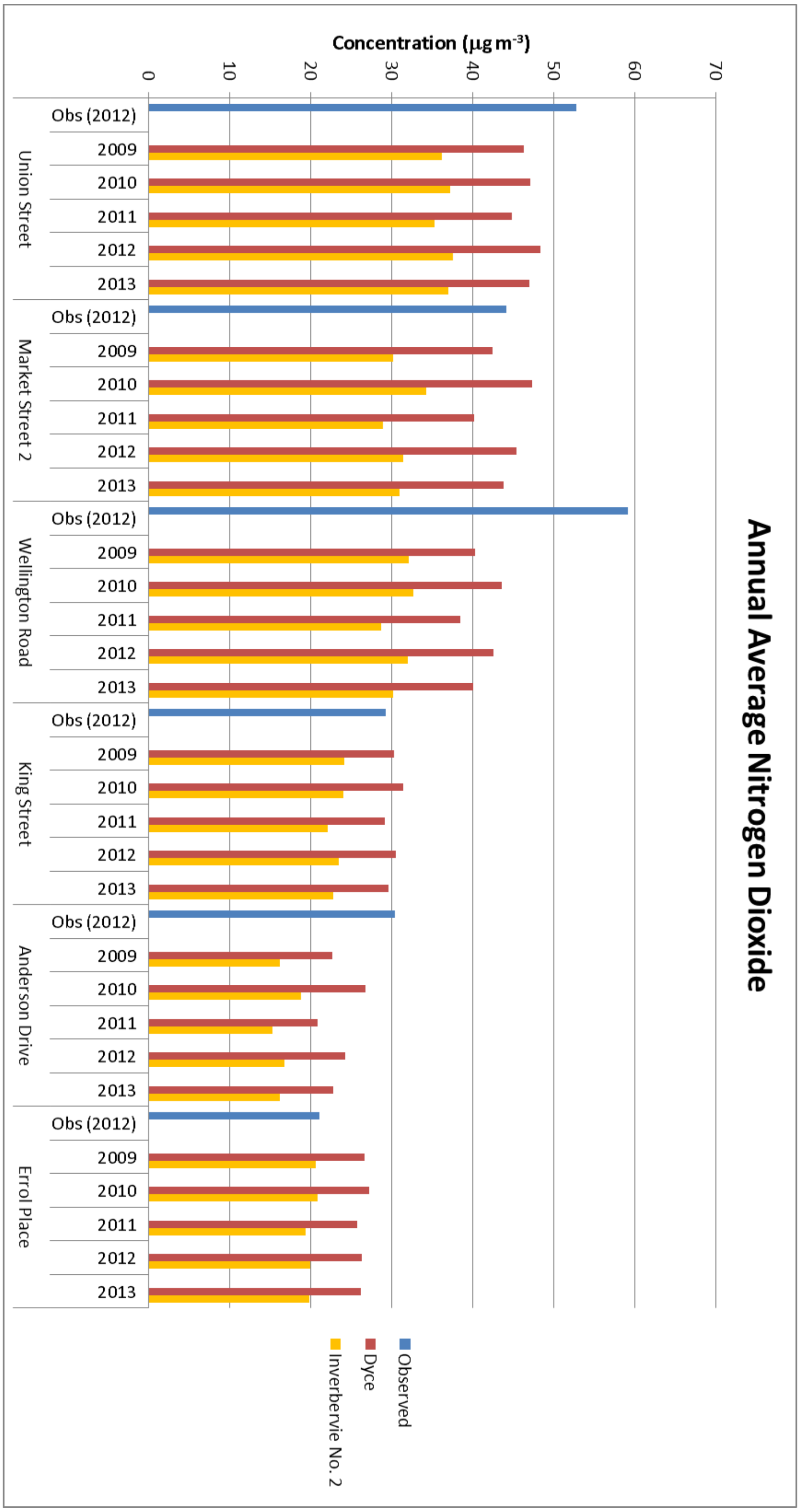
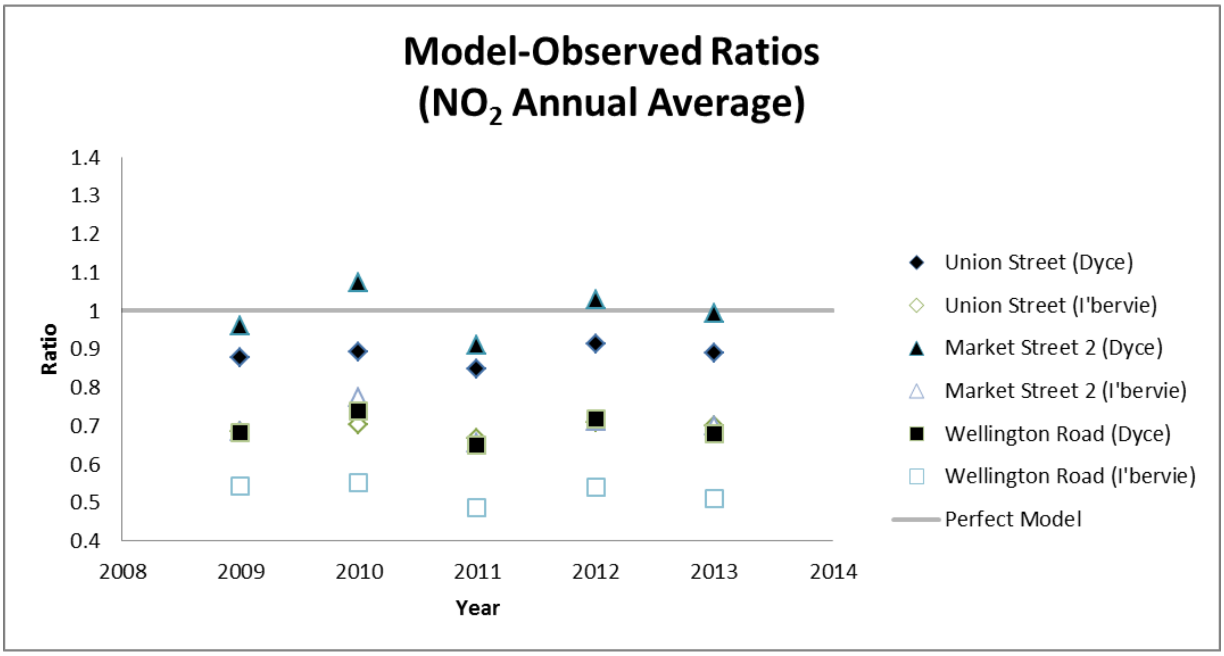


Figure 144: NO_2 Annual Average Concentrations for 2009 to 2013 (meteorological files, rural background files and Gridded Area Emissions, Scenario M3)



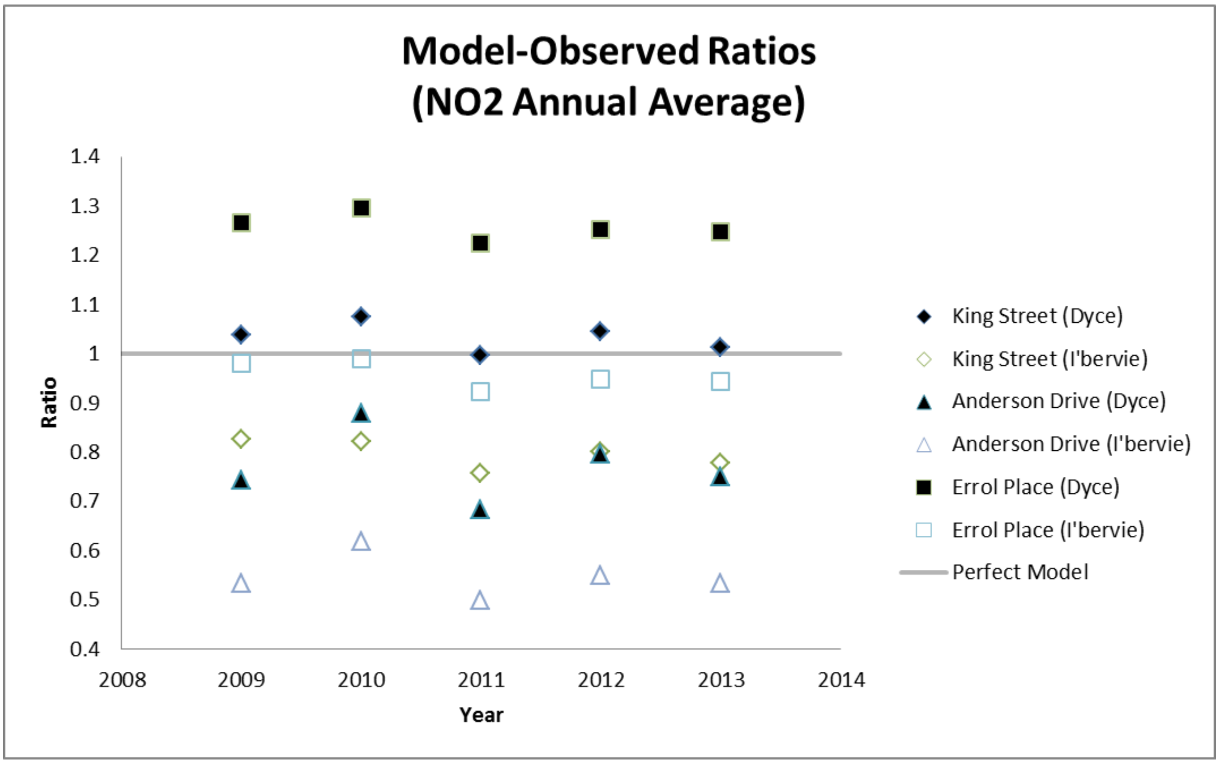


Figure 145: NO_2 Annual Average Ratios (Scenario M3)

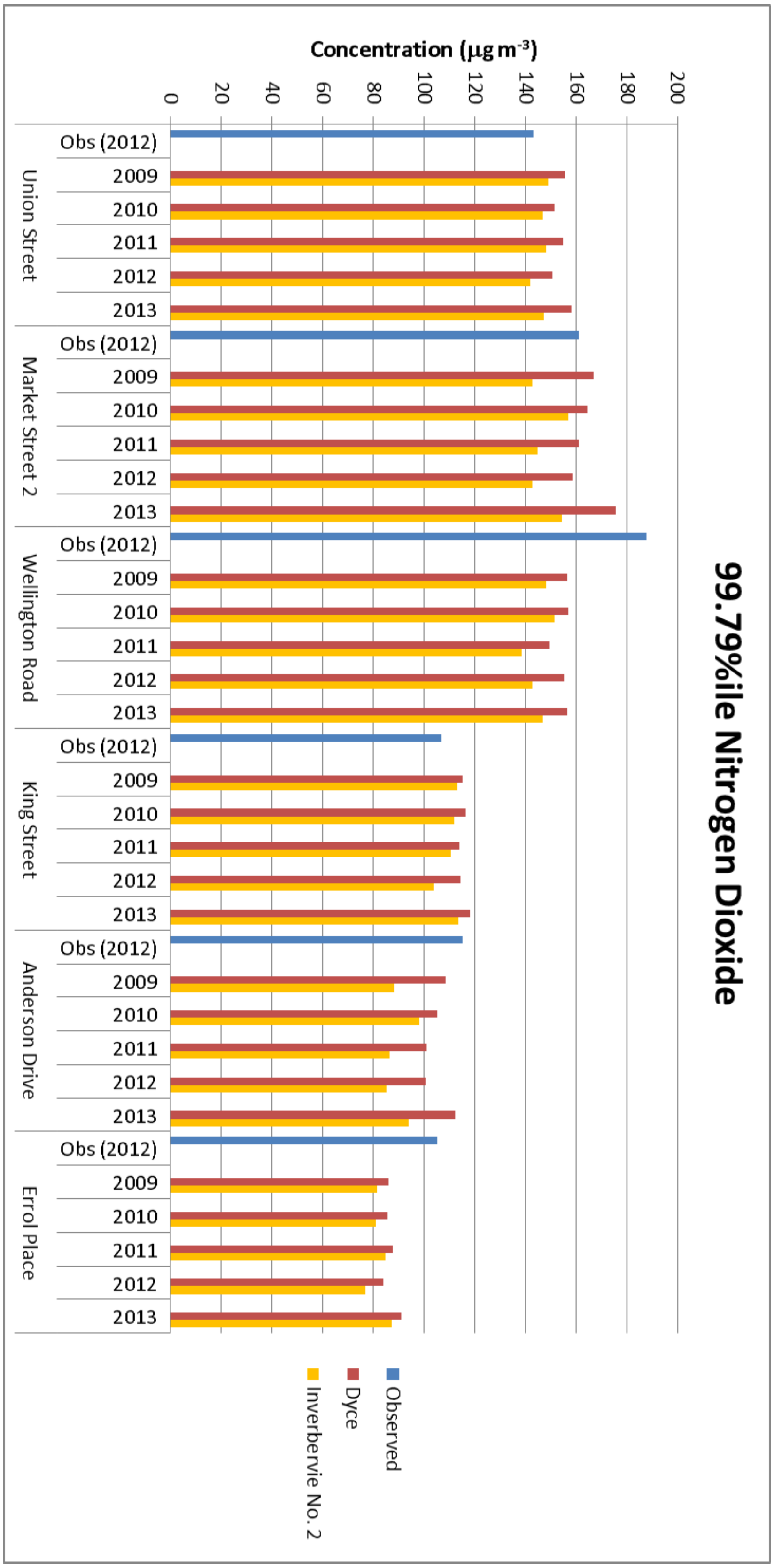


Figure 146: NO_2 99.79th Percentile Concentrations for 2009 to 2013 (meteorological files, rural background files and Gridded Area Emissions, Scenario M3)

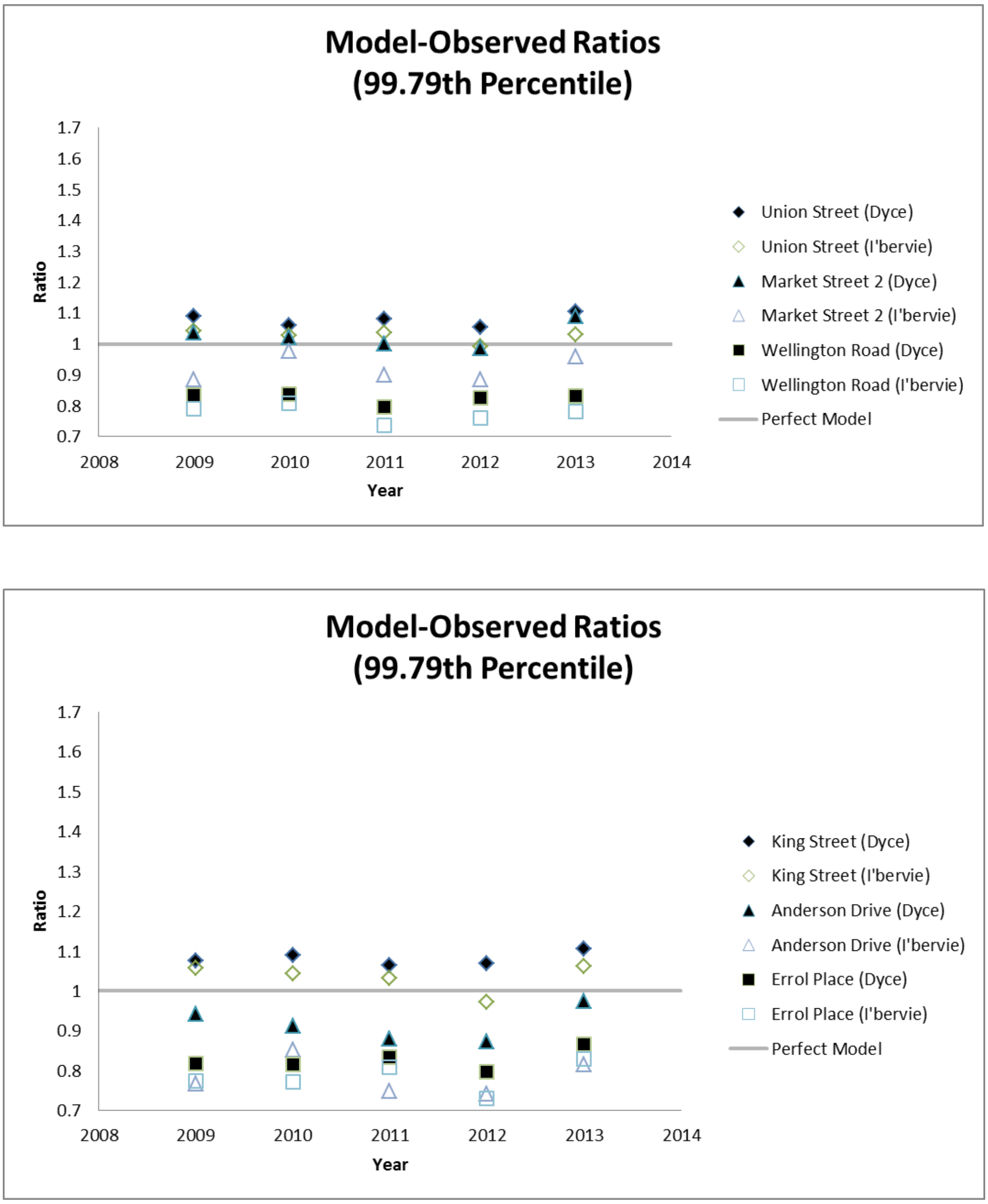


Figure 147: NO_2 99.79th %ile Ratios (Scenario M3)

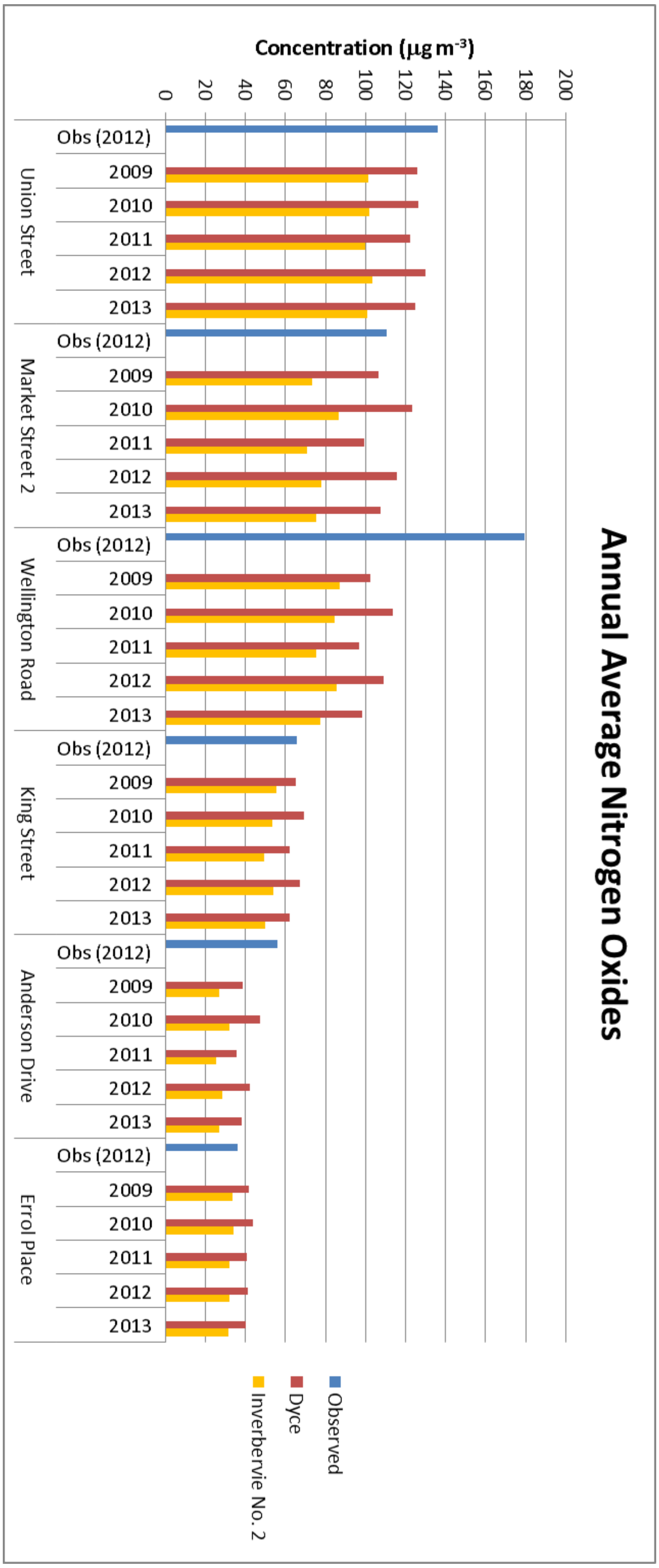
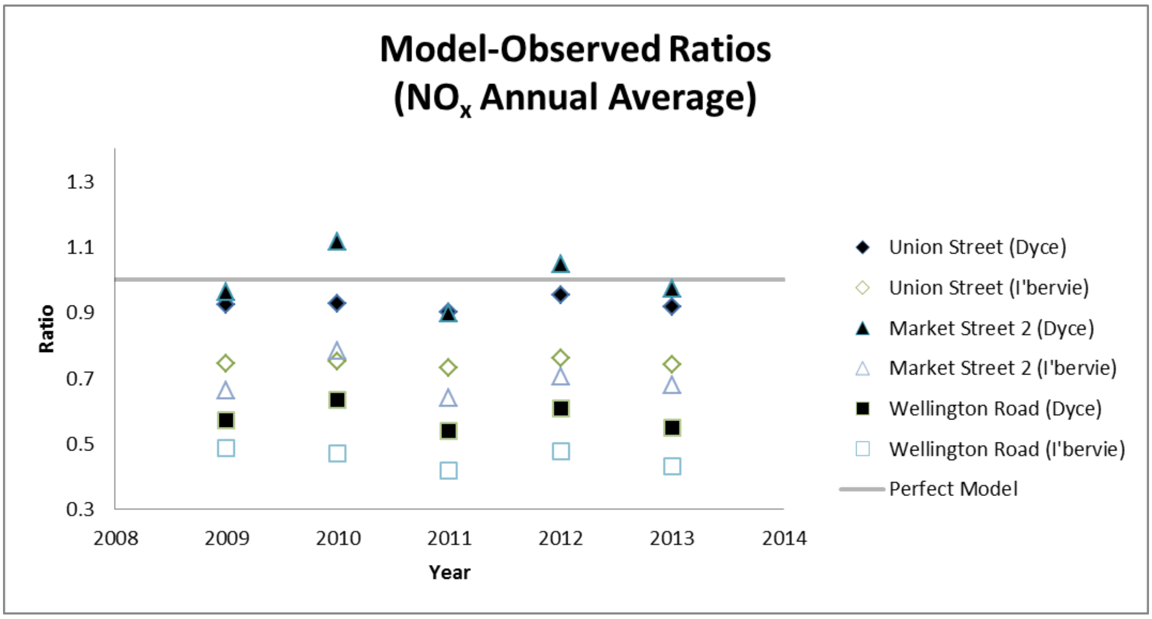


Figure 148: NO_x Annual Average Concentrations for 2009 to 2013 (meteorological files, rural background files and Gridded Area Emissions, Scenario M3)



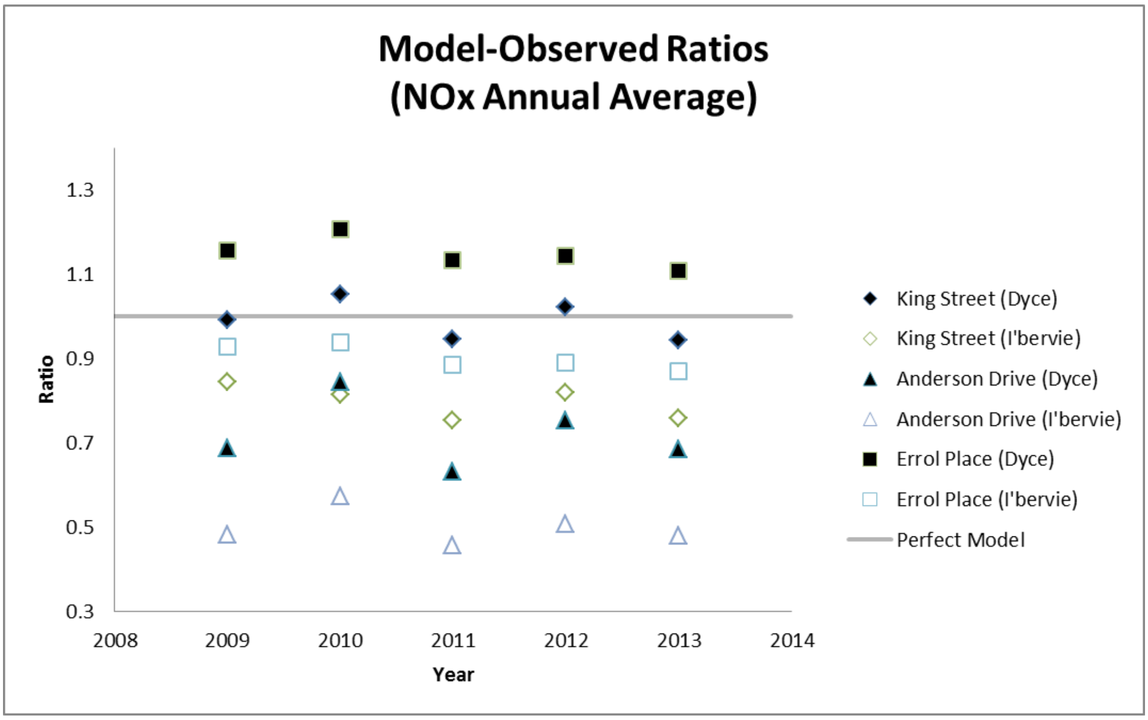


Figure 149: NO_x Annual Average Ratios (Scenario M3)

Scenario M4

Scenario M4 is the same as Scenario M3, with the exception that road source **emissions rates represent the <u>year</u>** that is being modelled (Section 3.8). Detailed results can be found in Appendix A3.4.

NO_2 annual mean

Similarly to Scenario M3, using Inverbervie No.2 meteorological data predicts lower concentrations using Dyce meteorological data.
Using Dyce data, the M4 model under-predicts at Wellington Road for all years, which is consistent with all other model scenarios, Otherwise, at other roadside locations, although there is a tendency for the model to under-predict, it is mostly within 10% of the observed value.

However, at Errol Place, Dyce data performs poorly (5-28% over-prediction); although Inverbervie data tends to under-predict, the difference from the observed value is less than 5% for 3 of the years modelled (Figure 150, Figure 151).

99.79th percentile

Scenario M4 has less variance and better predictions of the observed concentration when compared to scenario M2 (Figure 152, Figure 153) and data from both meteorological stations produce similar predictions, indicating that in most cases, the choice of meteorological data may not be important to predict peak concentrations at roadside locations.

The M4 model does, however, under-predict at Wellington Road, and there is quite a bit of model variability for different years (e.g. Union Street varies between -23% to +15%).

NO_x annual mean

Similarly to M3, model predictions for M4 perform well (with the exception of Wellington Road) though there is some variability (King Street, the model predictions vary between -7% to +12%).

At Errol Place, Dyce data tends to over-predict, whilst Inverbervie data tends to under-predict.

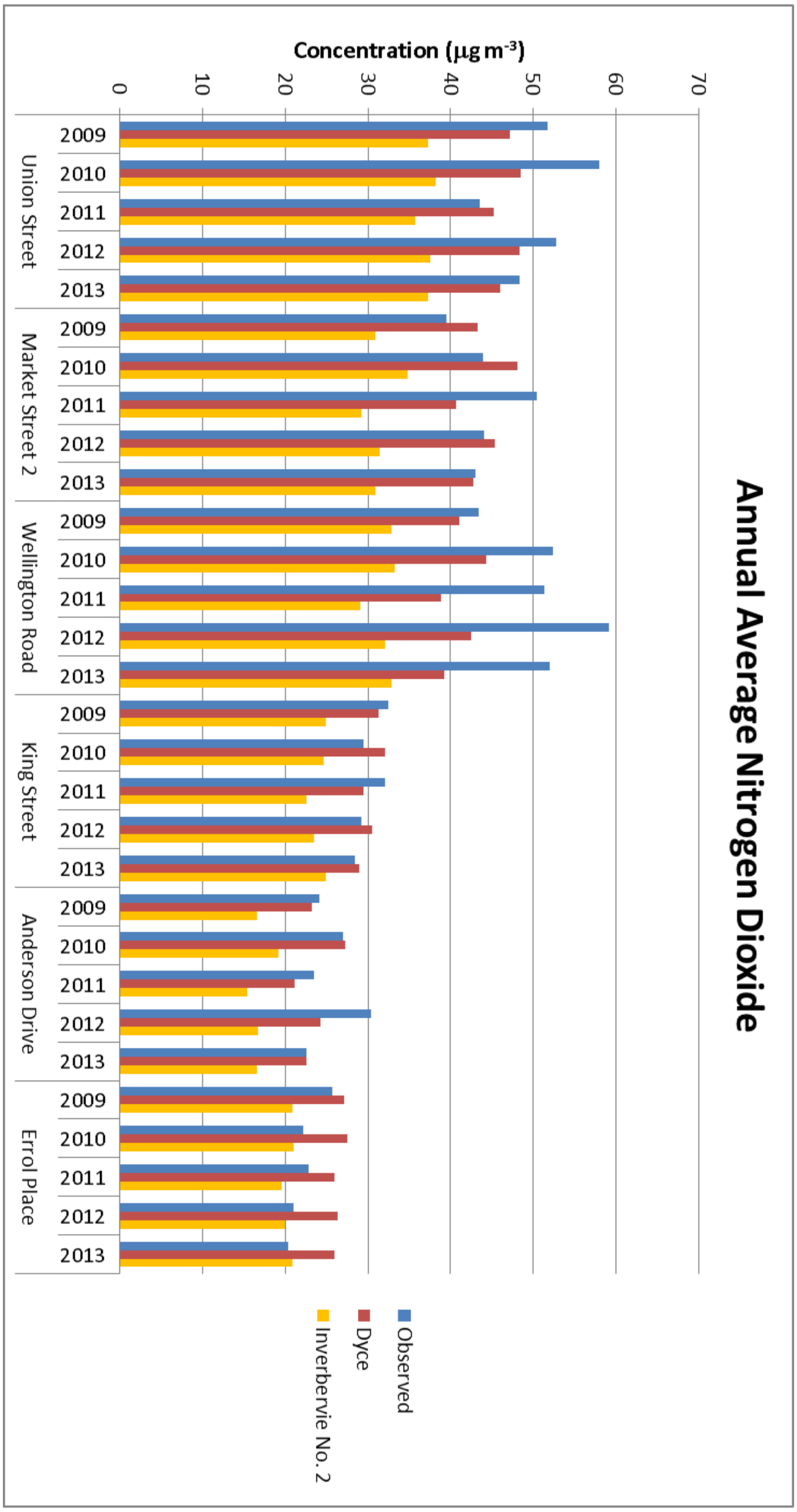
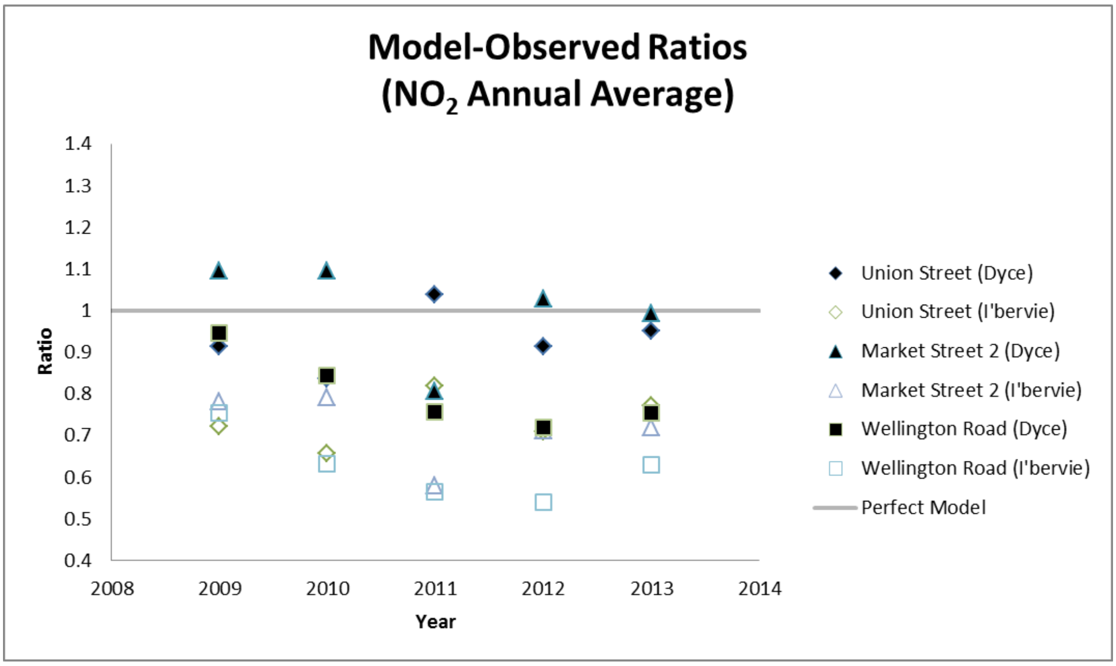


Figure 150: NO$_2$ Annual Average Concentrations for 2009 to 2013 (meteorological files, rural background files Gridded Area Emissions (2012) and Emission Factors)



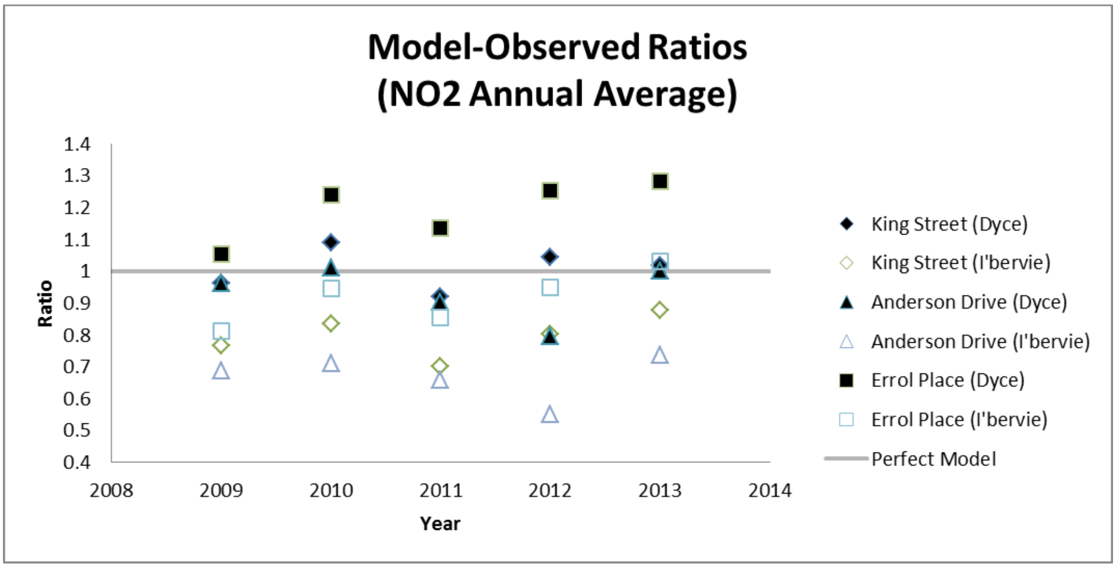


Figure 151: NO_2 Annual Average Ratios (Scenario M4)

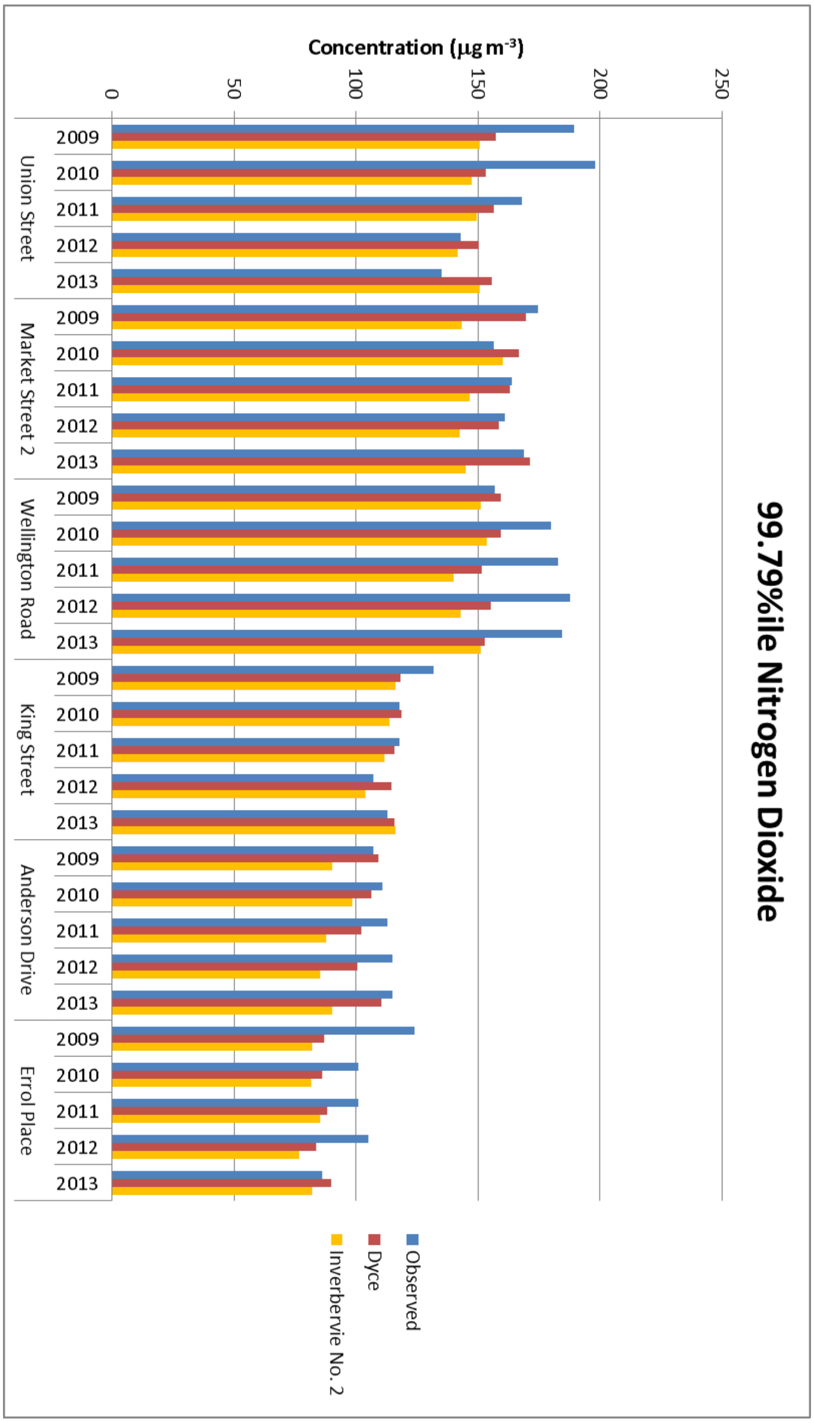
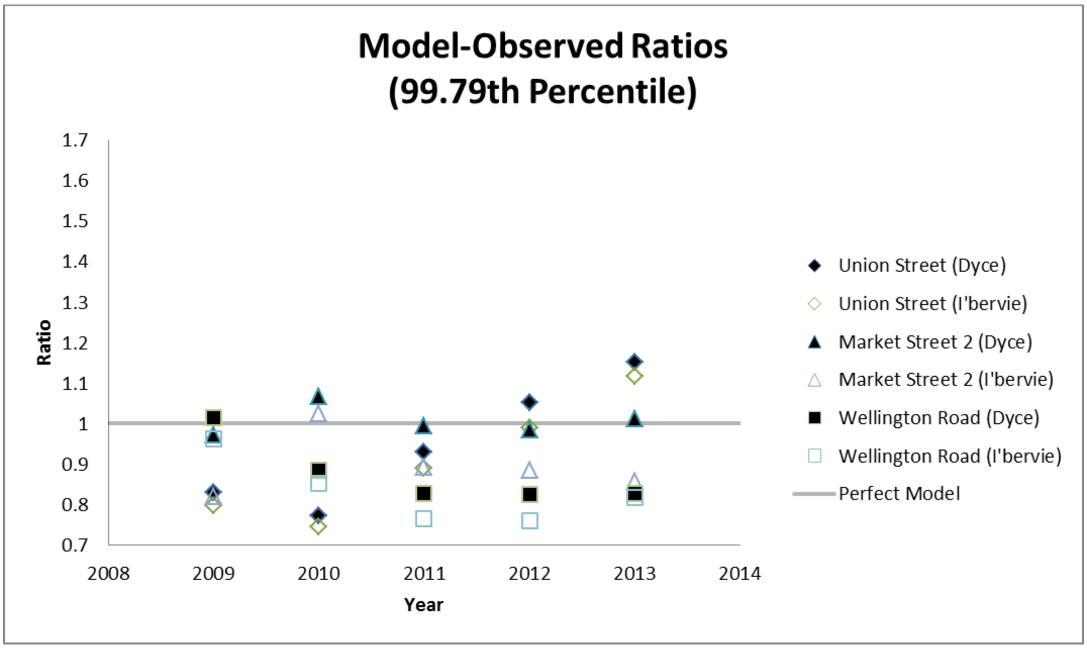


Figure 152: NO_2 99.79th %ile Concentrations for 2009 to 2013 (meteorological files and rural background files and Gridded Area Emissions (2012) and Emission Factors)



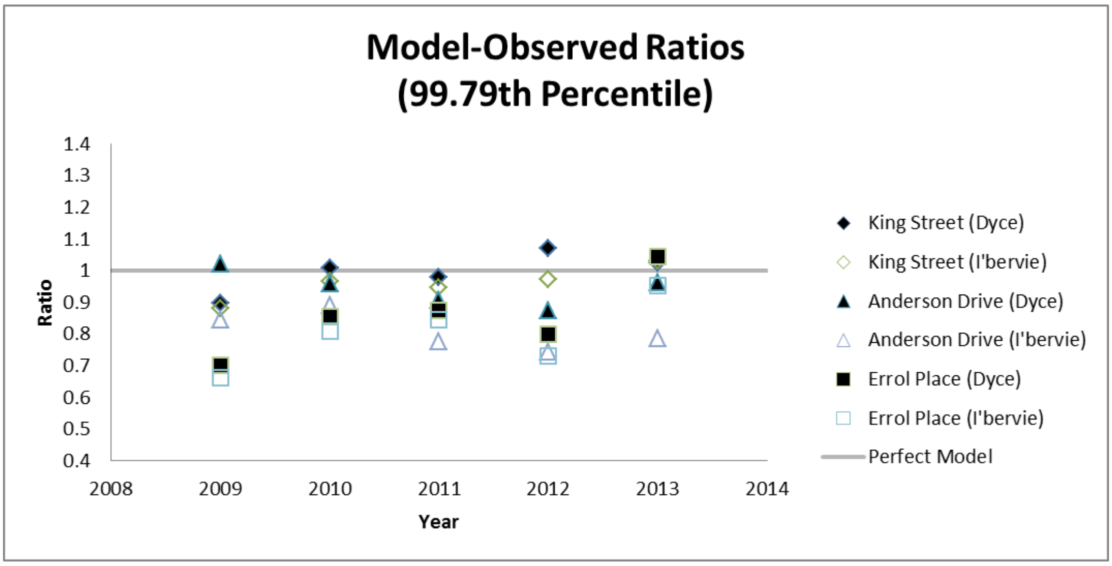


Figure 153: NO_2 99.79th %ile Ratios (Scenario M4)

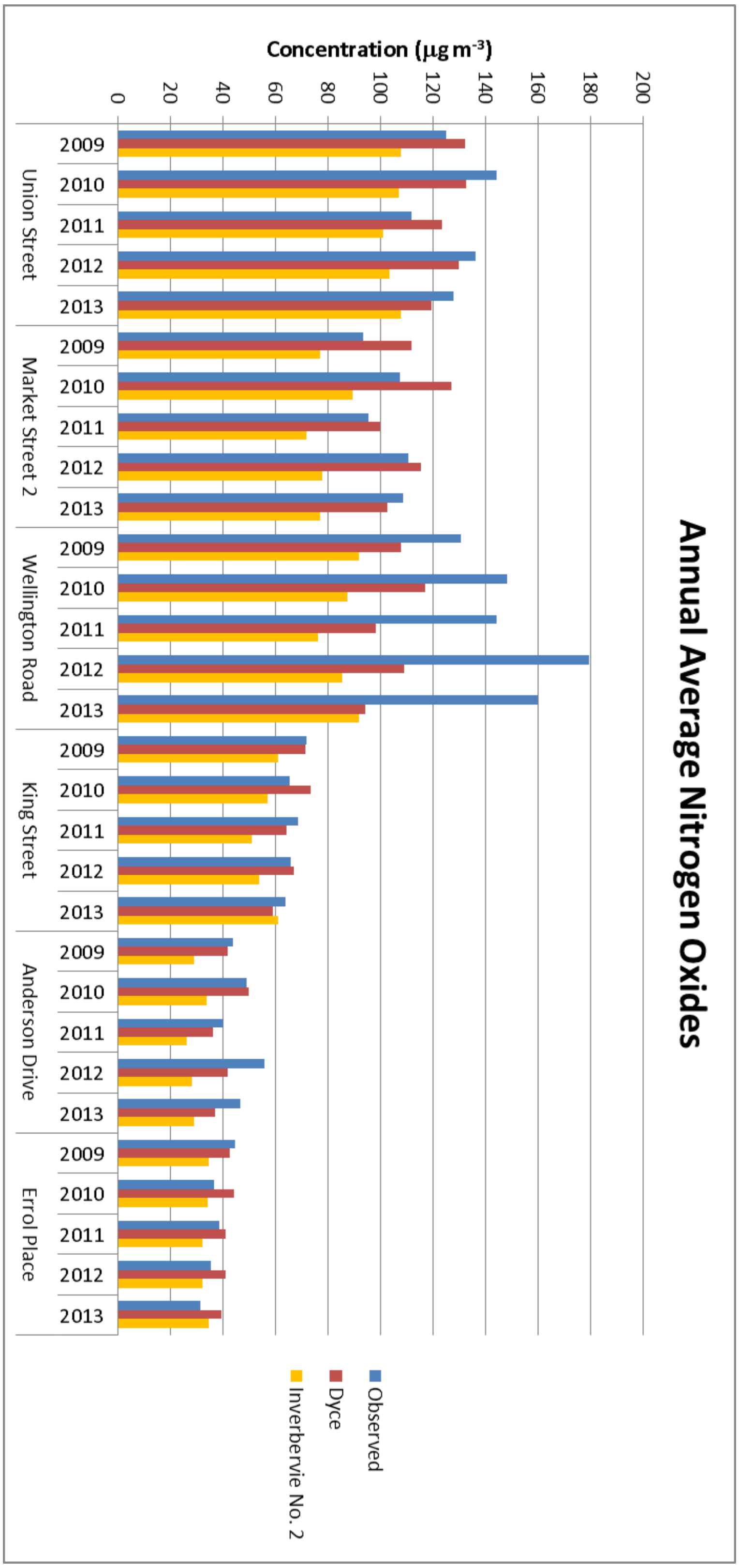


Figure 154: NO_x Annual Average Concentrations for 2009 to 2013 (meteorological files, rural background files and Gridded Area Emissions (2012) and Emission Factors)

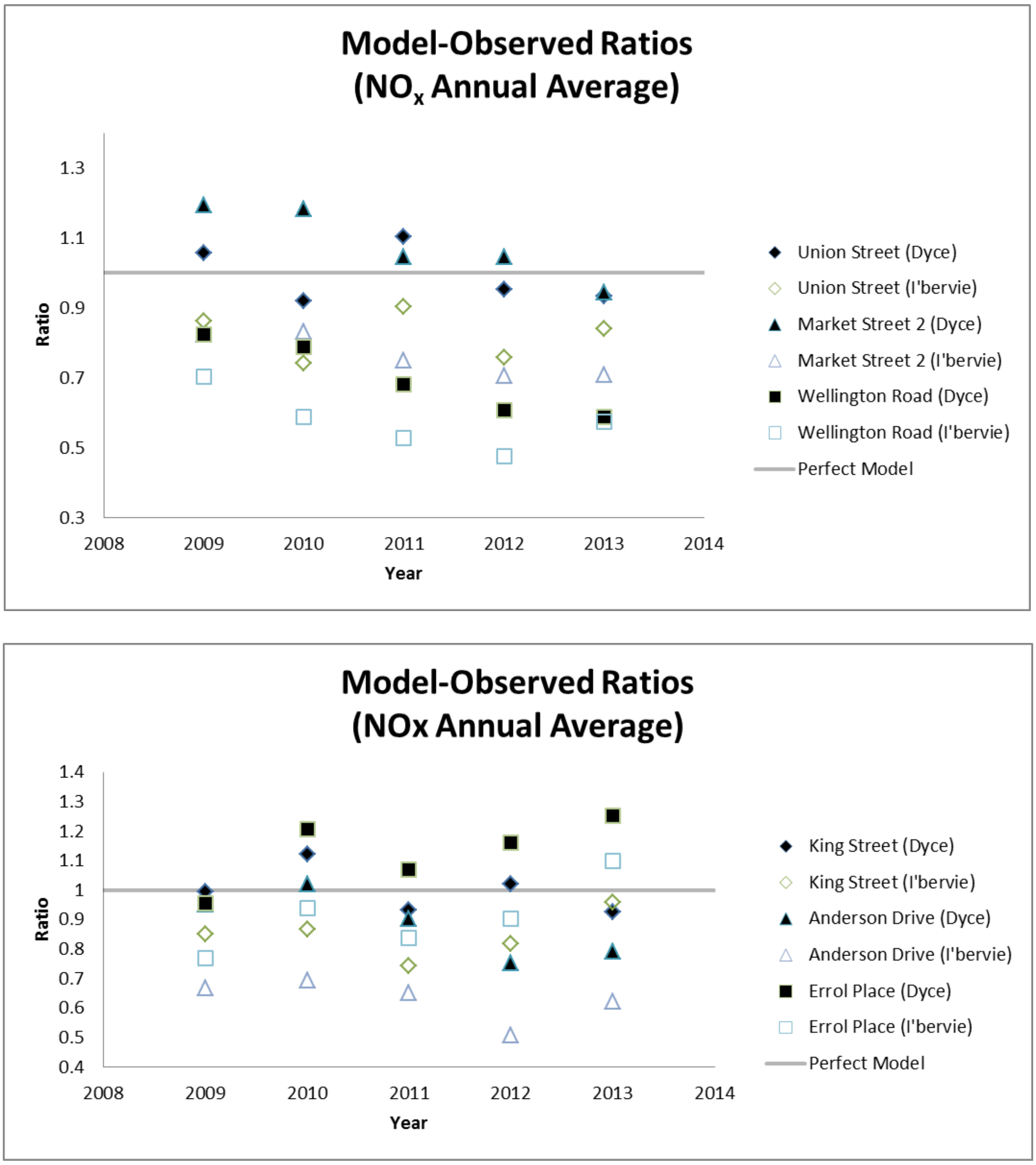


Figure 155: NO_x Annual Average Ratios (Scenario M4)

Diffusion Tubes

When the model predictions are compared to observed diffusion tube values (Figure 156, Figure 157) for each year, the models are shown to be under-predicting at the majority of locations for both methodologies; however a review of diffusion tube measurement methodologies suggests that diffusion tubes are most likely to over-read due to limitations in the methodology (8).

However, it is useful to note that for both methodologies, most model predictions at Diffusion tube locations are within a factor of 2 (the Base Run performs slightly better).

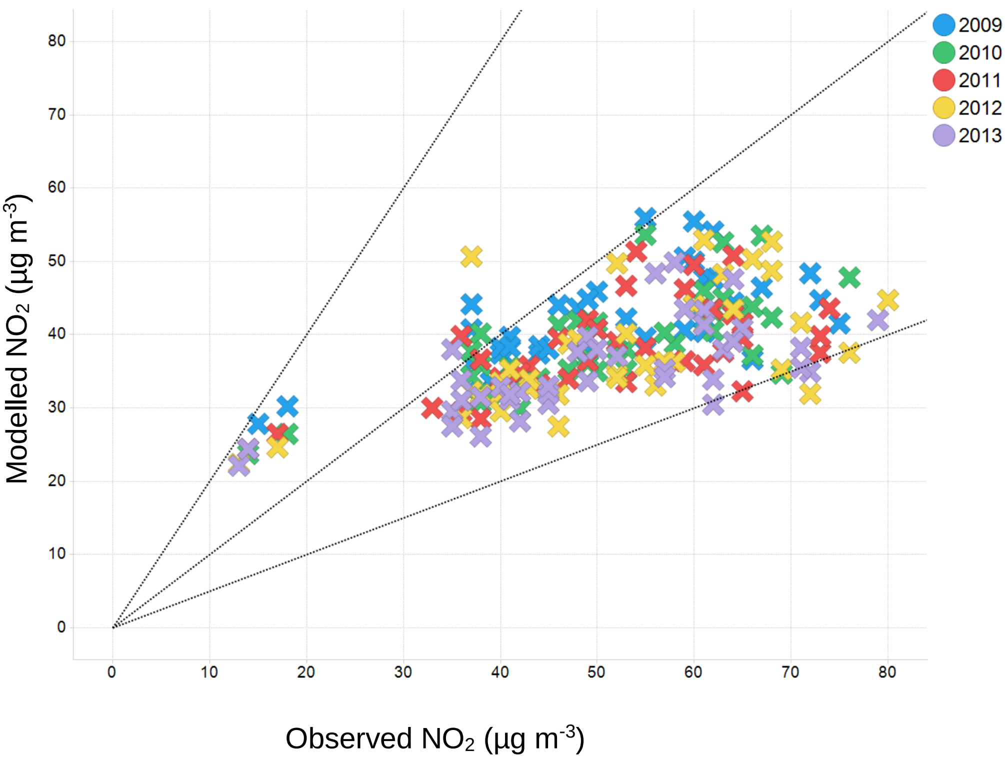


Figure 156: Unadjusted Observed v Modelled concentrations at Diffusion tube locations (2009 – 2013; Base Run, Units: µg m^{-3}).

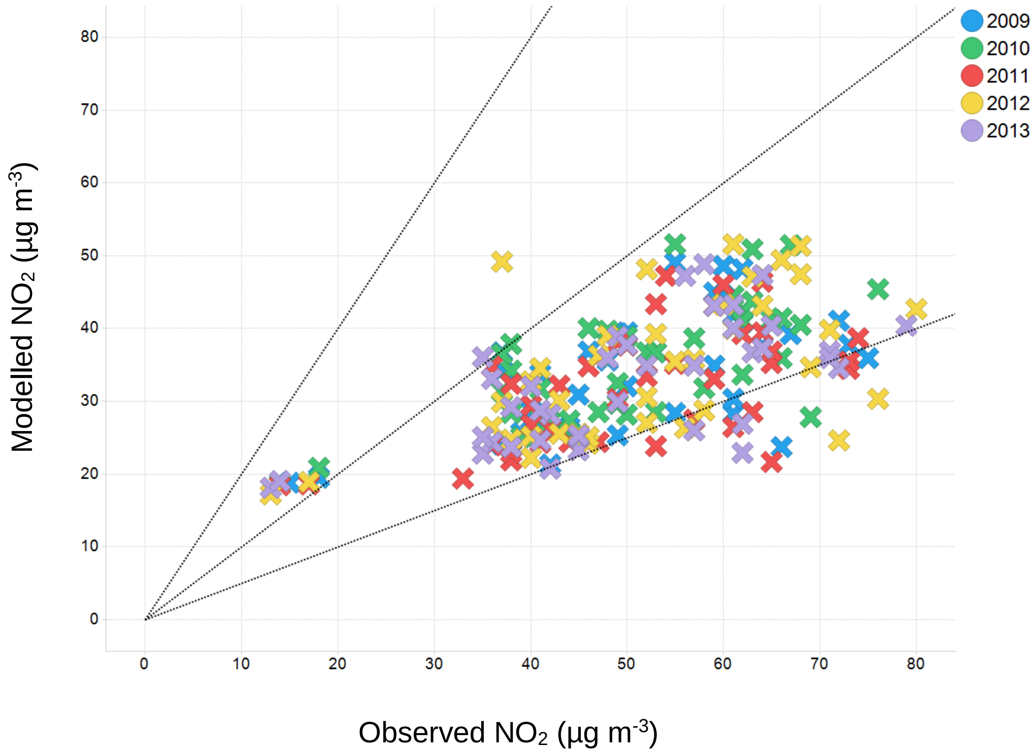


Figure 157: Unadjusted Observed v Modelled concentrations at Diffusion tube locations (2009 – 2013; Background Area Emissions, Units: µg m^{-3}).

Inter-Annual Variation Summary

The Inter-annual variation sensitivity tests show that variations in model predictions can be different at each monitoring location. The percentage variation reported is the variation in model results of the 5 years.

Scenario M1

Model predictions at monitoring locations for different years vary between 9 and 15% (Dyce data) and 10 and17% (Inverbervie No.2 data) for the NO_2 annual mean. Model variation for the 99.79th percentile is much larger (between 15 and 35%). Variations for NO_x annual mean predictions are between 9 and 23% (Table 55). Union Street and Market Street 2 variations are smaller than other monitoring locations.

Scenario M3

Model predictions for NO_2 at monitoring locations for different meteorological years vary between 5.5 and 22% (Dyce data) and 6 and 19% (Inverbervie No.2 data). In contrast to Scenario M1, the 99.79th percentile variations are between 3.6% and 13%. Variations for NO_x annual mean predictions are between 3 and 25%.
In summary, Union Street has the lowest annual mean variations for Scenario M1; however, Market Street 2, which has a low percentage variation for Scenario M1, has the 2nd highest percentage variation for Scenario M3 (Table 56).

The difference in variations may be that for Scenario M1, the use of urban background monitoring data (Errol Place) is capturing measured peak concentrations which are declining over the 5 year period, whereas for Scenario M3, these peaks are not captured as the rural background emissions are stable over the same 5 year period.

Table 55: Percentage Variation using 2009-2013 meteorological data for Scenario M1

Scenario M1	Annual Mean NO_2		99.79th Percentile		Annual Mean NO_x	
	Dyce	Inverbervie No2	Dyce	Inverbervie No2	Dyce	Inverbervie No2
Union Street	9.5	10.1	20.7	23.4	9.4	10.6
Market Street 2	9.4	11.6	15.0	17.6	13.9	11.0
Wellington Road	12.5	16.6	25.3	23.9	13.8	20.4
King Street	14.3	16.7	28.0	27.4	16.9	22.0
Anderson Drive	14.9	15.7	28.6	34.3	19.8	22.8

Table 56: Percentage Variation using 2009-2013 meteorological data for Scenario M3

Scenario M3	Annual Mean NO_2		99.79th Percentile		Annual Mean NO_x	
	Dyce	Inverbervie No2	Dyce	Inverbervie No2	Dyce	Inverbervie No2
Union Street	7.2	5.9	4.7	4.8	5.8	3.6
Market Street 2	15	15.5	9.6	9.2	19.7	18.5
Wellington Road	11.9	12.2	4.8	8.7	14.5	13.7
King Street	7.3	8.3	3.6	8.5	10.4	10.8
Anderson Drive	22.1	19.1	10.3	13	25.2	20.6
Errol Place	5.5	6.7	7.9	12	8.3	7.4

Scenario M2 and M4

Inter-annual predicted/observed plots (Figure 158 and Figure 159) show variations due to year and monitoring location. In particular, the site specific plot (Figure 159) shows the cluster of predictions for each site and how they spread. For lower concertation locations, over-predictions are observed, whilst at higher concentration locations, over and under-predictions are observed.

Comparing Scenarios M2 and M4 indicates that for a large number of model runs (year and monitoring location), a modelled-observed trend line has a gradient less than 1.

Scenario M2 over-predictions occur at locations where observations are low (e.g. Anderson Drive), and under-predict in locations where observations are high, therefore. Scenario M4 is similar though has more scatter and under-predicts in all cases (Figure 159).
A similar pattern is observed for the NO_x annual mean (Figure 161).

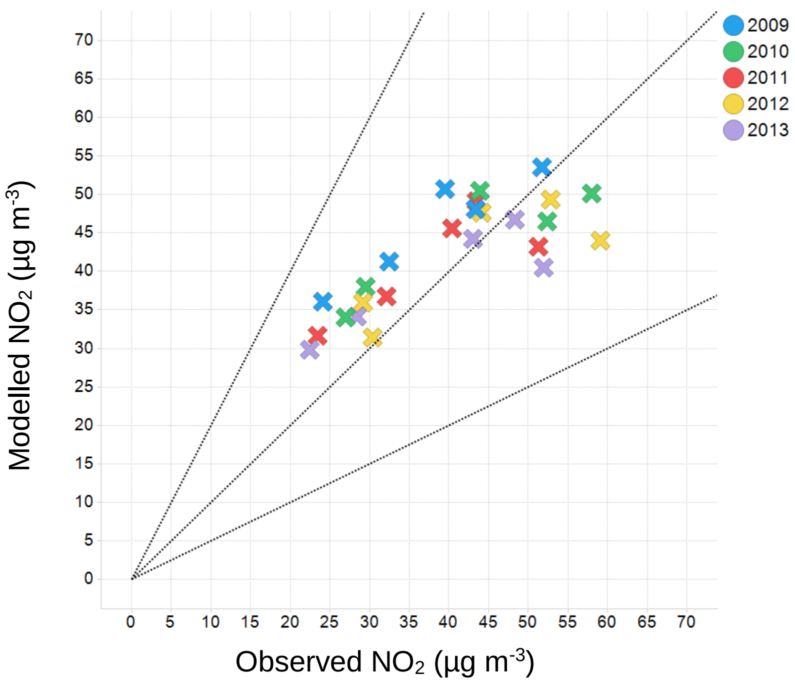
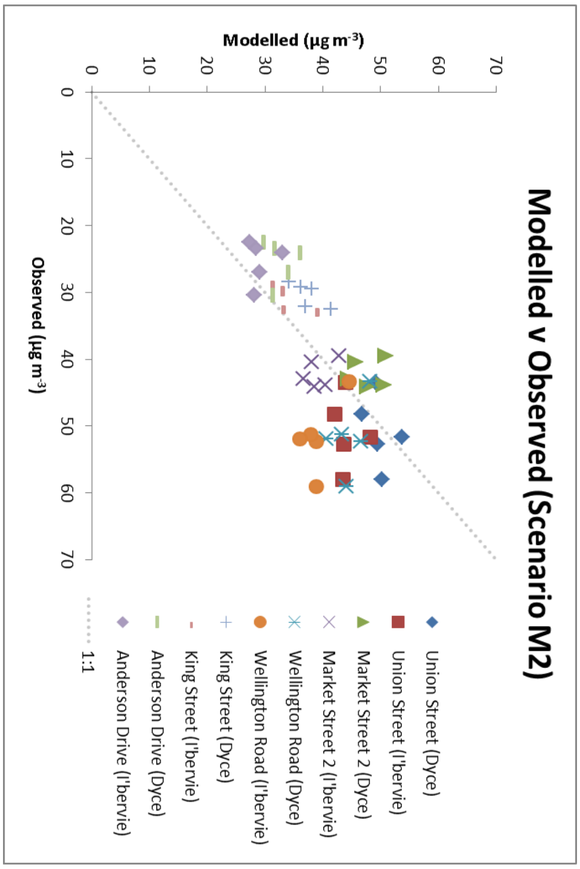


Figure 158: Annual Mean NO_2 concentrations (µg m^{-3}) at Automatic monitors for Scenario M2 (year dependant) (Dyce meteorological data; Units: µg m^{-3})



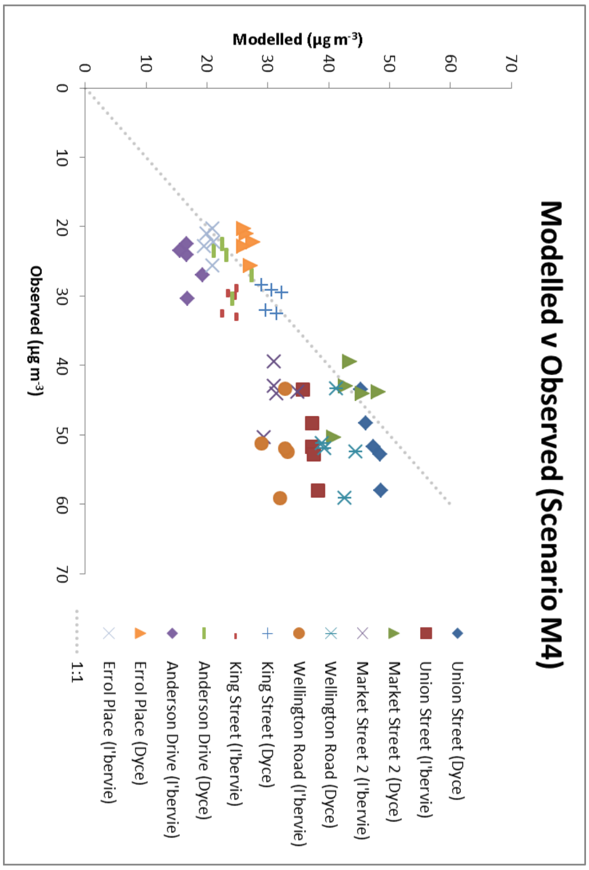
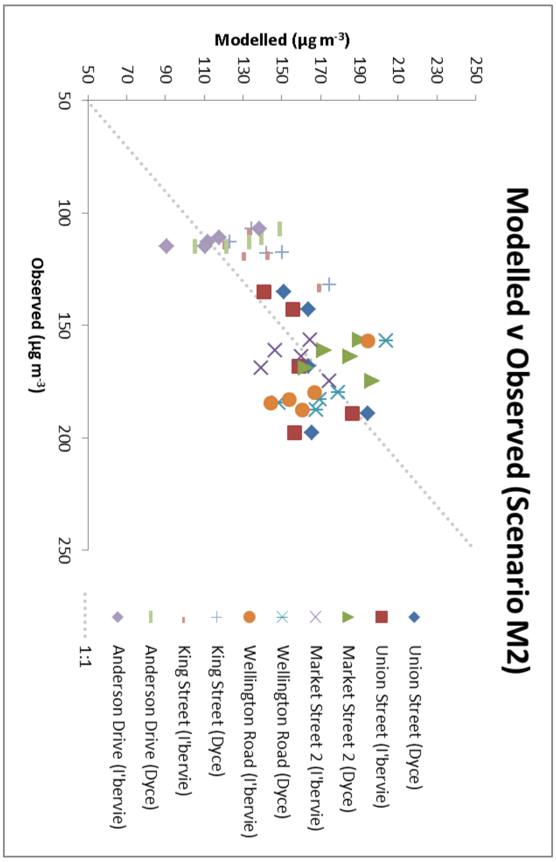


Figure 159: NO_2 Annual Average Inter-Annual variation Summary



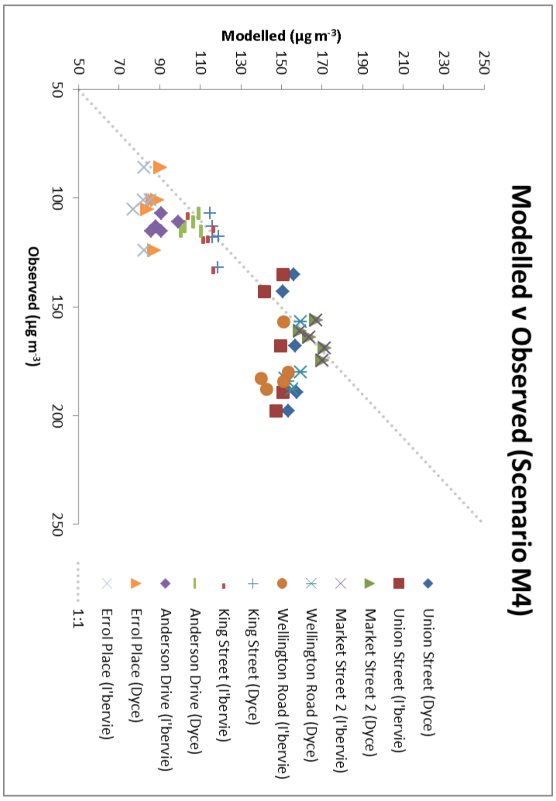
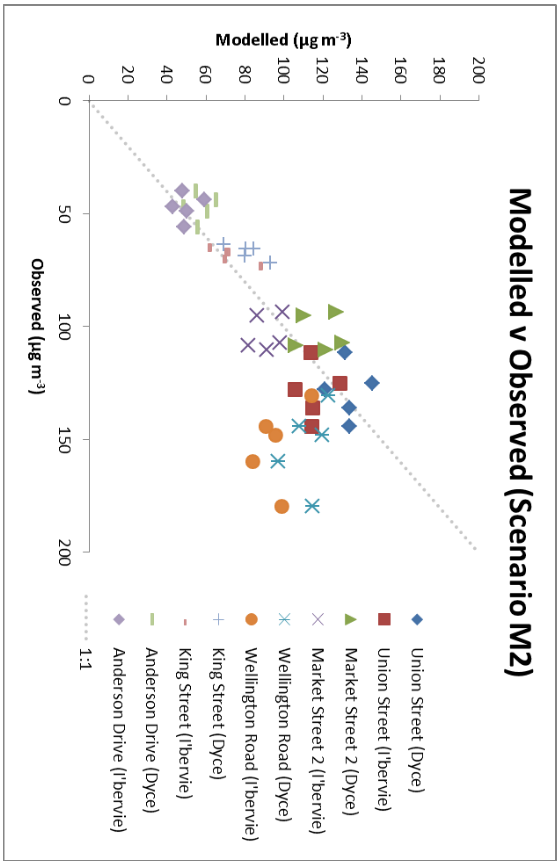


Figure 160: NO2 99.79th Percentile Inter-Annual variation Summary



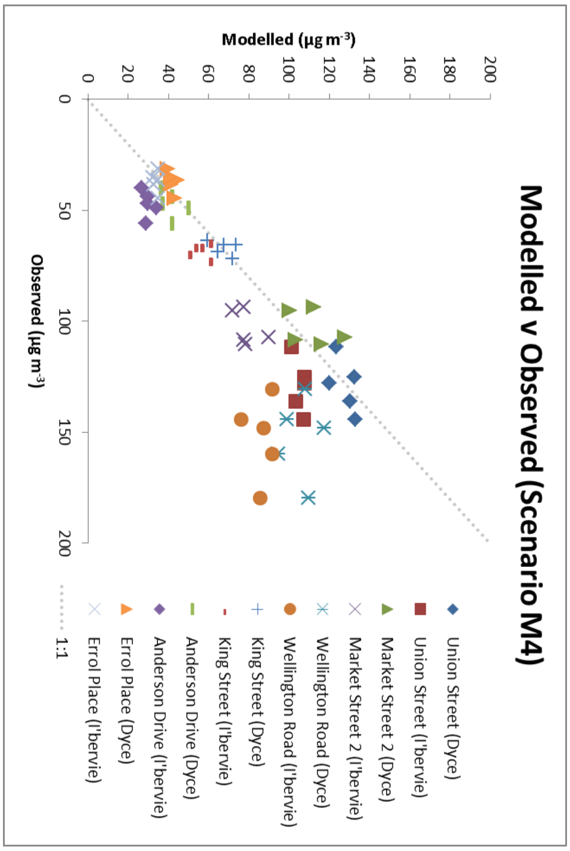


Figure 161: NO_x Annual Average Inter-Annual variation Summary

4.4.2 Chemistry Scheme Sensitivity Tests

The chemistry schemes available in ADMS-Urban are the ‘Chemistry Reaction Scheme’ and the ‘Chemistry Correlation Scheme’ (Section 3.9). The Chemistry Reaction Scheme’ was used in the ‘Base Run’; however, a sensitivity test using the correlation scheme was set up (Table 57) for comparison to the ‘Base Run’.

Table 57: Chemistry Module Sensitivity Tests

Scenario	Details
C1	Chemistry Reaction Scheme, Hourly background (Base Run)
C2	Hourly background only (no chemistry)
C3	NO_x-NO_2 correlation scheme. Hourly background values
C4	NO_x-NO_2 correlation scheme. Background NO_x value of 36 µg/m^3 (from Errol Place)

Union Street

At the Union Street monitor the NO_2 annual mean was closely predicted in Scenarios C1, C3 and C4 (Table 92, Figure 162 and Figure 163). Scenario C4 correctly predicts the NO_2 annual mean, however, is the worst prediction of the NO_2 99.79th percentile.

Detailed analysis shows that scenarios C2 and C3 fail some of the statistical tests outlined in Section 4.1, whilst C1 and C4 perform well according to these statistics (Table 58). However, the NO_2 Q-Q plots (Figure 164 to Figure 167) indicate that Scenario C4 performs poorly. Therefore it can be concluded that Scenario C1 (the ‘Base Run) is the best performing model run.

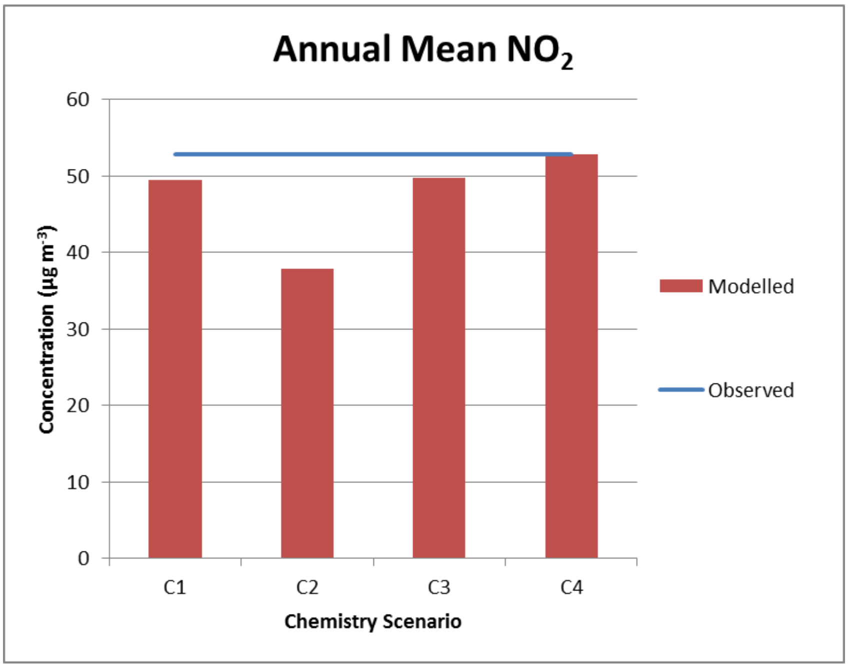


Figure 162: Annual Mean NO_2 Predictions for chemistry scenarios at Union Street Monitor

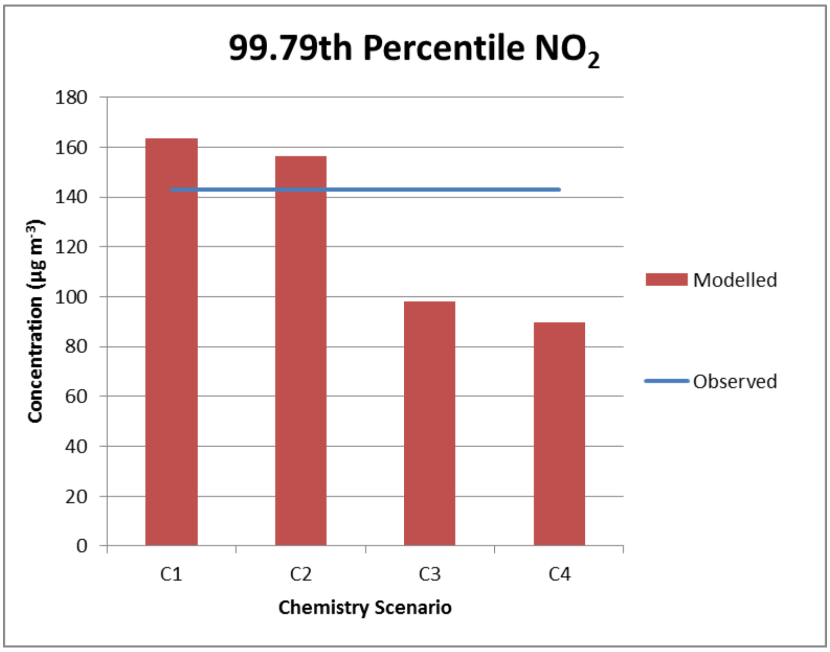


Figure 163: 99.79th Percentile NO_2 predictions for chemistry scenarios at Union Street Monitor

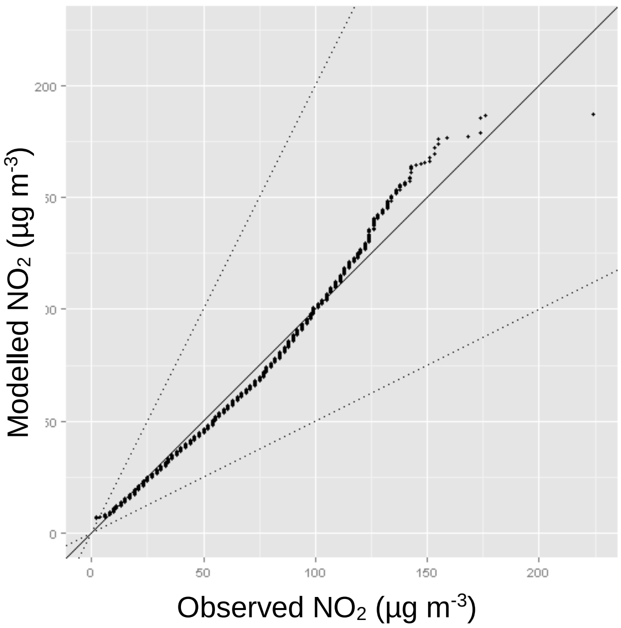


Figure 164: Union Street; C1; Chemistry Module On (Units: µg m^{-3})

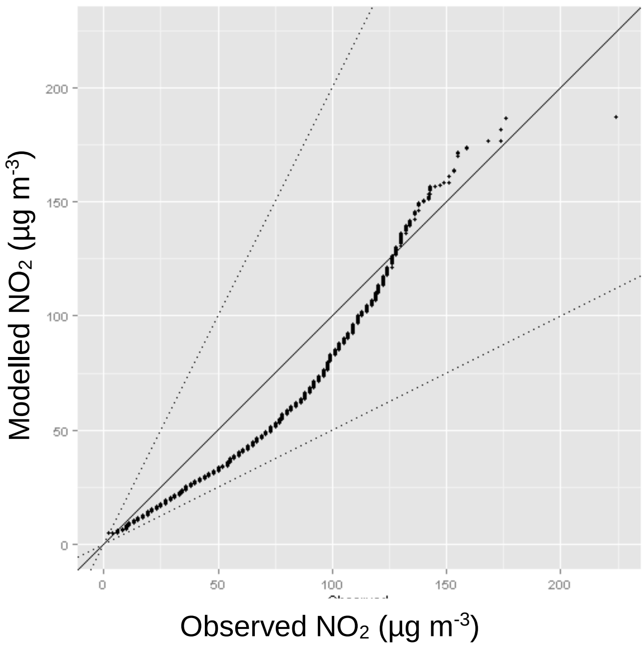


Figure 165: Union Street; C2; Chemistry Module Off, Hourly Background (Units: µg m^{-3})

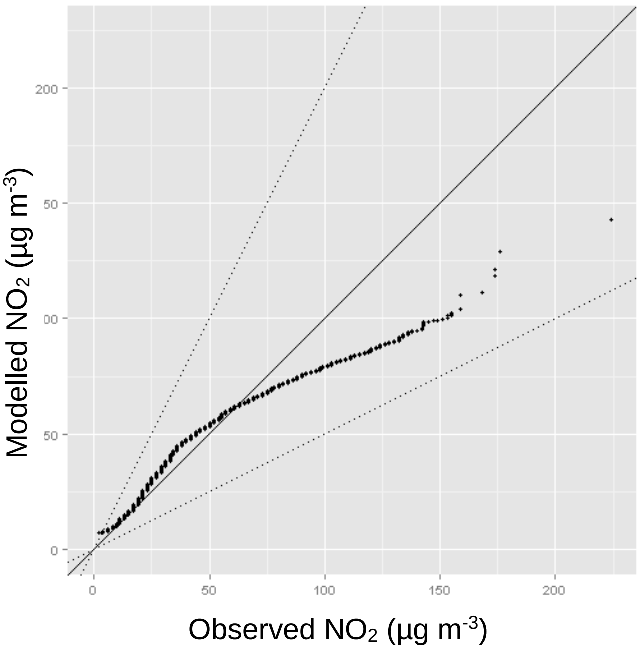


Figure 166: Union Street; C3; NO_x-NO_2 correlation, Hourly Background (Units: µg m^{-3})

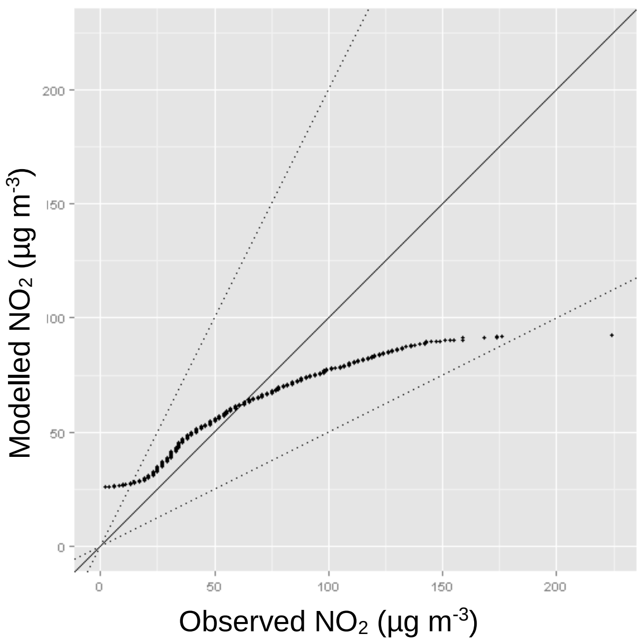


Figure 167: Union Street; C4; NO_x-NO_2 correlation, (NO_x 36µg/m^3 background) (Units: µg m^{-3})

Table 58: Statistical Results for NO_2 concentrations using different Chemistry methods (Union Street) (bold shows parameters which have failed tests described in Section 4.1)

Statistic	MG	VG	NMSE	FB	Fac2	MB	R
C1	0.91	1.48	0.28	-0.06	0.75	-3.24	0.59
C2	**0.68**	1.82	0.47	**-0.33**	0.62	-14.84	0.55
C3	0.97	1.37	0.21	**1.37**	0.81	-3.08	0.63
C4	1.14	1.36	0.2	0	0.81	-0.04	0.6

Market Street 2

Performance of the models at the Market Street 2 monitor is similar to the Union Street results. The NO_2 annual mean predictions are good for Scenario C1, C3 and C4 (Table 93, Figure 168 and Figure 169), with scenario C3 correctly predicting the NO_2 annual mean. However, scenario C3 poorly predicts the NO_2 99.79th percentile.

More detailed statistical analysis indicates (Table 59) that all scenarios meet the tests outlined in Section 4.1, though scenario C4 just falls within the Geometric Mean Bias acceptable range.

The NO_2 Q-Q plots (Figure 170 to Figure 173) indicate that scenarios C3 and C4 do not perform well, and it can be concluded again that scenario C1 performs the best.

Chemistry Sensitivity Test Summary

Sensitivity testing has shown that using the Chemistry Reaction scheme should be included in future model runs, and also highlights the importance of including chemistry in the models to simulate the formation of secondary NO_2.

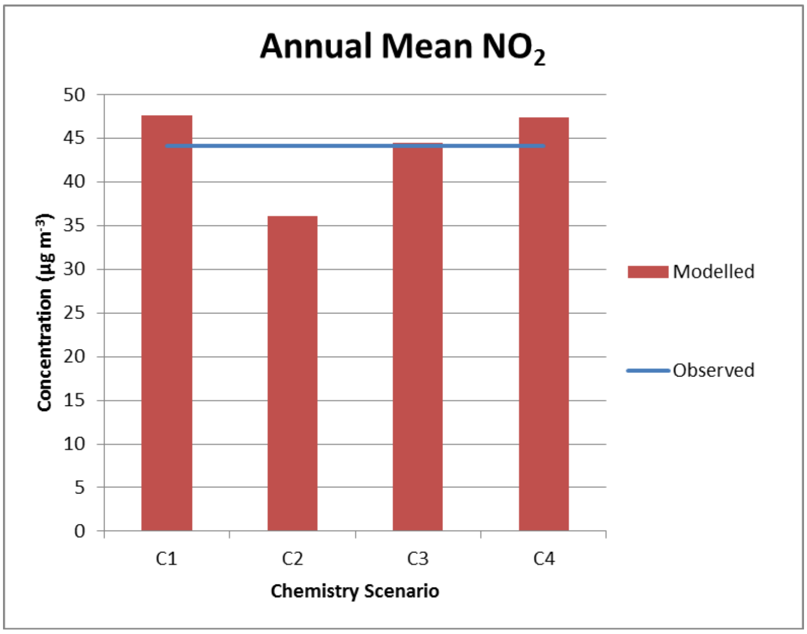


Figure 168: Annual Mean NO_2 Predictions for chemistry scenarios at Market Street 2 Monitor

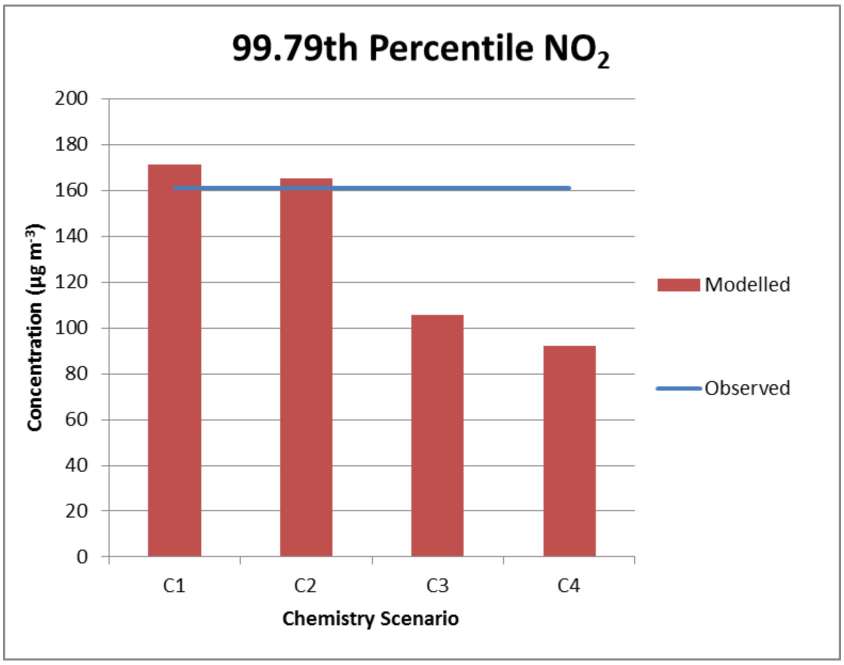


Figure 169: 99.79th Percentile NO_2 predictions for chemistry scenarios at Market Street 2 Monitor

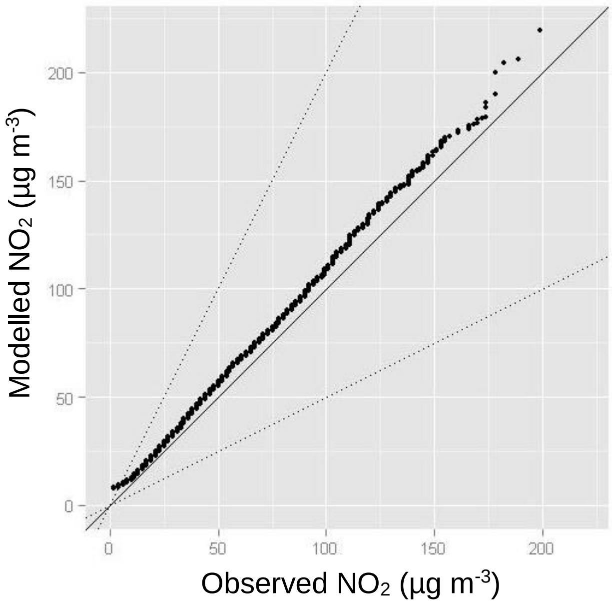


Figure 170: Market Street; C1; Chemistry Module On (Units: µg m^{-3})

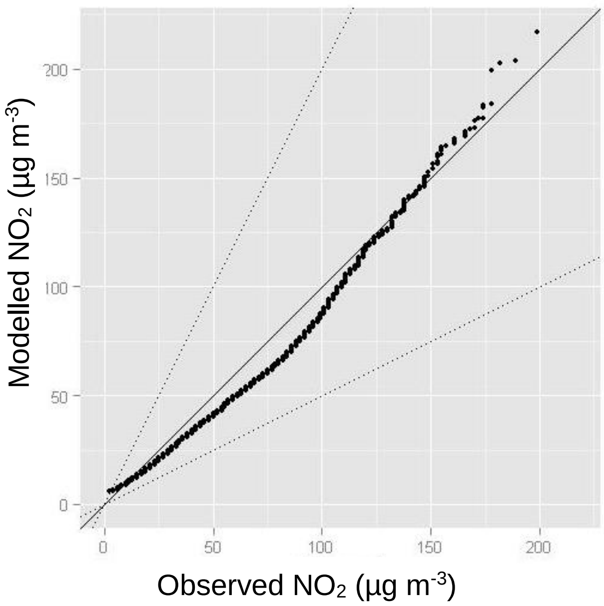


Figure 171: Market Street; C2; Chemistry Module Off, Hourly Background (Units: µg m^{-3})

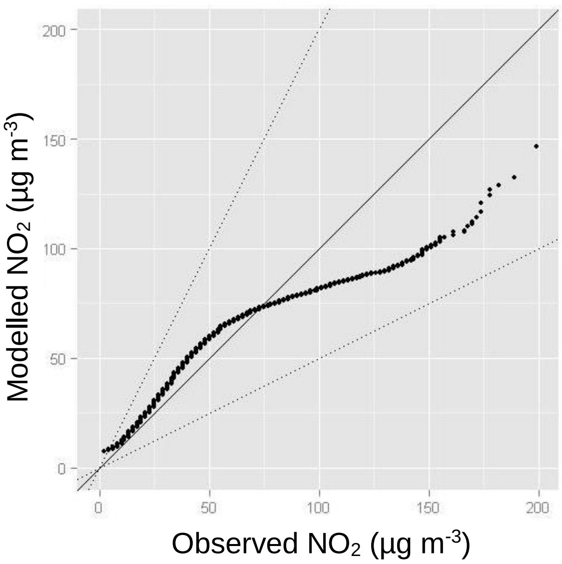


Figure 172: Market Street; C3; NO_x-NO_2 correlation, Hourly Background (Units: µg m^{-3})

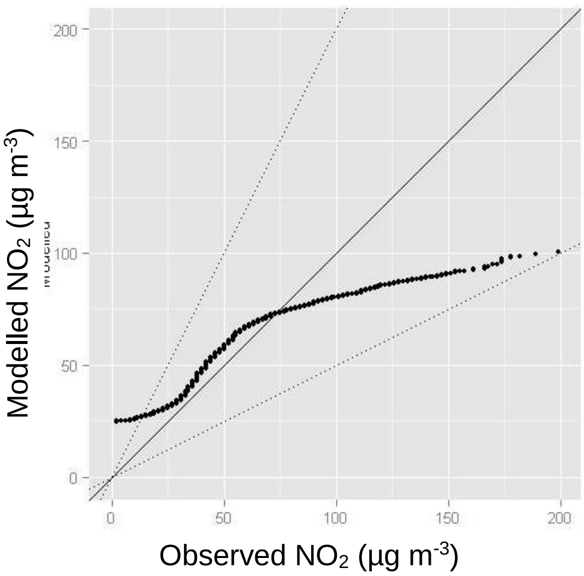


Figure 173: Market Street; C4; NO_x-NO_2 correlation, (NO_x 36µg/m^3 background) (Units: µg m^{-3})

Table 59: Statistical Results for NO_2 concentrations using different Chemistry methods (Market Street) (bold shows parameters which have failed tests described in Section 4.1)

Statistic	MG	VG	NMSE	FB	Fac2	MB	R
C1	1.11	1.63	0.42	0.1	0.72	4.69	0.55
C2	0.82	1.77	0.55	-0.17	0.68	-7.06	0.48
C3	1.08	1.53	0.29	0.03	0.76	1.51	0.61
C4	1.29	1.57	0.27	0.09	0.75	4.01	0.6

4.4.3 Time-Varying Emissions Sensitivity Test

Time-varying emissions (Section 3.6) simulate the variation of emissions depending on time of day and day of week. To test the effect of using time-varying emissions, a sensitivity test modifying emissions in the 'Base Run' to be **constant** was set up.

NO_2 Annual Mean

When emissions are **constant**, the NO_2 annual mean concentrations are predicted to be greater than the Base Run (Table 94; Figure 174).

In the **Base Run (time varying scenario)**, during high NO_x emission periods (daytime and at rush hour), conversion to NO_2 will be limited by the availability of Ozone.

In the **non-time-varying** scenario, as emissions are **constant** at all times, conversion to NO_2 may not be constrained as frequently due to the fact that Ozone availability may not be a limiting factor (e.g. at night time periods when emissions will be over-estimated in this scenario), and therefore a higher NO_2 annual mean is predicted.

99.79th Percentile

The 'Base Run' predicts higher 99.79th percentile concentrations which is likely due to the time-varying emissions option predicting peak emissions during rush hour periods (Table 95; Figure 175) which is not the case when non-time varying emissions are applied.

NO_x Annual Mean

For the NO_x annual mean, similarly to NO_2, predicted NO_x concentrations are greater in the **non-time-varying** scenario (Table 96; Figure 176).

Statistical Tests

The Q-Q plots for the Union Street and Market Street 2 monitors (Figure 177 to Figure 184) show that for the **non-time varying** emissions scenario, the model tends to over-predict concentrations when observed concentrations are low, and under-predict concentrations when observed concentrations are high.

Although using time varying emissions may result in a poorer prediction of the annual mean (such as in the case of Wellington Road), the Q-Q plots for time-varying emissions tend to have a straighter line closer to the 1:1 showing that model predictions are better when using time-varying emissions.

Detailed statistical analysis of the **non-time varying** emissions scenario indicate that the 'Base Run' performs better in all cases for NO_2, with the exception of the Fractional Bias (FB) for Union Street (though the difference is very small and both scenarios perform well), and Geometric Mean at Wellington Road, where air flow has been found to be complex (Table 28, Table 60).

In the case of NO_x, the detailed statistics indicate the **non-time varying** scenario fails at least one of the tests outlined in Section 4.1 (Table 61) at each monitoring location. Therefore, it is important that time-varying emissions are included in future models.

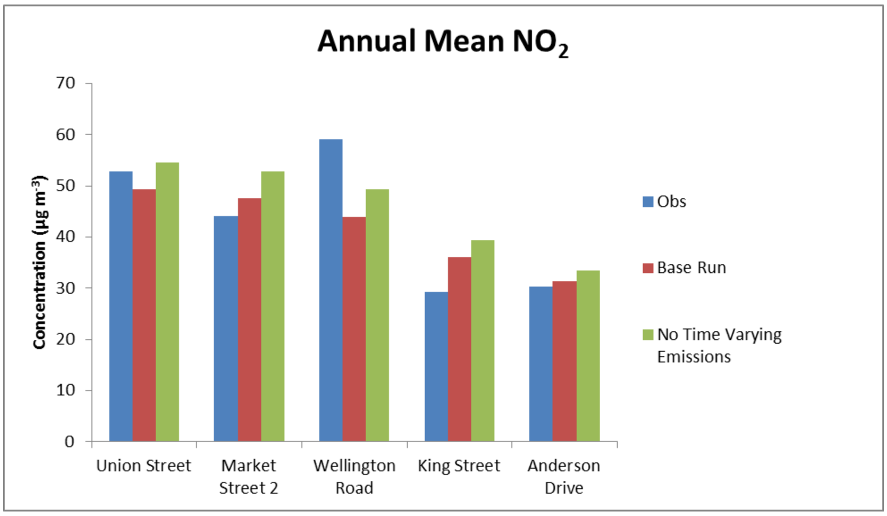


Figure 174: NO_2 Annual Mean Concentration for Time-varying emissions sensitivity test

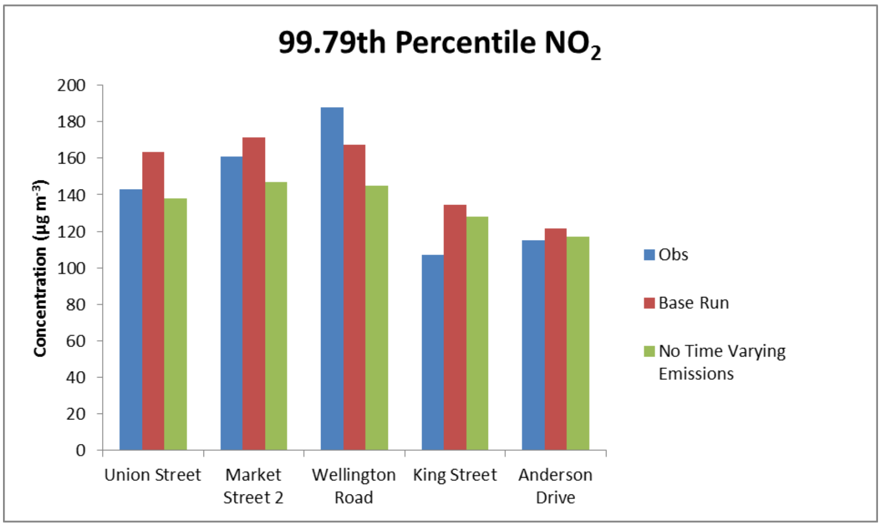


Figure 175: NO_2 99.79th Percentile Concentration for Time-varying emissions sensitivity test

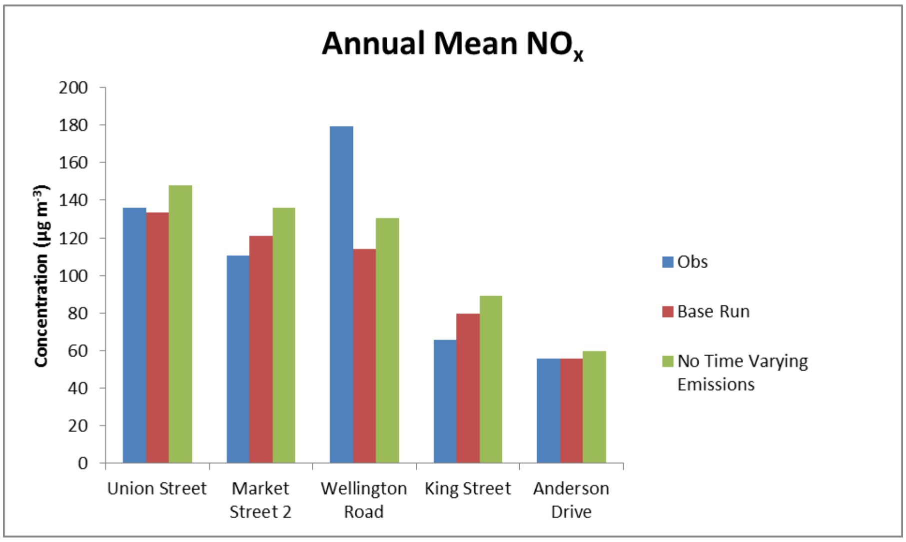


Figure 176: NO_x Annual Mean Concentration for Time-varying emissions sensitivity test

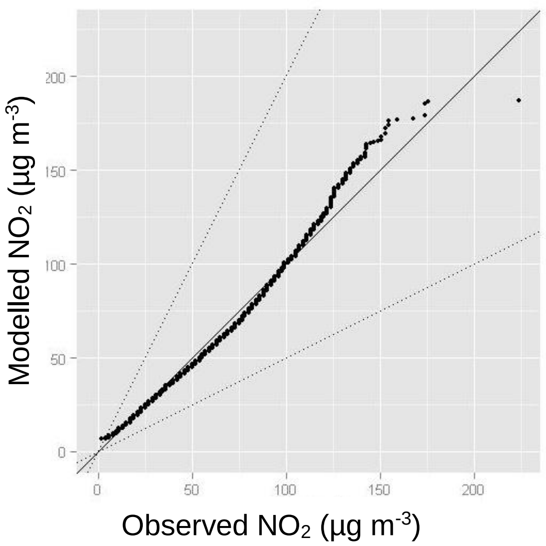


Figure 177: Union Street NO_2 Q-Q Plot (Base Run) (Units: µg m^{-3})

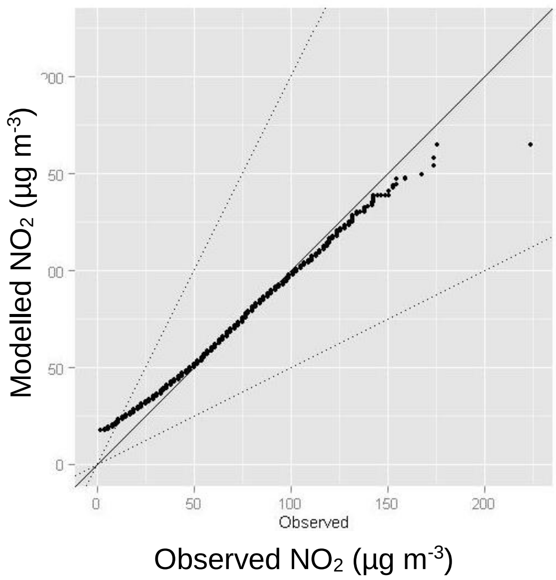


Figure 178: Union Street NO_2 Q-Q Plot (No Time Varying Emissions) (Units: µg m^{-3})

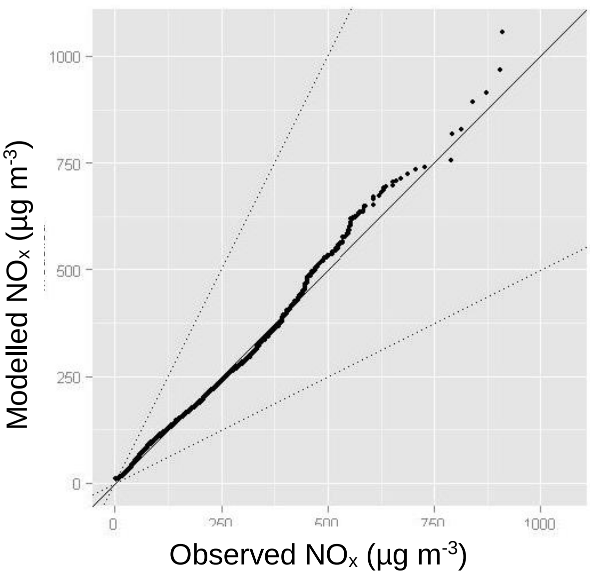


Figure 179: Union Street NO_x Q-Q Plot (Base Run)(Units: µg m^{-3})

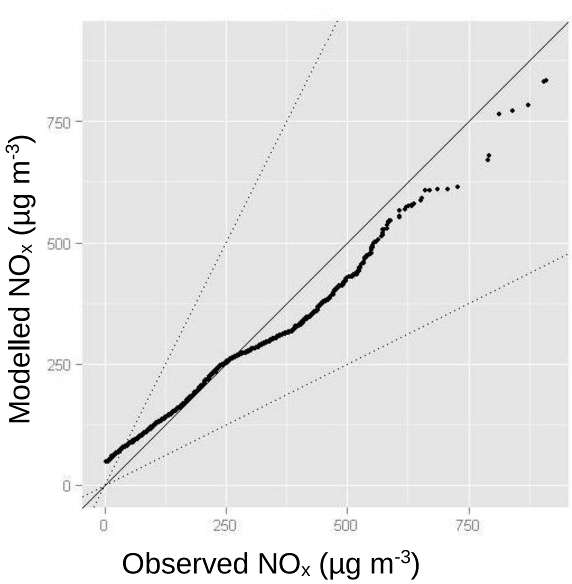


Figure 180: Union Street NO_x Q-Q Plot (No Time Varying Emissions)(Units: µg m^{-3})

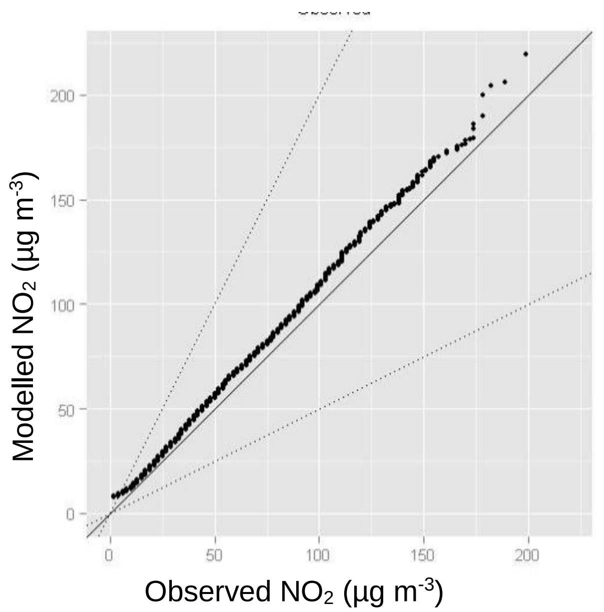


Figure 181: Market Street 2 NO_2 Q-Q Plot (Base Run) (Units: µg m^{-3})

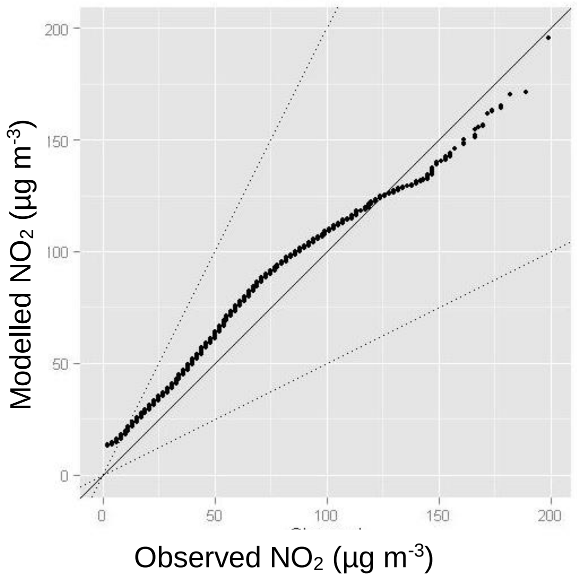


Figure 182: Market Street 2 NO_2 Q-Q Plot (No Time Varying Emissions) (Units: µg m^{-3})

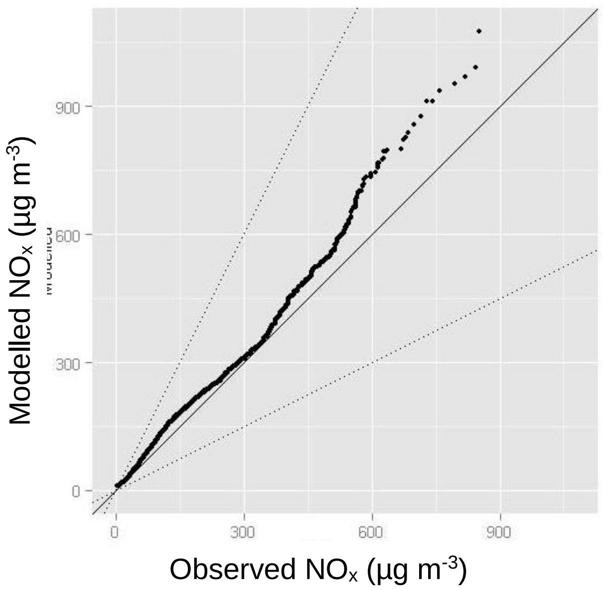


Figure 183: Market Street 2 NO_x Q-Q Plot (Base Run) (Units: µg m^{-3})

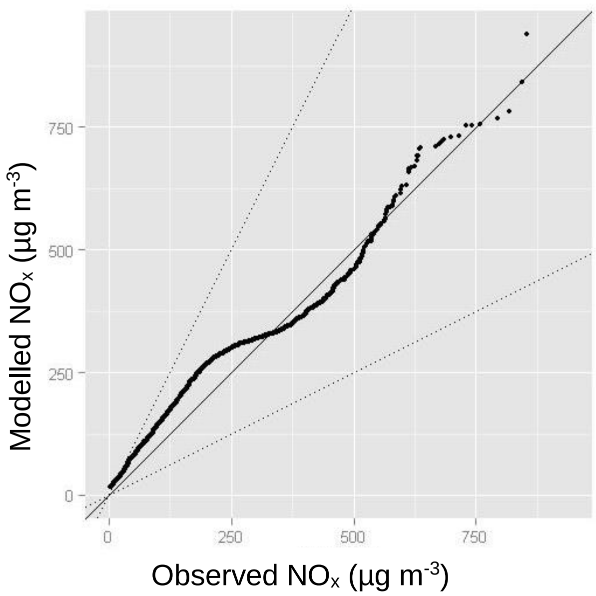


Figure 184: Market Street 2 NO_x Q-Q Plot (No Time Varying Emissions) (Units: µg m^{-3})

Table 60: Statistical Results for NO_2 concentrations when time-varying emissions are removed (bold shows parameters which have failed tests described in Section 4.1)

Monitoring Point	MG	VG	NMSE	FB	Fac2	MB	R
Union Street	1.12	1.79	0.4	0.03	0.64	1.88	0.26
Market Street 2	1.29	1.93	0.58	0.18	0.63	8.76	0.28
Wellington Road	0.87	3.61	0.77	-0.18	0.53	-9.72	0.1
King Street	**1.31**	2.15	0.44	0.27	0.64	9.17	0.57
Anderson Drive	1.23	2.12	0.69	0.1	0.52	3.32	0.27

Table 61: Statistical Results for NO_x concentrations when time-varying emissions are removed (bold shows parameters which have failed tests described in Section 4.1)

Monitoring Point	MG	VG	NMSE	FB	Fac2	MB	R
Union Street	**1.35**	2.8	0.7	0.08	0.51	11.94	0.31
Market Street 2	**1.38**	2.95	1.28	0.2	0.53	25.05	0.25
Wellington Road	0.81	**8.44**	1.49	**-0.32**	**0.39**	-49.28	0.2
King Street	**1.38**	3.32	0.75	0.27	0.53	20.43	0.59
Anderson Drive	1.28	2.64	1.43	0.08	**0.45**	4.5	0.26

4.4.4 Emission Inventory Sensitivity Test

Different emission inventories (Section 3.8) are published (NAEI2012 and EfTv5.2 at the time of this work) for the calculation of emission rates. As the NAEI2012 inventory is used in the 'Base Run', a sensitivity test was set up using emission rates generated using the EfTv5.2 inventory (within EMIT) representing 2012.

NO_2 Annual Mean

Using EfTv5.2 emission rates predicts higher concentrations than using the NAEI2012 inventory for the NO_2 annual mean (Table 62, Figure 185) at all automatic monitoring locations. At the Union Street and Wellington Road monitor, the EFTv5.2 inventory predicts concentrations closer to the observed value; at the other monitors, the model predictions are further from the observed values.

99.79th Percentile

A similar pattern is observed for the NO_2 99.79th percentile; the use of EFTv5.2 predicts greater concentrations than NAEI2012 (Table 63, Figure 186) at all locations except Anderson Drive (where there is a small decrease). However, EfTv5.2 over-predicts at all monitoring locations (24-32 % at Union Street, Market Street 2 and King Street).

NO_x Annual Mean

Modelling NO_x concentrations using EfTv5.2 indicates that there are small differences when compared to the 'Base Run' (Table 64, Figure 187), though at 3 monitoring locations, NO_x concentrations are greater, and at 2 locations, they are lower.

Table 62: Annual Mean NO_2 model predictions (NAEI2012 and EfT v5.2 comparison)

Monitoring Point	Annual Mean NO_2 (µg m^{-3})			Observed/Modelled Ratios	
	Observed	Model		Base Run: NAEI2012 (2012)	EfT v5.2 (2012)
		Base Run: NAEI2012 (2012)	EfT v5.2 (2012)		
Union Street	52.8	49.4	52.5	0.94	0.99
Market Street 2	44.1	47.6	52.1	1.08	1.18
Wellington Road	59.1	44	48.2	0.74	0.82
King Street	29.2	36	37.4	1.23	1.28
Anderson Drive	30.4	31.4	31.6	1.03	1.04

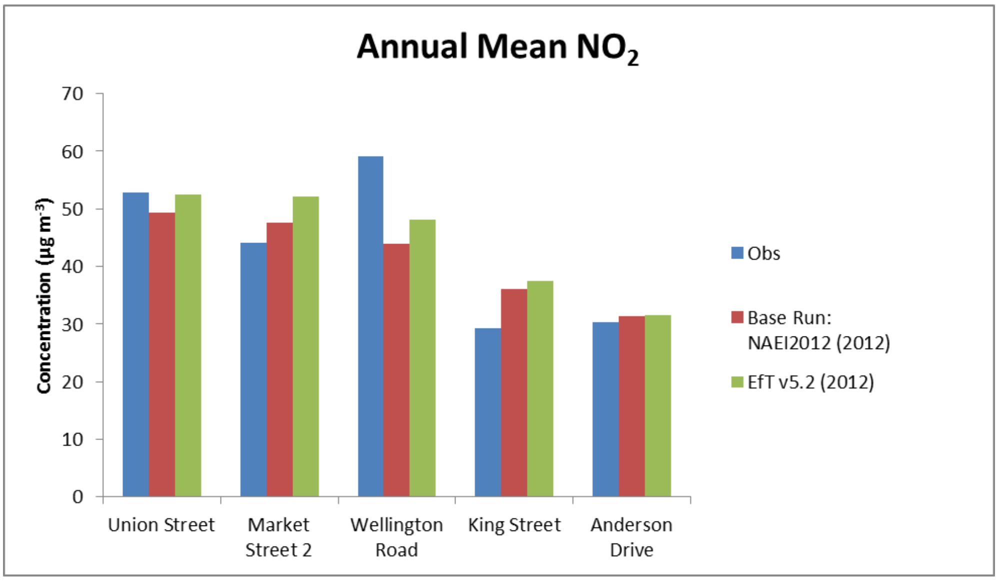


Figure 185: NO_2 Annual Mean Concentration using NAEI2012 and EfTv5.2 emission inventories for 2012

Table 63: 99.79th Percentile NO_2 model predictions (NAEI2012 and EfT v5.2 comparison)

Monitoring Point	99.79th Percentile of 1hr Means NO_2 (µg m^{-3})			Observed/Modelled Ratios	
	Observed	Model		Base Run: NAEI2012 (2012)	EfT v5.2 (2012)
		Base Run: NAEI2012 (2012)	EfT v5.2 (2012)		
Union Street	143	163.5	182.5	1.14	1.28
Market Street 2	161	171.5	199.1	1.07	1.24
Wellington Road	187.8	167.6	191.2	0.89	1.02
King Street	107	134.3	141.7	1.26	1.32
Anderson Drive	115	121.4	120.8	1.06	1.05

Table 64: Annual Mean NO_x model predictions (NAEI2012 and EfT v5.2 comparison)

Monitoring Point	Annual Mean NO_x (µg m^{-3})			Observed/Modelled Ratios	
	Observed	Model		Base Run: NAEI2012 (2012)	EfT v5.2 (2012)
		Base Run: NAEI2012 (2012)	EfT v5.2 (2012)		
Union Street	136.2	133.3	129	0.98	0.95
Market Street 2	110.5	120.9	125.2	1.09	1.13
Wellington Road	179.5	114.3	118.6	0.72	0.66
King Street	65.7	79.9	81.7	1.22	1.24
Anderson Drive	55.8	55.7	57.6	1.0	1.03

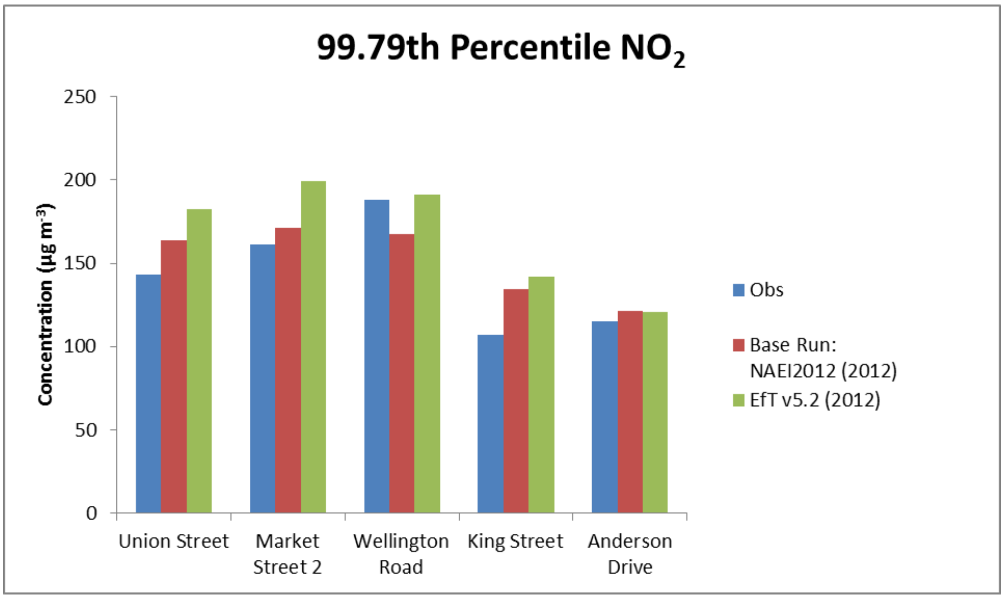


Figure 186: NO_2 99.79th percentile concentration using NAEI2012 and EfTv5.2 emission inventories for 2012

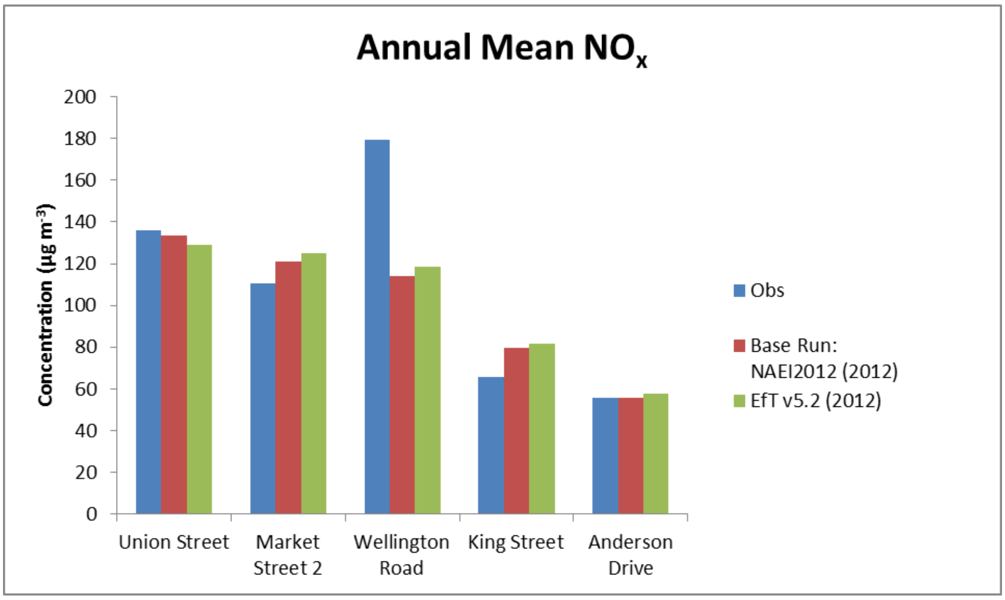


Figure 187: NO_x Annual Mean Concentration using NAEI2012 and EfTv5.2 emission inventories for 2012

4.4.5 Traffic Speed Sensitivity Test

An average traffic speed for each road section needs to be selected as emission rates are calculated as a function of speed (Section 3.2.4). Different models were set up using the same average speed for all roads; these speeds range from 10 km/hr to 80 km/hr, in 10 km/hr increments. As speed is increased, emission factors (g/km) decrease.

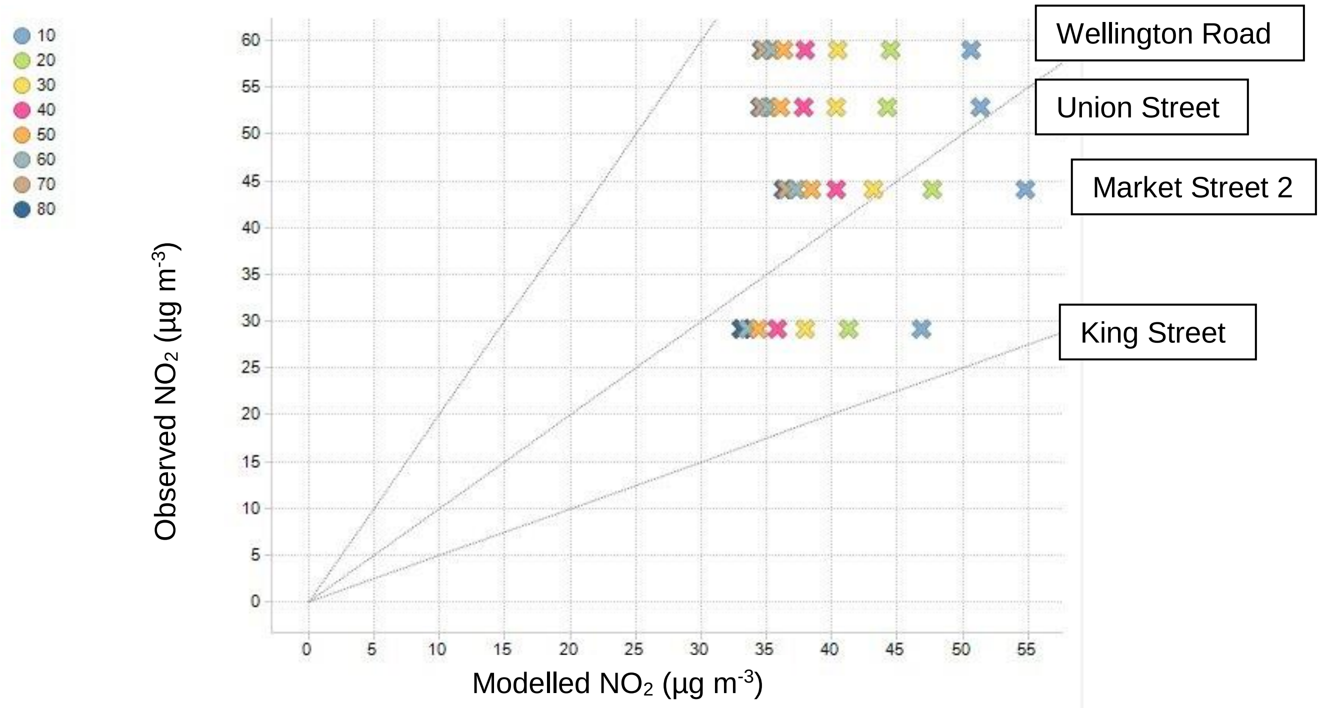


Figure 188: Modelled NO_2 annual mean predictions for different traffic speeds (km/hr) at 4 Automatic Monitoring locations plotted against observed values (Units: µg m^{-3}). Note: Due to a technical reason, above 1:1 line is model underestimate

Even if traffic on King Street was travelling at 80km/hr, therefore reducing emission rates, NO_2 annual mean concentrations would still have been over-predicted. However, the opposite is the case at Wellington Road; when selecting a speed of 10km/hr, which increases emission rate to the highest possible for the traffic flows, the model is under-predicting concentrations.

At the Union Street monitor, where a traffic speed of 10km/hr was chosen for the 'Base Run', the concentrations are close to the observed values, whereas at the Market Street 2 monitoring location, the predicted concentrations would match the observed concentrations if a speed of between 20 and 30 km/hr was selected.

This sensitivity test shows that over-predictions and under-predictions may not be entirely due to selecting of traffic speed and poor model performance will occur at some locations regardless of traffic speed selected. This reinforces the need for good quality fleet and traffic data, and appropriate emission factors; however there may be other factors, such as building geometry which influence this.

4.4.6 Vehicle Induced Turbulence Sensitivity Test

As discussed in Section 3.13.1, when using the user-defined emissions option, ADMS-Urban calculates the effect of vehicle induced turbulence by assuming a traffic split of 5% Heavy vehicles and 95% Light vehicles. **This approach does not change the emission rates or vehicle flows, only the vehicle induced turbulence and mixing parameters.**

As a sensitivity test, the model was set up for 3 scenarios (using the *.uai additional model option file extension in ADMS-Urban):

- 90% Light vehicles, 10% Heavy vehicles
- 85% Light vehicles, 15% Heavy vehicles
- 80% Light vehicles, 20% Heavy vehicles

It was found that when changing the Heavy/Light vehicle split to alter turbulence mixing parameters, that there were negligible differences in model predictions (Table 65) and therefore this option was not explored further.

Table 65: Annual Mean NO_2 predicted concentrations sensitivity test for Heavy/Light Vehicle Test

Monitoring Point	Annual Mean NO_2 ($\mu g\ m^{-3}$)				Model Ratios		
	Base Run	90% Light	85% Light	80% Light	90% Light	85% Light	80% Light
Union Street	49.4	49.5	49.6	49.7	1.00	1.00	1.01
Market Street 2	47.6	47.7	47.7	47.7	1.00	1.00	1.00
Wellington Road	44	44	44.1	44.1	1.00	1.00	1.00
King Street	36	36.1	36.1	36.1	1.00	1.00	1.00
Anderson Drive	31.4	31.4	31.4	31.4	1.00	1.00	1.00

5 Modelling Future Scenarios

5.1 Modelling Impacts in Future Years

To simulate how air quality may change in future years due to changes in the national vehicle fleet (e.g. lower emitting vehicles entering the national fleet), the published emission inventories include estimations for future years, although these predictions are based on many assumptions (e.g. number of new vehicle purchased and scrapped). It is assumed that traffic flows will remain the same; there is no reliable data available to adjust traffic flows for future years. Emission rates for 2015, 2020 and 2025 were calculated in EMIT for use in model scenarios; these calculations account for predicted changes to the vehicle fleet due to introduction of cleaner vehicles (although this is subject to uncertainties).

The projected emissions were applied to both the Base Run and Background Area Emissions methodologies. In all cases, 2012 background concentrations are used. As background concentrations are likely to decrease in future years predictions in future years will be overestimates. Future background concentrations at Errol Place are unavailable, and estimated gridded area emissions for future years are not published in advance.

5.1.1 Future Years: Base Run (Errol Place background)

When modifying the emissions used in the 'Base Run', the NO_2 annual mean concentrations are predicted to be in compliance of Air Quality Standards at all monitors by 2020 (Figure 189). As discussed previously, the measured background concentrations at Errol Place are also likely to be lower in future years due to reduced emissions, therefore this can be considered to be worst case. However, the rate at which future emissions decline is uncertain as there may be increased traffic volumes and congestion due to new car sales and/or population growth due to new developments.

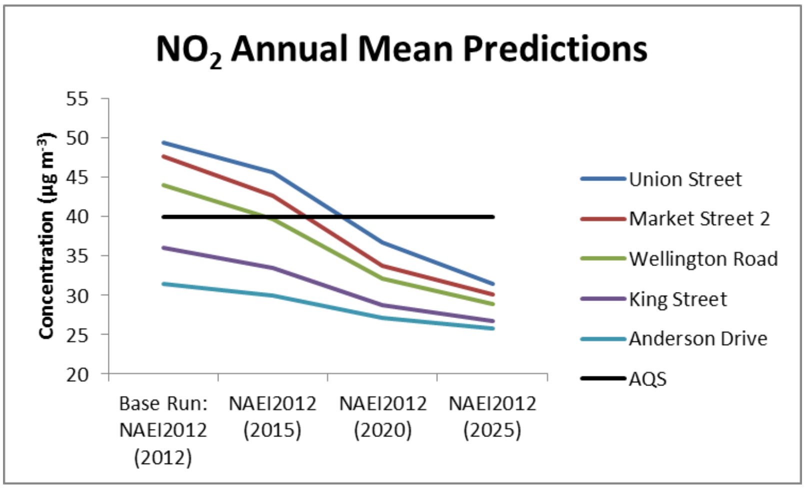


Figure 189: Predicted NO_2 Annual Mean concentration trends at automatic monitors using NAEI2012 predicted emission factors (Base Run)

When predicted concentrations at roadside points for future years are analysed using Spotfire, there is a large reduction in locations were exceedances are predicted between 2015 and 2020 (Figure 190, Figure 191). By 2025, it is predicted that the NO_2 annual mean will fall below the AQS at almost all roadside points, however there are a few locations at the east end of Union Street where compliance is not achieved (Figure 192).

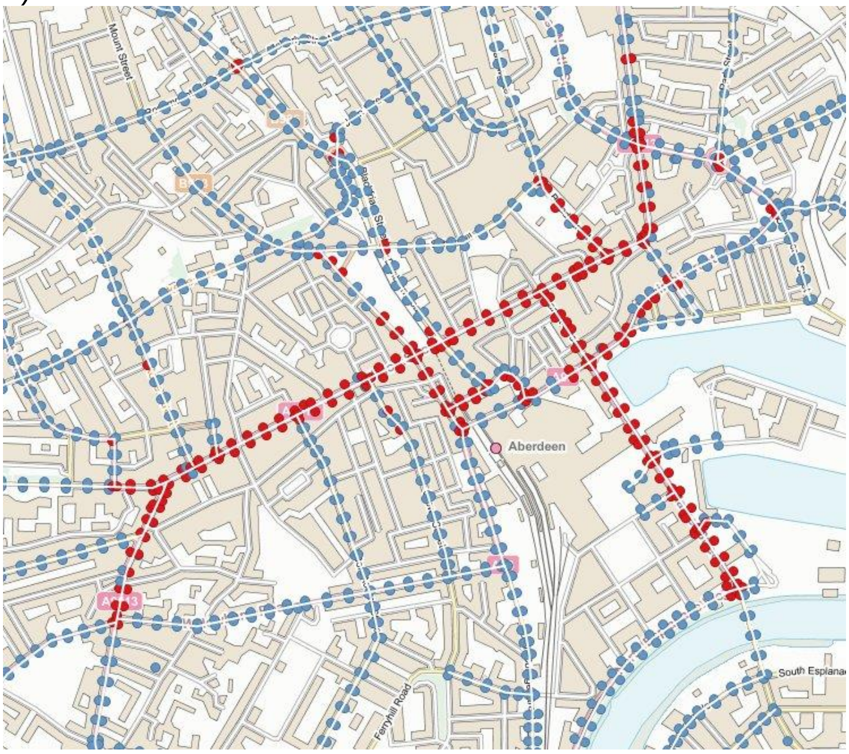


Figure 190: Annual Mean NO_2 concentration predictions with 2015 emissions (Blue: < 40 µg m^{-3}; Red: > 40 µg m^{-3})

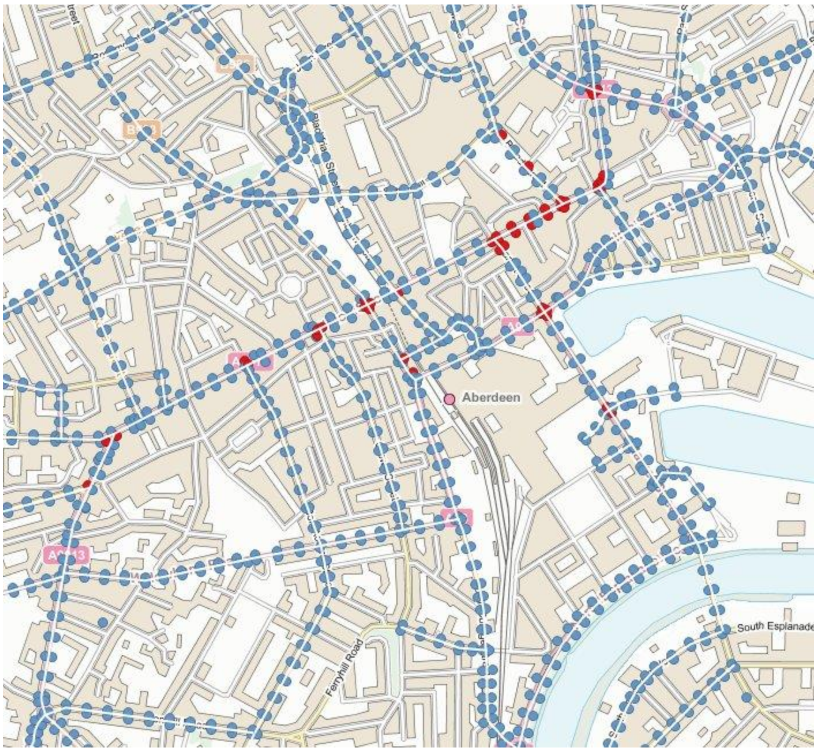


Figure 191: Annual Mean NO_2 concentration predictions with 2020 emissions (Blue: < 40 µg m^{-3}; Red: > 40 µg m^{-3})

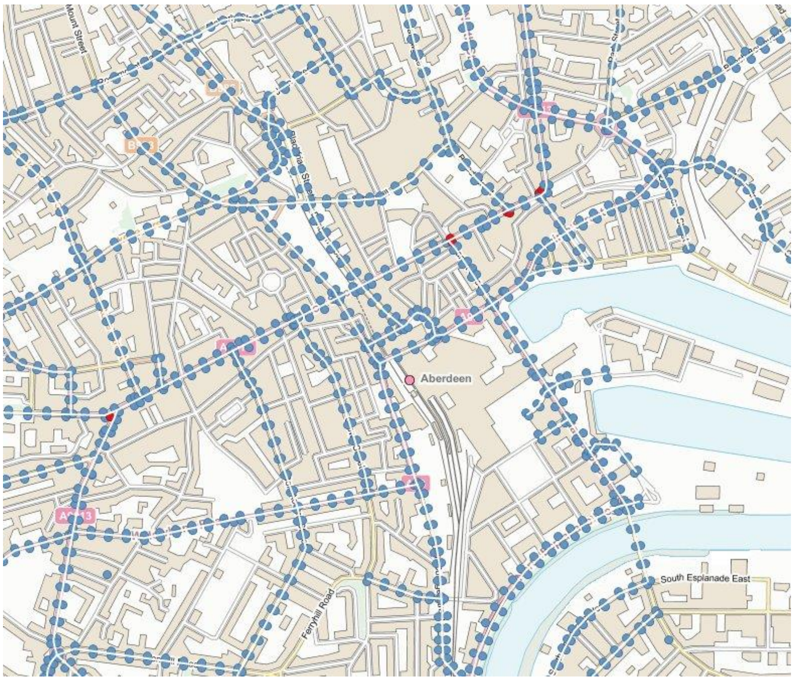


Figure 192: Annual Mean NO_2 concentration predictions with 2025 emissions (Blue: < 40 µg m^{-3}; Red: > 40 µg m^{-3})

Although compliance for the NO_2 99.79th percentile is already being achieved, by 2020 predictions for this AQS will decrease by around 35% at Market Street 2 and Wellington Road (Table 99, Figure 193)

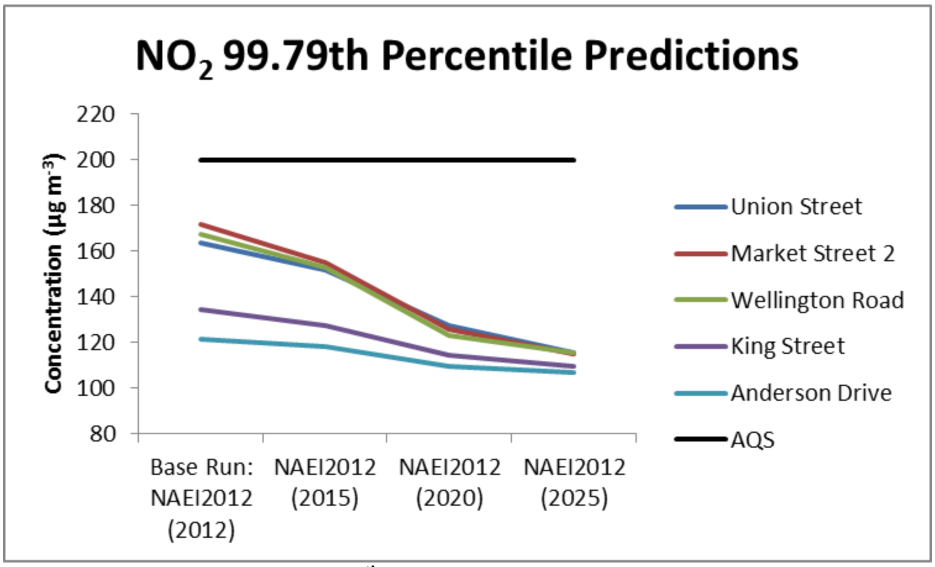


Figure 193: Predicted NO_2 99.79th Percentile Concentrations trends at automatic monitors using NAEI2012 predicted emission factors (Base Run)

5.1.2 Future Years: Background Area Emissions Method

When the model was run for future years using the Background Area Emissions approach, reductions in NO_2 concentrations are predicted to be of a similar percentage as the Base Run approach (Table 98, Table 99, Table 100, Table 101; Figure 194, Figure 195).
However, when using this approach, predicted annual mean NO_2 concentrations at the Errol Place urban background monitor are predicted to be greater than at the Anderson Drive and King Street roadside monitor. This is unlikely to be the case in reality; this is a weakness of using this methodology and may be due to uncertainties in the emissions inventory and the difficulty of predicting emissions in the future (in this case, a 2012 emission inventory has been used for all non-traffic sources as no other data is available). Using the approach outlined in Section 4.4.4, where emission factors are increased may provide a more realistic answer.

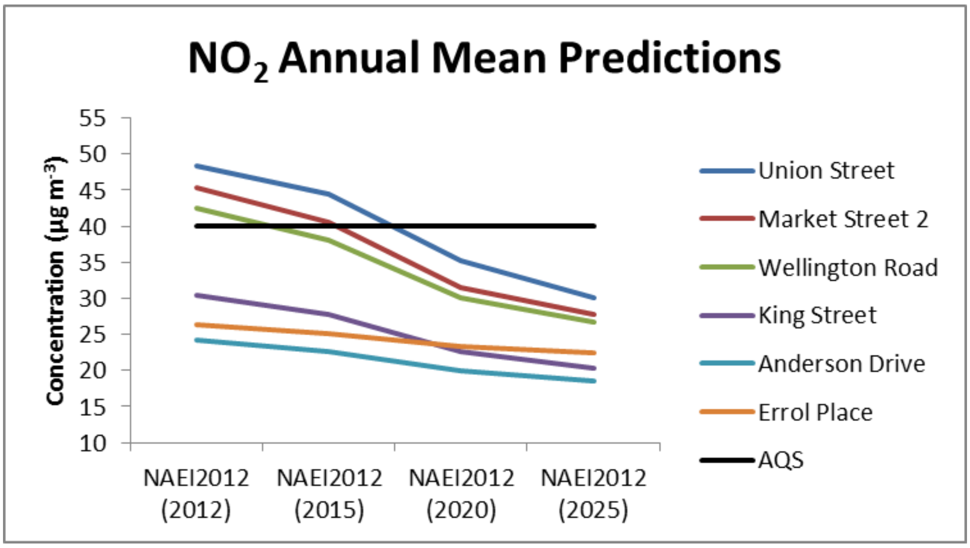


Figure 194: Predicted NO_2 Annual Mean Concentrations trends at automatic monitors using NAEI2012 predicted emission factors (Gridded Area Emissions and Rural Background Run)

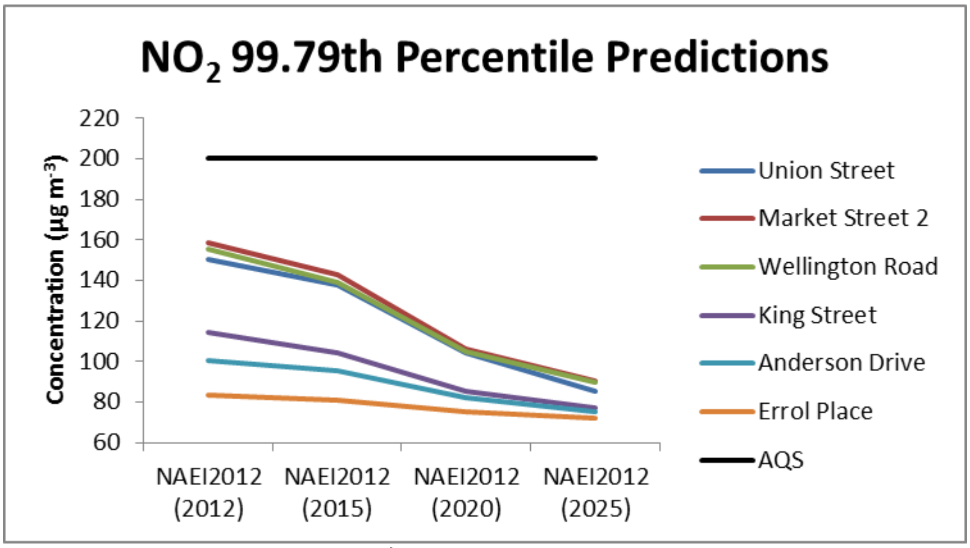


Figure 195: Predicted NO_2 99.79th Percentile Concentrations trends at automatic monitors using NAEI2012 predicted emission factors (Base Run)

5.2 Low Emission Zone (LEZ) Scenarios

Work published previously for Aberdeen City Council by AECOM concluded that there were 3 potential Low Emission Options (Table 66) that could form part of a Low Emission Zone in Aberdeen (4). This approach was applied to all roads in the 'Base Run' model, but could also be applied to a particular zone (e.g. Aberdeen City Centre) in future work.

Table 66: Low Emission Options

Option	Low Emission Options
A	All Euro 1, 2 and 3 HGV's replaced with Euro 6 HGV's.
B	All Euro 1, 2 and 3 Buses replaced with Euro 6 Buses.
C	All Diesel cars replaced with petrol of an equivalent age

Using the 3 emission options as unique options or in combinations, 7 unique Low Emission Scenarios were generated (Table 67). Only the NAEI2012 emission inventory could be used to simulate changes to the fleet composition to represent the scenarios in Table 67, as EMIT allows the fleet composition to be edited (e.g. % Euro 3 HGV's) for NAEI 2012, but not for the EfT inventory. These 7 emission scenarios were applied to the 'Base Run'; the predicted NO_2 annual mean concentrations at the automatic monitors indicate that only Scenario L7 predicts compliance at all automatic monitors (Figure 196)

Table 67: Low Emission Scenarios

Low Emission Scenario	Emission Options
L1	A
L2	B
L3	C
L4	A and B
L5	A and C
L6	B and C
L7	A, B and C

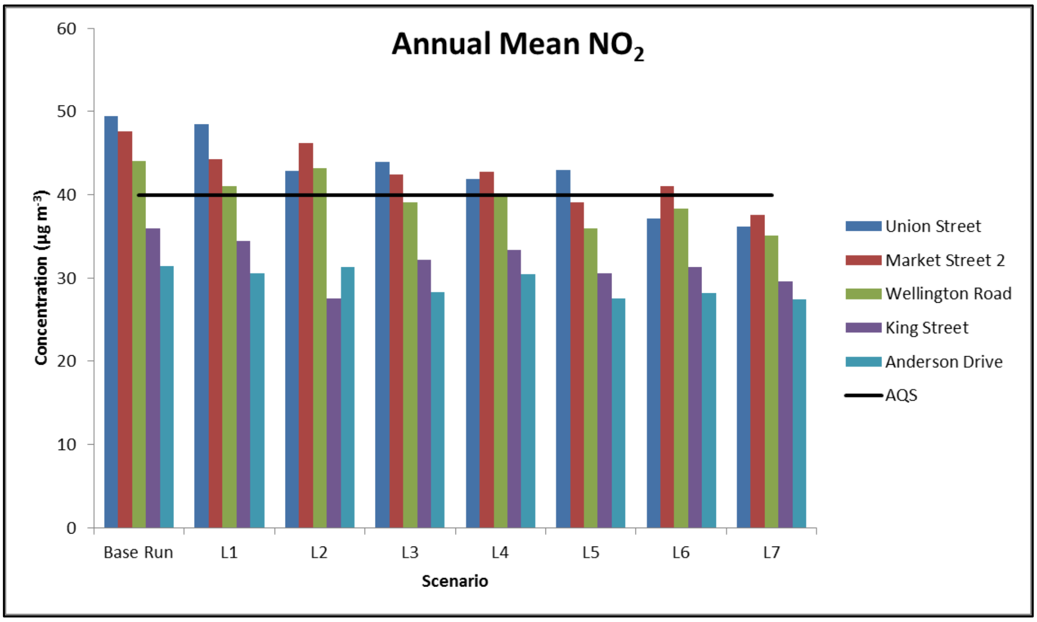


Figure 196: Predicted Annual Mean NO_2 Concentrations for Low Emission Scenarios

At the Union Street monitor, it is predicted that upgrading the bus fleet alone (Scenario L2), will not in itself improve the air quality sufficiently to comply with the Air Quality Standards, and that, as a minimum, Option C (reducing emissions from car traffic) is also required.

At the Market Street 2 monitor, upgrading the HGV fleet as suggested in Scenario L1 will not be enough to comply with the Air Quality standard, and again, as a minimum, Option C is also required (reducing emissions from car traffic).

At the Wellington Road monitor, despite predictions that Scenario L7 will result in compliance of the AQS, it is known that the 'Base Run' is under-predicting at this location by around 26%; therefore an exceedance of the AQS may still occur. However, as discussed above, this may not be representative of the wider Air Quality conditions along Wellington road.

The roadside points analysis plots (Figure 197 to Figure 204) show that for all 7 scenarios, concentrations in excess of 40 µg m^{-3} are predicted. Despite scenario L7 predicting compliance at the automatic monitor, exceedances are still predicted to occur at many locations on Market Street and at the east end of Union Street, which could be due to particularly high traffic volumes at these locations (particularly HGV's and buses.

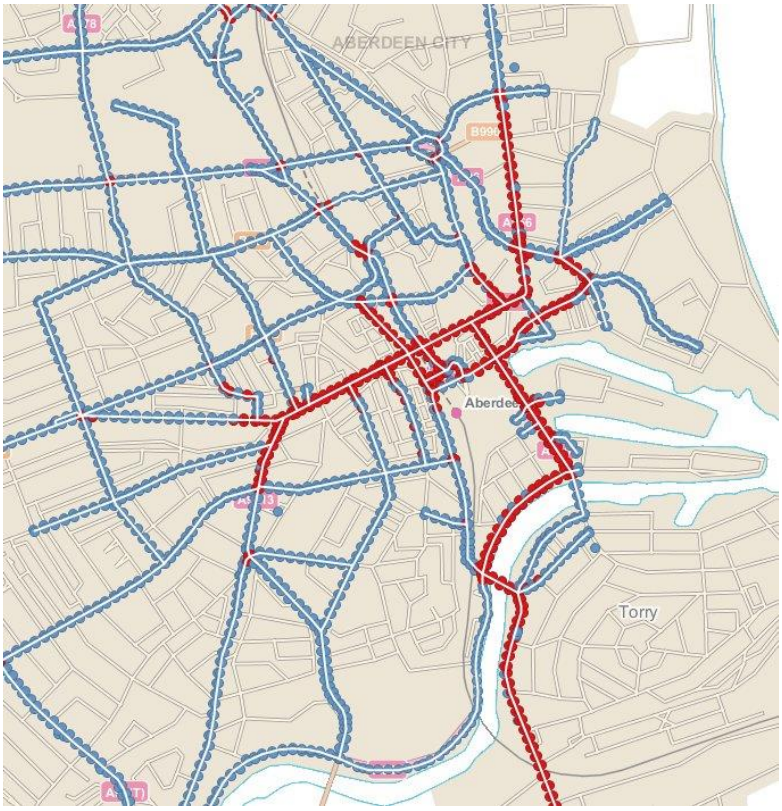


Figure 197: Base Run Roadside Points
(Blue: < 40 µg m^{-3}; Red: > 40 µg m^{-3})

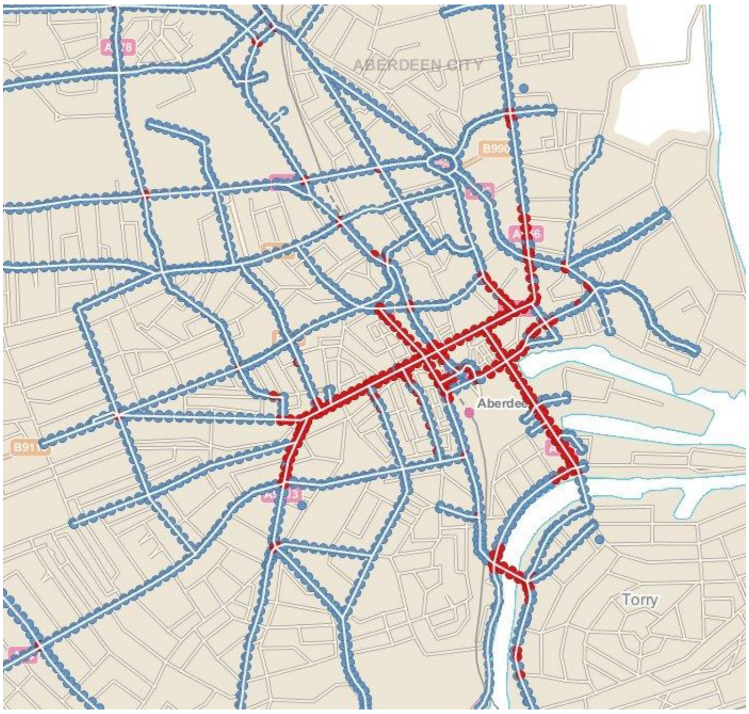


Figure 198: Scenario L1 Roadside Points
(All Euro 1, 2 and 3 HGV's replaced with Euro 6 HGV's.)
(Blue: < 40 µg m^{-3}; Red: > 40 µg m^{-3})

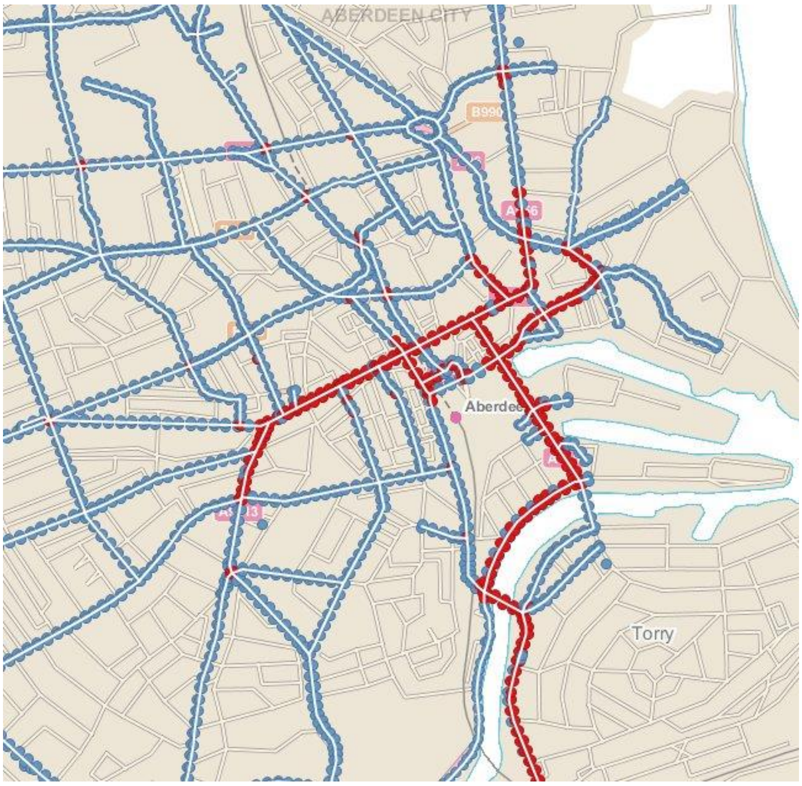


Figure 199: Scenario L2 Roadside Points
(All Euro 1, 2 and 3 Buses replaced with Euro 6 Buses.)
(Blue: < 40 µg m^{-3}; Red: > 40 µg m^{-3})

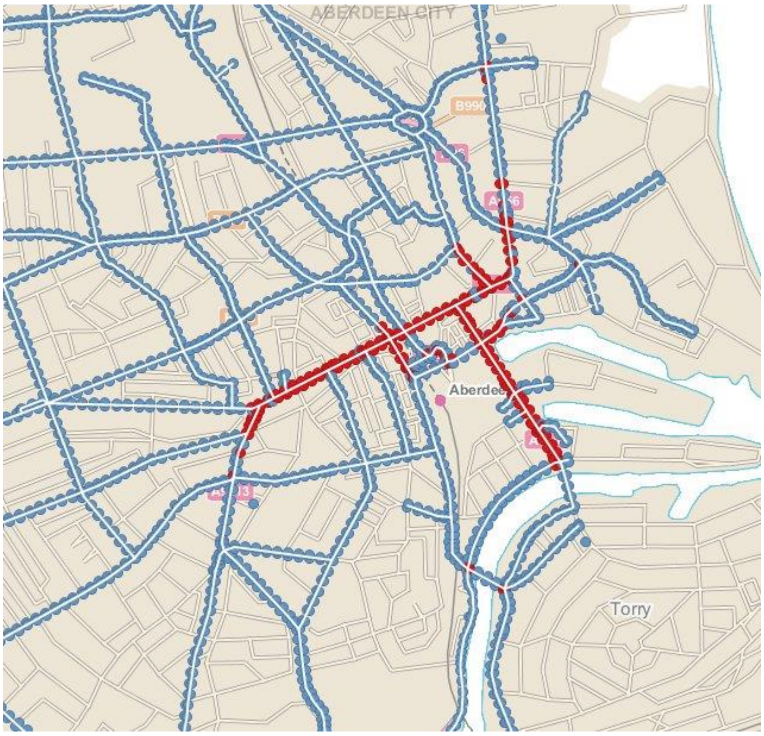


Figure 200: Scenario L3 Roadside Points
(All Diesel cars replaced with petrol for an equivalent age
(Blue: < 40 µg m^{-3}; Red: > 40 µg m^{-3})

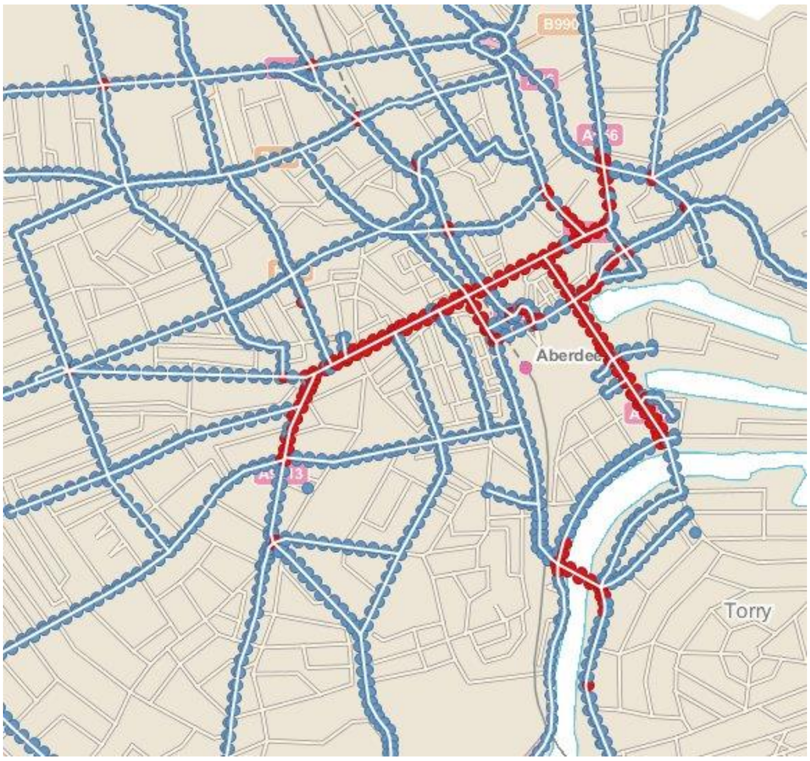


Figure 201: Scenario L4 Roadside Points
(All Euro 1, 2 and 3 HGV's and Buses replaced with Euro 6 HGV's and Buses)
(Blue: < 40 µg m^{-3}; Red: > 40 µg m^{-3})

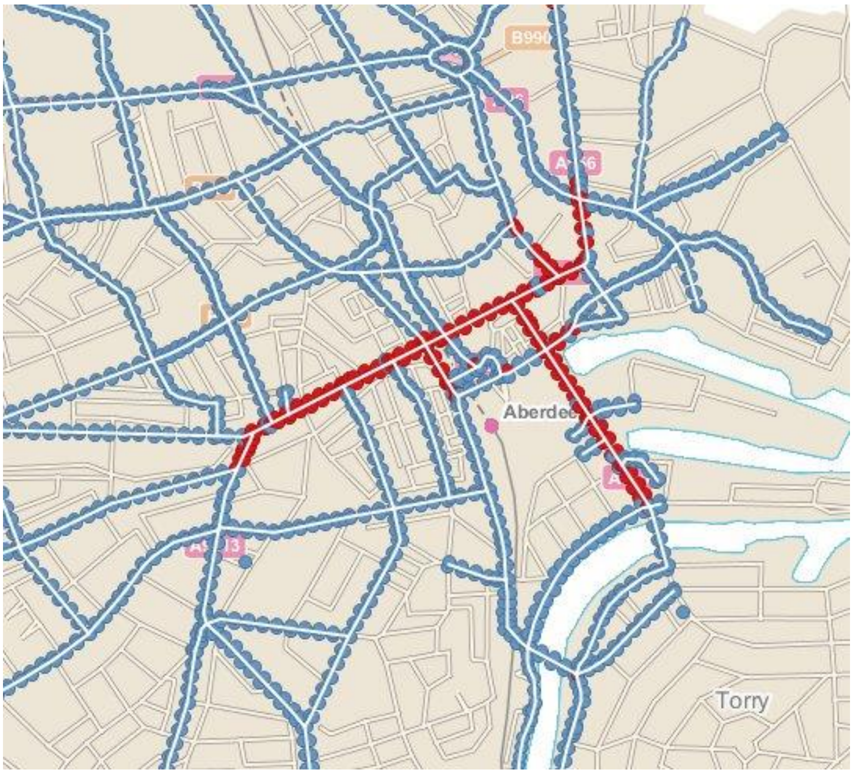


Figure 202: Scenario L5 Roadside Points
(All Euro 1, 2 and 3 HGV's replaced with Euro 6 HGV's; Diesel cars replaced with Petrol)
(Blue: < 40 µg m^{-3}; Red: > 40 µg m^{-3})

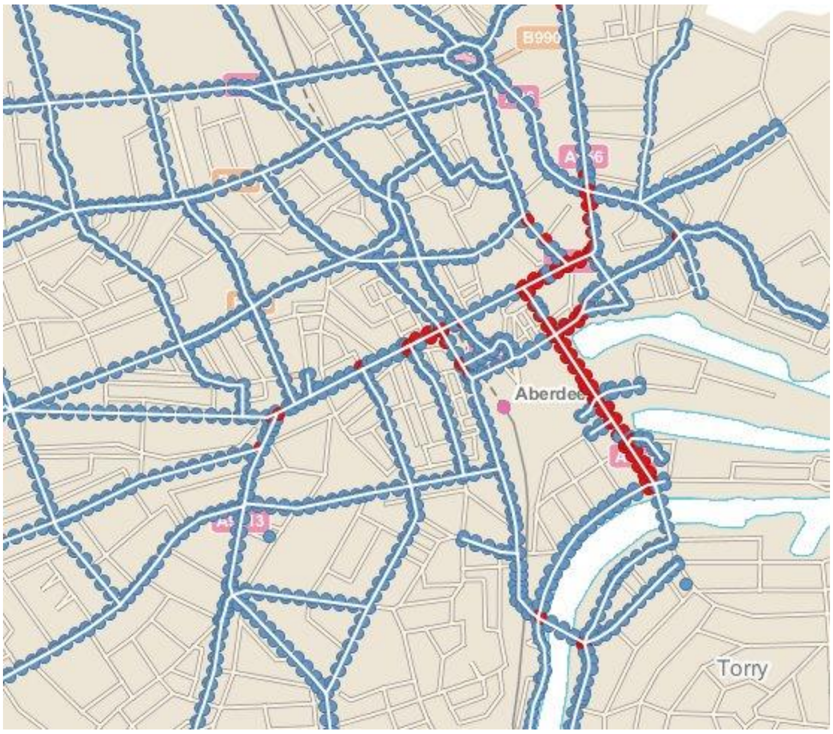


Figure 203: Scenario L6 Roadside Points
(All Euro 1, 2 and 3 Buses replaced with Euro 6 Buses; Diesel cars replaced with Petrol)
(Blue: < 40 µg m^{-3}; Red: > 40 µg m^{-3})

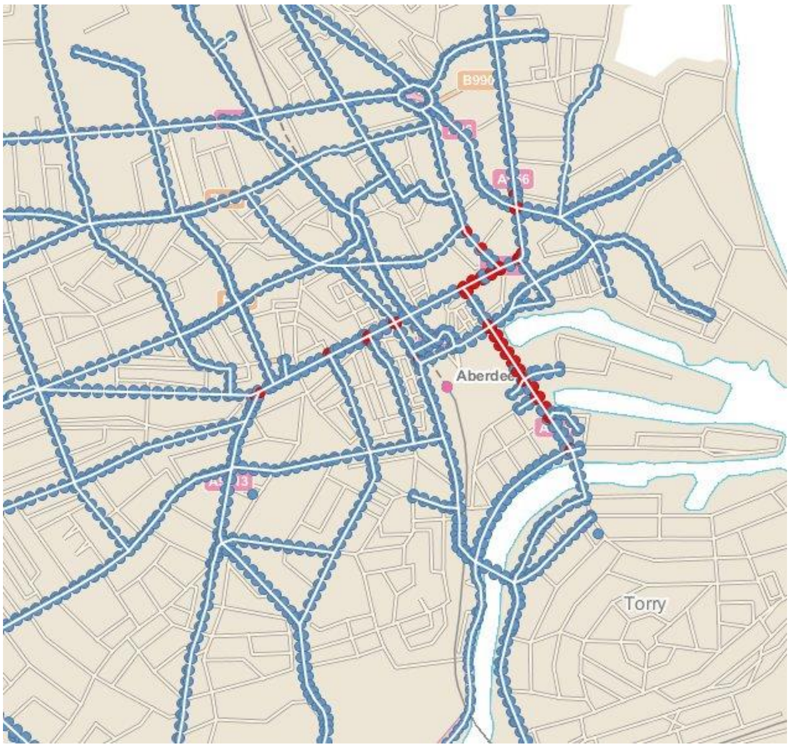


Figure 204: Scenario L7 Roadside Points
(All Euro 1, 2 and 3 HGV's and Buses replaced with Euro 6 HGV's and Buses; Diesel cars replaced with Petrol)
(Blue: < 40 µg m^{-3}; Red: > 40 µg m^{-3})

5.3 Unit Release Scenarios

To examine the impact from each source on each receptor, a unit release approach was set up so that a scaling approach could be utilised in Spotfire where emission factors could be applied without explicitly running ADMS-Urban.

The emissions for each road source were set to 0.25 g/km/s as it was between the NO_x and NO_2 emission rates for most roads in Aberdeen. If the emission rate was set to be too large, the effect of the vehicle induced turbulence would be too high which would affect the dispersion calculations (ADMS-Urban back calculates an approximate number of vehicles when using a ‘user-defined’ emission rate as discussed in Sections 3.13.1 and 4.4.6). An emission rate of 1g/km/s of pollutant equates to approximate AADF of 168000 vehicles/day is therefore unrealistically large (personal communication, Jenny Stocker, CERC).

This approach also uses the group source approach in ADMS-Urban, where the impact of each source on each receptor is part of the model output; this allows emission rates for each road section to be modified in isolation.

Unit Release runs did not include chemistry, but do include diurnal cycle and Dyce 2012 meteorological data.

More details on this approach, methods and outcomes are detailed in a separate report “Emissions Scaling Tool: Aberdeen City”.

6 Summary and Conclusions

Overall, this approach to investigating atmospheric pollution in urban areas has been tested using various different modelling methodologies. It has been found that when using ADMS-Urban, using both the background methodologies (Base Run and Background Gridded Emission) generally performs well when tested against observed data. We believe this is due to a combination of factors, which are discussed below. However, the background concentration which is an important component is difficult to quantify at all locations.

Traffic Data, Fleet Composition and Vehicle Emissions

This pilot study has shown the importance of having comprehensive high quality traffic data so that vehicle flows and emission rates can be calculated with a good level of confidence for use in the model.

Junction Turn Counts (JTC)

Currently, it is normal practice to collect junction turn count traffic data over a 12 hour period which covers the peak traffic flow periods; however for air modelling purposes, classified traffic data for a 24-hour period is required, therefore 24 hour junction turn counts should be included in future data collection studies.

This will reduce the uncertainties that can develop when using the AADF conversion factors with 12 hour data, as the generic conversion factor may not be accurate for all streets, and therefore incorrectly predict 24 hour traffic flows. This data should also include traffic flows for the diurnal cycle for each vehicle category. This enhanced data will also allow concentration peaks and troughs to be modelled with more certainty. As there also appears to be large differences when using the published DfT traffic data compared to measured traffic flows, the DfT data should be treated with caution.

It is also important that in future traffic data collection studies, the vehicle class used to report traffic data is as detailed as possible. It is currently common to collect HGV data in 2 categories (OGV1 and OGV2), however, as ADMS-Urban requires traffic data for the 11 vehicle classes outlined in Table 6, this would allow a more detailed assessment of the impact of each traffic category on air quality to be included in the analysis, and emission rates calculations.

Automatic Traffic Counts (ATC)

Although ATC data is unable to accurately report traffic data in detailed classification in the way that JTC data can, it can provide flows along a road section, and is more cost effective in collecting data over a longer period of time than JTC counters. This can therefore provide traffic data that covers a week which can be used to generate diurnal cycles of traffic flows. It is therefore important to include these in a traffic data collection study by Automatic Air Quality monitors, and at other locations where a diurnal cycle would provide useful information.

Automatic Number Plate Recognition (ANPR)

ANPR data can also provide a detailed vehicle information which can be linked to the DVLA database to provide information such as the year of registration and Euro class engine; this allows a detailed fleet composition to be generated for specific streets (such as feeder roads) each city. This data is useful for generating pollutant emission rates as the EMIT tool uses fleet composition in this calculation and this can be edited, therefore ANPR data will be included in future studies.

Vehicle Emissions

Understanding how much pollutant can be emitted into a road is an important aspect in solving air quality problems. In many studies, it appears that the underlying traffic data is not sufficiently extensive or detailed enough to capture the emissions from such a dominant source, or traffic data are derived from traffic models or third party sources such as public transport timetables. Inevitably, all sources of traffic data are subject to uncertainty and it is important to understand the value and limitations of each.

There is debate over the accuracy of emission factors; however the measured car emission factors collected in the ANPR (25) study compare well with the published NAEI2012 and EfT emission factors (there may be discrepancies for specific vehicle types). However, this comparison is not as readily available for HGV's and buses.

In this study, the Aberdeen vehicle fleet emissions in 2012 may have been close to the published emission factors for each vehicle class, however this may not always be the case and having detailed traffic data to complement these appears to have been influential on model performance.

Background Concentrations

Gaussian dispersion models, such as ADMS, rely heavily on the addition of an hourly "background concentration" to sources being modelled. This is required to simulate the influence of other pollutant sources (long range or those not explicitly modelled) and the possible accumulation of pollutants across the city over timescales longer than one hour during low wind speed conditions (35), (36). The background concentration can be estimated by including gridded emissions which are published in emissions inventories in the model as 'grid sources' or by the addition of measured concentration data which is in an area where pollution is well-mixed and not located by major sources (urban background). In reality the development of the concentration field throughout a city or town will be complex and be spatially varying, especially where there is a dense network of urban canyons.

The choice of background in the Aberdeen Pilot project (Errol Place Urban Background Monitoring *or* Background Area Emissions and Rural Background Monitoring) can have an influence on model performance.

The Errol Place background data has the advantage that when dispersion conditions are poor, there may be a build-up of pollutant concentrations, which will be reflected in the monitored data. However, the urban background data will be influenced by its location: in Aberdeen the urban background monitor is located in the north-east of the city and may not accurately reflect the temporal or spatial background concentrations in other areas of the city.

The advantage of using the emissions inventory data as background area emissions is that these are spatially varying which reflects differing levels of activity in the different areas of the city; however these data are based on emission factors and knowledge of activity (which has uncertainties) and are normally 2-3 years out of date. However this method will not capture pollution episodes due to build-up of pollutants in low dispersion episodes from explicit sources in the model, and relies on there being a nearby representative rural monitoring station (for Aberdeen, the nearest is close to Edinburgh). As inconsistencies were found using this method for future year scenarios, this method may only be useful for a few years in advance.

Although the Base Run (Errol Place urban background data) results were slightly better for the Aberdeen pilot study, this may not be the case for other cities and **both methods should be used and verified** in future studies. Background data is always likely to be a complexity in air quality modelling as it is difficult to predict what background concentrations will be in the future, and how this will vary spatially.

Model Verification and Evaluation

Model predictions are good for NO_2 and NO_x at the automatic monitoring locations, with the exception of Wellington Road, though data analysis and CFD modelling has shown this is likely to be due to local building geometry influencing the air flow. The scatter and Q-Q plots show that while ADMS-Urban is not always able to predict peaks and troughs in line with the monitoring data, there is generally good statistical agreement for the Base Run and Background Area Emissions methods.

At diffusion tube locations, the models tends to under-predict, though this may be more complex as diffusion tubes tend to measure higher values than automatic monitors when they are co-located, due to the limitations in this monitoring method.

The model consistently under-predict PM_{10} concentrations, though there are fewer monitoring sites for PM_{10} which makes model verification more challenging. Also, there are many additional PM_{10} sources (brake/tyre/road wear, sea salt and resuspension) which are difficult to quantify (e.g. resuspension is a function of wind speed, but is not represented as such in ADMS-Urban), as well as deposition processes which need to be considered.

Use of Different Models

ADMS-Urban has been shown to provide good predictions across Aberdeen; however there was poor performance at Wellington Road which highlighted a weakness in Gaussian type models where building geometry is complex. CFD models have provided additional information which has usefully helped to explain the effects of the building geometry on pollutant dispersion at Wellington Road; however, it is not currently feasible to run a CFD model using meteorology for a year to calculate an annual average.

ADMS-Urban is the most suitable model for a city-wide scale as it can cover a large domain, whilst CFD models can examine localised flow on a case-by-case basis. This method can be used where building geometry is complex and may also be useful in providing detailed information at automatic monitoring locations (e.g. how well does an automatic monitor represent the locality). Also, CFD tools can help in identifying locations where dispersion may be low and where pollutant concentrations may in reality be greater than ADMS-Urban modelling and nearby monitoring suggests.

Model Sensitivity Tests

It is important to test the sensitivities of the model by varying input data (e.g. meteorology or emission rates) or using different modules (e.g. chemistry). These sensitivity tests have shown that the ADMS-Urban model is performing well in most cases and that the following modules should be used in future model runs:

- **Chemistry scheme module**: Considering the impact of chemistry is important, the use of the chemistry scheme module produced the best results
- **Time-varying emissions**: This needs to be included although it is hoped that future 24-hour traffic data will be able to provide time-varying emission profiles for each city
- **Meteorology**: Five years of meteorological data from two weather stations were used and a variation in annual mean results of around 10-15% was found for each of the weather stations; this can be accounted for when considering impacts on for future years. The effects of different meteorology (years, and where available, weather stations) is a sensitivity test that will need to be carried out for all cities.
- **Emissions**: As there is more than one emission inventory available to calculate traffic emissions, and as emissions are a function of several factors such as traffic volumes, gradient, traffic speed, AADF conversion factors (where 24 hour data is unavailable), varying emissions is an important sensitivity test. A simple way to test the model sensitivity may be to vary emission rates by a small percentage, and should be carried out for each city.
  Background: Using both Urban Background and Background Area Emissions is an important test as both methods have advantages and disadvantages.

Future Years and Low Emission Zones

Emissions can be adjusted to represent pollutant emissions in future years and for implementation of Low Emission Zones.

Emissions Rates for future years are based on assumptions that newer and cleaner vehicles are entering the fleet (emission factors do not change; percentage of cleaner vehicles increase), however, the actual composition of the fleet in years is based on many assumptions and is uncertain, and it is assumed that vehicle emission factors will remain the same as vehicles age (for example, emissions from a Euro 6 vehicle may increase as the vehicle ages). It should be noted that this approach will not take into future traffic management changes, and liaison with traffic modellers and planners may be required for this approach.

The effect of low emission zones also can be modelled by altering the vehicle composition in specific areas to represent a clean vehicle fleet. The limitations of this does not consider resultant changes to traffic flows and vehicle composition in other areas of the city which may increase emissions elsewhere; therefore liaison with traffic modellers is important when considering this option. However, with good quality traffic flow data, which takes this into account, the impact of a Low Emission Zone on changes to air quality concentrations can be predicted.

This study highlighted that in Aberdeen, predicted emissions for future years will still result in air quality exceedances and that interventions such as Low Emission Zones may still be required.

7 Recommendations

This study shows that there is no one method which is correct; it is important that any modelling study that a range of scenarios are used to provide a level of confidence that that the model is performing well so that decisions can be informed using its predictions.

Refinements and improvements can be made to the model:

- Traffic data which covers a 24-hour period should be collected as AADF conversion factors would not need to be relied upon and time-varying emissions could be calculated.
- Specific local emission factor data obtained via Automatic Number Plate Recognition (ANPR) and Tail Pipe emission measurements
- Future traffic data should include ANPR, Automatic Traffic Counts (ATC) and Junction Turn Counts (JTC) data. JTC data is best for most locations (more detailed and accurate vehicle classifications, flows for each road entering the junction); ATC data is best for a flow over a longer period to examine traffic cycles (i.e. a week); ANPR (linking to DVLA database) is best for providing information on fleet composition (Euro classes etc.).
- Source attribution should be included in future studies as the most recent version of EMIT has added this feature, allowing the relative contribution of each vehicle category at each receptor point to be analysed and assessed for different scenarios (removing the effect of background).
- Using the most up to date ADMS-Urban version which includes an advanced canyon module
- Using more up to date and revised emission factors (e.g. NAEI2014), although these will also have uncertainties
- Including the effect of gradients in the generation of emission factors which will increase emissions to account for gradients. This is not currently the ability to account for this in EMIT, but adjustments can be made to AADF values to account for this (based on Defra LAQM guidance (23)).
- Using an adjusted urban background where the modelled contribution of explicit traffic sources at the Errol Place monitor is removed from the measured data (this will remove double counting).
- Use updated NAEI background emission maps when they become available for the Background Area Emissions approach, and develop a method to include shipping emissions.
- Splitting long road sections up to account for speed changes at junctions and faster flowing sections of road.
- Splitting long road sections where there is a significant change in building layout which may affect dispersion due to canyons.
- Road widths to be calculated for different model scenarios (non-canyons/ basic canyons module/advanced canyon module).
- Drive Cycle data may provide useful information on emission variations and could form part of future data collection studies.
- CFD modelling to assist in locating air quality monitors would provide evidence on how representative the monitoring location is within the vicinity.

8 Acknowledgements

We would like to thank Aberdeen City Council, The Scottish Government, Transport Scotland and AECOM.

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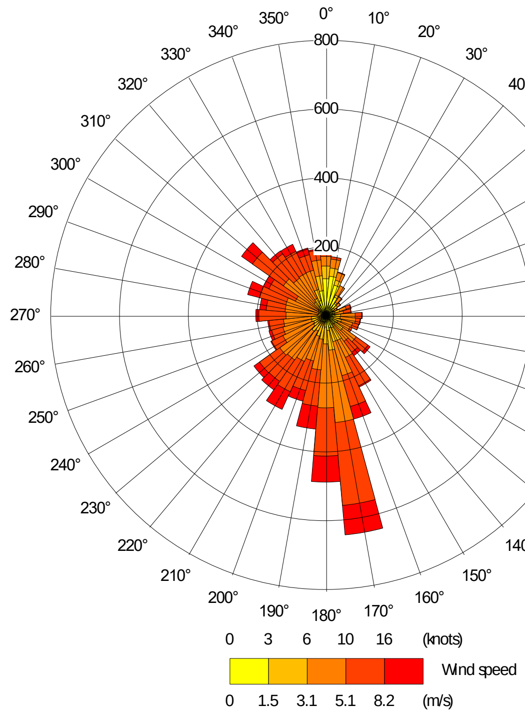
A1 Appendix: Wind Roses

Dyce

2009



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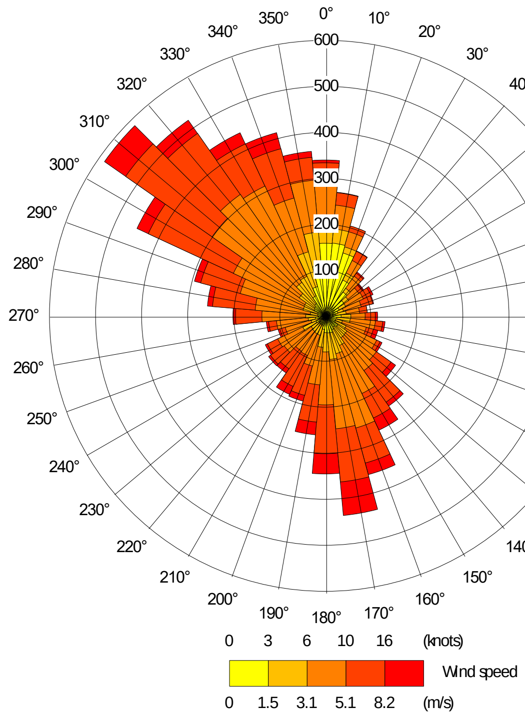

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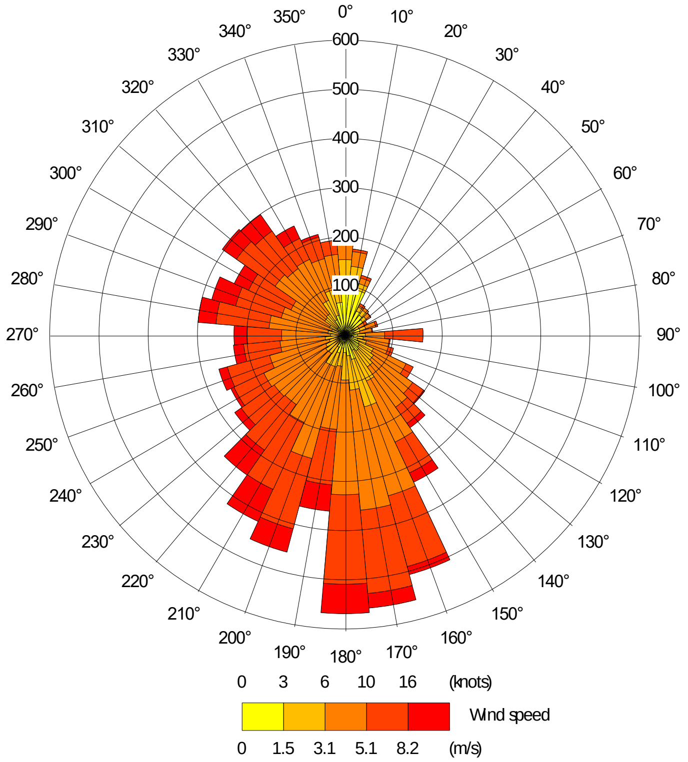
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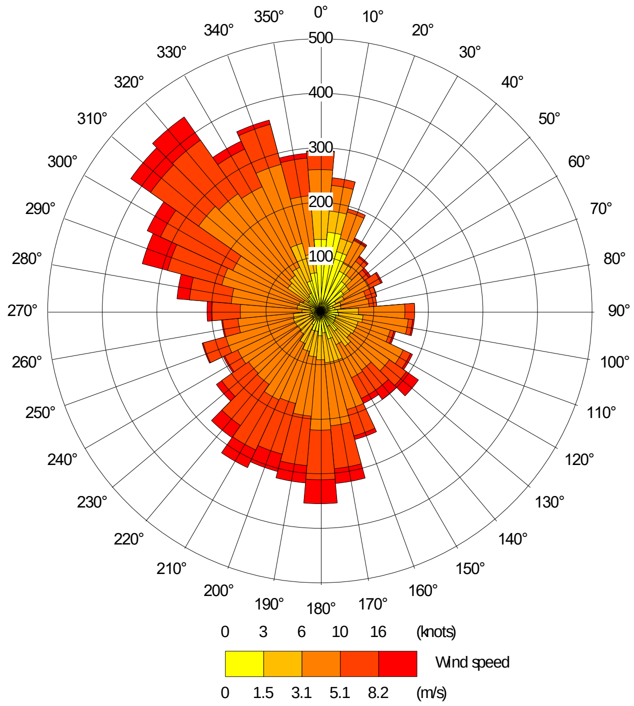
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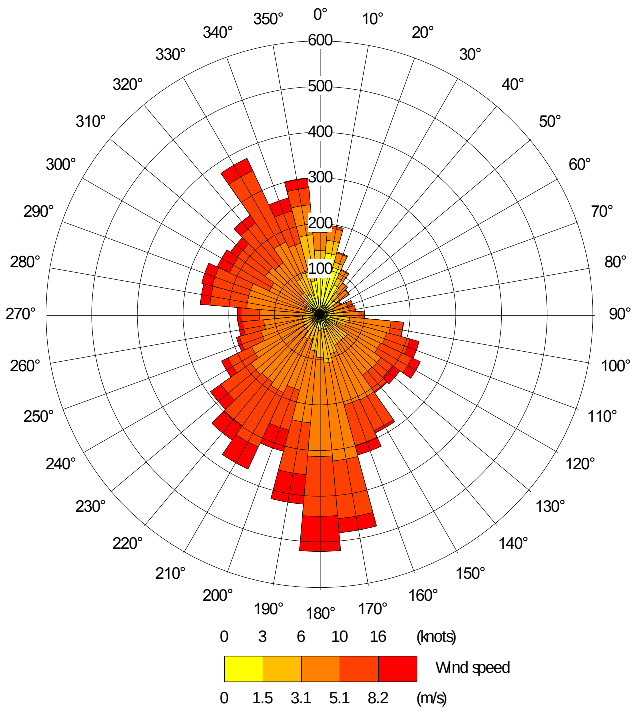

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Inverbervie No 2

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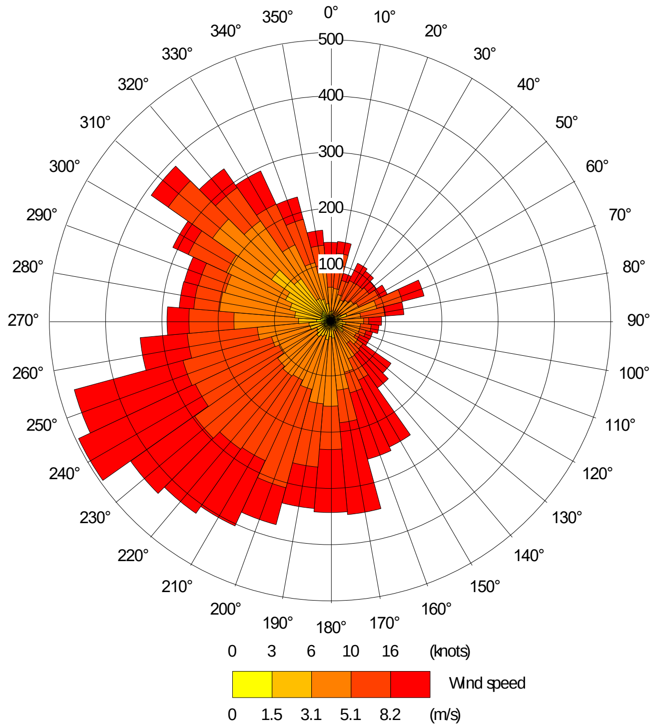

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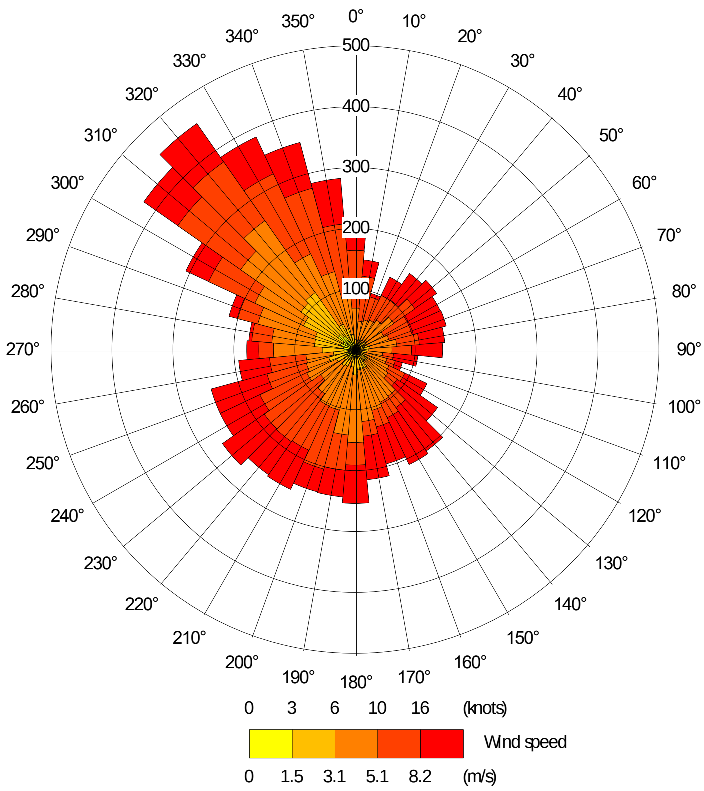

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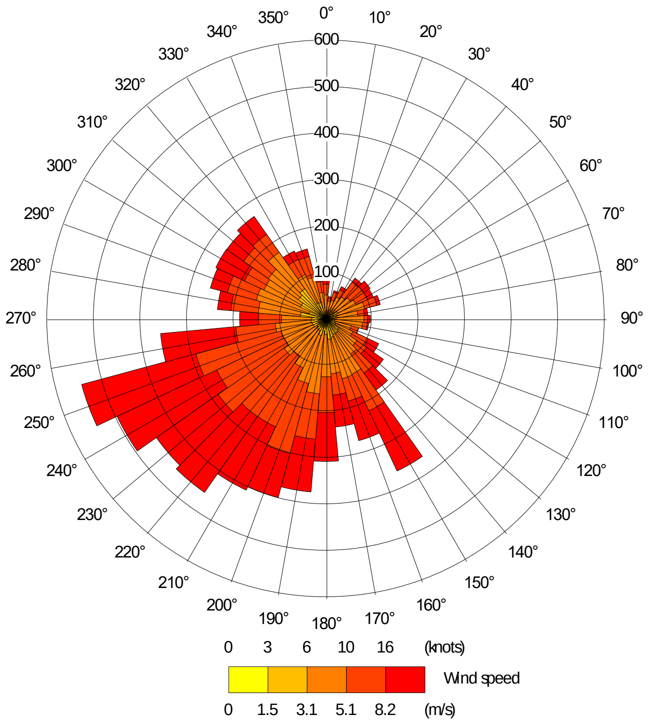
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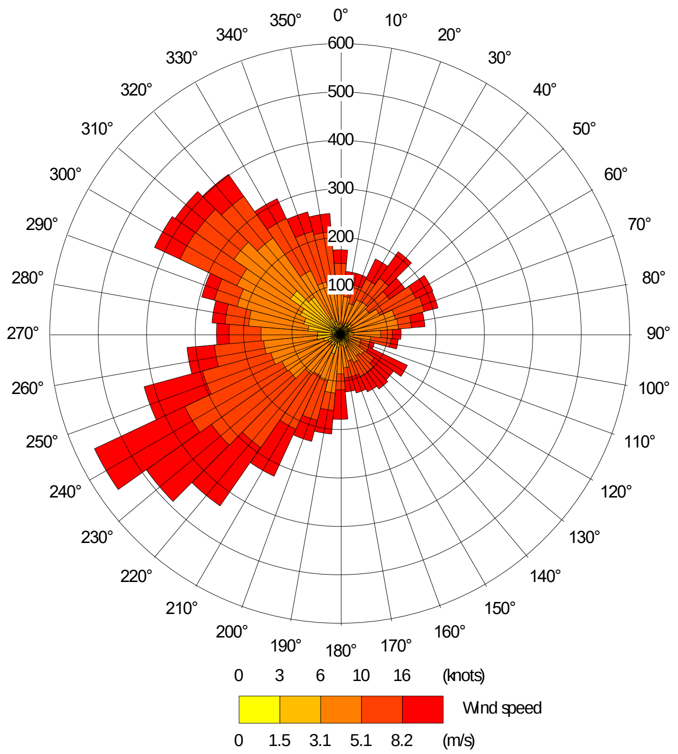
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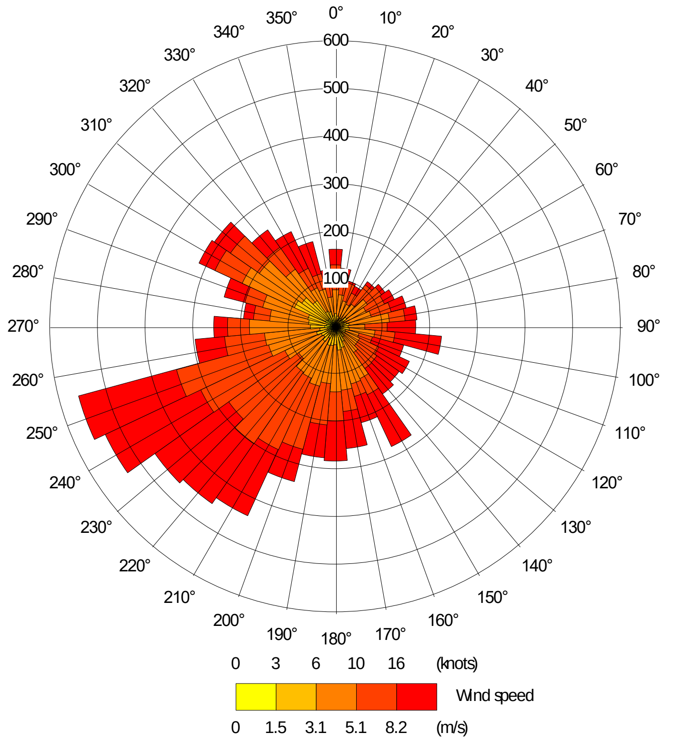

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A2 Appendix: Detailed Model Results for Base Run and Gridded Background Area Source Inter-comparison-

Table 68: Model Intercomparison of NO_2 predicted concentrations Base Model Run and Background Gridded Emissions Model

Monitoring Point	Annual Mean (µg m^{-3})			99.79th Percentile of 1hr Means (µg m^{-3})		
	Base Run	Background Emissions Run	Ratio	Base Run	Background Emissions Run	Ratio
Union Street	49.4	40.3	0.82	163.5	149.9	0.92
Market Street 2	47.6	37.4	0.79	171.5	158.8	0.93
Wellington Road	44	35.2	0.80	167.6	155.5	0.93
King Street	36	25.5	0.71	134.3	116.3	0.87
Anderson Drive	31.4	19.1	0.61	121.4	102	0.84
Errol Place	28.1	19	0.67	111	83.9	0.76

Table 69: Model Intercomparison of NO_x predicted concentrations Base Model Run and Background Gridded Emissions Model

Monitoring Point	Annual Mean (µg m^{-3})		
	Base Run	Background Emissions Run	Ratio
Union Street	133.3	113.3	0.84
Market Street 2	120.9	98.1	0.81
Wellington Road	114.3	94	0.82
King Street	79.9	58.9	0.74
Anderson Drive	55.7	33.8	0.61
Errol Place	46.5	29.1	0.62

A3 Appendix: Detailed Model Results for Model Inter-Annual Variation

A3.1.Scenario M1

Table 70: Annual Mean NO_2 Observed and Model Predictions, 2009-2013, Dyce and Inverbervie No.2, Urban Background

$\mu g\ m^{-3}$	Obs	Dyce Meteorological Data					Inverbervie No.2 Meteorological Data				
	2012	2009	2010	2011	2012	2013	2009	2010	2011	2012	2013
Union Street	52.8	52.7	48.8	48.7	49.4	47.7	47.3	42.5	43.5	43.7	42.7
Market Street 2	44.1	49.8	49.7	45.1	47.6	45.3	42.1	39.9	37.7	38.5	37.2
Wellington Road	59.1	47.3	45.8	42.8	44	41.4	44	38.4	37.5	38.9	36.7
King Street	29.2	40.5	37.3	36.4	36	34.7	38.3	32.6	33	33	31.9
Anderson Drive	30.4	35.5	33.5	31.4	31.4	30.2	32.5	28.6	28.1	28.1	27.4

Table 71: 99.79th Percentile NO_2 Observed and Model Predictions, 2009-2013, Dyce and Inverbervie No.2, Urban Background

$\mu g\ m^{-3}$	Obs	Dyce Meteorological Data					Inverbervie No.2 Meteorological Data				
	2012	2009	2010	2011	2012	2013	2009	2010	2011	2012	2013
Union Street	143	192.1	162.2	160.4	163.5	152.4	184.2	154.7	157.6	156	141.1
Market Street 2	161	194.7	187.5	183.4	171.5	165.4	173	162.3	158.1	146.1	142.6
Wellington Road	187.8	202.2	177.3	167.6	167.6	151	193.9	165.5	152	160.6	147.6
King Street	107	173.1	148.2	139.7	134.3	124.7	167.8	141.6	128.8	133.2	121.9
Anderson Drive	115	149.1	139.3	133.2	121.4	106.4	138	116.9	111.1	110.2	90.6

Table 72: Annual Mean NO_x Observed and Model Predictions, 2009-2013, Dyce and Inverbervie No.2, Urban Background

$\mu g\ m^{-3}$	Obs	Dyce Meteorological Data					Inverbervie No.2 Meteorological Data				
	2012	2009	2010	2011	2012	2013	2009	2010	2011	2012	2013
Union Street	136.2	139	127	130	133.3	126	122.2	109.3	112.6	114.8	109.4
Market Street 2	110.5	121.2	125.9	108.4	120.9	110.5	95.4	95	84.9	90.7	84.9
Wellington Road	179.5	117.3	115.7	106.3	114.3	101.1	109.9	93.4	90	98.9	87.5
King Street	65.7	86.2	80.1	77.5	79.9	71.6	82.3	67.4	68	71.7	64.2
Anderson Drive	55.8	62	58.1	53.8	55.7	49.7	56.6	47.9	47	48.5	43.7

A3.2.Scenario M2

Nitrogen Dioxide

Table 73: NO_2 Results for Air Quality Standards/Objectives using 2009 meteorological data and background data (Note: Market Street 2 data only available from 01/06/2009), Urban Background

µg m^{-3}	Annual Mean			99.79th Percentile of 1hr Means		
	Observed	Dyce	I'bervie	Observed	Model	I'bervie
Union Street	51.7	53.6	48.3	189.2	194.1	186.6
Market Street 2	39.5	50.7	42.7	174.7	196.6	174.5
Wellington Road	43.4	48.1	44.6	157	203.8	194.4
King Street	32.5	41.3	39	132	174.3	169.2
Anderson Drive	24.1	36.1	32.9	107	149.2	138.1

Table 74: NO_2 Results for Air Quality Standards/Objectives using 2010 meteorological data and background data, Urban Background

µg m^{-3}	Annual Mean			99.79th Percentile of 1hr Means		
	Observed	Dyce	I'bervie	Observed	Dyce	I'bervie
Union Street	58	50.2	43.5	197.9	165.2	156.8
Market Street 2	43.9	50.5	40.4	156.3	190.1	164.4
Wellington Road	52.4	46.5	38.9	180	178.6	167
King Street	29.5	38	33.1	117.7	149.7	142.5
Anderson Drive	27	34	28.9	111	139.7	117.3

Table 75: NO_2 Results for Air Quality Standards/Objectives using 2011 meteorological data and background data, Urban Background

µg m^{-3}	Annual Mean			99.79th Percentile of 1hr Means		
	Observed	Dyce	I'bervie	Observed	Dyce	I'bervie
Union Street	43.5	49.1	43.9	168	163.5	158.9
Market Street 2	40.4	45.6	38	164	185.2	160
Wellington Road	51.3	43.2	37.9	183	169.5	153.9
King Street	32.1	36.8	33.3	118	141.6	130.3
Anderson Drive	23.4	31.6	28.3	113	133.4	111.5

Table 76: NO_2 Results for Air Quality Standards/Objectives using 2012 meteorological data and background data, Urban Background

µg m^{-3}	Annual Mean			99.79th Percentile of 1hr Means		
	Observed	Dyce	I'bervie	Observed	Dyce	I'bervie
Union Street	52.8	49.4	43.7	143	163.5	156
Market Street 2	44.1	47.6	38.5	161	171.5	146.1
Wellington Road	59.1	44	38.9	187.8	167.6	160.6
King Street	29.2	36	33	107	134.3	133.2
Anderson Drive	30.4	31.4	28.1	115	121.4	110.2

Table 77: NO_2 Results for Air Quality Standards/Objectives using 2013 meteorological data and background data, Urban Background

µg m⁻³	Annual Mean			99.79th Percentile of 1hr Means		
	Observed	Dyce	I'bervie	Observed	Dyce	I'bervie
Union Street	48.3	46.7	42	135	150.6	140.9
Market Street 2	43	44.3	36.5	169	162.1	139
Wellington Road	52	40.5	36	184.4	148	144.7
King Street	28.4	34.1	31.4	113	123	120.6
Anderson Drive	22.5	29.8	27.2	115	105.4	90.3

Nitrogen Oxides

Table 78: NOx Results using 2009 and 2010 meteorological data, background data (Note: Market Street 2 data only available from 01/06/2009), Urban Background

µg m⁻³	Annual Mean					
	2009			2010		
	Observed	Dyce	I'bervie	Observed	Dyce	I'bervie
Union Street	125	145.1	128.7	144.1	133.4	114.2
Market Street 2	93.6	126.5	99	107.4	129.7	97.7
Wellington Road	130.6	122.4	114.4	148.3	119.1	96
King Street	71.7	92.5	88	65.5	84.3	70.8
Anderson Drive	43.8	65.3	58.8	48.9	60.8	49.7

Table 79: NO_x Results using 2011 and 2012 meteorological data and background data, Urban Background

µg m⁻³	Annual Mean					
	2011			2012		
	Observed	Dyce	I'bervie	Observed	Dyce	I'bervie
Union Street	111.7	130.9	113.8	136.2	133.3	114.8
Market Street 2	95.4	109.8	85.9	110.5	120.9	90.7
Wellington Road	144.2	107.7	91.1	179.5	114.3	98.9
King Street	68.7	79.5	69.5	65.7	79.9	71.7
Anderson Drive	40.1	54.7	47.7	55.8	55.7	48.5

Table 80: NO_x Results using 2013 meteorological data and background data, Urban Background

µg m⁻³	Annual Mean		
	Observed	Dyce	I'bervie
Union Street	127.9	120.5	105.6
Market Street 2	108.6	105.7	81.5
Wellington Road	159.8	96.8	84
King Street	63.8	68.7	61.8
Anderson Drive	46.8	48.3	42.8

A3.3.Scenario M3

Table 81: Annual Mean NO2 Observed and Model Predictions, 2009-2013, Dyce and Inverbervie No.2, Rural Background

µg m^{-3}	Obs	Dyce Meteorological Data					Inverbervie No.2 Meteorological Data				
	2012	2009	2010	2011	2012	2013	2009	2010	2011	2012	2013
Union Street	52.8	46.3	47.1	44.8	48.3	47	36.2	37.2	35.3	37.5	37
Market Street 2	44.1	42.4	47.3	40.2	45.4	43.8	30.2	34.2	28.9	31.4	30.9
Wellington Road	59.1	40.3	43.6	38.4	42.5	40.1	32.1	32.7	28.7	32	30.1
King Street	29.2	30.3	31.4	29.1	30.5	29.6	24.1	24	22.1	23.4	22.7
Anderson Drive	30.4	22.6	26.7	20.8	24.2	22.8	16.2	18.8	15.2	16.7	16.2
Errol Place	21	26.6	27.2	25.7	26.3	26.2	20.6	20.8	19.4	19.9	19.8

Table 82: 99.79th Percentile NO2 Observed and Model Predictions, 2009-2013, Dyce and Inverbervie No.2, Rural Background

µg m^{-3}	Obs	Dyce Meteorological Data					Inverbervie No.2 Meteorological Data				
	2012	2009	2010	2011	2012	2013	2009	2010	2011	2012	2013
Union Street	143	155.8	151.4	154.7	150.5	158	148.9	146.9	148	141.7	147.2
Market Street 2	161	167	164.4	160.9	158.7	175.6	142.6	157	144.6	142.6	154.2
Wellington Road	187.8	156.6	157	149.4	155.1	156.3	148.2	151.6	138.4	142.9	146.8
King Street	107	115.1	116.6	114	114.4	118.2	113.2	111.7	110.4	104	113.7
Anderson Drive	115	108.3	105	101.2	100.5	112.1	88.2	98	86.2	85.3	93.8
Errol Place	105	85.9	85.6	87.5	83.7	90.9	81.2	81.1	84.9	76.7	87.2

Table 83: Annual Mean NOx Observed and Model Predictions, 2009-2013, Dyce and Inverbervie No.2, Rural Background

Monitoring Point	Obs	Dyce Meteorological Data					Inverbervie No.2 Meteorological Data				
	2012	2009	2010	2011	2012	2013	2009	2010	2011	2012	2013
Union Street	136.2	126	126.2	122.5	130	125	101.2	102.1	99.7	103.4	101
Market Street 2	110.5	106.5	123.4	99.1	115.6	107.5	73.4	86.7	70.7	78	75.1
Wellington Road	179.5	102.6	113.5	97	109.2	98.4	87.3	84.7	75.3	85.6	77.3
King Street	65.7	65.1	69.2	62.2	67.1	62	55.5	53.6	49.5	53.8	49.9
Anderson Drive	55.8	38.4	47.2	35.3	42	38.3	26.9	32.1	25.5	28.4	26.8
Errol Place	36	41.6	43.5	40.8	41.2	39.9	33.4	33.8	31.9	32.1	31.3

A3.4. Scenario M4

Nitrogen Dioxide

Table 84: NO_2 Results for Air Quality Standards/Objectives using 2009 meteorological data and background data (Note: Market Street 2 data only available from 01/06/2009), Rural Background

$\mu g\ m^{-3}$	Annual Mean			99.79th Percentile of 1hr Means		
	Observed	Dyce	I'bervie	Observed	Dyce	I'bervie
Union Street	51.7	47.2	37.3	189.2	157.3	150.8
Market Street 2	58	43.3	30.9	197.9	169.7	143.2
Wellington Road	43.5	41.1	32.8	168	159.3	151
King Street	52.8	31.3	24.9	143	118.3	116.3
Anderson Drive	48.3	23.2	16.6	135	109.2	90.4
Errol Place	25.7	27.1	20.9	174.7	86.9	82

Table 85: NO_2 Results for Air Quality Standards/Objectives using 2010 meteorological data and background data, Rural Background

$\mu g\ m^{-3}$	Annual Mean			99.79th Percentile of 1hr Means		
	Observed	Dyce	I'bervie	Observed	Dyce	I'bervie
Union Street	58	48.5	38.2	197.9	153	147.5
Market Street 2	43.5	48.1	34.8	168	166.7	160.3
Wellington Road	52.8	44.3	33.2	143	159.2	153.6
King Street	48.3	32.1	24.6	135	118.6	113.8
Anderson Drive	39.5	27.3	19.2	174.7	106.3	98.7
Errol Place	43.9	27.5	21	156.3	86.3	81.5

Table 86: NO_2 Results for Air Quality Standards/Objectives using 2011 meteorological data and background data, Rural Background

$\mu g\ m^{-3}$	Annual Mean			99.79th Percentile of 1hr Means		
	Observed	Dyce	I'bervie	Observed	Dyce	I'bervie
Union Street	43.5	45.2	35.7	168	156.4	149.5
Market Street 2	52.8	40.7	29.2	143	163.2	146.6
Wellington Road	48.3	38.8	29	135	151.5	140.2
King Street	39.5	29.5	22.5	174.7	115.6	111.6
Anderson Drive	43.9	21.1	15.4	156.3	102.3	87.8
Errol Place	50.4	25.9	19.5	164	88.4	85.2

Table 87: NO_2 Results for Air Quality Standards/Objectives using 2012 meteorological data and background data, Rural Background

µg m^{-3}	Annual Mean			99.79th Percentile of 1hr Means		
	Observed	Dyce	I'bervie	Observed	Dyce	I'bervie
Union Street	52.8	48.3	37.5	143	150.5	141.7
Market Street 2	48.3	45.4	31.4	135	158.7	142.6
Wellington Road	39.5	42.5	32	174.7	155.1	142.9
King Street	43.9	30.5	23.4	156.3	114.4	104
Anderson Drive	50.4	24.2	16.7	164	100.5	85.3
Errol Place	44.1	26.3	19.9	161	83.7	76.7

Table 88: NO_2 Results for Air Quality Standards/Objectives using 2013 meteorological data and background data, Rural Background

µg m^{-3}	Annual Mean			99.79th Percentile of 1hr Means		
	Observed	Dyce	I'bervie	Observed	Dyce	I'bervie
Union Street	48.3	46	37.3	135	155.6	150.8
Market Street 2	39.5	42.7	30.9	174.7	171.2	145
Wellington Road	43.9	39.2	32.8	156.3	152.9	151
King Street	50.4	28.9	24.9	164	115.7	116.3
Anderson Drive	44.1	22.5	16.6	161	110.5	90.4
Errol Place	43	26	20.9	169	89.9	82

Nitrogen Oxides

Table 89: NOx Results using 2009 and 2010 meteorological data, background data (Note: Market Street 2 data only available from 01/06/2009), Rural Background

µg m^{-3}	Annual Mean					
	2009			2010		
	Observed	Dyce	I'bervie	Observed	Dyce	I'bervie
Union Street	125	132.1	107.7	144.1	132.6	107
Market Street 2	144.1	111.8	77.1	111.7	127.2	89.4
Wellington Road	111.7	107.7	91.8	136.2	117	87.3
King Street	136.2	71.4	61.1	127.9	73.4	56.9
Anderson Drive	127.9	41.7	29.2	93.6	49.9	33.9
Errol Place	93.6	42.8	34.5	107.4	44.2	34.4

Table 90: NO_x Results using 2011 and 2012 meteorological data and background data, Rural Background

µg m^{-3}	Annual Mean					
	2011			2012		
	Observed	Dyce	I'bervie	Observed	Dyce	I'bervie
Union Street	111.7	123.3	101	136.2	130	103.4
Market Street 2	136.2	99.8	71.7	127.9	115.6	78
Wellington Road	127.9	98.4	76.4	93.6	109.2	85.6
King Street	93.6	64.1	51	107.4	67.1	53.8
Anderson Drive	107.4	36.2	26.2	95.4	42	28.4
Errol Place	95.4	41.2	32.2	110.5	41.2	32.1

Table 91: NO_x Results using 2013 meteorological data and background data, Rural Background

µg m^{-3}	Annual Mean		
	Observed	Dyce	I'bervie
Union Street	127.9	119.5	107.7
Market Street 2	93.6	102.7	77.1
Wellington Road	107.4	94.1	91.8
King Street	95.4	59.1	61.1
Anderson Drive	110.5	37	29.2
Errol Place	108.6	39.3	34.5

A4 Appendix: Detailed Model Results for Chemistry Sensitivity Tests

Table 92: Union Street NO_2 Air Quality Standards for different Chemistry methods

Scenario	Annual Mean (µg m^{-3})			99.79%ile of Hourly Mean (µg m^{-3})		
	Observed	Modelled	Ratio	Observed	Modelled	Ratio
C1	52.8	49.4	0.94	143	163.5	1.14
C2	52.8	37.8	0.72	143	156.5	1.09
C3	52.8	49.8	0.94	143	98.2	0.69
C4	52.8	52.8	1	143	89.7	0.63

Table 93: Market Street NO2 Air Quality Standards for different Chemistry methods

Scenario	Annual Mean (µg m^{-3})			99.79%ile of Hourly Mean		
	Observed	Modelled	Ratio	Observed	Modelled	Ratio
C1	44.1	47.6	1.08	161	171.5	1.07
C2	44.1	36.1	0.82	161	165.2	1.03
C3	44.1	44.5	1.01	161	105.5	0.66
C4	44.1	47.4	1.07	161	92.4	0.57

A5 Appendix: Detailed Model Results for Time-varying Emissions Sensitivity Test

Table 94: NO_2 Annual Mean Model Predictions and ratios for time-varying emissions sensitivity test

Monitoring Point	Annual Mean (µg m^{-3})			Observed/Modelled Ratios	
	Obs	Base Run	No Time Varying Emissions	Base Run	No Time Varying Emissions
Union Street	52.8	49.4	54.5	0.94	1.03
Market Street 2	44.1	47.6	52.9	1.08	1.2
Wellington Road	59.1	44	49.4	0.74	0.84
King Street	29.2	36	39.4	1.23	1.35
Anderson Drive	30.4	31.4	33.5	1.03	1.1

Table 95: NO_2 99.79th Percentile Model Predictions and ratios for time-varying emissions sensitivity test

Monitoring Point	99.79th Percentile of 1hr Means (µg m^{-3})			Observed/Modelled Ratios	
	Obs	Base Run	No Time Varying Emissions	Base Run	No Time Varying Emissions
Union Street	143	163.5	138.1	1.14	0.97
Market Street 2	161	171.5	147	1.07	0.91
Wellington Road	187.8	167.6	145.1	0.89	0.77
King Street	107	134.3	127.8	1.26	1.19
Anderson Drive	115	121.4	117.2	1.06	1.02

Table 96: NO_x Annual Mean Model Predictions ratios for time-varying emissions sensitivity test

Monitoring Point	Annual Mean (µg m^{-3})			Observed/Modelled Ratios	
	Obs	Base Run	No Time Varying Emissions	Base Run	No Time Varying Emissions
Union Street	136.2	133.3	148	0.98	1.09
Market Street 2	110.5	120.9	135.8	1.09	1.23
Wellington Road	179.5	114.3	130.6	0.72	0.73
King Street	65.7	79.9	88.9	1.22	1.35
Anderson Drive	55.8	55.7	59.6	1.0	1.07

A6 Appendix: Low Emission Zone Scenario Model Results

Table 97: Predicted NO_2 Annual Average Concentrations for each Low Emission Scenario

Monitoring Point	Annual Mean NO_2 ($\mu g\ m^{-3}$)							
	Base Run	L1	L2	L3	L4	L5	L6	L7
Union Street	49.4	48.5	42.9	43.9	41.9	43	37.2	36.2
Market Street 2	47.6	44.3	46.2	42.4	42.8	39.1	41	37.6
Wellington Road	44	41	43.2	39.1	40.1	36	38.3	35.1
King Street	36	34.4	27.6	32.2	33.4	30.6	31.3	29.6
Anderson Drive	31.4	30.6	31.3	28.3	30.5	27.6	28.2	27.4

A7 Appendix: Future Years

Table 98: Predicted NO_2 Annual Mean concentrations using NAEI2012 emission factor estimates for future years (Base Run)

Monitoring Point	Annual Mean NO_2 ($\mu g\ m^{-3}$)			
	Base Run: NAEI2012 (2012)	NAEI2012 (2015)	NAEI2012 (2020)	NAEI2012 (2025)
Union Street	49.4	45.7	36.7	31.5
Market Street 2	47.6	42.7	33.8	30.1
Wellington Road	44	39.7	32.1	28.9
King Street	36	33.5	28.8	26.7
Anderson Drive	31.4	30	27.1	25.8

Table 99: Predicted NO_2 99.79th Percentile concentrations using NAEI2012 emission factor estimates for future years (Base Run)

Monitoring Point	99.79th Percentile of 1 hour Mean NO_2 ($\mu g\ m^{-3}$)			
	Base Run: NAEI2012 (2012)	NAEI2012 (2015)	NAEI2012 (2020)	NAEI2012 (2025)
Union Street	163.5	151.9	127.7	115.6
Market Street 2	171.5	154.9	125.9	115.3
Wellington Road	167.6	152.7	122.9	115.6
King Street	134.3	127.3	114.3	109.9
Anderson Drive	121.4	118.2	109.7	107.2

Table 100: Predicted NO_2 Annual Mean concentrations using NAEI2012 emission factor estimates for future years (Gridded Area Emissions and Rural Background Run)

Monitoring Point	Annual Mean NO_2 ($\mu g\ m^{-3}$)			
	NAEI2012 (2012)	NAEI2012 (2015)	NAEI2012 (2020)	NAEI2012 (2025)
Union Street	48.3	44.5	35.3	30
Market Street 2	45.4	40.5	31.5	27.8
Wellington Road	42.5	38	30	26.7
King Street	30.5	27.7	22.6	20.4
Anderson Drive	24.2	22.7	19.9	18.6
Errol Place	26.3	25.2	23.3	22.4

Table 101: Predicted NO_2 99.79th Percentile concentrations using NAEI2012 emission factor estimates for future years (Gridded Area Emissions and Rural Background Run)

Monitoring Point	99.79th Percentile of 1 hour Mean NO_2 ($\mu g\ m^{-3}$)			
	NAEI2012 (2012)	NAEI2012 (2015)	NAEI2012 (2020)	NAEI2012 (2025)
Union Street	150.5	137.9	104.5	85.4
Market Street 2	158.7	142.7	105.9	90.1
Wellington Road	155.1	138.9	105.2	89.8
King Street	114.4	104.3	85.2	77.1
Anderson Drive	100.5	95.6	82.1	75.2
Errol Place	83.7	81.1	75	72.2

A8 Appendix: Statistics

The model performance should be assessed on a range of statistical parameters as outlined in Section 4.1 and suggested by Chang and Hanna (31).

A8.1.Mean Bias (MB)

The Mean Bias (MB) is the average difference between modelled and observed values, though can be dominated by outlier values.
A negative value (MB<0) indicates the model is under-predicting, and a positive value (MB>0), indicates that the model is over-predicting. An ideal model would have a MB value of 0.

Equation 6: Mean Bias

$$MB = \left(\overline{C_p - C_o}\right)$$

where C_p is the predicted model concentration, and C_o is the observed concentration

A8.2.Fractional Bias (FB)

The Fractional Bias (FB) is when the bias is normalised. The Fractional Bias varies between +2 and -2.
A negative value (FB<0) indicates the model is under-predicting, and a positive value (FB>0), indicates that the model is over-predicting. An ideal model has an FB value of 0.

Equation 7: Fractional Bias

$$FB = \frac{\left(\overline{C_p} - \overline{C_o}\right)}{0.5\left(\overline{C_p} + \overline{C_o}\right)}$$

where C_p is the predicted model concentration, and C_o is the observed concentration

A8.3.Geometric Mean Bias (MG)

The Geometric Mean Bias (MG), is similar to the Mean Bias, however, this is based on the logarithmic scale and is useful for lognormal distributions.
A negative value (FB<0) indicates the model is under-predicting, and a positive value (FB>0), indicates that the model is over-predicting. An ideal model has an MG of 1.

Equation 8: Geometric Mean Bias

$$MG = exp\left(\overline{\ln C_p} - \overline{\ln C_o}\right)$$

where C_p is the predicted model concentration, and C_o is the observed concentration

A8.4.Normalised Mean Square Error (NMSE)

The Normalised Mean Square Error (NMSE) is an estimate of the data scatter. An ideal model has an NMSE of 0.

Equation 9: Normalised Mean Square Error

$$NMSE = \frac{\overline{(C_p - C_o)^2}}{\overline{C_p}\,\overline{C_o}}$$

where C_p is the predicted model concentration, and C_o is the observed concentration

A8.5. Geometric Variance (VG)

The Geometric Variance (VG) is an estimate of scatter and how far apart the observed and predicted values are. An ideal model has a VG of 1.

Equation 10: Geometric Variance

$$VG = exp\left[\overline{(\ln C_p - \ln C_o)^2}\right]$$

where C_p is the predicted model concentration, and C_o is the observed concentration

A8.6. Correlation coefficient (R)

The correlation coefficient (R) is a measure of the scatter and estimates the linear relationship of the observed and predicted variables. An ideal model will have an R of 1.

Equation 11: Correlation

$$R = \frac{\overline{(C_p - \overline{C_p})(C_o - \overline{C_o})}}{\sigma_{C_p}\sigma_{C_o}}$$

where C_p is the predicted model concentration, C_o is the observed concentration, σ_{C_p} is the standard deviation of C_p, σ_{C_o} is the standard deviation of C_o.

A8.7. Factor of 2 (Fac2)

This is the number of predicted values which fall within a factor of 2 of the observed values.

Equation 12: Factor of 2

$$0.5 < \frac{C_p}{C_o} < 2$$

A9 Appendix: Methodology Update for since Aberdeen Pilot Study

Since the Aberdeen Pilot Project was completed, there have been a number of changes to the methodology.

A9.1.Traffic Data Collection

Traffic Data collection studies were designed for 4 cities (Aberdeen, Dundee, Edinburgh and Glasgow)

- The data extracted from Junction Turn Count (JTC) cameras was classified into 12 vehicle classes (so that no assumptions on OGV vehicle classes were required for use in the detailed NAEI emission inventory). These are:
  - Cars
  - Buses
  - Motorcycles
  - Taxis
  - LGV's
  - Rigid HGV 2 axle
  - Rigid HGV 3 axle
  - Rigid HGV 4+axle
  - Artic HGV 3&4 axle
  - Artic HGV 5 axle
  - Artic HGV 6+ axle
  - Pedal Cycles
- To optimise the number of JTC locations (to increase coverage and reduce costs), the traffic flows are calculated along a complete road section based on the data 1 JTC location. This differs from the pilot project where the average flow from 2 JTC's located at either end of each road section were used. In most cases there are now no longer JTC cameras at both ends of each road section.
- At key locations across each city, the JTC's covered a full 24 hour period. These key locations included traffic flows by an Automatic Air Quality Monitor or at key junctions. The 24 hour JTC locations enabled an AADF conversion ratio to be calculated for each traffic class and area of the city. These AADF conversion ratios were then applied to JTC's which only covered a 12 hour period, so that an Annual Average Daily Flow (AADF) was calculated for each road section.
- Automatic Traffic Counters (ATC) were deployed for a week at various key locations (including by automatic air quality monitors); although they are not able to provide a detailed class breakdown they are able to provide a diurnal cycle for each day of the week.
- Automatic Number Plate Recognition (ANPR) camera's collected vehicle registration data at key locations across city and roads entering city. This data can be linked to DVLA database to get a greater understanding of traffic fleet in city (e.g. Euro classes, % of diesel/petrol vehicles etc), though caution is

required as the DVLA database does not contain Euro class data for all vehicle types.

A9.2. Road Network

- The ADMS Advanced Canyon module has been released by CERC since the Aberdeen pilot project. This allows complex and 1-sided canyons to be modelled in ADMS-Urban and requires building data in a shapefile format (building polygons and heights), which is available from Ordnance Survey.
- Road sections are split to account for differing road geometry in the section (e.g. changing widths or canyon characteristics along the road section) whilst retaining the same traffic flows. The Advanced Canyon module can be used for all roads considered to have a complex canyon, though is also used across the entire city as a sensitivity test to compare with the Basic Canyon module.

A9.3. Modelling Methodology

- The Local Night time chemistry module is used
- For calculating emissions, a Speed value needs to be specified. In addition to Speed limits, model runs with 10km/hr are carried out to simulate congestion.
- Shipping Emissions from NAEI emission maps are now accounted for in model as separate elevated volume source (this is most important for Aberdeen work, where shipping emissions are significant in the city centre)
- Output concentrations are modelled for all monitoring locations and kerbside points approximately every 50 metres along each road section.
- Source apportionment modelling is now available in EMIT for NO_x (EMIT allows emissions for each vehicle class to be calculated, though this is modified to distinguish Taxis from private diesel cars).