# Leeds Clean Air Zone

## Full Business Case Appendix 5
## Air Quality Modelling Methodology Report

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# Contents

# 1 Introduction

This Technical Report details the methodology, data sources and associated outcomes of the process followed by Leeds City Council to calculate the vehicle emissions and resulting concentrations of nitrogen dioxide ($NO_2$) and fine Particulates PM2.5 for the 2015 base year and different future year scenarios in 2020 and 2022 to support the development of a future Clean Air Zone.

A previous round of modelling was undertaken to compare the likely impacts of different classes of a Clean Air Zone with boundaries broadly based around the outside of the Leeds Inner Ring Road and the Inside of the Leeds Outer Ring Road. Classes B and C were modelled based with the Inner Ring Road boundary and Classes B, C and D were modelled based on the Outer Ring Road Boundary. In all cases of CAZ B and C, the likely impact of introducing restrictions on hackney carriage and private hire vehicles were not fully reflected across the whole modelled network.

The result of this first round of modelling identified that a Class B Clean Air Zone based on the Outer Ring Road boundary was likely to achieve legal compliance with the EU Air Quality Directive by 2020 and significantly reduce concentrations in other areas of concern in Leeds if additional measures were also implemented.

Whilst the first round of modelling was being undertaken, a number of datasets, modelling toolkits and guidance notes were revised and updated. In addition, analysis of the results identified that although the relative change in total emissions was valid, there were some errors present in the way they were matched to the modelled network. It was therefore decided that a second round of modelling should be undertaken which would utilise all the latest guidance, toolkits and data sets available and improve on the original modelling process where possible. Due to time constraints, the decision was made that this second round of modelling would concentrate upon the Do Minimum base year scenarios and variations of a Class B Clean Air Zone based on the outer Ring Road Boundary. However, in the event that the new results identified that a variation of a Class B CAZ would not achieve compliance a Class D CAZ was also re-modelled.

This report concentrates on the process and outcomes of the second round of modelling but does reference some changes which have occurred from the first round of modelling.

The four scenarios focused on in this round of modelling are;

- **2020 DM** – The Do-Minimum scenario.
- **2020 CAZ-B+** A standard CAZ-B but with Taxi and Private Hire switching to Petrol-Hybrids and a full enforceable boundary extending south to the M62.
- **2020 CAZ-B+ Reduced** - As above but with a reduced southern boundary to the M621.
- **2020 CAZ-D Reduced** - A standard CAZ D with a reduced southern boundary of the M621.

The two different CAZ boundaries are displayed in the accompanying documents.

# 2 Outline of the Modelling Process

The air quality modelling process followed a number of sequential steps to calculate the following for each scenario and base year considered;

- Expected traffic volumes, vehicle types and speeds.
- Emissions attributed to the predicted traffic flows.
- Resulting concentrations of $NO_2$ and $PM_{2.5}$.

Each step is covered in detail within this report or referenced to other accompanying reports, but an outline of each step of the process is summarised below.

## 2.1 Traffic Data

The annual average daily traffic (AADT) for each relevant base year and CAZ scenario was derived from the SATURN (Simulation and Assignment of Traffic to Urban Road Networks) based Leeds Transport Model (LTM). The model outputs provide average weekday traffic volumes by vehicle class/purpose and average speeds by road link for seven separate time periods between the hours 0700-1900. The modelled outputs for each time period were factored using locally derived data to generate annual average daily volumes for the following four time periods split by vehicle class (cars, LGVs, HGVs and PSVs).

- AM Peak 0700 – 1000Hrs
- Inter-Peak 1000 – 1600Hrs
- PM Peak 1600 – 1900Hrs
- Off-Peak 1900 – 0700Hrs

Car, LGV and HGV user classes were also split into separate compliant and non-compliant vehicle flows to allow any diversion impacts of a CAZ related charge to be modelled. The vehicle classes within the LTM were subsequently proportioned in to different fuel and sub classes using local data collected from a combination of previous manual classified traffic counts and more recent Automatic Number Plate Recognition (ANPR) data across a number of representative sites within the central urban area.

## 2.2 Road Traffic Emission Calculations

The modelled road links were split in to two road-type subgroups of Motorway and Urban Non-Motorway links. For each road type, the total traffic flow in each time period along with the proportion of each vehicle sub-class and relevant link speeds was entered in to the Defra Emission Factor Toolkit (EFT) v8.0.1 to calculate the total emissions of Oxides of Nitrogen (NOX), percentage of f-$NO_2$ and $PM_{2.5}$ on a link by link basis.

Prior to the calculations, the proportion of fuel type, weight class and Euro standards of the compliant and non-compliant vehicles was used to populate the EuroUser worktab in the EFT. The fleet profiles for the Non-Motorway road links were calculated using a EuroUser worktab generated using the ANPR data collected within Leeds. The Motorway road links used the EFT default UK motorway values.

One change from the first round of modelling is that road links representing the M621 were treated as an urban Non-Motorway as this was felt the fleet profile using this road was closer to the general fleet in Leeds than the wider national motorway network.

## 2.3 Emissions Dispersion Modelling

The emissions of NOx, $PM_{2.5}$ and primary $NO_2$ (f-$NO_2$) which were calculated for each road-type and time period were joined to a georeferenced Shapefile representing the road centre lines of the LTM network. The shapefiles were then loaded in to Leeds City Council air quality model known as Airviro to create an Emission Database representing each scenario and each pollutant.

Airviro was set up to apply the emission rates for each of time periods calculated in the EFT to the relevant time periods in the Emission Database. Additional, these emission rates for each time period were factored so that they represented the relative difference between weekdays, Saturdays and Sundays. This was done using the relative difference in traffic flows for each time period of these days compared to the Annual Average Daily Total.

Model runs were set up to apply meteorological data representing the 2015 calendar year to disperse the emissions and calculate the resulting annual average concentration of NOx, f-$NO_2$ and PM2.5 derived from the modelled road network.

Concentrations of the different pollutants were calculated at different receptor points representing locations such as those required to report on the Air Quality Directive, locations relevant to Local Air Quality Management considerations and locations representative of distributional exposure assessment. Modelled concentrations representing $NO_2$ monitoring locations in 2015 were also calculated and used to in the model verification process.

The modelled road NOx correction factors were subsequently used to adjust the future base year and CAZ scenario dispersion results.

## 2.4 $NO_2$ Concentration Calculations

Background pollution concentrations across the Leeds area were based on Defra's published 2015-based 1km x 1km grid values. The published values also report the contribution from different sectors such as motorways, main and minor roads, industry and domestic heating from inside and outside each 1km x1km grid.

The road network modelled within the LTM /Airviro was reviewed to identify the appropriate road sector(s) contributions represented within each 1km x 1km grid and removed the appropriate contribution from the total background values in each grid square. This process avoided double counting of those vehicle emissions from roads which are included in the dispersion model.

The adjusted concentrations of modelled road NOx and f-$NO_2$ calculated within Airviro and the adjusted projected 1km x 1km background concentrations were then entered in to the approved Defra NOx to $NO_2$ conversion toolkit to calculate the annual average $NO_2$ concentration at each receptor point.

The resulting total $NO_2$ values calculated for the 2015 base year were subsequently used in the verification exercise to assess the overall performance of the modelling exercise with a secondary minor adjustment factor applied to create a final adjusted total $NO_2$ figure.

## 2.5 $PM_{2.5}$ Concentration values

Only two monitoring locations in Leeds measure of particulate matter with a diameter of less than 2.5micrometer ($PM_{2.5}$). Consequently the modelled concentrations were adjusted using the same verification factors derived from the Road NOx verification process.

The Defra published 1km x 1km background data was adjusted using the same sector removal process used for the $NO_2$ concentration calculation.

Unlike $NO_2$, the concentrations of $PM_{2.5}$ are not as readily affected by atmospheric chemistry and so the final modelled concentrations of $PM_{2.5}$ was simply derived by adding the adjusted modelled road concentration to the adjusted Background concentrations.

# 3 Relevant Guidance, Tools and Data

## 3.1 Guidance and Tools

This section provides an outline of the various data sets compiled and used to facilitate 2015 base year air quality modelling and the subsequent verification exercise. A full, more detailed verification report is provided separately.

The Air Quality modelling exercise has been completed with reference to Defra's LAQM.TG16 document, specifically:

- Section 4: Dispersion Modelling of Emissions
- Box 7.14: Initial Comparison of Modelled and Monitored Total $NO_2$ Concentrations
- Box 7.15: Comparison of Road-NOx Contributions Followed by Adjustment
- Box 7.16: Importance of an Approach to Verifying Modelled $NO_2$ Concentrations from Road Traffic
- Box 7.17: Methods and Formulae for Description of Model Uncertainty

Defra's LAQM tools[1] were utilised throughout the verification process, comprising:

- Emissions Factors Toolkit v8.0.1
- 2015-based Background Pollutant Maps
- $NO_2$ Adjustment for NOx Sector Removal Tool v6.1.
- NOx to $NO_2$ Calculator v6.1.

## 3.2 LCC Air Quality Monitoring Data

For the verification and adjustment of $NO_X$ / $NO_2$, a combination of continuous monitoring and diffusion tubes is recommended. Given the extent of the Leeds city area and the modelled road network, it is important to have multiple sites throughout the network to verify modelled results against.

The verification process undertaken for the first round used monitoring from 72 locations including 10 continuous real-time analysers at varying distances from the nearest road source(s). Each automatic site is operated by LCC on behalf Defra. Following a review of the monitoring data and first round verification process 31 sites were removed from the verification process for the second round due to;

- Low Data Capture
- Duplication of sites (co-located diffusion tubes on continuous analysers)
- Non-representative locations such as diffusion tubes sited on facades or at traffic lights

### 3.2.1 Base Year Traffic Data

Traffic data for the 2015 base year were provided for each road link using Leeds City Council's SATURN based Traffic Model (LTM). The modelled traffic flows were factored to represent four different time periods;

- AM Peak 0700 – 1000Hrs
- Inter-Peak 1000 – 1600Hrs
- PM Peak 1600 – 1900Hrs
- Off-Peak 1900 – 0700Hrs

The LTM provides the average speed, by direction, for each time period modelled and the actual length of each link modelled. The outputs provided the vehicle flow data split into four different user classes,

[1] LAQM tools provided by Defra and DfT Joint Air Quality Unit (JAQU) to LCC specifically in relation to CAZ studies

comprising of cars, LGVs (vehicles under 3.5t), HGVs (vehicles over 3.5t) and scheduled Public Service Vehicles (buses/coaches).

Unlike the other vehicle classes in modelled in the LTM, the scheduled bus routes are fixed and not allowed to change route depending on the modelled traffic conditions or other constraints. Non-scheduled bus and coaches journeys are not modelled as a separate user class and are included within the HGV flows. The LTM is also unable to model Taxi and Private Hire (T&PH) as a separate user class and are included within the modelled car flows. The traffic modelling data supplied to enable the emission and air quality modelling to be undertaken was completed in accordance with the Defra and DfT Joint Air Quality Unit (JAQU) criteria[2] and supported by LCC's '*Local Model Validation Report: Highway Assignment Transport Model Car, LGV and HGV' (2017).*

The results of ANPR surveys completed in spring 2016 on a number of roads around the central urban area of Leeds were collated and aggregated to generate a vehicle fleet breakdown more representative to the Leeds urban area. This enabled total vehicle journeys on all links to be proportioned according to characteristics such as:

- Vehicle size and class distributions
- Fuel splits (e.g. petrol, diesel, LPG, hybrid, electric)
- Estimated Euro emission standard based on year of manufacture
- Rigid and articulated HGV split

Table 1 summarises the age profile of each vehicle class captured by the Leeds ANPR survey and used to inform the localised fleet Euro standard profile.

*Table 1 Age Profile of Vehicle Fleet Captured by the ANPR Survey for Leeds April & June 2016*

| Age | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | >20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | 2016 | 2015 | 2014 | 2013 | 2012 | 2011 | 2010 | 2009 | 2008 | 2007 | 2006 | 2005 | 2004 | 2003 | 2002 | 2001 | 2000 | 1999 | 1998 | 1997 | 1996 | <1996 |
| Bus | 6% | 6% | 6% | 4% | 11% | 8% | 3% | 9% | 9% | 5% | 6% | 3% | 4% | 3% | 4% | 3% | 3% | 2% | 1% | 0% | 1% | 2% |
| Car | 11% | 11% | 9% | 8% | 7% | 6% | 6% | 6% | 6% | 6% | 5% | 5% | 4% | 3% | 3% | 2% | 1% | 0% | 0% | 0% | 0% | 0% |
| HGV | 13% | 13% | 9% | 14% | 10% | 7% | 5% | 4% | 5% | 5% | 4% | 4% | 2% | 2% | 1% | 1% | 0% | 0% | 0% | 0% | 0% | 0% |
| LGV | 14% | 14% | 12% | 9% | 7% | 7% | 5% | 3% | 5% | 5% | 4% | 3% | 3% | 2% | 1% | 1% | 1% | 0% | 0% | 0% | 0% | 0% |
| PTW | 9% | 9% | 6% | 6% | 5% | 6% | 4% | 4% | 5% | 5% | 5% | 5% | 4% | 3% | 5% | 3% | 2% | 2% | 2% | 2% | 1% | 8% |
| Taxi | 2% | 2% | 1% | 3% | 4% | 9% | 11% | 14% | 19% | 18% | 5% | 6% | 2% | 2% | 0% | 0% | 0% | 1% | 0% | 0% | 1% | 1% |

Motorcycles and mopeds, also known as Powered Two Wheelers (PTW) are not represented in the modelled traffic flows and have not been included in the emission modelling process. However, the proportion of PTWs within the overall fleet is very small and unlikely to have any noticeable impact on modelled results at this initial scale of modelling.

### 3.2.2 Future Base year traffic Data

The LTM was set up to calculate the expected traffic flow data (volume and average link speed) for 2020 and 2022 taking in to account expected changes resulting from traffic management and policy changes, such as completed Park and Ride schemes and highway and junction improvement schemes. Expected Traffic growth used in the modelling was been generated using Tempro software and the National Trip End Model (NTEM) v7.2 in line with national guidance. Expected completion dates for developments with existing planning permissions is accounted.

### 3.2.3 Future Clean Air Zone Scenario Traffic Data

Using the criteria laid out for each class of Clean Air Zone and the available data on the age and fuel profile of the different elements of the vehicle fleet, the LTM was adjusted to split the Car, LGV and HGV classes into compliant and non-compliant elements. As scheduled Public Service Vehicles are not allowed to change route within the LTM, they were not split in to compliant and non-compliant trips.

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[2] Joint Air Quality Unit (22/12/2016) Specification for Clean Air Zone feasibility modelling studies

The JAQU behavioural change assumptions (August 2017) were used to alter the number of vehicle class trips which would change from non-compliant to compliant depending on the scenario and the location of the boundary being modelled. To be consistent with the Transport model, the vehicle kilometres replaced figures were used. The LTM was then allowed to decide if trips paid or avoided the zone and assign different elements of each vehicle class to different routes depending on the modelled journey time and financial impact of the charge levied on certain vehicle types when crossing the Clean Air Zone boundary. The traffic model does not allow trips to be cancelled which may have resulted in slightly conservative impacts of the scenarios modelled.

The first round of modelling the LTM was set up to run Class B, C and D CAZ scenarios. Table 2 below indicates which vehicles are affected by each class of CAZ modelled. The term "Taxis" in this instance has been used to include both Hackney Carriage and Private Hire vehicles. One area of uncertainty for all scenarios was the inability to model T&PH journeys separately within the LTM and how to assess their impact within the air quality model.

*Table 2 Clean Air Zone Classifications*

| CAZ class | Vehicles Included to meet Euro 6 Diesel or Euro 4 Petrol standard |
|---|---|
| A | Buses, coaches and taxis |
| B | Buses, coaches, taxis and heavy goods vehicles (HGVs) |
| C | Buses, coaches, taxis, HGVs and Light Goods Vehicles (LGVs) |
| D | Buses, coaches, taxis, HGVs, LGVs and cars (option to include motorbikes and mopeds) |

For the Second Round of modelling, a review of historic classified traffic counts across the city in conjunction with analysis of the ANPR data matched to registered T&PH vehicles in Leeds allowed some broad assumptions to be made in order to better assess the full impact of any interventions applying to T&PH. Future year scenarios assume an increase in the overall number of T&PHs based on historic trends.

## 3.3 Vehicle Emission Inventories

Vehicle emissions inventories were compiled for all the modelled road links within the LCC area, using Defra's emissions factors toolkit (EFT v 8.0.1) which incorporates the most up to date average speed emission coefficient equations taken from the European Environment Agency (EEA) COPERT 5 emission calculation tool[3].

Traffic inputs were compiled separately for '*motorway*' and '*non-motorway*' road link representing each AM, peak, PM peak, Inter-peak and Off-peak time period modelled in the LTMs.

### 3.3.1 2015 Base Year Traffic data

The LTM was validated against 2015 traffic counts and relevant validation reports are provided separately for the Traffic modelling. The car flows for the non-motorway roads were adjusted with an appropriate percentage of cars removed from each link to and modelled separately to represent T&PH movements and labelled as "taxis" within the modelling. It was assumed that the impact of T&PHs on Motorways would be insignificant compared the overall traffic volume.

[3] http://emisia.com/products/copert/copert-5

The level of detail available from local data collected by ANPR and classified traffic counts in Leeds allowed the traffic flows modelled within the LTM for the non-motorway links to be further split in to more detailed vehicle class sub-types. The data was therefore input using the EFT format for 'Detailed Option 3 + Alternative Technologies' which includes the proportion of different fuel types and engine technologies for different vehicle classes. Leeds-specific Euro standard proportions by vehicle type and size distributions were utilised within the EFT via the 'UserEuro' tab to create specific emission profiles for each element of the vehicle fleet.

Equivalent ANPR surveys were not available for motorway links, thus the traffic data relevant to these links were entered into the EFT in a format for '*Detailed Option 2*'. This results in the national defaults being applied on all motorway links with respect to the proportion of car fuel splits and vehicle sub-type and size distributions.

All EFT calculations were run for the year 2015, with the area selected as '*England (not London)*' and all road types set to '*Urban (not London)*' for the non-motorway links and '*Motorway (not London)*' for all motorway links with the exception of the sections of the Inner ring road classed as motorway and the M621 as it is expected that the speeds and vehicle fleet make up on these roads are nearer to the urban roads than the National Motorway network.

### 3.3.2 2020 and 2022 Base Year (Do Nothing) Vehicle Emission Inventories

The emissions were generally calculated for the 2020 and 2022 base years as described in section 3.3.1 using the modelled traffic flows from the LTM. However the input data for the motorway and non-motorway road types were further split up to represent the '*Compliant*' and '*Non-compliant'* elements of each vehicle class

The Motorway links were run in exactly the same way as the 2015 base year with the exception of the relevant year being set to either 2020 or 2022. For the Non-motorway links the traffic flows were entered as "*Detailed Option 3*" which requires the proportion of the petrol and diesel cars to be entered, but otherwise relies on the UK default to predict the proportion of alternative technology vehicles included within the fleet by 2020 and 2022.

The fuel split for Cars was projected forwards following guidance from JAQU using statistical methods to growth the proportion of journeys expected in 2020 and 2022. The process involved calculating the ratio of total trips made by each fuel type to the number of unique vehicles of each fuel type as captured by the local ANPR survey. This data was then projected forwards based on the change expected in the ratio of petrol and diesel cars sold across the UK between 2015, 2020 and 2022. Because T&PHs are being modelled separately, known T&PHs were separated from the ANPR data used in the fuel projection calculations.

The proportion of sub-types and weight classes within each vehicle user class have been assumed to remain constant between the 2015 base year and the future year scenarios. The future age profile of the vehicle fleet was projected using simple polynomial fits to the existing observed age profile collected via the ANPR surveys; plus an estimated constant residual number of vehicles over 20 years. Figure 1 illustrates the equations which were used to project the changing fleet profiles.

The Bus fleet for future year scenarios were based on projections supplied by the West Yorkshire Combined Authority (WYCA).

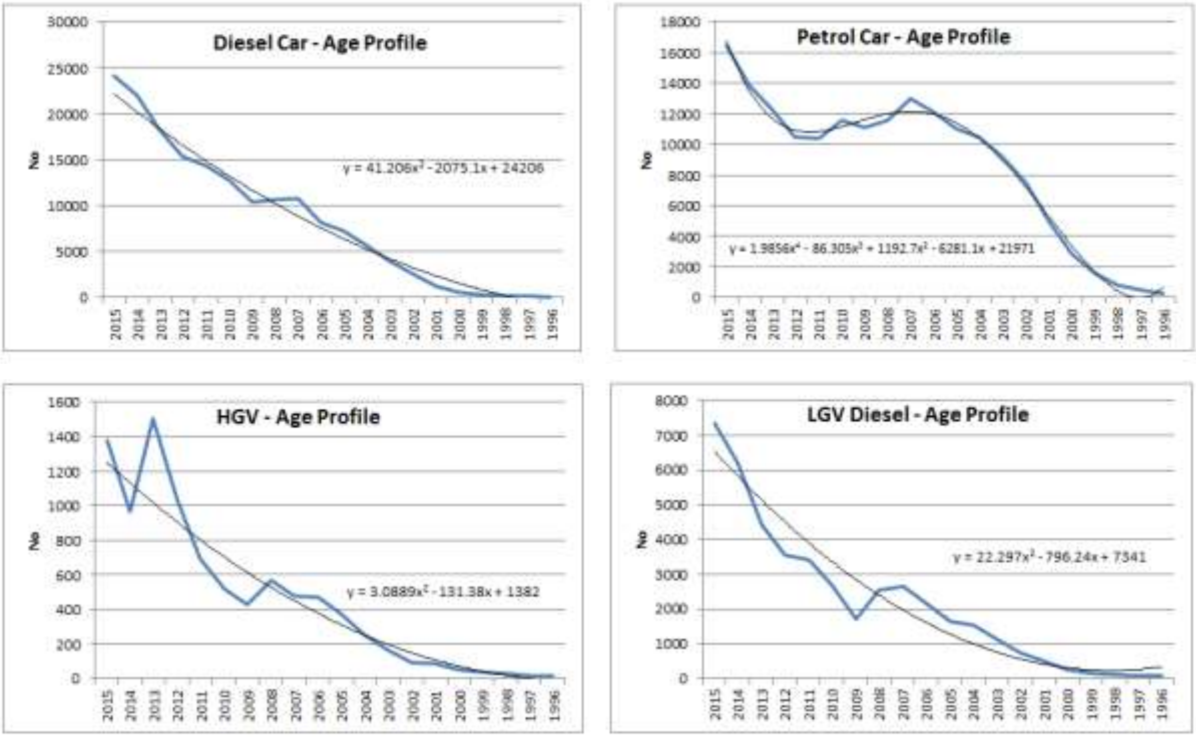


*Figure 1: Change in vehicle fleet profiles*

The projected fleet age profile data was converted in to percentages of each euro standard expected in future base years in the local fleet. This data was used to populate the EFT "*UserEuro*" tab for the non-motorway road links to ensure the best estimate of the changes to the local fleet profile are represented when calculating the emissions. There was insufficient data available to make any meaningful assessment of the petrol LGVs and UK default data was used to represent this user class.

Table 3 and Table 4 below give a high level summary of the 2020 and 2022 base year fleet projections indicating the of the expected level of compliance with a relevant CAZ for each vehicle class. To be consistent with the way the LTM and the EFT work, the tables are based on number of total journeys by vehicle type euro standard rather than the number of individual vehicles.

*Table 3 Projected Leeds Journey Profile for 2020 Base*

| Euro Std | Bus | Car (Diesel) | Car (Petrol) | LGV (Diesel) | LGV Petrol | HGV Rigid | HGV Artic |
|---|---|---|---|---|---|---|---|
| Euro 0 | 0% | 1% | 0% | 0% | 0% | 0% | 0% |
| Euro 1 / I | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| Euro 2 / II | 0% | 0% | 0% | 1% | 1% | 0% | 0% |
| Euro 3 / III | 0% | 1% | 5% | 3% | 4% | 3% | 1% |
| euro 4 / IV | 10% | 14% | 27% | 16% | 12% | 7% | 2% |
| Euro 5 / V | | 31% | 29% | 20% | 26% | | |
| Euro V EFG | 11% | | | | | 7% | 5% |
| Euro V SCR | 33% | | | | | 21% | 14% |
| Euro 6 / VI | 46% | 14% | 10% | 15% | 20% | 62% | 79% |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Euro 6c | | 29% | 29% | 45% | 38% | | |
| euro 6d | | 10% | | | | | |

*Table 4 Projected Leeds Journey Profile for 2022 Base*

| Euro Std | Bus | Car (Diesel) | Car (Petrol) | LGV (Diesel) | LGV Petrol | HGV Rigid | HGV Artic |
|---|---|---|---|---|---|---|---|
| Euro 0 | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| Euro 1 / I | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| Euro 2 / II | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| Euro 3 / III | 6% | 0% | 1% | 0% | 2% | 1% | 1% |
| euro 4 / IV | 7% | 10% | 18% | 11% | 5% | 5% | 0% |
| Euro 5 / V | | 24% | 30% | 22% | 17% | | |
| Euro V EFG | 7% | | | | | 5% | 2% |
| Euro V SCR | 21% | | | | | 15% | 7% |
| Euro 6 / VI | 59% | 13% | 8% | 11% | 13% | 74% | 90% |
| Euro 6c | | 25% | 43% | 25% | 63% | | |
| euro 6d | | 28% | | 31% | | | |

### 3.3.3 Future Year Emission Inventories for Clean Air Zone Scenarios

The LTM modelled the expected response of the different elements of the vehicle classes depending on how the charge is applied and the location of the CAZ boundary. Regardless of the scenario being modelled, the user classes within the LTM ware split in to the CAZ “compliant” and “non-compliant” elements so that each link in the model reflected the estimated proportion of vehicle mixes depending on which CAZ scenario was being modelled. Similarly, regardless of whether the vehicle class was included in the CAZ scenario being modelled, each Car, LGV and HGV sub-type was entered in to the EFT as ‘CAZ Compliant’ and ‘CAZ non-compliant’ flows.

Appropriate settings within the UserEuro worktab were adjusted to represent the expected effect on the different vehicle user class depending on the assumptions made relevant to the scenario being modelled. The total volume of compliant and non-compliant vehicles on each road link modelled is provided through the output of the LTM and varies between each scenario modelled. The variations of sub-groups and the fuel types are provided through the relevant adjustment the flows in the UserEuro work tab.

Table 5 gives examples of how the Euro Standards proportions the Car fleet and is projected onto the 2020 Do-Minimum and re-proportioned in to a CAZ compliant and non-compliant elements for use within the EFT calculations.

*Table 5 Example of Engine Euro Standards for the Base Fleet and the Re-proportioning in to their Separate Complaint and Non-compliant Elements*

| Petrol Cars | Projection For Do-Minimum | Adjsted Projection normalised to Non-Compliant Vehicles only | Adjsted Projection normalised to Compliant Vehicles only | | Projected Car Fleet For a Class D CAZ | Adjsted Projection normalised to Non-Compliant Vehicles only | Adjsted Projection normalised to Compliant Vehicles only |
|---|---|---|---|---|---|---|---|
| 1Pre-Euro 1 | 0.2% | 2.8% | 0% | | 0.0% | 2.8% | 0% |
| 2Euro 1 | 0.2% | 2.0% | 0% | | 0.0% | 2.0% | 0% |
| 3Euro 2 | 0.7% | 8.4% | 0% | | 0.1% | 8.4% | 0% |
| 4Euro 3 | 6.9% | 86.9% | 0% | | 1.0% | 86.9% | 0% |
| 5Euro 4 | 27.6% | 0% | 30.0% | | 31.5% | 0% | 31.9% |
| 6Euro 5 | 27.2% | 0% | 29.5% | | 30.8% | 0% | 31.1% |
| 7Euro 6 | 9.1% | 0% | 9.9% | | 7.6% | 0% | 7.6% |
| 7Euro 6c | 28.2% | 0% | 30.6% | | 29.0% | 0% | 29.3% |

| Diesel Cars | Projection For Do-Minimum | Adjsted Projection normalised to Non-Compliant Vehicles only | Adjsted Projection normalised to Compliant Vehicles only | | Projected Car Fleet For a Class D CAZ | Adjsted Projection normalised to Non-Compliant Vehicles only | Adjsted Projection normalised to Compliant Vehicles only |
|---|---|---|---|---|---|---|---|
| 1Pre-Euro 1 | 0.0% | 0.1% | 0% | | 0.01% | 0.1% | 0% |
| 2Euro 1 | 0.0% | 0.1% | 0% | | 0.01% | 0.1% | 0% |
| 3Euro 2 | 0.0% | 0.0% | 0% | | 0.00% | 0.0% | 0% |
| 4Euro 3 | 1.1% | 2.5% | 0% | | 0.28% | 2.5% | 0% |
| 5Euro 4 | 16.8% | 37.2% | 0% | | 4.28% | 37.2% | 0% |
| 6Euro 5 | 27.2% | 60.1% | 0% | | 6.93% | 60.1% | 0% |
| 7Euro 6 | 14.9% | 0% | 27.3% | | 29.2% | 0.0% | 33.0% |
| 7Euro 6c | 29.8% | 0% | 54.5% | | 42.4% | 0.0% | 48.0% |
| 7Euro 6d | 9.9% | 0% | 18.2% | | 16.8% | 0.0% | 19.0% |

NB vehicles identified as T&PHs were removed from the car fleet prior to it being projected to 2020

All PSVs (scheduled bus and coach services) were assumed to switch to 100% compliant for every CAZ scenario modelled. Non-scheduled coach and bus journeys are included within the HGV fleet and so their behavioural response has been treated in the same way which is a lower response rate than the figures included in the national guidance.

The number of HGV and LGVs which upgraded to become compliant followed the behavioural change guidance issued by JAQU except that it has been assumed that no journeys are cancelled. The proportion of non-compliant vehicles remaining in the fleet has been assumed to retain the same proportion of euro standards as the base year fleet projections.

Cars were more complex to consider with the expectation that significant numbers would choose to change fuel as part of the upgrading process. Figure 2 provides a visual guide of the calculation process followed to estimate the changes in fuel types expected for the non-compliant cars which would choose to upgrade to a compliant vehicle with a CAZ D scenario. When modelling the standard Class B CAZ, This process was used to determine how the Hackney Carriage and Private Hire trade would choose to upgrade their fleet also.

T&PH are a vehicle type which is included within every Class of CAZ. However, they are not recognised as a separate vehicle type within the LTM. Similarly, the ANPR data returned from the Department for Transport (DfT) only identifies those vehicles which are purpose built for the role as “taxis”. There were only 11 London Taxi Cabs registered in Leeds in 2015 with the vast majority of Hackney Carriages and Private Hire Vehicles only recognised as Cars or Minibuses within the ANPR data.

In the first round of modelling it was assumed that with a Class D CAZ, T&PHs would be included within the general mix of cars and were deemed to have upgraded to become compliant as part of that user class. For the other CAZ scenarios the impact of compliant taxis was not fully reflected in the modelling due to the complexity of assessing what proportion of car trips are made by T&PH vehicles on any given f road link.

For the second round of modelling, the ANPR data has been cross matched against T&PH vehicles registered with Leeds City Council during the same period the counts were taken. This information was used to create different emission profiles for the general car fleet and a Leeds T&PH fleet, with a different base year and projected proportions of fuel, body weight and engine sizes.

A combination of the ANPR data and historic classified junction counts indicate that taxis accounted for anything up to 18% of all car related journeys within the central urban area depending on the individual road. Depending the road type and location different percentages of the LTM car flows were subtracted and assumed to be T&PH.

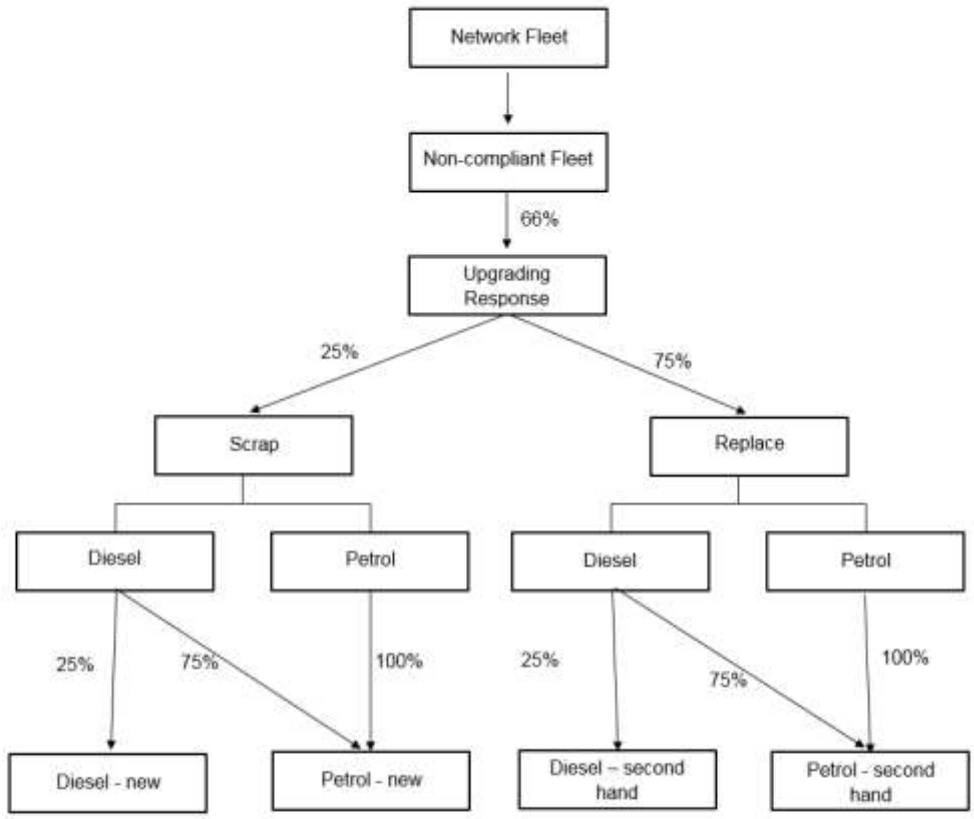


*Figure 2 Route to Compliance for Cars with a CAZ D scenario*

The Process above resulted in the total percentage of trips made by diesel vehicle son the Non-Motorway roads in Leeds reducing from 51% to 34% for non- T&PH based trips. For T&PHs, the proportion of Diesel based trips reduced from 87.7% to 50 %.

## 3.4 Atmospheric Dispersion Modelling

LCC uses version 4 of the dispersion model developed by the Swedish Meteorological and Hydrological Institute (SMHI) known as Airviro to simulate vehicle emissions. The Airviro system includes different modules which are combined to predict the pollution concentrations within a modelled domain and a specified time period;

- The Emission Database (EDB) Module accepts pollutant emission data with temporal and spatial variation to inform where and when the emission are released.
- The Dispersion Module is set up with basic terrain land height and surface roughness information based on land use to form a topographical base map of the area being modelled.

The methodology adopted by LCC to model vehicle emissions within Airviro adhered to the modelling criteria agreed with the Joint Air Quality Unit (JAQU)[4]. Emissions from all major road sources within the Leeds district boundary, including the pollution climate mapping (PCM) road links as defined by Defra[5] are included.

### 3.4.1 Input Data

The SATURN based LTM traffic model network is represented visually by a simplified "Stick Diagram" with each link intersection given a node reference number. Each link is identified by a unique reference system based on combining its "A node" and "B node" based on its direction of travel. For example a 2-way road can be identified as "A_B" in one direction and "B_A" in the other direction. The road network modelled within the LTM was separately linked to the Intelligent Transport Network (ITN) road centre line data through a geo-referencing process to create a Shapefile with each road link spatially matched to create a real-world representation. Each link was labelled with the unique "A_B" reference Identification code and where applicable, the relevant "B_A" reference.

The vehicle emissions which were calculated within the EFT (see Section 3.3) for each element of the traffic fleet were collated to create an input file which included a single annual average emission rate for each of the four modelled time periods on each modelled road link. This data was subsequently linked to the geo-referenced road network file using the unique "A_B" link reference. This process created an input shapefile for Airviro which combined the spatially correct location of the modelled road links with the corresponding emission rates for each modelled time period. Figure 3 shows an example of the road network input data depicting the variation in the modelled annual emission rates.

The emissions networks created for each scenario were input in to the Airviro EDB module using a bespoke script which proportions the total emission rates calculated over the four time periods in to the corresponding individual hours of the day. Because the emissions were calculated as time period flow averaged over 7 days, the script allowed the emission rates to be further proportioned within the Airviro EDB dependent on the ratio of the traffic flow characteristics experienced between weekdays, Saturdays and Sundays to the seven day average. This process allows a more representative variation of emissions to be modelled for each time period and each day type within the respective EDBs. A typical example of how the final emission rates vary between different time periods and different day types is shown in Figure 4

### 3.4.2 Gaussian Dispersion Model

The Gaussian model simulates hourly mean concentration values as it is known that the wind conditions can be more or less constant during such a period and that daily averages are not sufficiently detailed. In order to reduce modelling time, the plume lengths in the Airviro Gauss model are estimated based on wind speed and the travel time for the actual stability conditions present in the hour being modelled. For example, it would add no value to the final results to model an emission plume over a 6 hour period with a 2km/hr wind speeds if the model domain is only 10 km across. All the separate hourly calculated plumes are superimposed which provides a result similar (but not identical) to what might be expected with a gridded eulerian model.

Data on surface features like buildings, crops and woodland are entered into the model through local surface roughness indices which in turn influence the localised wind fields which are used within the dispersion model.

The Airviro Gaussian model is not a Fluid Dynamics Model and is therefore not able to resolve individual buildings. This means that it is not possible reflect the "true" wind conditions at street level which will be particularly influenced by the 'blocking' and 'flushing' effects of buildings in densely built-up areas such as

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[4] Defra PCM data referred to in this document is based on '*2017* $NO_2$ *projections data (2015 reference year)*', obtained from https://uk-air.defra.gov.uk/library/NO2ten/2017-NO2-projections-from-2015-data, accessed October 2017

the city centre. The Airviro concept to solve this problem is to interpret the calculated fields as located to roof top level.

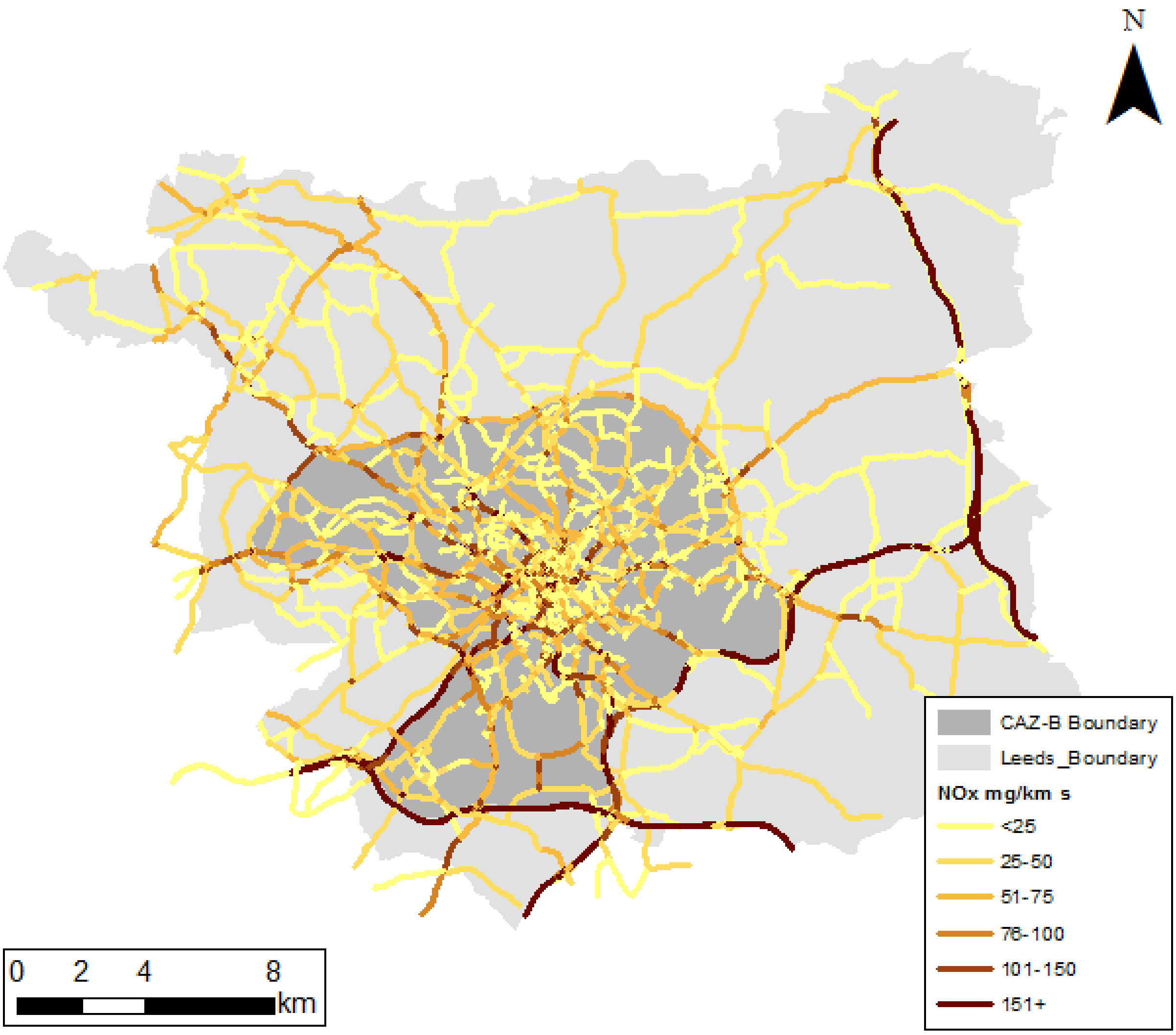



*Figure 3 Modelled Annual Emissions from the SATURN Network for 2015 Matched to Geo-Referenced Road Centre Line Data*

## Time Variation >> Day type

### Day type variation

| | Mon-Thu | Fri | Sat | Sun |
|---|---|---|---|---|
| 00 - 01 | 8.40964 | 8.40964 | 6.21253 | 5.15185 |
| 01 - 02 | 8.40964 | 8.40964 | 6.21253 | 5.15185 |
| 02 - 03 | 8.40964 | 8.40964 | 6.21253 | 5.15185 |
| 03 - 04 | 8.40964 | 8.40964 | 6.21253 | 5.15185 |
| 04 - 05 | 8.40964 | 8.40964 | 6.21253 | 5.15185 |
| 05 - 06 | 8.40964 | 8.40964 | 6.21253 | 5.15185 |
| 06 - 07 | 8.40964 | 8.40964 | 6.21253 | 5.15185 |
| 07 - 08 | 35.586 | 35.586 | 26.2888 | 21.8004 |
| 08 - 09 | 35.586 | 35.586 | 26.2888 | 21.8004 |
| 09 - 10 | 35.586 | 35.586 | 26.2888 | 21.8004 |
| 10 - 11 | 31.1661 | 31.1661 | 23.0236 | 19.0928 |
| 11 - 12 | 31.1661 | 31.1661 | 23.0236 | 19.0928 |
| 12 - 13 | 31.1661 | 31.1661 | 23.0236 | 19.0928 |
| 13 - 14 | 31.1661 | 31.1661 | 23.0236 | 19.0928 |
| 14 - 15 | 31.1661 | 31.1661 | 23.0236 | 19.0928 |
| 15 - 16 | 31.1661 | 31.1661 | 23.0236 | 19.0928 |
| 16 - 17 | 35.051 | 35.051 | 25.8935 | 21.4727 |
| 17 - 18 | 35.051 | 35.051 | 25.8935 | 21.4727 |
| 18 - 19 | 35.051 | 35.051 | 25.8935 | 21.4727 |
| 19 - 20 | 8.40964 | 8.40964 | 6.21253 | 5.15185 |
| 20 - 21 | 8.40964 | 8.40964 | 6.21253 | 5.15185 |
| 21 - 22 | 8.40964 | 8.40964 | 6.21253 | 5.15185 |
| 22 - 23 | 8.40964 | 8.40964 | 6.21253 | 5.15185 |
| 23 - 24 | 8.40964 | 8.40964 | 6.21253 | 5.15185 |

*Figure 4 Typical Example of Emission Rate Variation Between Hours of the Day and Different Day Types.*

As buildings create a much rougher surface, this higher friction results in lower wind speeds in built up areas than farmland for example, which in turn creates a lower rate of dispersion. Over a city centre area, where the land use data includes information on building heights which are predominately above 10m in height, the wind model effectively uses this average roof height as a proxy ground height with an increased surface roughness characteristics to generate the localised wind fields as part of the dispersion process. The approach is similar to the use of zero displacement height, applied in many other models.

The default height for receptor concentration calculations in the Airviro Gaussian dispersion model is 2m above ground level and this setting has been used during this modelling process. The adjustments factors calculated through the model verification and calibration process has also been undertaken by comparing modelled concentrations against those measured at between 1.5 and 2.5m from ground level.

As part of the calibration process, the city centre area, where the dispersion model is most influenced by the complex building height and surface roughness conditions, is treated as a separate verification zone. This ensures that the adjustment factors used to adjust the modelled road NOx and final adjusted $NO_2$ concentrations within this zone specifically account for the added complexity within this zone.

Given the significant impact of large buildings on the local wind flow and resulting emission dispersion at ground level, it is our belief that the approach used by the Airviro model is the best approach possible as can be reasonably expected in the absence of using fluid dynamics modelling.

### 3.4.3 Airviro Wind Model

Usually, Gaussian plume models are applied to horizontally homogeneous wind fields. However the Airviro Gaussian model uses its own wind field model which allows it to “feel” the topography and create its own realistic localised wind field within the area being modelled. This means that the effect of local topography, surface roughness distribution and horizontal variations in surface heating/cooling is used within the dispersion calculations.

The Airviro system uses the Danard Wind Model to generate localised wind fields as part of the Gauss dispersion modelling process. The wind model is a diagnostic, time dependent dynamical model based on a concept where mesoscale winds are generated by using:

- Horizontal momentum equation
- Pressure tendency equation
- First thermodynamical equation

The concept assumes that small-scale winds can be seen as a local adoption of the larger scale (free) winds recorded within the same model domain. Within the dispersion process, each hourly time step is initialised with the monitored wind speed, wind direction and vertical temperature difference (for stability considerations). The monitored data are expanded up to free wind level, and then calculated down for each grid square within the modelled domain using the local topography and surface roughness. In this way a nonhomogeneous surface wind field influenced by the topography and surface roughness is generated from a single input. Full information on how the Danard Wind Model works is included in Appendix 1.

The wind field generated has one unique resolution regardless of the size or scale of the dispersion area, which depends upon the input of topographic and physiographic information. First round modelling generated a wind field using topography and land use data based on a 500m x 500m grid. The updated physiographic information used in the second round modelling generates a local wind field with a 100 x 100m grid. The updated topography data allows the wind field generated within the dispersion calculation to better reflect the impact of funnelling effects of valleys and greater resolution of the land use and building heights on the surface roughness effects. An example of how the Wind Flows can be affected within the modelled domain is included in Appendix 7 which also includes information on the Topography and surface roughness factors used within the wind field generation process.

### 3.4.4 Meteorological Data used in the Dispersion Modelling Process

When the Airviro system was first installed in Leeds, a local meteorological station able to provide input data in to the dispersion model was also set up and its location identified within dispersion module. The dispersion module uses the data collected from this local meteorological station as its primary ‘free wind’ input when running dispersion models.

Unfortunately, the data collected by this local station in 2015 was not considered robust enough for the purpose. However, the Swedish Meteorological and Hydrological Institute (SMHI), who developed the Airviro model were able to provide a solution which generated appropriate, localised weather input data applicable to the Leeds urban area using hourly sequential meteorological data obtained from the Leeds-Bradford Airport for year 2015.

SMHI, used their own weather prediction models to project the appropriate weather data to the location of the Leeds City Council meteorological mast. The projected data was then loaded in to Airviro' time series database so that the dispersion module could interoperate this data in the same way it treats data collected at the mast itself. SMHI confirmed that although not ideal, the data obtained and projected in this way is justifiable and sufficiently robust to be used due to the reasons outlined in section 3.4.2 above. Appendix 7 includes a comparison of the wind direction that was measured locally and the projected data by SMHI.

### 3.4.5 Dispersion Model Set-up

As outlined above, the Gaussian dispersion model normally works by simulating mean hourly concentration levels using sequential hourly meteorological data and corresponding emission input data broken down in to annual average hourly emission rates for each day of the week. However, to calculate annual mean values over a large modelled area at the required resolution of 10m x 10m grids was taking approximately 3 weeks to produce a result when using the original 500m x 500m topography data. This was expected to increase to nearer 7 weeks when applied to the new 100m x 100m topography data set. This time scale was considered prohibitive within the overall timescale available.

To make it possible to simulate the long-term impacts of emissions, such as the annual average concentrations, without running through a very long time series data, Airviro includes a '*Scenario*' technique which applies a statistical approach. By extracting a sample of the joint variation of annual weather and emissions, expected mean values and extreme values of air quality can be simulated based on a much reduced number of representative hours. The basic principles of the *Scenario* function is as follows:

'Scenarios' are defined in special configuration files.  A statistical sample is generated by selecting specific dates and hours representing different weather and emission event periods which is to be generated with a figure describing the frequency of occurrence. The weather information provided in the time series database is extracted, using the dates/hours defined in the configuration file as the selection criteria, and the frequencies of the various weather classes will be used to estimate mean values and extremes (95-99 percentile).

Prior to the first round of modelling, a comparison of model outputs using both the full annual time-series meteorological data set and the "*scenario*" data was undertaken for the purpose of sensitivity testing on the 2015 base year model using the original topography data. This demonstrated that predicted road-$NO_x$ concentrations were generally around  +/-10% agreement between the two methods.  By using the '*Scenario*' option, the model run-time was reduced from approximately 15 days to around 3 days. In terms of comparing different baselines and CAZ based scenarios, this time reduction was significant in enabling analysis of the modelling results to be undertaken quickly enough to consider their impacts.

Reasons for the discrepancy are likely to be due to factors such as the specific hour chosen for use in the model for a specific direction may represent an hour in the day, or day of the week, when the emissions present were lower or higher than the average number of times that wind direction was present thought a year.  Because the resulting outputs are ultimately subjected to adjustment as part of the calibration and verification process, it was concluded that due to the time constraints the results produced via the 'scenario' method are robust enough to use for the purpose required.

### 3.4.6 Generating Statistical Samples of Weather to Create a Weather Scenario

Airviro includes a utility program called *'klmstat'* to prepare statistical samples based on long term measurements of weather. In order to achieve a climatology that reflects the local variation of weather conditions when at least one year's monitoring data of the horizontal wind vector, the air temperature and the vertical temperature gradient is available. Additional measurements of the standard deviation of the horizontal wind direction and of the vertical wind velocity, the solar radiation and the precipitation, is recommended and this data was available for Leeds.

Provided that the monitoring data described above is available in the time series database, the 'klmstat' program extracts representative samples using the following technique:

- The data is classified according to different primary wind directions. The user can decide how many classes to use. As default, it is recommended to use 60, i.e. each class representing a sector of $6^o$.
- All events falling into a specific sector are then classified according to the atmospheric stability conditions discriminated by intervals of Monin-Obukhov lengths.
- When all the data has been sorted, frequencies of all the classes are estimated and the median values of the Monin-Obukhov lengths of each class (in this case 360 classes) are identified, including the specific date and hour when each class example occurred.

The number of classes required depends on the characteristics of the area. In several countries, regulations concerning the number of classes exist. The number of classes should be chosen as a balance between the required quality of the calculation results and the computing time.

Based on advice from SMHI, Leeds has used 60 wind directions and 3 stability classes ('*Moderately Unstable', 'Neutral Positive' and 'Very stable*'). The combined representative dates/hours that have been determined have been plotted and the weighted diurnal distribution of hours extracted from the sample. The distribution of chosen hours has been assessed and found to have a reasonably uniform distribution when compared to the four time periods for which emissions have been calculated.

The scenario set-up is undertaken by setting the parameters up within a template file called Clim.rf. The utility programme 'Klimstat' is then used to create a file called 'climSH.freq' which is a data file in ASCII format which controls which dates and hours and what weighting each one is given within the relevant Scenario based dispersion calculation. The Clim.rf and the relevant extract of the climSH.freq file which represents the scenario generated to represent the full 2015 weather conditions is included in Appendix 4, including the relevant boundary layer heights and Monin-Obukhov lengths.

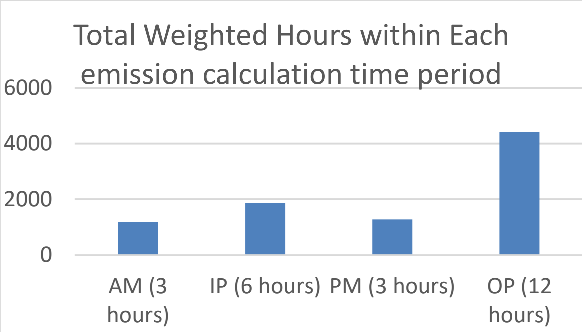
Figure 5 below compares the weighted number of hours of the day included within the statistical meteorological data set chosen to represent the full year weather conditions. On the left, the hours chosen to represent each of the representative hours are grouped in to the periods of the day for which different emission rates have been calculated. This shows the data used is a reasonable reflection of the number of hours within each time period. On the right, the weighted hours have been divided by the number of hours within each of the emission calculation periods. This shows that the hours used within the statistical data set slightly over represent the time periods with the higher emission periods and slightly under-represent the night time period when the emissions will be at their lowest.

Overall, Figure 5 confirms that the resulting outputs should demonstrate a reasonable distribution between the hours chosen to represent the full 2015 weather conditions and the corresponding emission rates that are used to calculate the annual average concentrations, compared to using the full sequential hourly dataset.

### 3.4.7 Comparison of Wind Rose data Between the Scenario and the Full 2015 data set

The date and time periods used to generate each specific scenario are specified within the *clim.rf* file. The hours selected for the scenario generated to represent 2015 can be compared against the full data set by comparing the wind roses of the two sets of data.

Figure 6 and Figure 7 compare the wind rose for the 360 hours selected and weighted in the 2015 scenario against the full 2015 data and can be seen to be very similar to each other. The scenario data is also split in to the 3 different stability classes. In the case of the 2015 scenario configuration, each of the 60 wind direction intervals has three representative hours, one for each stability class which are then weighted according to relative frequency that such situations occurred in the full years met data. Figure 8 shows the separate wind rose data for each stability class used within the scenario weather setting.



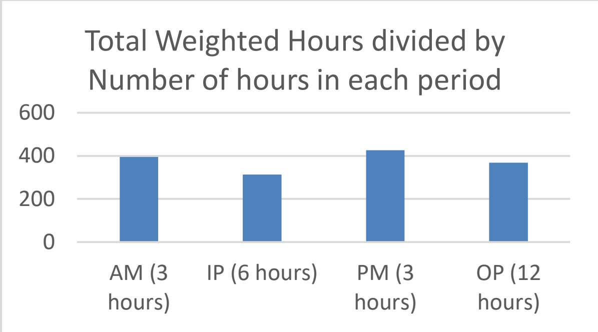
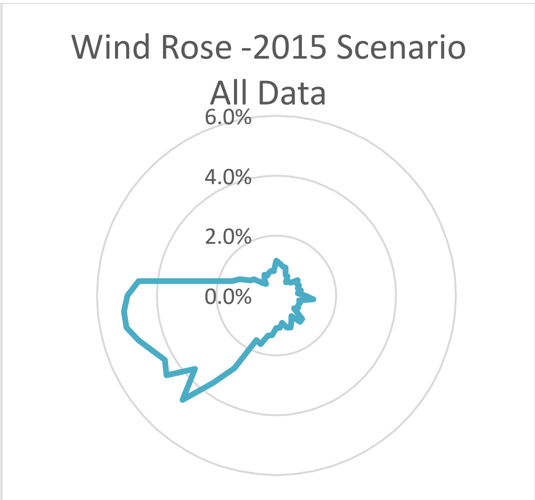




*Figure 5 Comparison of Weighted Hours Used in the 2015 Scenario to Represent the Full Year*

### 3.4.8 Dispersion Model Settings

For all base year and CAZ scenario model runs, the Gaussian dispersion model was used with a uniform 10m x 10m dispersion grid covering the entire modelled domain and the scenario weather function set to use data representing the base year of 2015. All second round model runs have used the recently acquired terrain and land use data which generates its own localised wind field with a 100m x 100m resolution. From identical EDB inputs, the modelled Road NOx concentration values using the higher resolution wind field were on average 40% higher than those results obtained using the original 500m x 500m wind field data although there were occasional exceptions with a small number of sites reducing by up to 10%.

To run the dispersion models with these settings and generate a full concentration grid across the whole model domain would take approximately 7 weeks for the 2015 base year. Due to the time restraints and the need to compare a number of different base year and scenario even options this option was considered too restrictive when needing to model 3 different pollutants for each scenario. Consequently a script was provided by SMHI which enabled concentrations to only be calculated for pre-defined receptors located by their 12 digit grid references. This option allows the concentrations of modelled road concentrations to be returned for the locations required with a reduced run time of around 4 hours per pollutant.



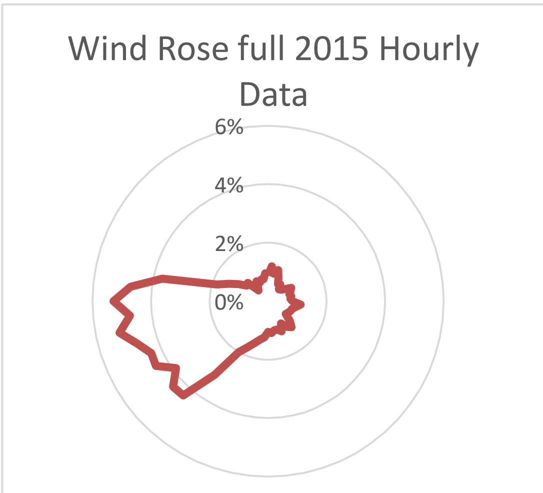




*Figure 6 Weighted Hours Wind Rose Data generated for the 2015 Scenario (Left)*

*Figure 7 Wind Rose for the Entire 8760 hours during 2015 (Right).*

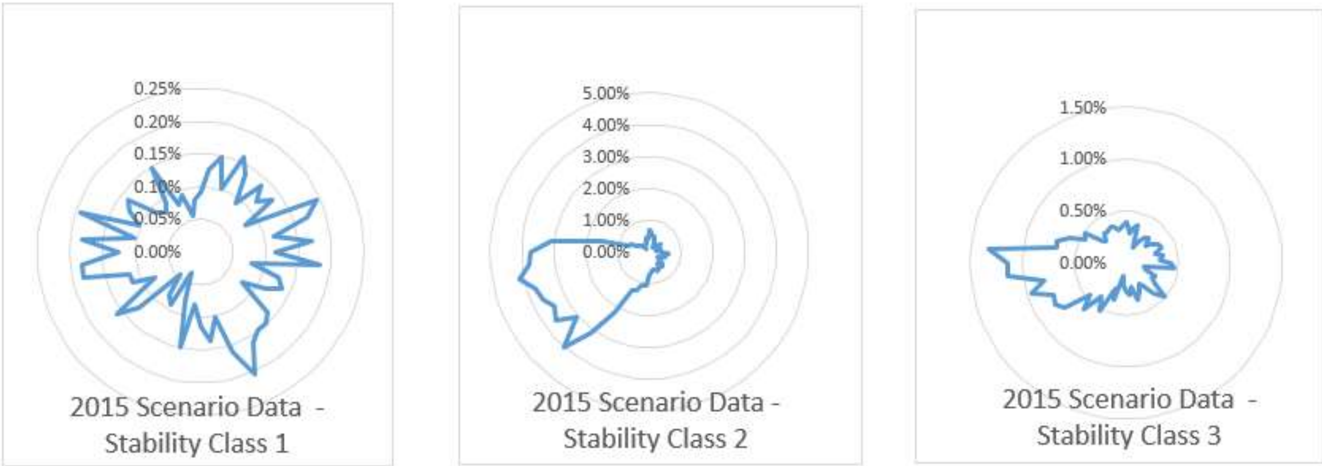



*Figure 8 Weighted hours Wind Rose Data Chosen for the Scenario Separated by Stability Class*

The model was set to provide annual mean concentrations for road NOx, f-$NO_2$ and $PM_{2.5}$ for each base year and CAZ scenario for the pre-defined receptor points which represent;

- LCC air quality monitoring locations,
- Locations which meet the criteria set by JAQU to compare against the national model and to be used for determining whether compliance with the Air Quality Directive is expected to be achieved or not.
- Locations representing areas of local air quality concern plus a notional point 4m from the kerb at Air Quality Management Areas.
- Locations representing the population weighted centroid for each Local Super Output Area (LSOA) to determine concentration distribution for use in the economic assessment for each scenario.

Although Airviro has the ability to apply post-dispersion result equations to account for NOx to $NO_2$ chemistry and validation corrections, this functionality has not been used for this modelling process. There are a number of reasons for this, but primarily the decision was taken to be consistent with the JAQU guidance and to use the suite of DEFRA approved modelling toolkits. Localised adjusted background values projected from published 2015 based values and the modelled f-$NO_2$ values were utilised within the NOx to $NO_2$ calculator for each scenario to predict the total $NO_2$ values.

The predicted concentrations of modelled road $NO_x$ and f-$NO_2$ for those receptors where air quality monitoring was undertaken in 2015 were used in the verification exercise and subsequently used to adjust the other base year and scenario outputs. It should be noted that the first round of modelling used an earlier version of the EFT and so the NOx to $NO_2$ calculations used the default area wide f-NO2 value applied to all locations.

### 3.4.9 Background Concentrations

Background concentrations of $NO_x$ $NO_2$ and $PM_{2.5}$ across the whole Leeds district were derived from Defra's 2015-based 1km x 1km grid[6]. This data set provides estimates of the annual background concentrations and indicates the expected contribution from different sectors from inside and outside each grid including different road types.

To avoid double counting of the vehicle emissions for those roads included in the emission database, the road network modelled within the LTM and Airviro was reviewed to identify and remove the appropriate road sector contributions from the background values published for each 1km x 1km grid square. These

[6] Defra background mapped values accessed via: https://uk-air.defra.gov.uk/data/laqm-background-home

adjusted 2015 NOx and $NO_2$ background concentrations were used within the verification exercise. The same process was undertaken for 2020 and 2022 background data for use with future year predications

### 3.4.10 Complex Situations

The EFT provides emission factors which are essentially relevant to the average, free flow traffic conditions, generally considered to be representative mid-way between junctions. Whilst this is compatible with the traffic speed data which is provided by the LTM, it is not representative of how traffic will in general be accelerating and decelerating and/or queuing towards either end of the road links modelled junctions.

The base year for modelling the transport and air quality is 2015 for which Leeds City Council has a relatively large amount of monitoring data available. However, many of the monitoring locations were chosen with Local Air Quality Management issues in mind and were located in places where failure of the annual objective of 40ug/m3 was considered likely when taking relevant exposure in to account. Consequently a large number of the monitoring locations which were available for model validation were placed at locations which are not ideal for validating a typical air quality dispersion model using emission factors of the nature produced by the EFT, such as;

- Within 25m of junctions
- Close to bus stops, pelican crossings
- On or close to gradients
- Close to flyovers
- Semi-canyon and/or close to continuous façades at back of footpath
- In or close to car parks
- A combination of more than one of the above

The modelling and verification approach can therefore be classed as a conservative approach when including values monitored in locations as described above.

Whilst the Airviro model does have a complex terrain and land use dataset which generates its own localised detailed wind field data ( Sections 3.4.2 and 3.4.3), canyons, gradients and flyovers have not been specifically included within the modelling exercise. The model is not capable of accounting for situations such as road sources at different heights to each other in close proximity (such as flyovers, bridges and tunnels etc.)

In view of the location of most of the monitoring data available, receptor points chosen to represent the links modelled in the national model and used for the target determination are generally located closer to junctions with other links rather than a mid-link position. This type of location may sometimes be represented by a smaller sub-link with lower speeds reflecting that some queuing is present, however the speed related emission factors are still not likely to fully represent the interrupted nature of the traffic movements where the monitoring is located. However, it does mean that these points are likely to be influenced by emissions from other nearby roads within the model

A particular issue within a modelled area is that most if not all of the locations with complex situations have a unique combination of different complexities such as gradients, structures, alignments and interrupted traffic flows. This means that modelling each location separately would be difficult to do accurately as there is no way of validating each of the separate outputs.

Within the central area of Leeds where the concentration levels are of most concern, there are very few if any locations that can be classed as examples of one of a single complex feature. The Inner Ring Road is an example where the whole stretch of road between the A65 junction (which is on a flyover) and the A64 is characterised by a continuous stretch of road which is mainly within deep vertical retaining walls within a few meters of the carriageway which widen out to accommodate slip road junctions. The road also has over bridges, long and short tunnels and emerges on to a flyover at each end.

Although public access exists within 15m of the Inner Ring Road, the stretch of the Inner Ring Road does not include authorised public access within the areas classed as canyons. To understand how and where pollution eventually disperses from area is difficult to predict and represent in modelling of this nature and so the use of separate model verification zones has been used instead.

It should a be noted that other than the Inner Ring Road, there are no locations relevant to the Air Quality Directive Target Determination which are classified as a true canyon for at least 100m and/or being classed as a ‘typical representation’ of the wider road link in question.

Across the wider Leeds district, there are also very few target determination receptors which are located on gradients which would be considered as having a noticeable impact on the emission rates and be classed as typical of the link being reported unless monitoring already exists there. In most cases, where a target determination point is located on a gradient it could equally have been located on a length of the link with no gradient present and still being classed as being “typically representative” of the wider link.

A further consideration with regards to inclusion of any gradient adjustments is that whilst there may be some under prediction of Road NOx emissions at some locations in the existing base year, this will generally be reflected to a greater of lesser extent in the model correction factors derived in the verification process.

The guidance for gradient correction provided in TG16 does not include a correction for Euro VI HDVs. This means that the corrections factors derived for the 2015 base year are likely to be more conservative when applied to the future year model outputs when there is a much higher rate of Euro VI HDVs represented in the fleet this will be especially the case when applied to the CAZ scenarios which have a far higher proportion of Euro VI HDVs within the fleet than the base years.

Because the Airviro model can only treat all roads sources as been at ground level, the expectation is that the areas immediately surrounding flyovers and over bridges will be over predicted within the model. For this reason, where monitoring data exists within such an area it has not been used in the calibration process in case it unduly influences the rest of verification zone.

Further discussion and examples of some of the complex areas are included in Appendix 7.

# 4 Dispersion Model Verification

This sections provides a technical detail of the Dispersion model verification process. Verification of the CAZ model was undertaken following guidance in Local Air Quality Management Technical Guidance (TG16) published by DEFRA in April 2016. Direction given by JAQU recommended the base year used for verification was 2015.

## 4.1 Monitored NO2

The Leeds City Council monitoring network is managed and operated by a team of officers within the Environmental Protection Team (EP Team) of the Environment and Housing Directorate. The combined expertise of this group covers all aspects of the management of the network from routine site procedures through calibration to data ratification. Appropriate training both internal and from external agencies such as EMAQ has been received by officers within the team.

### 4.1.1 Automatic Monitoring Sites

Automatic (continuous) monitoring was undertaken at 10 sites during 2015 in the Leeds City Council district. Eight of the sites were operated exclusively by the city council while one is part of the Automatic Urban and Rural Network (AURN) and the other an affiliated site owned by the city council but with results accepted into the national network. Details of the sites are included extracted from the Air Quality Annual Status Report submitted in 2016 and included in Table A.1 in Appendix 2

### 4.1.2 Non-Automatic Monitoring Sites

Leeds City Council undertook non-automatic (passive) monitoring of NO2 at 67 sites during 2015. Table A.2 in Appendix 2 is also taken form the 2016 Air Quality Annual Status Report and shows the addresses of the sites together with a very brief description of the location and a 12-figure National Grid Reference to identify the precise position.

Further details on Quality Assurance/Quality Control (QA/QC) and bias adjustment for the diffusion tubes are included in Appendix 2

### 4.1.3 Quality Assurance and Control of Monitoring Data

The QA/QC for the Leeds Centre AURN site and the affiliated Leeds Headingly Roadside site is carried out by Ricardo Energy & Environment (E&E). Relevant information is extracted from the 2016 Annual Statius Report and included in Appendix 2

## 4.2 Comparison of Modelled (unadjusted) Against Monitored Road - NOx

Of the seventy seven sets of monitored data, thirty six were excluded from verification process for either;

- Not being in a relevant or representative location (kerbside of roads not modelled)
- Having poor data capture (less than 85%)
- Being a duplicate of another site (e.g; triplicate tubes next to continuous analysers)

Monitoring was carried out in 2016 at additional sites to those included in 2015. Comparison of 6 continuous analysers for the 2015 and 2016 periods resulted in an adjustment factor of 1.062 being applied to the 2016 results to elevate to 2015 levels. However where diffusion tubes were in common locations, there were large discrepancies between the 2015 and adjusted 2016 results. The additional tubes from 2016 were sited in two specific areas and were so different from tubes in the vicinity that it would have required the creation of two additional verification zones. On this basis, verification was conducted using the 2015 data only. Having removed a number of monitoring sites form the verification process for the reason stated above, there was insufficient sites left to split the verification process up in to different distance bands.

### 4.2.1 Verification Process

The modelled road NOx was processed using the DEFRA 'NOx to NO2 calculator v6.1'. The outputted $NO_2$ values added to the sector removed background values and then compared to the monitored levels of $NO_2$. Table 6 gives the values of model performance as described in TG16 and shows model performance for the 2015 scenario. Only 12 of the 41 sites are within 25% of the monitored concentrations. Fractional Bias of 0.37 indicates the model is under predicting. Figure 9 plots modelled against monitored points and it is clear from this that the modelled concentrations are generally under predicting road contributions.

To improve model performance a two-step adjustment process was used. From the monitored roadside $NO_2$ values, roadside NOx levels were obtained using the 'NOx-to-$NO_2$ calculator v6.1'. The background NOx was subtracted from this value to create monitored road NOx and compared against the modelled road NOx. The relationship between modelled and monitored road NOx was calculated using a Least Squares method to obtain the NOx Road Factor of 2.367.

The NOx Road Factor was applied to the modelled Road NOx, which was then run through the NOx-to-$NO_2$ Calculator to obtain modelled road $NO_2$ contribution. Using the same Least Squares method to compare modelled and monitored road $NO_2$, a $NO_2$ road factor of 1.052 was obtained to apply fine adjustment to the modelled values. This improved model performance decreasing fractional bias to 0.07 bringing 27 of the 41 modelled sites within 25% of the monitored value. A comparison of model performance statistics is shown in Table 6

*Table 6: Model Performance – One Zone*

| NOx and NO2 Roads Contribution Adjustment | No Adjustment | All sites |
|---|---|---|
| Number of sites | 41 | 41 |
| Mod NOx Rds v Mon NOx Rd Factor | - | 2.367 |
| Mod NO2 Rds v Mon NO2 Rd Factor | - | 1.052 |
| Root Mean Square Error 1-stage | 11.7 | 7.9 |
| Fractional Bias 1-stage | 0.37 | 0.07 |
| Correlation Coefficient 1-stage | 0.55 | 0.58 |
| No with +-25% 1-stage | 12 | 27 |
| No with +-10% 1-stage | 4 | 14 |

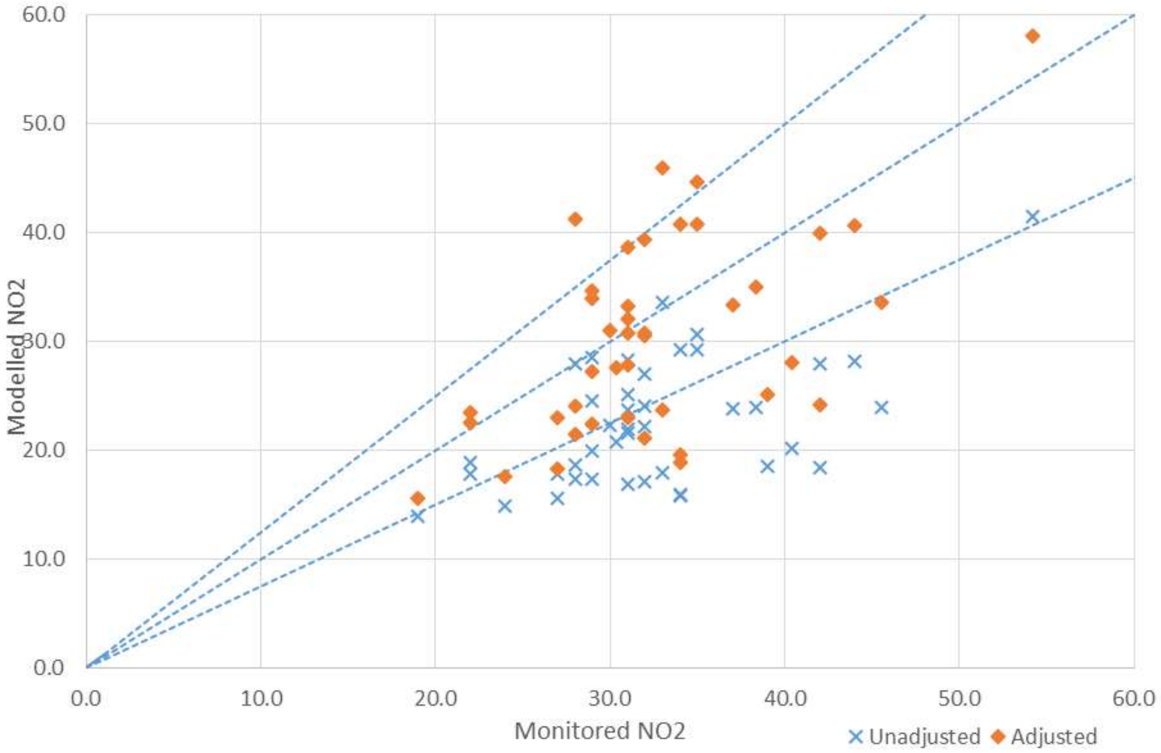



*Figure 9: No Adjustment vs 1 zone Adjustment for NO2 (µgm-3)*

## 4.3 Verification Zoning and Specific Area Analyses

To further improve model performance, sites can be grouped into zones based on geographic factors such as density of road network or similarity in local terrain.

### 4.3.1 Zonal Verification

Given the geographical extent of the modelled area, verification was primarily based on a zonal approach, comprising monitoring sites located within the following:

- Central Zone (inside Leeds Inner Ring Road);
- Intermediate Zone (outside Inner Ring Road, but within Outer Ring Road); and
- Outer Zone (outside of Intermediate Zone, including M62)

The zones are depicted in Figure 10 below.

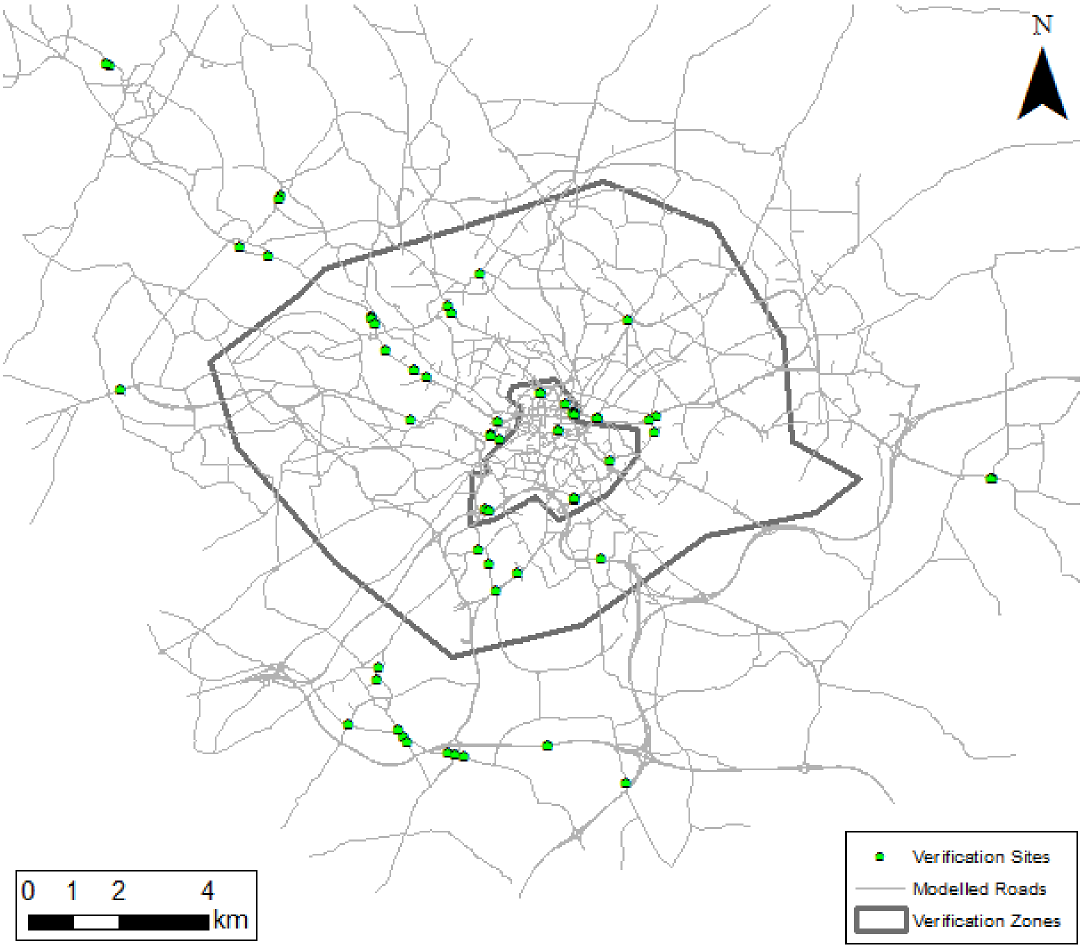
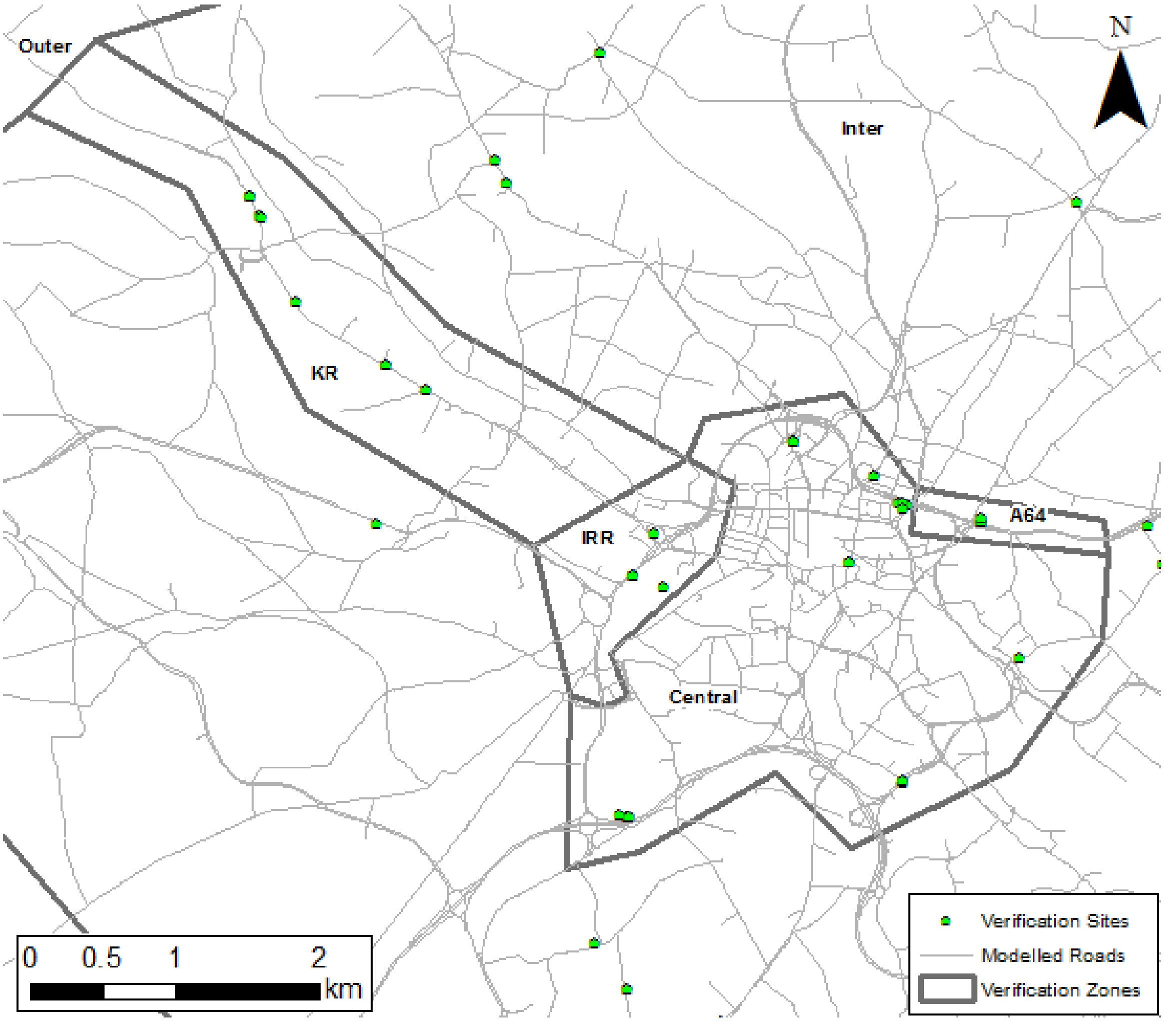



*Figure 10: General Verification Zones*

### 4.3.2 Specific Area Verification

Due to the presence of a number of monitoring sites within specific areas of air quality concern, separate 'localised' model verification was possible. Within the Central Zone, two areas were identified where localised verification was deemed appropriate, based on Defra PCM modelled and/or LCC monitored exceedances of the annual mean $NO_2$ limit value. Similarly, within the Intermediate Zone, one area was identified that would benefit with localised verification. The three locations are shown in Figure 11 and detailed below:

- **A58 Inner Ring Road West**: Comprising A58 Wellington Road between Armley Gyratory and Westgate. Defra's PCM model and LCC monitoring within 10m of the A58(M) have both recorded exceedances of the annual mean $NO_2$ limit value in 2015
- **A64(M) Burmantofts**: Comprising junction of A64(M), York Road, Burmantofts Street, and Haslewood Close. This is a declared AQMA and Defra's PCM model predicted exceedances of the annual mean $NO_2$ limit value in 2015 within 5m of the A64(M)
- **A65 Kirkstall Road**: Comprising A65 Kirkstall Road, Norman Row, Back Norman Mount, De Lacey Mount, Norman Street, and Haddon Place. Whilst the Defra PCM model and LCC monitoring did not record exceedances of the annual mean limit value in 2015, this area includes a declared AQMA and has been subject to monitored exceedances in recent years.




***Error! Reference source not found.****Figure 11: Specific areas identified for 'localised' model verification zones*

The modelled road-$NO_x$ adjustment factors derived from both the zonal and specific analyses have been applied to all future year modelled road-$NO_x$ values at receptors and/or grid points located within the respective zones.

Table 7 shows how grouping sites into six specific zones improved all measures of model performance compared to either grouping into one zone or applying no adjustment.

*Table 7: Model Performance - Zoned*

| NOx and NO2 Roads Contribution Adjustment | No Adjustment | One Zone | Six Zones | KR | IRR | A64 | Central | Inter | Outer |
|---|---|---|---|---|---|---|---|---|---|
| No. sites | 41 | 41 | 41 | 6 | 4 | 3 | 8 | 10 | 10 |
| Mod NOx Rds v Mon NOx Rd Factor | - | 2.367 | - | 3.742 | 2.088 | 1.574 | 2.266 | 2.143 | 5.599 |
| Mod NO2 Rds v Mon NO2 Rd Factor | - | 1.052 | - | 1.007 | 0.999 | 1.000 | 1.064 | 1.001 | 1.008 |
| Root Mean Square Error 1-stage | 11.7 | 7.9 | 5.9 | 5.4 | 6.7 | 1.0 | 6.0 | 6.5 | 6.0 |
| Fractional Bias 1-stage | 0.37 | 0.07 | 0.03 | 0.01 | -0.01 | 0.00 | 0.03 | 0.05 | 0.04 |
| Correlation Coefficient 1-stage | 0.55 | 0.58 | 0.64 | 0.28 | 0.12 | 0.97 | 0.75 | 0.22 | 0.55 |
| No with +-25% 1-stage | 12 | 27 | 33 | 5 | 3 | 3 | 6 | 8 | 8 |
| No with +-10% 1-stage | 4 | 14 | 16 | 2 | 0 | 3 | 4 | 4 | 3 |

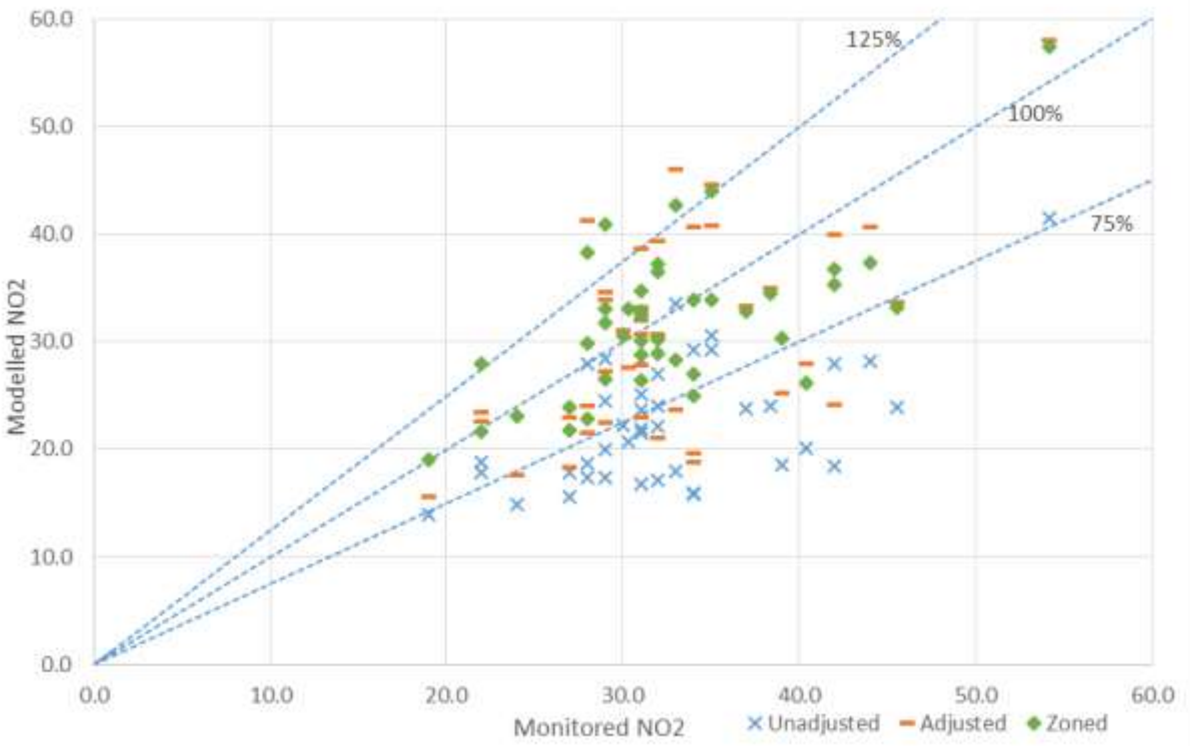



*Figure 12: NO2 Adjusted by Zone against Monitored NO2 (µgm$^{-3}$)*

## 4.4 Model Adjustment Summary

The predicted road-NOx concentrations in future base years and 'with CAZ' scenarios are adjusted based on their location in relation to the geospatial boundaries displayed in using the factors presented in Table 7. Once the adjusted road $NO_X$ is run through the $NO_X$-$NO_2$ Calculator, the resulting road $NO_2$ is further adjusted using smaller $NO_2$ factor for each zone.

Following adjustment of modelled road-$NO_x$, there is no apparent tendency for the dispersion model to over or under predict total $NO_2$ within each of the verification zones / specific areas. 80% of $NO_2$ concentrations that are within +/-25% of the monitored equivalents, as a result of model verification and adjustment. This equates to 33 of 41 monitoring sites included in the verification process. The model average RMSE is 6, indicating variance of +/- 6µgm$^{-3}$, slightly higher than the usual accepted limit of +/- 4µgm$^{-3}$. This can be explained by small variances within each zone where the model under or over predicts. To improve this would require more diffusion tubes located at appropriate sites to validate against.

# 5 NOx and $NO_2$ Results & Source Apportionment

## 5.1 National Modelling

By the 2020 Do-Min the DEFRA PCM projections predict most roadsides within the district of Leeds to be compliant, with exceedances restricted to the M621, parts of the Inner Ring Road between the city centre and Armley Gyratory would remain non-compliant in 2020 as well as the Inner Ring Road near St Peter's Street, Leeds city centre.

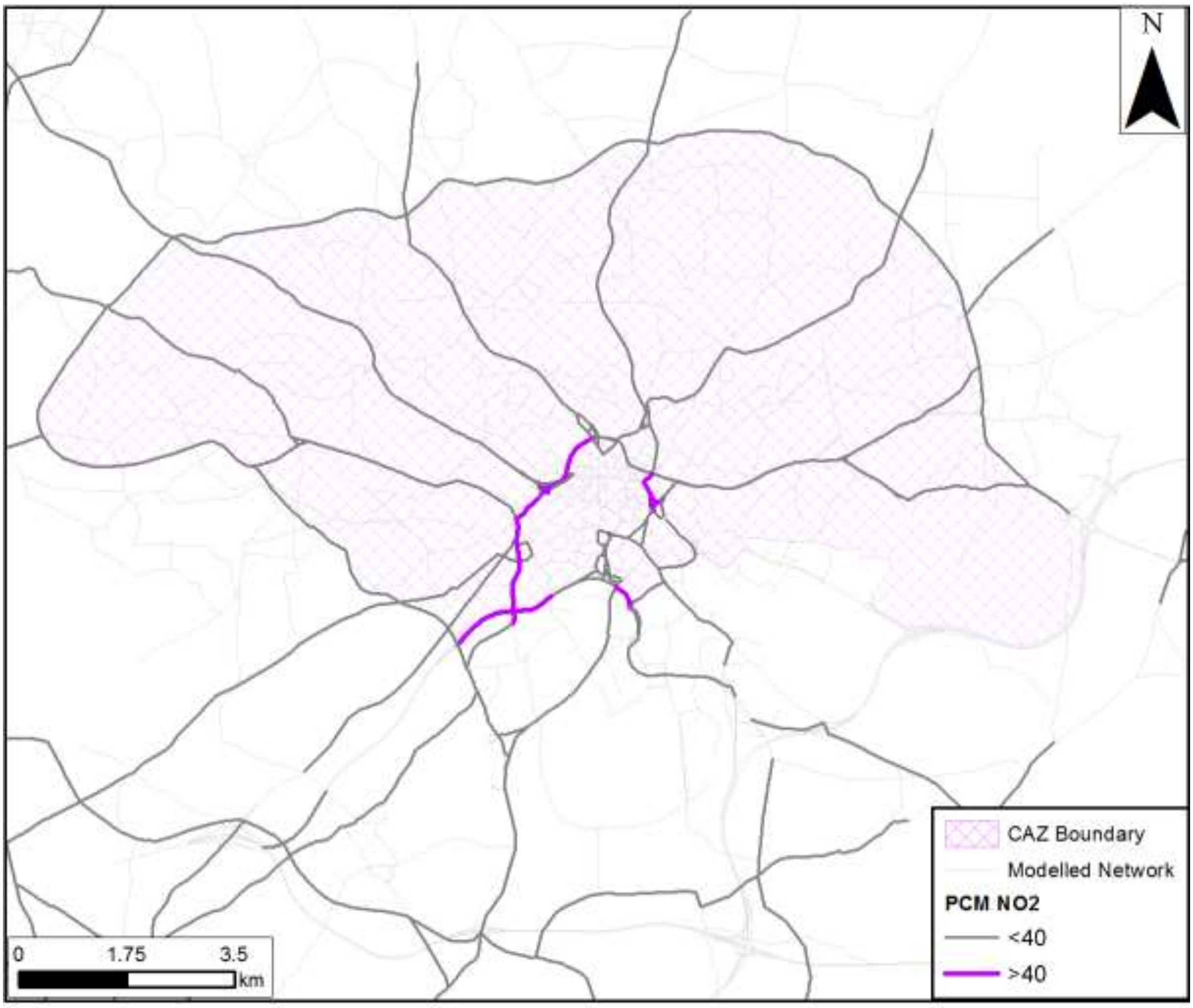



*Figure 13: DEFRA PCM Network exceedances in 2020 in Leeds*

## 5.2 Local Modelling

### 5.2.1 Baseline Modelling for Target Determination Purposes

Leeds has undertaken baseline modelling for emissions and resulting concentrations for 2015 and 2020, with an interpolated interim year concentrations for a 2018 baseline.

The Leeds Local Model (LLM) has generally reported lower concentrations than those given in the PCM outputs. However the results broadly correlate to the links identified in the government's national modelling and confirm that the $NO_2$ concentrations in Leeds would be higher than legal limits beyond 2020. The LLM indicates that, consistent with our local monitoring, that there are other locations within the inner city that not included in the national model which have some of the most significant NO2 issues.

Non-compliant levels were modelled in the 2015 Baseline scenarios, specifically around the city centre in proximity to the bus station, A58/A65 junction and along the M621. There were additional areas of high concentrations but below the 40ugm3 limit along the A58(M) ring road near Armley Gyratory

Whilst modelling 2020 'do minimum' scenario, improvements within the transport infrastructure have been reflected. For example additional train rolling stock will be available by the end of 2019, city connect cycle superhighway will have increased capacity and the new Park and Rides at both Elland Road and Temple Green and their impact have been incorporated.

The model indicates high concentrations of $NO_2$ will persist around the A61 in proximity to the bus station and the Inner Ring Road. However, other areas of concern in the national model are indicated to be fall below 40ugm3 of $NO_2$ by 2020.

In the baseline model year (2015) there were 17 sites which indicated to have concentrations of 39 $\mu g/m^3$ or above, this reduces to 5 sites by the interim model year of 2018 and to 4 sites by 2020. The highest recording reduces from 52.6 $\mu g/m^3$ (2015) to 47.8 $\mu g/m^3$ (2018) to 43.7 $\mu g/m^3$ (2020 – do minimum).

The LLM base line modelling therefore confirms that compliance will not be achieved by 2020 without further intervention. Figure 14 and Figure 15 below show the receptor locations modelled in the LLM against the local modelled network and the Links identified to be at risk of exceeding compliance levels by the National model.

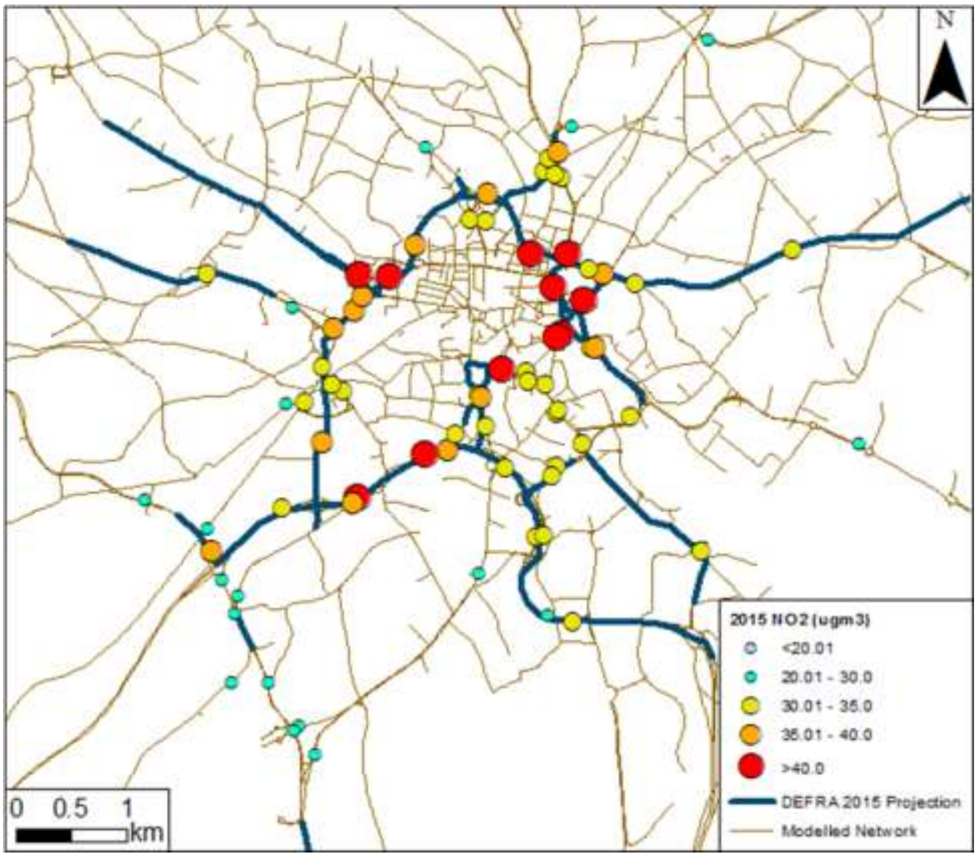



*Figure 14: 2015 NO2 (ugm3) results for the city centre area. DEFRA PCM projections shown for links with roadside concentrations greater than 39 ugm3.*

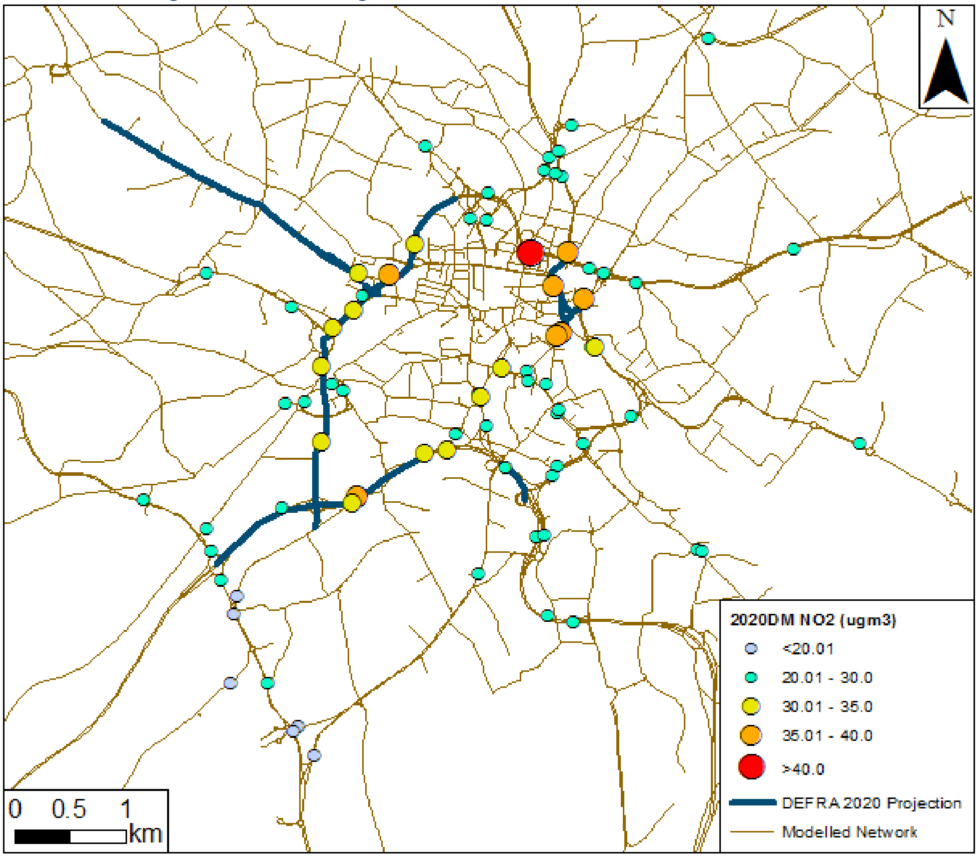



*Figure 15: 2020 NO2 (ugm3) results for the city centre area. DEFRA PCM projections shown for links with roadside concentrations greater than 39 ugm3.*

## 5.3 Baseline and Do-Minimum NOx Source Apportionment

The modelled NOx tonnages as calculated by the EFT for the 2015 baseline and 2020 'do minimum' scenarios are given in Table 8 and broken down into the different broad vehicle classes which affected by different levels of CAZ. Source apportionment shows that vehicles affected by the proposed CAZ-B (Buses, HGVs & T&PHs) contribute 28% of total emissions in 2015 and 20% of 2020 emissions.

*Table 8: Total Modelled Vehicle NOx in Tonnes per year*

| Year | Car | LGV | HGV | Taxi | Bus | Totals |
|---|---|---|---|---|---|---|
| 2015 Base | 1534 | 577 | 562 | 33 | 255 | 2961 |
| (% of 2015 total) | 51.8% | 19.5% | 19.0% | 1.1% | 8.6% | |
| 2020 Do Minimum | 1372 | 522 | 306 | 31 | 151 | 2381 |
| (% of 2020 total) | 57.6% | 21.9% | 12.8% | 1.3% | 6.3% | |

An ANPR assessment of vehicles travelling close to the city centre indicated that Leeds registered T&PH vehicles completed on average twice as many trips as a non-Leeds registered vehicles. This does not account for vehicles registered to other local authorities which could be affecting the results. The same data indicates that T&PH complete approximately 10% of all Car based trips.

Reflecting on T&PH movements in the model was difficult, within the timeframe required for reporting to JAQU because there was no opportunity to arrange for specific T&PH counts on key roads. Consequently, historical counts made were used to assess T&PH movements, but there was uncertainty around the method for counting "taxis" in these surveys. Conservative assumptions were made which assigned a fixed percentage per link of modelled car movements as taxi trips. T&PH movements were then calculated separately using the Emission Factor Toolkit with Euro class based on the 2016 registered Leeds T&PH. This methodology, in all likeliness underestimates modelled T&PH movements and fails to capture the impact of vehicles registered with other local authorities.

The 2020 'do-Minimum' emissions were further grouped into the zones across the city as shown in Figure 16. The contributions for the M621, M62 and M1 fall into the outer zone. Table 9 shows the further breakdown and highlights that in the city centre CAZ B vehicles account for an estimated 52% of total road based NOx emissions with buses alone expected to contribute 42%.

*Table 9 Modelled vehicle NOx in Tonnes per year for 2020 Do-Minimum with additional Source Apportionment by zone*

| | **Car** | **LGV** | **HGV** | **Taxi** | **Bus** | **Total** |
|---|---|---|---|---|---|---|
| North | 233 | 65 | 34 | 14 | 73 | 419 |
| (% of 2020 total) | 56% | 16% | 8% | 3% | 17% | |
| South | 80 | 26 | 20 | 4 | 17 | 147 |
| (% of 2020 total) | 54% | 18% | 14% | 3% | 12% | |
| City Centre | 26 | 7 | 4 | 2 | 28 | 66 |
| (% of 2020 total) | 39% | 10% | 7% | 3% | 42% | |
| Outer | 1033 | 423 | 247 | 11 | 34 | 1749 |
| (% of 2020 total) | 59% | 24% | 14% | 1% | 2% | |
| Total | 1372 | 522 | 306 | 31 | 151 | 2381 |
| (% of 2020 total) | 58% | 22% | 13% | 1% | 6% | |

A further sub-section referred to as the IRR(M) North covers the section of inner ring road running from J2 of the M621 on the A643, A58(M) and A64(M) to the junction with the A61 just north of the bus station. It is roads in this section that are expected by the DEFRA model to be exceeding in 2020. This section is a sub-selection of the North zone and accounts for 10% of the total emissions within the zone. Of this, CAZ-B vehicles account for an estimated 18% of emissions. As discussed earlier, it is thought that a conservative estimate in the percentage of journeys being made by T&PHs using these links has been used.

| | Car | LGV | HGV | Taxi | Bus | Total |
|---|---|---|---|---|---|---|
| IRR(M) North | 26 | 10 | 4 | 1 | 3 | 44 |
| (% of 2020 total) | 59% | 23% | 9% | 3% | 6% | |

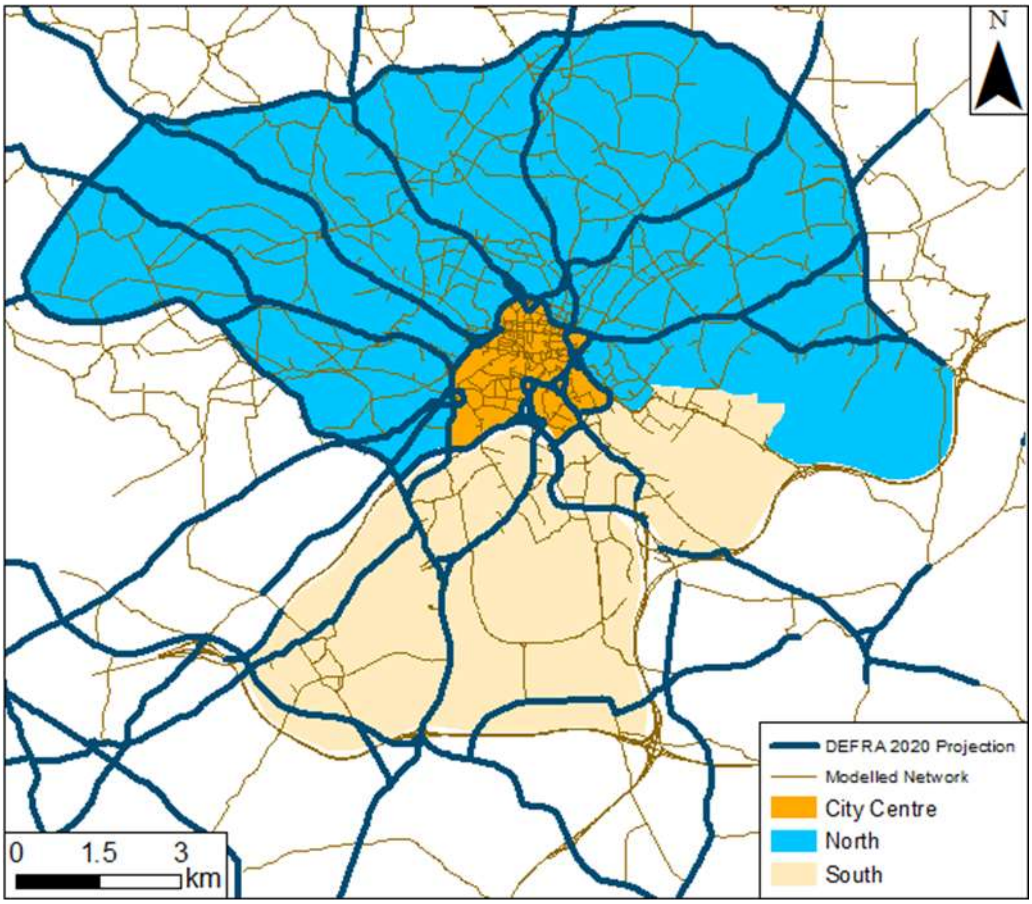



*Figure 16 Sub-Zones used to Identify Source Apportionment*

### 5.3.1 Source Apportionment for selected CAZ Scenarios

Applying measures to the buses is expected to deliver the biggest reduction in vehicle emissions around the bus station and across much of the city centre area. However there is less impact on the inner ring road as the majority of bus services travel radially rather than via orbital routing. This suggests against using a CAZ-A option only.

In order to reduce emissions from the ring road as well, it was necessary to move to the next class of CAZ to include HGVs as well as buses, coaches and Hackney Carriage and Private Hire vehicles.

Table 10 shows the results of matching the vehicle data collected from the ANPR traffic counts against those vehicles registered as Hackney Carriage or Private Hire in Leeds and highlights the prevalence of taxi movements in certain locations of the city centre. Analysis of the Leeds registered T&PH fleet shows that although there is growing number of petrol hybrids in the fleet, 87% are still diesel which is approximately double the rate of the general car fleet.

Combined with the average mileage of the HC&PH fleet being anywhere between 20,000 and 50,000 miles per year compared to estimate national average of 7,800 in 2016 demonstrates the disproportionate effect that this element of the fleet contributes towards the total emissions within Leeds.

*Table 10 Analysis of Leeds Registered hackney Carriage & Private Hire movements at ANPR count sites*

| | ANPR Site | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | IRR_11_9 | IRR_5_1 | All Sites |
| ZONE | Outer | North | North | City | City | City | M621 | IRR(M) East | IRR(M) West | |
| No of Unique vehicles (All types) | 58,069 | 60,561 | 19,493 | 87,626 | 78,739 | 6,023 | 55,437 | 91,695 | 193,947 | 419,590 |
| No of journeys (all vehicle types) | 131,882 | 154,404 | 29,857 | 217,689 | 172,473 | 25,158 | 82,798 | 239,324 | 581,485 | 1,635,070 |
| No of Unique Cars/Taxis | 48,708 | 52,132 | 16,532 | 76,489 | 69,460 | 4,687 | 49,283 | 76,441 | 163,037 | 361,111 |
| No of journeys (Cars/Taxis) | 111,574 | 134,792 | 24,233 | 193,439 | 146,185 | 16,066 | 72,973 | 201,993 | 487,516 | 1,388,771 |
| No of Unique Leeds Licensed Taxis (matched to Cars/Taxis) | 290 | 1,899 | 1,087 | 2,711 | 2,944 | 1,493 | 1,063 | 2,893 | 3,541 | 3,647 |
| No of journeys by Leeds Licensed Taxis (matched to Cars/Taxis) | 841 | 7,926 | 2,126 | 21,005 | 33,361 | 10,605 | 1,988 | 16,959 | 38,204 | 133,015 |
| | | | | | | | | | | |
| % Licensed Taxis (all vehicles) | 0.50% | 3.14% | 5.58% | 3.09% | 3.74% | 24.79% | 1.92% | 3.16% | 1.83% | 0.87% |
| % Licensed Taxis (all journeys) | 0.64% | 5.13% | 7.12% | 9.65% | 19.34% | 42.15% | 2.40% | 7.09% | 6.57% | 8.14% |
| | | | | | | | | | | |
| % Licensed Taxis (all Cars/Taxis) | 0.60% | 3.64% | 6.58% | 3.54% | 4.24% | 31.85% | 2.16% | 3.78% | 2.17% | 1.01% |
| % Licensed Taxis (all Cars/Taxis journeys) | 0.75% | 5.88% | 8.77% | 10.86% | 22.82% | 66.01% | 2.72% | 8.40% | 7.84% | 9.58% |

Following the initial modelling results and subsequent period of consultation, a short list of potential CAZ scenarios were identified to proceed with a more detailed analysis. The options considered and included in the modelled scenario results are;

1. CAZ D with a smaller boundary using the M621, the Inner Ring Road and A63 as the southern boundary. Referred to as *'CAZ-D Reduced'*.
2. A CAZ B with additional measures such as requiring a better standard of emissions for T&PH vehicles but using the same smaller boundary as the CAZ D. Referred to as *'CAZ-B+ Reduced'*
3. A CAZ B with a larger boundary, broadly using the M62 and the M1 as the southern and eastern boundaries. Referred to as *'CAZ-B'*

Referring to Figure 15, the reduced CAZ boundary effectively excludes the southern zone from the enforceable CAZ area. The total modelled NOx tonnages for the year 2020 as calculated by the EFT for the shortlisted CAZ scenarios. The totals are broken down between vehicle classes affected by different levels of CAZ and compared against the do minimum totals in Table 11.

*Table 11 Modelled NOx Tonnages*

| NOx Tonnes/year | Car | LGV | HGV | Taxi | Bus | Total | % of DM |
|---|---|---|---|---|---|---|---|
| 2020 Do Minimum | 1372 | 522 | 306 | 31 | 151 | 2381 | - |
| 2020 CAZ-D Reduced | 1210 | 501 | 248 | 17 | 25 | 2000 | 84% |
| 2020 CAZ-B+ | 1372 | 522 | 218 | 11 | 25 | 2148 | 90% |
| 2020 CAZ-B+ Reduced | 1371 | 522 | 248 | 11 | 25 | 2177 | 91% |

The *CAZ-D reduced* clearly offers the largest reductions in NOx, primarily due to the change in the car fleet. The major difference between a *CAZ-B+* and *CAZ-B+ reduced* is that a larger number of HGVs remain non-compliant due to the smaller boundary, contributing an extra 30 Tonnes of NOx per year, this equates to around 1.5% of the total do-minimum scenario

Because they generally all operate in the city centre, changing the boundary has very little impact on compliance levels and the impacts to Bus and T&PH services are broadly the same across all CAZ scenarios. Pushing the T&PH fleet from the minimum Euro 4 petrol / Euro 6 diesel standard to a cleaner Petrol Hybrid predicts an additional saving of 6 tonnes of NOx per year, even with exemptions made for specialist older vehicles.

The low level of change to LGV total emissions from 522 to 501 tons of annual NOx is due to 60% of LGVs expected to be compliant by 2020 in the Do-Minimum scenario but expected to rise to 75% compliance with a CAZ-D scenario

Table 12 shows the total modelled NOx tonnages within the full CAZ boundary for the year 2020 as calculated by the EFT for the shortlisted CAZ scenarios. The totals are broken down between vehicle classes and compared against the do minimum totals. These totals are made up of the combined total emissions calculated within the City Centre, Northern and Southern zones depicted in Figure 16

*Table 12 Modelled NOx Tonnages within the CAZ Boundary*

| Nox Tonnes / Year | Car | LGV | HGV | Taxi | Bus | Total |
|---|---|---|---|---|---|---|
| 2020DM | 338 | 99 | 59 | 20 | 118 | 633 |
| | | | | | | |
| 2020 CAZ-D Reduced | 261 | 86 | 29 | 11 | 20 | 407 |
| % of 2020 do minimum | 77% | 87% | 49% | 55% | 17% | 64% |
| 2020 CAZ-B+ | 338 | 98 | 22 | 7 | 20 | 486 |
| % of 2020 do minimum | 100% | 100% | 37% | 35% | 17% | 77% |
| 2020 CAZ-B+ Reduced | 338 | 98 | 29 | 7 | 20 | 493 |
| % of 2020 do minimum | 100% | 100% | 49% | 35% | 17% | 78% |
| 2020 CAB Low Compliance | 350 | 98 | 30 | 11 | 79 | 569 |
| % of 2020 do minimum | 104% | 100% | 51% | 55% | 67% | 90% |

The results show that although there is a substantial reduction in the size of the enforceable CAZ boundary the smaller boundary size only generates an additional 7 Tonnes (1%) of NOx emissions across the area concerned by the *CAZ B+ reduced* scenario than the larger *CAZ B+* scenario.

### 5.3.2 Vehicle Effect on Emission Contributions

The overall assumed compliance rate of different vehicle classes was informed by the behavioural response outcomes provided by JAQU. The decision as to whether non-compliant vehicles chose to divert or pay the charge was decided within the Leeds traffic Model. The traffic model did not allow the option of a trip to be cancelled altogether. The assumption has been made that if a commercial journey was required originally, then any trip cancelled due to the operator having a non-compliant vehicle will be replaced by another operator.

Table 13 shows the overall compliance levels used within the different modelled scenarios compared with the 2020 do minimum scenario. A ‘Standard’ CAZ-B with a reduced compliance rate has also been modelled.

*Table 13 The Total proportion of Compliant Vehicles Modelled by Scenario*

| Scenario | Car | LGV | HGV | Taxi | Bus |
|---|---|---|---|---|---|
| 2020 do minimum | 72% | 83% | 66% | 46% | 35% |
| 2020 CAZ-D Reduced | 88% | 62% | 94% | 96% | 100% |
| 2020 CAZ B+ | 72% | 62% | 94% | 82% | 100% |
| 2020 CAZ-B+ Reduced | 72% | 62% | 94% | 82% | 100% |
| 2020 CAZ-B Low Compliance | 72% | 62% | 89% | 96% | 46% |

### 5.3.3 Hackney Carriage and Private Hire

Hackney Carriage or Taxis and Private Hire Vehicles (T&PHs) are modelled as a subset of the general car fleet. However, there is an additional influence in driving up levels of compliance rates, especially for those vehicles registered by Leeds City Council.

Although both the 'enhanced' CAZ-B+ scenarios have a lower rate of compliance for PH&HC vehicles than in the 'Standard' CAZ-B and CAZ-D scenarios, they deliver a greater reduction of emissions. Guidance on how drivers of non-compliant diesel cars will change their vehicles results in the PH&HC fleet becoming 46% diesel (from 87% in the 2015 base year). The overall compliance rate for the CAZ-D and 'standard' CAZ-B has not accounted for any potential exemptions that might be required in order to maintain a suitable number of wheelchair accessible vehicles (WAVs) within the fleet for example.

Emissions have been modelled for the enhanced CAZ-B+ scenarios with the assumption that PH&HC vehicles registered in Leeds will meet a minimum standard of a full petrol hybrid where there is viable option. However the scenarios also take in to account that most of the existing WAVs will not be able to meet this standard prior to 2021 and will require temporary exemptions. They have therefore been modelled as diesel within the CAZ-B+ scenarios.

The CAZ-B+ scenarios have therefore assumed that 73% of the T&PH fleet would become full petrol hybrid with the remaining vehicles which remain as diesel either because there are currently no viable alternatives or because they are ad-hoc visits from non-compliant T&PHs. This situation compares against the 2020 do-minimum position which assumes and overall compliance rate of 46% with 88% of the fleet remaining diesel.

### 5.3.4 Buses

The LTM user class modelled as buses only represents scheduled Passenger Service Vehicles. These have been coded on fixed routes and do not have the option to divert within the model. The majority of this user class represents the local and regional bus services but does include some of the regular scheduled longer distance coach services. Because the vast majority of buses operating scheduled services access the city centre on a daily basis, the CAZ scenarios have assumed this user class will be come 100% compliant.

Chartered coaches and school buses are not included within the fixed 'Bus' routes and are included within the LTM under the wider category of Heavy Duty Vehicles. Not all these vehicles have a need to access the city centre on a regular basis, if at all, and operators would have the option of switching vehicles around, diverting routes or choosing to pay the charge. For this reason, it was deemed reasonable to assume that these vehicles would choose to become compliant at the same rate as the other Heavy Duty Vehicles included in this user group. This may prove to be a conservative approach as 123 Euro III and Euro IV school buses were retrofitted between 2013 and 2015 to an emission standard which exceeds Euro V standard and possibly meets Euro VI standard for NOx emissions. However, any of these buses which were captured by the ANPR cameras are still likely to have been labelled as a Euro III or IV vehicle

A low compliance CAZ-B test assumed that 90% of buses became Euro V or better which was in line with the existing bus strategy in place. Only 46% of buses are assumed to be Euro VI with 10 % remaining Euro IV. This test resulted in the expected reduction of annual emissions from buses falling by 50% , from a 98 tonne reduction under a full compliance scenario to just a 39 tonne reduction in the low compliance test. This 59 tonne difference represents approximately 40% of the total estimated emission reductions resulting from a fully compliant CAZ scenario.

### 5.3.5 HGVs

The behavioural response guidance suggested that 83% of the journeys undertaken by HGVs which were not already compliant would choose to become compliant if impacted by a CAZ. Euro VI standards for HGV was introduced earlier than most other vehicle classes and many of the larger operators turn over their fleet on a frequent basis. The local fleet projections indicate that under the do minimum scenario, 66% of HGV journeys will already be 66% compliant. This results in CAZ B scenarios modelling an assumed compliance rate of 94%.

A ‘low compliance’ CAZ-B model run was undertaken within the Transport Model to test the impact of only 66% of the non-compliant fleet choosing to become compliant. As only 34% of the journeys were non-compliant in the do –minimum situation, the overall impact only reduced compliant HGV trips from 94% to 89% and had minimal negative impacts on any diversionary routes.

Comparing the emissions expected from the low compliance CAZ-B scenario against the compliance rate expected from the behavioural response study is not easy. The low compliance CAZ-B scenario modelled with the larger boundary shows a 49% reduction in emissions of NOx from the do minimum within the CAZ boundary falling to a total of 30 tonnes. This compares to the expected 63% reduction down to 22 Tonnes per year within the CAZ boundary with the higher compliance rate. This indicates that if the HGV compliance rate is 5% lower than assumed, their emission contribution within the CAZ boundary is likely to be around 14% higher than modelled. However, this would only equate to an increase of 2.5% on total emissions.

The total emissions expected from HGVs with the higher compliance rate and a reduced CAZ boundary do not appear at first to compare well, with the smaller boundary appearing to reduce the expected improvements from HGVs by 12 % less than the full boundary. However, on closer inspection, this appears to mainly be attributed to a discrepancy in the way the LTM works. The additional HGV emissions from the reduced CAZ boundary appear to be mostly due to non-compliant vehicles being able to choose to use the M621 as a diversion route and hence their emissions are included within the totals calculated within the larger CAZ boundary.  In reality, these vehicles will be able to use the M621 in both situations as the M621 will not be subject to a CAZ, but the transport model is not able to accurately reflect the situation where there is in effect 2 separate CAZ boundaries.

No attempt has been made to quantify the potential impact of some HGV operators choosing to switch their older vehicles to LGVs, however it is anticipated that the impact on any single link will more than likely be an overall reduction in vehicle emissions.

### 5.3.6 LGVs

Of the scenarios reported here LGVs are only directly affected by the CAZ D scenario. The low compliance CAZ B scenario does not therefore effect the response of LGVs other than the potential of minor knock-on re-routing effects resulting from any non-compliant HGVs affecting LGV route choices.

There are very few petrol LGVs available and the Euro 6 diesel standard only became generally available from September 2015.  There appears to be a trend of increasing numbers of LGVs within the national fleet and the forward projection, which essentially maintains the same age profile within the local fleet results in a compliance rate of 62% in the 2020 do minimum situation. Following the behavioural response guidance A CAZ-D would result in LGV compliance increasing by 21% to a total of 83% and reduce their total emission contribution within the full CAZ boundary by approximately 13% (13 tonnes) from the do minimum scenario.

The figures suggest that there would be a relatively small contribution to the overall emission reduction achieved on a per vehicle basis over and above the do minimum scenario. Looking within the make up of the LGV fleet, it may be possible to address small sub-groups of LGV vehicles which contribute a disproportionate amount of pollution per vehicle to achieve similar total benefits.

### 5.3.7 Cars

As with LGVs, of the scenarios modelled, this vehicle class is only affected directly by the CAZ-D Redcued scenario, which has not been run with a lower compliance option. The CAZ-D Reduced option, as modelled, follows the behavioural response guidance provided by JAQU which assumes that 75% of non-compliant diesel cars will choose to replace with a petrol option.

The resulting impact of a CAZ-D Reduced is a 16% increase in compliant cars from 72% to 88% resulting in a 23% reduction in car based NOx emissions from the do minimum situation. Following guidance from JAQU, the do minimum situation assumed the proportion of trips made locally by diesel cars will continue to increase in line with national projections. Much of the emission improvements seen from cars is likely to result from the significant increase in petrol cars in the car fleet over the do minimum situation due to a CAZ-D Reduced being introduced. Recent evidence suggests that the trend in diesel car ownership increasing year on year is reversing. However, it is unclear whether this reversal is temporary (as the public await the outcome of the different CAZ zones around the country) or is the start of a longer term trend.

As with LGVs, there appears to be an indirect effect due to cars re-routing in response to a greater number of non-compliant HGVs choosing to either avoid the CAZ or paying and taking the most direct route through it in the low compliance CAZ-B scenario. As there are more cars than LGVs this affect is more pronounced and results in 12 tonne (4%) increase in NOx emissions contributions from cars within the CAZ boundary over the do minimum scenario. This would result in car contributions rising from 53% in the do-minimum to 61% in the low –compliance CAZ B scenario and 69% in a full compliance CAZ-B scenario. Cars are expected to contribute 53% of total emissions in a fully compliant CAZ-D.

## 5.4 Locally modelled concentrations of NO2

Comparison of the highest modelled concentrations shows a range of changes in roadside concentration levels between different CAZ based scenarios. This is due to concentration levels being dependent on the combination of traffic volume, speed and specific fleet make up on each individual link.Table 14 shows the predicted concentrations of $NO_2$ in 2020 for those sites which are predicted to be greater than 34µgm$^{-3}$ in the Do-Minimum situation compared to the predicted levels with the three short listed scenario options. This value has been chosen because whilst the fractional bias in the verification process shows the model does not have a tendency to either under or over predict $NO_2$ concentrations, the RMSE indicate the results could be incorrect by up to ± 6µgm$^{-3}$.

A full list of predicted concentration results at the target determination points can be found in Appendix 5.

*Table 14: Modelled Adjusted Target Determination Sites where 2020 Do-Minimum NO2 is greater than 34 µgm$^{-3}$*

| CP_ID | X | Y | Do-Min | CAZ-D | CAZ-B+ | CAZ-B+ M621 |
|---|---|---|---|---|---|---|
| TD9050 | 428923 | 431681 | 35.3 | 30.7 | 32.9 | 33.4 |
| TD18451 | 429216 | 433687 | 39.8 | 33.3 | 36.8 | 36.8 |
| TD26603 | 430829 | 433890 | 35.5 | 30.5 | 33.0 | 33.0 |
| TD28288 | 430766 | 433168 | 39.1 | 33.2 | 36.6 | 36.6 |
| TD29051 | 429541 | 432076 | 34.5 | 30.5 | 32.5 | 32.9 |
| TD36620 | 430698 | 433593 | 39.8 | 31.3 | 33.4 | 33.4 |
| TD58230 | 430502 | 433899 | **43.7** | 34.9 | 38.3 | 38.4 |
| TD74892 | 430978 | 433467 | 36.3 | 30.5 | 32.9 | 33.0 |
| TD81387 | 430724 | 433133 | 35.1 | 30.4 | 32.8 | 32.8 |
| TD28567 | 424040 | 428014 | 34.6 | 33.0 | 34.4 | 34.2 |
| TD47438 | 420263 | 434243 | 35.6 | 30.8 | 33.1 | 33.3 |
| TD8548 | 425067 | 428031 | 35.1 | 31.2 | 34.2 | 34.4 |
| TD36055 | 429507 | 426437 | 35.9 | 34.8 | 35.7 | 35.7 |

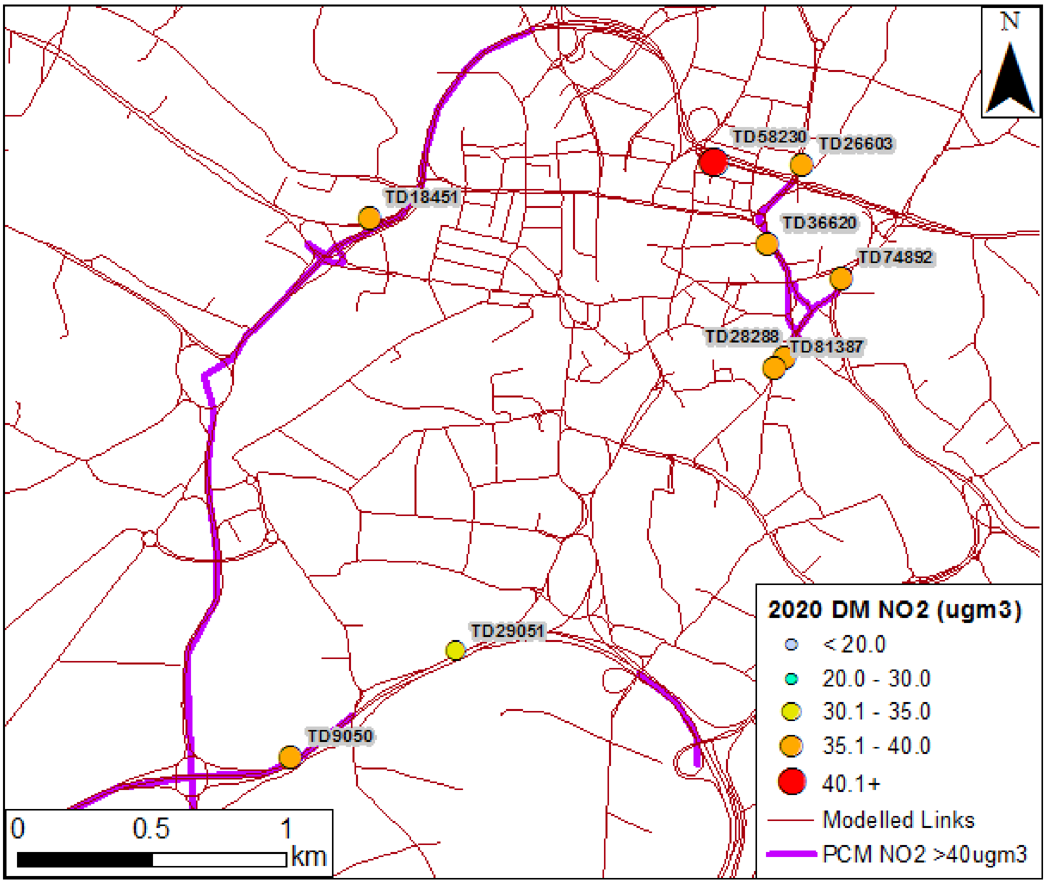



*Figure 17 Target Determination Points where the Local Modelling Predicts Levels Greater than 34 µgm$^{-3}$ in the 2020 Do Minimum Situation*

The majority of Target Determination points presented above are located around the Inner Ring Road of Leeds and are shown in Figure 17 of the four Target Determination points listed in Table 14 and not shown in Figure 18, three are located adjacent to the Motorway network and TD47438 represents the A647 between its junction with the A6120 (Outer Ring Road) and the District boundary.

Based on the approach adopted for the sensitivity testing, which is covered in the next section, it was possible to estimate the contribution from each vehicle class in two specific scenarios. Table 15 sets out the vehicle NOx contributions at the sites given in Table 14. Site TD58230 which is exceeding compliance in the Do-Min can be seen to have a very high NOx contribution from Cars and Buses. The high contribution from Buses is taken to be the major contributor in the CAZ scenarios to the reduction in $NO_2$ in the CAZ scenarios. Table 16 shows that the NOx contribution drops from 17.3 to 4.4µgm$^{-3}$ or 75%. The bus contribution to all borderline receptors decreases by 70% or more.

*Table 15: Road $NO_X$ contributions by Vehicle Type at receptors exceeding 34µgm$^{-3}$ of $NO_2$ in the 2020 Do-Min.*

| Site ID | X | Y | Zone | Road NOx Contribution (µgm$^{-3}$) | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | Car | LGV | HGV | Bus | Taxi |
| TD9050 | 428923 | 431681 | Central | 24.9 | 9.0 | 5.2 | 1.9 | 1.2 |
| TD18451 | 429216 | 433687 | IRR | 23.2 | 6.4 | 3.1 | 6.8 | 1.4 |
| TD26603 | 430829 | 433890 | A64 | 16.9 | 4.0 | 1.8 | 6.2 | 0.9 |
| TD28288 | 430766 | 433168 | Central | 21.3 | 5.0 | 2.1 | 5.6 | 1.1 |
| TD29051 | 429541 | 432076 | Central | 20.1 | 7.1 | 4.4 | 1.6 | 1.0 |
| TD36620 | 430698 | 433593 | Central | 14.3 | 3.4 | 2.1 | 21.0 | 0.8 |
| TD58230 | 430502 | 433899 | Central | 22.3 | 5.4 | 2.7 | 17.3 | 1.3 |
| TD74892 | 430978 | 433467 | Central | 15.5 | 3.5 | 2.0 | 8.5 | 0.8 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| TD81387 | 430724 | 433133 | Central | 15.3 | 3.9 | 1.8 | 5.1 | 0.8 |
| TD28567 | 424040 | 428014 | Outer | 29.9 | 9.6 | 6.8 | 0.2 | 0.2 |
| TD47438 | 420263 | 434243 | Outer | 30.0 | 7.4 | 3.6 | 6.3 | 0.5 |
| TD8548 | 425067 | 428031 | Outer | 29.0 | 12.9 | 3.8 | 0.3 | 0.1 |
| TD36055 | 429507 | 426437 | Outer | 33.1 | 11.3 | 6.9 | 0.3 | 0.1 |

*Table 16: Road NOx contributions in the 2020 CAZ-B+ Reduced scenario and the reduction compared to the 2020 Do-Min*

| Site ID | Road NOx Contribution ($\mu gm^{-3}$) | | | | | Reduction vs Do-Min (%) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Car | LGV | HGV | Bus | Taxi | Car | LGV | HGV | Bus | Taxi | Total |
| TD9050 | 24.7 | 8.9 | 3.1 | 0.3 | 0.4 | 1 | 0 | 40 | 84 | 71 | 11 |
| TD18451 | 23.0 | 6.4 | 1.1 | 1.3 | 0.6 | 1 | 1 | 63 | 81 | 56 | 21 |
| TD26603 | 16.8 | 4.0 | 0.7 | 1.3 | 0.3 | 0 | 0 | 60 | 78 | 67 | 22 |
| TD28288 | 21.2 | 5.0 | 0.9 | 1.2 | 0.3 | 0 | 1 | 57 | 79 | 71 | 19 |
| TD29051 | 20.1 | 7.1 | 2.6 | 0.3 | 0.3 | 0 | 0 | 42 | 82 | 70 | 11 |
| TD36620 | 13.7 | 3.3 | 1.0 | 5.6 | 0.3 | 4 | 4 | 55 | 73 | 67 | 43 |
| TD58230 | 22.2 | 5.4 | 1.1 | 4.4 | 0.5 | 0 | 0 | 59 | 75 | 63 | 31 |
| TD74892 | 15.4 | 3.5 | 0.9 | 1.8 | 0.3 | 1 | 0 | 57 | 79 | 69 | 28 |
| TD81387 | 15.2 | 3.9 | 0.8 | 1.1 | 0.3 | 1 | 0 | 55 | 79 | 69 | 21 |
| TD28567 | 29.8 | 9.6 | 6.3 | 0.0 | 0.1 | 0 | 0 | 8 | 84 | 64 | 2 |
| TD47438 | 29.8 | 7.3 | 2.2 | 1.6 | 0.1 | 1 | 0 | 39 | 75 | 76 | 14 |
| TD8548 | 29.0 | 12.9 | 2.5 | 0.0 | 0.0 | 0 | 0 | 34 | 84 | 66 | 4 |
| TD36055 | 33.1 | 11.3 | 6.7 | 0.0 | 0.0 | 0 | 0 | 2 | 84 | 61 | 1 |

# 6 Sensitivity Testing

During the primary and secondary rounds of modelling, there was limited time and resources available to conduct sensitivity tests across all scenarios. Initially only one traffic model sensitivity test was run. Further additional testing has now been undertaken by altering emission rates in an attempt to predict the potential impact of lower vehicle upgrade rates amongst the CAZ impacted vehicles although using the same total vehicle flows.

The modelling is split into three sections;

- **Traffic Modelling** used the Leeds Transport Model (LTM) which combines a SATURN model with a trip and modal assignment model which was used to reflect the behavioural impact of applying a CAZ charge and the boundary to which it applied.
- **Emission Modelling** used the LTM outputs and the Government provided Emission Factor Toolkit (EFT) to create an emission rate for each road link over four time periods.
- **Dispersion Modelling** used the Airviro model to predict the concentrations of NOx at a number of representative locations across Leeds. Although the Dispersion model can be impacted by a number of factors, no changes were made as part of the sensitivity testing.

## 6.1 Traffic Modelling

The traffic modelling was the resource that primarily constrained the rest of the modelling process, taking the longest time to run and requiring a complex set-up to properly reflect the charging boundary and resulting impacts. The LTM is also used to assess all highways schemes in Leeds and so was under high demand as a resource from other teams within the council. As such, a limited number of scenarios could be run, particularly further in to the process;

- Base 2015
- Do-Min 2020
- CAZ-B 2020
- CAZ-B 2020 Low Compliance
- CAZ-B Reduced Boundary 2020
- CAZ-D Reduced Boundary 2020
- Do-Min 2022
- Do-Other 2022
- CAZ-B & Do-Other 2022
- CAZ-B Reduced Boundary & Do-Other 2022

Of these, all were direct scenario tests with the exception of the CAZ-B 2020 Low Compliance run. This modelled the impact of a lower upgrade rate of HGVs. The Do-Other option in 2022 incorporates some expected but not confirmed changes to the city centre including the closure of a major thoroughfare that is expected to impact significantly on air quality around Leeds Rail Station.

In the 2020 Do-Min (No-CAZ) scenario, 66% of the HGVs started out as Euro VI compliant which was based on fleet projections determined using the 2016 ANPR study. In the modelled 2020 CAZ-B and CAZ-D scenarios, in line with guidance provided by JAQU, a modelled uptake value of 83% was applied to non-compliant vehicles which resulted in a total of 95.5% of modelled HGV vehicles driving within the CAZ being Euro VI compliant. For the Low Compliance scenario the modelled uptake value was reduced to 66% which resulted in the total Euro VI compliance rate inside the CAZ boundary reducing to 88.4%.

Scheduled Buses are modelled as a constant flow along fixed routes in all scenarios, with bus speeds being the only variation. T&PH assignment was assumed to be a fixed percentage of car flows on a link, so this would vary between scenarios based on the re-assignment of car trips. Therefore variation in compliance for Bus and T&PH was not covered within the traffic model. As compliance was already expected to be achieved by a CAZ-B, no sensitivity testing was performed for a CAZ-D scenario in order to focus resources.

The output from the LTM divided traffic flows in to Car, LGV, HGV and Scheduled Bus Services, with the first three being divided further into compliant and non-compliant vehicles. This means that on any given link, depending on the origin destination matrix within the LTM, there can be a variation in the ratio of compliant to non-compliant vehicles. However, the compliance rate averages out across all links within the CAZ boundary to match the specified levels.

## 6.2 Emission Modelling

The key scenario emission modelling split the traffic flows into five categories;

- Motorway – Compliant
- Motorway – Non Compliant
- Non-motorway – Compliant
- Non-motorway – Noncompliant
- Non-motorway – Taxi Only

An EFT workbook was used to calculate emission rates for each of the five categories. For each scenario the emission rates were then combined to be dispersed via Airviro. The Low Compliance scenario utilises the same methodology but applies a different Euro fleet mix to the Buses in the 'Non-motorway Compliant' calculation and to T&PH in the 'Non-motorway – Taxis Only' calculation. The change in HGVs was governed by the LTM and consequently the flows already had a different number of vehicles between the compliant and non-compliant workbooks.

### 6.2.1 Scheduled Bus Services

The bus routes operate on a fixed basis so there was no change in vehicle movements due to the CAZ. As the buses are modelled as a separate category of vehicle no additional traffic modelling was required to assess impact. It was assumed under any CAZ scenario that all buses would be 100% compliant as it would not be economically feasible to run the services daily and pay the initially proposed CAZ entry fee of £100 per day.

Details of the bus fleet for the 2015 base and projected 2020 Do-Min were provided by the West Yorkshire Combined Authority which listed the number of vehicles in the fleets of the five biggest local operators. The Do-Min would be the vehicle fleet if vehicles were naturally allowed to reach the end of their life cycle without additional external funding. There is an internal WYCA target to have 90% of the Leeds Bus fleet as Euro 5+ by 2020 which would have been subject to WYCA securing additional funding so was not deemed appropriate to replace the Do-Min.

However, if excessive legal pressure were applied by the operators to the point of providing exemptions from charging, it is assumed that this is the minimum fleet compliance level that could be achieved. This would assume that vehicles are of the ratio Euro IV/V/VI in proportions 10/45/45%. That would only require 10% of the fleet to upgrade from Euro III and IV to Euro VI compared to the Do-Min.

### 6.2.2 Taxi and Private Hire

Currently the LTM does not independently model T&PH movements. Based on historical count data, a conservative estimation was made as to what percentage of car movements on different link types are attributable to T&PH and this figure was applied across the model, varying from 15% in the city centre to 2% on the outer areas. The same percentage of movements was applied uniformly across all scenarios. The mix of engine types for the Do-Min was based on the 2016 collected ANPR survey logging the number of trips by T&PHs. This was broken down into age groups which was then projected forward to 2020 for the Do-Min scenario.

The implementation of T&PH charging relies on the creation of the National Taxi Database by central government. Without this, compliance would have to be assessed using local data only. This would mean that drivers could register with a neighbouring authority, but still operate in the Leeds area without registering as T&PH vehicle. If the National Taxi Database cannot be implemented it would most likely be politically unacceptable to only apply charges to Leeds registered drivers. Hence for a Low Compliance scenario it was assumed that T&PH would not be covered by the CAZ and operate under a Do-Min arrangement.

### 6.2.3 Cars and LGVS

There is no expected change in the Car and LGV fleet as a result of a CAZ-B scenario.

## 6.3 Results

The results of the 2020Do-Min model run indicates that there would be 13 sites exceeding 34µgm$^3$ of NO2, with 1 of those exceeding 40µgm$^3$ . The figure of 34µgm$^3$ was chosen due to the model RMSE being 6, which indicates results could fluctuate by this value. The tables below show the number of exceedances in each scenario.

*Table 17: Number of Receptors exceeding limit*

| | DM | CAZb LC | CAZb | CAZbpN | CAZdN |
|---|---|---|---|---|---|
| >40µgm$^3$ | 1 | 1 | 0 | 0 | 0 |
| >38µgm$^3$ | 4 | 3 | 1 | 1 | 0 |
| >34µgm$^3$ | 13 | 12 | 6 | 6 | 2 |

Where;

- DM: 2020 Do-Minimum scenario
- CAZb LC: 2020 CAZ-B Low Compliance scenario
- CAZb: 2020 CAZ-B scenario
- CAZbpN: 2020 CAZ-B scenario with reduced boundary and T&PHs operating as petrol-hybrid
- CAZdN: 2020 CAZ-D scenario with reduced boundary

*Table 18: Receptors with predicted high levels of $NO_2$*

| Site ID | X | Y | Zone | DM | CAZb LC | CAZb | CAZbpN | CAZdN |
|---|---|---|---|---|---|---|---|---|
| TD9050 | 428923 | 431681 | Central | 35.3 | 34.2 | 33.0 | 33.4 | 30.7 |
| TD18451 | 429216 | 433687 | IRR | 39.8 | 38.9 | 36.9 | 36.8 | 33.3 |
| TD26603 | 430829 | 433890 | A64 | 35.5 | 34.8 | 33.0 | 33.0 | 30.5 |
| TD28288 | 430766 | 433168 | Central | 39.1 | 38.4 | 36.7 | 36.6 | 33.2 |
| TD29051 | 429541 | 432076 | Central | 34.5 | 33.6 | 32.6 | 32.9 | 30.5 |
| TD36620 | 430698 | 433593 | Central | 39.8 | 37.9 | 33.4 | 33.4 | 31.3 |
| TD58230 | 430502 | 433899 | Central | 43.7 | 42.2 | 38.5 | 38.4 | 34.9 |
| TD74892 | 430978 | 433467 | Central | 36.3 | 35.3 | 33.0 | 33.0 | 30.5 |
| TD81387 | 430724 | 433133 | Central | 35.1 | 34.4 | 32.8 | 32.8 | 30.4 |
| TD28567 | 424040 | 428014 | Outer | 34.6 | 34.7 | 34.4 | 34.2 | 33.0 |
| TD47438 | 420263 | 434243 | Outer | 35.6 | 34.6 | 33.2 | 33.3 | 30.8 |
| TD8548 | 425067 | 428031 | Outer | 35.1 | 34.5 | 34.2 | 34.4 | 31.2 |
| TD36055 | 429507 | 426437 | Outer | 35.9 | 35.8 | 35.7 | 35.7 | 34.8 |

Table 18 shows concentrations for all sites where the Do Min concentration is greater than 34 µgm$^3$. All sites modelled close to or exceeding the 40µgm$^3$ limit (highlighted in red) are located in the city centre area. When accounting for background NO2, the Low Compliance scenarios only achieves a 5% reduction on average in Road NO2 across these 13 sites, while the CAZb and CAZbpN scenarios results in a 14% reduction and the CAZdN achieves a 27% reduction. The concentrations show that in a Low Compliance Scenario, achieving compliance at all target determination points is unlikely.

To fully understand the impact of different vehicles operating within the city centre, it is intended to utilise the ANPR survey data within the city centre combined with a recently developed AIMSUM traffic model, but this was not possible with the time constraints of this exercise.

## 6.4 Additional Sensitivity Work

An alternate method was developed to enable faster testing of the likely impacts of different upgrade rates for non-compliant vehicles. The method did not use additional traffic modelling, but relied on varying the level of different vehicle upgrades in the Emissions Model. This provided a rough approximation of the impact of different levels of compliance might have but assumed the same overall traffic flows on each link.

The traffic flows for the 2020 Reduced Boundary CAZ-B scenario were separated into five classes representing the different vehicle flows (Car, LGV, HGV, Bus, Taxi). Alterations were then made to the proportion of CAZ compliant vehicles to include some non-compliant types to match different upgrade rates. The weakness using this process is that for modelling a stated level of HGV compliance inside the CAZ area, this method also applied a blanket reduction on all roads outside the CAZ boundary, as compared to the link specific compliance rates used in the original set of results. The lower the modelled ratio on the link, the greater the skew. As such the results should be considered as indicative rather than specific.

The resulting emissions from individual vehicle classes were modelled separately in the Airviro Dispersion Model and the resulting raw NOx concentrations at each location were then combined. When this layered approach was compared to the original combined source approach, the result was 98% similar, apart from sites at the extreme edges of the model. As all the sites of interest within the CAZ all fell into the -2% range, it is considered that layered vehicle emission rates were close enough to use for sensitivity testing and indicative source apportionment, with the differences can be attributed to the internal workings of the dispersion model.

Using this approach additional layers were modelled with the Bus compliance rate set at 80%, (vs 100% in CAZ) and with HGV compliance rates set at 50%, 66%, 75%, 84% and 94%. The ratio of non-compliant Euro classes was maintained to match that modelled in the Do Min scenario. For T&PH 3 scenarios were modelled, “Exempt” (same as Do-Min), “Euro 6” (standard CAZ requirement) and “Hybrid”. Car and LGV contributions were assumed not to change and remained the same in all sensitivity scenarios.

By combining the results of the individual layers, a variety of different scenarios could be assessed. Table 19 shows the number of sites modelled for Target Determination points that exceed three different levels. The first level is 34 µgm$^3$ because the model RMSE is approximately 6µgm$^3$, 38µgm$^3$ to indicate the number of sites at greater risk of exceedance and those above the 40µgm$^3$ legal limit.

*Table 19 Compliance Rate and Receptors Exceeding limit*

| Compliance Rate | | | NO2 | | |
|---|---|---|---|---|---|
| Bus | HGV | Taxi | >34µgm$^3$ | >38µgm$^3$ | >40 gm$^3$ |
| 80% | 50% | Exempt | 13 | 3 | 1 |
| | | Euro 6 | 13 | 2 | 1 |
| | | Hybrid | 12 | 2 | 1 |
| | 66% | Exempt | 13 | 2 | 1 |
| | | Euro 6 | 12 | 2 | 1 |
| | | Hybrid | 11 | 2 | 1 |

| Compliance Rate | | | NO2 | | |
|---|---|---|---|---|---|
| Bus | HGV | Taxi | >34µgm$^3$ | >38µgm$^3$ | >40 gm$^3$ |
| 100% | 50% | Exempt | 12 | 2 | 0 |
| | | Euro 6 | 10 | 2 | 0 |
| | | Hybrid | 10 | 1 | 0 |
| | 66% | Exempt | 10 | 1 | 0 |
| | | Euro 6 | 10 | 1 | 0 |
| | | Hybrid | 9 | 1 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| | 75% | Exempt | 12 | 2 | 1 |
| | | Euro 6 | 10 | 1 | 1 |
| | | Hybrid | 10 | 1 | 1 |
| | 87% | Exempt | 10 | 2 | 1 |
| | | Euro 6 | 9 | 1 | 1 |
| | | Hybrid | 7 | 1 | 1 |
| | 94% | Exempt | 9 | 1 | 1 |
| | | Euro 6 | 7 | 1 | 0 |
| | | Hybrid | 7 | 1 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| | 75% | Exempt | 9 | 1 | 0 |
| | | Euro 6 | 8 | 1 | 0 |
| | | Hybrid | 8 | 1 | 0 |
| | 87% | Exempt | 7 | 1 | 0 |
| | | Euro 6 | 7 | 1 | 0 |
| | | Hybrid | 7 | 1 | 0 |
| | 94% | Exempt | 8 | 1 | 0 |
| | | Euro 6 | 7 | 1 | 0 |
| | | Hybrid | 7 | 1 | 0 |

The results indicate that of the sites reported, buses have the largest impact on concentrations with limited impact from HGVs and T&PHs. The site exceeding the 40µgm$^3$ limit in the lower compliance scenarios is the Target Determination point 58230 located on the inner ring road. By analysing the contribution from each layer, the estimated NOx contribution can be attributed to specific vehicle classes. In the 2020 Do-Minimum scenario, Bus contributions are estimated to form 35.3% of total NOx.

*Table 20: Vehicle Road NOx Contributions at TD58230*

| Scenario | Compliance Rate | | | Total Road NOx (µgm$^3$) | Car | LGV | HGV | Bus | Taxi |
|---|---|---|---|---|---|---|---|---|---|
| | Bus | HGV | Taxi | | | | | | |
| Do-Min | 35 | 66 | Exempt | 48.9 | 22.3 | 5.4 | 2.7 | 17.3 | 1.3 |
| CAZ-Bplus North | 100 | 94 | Hybrid | 33.5 | 22.2 | 5.4 | 1.1 | 4.4 | 0.5 |
| CAZ-Bplus North | 100 | 50 | Exempt | 36.6 | 22.1 | 5.3 | 3.5 | 4.4 | 1.3 |
| CAZ-Bplus North | 80 | 87 | Hybrid | 37.7 | 22.1 | 5.3 | 2.1 | 7.7 | 0.5 |

It was not possible to directly attribute NO2 contributions to specific vehicle types as the chemistry reaction is difficult to separate out for specific vehicles, and the secondary chemistry applies to total concentrations. It is possibly something that could be explored in later work.

However, if raw NOx is accepted as a proxy for equivalent $NO_2$ contribution, then this indicates that this site is very dependent on the high upgrade rate of f buses to meet the compliance target. If expected vehicle upgrade is achieved (100/94/Hybrid), it results in a 32% reduction in road NOx. This reduces to 25% if HGVs are only 50% compliant and T&PHs remain as the projected Do-Min. If buses are only 80% compliant and HGVs 87% that results in only a 23% reduction even with Hybrid T&HPs, which is enough to result in a breach of the 40µgm$^3$ target for NO2.

Of the two sites that have the highest bus contribution to NOx, one is TD58230 at 35% and the other is TD36620 at 50%. TD36620 has a range of 35.1-37.8µgm$^3$ of $NO_2$ across the sensitivity scenarios and is only just compliant at 39.8 µgm$^3$ in the Do-Min. The high levels at this site are realistic as the site is located next to the bus station. There are a further 12 sites that have a Bus NOx contribution greater than 20%, but only 2 of those have a Do-Min $NO_2$ concentrations greater than 34µgm$^3$.

## 6.5 Sensitivity Testing Conclusion

Indicative source apportionment work suggests that buses can be responsible for up to 50% of vehicle NOx emissions in the modelled area with HGVs and T&PH contributing up to 24% and 4% respectively. Of the sites that are at risk of exceedance, buses are the biggest contributor to NOx.

This was expected due to the low number of HGVs operating within the city centre. However it is believed that the T&PHs contribution is being underestimated on the links at risk. Because recent information on the number of T&PH operating across the modelled area was unavailable, historical data was used to estimate the number of T&PH trips around the city centre. More up to date survey information has since been commissioned and early analysis indicates that the contribution of the T&PH fleet will be much higher than modelled on many central links, including those at greatest risk of exceedance.

The sensitivity testing indicates there would be more tolerance for compliance to be achieved with lower upgrade responses within the HGV fleet than with the scheduled buses and T&PH fleets compared to the assumptions used in the model. The assumed upgrade rate for buses and the T&PH fleet is considered more likely to be achieved, regardless of the reduced penalty charge as these vehicles are known to make high a volume or repeated trips within the proposed CAZ boundary and there are already have retrofit options available within the market as well as the replacement vehicle option.

# 7 Additional & Supplementary Supporting Measures and Exemptions

In addition to the proposed Charging Clean Air Zone, a number of additional and supplementary measures have been proposed which should deliver further emission reductions and provide mitigation against the negative impact of those vehicles which will receive either exemptions or sunset periods.

An estimation has been made on the total tonnage of NOx expected to be saved or retained within the CAZ boundary due to the most significant measures and exemptions proposed. However, it is difficult to attribute the changes in contribution to any specific link without highly detailed knowledge of where individual vehicles will be operating. As such these impacts have not been included in the dispersion modelling and a qualitative assessment of their impact upon the predicted concentrations has been provided.

In most locations of concern, the number of vehicles concerned are likely be so few in both number and trips compared to the remainder of the fleet that the impact on annual average concentration levels will be negligible either way. However, it is assumed that the overall benefits of targeted additional measures to reduce emissions form certain key vehicle types will more than offset the negative effect of those vehicles which will be granted exemptions and sunset periods and as well as provide some mitigation towards the uncertainty contained within the modelling process.

## 7.1 Exemptions

The exemptions are being offered in a variety of cases and for a number of reasons.

- Emergency vehicles are exempt as equipment necessary for the preservation of life. All services have internal long-term commitments to move towards cleaner vehicles. It is complicated to model as the vehicles would generally have specific focal points such as hospitals or fire stations but the number and location of specific destinations are unknown.
- Showman's guild vehicles have been exempted as these are specialist vehicles and make a very small number of trips in the CAZ per year. The Air Quality impact is negligible.
- Vehicle's where it would be cost prohibitive or change the nature of the vehicle beyond its origin is exempted. The range of vehicles this covers ranges from a limited number of trips per year such as vintage buses, to others such as cement mixers, which could make many regular repeated trips but with a changing distribution pattern over the year.
- Older HGVs or Buses that are awaiting replacement or retrofit but are delayed due to supply chain constraints.
- Existing Euro 6 or Wheelchair Accessible Taxi and Private Hire Vehicles have a sunset period before being eligible for charging.
- School bus services are exempt as there is a continuing programme to replace or retrofit these vehicles, mileage is limited and impacts on vulnerable groups could be large.

Total emissions attributable to those vehicles which could be given exemptions or sunset periods, or vehicles which might be targeted to reduce emissions beyond the minimum requirement can be estimated reasonably accurately based on the expected annual distance covered within the proposed Clean Air Zone boundary. However, because the specific routes that these vehicles will travel on are not known, the impact of any additional measure or exemption on concentrations at any specific receptor cannot be calculated with any confidence as their impact will be averaged out across the entire modelled network.

## 7.2 Additional Measures

### 7.2.1 Electric LGVs

The LGV sector is not included in the CAZ but some additional measures are targeted to increase the uptake of electric vans. The council itself has already committed to procure a further two hundred electric vans by

2020, bringing its total electric fleet to circa 300 as well as ensuring its whole fleet is CAZ compliant or better, even for those vehicles not within the CAZ categories.

LCC is exploring options with Highways England to establish a regional centre of excellence for Electric and Hybrid LGVs that will serve as a demonstration, rental and sales hub and provide training to vehicle mechanics for the skills needed to maintain and repair the electrical systems on new vehicles. The expectation is that around 650 additional electric vans will be introduced into the Leeds City region.

### 7.2.2 Amendment of Taxi and Private Hire Standards

It is proposed to amend the existing licensing requirement for Taxis and Private Hire (T&PH) registered by Leeds City Council to allow more hybrid and electric vehicles to be eligible for service in the T&PH fleet. As a fleet, these vehicles, generally cover much higher mileage than the average car. Consequently for every g/km improvement in emissions gained from a T&PH vehicle would be the equivalent of upgrading up to four or five cars within the private car fleet. In addition, T&PH cars tend to focus their journeys around key locations within the city centre, leading to many more repeated trips within the areas of greatest exposure than other cars.

Currently 87% of vehicles registered as T&PH in Leeds are diesel. Moving the Leeds T&PH fleet beyond the standard CAZ requirement (Euro 4 petrol or Euro 6 diesel) to one which requires vehicles with a viable alternative to switch Electric, Petrol Hybrid or LPG will deliver the NOx benefits associated with petrol whilst retaining the carbon benefits diesel.

## 7.3 Supplementary and Supporting Measures

### 7.3.1 Accelerated uptake of ULEVs

Methods to increase the number of low and ultra-low emission vehicles (ULEVs) operating in the local fleet are been investigated.  Leeds City Council was an active partner in a successful bid by the West Yorkshire Combined Authority for funding from OLEV's ULEV Taxi fund aimed at increasing the uptake of plug-in vehicles within the local T&PH fleet. 2019 will see the first of up to 88 chargepoints installed with the aim of providing a West Yorkshire wide to provide a rapid and fast network to support both the public and the T&PH fleet.

It is expected that the knock on effect of introducing stricter T&PH conditions plus a significant number amount of infrastructure and supporting work with the T&PH fleet will be to encourage an accelerated uptake of ULEVs in to the T&PH fleet. It is also hoped that increasing numbers of hybrid and ULEVS in to a high profile fleet, more members of the public will get positive direct experience of travelling in these vehicles which will influence their next vehicle purchase.

Through the early measures fund, Leeds City Council is also working towards a scheme which will allow businesses to trial electric vehicles to act as a catalyst to uptake. However, we know that some larger businesses are already showing a desire to upgrade their electric fleet but are struggling with the need to upgrade the grid infrastructure at their depots to support wholesale changeovers.

### 7.3.2 Natural Gas Propulsion

For several years the council has operated a fleet of 11 CNG powered vehicles including five 26 tonne refuse collection vehicles (RCVs). There is currently a plan to build a high capacity CNG refuelling station in the south of the city to provide capacity for the rest of the councils RCV fleet and provide a publicly accessible CNG refuelling station. This will generate an additional reduction in nitrogen dioxide and carbon dioxide from council vehicles over and above that delivered by Euro VI diesel and encourage the uptake of CNG in the private HGV sector.

### 7.3.3 Anti- Idling

The council is also be looking to deliver a comprehensive anti-idling campaign citywide and has consulted on this during the statutory consultation period. The scheme is intended to be supported by citywide signage that will be funded via the early measures funding. This will initially be targeted around schools and taxi ranks. Whilst there may be some specific locations which will benefit from reduced local exposure from such as scheme, it is very difficult to quantify the benefits in concentration terms and the overall benefit may be through amplifying the importance of air quality.

### 7.3.4 Transportation and Traffic Management Schemes

The council is already progressing its plan to reduce vehicles within the city centre as part of its city centre package. This will see all vehicles other than buses and taxis removed from city square. This scheme will be delivered by 2023 and will in effect go further than a CAZ D for this highly populated area by removing a substantial number of vehicles from the centre of the city altogether contributing towards improving air quality beyond compliance levels in locations with high exposure rates.

The expected transport impacts of the completed city centre package has been included in the Leeds traffic Model for the year 2022 and has therefore been included in the air quality impacts modelled for that year. This has been done primarily to ensure that the projected further improvement in the fleet emission profile are not outweighed by increased traffic flows introduced any areas of non-compliance due to any diverted traffic flows.

The effects of any temporary changes and disruption to traffic flows caused during the construction phase of the city centre package and the many other scheduled transport improvement schemes planned for delivery within the next five years has not been assessed. However the once in operation, the schemes listed below will ultimately contribute to directly or indirectly improving reducing overall emissions and population exposure across Leeds. Each scheme will be assessed for its own impact on Air quality as part of the scheme design process. .

- Specific junction and corridor improvement schemes delivered as part of the wider Leeds Public Transport Investment Programme, Housing Infrastructure Fund and West Yorkshire Transport Fund.
- Further development of the cycle superhighway network on the A6120 Outer Ring Road of Leeds
- Introduction of SCOOT traffic management system in to 35 junctions and 20 pedestrian crossings funded through the National Productivity Investment Fund, which aims to alleviate congestion hotspots.
- HS2 enablement works.
- Park and Ride schemes

A qualitative assessment of the impact of the proposed exemptions and the additional and supporting measures (excluding the transportation and traffic management schemes is provided in

Table 21 and Table 22 below.

*Table 21 Qualitative Summary Assessment of Emission and Air Quality Impacts of Vehicles Proposed for Exemptions or Sunset Period*

| Vehicle Type as registered on ANPR | Represented in Emission modelling | Expected impact on Air Quality | Notes |
|---|---|---|---|
| **Emergency Vehicles** | As per age and weights class based on ANPR / Dft data/<br><br>Emergency vehicles which would otherwise be impacted by a CAZ B were represented in the modelling within whichever weight class they fell. Ie. Fire Engines were mainly treated as 15T rigid HGVs.<br><br>However, they represent a very small proportion of the overall HGV fleet. | **Minor negative impact**<br><br>Modelled impacts will be averaged across the network. In reality there will be some additional impacts within close proximity to the fire stations were there will be more repeatable trips.<br><br>Only 3 out of the 12 Fire Stations serving Leeds fall within the CAZ boundary. It is unknown how often Fire Engines travel on the roads that are most concern. | Emergency Vehicles do not move through the network in the same way that other vehicles do for around 50% of the time and their movements cannot be replicated within a traffic model. |
| **Showmen's Guild vehicles** | ANPR picked up a small amount of Special purpose HGVs which were split in to sub-weight categories based on ANPR / DfT data. However Showmen's vehicles are unlikely to have been included due to the rarity of their appearance in Leeds | **Imperceptible negative impact**<br><br>Extremely small number of vehicles doing very low number of trips. Their impact is not included in any data collected or subsequent modelling. | Showmen's vehicles are expected to travel less than 2000 miles between them within the Leeds district and therefore have negligible impact on annual average concentrations within the CAZ. |
| **Vintage buses (commercial versus non-commercial).** | Vintage buses captured under ANPR will have influenced the base year age profile but pre-euro buses equated to 0.08% of pre-euro buses.<br><br>Future base years profiled buses based on WYCA bus projections for scheduled service buses | **Minor negative impact**<br><br>Vintage buses are not expected to be high mileage or regular trip repeaters and represent a negligible percentage of total vehicle movements.<br><br>Non-scheduled services modelled as HGVs not buses leading to a potential slight under estimation of bus /coach impacts in the base years. Consequently, there is likely to be a slight under estimation of benefits attributed to compliant bus/ coaches in CAZ scenarios. | Mileage of vintage buses within the CAZ zone is expected to be very small and therefore to have negligible influence on whether compliance is met or not.<br><br>Overall the modelling includes a percentage of the HGVs remaining non-compliant in CAZ scenarios. Some of eth benefits attributed to HGVs will balance those underestimated form the non PSV bus/ coach fleet. |
| **Historic vehicles** | Any Historic vehicles captured within the ANPR data will have had some influence in the overall emission profile of the by being treated as Pre Euro standard | **Negligible negative Impact**<br><br>Fleet projections for future years retained the small percentage of Pre Euro vehicles as a constant within the emission modelling | The Emission model has retained the same proportion of non-compliant euro standards within the non-compliant vehicle flows. |

| Vehicle Type as registered on ANPR | Represented in Emission modelling | Expected impact on Air Quality | Notes |
|---|---|---|---|
| **Military Vehicles** | No Military vehicles were knowingly captured within the ANPR camera survey. | **Negligible negative Impact** | It is not expected that many military vehicles will regularly travel within the Leeds CAZ boundary. |
| **School buses** | Euro III and IV School buses operated on behalf of WYCA have been retrofitted but will not be picked out as such by the ANPR. | **Minor negative impact**<br><br>The benefits of non-scheduled buses becoming compliant could be slightly under-estimated because they will be included within the HGV flows. However, they tend to do lower mileage than HGVs and scheduled buses and their impacts will be spread out equally across all links. | Overall, school bus movements are small compared to other fleet movements and particularly small on links at risk of not achieving compliance due to their proximity to central Leeds. |
| **Specialist Vehicles** | Specialist vehicles are deemed to be those that are bought for specific purposes and will be difficult and expensive to replace or retrofit due to their nature. E.g. cement wagons, tower cranes and other specifically adapted vehicles.<br><br>Any vehicle falling in to this category has been included within the relevant weight categories to influence the emission calculations. | **Negligible negative impact**<br><br>No specific contributions have been modelled, their influence on the relevant vehicle class in terms of weight category will be averaged out across the network within the model. | Vehicles will be spread sparsely across the network and total numbers are not sufficiently high to influence annual average concentrations either way. |
| **Wheelchair Accessible Taxi and Private Hire Vehicles. (WAVs)** | In the base year they are captured within the ANPR data and included in the fleet fuel and age profile.<br><br>It has been assumed that all T&PH vehicles travel undertake the same number of trips. | **Unknown whether the overall impact is positive of negative**<br><br>An attempt has been made to provide a conservative but variable proportion of T&PH to different road links. Overall the impact of T&PH is expected to be underestimated in the model on many of the roads around the city centre.<br><br>With CAZ scenarios, it is uncertain how the impact of WAVs and other T&PH vehicles which will be exempted from becoming a petrol hybrid or ULEV will compare against the rest of the fleet | Most WAV vehicles are adapted by third parties and have limited alternatives.<br><br>It is generally considered that there needs to be more WAVs in the overall T&PH fleet. Sunset periods are considered necessary to ensure that numbers do not reduce further. |

*Table 22 Qualitative Summary Assessment of Emission and Air Quality Impacts for Proposed Additional and Supplementary Measures*

| Vehicle Type as registered on ANPR | Represented in Emission modelling | Expected impact on Air Quality | Notes |
|---|---|---|---|
| **ULEVs and petrol hybrids in Taxi Fleet.** | In the CAZ scenario with taxis modelled with petrol Hybrid option, 3.5% of hybrids were assumed to be plug-in ULEVs.<br><br>Leeds currently installing EVCPs partly funded by the ULEV Taxi grant | **Minor under estimate of benefits**<br><br>ULEVS and full hybrids will operate as a zero emission vehicle within congested areas, however the modelling assumes the overall lower emission rate is averaged out across the network | T&PH will dominate certain routes around the city centre area and generally become less significant further out. A previous study by Leeds University[7] indicates that up to 75% of taxi journeys are unlikely to travel beyond the Outer Ring Road. |
| **Increasing the number of electric vans** | The volume of emissions which could be removed can be estimated using the average mileage and vehicle type that an EV would be replacing. However the impact cannot be accurately represented in terms of concentrations. | **Minor under estimate of benefits**<br><br>The impact has not been modelled.<br>There is no certainty on which links electric LVG's would replace existing diesel variants, but the benefits are assumed to be greater within central areas where most businesses are located | The council has committed to purchase Circa 300 Electric vans.<br><br>Additional measures could target operators which cover the majority of their trips within the city centre such as couriers. |
| **Anti – Idling measures** | | **Minor under estimate of benefits.**<br><br>Impacts not modelled<br><br>No attempt to include the concentration impacts of these measures has been made within the model. | The biggest benefits from anti – idling measures are likely to be at locations such as schools which will have exposure benefits to younger age groups. |
| **CNG powered Refuse Collection Fleet** | Leeds is working towards installing a large capacity CNG station to increase the fleet of CNG RCVs and provide eth option for other HGVs to switch from diesel | **Minor under estimate of benefits**<br><br>No CNG impacts are incorporated within the model. It is not certain how many will be in fleet by 2020 and their movements are not reflected within the LTM | Due to their Duty Cycle, There are likely to be reductions in NOx emissions from RCVs within the residential areas which are not included within the modelled network. |

[7] **Real-world CO2 emission, and cost benefit, of a switch to hybrid electric vehicles in taxi fleets,** Richard RILEY*, James TATE**, Hu LI* & ZiaWADUD

## 7.4 Summary of the combined Impact of the Additional Measures and Exclusions

The negative impact on the performance of the CAZ B meeting compliance due to sunset periods and exemptions being allowed for small numbers of discreet vehicle types is difficult to assess with great certainty. This is due to limited knowledge of exactly when and which routes those vehicles will travel through the network. However there is confidence that the total number of vehicles falling in to this category relative to the total amount of trips undertaken by other vehicle types is very small in comparison.

Similar to the impact of exemptions and sunset periods, assessing the direct impact of the proposed additional measures is also difficult to do with confidence due to the uncertainty of exactly which routes the additional measures such as increased uptake of ULEVs will have the greatest impact.

Overall, in emission terms, analysis suggests the total benefits of the proposed additional measures (excluding Transport and Traffic Management schemes) will contribute a reduction of 4.5 Tonnes of NOx in 2020 compared to the 1.2 Tonnes of NOx expected to remain due to the vehicles exemptions and sunset periods.

However, the exact location of these additional savings cannot be determined and it is unclear whether the full benefit will be realised by 2020. The ratio between the predicted emission savings and the residual impacts resulting from the exemptions is considered reasonable when taking in to account uncertainties within the modelled options.

# 8 Target Determination and Technical Independent Review Panel

The process outlined in this section has been completed and the response from JAQU is that the modelling work is suitable to report on Air Quality in Leeds for purposes of assessing compliance.

## 8.1 Target Determination

National Air Quality modelling has previously utilised the national Pollution Climate Mapping (PCM) model commissioned by DEFRA to fulfil the UK requirements to report on a range of pollutants under European Directive 2008/50/EC.

Target Determination (TD) is one component of the wider evidence assurance process that JAQU is conducting for all local authorities named in the $NO_2$ Plan. TD involves sense checking each local authority's air quality model against the national PCM model. The sense check complements JAQU's check of local authorities' models against minimum modelling requirements[8] and JAQU's evidence review by independent experts (known as the Technical Independent Review Panel). Together, the three processes help ensure that each local authority's modelling is as robust as possible. The PCM model only contains major roads, therefore only the major road links within the local models can be sense checked against the PCM.

The purpose of TD is to establish whether the local modelling contains any obvious errors or mistakes. The PCM model has been designed very differently to the local models and its inputs are considerably less granular. Therefore, some differences in the outputs are expected and are not necessarily indicative of errors. Additionally, similarities in the outputs from the two models don't necessarily indicate that the local modelling is error free. This means that in order to conduct a thorough sense check, inputs must be considered as well as outputs.

TD is broken down into two stages. The first stage involves comparing the concentrations outputted by the two models to identify discrepancies (significant or unusual differences in concentration) and similarities (very similar concentrations). The second stage compares the inputs and data sources used in the models, to investigate the causes of both similarities and discrepancies and to assess whether these causes are reasonable and do not result from errors or mistakes.

The first stage of target determination has been completed for Leeds and a draft report was produced by JAQU (TD1). TD1 summarised the discrepancies and similarities between the models and identified road links to investigate further.

The second stage of the Target Determination (TD2) investigated the methodology and assumptions included in the modelling process. Then, differences and likenesses in both the input data and the sources of input data for each road link identified in TD1 were analysed. Finally, a 'reasonability assessment' of the causes of each similarity and discrepancy is presented, before concluding remarks are made.

### 8.1.1 Outputs Required

This is a key step in designing a scheme as it sets the benchmark as to whether a scheme option is fit for purpose and can be considered further. This allows assessment of the main critical success factor as part of the economic case. The process of target determination is needed once a local authority has completed their baseline local air quality modelling.

The PCM predicts annual average $NO_2$ concentrations at 4m from the kerb for those main roads which fall within an urban agglomeration. JAQU therefore require Local Authorities to provide typical concentration values, at a distance of 4m from the kerb derived from the local modelling at a single point which has been judged as "typically representative" of each of the links concerned. Concentration levels have been

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[8] These requirements follow Defra's Technical Guidance 16 (TG16) for air quality modelling and DfT's WebTAG (Transport analysis guidance) for transport modelling.

modelled for the 2015 and 2020 base years. In interim year has also been reported for 2018 using values interpolated between those modelled for 2015 and 2020.

### 8.1.2 Receptor Points

A set of receptor points were chosen to represent each link modelled in the National PCM referenced by the link census point number. Whilst generally looking to meet the criteria of “representative” of the link as whole, a balance was struck to take in to account of the lengths of the links, where the greatest chance of exposure is likely to occur, the expected range of concentrations that might be found along that link.

The criteria set for the receptor locations reported and used to determine compliance are summarises as;

- 4m from the kerb at a height of 2m
- Representative of links within the PCM model where there is deemed to be;
  - Public access within 15m of the kerb for a continuous length of at least 100m
  - Representative of “typical” conditions found along the link
  - More than 25m from a junction (defined as where the main flow is interrupted).

Figure 18 illustrates the location of all receptors where kerbside values have been calculated during the process compared with those road links reported in the national PCM. Whilst following the criteria laid out above, Figure 18 indicates how locations have generally been located closer rather than further away from junctions to ensure a conservative response and reflect the higher end of the concentration range due to the influence of additional nearby sources.

It is recognised that some locations may be included where the location criteria such as public access is borderline but exposure is present. A policy of “if in doubt, include it” has been adopted on the basis that these could be reviewed and removed from process at a later stage. A full comparison of annual average $NO_2$ concentrations predicted at all the kerbside locations identified in Figure 18 can be found in Appendix 5.

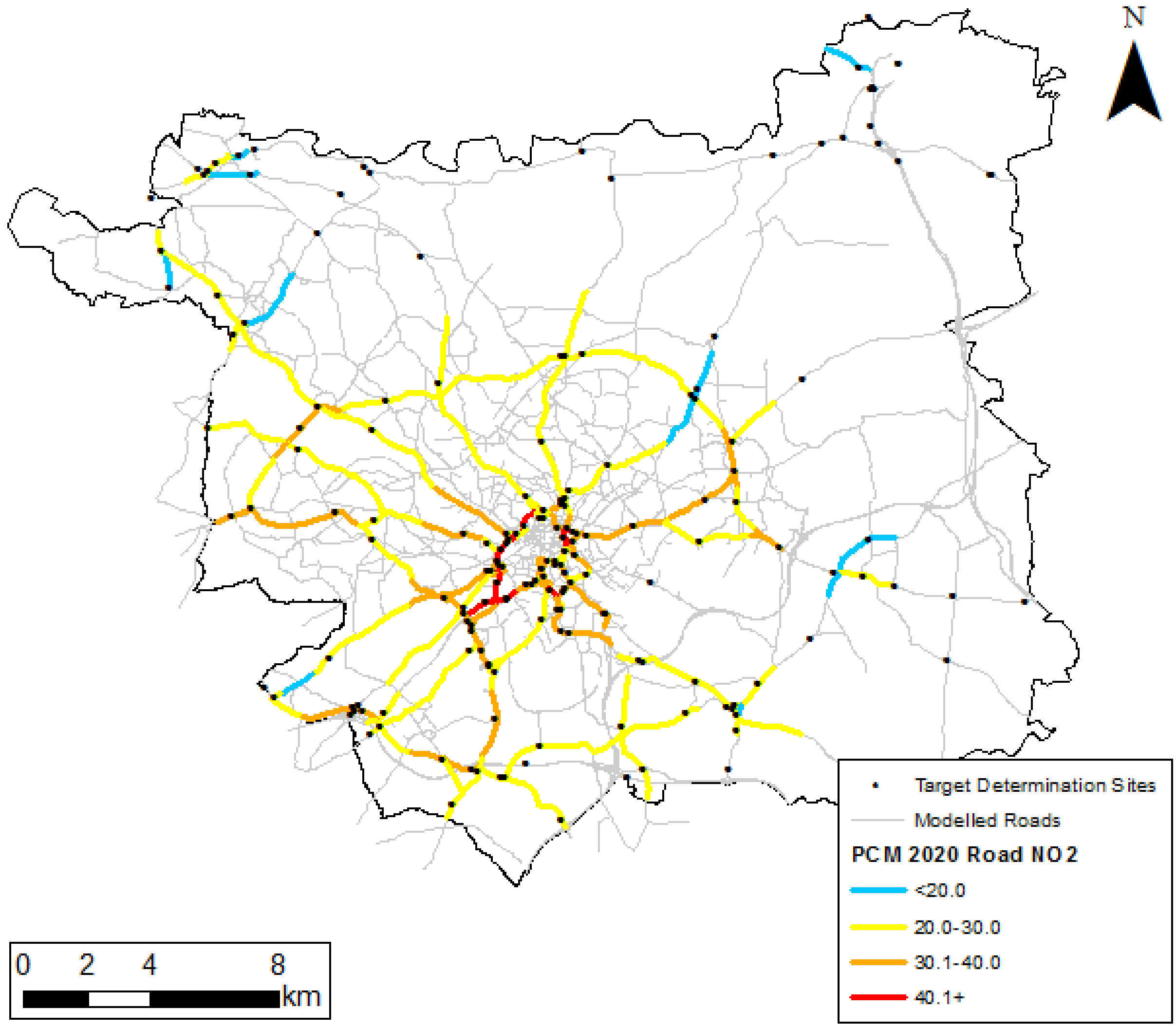



*Figure 18: Location of Receptor Points Returned from the Local Modelling Compared Against the Modelled PCM Network.*

### 8.1.3 2018 Interim Year Interpolation Method

The LTM takes in to account all expected developments which impact on increased or decreased traffic generation between 2015 and 2020. There are very few changes in the road network expected to be completed between 2015 and 2020 which will affect route choice or traffic generation. One possible exception to this is a new road, Manston Lane Link Road, expected to be completed by late 2018. Its anticipated affect will be to reduce traffic flows on the existing parallel route of the Outer Ring Road around the Cross Gates Area of Leeds, a more populated area which already met compliance in 2015.

The remainder of the road network in Leeds is not expected to change so it was deemed as reasonable to interpolate a set of interim receptor values for 2018 as accurately as possible, rather than follow a more expensive and time consuming process of running the LTM for 2018 and modelling everything from first principals. The interpolation process used the following method;

1. Calculate the difference between the adjusted modelled road-NOx and modelled f-NO2 in 2015 and 2020
2. Deduct 3/5ths of the difference from the 2015 values
3. Calculate the 2018 1km x 1km background values with sector removal applied following the same methods used for 2015 and 2020 values.
4. Apply the three values calculated above in to the Defra NOx to $NO_2$ calculator with the year set to 2018.

It is recognised that this could result in under estimating the interim values around the Cross Gates area. However, the levels are already lower than the target level and the area is modelled correctly for the 2020 period. Similarly, any impacts of the related junction improvements on the northern section of the Outer Ring Road will be included in within the 2020 scenarios.

## 8.2 Technical Review of the Modelling Process

In addition to the Target Determination process outlined in Section 6, JAQU have appointed a Technical – Independent Review Panel (T-IRP) to complete a full review of modelling process undertaken and suggest any further development that they feel should be included in the modelling process and areas which need to be further explained, or clarified within the Transport and Air Quality modelling technical reports.

At the time of writing this report specific draft responses to the queries raised have been submitted back to the panel T-IRP and incorporated in to the relevant sections of this repot where appropriate to provide further clarity.

## 8.3 Analytical Assurance Statement

The original Analytical Assurance Statement included within the last version of this technical report has since been reviewed and updated as both the evidence is analysed and feedback form the JAQU Target Determination process and T-IRP feedback has been received. The full Analytical Assurance Statement which covers the transport modelling, subsequent air quality modelling and the expected economic impacts has now submitted as a separate document.

# 9 Conclusion

The local modelling has been completed following current best practice and has been reviewed internally and externally. The JAQU review process did find some small methodological differences that can be explained by the availability of local data, but overall did not highlight any significant areas of concern with the local modelling methodology.

The source apportionment and sensitivity testing indicates that most locations of concern which show an improvement as a result of introducing a B class Clean Air Zone are influenced by buses more than any other affected vehicle types and that NO2 concentrations are forecast to reduce significantly to below or close to the compliance level if all scheduled buses were to meet the required standard.

There are some links which indicate that achieving compliance might be considered less than probable with an A class CAZ A scenario due to the margin of error within the modelling process. It is therefore considered necessary to introduce further measures to meet the requirement of delivering compliance as soon as possible

The results generated by the model indicate that a B-class Clean Air Zone targeting Buses, HGVs and T&PHs is sufficient to deliver compliance with the 40ugm3 target for locations specified in 8.1.2. Sensitivity testing indicates there is more tolerance of still achieving compliance with a lower upgrade responses than assumed in the model within HGV and T&HP fleets if upgrade responses for scheduled buses are close to the assumptions used. This is considered more likely, regardless of the reduced charge as these vehicles are known to make high volume trips within the zone and already have retrofit and replacement options available within the market.

Overall, the proposed additional measures are expected to balance out the proposed exemptions and sunset periods granted certain vehicle types and play a part in delivering reduced exposure to elevated concentrations levels as soon as possible.

It is highly probable that a D Class CAZ, targeting all vehicles will deliver compliance with the target with a greater degree of confidence, but is discounted both for reasons given in the economic business case.

# Appendix 1: Extract from the Airviro User Manual – Implementation of Wind Model and Localised Wind Fields

## 2A.1 Principles of Wind Field Calculations

The wind field calculation is based on the concept first described by Danard (1976), where mesoscale winds are generated by using:

- horizontal momentum equation
- pressure tendency equation
- first thermodynamic equation

This concept assumes that small-scale winds can be seen as a local adaptation of large scale winds (free winds) due to local fluxes of heat and momentum from the sea or earth surface. Any non-linear interaction between the scales is neglected. Danard assumes that the adaptation process is very fast, 1.5 hours for model resolutions of 10*10 km. It is also assumed that horizontal processes can be described by non-linear equations while the vertical processes can be parametrised as linear functions.

The large-scale winds as well as vertical fluxes of momentum and temperature are estimated from profile measurements in one or several meteorological masts (called principal masts). When the topography is relatively smooth, without dominating ridges or valleys, the free wind is assumed to be horizontally uniform.

For deep bi-directional valleys, this is not possible. A channel flow approach has been used to include the governing effects on the free winds in deep valleys.

For larger areas or for areas with complex meteorological situations (such as sea breeze) information from more than one meteorological station is needed. The data from these stations will then pass through a mesoscale interpolation before entering the wind model.

### 2A.1.1 Wind Model Equations

The equations below are solved in a terrain-following coordinate system (s-coordinates):

$$\frac{\partial V_s}{\partial t} = -V_s \cdot \nabla V_s - (g \nabla Z_s + RT_s \nabla \ln p_s) - fK \times V + F + K_m \nabla^2 V \quad \text{(eq 2A.1.1)}$$

$$\frac{\partial \Theta_s}{\partial t} = -V \cdot \nabla \Theta_s + K_t \nabla^2 \Theta_s + Q/C_p \quad \text{(eq 2A.1.2)}$$

$$\frac{\partial p_s}{\partial t} = \frac{g}{R \Theta_s T_s} \cdot \int_0^H \frac{\partial \Theta}{\partial t} dz \quad \text{(eq 2A.1.3)}$$

V = horizontal wind

$\Theta = T_s \left( \frac{P_0}{P_s} \right)^{\frac{R}{C_p}}$ = potential temperature

$F = c \cdot C_D \cdot \frac{V^2}{H}$ = friction, the drag coefficient: $C_D = \left[ \frac{\kappa}{\ln\left(\frac{z}{z_0}\right)} \right]^2$

p = air pressure

H = boundary layer height

(all variables with index s refer to the surface, i.e. 10m above ground)

### 2A.1.2 Initialisation

Boundary scaling parameters are determined from one or several profile measurements in the area, giving estimates of boundary layer heights (H), diabatic heating (Q) and potential temperature distribution at ground level ($\Theta_s$). Physiographical information (surface characteristics) is used for area interpolation of H, Q and Θs. A free wind, i.e. an estimate of a wind at the location of the mast, at the level (H) where the wind is not affected by surface fluxes of heat and momentum, is estimated based on the profile measurements and extrapolation procedures suggested by Holtslag (1984). The free wind field is estimated according to one of the methods suggested in *2A.1 Principles of Wind Field Calculations*.

When the free wind field is estimated, the initial surface pressure field is determined in accordance with a geostrophic balance. The initial wind field at the surface is estimated by running the first equation (eq 2A.1.1) until two successive estimations of the average wind component do not differ by more than 2%.

### 2A.1.3 Stability and Turbulence Estimation - Preprocessing of Meteorological Data

Stability and turbulence conditions in the boundary layer are evaluated at the locations of the principal masts, i.e. where information about both the temperature gradient and the wind speed at one or two levels is available. These data are used to calculate the boundary layer scaling parameters.

The two most important parameters for the scaling of the atmospheric stability and turbulence in the surface boundary layer are the vertical heat flux H and the friction velocity $u_*$. From these, a characteristic length scale - the Monin-Obukhov length - can be calculated:

$$L = \frac{T}{g} \cdot \frac{u_i^3 \rho c_p}{\kappa H}$$

where $T$ is the average surface air temperature, g is gravity, κ is the von Kárman constant and $\rho c_p$ is the specific heat capacity. In the Airviro dispersion models, the Monin-Obukhov length is extensively used as a discriminator of different meteorological regimes.

The determination of the Monin-Obukhov length (L) follows the profile method discussed by Berkowicz and Prahm (1982). With measured values of potential temperature difference (Δq) close to the ground and wind speed (U) at one or two levels, L is calculated with an iterative method. The local value of the ground roughness length $z_0$ must also be estimated (see tabulated values in textbooks, i.e. Panofsky and Dutton (1984), Table 5.1 and 5.2). For the case that two temperatures and one or two velocities are available, it is possible to calculate two other scaling variables $u_*$(friction velocity) and $T_*$ (temperature scale):

$$u_* = \frac{\kappa(U_{z2} - U_{z1})}{\ln\left(\frac{z_{u2}}{z_{u1}} - \Psi_{m2} + \Psi_{m1}\right)}$$

$$T_* = \frac{H}{\rho c_p u_*} = \frac{\kappa \Delta\theta}{\ln\left(\frac{z_{t2}}{z_{t1}} - \Psi_{H2} + \Psi_{H1}\right)}$$

The measurement heights are $z_{u2}$, $z_{u1}$, $z_{t2}$ and $z_{t1}$. If wind is measured at only one level ($z_{u2}$), $z_{u1}$ is set equal to $z_0$ and $U_{z1}$ to 0.

The similarity functions $\Psi_m$ and $\Psi_H$ are functions of (z/L). For stable conditions (L > 0) we can use (Dyer, 1974):

$$\Psi_m = -5 \cdot \frac{z}{L}$$

$$\Psi_H = -5 \cdot \frac{z}{L}$$

For unstable conditions (L< 0) Paulson (1970) proposes

$$\Psi_m = \ln\left[\left(\frac{1+x^2}{2}\right)\left(\frac{1+x}{2}\right)^2\right] - 2\arctan(x) + \frac{\pi}{2}$$

where

$$x = \left(\frac{1-16z}{L}\right)^{\frac{1}{4}}$$

and

$$\Psi_H = 2\ln\left[\frac{1}{2}\left(1 + \sqrt{1 - \frac{16z}{L}}\right)\right]$$

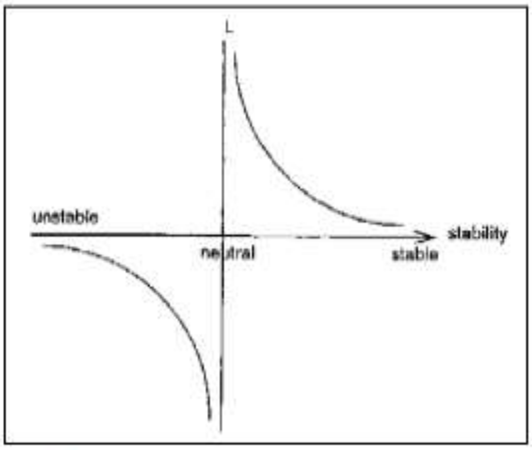



*Figure 2A.1 The Monin-Obukhov length (L) behaviour as a function of stability*

The calculated Monin-Obukhov length (L) is further used to classify the stability conditions. The depth of the boundary layer (Zi) is a key parameter, since the pollutants released close to ground will be more or less trapped inside this layer.

For stable conditions (L > 0) the Zilitinkevich (1972) estimation is used:

$$Zi = 0.4\sqrt{\frac{u_{*}}{f}L}$$

Note that this estimate relies on the assumption that the inversion is caused by local cooling. It will not serve for cases with (relatively high) inversions that are caused by advective air masses.

The corresponding expression for neutral and unstable conditions (L < 0) is (Panofsky and Dutton, 1984):

$$Zi = 0.3\left(\frac{u_{*}}{f}\right)$$

In practice the mixing height (mixh) often cannot be set equal to the boundary layer height (Zi). Here the relationship between these two heights is given in a resource file, by default

$$mixh = 50 + 10 \times \sqrt{Zi + 1}$$

Note that mixh varies with latitude.

This empirical relationship was obtained from a data set for Göteborg (see Indic, 1990).

It is possible as an option to set Zi equal to mixh.

Direct measurements of velocity fluctuations may be used to evaluate the dispersion coefficients $\sigma_y$ and $\sigma_z$ that regulate lateral and vertical diffusion of the Gaussian plume. The measured quantities are the standard deviation of wind direction ($\sigma_\alpha$) and vertical wind speed ($\sigma_\omega$). The technique suggested by Draxler (1976) is as follows:

$$\sigma_y = \sigma_\alpha X \frac{1}{\left[1 + 0.9\sqrt{\left(\frac{X}{UT_i}\right)}\right]}$$

where $T_i$ is a Lagrangean time scale (see Table below for values recommended by Draxler). X is downstream distance (from source), U is horizontal wind velocity and $\sigma_\alpha$ the standard deviation of the horizontal wind direction.

A similar expression is used for the vertical coefficient:

$$\sigma_z = \frac{\sigma_\omega}{U} X \frac{1}{\left[1 + 0.9\sqrt{\left(\frac{X}{UT_i}\right)}\right]}$$

where $\sigma_\omega$ is the standard deviation of the vertical wind speed.

*Figure 2A.2 Recommended values of $T_i$ according to Draxler (1976). Sources higher than 30 m is considered as elevated.*

| | Surface Sources | | Elevated Sources | |
|---|---|---|---|---|
| | Stable | Unstable | stable | unstable |
| Lateral | 300 | 300 | 1000 | 1000 |
| Vertical | 50 | 100 | 100 | 500 |

Note that all calculated meteorological parameters should be valid for simulation of one-hour values.

### 2A.1.4 Mesoscale Interpolation

**Influence areas**

Each grid point belongs to an influence type area and within each area the meteorological conditions are considered as similar. The influence areas can be for example sea, sea close to land, land, land close to sea, urban, suburban, and so on. There can be several different areas of the same kind, for instance two separate valleys. These influence areas must exist in a resource file with names and type numbers.

**Observation places**

Each observation place must be classified with an influence type number. The influence from every observation place on different areas must be stated with a real number $a_k(n)$, in the interval [0,1], where k is an index for the observation and n the area type number.

**Analysis method**

Each grid point should be classified with an influence type number, say nn (see appendix D3.3 in Airviro Specification Part II). For every grid point (i,j) a value is interpolated from all observation places:

$$value(i,j) = \frac{\sum_k obs(k) \times weight(i,j,k)}{\sum_k weight(i,j,k)}$$

where $weight(i,j,k) = \frac{\alpha_k(nn)}{d_k(i,j)}$

$d_k(i,j)$ = distance between the grid point (i,j) and the observation place k.

The resulting grid will thus be affected by the observations and to some extent also by different influence type areas.

**L, $u_*$, $T_*$, $w_*$, Zi and mixh**

The Monin-Obukhov length (L), friction velocity ($u_*$), temperature scale ($T_*$), convective velocity scale ($w_*$), boundary layer (Zi) and mixing height (mixh) are treated in much the same way.

The input data is taken from the pre-processor: L, $u_*$, $T_*$, $w_*$ and Zi. It is also possible for Zi to be measured directly, for instance from a SODAR.

If no principal station data exists within a zoomed area then data from the nearest principal mast is used as a constant value over the whole area.

The *heat island effect* is taken into account by adjusting stable conditions to neutral conditions over urban areas. The areas of distribution for which this correction is to be applied is defined in a grid - see appendix D3.3 in Airviro Specification Part II.

The location of this effect is given in a grid, see appendix D3.3 in Airviro Specification Part II.

**Surface temperature**

The input data are temperature observations from all places with at least two sensors in the vertical and in addition an analysed grid of L, $u_*$, $T_*$ and Zi from above.

With this information a surface temperature $T_s$ and $T_{init}$, which assumes a surface zero heat flux flow, is computed for every observation.

If data are missing within a zoomed area the main mast is used as a constant value over the whole area.

**Free wind**

Input data are all wind observations and the analysed grid of L.

The wind speed is first extrapolated to 150 m with help of a power law and the wind direction is twisted according to empirical data (Holtslag).

If there is no principal mast data available within a zoomed area then data from the nearest principal mast is used as a constant value over the whole area.

### 2A.1.5 Procedures for Solving the Wind Model Equations

When the initial conditions have been estimated, the thermodynamic equation (eq 2A.1.2) is used to estimate the local change in potential temperature. The tendency equation (eq 2A.1.3) is then utilised in order to estimate the local pressure tendency due to temperature effects. The change in local pressure at ground level is then used in the momentum equation (eq 2A.1.1) to estimate a wind tendency. Thereafter, the slightly changed wind field is used to estimate the tendency in the surface potential temperature and so on.

By iterating in this way, a quasi-steady-state condition will usually be reached within a few time steps (10-20). According to the initial assumptions, the length of the time steps is not allowed to be larger than a few seconds, in order to have an adaption process within a few minutes. The Danard concept is to some extent a contradiction. The concept is a diagnostic model, trying to identify the small scale variations in the wind field due to the forcing at the surface. To do this, prognostic equations are applied, but for periods so short that the large scale transient effects such as wind rotation due to the Coriolis force are filtered out. Consequently, it is not possible to describe the evolution of a see breeze, but to diagnose the see breeze if relevant input data (mast data) is present.

It is worthwhile observing that the model is not mass conservative.

### 2A.1.6 Numerical Methods

Generally, centred time and space differences have been used, i.e. the so-called leapfrog method. An upstream formula has been used for the advection terms.

The length of the time steps ($\Delta t$) depends upon the resolution of the grid ($\Delta s$) and the wind speed of the large scale wind ($V_g$), i.e.

$$\Delta t = \frac{(0.125 \times \Delta s)}{V_g}$$

Normally, for a 250*250 m resolution and a typical large-scale wind of 5 m/s, the length of the time steps would be 6 seconds. The total number of time steps has a maximum of 40. Consequently, the total adaption period in this case is 4 minutes.

### 2A.1.7 Reference Literature

Readers that are interested in further theories and experience with the Danard model are referred to: Danard (1977), Mass (1981), Mass (1984), Alpert and Getenio (1988). Numerical methods can be found in: Richtmeyer and Morton (1967), Messinger and Arakawa (1976).

# Appendix 2: Monitoring and Calibration - Extract from Leeds' 2016 Annual Status Report

## A2.1 Individual Pollutants

The air quality monitoring results are, where relevant, adjusted for "annualisation" and bias. Further details on adjustments are provided in Appendix 4. Real time monitoring is undertaken for Particulate Matter (PM10 and PM2,5) and Nitrogen Dioxide (NO2). Diffusion Tube monitoring is also undertaken for NO2. The details of each sites location, pollutant monitored and type of monitoring undertaken are include in Tables A.1 and A2 below.

**Table A.1 – Details of Automatic Monitoring Sites**

| Site ID | Site Name | Site Type | X OS Grid Ref | Y OS Grid Ref | Pollutants Monitored | In AQMA ? | Monitoring Technique | Distance to Relevant Exposure (m) (1) | Distance to kerb of nearest road (m) (2) | Inlet Height (m) |
|---|---|---|---|---|---|---|---|---|---|---|
| A1 | Leeds Centre (AURN) | Urban Centre | 429969 | 434259 | $NO_2$, $PM_{2.5}$ $PM_{10}$ (+$SO_2$, CO, $O_3$) | N | Chemiluminescent FDMS | N/A | N/A | 2.7 |
| A2 | Corn Exchange | Kerbside | 430358 | 433422 | $NO_2$, $PM_{10}$ | N | Chemiluminescent TEOM | 1 (1hr $NO_2$) | 1 | 2.7 |
| A3 | Headingley (AURN Affiliated) | Kerbside | 427989 | 436045 | $NO_2$, $PM_{2.5}$, $PM_{10}$ | N | Chemiluminescent FDMS | 1 (1hr $NO_2$) | 1 | 2.7 |
| A6 | Haslewood Close | Urban roadside | 431268 | 433701 | $NO_2$ | Y | Chemiluminescent | 0 | 7 | 3.3 |
| A7 | Queen St, Morley | Urban roadside | 426332 | 427870 | $NO_2$ | Y | Chemiluminescent | 0 | 5 | 3.0 |
| A9 | Jack Lane, Hunslet | Urban roadside | 430731 | 431911 | $NO_2$ | N | Chemiluminescent | N/A | 5 | 2.7 |
| A12 | Norman Row | Urban roadside | 426277 | 435816 | $NO_2$ | Y | Chemiluminescent | 1 | 2 | 1.5 |
| A17 | Kirkstall Rd | Urban roadside | 427147 | 434789 | $NO_2$ | N | Chemiluminescent | N/A | 5 | 2.7 |
| A18 | Temple Newsam | Semi-rural (b'ground) | 435940 | 432271 | $NO_2$ | N | Chemiluminescent | N/A | N/A | 2.4 |
| A19 | Tilbury Terrace | Urban roadside | 428830 | 431657 | $NO_2$ | Y | Chemiluminescent | 1 | 15 | 1.5 |

(1) 0m if the monitoring site is at a location of exposure (e.g. installed on the façade of a residential property).

(2) N/A if not applicable.

## Table A.2 – Details of Non-Automatic Monitoring Sites

| Site ID | Site Name | Site Type | X OS Grid Ref | Y OS Grid Ref | Pollutants Monitored | In AQMA? | Distance to Relevant Exposure (m) (1) | Distance to kerb of nearest road (m) (2) | Tube collocated with a Continuous Analyser? | Height (m) |
|---|---|---|---|---|---|---|---|---|---|---|
| D2 (A3) | Headingley (Affiliated) | Kerbside | 427989 | 436045 | $NO_2$ | N | N/A | 1m | Y | 2.7 |
| D6 (A6) | Haslewood Close, Wall corner (R) | Co-loc'd resid'tial façade | 431268 | 433701 | $NO_2$ | Y | 0 | 7m (to A64) | Y | 3.3 |
| D7 (A6) | Haslewood Close, Wall corner (L) | | | | | | | | | |
| D8 | Haslewood Close Gable | Resid'tial façade | 431264 | 433704 | $NO_2$ | Y | 0 | 8m | N | 2.4 |
| D9 | Haslewood Close facing open area | Resid'tial façade | 431269 | 433720 | $NO_2$ | Y | 0 | 27m | N | 2.4 |
| D17 | 19/20 Ladybeck Cl (rear) DP | Resid'tial façade | 430750 | 433813 | $NO_2$ | Y | 0 | 13m | N | 2.4 |
| D19 | Ladybeck Reception (rear) | Resid'tial façade | 430695 | 433835 | $NO_2$ | Y | 0 | 14m | N | 2.4 |
| D20 | 25 Ladybeck Cl, rear block (side) | Resid'tial façade | 430727 | 433834 | $NO_2$ | Y | 0 | 6m (to A64) | N | 2.4 |
| D24 | West Street Car Park | Urban Centre | 429011 | 433617 | $NO_2$ | N | N/A | 25m | N | 2.7 |
| D26 D27 D28 (A1) | Leeds Centre AURN (L) (R) (M) | Urban Centre | 429969 | 434259 | $NO_2$ | N | N/A | 30m | Y | 2.7 |

| Site ID | Site Name | Site Type | X OS Grid Ref | Y OS Grid Ref | Pollutants Monitored | In AQMA? | Distance to Relevant Exposure (m) (1) | Distance to kerb of nearest road (m) (2) | Tube collocated with a Continuous Analyser? | Height (m) |
|---|---|---|---|---|---|---|---|---|---|---|
| D31 | Railway Terrace, East Ardsley | Resid'tial façade | 430151 | 426388 | $NO_2$ | N | 0 | 14m (to M62) | N | 2.4 |
| D35 | 110 Jack Lane, Hunslet | Resid'tial façade | 430720 | 431898 | $NO_2$ | N | 0 | 7m | N | 2.4 |
| D43 | 82 New Road Side, Horsforth | Resid'tial façade roadside | 423925 | 437335 | $NO_2$ | N | 0 | 1m | N | 2.4 |
| D44 | 253 New Road Side, Horsforth | Resid'tial façade roadside | 423269 | 437505 | $NO_2$ | N | 0 | 2m | N | 2.4 |
| D45 | 2 Norman Row, pipe, Kirkstall | Resid'tial façade roadside | 426276 | 435820 | $NO_2$ | N | 0 | 2m | N | 2.4 |
| D46 | 4 De Lacey Mount, Kirkstall | Resid'tial façade | 426214 | 435955 | $NO_2$ | N | 0 | 7m | N | 2.4 |
| D47 | 2 Back Norman Mount, Kirkstall | Resid'tial façade roadside | 426216 | 435945 | $NO_2$ | N | 0 | 3m | N | 2.4 |
| D48 | 2 Haddon Place, Kirkstall | Resid'tial façade roadside | 427437 | 434618 | $NO_2$ | N | 0 | 3m | N | 2.4 |
| D52 | 78 Selby Rd, Garforth LP | Suburb'n kerbside | 440063 | 432361 | $NO_2$ | N | 0 | 2m | N | 2.4 |
| D53 | 1 Gilbert Mount, Kirkstall | Resid'tial façade | 426531 | 435222 | $NO_2$ | N | 0 | 17m (to A65) | N | 2.4 |

| Site ID | Site Name | Site Type | X OS Grid Ref | Y OS Grid Ref | Pollutants Monitored | In AQMA? | Distance to Relevant Exposure (m) (1) | Distance to kerb of nearest road (m) (2) | Tube collocated with a Continuous Analyser? | Height (m) |
|---|---|---|---|---|---|---|---|---|---|---|
| D59 (A2) | Corn Exchange | Urban Centre | 430358 | 433422 | $NO_2$ | N | 0 | 1m | Y | 2.7 |
| D60 | Kirkstall Rd/ Woodside Terr. | Co-loc'd roadside | 427147 | 434789 | $NO_2$ | N | 0 | 5m | Y | 2.7 |
| D66 | 131 Harehills Lane | Resid'tial façade | 431928 | 435910 | $NO_2$ | N | 0 | 7m | N | 2.4 |
| D68 (A9) | Jack Lane GH | Resid'tial roadside | 430731 | 431911 | $NO_2$ | N | N/A | 5m (to A61) | Y | 2.7 |
| D70 | Ladysmith Workwear, Easy Road | R'dside | 431534 | 432764 | $NO_2$ | N | 0 | 7m | N | 2.4 |
| D74 | Norman Street, Kirkstall Rd LP | R'dside | 426291 | 435800 | $NO_2$ | N | 0 | 12m | N | 2.4 |
| D76 | 302 York Road | Resid'tial façade | 432569 | 433764 | $NO_2$ | N | 0 | 8m | N | 2.4 |
| D78 | 2 Eyres Terrace | Resid'tial façade | 427089 | 433686 | $NO_2$ | N | 0 | 6m | N | 2.4 |
| D95 | High Street LP, Wetherby | R'dside | 440442 | 448133 | $NO_2$ | N | 0 | 2m | N | 2.4 |
| D96 | 21 St James St, Wetherby | Resid'tial R'dside | 440408 | 448407 | $NO_2$ | N | 0 | 1m | N | 2.4 |
| D98 | 76 Woodhouse Hill Rd | Resid'tial façade | 431347 | 430578 | $NO_2$ | N | 0 | 22m (to M621) | N | 2.4 |
| D105 | 76 Selby Rd, Garforth | Suburb'n kerbside | 440034 | 432364 | $NO_2$ | N | 0 | 4m | N | 2.4 |

| Site ID | Site Name | Site Type | X OS Grid Ref | Y OS Grid Ref | Pollutants Monitored | In AQMA? | Distance to Relevant Exposure (m) (1) | Distance to kerb of nearest road (m) (2) | Tube collocated with a Continuous Analyser? | Height (m) |
|---|---|---|---|---|---|---|---|---|---|---|
| D109 | 107 Bradford Rd, Otley | Resid'tial façade roadside | 419598 | 445168 | $NO_2$ | N | 0 | 3m | N | 2.4 |
| D110 | 23 Westgate, Otley | Resid'tial façade roadside | 420037 | 445462 | $NO_2$ | N | 0 | 2m | N | 2.4 |
| D114 | 8 Main Street, Pool | Resid'tial façade roadside | 424507 | 455151 | $NO_2$ | N | 0 | 2m | N | 2.4 |
| D115 | 66 North Street, Wetherby | Resid'tial façade roadside | 440537 | 448514 | $NO_2$ | N | 0 | 2m | N | 2.4 |
| D117 | 15 Ashfield Road, Morley | Resid'tial façade roadside | 425691 | 426879 | $NO_2$ | N | 0 | 2m | N | 2.4 |
| D118 | 1 Rein Road, Morley | Resid'tial façade roadside | 426914 | 426605 | $NO_2$ | N | 0 | 2m | N | 2.4 |
| D119 | 109 Bridge Street, Morley | Resid'tial façade roadside | 426788 | 426773 | $NO_2$ | N | 0 | 6m | N | 2.4 |
| D120 | 2 Chapel Hill, Morley | Resid'tial façade roadside | 426362 | 428162 | $NO_2$ | N | 0 | 2m | N | 2.7 |

| Site ID | Site Name | Site Type | X OS Grid Ref | Y OS Grid Ref | Pollutants Monitored | In AQMA? | Distance to Relevant Exposure (m) (1) | Distance to kerb of nearest road (m) (2) | Tube collocated with a Continuous Analyser? | Height (m) |
|---|---|---|---|---|---|---|---|---|---|---|
| D121 | adj 32 Otley Road, Headingley | Resid'tial façade roadside | 427906 | 436195 | $NO_2$ | N | 0 | 2m | N | 2.4 |
| D122 | North Street, LS2 (o/s Northern Intelligence) | Resid'tial façade roadside | 430522 | 434022 | $NO_2$ | N | 0 | 2m | N | 2.4 |
| D123 | Victoria Avenue | Resid'tial façade roadside | 432419 | 433674 | $NO_2$ | N | 0 | 15m (to A64) | N | 2.4 |
| D124 | 21 Rein Road, Morley | Resid'tial façade roadside | 426990 | 426466 | $NO_2$ | N | 0 | 4m | N | 2.4 |
| D125 | 12 Tilbury Terrace | Resid'tial façade | 428824 | 431658 | $NO_2$ | Y | 0 | 17m (to M621) | N | 2.4 |
| D126 | 73 East Park Parade | Resid'tial façade roadside | 432527 | 433409 | $NO_2$ | N | 0 | 2m | N | 2.4 |
| D128 | 51 Long Row, Horsforth | Resid'tial façade roadside | 424168 | 438668 | $NO_2$ | N | 0 | 1m | N | 2.4 |
| D129 | 33 Long Row, Horsforth | Resid'tial façade roadside | 424143 | 438610 | $NO_2$ | N | 0 | 4m | N | 2.4 |
| D133 | St Wilfrid's Terrace, Main Street, Pool | Resid'tial façade roadside | 424405 | 445305 | $NO_2$ | N | 0 | 1m | N | 2.4 |

| Site ID | Site Name | Site Type | X OS Grid Ref | Y OS Grid Ref | Pollutants Monitored | In AQMA? | Distance to Relevant Exposure (m) (1) | Distance to kerb of nearest road (m) (2) | Tube collocated with a Continuous Analyser? | Height (m) |
|---|---|---|---|---|---|---|---|---|---|---|
| D135 | Gotts Road (L) | R'dside | 428866 | 433332 | $NO_2$ | N | N/A | 7m (to A58M) | N | 2.4 |
| D136 | Gotts Road (R) | R'dside | 428858 | 433327 | $NO_2$ | N | N/A | 7m (to A58M) | N | 2.4 |
| D137 | 362 Bradford Rd, Thornbury | Resid'tial façade roadside | 420612 | 434359 | $NO_2$ | N | 0 | 4m | N | 2.4 |
| D144 | Railway Terrace, East Ardsley LP | R'dside | 430142 | 426388 | $NO_2$ | N | 0 | 12m (to M62) | N | 2.4 |
| D145 | 256 Lingwell Gt Lane | Resid'tial façade | 431883 | 425566 | $NO_2$ | N | 0 | 70m (to M1) | N | 2.4 |
| D147 | Queensway Roadsign | Kerbside | 420369 | 441588 | $NO_2$ | N | N/A | 0 | N | 2.4 |
| D148 | Queensway Telegraph post | Kerbside | 420294 | 441598 | $NO_2$ | N | N/A | 0 | N | 2.4 |
| D149 | Tilbury Row new tube | Kerbside | 428762 | 431670 | $NO_2$ | Y | 0 | 35m (to M621 on-slip) | N | 2.4 |
| D150 | 582 Meanwood Road | Resid'tial façade roadside | 428630 | 436940 | $NO_2$ | N | 0 | 2m | N | 2.4 |
| D151 | Sunbeam Terrace, 2 Bradford Road, Tingley | Resid'tial façade roadside | 428280 | 426170 | $NO_2$ | N | 0 | 5m | N | 2.4 |
| D152 | Seven Hills School, Morley | | 426700 | 427900 | $NO_2$ | N | 0 | 22m | N | 2.4 |

| Site ID | Site Name | Site Type | X OS Grid Ref | Y OS Grid Ref | Pollutants Monitored | In AQMA? | Distance to Relevant Exposure (m) (1) | Distance to kerb of nearest road (m) (2) | Tube collocated with a Continuous Analyser? | Height (m) |
|---|---|---|---|---|---|---|---|---|---|---|
| D153 | 3 Oban Terrace, Bradford Road, Tingley | Resid'tial façade | 427900 | 426240 | $NO_2$ | N | 0 | 10m | N | 2.4 |
| D154 | The Brambles, Bradford Road, Tingley | Resid'tial façade | 428080 | 426220 | $NO_2$ | N | 0 | 27m | N | 2.4 |
| D155 | 9 Ladybeck Close | Resid'tial façade | 430720 | 433785 | $NO_2$ | Y | 0 | 12m | N | 2.4 |
| D156 | 368 Dewsbury Road | Resid'tial façade | 429465 | 430247 | $NO_2$ | N | 0 | 6m | N | 2.4 |
| D157 | Maple Court | Resid'tial façade | 428599 | 430790 | $NO_2$ | N | 0 | 15m | N | 2.4 |
| D158 | 69 Jessamine Avenue | Resid'tial façade | 428817 | 430464 | $NO_2$ | N | 0 | 6m | N | 2.4 |
| D159 | 659 Dewsbury Road | Resid'tial façade | 428990 | 429855 | $NO_2$ | N | 0 | 16m | N | 2.4 |
| D160 | 79 Faroe off Gotts Road | Resid'tial façade | 429070 | 433250 | $NO_2$ | N | 0 | N/A | N | $5^{th}$ Floor |

(1) 0m if the monitoring site is at a location of exposure (e.g. installed on/adjacent to the façade of a residential property).
(2) N/A if not applicable.

# Appendix 3: Quality Assurance and Control of Monitoring Data Extract from Leeds' 2016 Annual Status Report

## A3.1 Automatic Monitoring Network and data

The Leeds City Council monitoring network is managed and operated by a team of officers within the Environmental Protection Team (EP Team) of the Environment and Housing Directorate. The combined expertise of this group covers all aspects of the management of the network from routine site procedures through calibration to data ratification. Appropriate training both internal and from external agencies such as EMAQ has been received by officers within the team.

The QA/QC for the Leeds Centre AURN site and the affiliated Leeds Headingley Roadside site is carried out by Ricardo Energy & Environment (E&E). Officers within the EP Team provided LSO support for the Leeds Centre site between 1993 and 2009 and continue in this role at Headingley.

### A3.1.1 Instrumentation

A combination of API and Monitor Labs instruments is used to monitor oxides of nitrogen (NOx) to establish $NO_2$ concentrations in the network together with a R&P TEOM to monitor $PM_{10}$ particles.

All stations are air conditioned with the exception of Temple Newsam where the analyser is sited in a large brick-built store room/unused office.

### A3.1.2 Servicing

Service contracts are in place so that all analysers are serviced every 6 months together with 6 monthly GPT testing of the gas analyser at the Headingley site and annual GPT testing elsewhere. The contract also requires attendance to breakdowns within 48 hours of callout.

All service and breakdown visits by engineers are recorded in the form of engineers' reports and stored within the Department for later use (during data ratification, assessment of long-term analyser performance etc.).

### A3.1.3 Calibration

Sites are attended fortnightly for manual calibration, routine site checks and maintenance. The procedures for these site visits are documented in internal guidance documents based on the instrument manufacturers' operation manuals and the AURN Site Operators Manual.

Pre-calibration checks are made which check ancillary equipment such as modems and air conditioning and to record instrument status.

Zero response to clean air is carried out through the use of in-line scrubbers.

Span checks are carried out using nitric oxide calibration gas of known concentration with a certified concentration ± 5%.

Instrument and TEOM filters are changed if required followed by post-zero and span checks to ensure that everything is operational before leaving site.

All Calibration visits are recorded on calibration forms and on site specific spreadsheets kept within the Department.

### A3.1.4 Data collection

Automatic data collection from the stations is achieved using the Airviro data administration module. 15-minute un-scaled data is collected from the on-board memory of each analyser.

The data is reviewed daily to determine that the collection protocols are working, that the data looks sensible and to identify faults. This involves viewing and comparing data from different locations.

Should assessment of the data lead to action being taken, this is recorded within a spreadsheet kept by the Department.

### A3.1.5 Site Audits

A locally operated auditing system for calibration gases is employed in house by the EP Team. Gas cylinders are audited against Air Liquide gases independently analysed by Ricardo E&E.

All audit visits and the results of the audit are kept in site-specific spreadsheets, together with the certificate of analysis for the audit gas.

### A3.1.6 Data ratification

While this process was carried out in-house, in recent years data ratification has been carried out externally by Air Quality Data Management.

Electronic analysers suffer drifts in their response to the zero (baseline) gas and sensitivity changes with time. Raw data from the NOx instruments are therefore scaled into concentrations using the latest values derived from the manual and automatic calibrations.

The ratification process finalises the data to produce the measurements suitable for reporting. All available information (including fortnightly calibrations, service records and audit reports) is critically assessed so that the best data scaling is applied and all anomalies are appropriately edited. Generally this operates at three, six or twelve month intervals. However, unexpected faults can be identified during the instrument routine services or independent audits which are often at 6-monthly intervals. In practice, therefore, the data can only be fully ratified in 12-month or annual periods. The data processing performed during the three and six monthly cycles helps build a reliable dataset that is finalised at the end of the year.

In addition to overcoming the drift in analyser performance, anomalies in the collected data can occur for a variety of reasons that could result in data being discarded. Instruments and infrastructure can fail in numerous ways that significantly and visually affect the quality of the measurements. These may include:

- ignoring calibrations that were poor e.g. a spent zero scrubber
- closely tracking rapid drifts or eliminating the data
- comparing the measurements with other pollutants and nearby sites
- corrections due to span cylinder drift
- corrections due to flow drifts for the particulate instruments
- corrections for ozone instrument sensitivity drifts
- eliminating measurements for $NO_2$ conversion inefficiencies
- eliminating periods where calibration gas is in the ambient dataset
- identifying periods were instruments are warming-up after a powercut
- identification of anomalies due to mains power spikes
- correcting problems with the date and time stamp
- observations made during the sites visits and services

The identification of data anomalies, the proper understanding of the effects and the application of appropriate corrections requires expertise gained over many years of operational experience.

#### A3.1.7 $PM_{10}$ corrections

Monitoring of PM10 (and PM2.5) as part of the national AURN is carried out using fdms (filter dynamics measurement system) equipment. However, the PM10 monitor installed in the Corn Exchange monitoring station is an older TEOM (Tapered Element Oscillating Microbalance) instrument. Results from this equipment has been corrected to a 'gravimetric equivalent' (ie the fdms system) using the TEOM VCM (Volatile Correction Model).

### A3.2 QA/QC of diffusion tube monitoring

#### A3.2.1 Diffusion tube precision and 'AIR $NO_2$ PT' performance

The West Yorkshire Analytical Services laboratory (WYAS) supply nitrogen dioxide diffusion tubes to the city council for its investigations. AIR NO2 PT is an independent analytical proficiency-testing scheme run on behalf of Defra. Performance reports on all analytical laboratories taking part in AIR NO2 PT are described as satisfactory. In terms of the precision associated with the analysis of multiple tubes, there is no more than one occasion in each of the last three years when the performance of WYAS was described as anything other than 'Good'.

#### A3.2.2 Diffusion tube bias adjustment factors

The preparation method of the nitrogen dioxide diffusion tubes supplied to the city council has been 50% TEA in acetone manufactured by Harwell Scientific Services. A spreadsheet compiled by the National Physical Laboratory reports bias corrections reflecting the difference between results obtained from automatic analysers compared with those obtained from co-located diffusion tubes analysed by individual laboratories. The number of co-located tubes has decreased in recent years but from the six co-located sites, the reported bias correction to be used for this diffusion tube and WYAS as the analyst is 0.77 for 2015.

# Appendix 4: Clim.rf set up file and resulting ClimSH.Freq for the 2015 Scenario

## A4.1 Clim.rf set up file.

Lines beginning with *" ! "* are excluded from the set up when run using the Klmstat command.

```
clim.lat_lon:        53.75   -1.5
!           "season" classes (max 20)

clim.NS:             8
clim.season1:        1001 0331        WINTER_8m
clim.season2:        0401 0930        SUMMER_8m
clim.season3:        0101 1231        YEARLY_8m
clim.season4:        000101 001231    2000_8m
clim.season5:        010101 011231    2001_8m
clim.season6:        020101 021231    2002_8m
clim.season7:        950404 991231    4.5_YEAR
clim.season8:        150101 151231    2015

!     stability classes (max 10)
clim.NCLASS:          3
clim.stabclass1:      -0.00505      MOD.UNSTABLE
clim.stabclass2:      0.00455       NEUTRAL_POS
clim.stabclass3:      99.9999       VERY_STABLE

!           no. of direction classes
!clim.NDDKL:                30
clim.NDDKL:                 60
clim.PERIOD:                950404 170101
!           Timelengths in Gauss model
!     For NCLASS=3
clim.LAST.month: 100 100 100 100 100 100 100 100 100 100 100 100
clim.LAST.s1_am: 1  1  1  1  1  1  1  1  1  1  1  1
clim.LAST.s1_pm: 1  1  1  1  1  1  1  1  1  1  1  1
clim.LAST.s2_am: 1  1  1  1  1  1  1  1  1  1  1  1
clim.LAST.s2_pm: 1  1  1  1  1  1  1  1  1  1  1  1
clim.LAST.s3_am: 6  6  6  6  6  6  6  6  6  6  6  6
clim.LAST.s3_pm: 6  6  6  6  6  6  6  6  6  6  6  6

!  CASE     stability classes (max 10)
case.NCLASS:                6
case.class1:        -0.100     UNSTABLE       425.  0.5 10. -0.35  14.0
case.class2:        -0.020   MOD.UNSTABLE     395.  0.5 10. -1.00  14.0
case.class3:        -0.002     NEUTRAL_NEG    375.  0.5 20. -0.15  10.0
case.class4:         0.002     NEUTRAL_POS    270.  0.5 20.  0.15  10.0
case.class5:         0.020   MOD.STABLE       165.  0.5 10.  1.00   6.0
case.class6:         0.100     VERY_STABLE    120.  0.5 10.  4.00   6.0
!          1/L                mixh  ff1 ff2  dt/dz temp
!case.sigy1:        0.32*x1/sqrt(1.+0.0004*x1)
case.sigy2:         0.22*x1/sqrt(1.+0.0004*x1)
case.sigy3:         0.16*x1/sqrt(1.+0.0004*x1)
case.sigy4:         0.16*x1/sqrt(1.+0.0004*x1)
case.sigy5:         0.11*x1/sqrt(1.+0.0004*x1)
```

| | |
|---|---|
| case.sigy6: | 0.11*x1/sqrt(1.+0.0004*x1) |
| case.sigz1: | 0.24*x1*sqrt(1.+0.001*x1) |
| case.sigz2: | 0.20*x1 |
| case.sigz3: | 0.14*x1/sqrt(1.+0.0003*x1) |
| case.sigz4: | 0.14*x1/sqrt(1.+0.0003*x1) |
| case.sigz5: | 0.08*x1/sqrt(1.+0.00015*x1) |
| case.sigz6: | 0.08*x1/sqrt(1.+0.00015*x1) |

## A4.2 2015 Scenario ClimSH.rf file Weighted Hours Chosen to Represent the Full 2015 Meteorological Data

- The first column is the season class number, which relates to what is defined in the file clim.rf set-up file 8 = 2015 full year
- The next column is just an index string.
- The third column is the mean value of the wind direction in within the wind direction interval class.
- The fourth column is the stability class number, which relates to the definition in the clim.rf set-up file
- The next columns are the dates (YY-MM-DD) and the hour chosen to represent the stability and widn direction interal. (Note that hour should be in the interval [1,24]. If date equals -99 no individual has been found for that class and the model continues with the next class
- The 7th column is the percentage weighting for the class.

The rest of the values are not used in the model (they are; the number of hours in the class together with wind force, temperature, boundary layer height and inverse Monin-Obukov-length).

| Season | mean wind Dir | Stability class | DATE YYMMDD | HOUR | WEIGHTING | Number in the Class | Wind Force | TEMP | BOUNDARY LAYER HEIGHT | Inverse Monin-Obukhov length |
|---|---|---|---|---|---|---|---|---|---|---|
| 8 | 3 | 1 | 150325 | 10 | 0.091 | 8 | 2.7 | 4.5 | 1016.21 | -0.01037 |
| 8 | 9 | 1 | 150206 | 11 | 0.126 | 11 | 2.4 | 2 | 911.62 | -0.01173 |
| 8 | 15 | 1 | 150907 | 12 | 0.148 | 13 | 1.6 | 14.7 | 656.49 | -0.01571 |
| 8 | 21 | 1 | 150416 | 8 | 0.103 | 9 | 1.9 | 6.2 | 736.77 | -0.01222 |
| 8 | 27 | 1 | 150916 | 10 | 0.16 | 14 | 2.9 | 11.6 | 1081 | -0.00609 |
| 8 | 33 | 1 | 151019 | 9 | 0.137 | 12 | 2.1 | 8.7 | 815.67 | -0.0115 |
| 8 | 39 | 1 | 150613 | 8 | 0.091 | 8 | 2.3 | 13.1 | 888.89 | -0.01057 |
| 8 | 45 | 1 | 150421 | 13 | 0.137 | 12 | 1.7 | 14.8 | 705.88 | -0.02247 |
| 8 | 51 | 1 | 151028 | 11 | 0.114 | 10 | 1 | 11 | 387.1 | -0.01651 |
| 8 | 57 | 1 | 150612 | 9 | 0.137 | 12 | 2.3 | 13.2 | 894.27 | -0.01453 |
| 8 | 63 | 1 | 150610 | 8 | 0.08 | 7 | 2 | 10.1 | 778.39 | -0.01405 |
| 8 | 69 | 1 | 150824 | 12 | 0.194 | 17 | 1.9 | 16.4 | 747 | -0.01404 |
| 8 | 75 | 1 | 150610 | 12 | 0.171 | 15 | 2.7 | 14 | 1013.82 | -0.00992 |
| 8 | 81 | 1 | 151010 | 11 | 0.114 | 10 | 1.9 | 9.9 | 691.38 | -0.0072 |
| 8 | 87 | 1 | 150908 | 15 | 0.171 | 15 | 1.7 | 12.8 | 651.56 | -0.00929 |
| 8 | 93 | 1 | 150611 | 9 | 0.114 | 10 | 2.2 | 12.2 | 857.21 | -0.01257 |
| 8 | 99 | 1 | 150908 | 13 | 0.183 | 16 | 1.5 | 11.8 | 600.02 | -0.01897 |
| 8 | 105 | 1 | 150908 | 12 | 0.08 | 7 | 1.3 | 11.3 | 564.33 | -0.02328 |
| 8 | 111 | 1 | 150416 | 14 | 0.126 | 11 | 1.8 | 11.5 | 731.59 | -0.0212 |
| 8 | 117 | 1 | 150703 | 13 | 0.137 | 12 | 2.5 | 21.3 | 954.09 | -0.01078 |
| 8 | 123 | 1 | 150604 | 8 | 0.114 | 10 | 2 | 12 | 793.95 | -0.01252 |

| Season | mean wind Dir | Stability class | DATE YYMMDD | HOUR | WEIGHTING | Number in the Class | Wind Force | TEMP | BOUNDARY LAYER HEIGHT | Inverse Monin-Obukhov length |
|---|---|---|---|---|---|---|---|---|---|---|
| 8 | 129 | 1 | 150408 | 11 | 0.08 | 7 | 2.5 | 11.8 | 969.89 | -0.01061 |
| 8 | 135 | 1 | 150926 | 13 | 0.137 | 12 | 1.8 | 14.9 | 714.36 | -0.01661 |
| 8 | 141 | 1 | 151102 | 14 | 0.148 | 13 | 1.9 | 10.6 | 717.62 | -0.0115 |
| 8 | 147 | 1 | 150927 | 14 | 0.148 | 13 | 1.9 | 13 | 751.68 | -0.01347 |
| 8 | 153 | 1 | 150615 | 11 | 0.16 | 14 | 2.2 | 13.1 | 836.8 | -0.0113 |
| 8 | 159 | 1 | 151004 | 15 | 0.205 | 18 | 2 | 13.1 | 775.72 | -0.01046 |
| 8 | 165 | 1 | 150325 | 17 | 0.16 | 14 | 1.3 | 5.9 | 513.32 | -0.01743 |
| 8 | 171 | 1 | 151004 | 13 | 0.103 | 9 | 1.7 | 12.5 | 691.98 | -0.01656 |
| 8 | 177 | 1 | 151101 | 14 | 0.137 | 12 | 0.9 | 14.4 | 431.46 | -0.05092 |
| 8 | 183 | 1 | 150212 | 13 | 0.114 | 10 | 2.1 | 5.1 | 816.77 | -0.01048 |
| 8 | 189 | 1 | 150703 | 9 | 0.08 | 7 | 1.3 | 17.6 | 590.05 | -0.03544 |
| 8 | 195 | 1 | 150317 | 14 | 0.148 | 13 | 1.3 | 7.1 | 553.51 | -0.02748 |
| 8 | 201 | 1 | 150409 | 13 | 0.08 | 7 | 1.6 | 15.3 | 666.3 | -0.02386 |
| 8 | 207 | 1 | 150702 | 14 | 0.034 | 3 | 2.4 | 20.9 | 909.36 | -0.01089 |
| 8 | 213 | 1 | 150410 | 7 | 0.091 | 8 | 2 | 7.3 | 752.62 | -0.00956 |
| 8 | 219 | 1 | 150212 | 10 | 0.08 | 7 | 1.7 | 1.6 | 700.82 | -0.01861 |
| 8 | 225 | 1 | 150926 | 10 | 0.046 | 4 | 1.3 | 13.1 | 581.97 | -0.02784 |
| 8 | 231 | 1 | 150515 | 9 | 0.126 | 11 | 1.8 | 7.9 | 736.03 | -0.01817 |
| 8 | 237 | 1 | 150409 | 17 | 0.16 | 14 | 1.6 | 15 | 657.69 | -0.01991 |
| 8 | 243 | 1 | 150427 | 8 | 0.08 | 7 | 1.9 | 3.9 | 732.05 | -0.01352 |
| 8 | 249 | 1 | 151002 | 12 | 0.114 | 10 | 1.7 | 13.4 | 688.85 | -0.01827 |
| 8 | 255 | 1 | 150616 | 9 | 0.114 | 10 | 1.8 | 16.1 | 721.47 | -0.01998 |
| 8 | 261 | 1 | 150722 | 11 | 0.183 | 16 | 2.4 | 13.8 | 897.05 | -0.00908 |
| 8 | 267 | 1 | 150623 | 15 | 0.183 | 16 | 1.7 | 16.3 | 693.21 | -0.0146 |
| 8 | 273 | 1 | 150623 | 17 | 0.126 | 11 | 2.7 | 16.3 | 1011.39 | -0.00903 |
| 8 | 279 | 1 | 150830 | 9 | 0.183 | 16 | 1.7 | 15.2 | 657.73 | -0.01016 |
| 8 | 285 | 1 | 150406 | 16 | 0.103 | 9 | 2 | 15.9 | 778.74 | -0.01013 |
| 8 | 291 | 1 | 150402 | 11 | 0.194 | 17 | 1.7 | 6.4 | 667.22 | -0.01624 |
| 8 | 297 | 1 | 150727 | 10 | 0.103 | 9 | 1.6 | 13.9 | 644.65 | -0.01847 |
| 8 | 303 | 1 | 150715 | 18 | 0.126 | 11 | 2.7 | 17.5 | 999.95 | -0.00842 |
| 8 | 309 | 1 | 150816 | 18 | 0.137 | 12 | 1 | 16 | 400.61 | -0.02177 |
| 8 | 315 | 1 | 150730 | 10 | 0.091 | 8 | 1.8 | 12.6 | 702.75 | -0.01411 |

| Season | mean wind Dir | Stability class | DATE YYMMDD | HOUR | WEIGHTING | Number in the Class | Wind Force | TEMP | BOUNDARY LAYER HEIGHT | Inverse Monin-Obukhov length |
|---|---|---|---|---|---|---|---|---|---|---|
| 8 | 321 | 1 | 150426 | 7 | 0.08 | 7 | 2.7 | 3.8 | 1027.48 | -0.00772 |
| 8 | 327 | 1 | 150902 | 8 | 0.091 | 8 | 2.3 | 11.7 | 900.57 | -0.0133 |
| 8 | 333 | 1 | 150406 | 8 | 0.148 | 13 | 2.4 | 9.3 | 924.73 | -0.01344 |
| 8 | 339 | 1 | 150902 | 9 | 0.08 | 7 | 2.4 | 13.2 | 929.4 | -0.00931 |
| 8 | 345 | 1 | 150406 | 9 | 0.091 | 8 | 2.4 | 11 | 909.87 | -0.00821 |
| 8 | 351 | 1 | 150817 | 11 | 0.057 | 5 | 3 | 17.6 | 1098.46 | -0.00668 |
| 8 | 357 | 1 | 150907 | 7 | 0.08 | 7 | 2.2 | 9.8 | 821.94 | -0.00682 |
| 8 | 5 | 2 | 150313 | 8 | 0.673 | 59 | 5.5 | 3.5 | 1862.31 | 0.00026 |
| 8 | 11 | 2 | 150905 | 4 | 0.662 | 58 | 5.9 | 10.3 | 1063.74 | 0.00093 |
| 8 | 17 | 2 | 150321 | 15 | 0.502 | 44 | 5.9 | 6.7 | 2012.29 | -0.00032 |
| 8 | 23 | 2 | 150614 | 9 | 0.502 | 44 | 5.3 | 10.7 | 1818.35 | -0.00099 |
| 8 | 29 | 2 | 150614 | 16 | 0.422 | 37 | 4.5 | 10.1 | 1557.68 | -0.00119 |
| 8 | 35 | 2 | 150419 | 12 | 0.354 | 31 | 6.4 | 9.5 | 2216.15 | -0.00089 |
| 8 | 41 | 2 | 150315 | 5 | 0.16 | 14 | 4.5 | 3.2 | 597.09 | 0.0022 |
| 8 | 47 | 2 | 150314 | 18 | 0.16 | 14 | 5.1 | 4.5 | 633.34 | 0.0022 |
| 8 | 53 | 2 | 150813 | 17 | 0.274 | 24 | 3.6 | 16.4 | 1228.92 | -0.00063 |
| 8 | 59 | 2 | 150315 | 14 | 0.445 | 39 | 6.1 | 7.2 | 2107.05 | -0.00061 |
| 8 | 65 | 2 | 150315 | 17 | 0.354 | 31 | 5.7 | 5.8 | 1285.73 | 0.00062 |
| 8 | 71 | 2 | 150314 | 12 | 0.274 | 24 | 5.2 | 5.6 | 1790.23 | -0.00097 |
| 8 | 77 | 2 | 150514 | 14 | 0.297 | 26 | 5.9 | 9 | 2028.69 | -0.00082 |
| 8 | 83 | 2 | 150914 | 14 | 0.365 | 32 | 4.2 | 12.5 | 1453.57 | -0.00128 |
| 8 | 89 | 2 | 150823 | 12 | 0.217 | 19 | 8.4 | 22.4 | 2905.83 | -0.00141 |
| 8 | 95 | 2 | 150502 | 23 | 0.411 | 36 | 5.5 | 5.1 | 935.19 | 0.00112 |
| 8 | 101 | 2 | 150909 | 17 | 0.605 | 53 | 4.4 | 14.5 | 1509.86 | -0.00002 |
| 8 | 107 | 2 | 151027 | 10 | 0.514 | 45 | 4.5 | 11 | 1544.26 | -0.00012 |
| 8 | 113 | 2 | 150912 | 3 | 0.514 | 45 | 5.2 | 12.1 | 893.25 | 0.00115 |
| 8 | 119 | 2 | 150726 | 18 | 0.354 | 31 | 4.9 | 11.7 | 1671.73 | 0.00005 |
| 8 | 125 | 2 | 150121 | 12 | 0.434 | 38 | 5.1 | 0.9 | 1692.56 | 0.00032 |
| 8 | 131 | 2 | 150726 | 16 | 0.308 | 27 | 6.1 | 12.2 | 2083.85 | -0.00045 |
| 8 | 137 | 2 | 150213 | 10 | 0.536 | 47 | 6.4 | 4.6 | 2167.17 | -0.00009 |
| 8 | 143 | 2 | 151228 | 6 | 0.628 | 55 | 5.8 | 8.8 | 1050.29 | 0.00093 |
| 8 | 149 | 2 | 150312 | 10 | 0.434 | 38 | 5.7 | 8.5 | 1947.2 | -0.00028 |

| Season | mean wind Dir | Stability class | DATE YYMMDD | HOUR | WEIGHTING | Number in the Class | Wind Force | TEMP | BOUNDARY LAYER HEIGHT | Inverse Monin-Obukhov length |
|---|---|---|---|---|---|---|---|---|---|---|
| 8 | 155 | 2 | 151203 | 13 | 0.605 | 53 | 3.7 | 8.5 | 915.74 | 0.00079 |
| 8 | 161 | 2 | 150312 | 15 | 0.673 | 59 | 6.8 | 12.3 | 2337.62 | -0.00011 |
| 8 | 167 | 2 | 151229 | 20 | 0.605 | 53 | 7.3 | 7.9 | 1691.96 | 0.00046 |
| 8 | 173 | 2 | 151229 | 24 | 0.594 | 52 | 9.2 | 10.1 | 2687.9 | 0.00023 |
| 8 | 179 | 2 | 151230 | 2 | 0.639 | 56 | 9.4 | 11.1 | 2846.13 | 0.00021 |
| 8 | 185 | 2 | 151117 | 13 | 0.696 | 61 | 5.7 | 9.5 | 1955.34 | 0.00006 |
| 8 | 191 | 2 | 150114 | 24 | 1.039 | 91 | 12.1 | 7.7 | 4123.67 | 0.00011 |
| 8 | 197 | 2 | 150228 | 18 | 1.096 | 96 | 7.8 | 8.1 | 1895.23 | 0.00039 |
| 8 | 203 | 2 | 151219 | 22 | 1.256 | 110 | 8.6 | 13.2 | 2261.18 | 0.0003 |
| 8 | 209 | 2 | 151222 | 3 | 1.336 | 117 | 8.6 | 9.5 | 2324.11 | 0.00029 |
| 8 | 215 | 2 | 151112 | 20 | 2.192 | 192 | 9.2 | 12.1 | 2633.32 | 0.00024 |
| 8 | 221 | 2 | 151226 | 9 | 3.139 | 275 | 8.3 | 12.1 | 2310.2 | 0.00028 |
| 8 | 227 | 2 | 151115 | 18 | 4.041 | 354 | 8.1 | 13.6 | 2156.78 | 0.00031 |
| 8 | 233 | 2 | 151111 | 17 | 3.082 | 270 | 8 | 13 | 1956.21 | 0.00038 |
| 8 | 239 | 2 | 150523 | 19 | 3.653 | 320 | 2.6 | 13.2 | 877.4 | 0.00038 |
| 8 | 245 | 2 | 151110 | 2 | 3.436 | 301 | 10.8 | 14.6 | 3450.27 | 0.00016 |
| 8 | 251 | 2 | 150711 | 5 | 3.653 | 320 | 3.7 | 14.9 | 1271.48 | 0.00021 |
| 8 | 257 | 2 | 151119 | 1 | 3.767 | 330 | 11.1 | 8.3 | 3478.77 | 0.00017 |
| 8 | 263 | 2 | 150127 | 15 | 4.144 | 363 | 6.3 | 6.3 | 2149.49 | -0.00016 |
| 8 | 269 | 2 | 150607 | 5 | 3.801 | 333 | 4.9 | 8.7 | 1656.24 | -0.0001 |
| 8 | 275 | 2 | 150110 | 15 | 3.71 | 325 | 10.7 | 4.3 | 3647.81 | 0.00011 |
| 8 | 281 | 2 | 150331 | 7 | 3.116 | 273 | 11.6 | 5.4 | 3947.81 | -0.00003 |
| 8 | 287 | 2 | 150221 | 15 | 1.541 | 135 | 6.1 | 4.7 | 2119.88 | -0.00095 |
| 8 | 293 | 2 | 150607 | 18 | 0.673 | 59 | 4.8 | 13 | 1692.82 | -0.0019 |
| 8 | 299 | 2 | 150824 | 17 | 0.628 | 55 | 2.7 | 17.1 | 925.92 | -0.00048 |
| 8 | 305 | 2 | 150903 | 7 | 0.422 | 37 | 2.8 | 10.1 | 854.36 | 0.00069 |
| 8 | 311 | 2 | 151121 | 12 | 0.308 | 27 | 6.8 | 1.7 | 2322.7 | -0.00051 |
| 8 | 317 | 2 | 150922 | 14 | 0.217 | 19 | 4.3 | 14 | 1522.17 | -0.00253 |

| Season | mean wind Dir | Stability class | DATE YYMMDD | HOUR | WEIGHTING | Number in the Class | Wind Force | TEMP | BOUNDARY LAYER HEIGHT | Inverse Monin-Obukhov length |
|---|---|---|---|---|---|---|---|---|---|---|
| 8 | 323 | 2 | 150904 | 7 | 0.148 | 13 | 4 | 9.8 | 1405.93 | -0.00196 |
| 8 | 329 | 2 | 150904 | 15 | 0.24 | 21 | 3.5 | 14.3 | 1233.98 | -0.00175 |
| 8 | 335 | 2 | 150201 | 5 | 0.297 | 26 | 9.4 | 2.2 | 2557.74 | 0.00026 |
| 8 | 341 | 2 | 150725 | 6 | 0.274 | 24 | 4.1 | 10.8 | 1346.04 | 0.00041 |
| 8 | 347 | 2 | 151121 | 8 | 0.342 | 30 | 9.8 | 1.7 | 2270.11 | 0.00034 |
| 8 | 353 | 2 | 151212 | 15 | 0.457 | 40 | 6 | 1.7 | 1137.6 | 0.00082 |
| 8 | 359 | 2 | 150614 | 6 | 0.4 | 35 | 3.7 | 10.4 | 1266.51 | 0.00005 |
| 8 | 7 | 3 | 150321 | 22 | 0.4 | 35 | 2.2 | 1.7 | 39.31 | 0.09272 |
| 8 | 13 | 3 | 150430 | 22 | 0.285 | 25 | 2.6 | 2.9 | 63.57 | 0.0566 |
| 8 | 19 | 3 | 150403 | 19 | 0.342 | 30 | 2.1 | 8.2 | 70.4 | 0.04304 |
| 8 | 25 | 3 | 151203 | 2 | 0.377 | 33 | 1.1 | 7.3 | 29.23 | 0.10631 |
| 8 | 31 | 3 | 151010 | 5 | 0.171 | 15 | 1.2 | 6.1 | 28.37 | 0.11284 |
| 8 | 37 | 3 | 150930 | 4 | 0.251 | 22 | 2.1 | 8.2 | 64.78 | 0.04763 |
| 8 | 43 | 3 | 150317 | 4 | 0.297 | 26 | 2.1 | 3.1 | 59.22 | 0.05357 |
| 8 | 49 | 3 | 151010 | 23 | 0.32 | 28 | 2.1 | 8.2 | 64.76 | 0.04769 |
| 8 | 55 | 3 | 151010 | 22 | 0.251 | 22 | 2.2 | 8.3 | 76.6 | 0.03874 |
| 8 | 61 | 3 | 150929 | 24 | 0.297 | 26 | 2 | 7.8 | 33.73 | 0.10417 |
| 8 | 67 | 3 | 150523 | 5 | 0.354 | 31 | 1.8 | 9.5 | 46.86 | 0.06529 |
| 8 | 73 | 3 | 150214 | 24 | 0.365 | 32 | 2.4 | 4.8 | 105.06 | 0.02632 |
| 8 | 79 | 3 | 150929 | 18 | 0.285 | 25 | 2.4 | 11.6 | 64.39 | 0.05297 |
| 8 | 85 | 3 | 150929 | 20 | 0.365 | 32 | 2.3 | 9.8 | 41.77 | 0.08873 |
| 8 | 91 | 3 | 151028 | 8 | 0.331 | 29 | 1.9 | 10.5 | 61.77 | 0.04693 |
| 8 | 97 | 3 | 151028 | 9 | 0.434 | 38 | 1.6 | 10.7 | 103.35 | 0.01987 |
| 8 | 103 | 3 | 151215 | 2 | 0.457 | 40 | 2.9 | 6.1 | 218 | 0.00944 |
| 8 | 109 | 3 | 150610 | 21 | 0.183 | 16 | 2.3 | 9.5 | 41.99 | 0.0882 |
| 8 | 115 | 3 | 151103 | 17 | 0.194 | 17 | 2.3 | 8.9 | 95.28 | 0.02928 |
| 8 | 121 | 3 | 150928 | 20 | 0.308 | 27 | 2.2 | 9.9 | 72.48 | 0.0419 |
| 8 | 127 | 3 | 150630 | 21 | 0.285 | 25 | 3 | 19.1 | 180.46 | 0.01339 |
| 8 | 133 | 3 | 151102 | 17 | 0.342 | 30 | 2.2 | 9.1 | 74.85 | 0.04067 |
| 8 | 139 | 3 | 151201 | 6 | 0.491 | 43 | 2.5 | 3.8 | 125.87 | 0.02044 |
| 8 | 145 | 3 | 150402 | 20 | 0.399 | 35 | 2 | 6.4 | 48.49 | 0.06737 |
| 8 | 151 | 3 | 151002 | 18 | 0.263 | 23 | 2.1 | 11.3 | 38.65 | 0.0938 |

| Season | mean wind Dir | Stability class | DATE YYMMDD | HOUR | WEIGHTING | Number in the Class | Wind Force | TEMP | BOUNDARY LAYER HEIGHT | Inverse Monin-Obukhov length |
|---|---|---|---|---|---|---|---|---|---|---|
| 8 | 157 | 3 | 151105 | 21 | 0.24 | 21 | 2 | 12.1 | 52.31 | 0.06122 |
| 8 | 163 | 3 | 150629 | 23 | 0.297 | 26 | 2 | 15.3 | 46.16 | 0.07208 |
| 8 | 169 | 3 | 150325 | 22 | 0.365 | 32 | 2.9 | 2.1 | 211.38 | 0.00999 |
| 8 | 175 | 3 | 151028 | 23 | 0.24 | 21 | 2.9 | 7.8 | 118.06 | 0.02513 |
| 8 | 181 | 3 | 151214 | 7 | 0.308 | 27 | 2.4 | 6.1 | 109.86 | 0.02453 |
| 8 | 187 | 3 | 150510 | 3 | 0.274 | 24 | 1.9 | 5.4 | 38.37 | 0.08848 |
| 8 | 193 | 3 | 151029 | 24 | 0.217 | 19 | 2.1 | 7.5 | 66.5 | 0.04616 |
| 8 | 199 | 3 | 150211 | 8 | 0.126 | 11 | 2.5 | 1.8 | 122.69 | 0.02124 |
| 8 | 205 | 3 | 150823 | 20 | 0.377 | 33 | 2.7 | 14.9 | 198.45 | 0.01047 |
| 8 | 211 | 3 | 150912 | 22 | 0.263 | 23 | 2.4 | 9 | 81.54 | 0.03819 |
| 8 | 217 | 3 | 151104 | 24 | 0.525 | 46 | 2.2 | 8 | 51.65 | 0.06674 |
| 8 | 223 | 3 | 150713 | 5 | 0.399 | 35 | 2 | 13.3 | 91.04 | 0.02867 |
| 8 | 229 | 3 | 150912 | 20 | 0.605 | 53 | 2.8 | 10.3 | 125.38 | 0.02243 |
| 8 | 235 | 3 | 150802 | 2 | 0.457 | 40 | 2.1 | 10.8 | 60.53 | 0.05172 |
| 8 | 241 | 3 | 151025 | 2 | 0.731 | 64 | 3 | 6 | 169.82 | 0.01483 |
| 8 | 247 | 3 | 151206 | 19 | 0.788 | 69 | 2 | 3.7 | 39.55 | 0.08585 |
| 8 | 253 | 3 | 150709 | 24 | 0.765 | 67 | 2.1 | 10.5 | 61.22 | 0.05086 |
| 8 | 259 | 3 | 150404 | 21 | 0.959 | 84 | 2 | 7.9 | 55.97 | 0.05685 |
| 8 | 265 | 3 | 150424 | 4 | 0.799 | 70 | 2.9 | 7 | 153.98 | 0.01663 |
| 8 | 271 | 3 | 150424 | 1 | 1.142 | 100 | 2.7 | 7.7 | 128.11 | 0.02115 |
| 8 | 277 | 3 | 150715 | 3 | 1.142 | 100 | 2.9 | 11.8 | 136.87 | 0.01994 |
| 8 | 283 | 3 | 150208 | 7 | 1.336 | 117 | 3 | -1.3 | 204.2 | 0.01075 |
| 8 | 289 | 3 | 150730 | 3 | 0.685 | 60 | 2.7 | 9.4 | 121.96 | 0.02276 |
| 8 | 295 | 3 | 150103 | 16 | 0.696 | 61 | 3.1 | 4 | 154.62 | 0.01751 |
| 8 | 301 | 3 | 150407 | 21 | 0.605 | 53 | 2.6 | 7.3 | 107.76 | 0.02715 |
| 8 | 307 | 3 | 150407 | 22 | 0.457 | 40 | 2.4 | 6.6 | 76.03 | 0.04184 |
| 8 | 313 | 3 | 150614 | 3 | 0.491 | 43 | 2 | 10.6 | 55.42 | 0.05732 |
| 8 | 319 | 3 | 151122 | 7 | 0.308 | 27 | 2 | 0 | 31.53 | 0.11487 |
| 8 | 325 | 3 | 150907 | 6 | 0.285 | 25 | 1.9 | 8 | 41.48 | 0.07918 |
| 8 | 331 | 3 | 151213 | 4 | 0.354 | 31 | 2.1 | 0.4 | 49.09 | 0.06828 |
| 8 | 337 | 3 | 150206 | 24 | 0.354 | 31 | 2 | 2.3 | 35.05 | 0.1006 |
| 8 | 343 | 3 | 150207 | 21 | 0.377 | 33 | 2.4 | 1.4 | 99.29 | 0.02888 |

| Season | mean wind Dir | Stability class | DATE YYMMDD | HOUR | WEIGHTING | Number in the Class | Wind Force | TEMP | BOUNDARY LAYER HEIGHT | Inverse Monin-Obukhov length |
|---|---|---|---|---|---|---|---|---|---|---|
| 8 | 349 | 3 | 150206 | 22 | 0.365 | 32 | 2.1 | 3.1 | 55.91 | 0.05828 |
| 8 | 355 | 3 | 151006 | 23 | 0.331 | 29 | 1.8 | 13.4 | 33.28 | 0.10091 |
| 8 | 1 | 3 | 150319 | 7 | 0.342 | 30 | 1.8 | 2.1 | 83.45 | 0.0305 |
| SUM | | | | | | | 100 | | 8760 | |

# Appendix 5: Predicated Kerbside $NO_2$ Concentrations at Target Determination Points

| CP_ID | X | Y | Do-Min | CAZ-D | CAZ-B+ | CAZ-B+ M621 |
|---|---|---|---|---|---|---|
| TD74814 | 431144 | 433700 | 29.3 | 24.5 | 26.4 | 26.4 |
| TD28003 | 428893 | 433365 | 33.6 | 27.6 | 31.0 | 31.1 |
| TD48049 | 428709 | 433215 | 30.9 | 26.1 | 28.8 | 28.8 |
| TD48535 | 428963 | 433502 | 29.5 | 24.9 | 27.2 | 27.3 |
| TD7850 | 430611 | 434643 | 27.7 | 23.9 | 26.0 | 26.0 |
| TD8540 | 429950 | 434204 | 27.3 | 23.1 | 24.7 | 24.8 |
| TD8554 | 431437 | 433615 | 25.7 | 22.6 | 23.9 | 23.9 |
| TD9050 | 428923 | 431681 | 35.3 | 30.7 | 32.9 | 33.4 |
| TD16577 | 430633 | 432696 | 27.3 | 24.1 | 25.7 | 25.7 |
| TD17950 | 428440 | 432538 | 26.9 | 23.7 | 25.6 | 25.6 |
| TD18246 | 430456 | 432816 | 27.1 | 23.9 | 25.4 | 25.5 |
| TD18451 | 429216 | 433687 | 39.8 | 33.3 | 36.8 | 36.8 |
| TD18523 | 429733 | 432099 | 32.1 | 28.7 | 30.0 | 30.5 |
| TD26074 | 431026 | 433742 | 27.0 | 23.4 | 25.0 | 25.1 |
| TD26603 | 430829 | 433890 | 35.5 | 30.5 | 33.0 | 33.0 |
| TD28005 | 428602 | 432182 | 30.6 | 26.4 | 29.3 | 29.2 |
| TD28288 | 430766 | 433168 | 39.1 | 33.2 | 36.6 | 36.6 |
| TD28289 | 428326 | 433400 | 23.9 | 21.3 | 22.6 | 22.6 |
| TD28291 | 430088 | 434188 | 27.2 | 23.3 | 25.0 | 25.0 |
| TD28378 | 430229 | 432840 | 33.9 | 28.1 | 30.7 | 30.9 |
| TD29051 | 429541 | 432076 | 34.5 | 30.5 | 32.5 | 32.9 |
| TD36603 | 428273 | 432520 | 24.3 | 21.8 | 23.2 | 23.2 |
| TD36620 | 430698 | 433593 | 39.8 | 31.3 | 33.4 | 33.4 |
| TD46069 | 429441 | 433967 | 33.2 | 29.2 | 31.4 | 31.5 |
| TD46614 | 430767 | 434573 | 26.1 | 22.6 | 24.4 | 24.4 |
| TD48416 | 430109 | 434436 | 29.8 | 25.5 | 28.0 | 28.1 |
| TD56009 | 430257 | 431940 | 29.2 | 25.8 | 27.4 | 27.8 |
| TD56063 | 428238 | 431575 | 26.6 | 24.0 | 25.2 | 25.6 |
| TD57696 | 428602 | 432864 | 30.2 | 25.8 | 28.3 | 28.3 |
| TD57702 | 430473 | 432734 | 26.1 | 23.3 | 24.5 | 24.6 |

| CP_ID | X | Y | Do-Min | CAZ-D | CAZ-B+ | CAZ-B+ M621 |
|---|---|---|---|---|---|---|
| TD58230 | 430502 | 433899 | 43.7 | 34.9 | 38.3 | 38.4 |
| TD70333 | 430091 | 432325 | 28.4 | 25.1 | 26.8 | 26.9 |
| TD74812 | 428792 | 432645 | 26.6 | 23.4 | 25.1 | 25.1 |
| TD74813 | 430013 | 432617 | 29.3 | 25.4 | 27.2 | 27.4 |
| TD74815 | 430717 | 434604 | 28.2 | 23.7 | 25.8 | 25.8 |
| TD74817 | 430651 | 434759 | 27.7 | 23.8 | 26.0 | 26.0 |
| TD74818 | 428934 | 433710 | 33.0 | 27.0 | 30.2 | 30.2 |
| TD74887 | 430733 | 431957 | 26.9 | 23.8 | 25.3 | 25.8 |
| TD74889 | 430966 | 432156 | 28.7 | 25.3 | 26.8 | 27.0 |
| TD74890 | 430731 | 432442 | 27.0 | 23.8 | 25.2 | 25.4 |
| TD74891 | 431038 | 433035 | 28.2 | 24.6 | 26.5 | 26.6 |
| TD74892 | 430978 | 433467 | 36.3 | 30.5 | 32.9 | 33.0 |
| TD75430 | 428698 | 432700 | 26.4 | 23.3 | 25.1 | 25.1 |
| TD75458 | 429805 | 432242 | 29.0 | 25.5 | 27.3 | 27.5 |
| TD81383 | 431402 | 432407 | 29.8 | 26.3 | 28.2 | 28.6 |
| TD81384 | 431081 | 433033 | 30.0 | 26.0 | 28.3 | 28.4 |
| TD81385 | 430749 | 432468 | 28.0 | 24.4 | 26.0 | 26.1 |
| TD81386 | 430046 | 432587 | 31.8 | 27.1 | 29.5 | 29.7 |
| TD81387 | 430724 | 433133 | 35.1 | 30.4 | 32.8 | 32.8 |
| TD81388 | 428884 | 431621 | 31.1 | 27.3 | 28.7 | 29.4 |
| TD81400 | 430686 | 431867 | 28.6 | 25.3 | 26.9 | 27.5 |
| TD7403 | 427772 | 429990 | 18.8 | 17.0 | 17.7 | 17.7 |
| TD7410 | 424768 | 434115 | 17.7 | 16.1 | 16.9 | 16.9 |
| TD7755 | 430647 | 439241 | 27.4 | 24.0 | 26.5 | 26.5 |
| TD8348 | 430537 | 431324 | 27.8 | 24.9 | 26.2 | 26.7 |
| TD16576 | 429991 | 436568 | 19.0 | 16.4 | 17.9 | 17.9 |
| TD16590 | 436065 | 435654 | 25.7 | 22.8 | 24.6 | 24.6 |
| TD16593 | 432875 | 433918 | 26.1 | 21.9 | 23.7 | 23.8 |
| TD16598 | 424672 | 436926 | 22.7 | 18.4 | 20.7 | 20.8 |
| TD17374 | 429540 | 434853 | 24.2 | 20.9 | 22.1 | 22.1 |
| TD17719 | 426982 | 431651 | 22.3 | 20.9 | 20.8 | 21.5 |
| TD17882 | 434989 | 433427 | 19.9 | 17.0 | 18.0 | 18.0 |
| TD26604 | 431991 | 431201 | 22.6 | 21.0 | 21.3 | 21.8 |

| CP_ID | X | Y | Do-Min | CAZ-D | CAZ-B+ | CAZ-B+ M621 |
|---|---|---|---|---|---|---|
| TD26618 | 437488 | 433275 | 32.9 | 28.7 | 30.6 | 30.7 |
| TD27414 | 434859 | 429039 | 20.8 | 19.2 | 19.9 | 20.3 |
| TD27827 | 427681 | 430927 | 22.0 | 20.1 | 20.8 | 21.3 |
| TD27833 | 425094 | 437868 | 25.5 | 22.4 | 24.2 | 24.1 |
| TD36619 | 430759 | 439275 | 26.8 | 22.9 | 25.8 | 25.7 |
| TD37477 | 427551 | 433702 | 25.3 | 21.0 | 22.7 | 22.7 |
| TD37861 | 424656 | 433533 | 17.6 | 16.6 | 16.7 | 17.0 |
| TD37867 | 431282 | 439305 | 25.6 | 22.7 | 24.7 | 24.6 |
| TD46625 | 427552 | 431385 | 22.8 | 20.4 | 21.4 | 21.8 |
| TD46630 | 436151 | 434685 | 30.7 | 26.9 | 29.0 | 29.1 |
| TD46633 | 435152 | 434720 | 20.5 | 17.9 | 19.2 | 19.2 |
| TD47827 | 427596 | 431193 | 27.6 | 25.3 | 25.6 | 26.5 |
| TD48328 | 428525 | 429338 | 18.1 | 17.1 | 17.4 | 17.5 |
| TD56007 | 430871 | 430540 | 25.7 | 23.3 | 24.4 | 24.9 |
| TD56479 | 432102 | 435834 | 23.3 | 20.1 | 21.8 | 21.8 |
| TD56599 | 430857 | 435038 | 22.7 | 19.8 | 21.3 | 21.4 |
| TD56621 | 438216 | 438559 | 14.0 | 12.8 | 13.6 | 13.6 |
| TD56895 | 438454 | 430381 | 16.5 | 15.7 | 16.0 | 16.1 |
| TD56986 | 434862 | 437929 | 21.5 | 19.4 | 20.8 | 20.8 |
| TD57091 | 427835 | 430783 | 19.6 | 17.9 | 18.6 | 18.8 |
| TD57092 | 427803 | 430617 | 19.6 | 18.0 | 18.7 | 18.9 |
| TD57485 | 430011 | 430986 | 24.1 | 21.4 | 22.2 | 22.5 |
| TD57490 | 426796 | 438403 | 23.9 | 20.1 | 22.4 | 22.4 |
| TD57751 | 428110 | 429992 | 20.5 | 18.9 | 19.6 | 19.7 |
| TD59050 | 430635 | 430599 | 23.2 | 21.3 | 22.1 | 22.5 |
| TD60050 | 428385 | 429603 | 19.7 | 18.5 | 18.8 | 19.0 |
| TD74810 | 428341 | 429555 | 19.9 | 18.3 | 19.0 | 19.2 |
| TD74816 | 430746 | 434806 | 28.8 | 24.2 | 26.5 | 26.5 |
| TD74888 | 430607 | 431333 | 27.3 | 24.5 | 25.6 | 26.3 |
| TD77660 | 436822 | 428945 | 18.6 | 17.7 | 17.9 | 18.1 |
| TD77663 | 435995 | 436583 | 27.1 | 23.5 | 25.5 | 25.5 |
| TD77664 | 434762 | 438041 | 21.2 | 19.2 | 20.6 | 20.5 |
| TD77665 | 434923 | 438253 | 19.6 | 17.3 | 18.8 | 18.8 |

| CP_ID | X | Y | Do-Min | CAZ-D | CAZ-B+ | CAZ-B+ M621 |
|---|---|---|---|---|---|---|
| TD81382 | 433463 | 432156 | 20.8 | 19.4 | 19.9 | 20.3 |
| TD81399 | 432041 | 431185 | 27.6 | 25.6 | 26.1 | 26.6 |
| TD99528 | 433053 | 429681 | 28.7 | 27.1 | 27.7 | 28.1 |
| TD99546 | 433183 | 429643 | 32.2 | 30.6 | 31.4 | 31.7 |
| TD73116 | 420357 | 439951 | 14.5 | 13.9 | 14.2 | 14.2 |
| TD6578 | 423313 | 429792 | 16.0 | 14.9 | 15.5 | 15.6 |
| TD6595 | 432521 | 427604 | 19.6 | 18.4 | 18.9 | 19.1 |
| TD6607 | 440103 | 432372 | 22.7 | 20.6 | 21.7 | 21.8 |
| TD6613 | 419845 | 441149 | 19.2 | 17.7 | 18.3 | 18.4 |
| TD7398 | 436023 | 428191 | 18.0 | 17.1 | 17.4 | 17.6 |
| TD7402 | 435874 | 426300 | 14.1 | 13.7 | 13.9 | 13.9 |
| TD7415 | 430653 | 424700 | 17.1 | 16.6 | 16.9 | 17.0 |
| TD7418 | 435862 | 428214 | 14.5 | 14.0 | 14.2 | 14.3 |
| TD8263 | 419532 | 445086 | 20.4 | 18.6 | 19.2 | 19.2 |
| TD8466 | 440449 | 447745 | 21.0 | 20.1 | 20.7 | 20.8 |
| TD8537 | 424121 | 428099 | 32.7 | 30.8 | 32.5 | 32.2 |
| TD16054 | 432722 | 426046 | 32.3 | 30.7 | 31.7 | 31.9 |
| TD16082 | 441245 | 445399 | 21.4 | 21.0 | 21.3 | 21.4 |
| TD16562 | 438814 | 445931 | 15.7 | 14.3 | 15.3 | 15.3 |
| TD17366 | 424390 | 428129 | 27.1 | 25.3 | 26.3 | 26.5 |
| TD17369 | 428571 | 427867 | 19.7 | 18.5 | 19.0 | 19.2 |
| TD17370 | 442976 | 431725 | 12.3 | 12.0 | 12.2 | 12.2 |
| TD17372 | 420708 | 440283 | 20.0 | 19.2 | 19.5 | 19.6 |
| TD17373 | 437295 | 445589 | 10.9 | 10.4 | 10.8 | 10.8 |
| TD17721 | 420910 | 434510 | 28.7 | 26.9 | 27.5 | 27.8 |
| TD18247 | 420870 | 444995 | 16.1 | 14.6 | 15.7 | 15.7 |
| TD18587 | 440400 | 446504 | 17.0 | 16.7 | 16.9 | 17.0 |
| TD18655 | 421627 | 428574 | 14.5 | 13.8 | 14.1 | 14.2 |
| TD26613 | 424243 | 428319 | 21.2 | 20.2 | 20.9 | 20.9 |
| TD26625 | 418075 | 442594 | 19.0 | 18.2 | 18.4 | 18.5 |
| TD27428 | 423547 | 434356 | 21.2 | 19.7 | 20.5 | 20.7 |
| TD27432 | 427841 | 426274 | 30.6 | 29.6 | 30.0 | 30.3 |
| TD27436 | 429986 | 427016 | 22.5 | 21.0 | 21.1 | 21.4 |

| CP_ID | X | Y | Do-Min | CAZ-D | CAZ-B+ | CAZ-B+ M621 |
|---|---|---|---|---|---|---|
| TD27439 | 422359 | 436351 | 19.9 | 17.0 | 18.3 | 18.3 |
| TD27442 | 444136 | 444995 | 8.9 | 8.7 | 8.9 | 8.9 |
| TD27442 | 444136 | 444995 | 8.9 | 8.7 | 8.9 | 8.9 |
| TD27443 | 419808 | 445355 | 16.3 | 15.8 | 16.0 | 16.0 |
| TD27802 | 426902 | 426580 | 24.7 | 23.9 | 24.0 | 24.3 |
| TD28237 | 424445 | 445220 | 15.8 | 15.4 | 15.6 | 15.6 |
| TD28495 | 440024 | 448373 | 9.8 | 9.7 | 9.7 | 9.7 |
| TD28567 | 424040 | 428014 | 34.6 | 33.0 | 34.4 | 34.2 |
| TD36604 | 435453 | 439858 | 12.1 | 11.4 | 11.8 | 11.9 |
| TD36634 | 445197 | 431577 | 11.9 | 11.5 | 11.7 | 11.8 |
| TD36642 | 422989 | 437690 | 23.3 | 20.7 | 21.9 | 22.1 |
| TD37463 | 439569 | 426164 | 15.9 | 15.0 | 15.3 | 15.4 |
| TD37488 | 424605 | 445064 | 15.2 | 14.7 | 15.0 | 15.0 |
| TD37489 | 431298 | 445721 | 9.0 | 8.5 | 8.9 | 8.9 |
| TD38343 | 436159 | 427977 | 16.0 | 15.2 | 15.5 | 15.5 |
| TD46600 | 440369 | 447696 | 12.4 | 11.8 | 12.2 | 12.2 |
| TD47438 | 420263 | 434243 | 35.6 | 30.8 | 33.1 | 33.3 |
| TD47443 | 428843 | 426001 | 27.1 | 26.1 | 26.5 | 26.8 |
| TD47443 | 428843 | 426001 | 27.1 | 26.1 | 26.5 | 26.8 |
| TD47446 | 428000 | 426210 | 27.7 | 26.6 | 27.1 | 27.4 |
| TD47449 | 419537 | 437020 | 21.9 | 20.4 | 21.5 | 21.5 |
| TD47451 | 439532 | 446128 | 9.6 | 9.3 | 9.5 | 9.5 |
| TD47808 | 417731 | 444241 | 8.3 | 8.2 | 8.2 | 8.2 |
| TD47831 | 422444 | 436984 | 24.3 | 22.9 | 23.7 | 23.8 |
| TD48329 | 419248 | 445150 | 18.1 | 16.5 | 17.5 | 17.5 |
| TD48671 | 440525 | 447675 | 12.7 | 12.4 | 12.6 | 12.6 |
| TD56883 | 420980 | 445763 | 15.9 | 15.5 | 15.7 | 15.7 |
| TD57442 | 424938 | 427596 | 25.2 | 23.8 | 24.5 | 24.6 |
| TD57448 | 442766 | 429736 | 11.7 | 11.3 | 11.5 | 11.5 |
| TD57589 | 436086 | 428291 | 16.9 | 16.3 | 16.4 | 16.6 |
| TD73113 | 421338 | 428866 | 13.7 | 13.4 | 13.6 | 13.6 |
| TD73117 | 418330 | 441394 | 15.5 | 15.0 | 15.3 | 15.3 |
| TD73663 | 427212 | 425171 | 20.3 | 19.6 | 20.0 | 20.1 |

| CP_ID | X | Y | Do-Min | CAZ-D | CAZ-B+ | CAZ-B+ M621 |
|---|---|---|---|---|---|---|
| TD73698 | 433204 | 426283 | 20.3 | 19.2 | 19.6 | 19.7 |
| TD73711 | 424624 | 427353 | 19.6 | 18.9 | 19.3 | 19.3 |
| TD74250 | 423731 | 444379 | 11.2 | 10.5 | 10.9 | 10.9 |
| TD77619 | 441090 | 432018 | 14.4 | 13.8 | 14.1 | 14.2 |
| TD77658 | 434568 | 428049 | 16.9 | 16.2 | 16.4 | 16.6 |
| TD77666 | 426239 | 442402 | 12.4 | 11.4 | 12.0 | 12.0 |
| TD77667 | 422992 | 443130 | 12.8 | 12.4 | 12.6 | 12.6 |
| TD77669 | 432254 | 444826 | 10.8 | 9.9 | 10.7 | 10.7 |
| TD77672 | 420541 | 445595 | 18.7 | 18.1 | 18.4 | 18.4 |
| TD80636 | 419422 | 444993 | 15.5 | 14.4 | 14.8 | 14.8 |
| TD81311 | 440626 | 445957 | 14.3 | 14.1 | 14.2 | 14.2 |
| TD81381 | 440030 | 448354 | 9.8 | 9.7 | 9.7 | 9.7 |
| TD99086 | 440296 | 449966 | 9.2 | 9.1 | 9.1 | 9.1 |
| TD99158 | 424066 | 428236 | 24.8 | 23.8 | 24.4 | 24.5 |
| TD99527 | 439232 | 432440 | 24.8 | 22.0 | 23.5 | 23.7 |
| TD99529 | 440316 | 433516 | 16.8 | 16.1 | 16.5 | 16.5 |
| TD99705 | 441244 | 448439 | 8.4 | 8.3 | 8.3 | 8.3 |
| TD99705 | 441244 | 448439 | 8.4 | 8.3 | 8.3 | 8.3 |
| TD77657 | 436176 | 427493 | 14.4 | 13.9 | 14.1 | 14.2 |
| TD8548 | 425067 | 428031 | 35.1 | 31.2 | 34.2 | 34.4 |
| TD36055 | 429507 | 426437 | 35.9 | 34.8 | 35.7 | 35.7 |

## Appendix 6: Modelled NO2 Concentrations in 2015 Monitoring Locations

| ID | X | Y | Location | Zone | NOx Adjustment Factor | NO2 Adjustment Factor | Monitored NO2 | Modelled NO2 |
|---|---|---|---|---|---|---|---|---|
| DT001 | 431144 | 433700 | Headingley | Inter | 2.143 | 1.001 | 37 | 35.4 |
| DT002 | 428893 | 433365 | Haslewood Close Co-Loc_1 | EX | 1.574 | 1.000 | 33 | 38.5 |
| DT003 | 428709 | 433215 | Haslewood Close Co-Loc_2 | A64 | 1.574 | 1.000 | 35 | 38.1 |
| DT004 | 428963 | 433502 | Haslewood Close Gable | A64 | 1.574 | 1.000 | 34 | 35.7 |
| DT005 | 430611 | 434643 | Haslewood Close facing open area | A64 | 1.574 | 1.000 | 31 | 33.5 |
| DT006 | 429950 | 434204 | 19/20 Ladybeck Cl (rear) DP | EX | 2.266 | 1.064 | 36 | 33.0 |
| DT007 | 431437 | 433615 | Ladybeck Reception (rear) | EX | 2.266 | 1.064 | 33 | 30.9 |
| DT008 | 428923 | 431681 | 25 Ladybeck Cl | EX | 2.266 | 1.064 | 34 | 41.7 |
| DT009 | 430633 | 432696 | West Street Car Park | IRR | 2.088 | 0.999 | 33 | 33.2 |
| DT010 | 428440 | 432538 | Leeds Centre AURN (L) | EX | 2.266 | 1.064 | 32 | 33.0 |
| DT011 | 430456 | 432816 | Leeds Centre AURN ® | EX | 2.266 | 1.064 | 32 | 33.0 |
| DT012 | 429216 | 433687 | Leeds Centre AURN (M) | EX | 2.266 | 1.064 | 34 | 47.5 |
| DT013 | 429733 | 432099 | Railway Terrace | EX | 5.599 | 1.008 | 32 | 37.2 |
| DT014 | 431026 | 433742 | 110 Jack Lane | C5 | 2.266 | 1.064 | 37 | 32.7 |
| DT015 | 430829 | 433890 | 82 New Road Side | EX | 5.599 | 1.008 | 38 | 43.0 |
| DT016 | 428602 | 432182 | 253 New Road Side | O5 | 5.599 | 1.008 | 34 | 38.0 |
| DT017 | 430766 | 433168 | 2 Norman Row | KR | 3.742 | 1.007 | 39 | 46.6 |
| DT018 | 428326 | 433400 | 4 De Lacey Mount | KR | 3.742 | 1.007 | 29 | 29.0 |
| DT019 | 430088 | 434188 | 2 Back Norman Mount | EX | 3.742 | 1.007 | 27 | 32.8 |
| DT020 | 430229 | 432840 | 2 Haddon Place | KR | 3.742 | 1.007 | 32 | 40.8 |
| DT021 | 429541 | 432076 | 78 Selby Rd | EX | 5.599 | 1.008 | 37 | 40.7 |
| DT022 | 428273 | 432520 | 1 Gilbert Mount | KR | 3.742 | 1.007 | 22 | 29.7 |
| DT023 | 430698 | 433593 | Corn Exchange | EX | 2.266 | 1.064 | 51 | 50.4 |
| DT024 | 429441 | 433967 | Kirkstall Rd/ Woodside Terr. | EX | 3.742 | 1.007 | 28 | 39.3 |

| ID | X | Y | Location | Zone | NOx Adjustment Factor | NO2 Adjustment Factor | Monitored NO2 | Modelled NO2 |
|---|---|---|---|---|---|---|---|---|
| DT025 | 430767 | 434573 | 131 Harehills Lane | I5 | 2.143 | 1.001 | 29 | 31.8 |
| DT026 | 430109 | 434436 | Jack Lane GH | EX | 2.266 | 1.064 | 42 | 36.1 |
| DT027 | 430257 | 431940 | Ladysmith Workwear | C5 | 2.266 | 1.064 | 32 | 34.8 |
| DT028 | 428238 | 431575 | Norman Street | KR | 3.742 | 1.007 | 33 | 32.5 |
| DT029 | 428602 | 432864 | 302 York Road | I5 | 2.143 | 1.001 | 32 | 33.8 |
| DT030 | 430473 | 432734 | 2 Eyres Terrace | I5 | 2.143 | 1.001 | 31 | 32.4 |
| DT031 | 430502 | 433899 | 76 Woodhouse Hill Rd | I5 | 2.143 | 1.001 | 31 | 52.6 |
| DT032 | 430091 | 432325 | 76 Selby Rd | EX | 5.599 | 1.008 | 41 | 33.7 |
| DT033 | 428792 | 432645 | 15 Ashfield Road | EX | 5.599 | 1.008 | 36 | 31.6 |
| DT034 | 430013 | 432617 | 1 Rein Road | O5 | 5.599 | 1.008 | 42 | 35.0 |
| DT035 | 430717 | 434604 | 109 Bridge Street | O5 | 5.599 | 1.008 | 28 | 34.5 |
| DT036 | 430651 | 434759 | 2 Chapel Hill | EX | 5.599 | 1.008 | 41 | 33.5 |
| DT037 | 428934 | 433710 | adj 32 Otley Road | EX | 2.143 | 1.001 | 39 | 40.7 |
| DT038 | 430733 | 431957 | North Street | C5 | 2.266 | 1.064 | 35 | 32.1 |
| DT039 | 430966 | 432156 | Victoria Avenue | I5 | 2.143 | 1.001 | 28 | 34.1 |
| DT040 | 430731 | 432442 | 21 Rein Road | O5 | 5.599 | 1.008 | 32 | 32.6 |
| DT041 | 431038 | 433035 | 12 Tilbury Terrace | EX | 2.266 | 1.064 | 29 | 33.3 |
| DT042 | 430978 | 433467 | 73 East Park Parade | I5 | 2.143 | 1.001 | 31 | 43.3 |
| DT043 | 428698 | 432700 | 51 Long Row | O5 | 5.599 | 1.008 | 34 | 31.1 |
| DT044 | 429805 | 432242 | 33 Long Row | O5 | 5.599 | 1.008 | 27 | 34.5 |
| DT045 | 431402 | 432407 | Gotts Road (L) | IRR | 2.088 | 0.999 | 42 | 35.0 |
| DT046 | 431081 | 433033 | Gotts Road (R) | IRR | 2.088 | 0.999 | 44 | 35.4 |
| DT047 | 430749 | 432468 | 362 Bradford Rd | O5 | 5.599 | 1.008 | 29 | 33.9 |
| DT048 | 430046 | 432587 | Railway Terrace | EX | 5.599 | 1.008 | 31 | 37.8 |
| DT049 | 430724 | 433133 | 256 Lingwell Gt Lane | O5 | 5.599 | 1.008 | 24 | 42.1 |
| DT050 | 428884 | 431621 | Queensway Roadsign | EX | 5.599 | 1.008 | 17 | 36.9 |
| DT051 | 430686 | 431867 | Queensway Telegraph post | O5 | 5.599 | 1.008 | 19 | 33.9 |
| DT052 | 427772 | 429990 | Tilbury Row new tube | C5 | 2.266 | 1.064 | 30 | 23.1 |
| DT053 | 424768 | 434115 | 582 Meanwood Road | I5 | 2.143 | 1.001 | 27 | 21.6 |
| DT054 | 430647 | 439241 | Sunbeam Terrace | O5 | 5.599 | 1.008 | 31 | 35.5 |
| DT055 | 430537 | 431324 | 3 Oban Terrace | EX | 5.599 | 1.008 | 34 | 33.8 |

| ID | X | Y | Location | Zone | NOx Adjustment Factor | NO2 Adjustment Factor | Monitored NO2 | Modelled NO2 |
|---|---|---|---|---|---|---|---|---|
| DT056 | 429991 | 436568 | The Brambles | EX | 5.599 | 1.008 | 34 | 23.2 |
| DT057 | 436065 | 435654 | 9 Ladybeck Close | EX | 2.266 | 1.064 | 37 | 33.9 |
| DT058 | 432875 | 433918 | 368 Dewsbury Road | EX | 2.143 | 1.001 | 28 | 32.3 |
| DT059 | 424672 | 436926 | Maple Court | EX | 2.143 | 1.001 | 23 | 29.4 |
| DT060 | 429540 | 434853 | 69 Jessamine Avenue | I5 | 2.143 | 1.001 | 22 | 29.9 |
| DT061 | 426982 | 431651 | 659 Dewsbury Road | I5 | 2.143 | 1.001 | 28 | 28.0 |
| DT062 | 434989 | 433427 | 79 Faroe off Gotts Road | IRR | 2.088 | 0.999 | 29 | 25.0 |
| DT063 | 431991 | 431201 | RT Leeds Centre (AURN) | C5 | 2.266 | 1.064 | 31.05 | 27.7 |
| DT064 | 437488 | 433275 | RT Corn Exchange | C5 | 2.266 | 1.064 | 54.2 | 43.1 |
| DT065 | 434859 | 429039 | RT Headingley (AURN Affiliated) | I5 | 2.143 | 1.001 | 40.41 | 26.7 |
| DT066 | 427681 | 430927 | RT Queen St | EX | 5.599 | 1.008 | 38.63 | 28.0 |
| DT067 | 425094 | 437868 | RT Jack Lane | C5 | 2.266 | 1.064 | 45.57 | 32.3 |
| DT068 | 430759 | 439275 | RT Kirkstall Rd | KR | 3.742 | 1.007 | 30.33 | 34.3 |
| DT069 | 427551 | 433702 | RT Tilbury Terrace | C5 | 2.266 | 1.064 | 38.38 | 31.3 |

# Appendix 7: Examples of Modelling Considerations.

## A7.1 Localised Wind Flow Effects

The three figures below provide a visual example of how the Wind Model used with in Airviro generates the localised wind fields within the modelled domain and the underlying data that is used within the calculations. Figure A7.1.1 demonstrates the how the wind speed and direction varies across the modelled area from the wind direction input data of 265 deg. The length of the white arrows signifies the relative wind speed in the direction of the arrow. The direction cannot be clearly seen in all cases as the effects of the terrain and topography creates lower wind speeds and therefore shorter arrows. However it does demonstrate how the wind conditions are calculated to vary across the modelled area within the same hour.

The example depicted is for 0500hrs 02-01-2015 and is displayed as 500m x500m calculation grid. It is selected purely as an example which adequately displays the variation in wind vectors produced in the model, particularly around the city centre area.

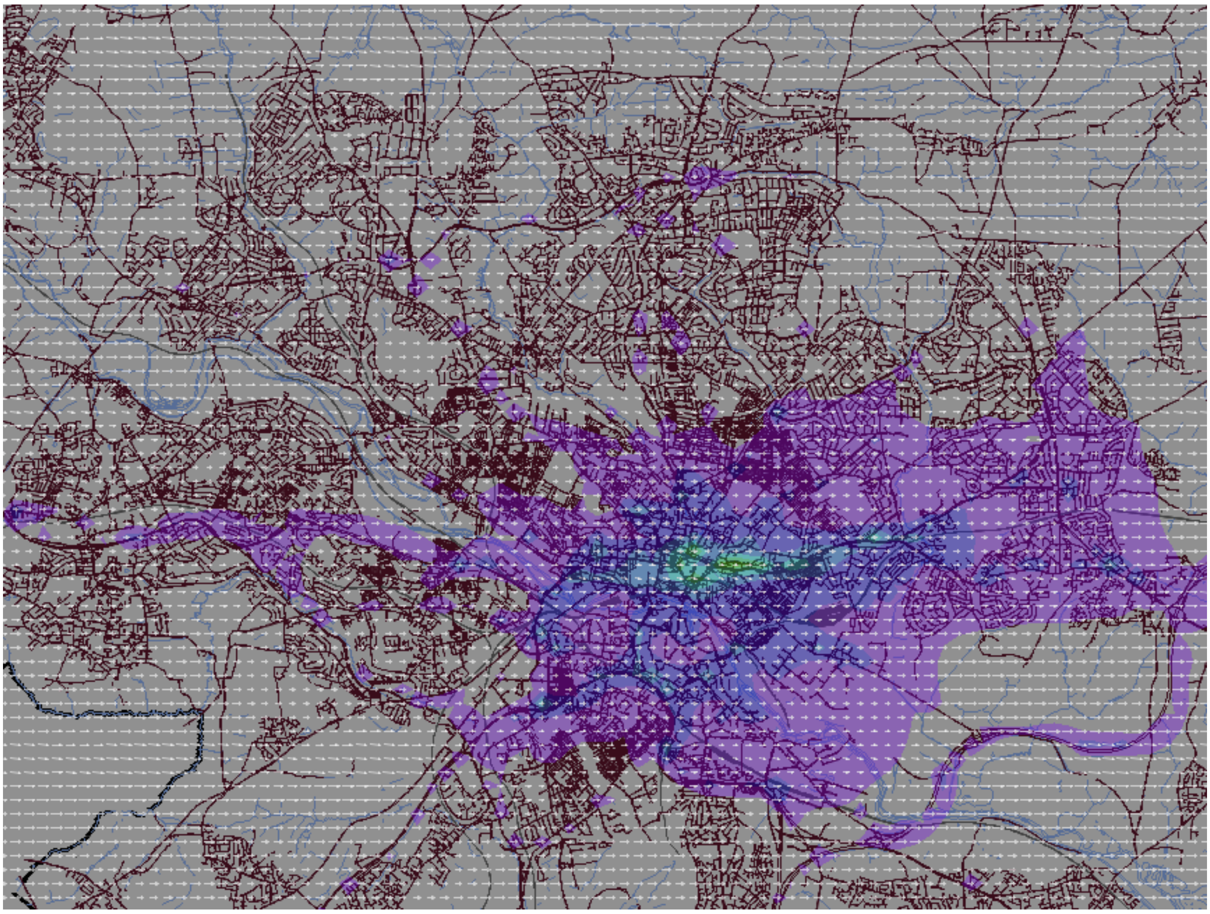


Figure A7.1.1 Example of the Projected Wind vectors Variation Within each Modelled Grid.

Figure A7.1.2 shows the terrain data used within the modelled domain by the Airviro wind model which influences variation in the localised direction based on the single input direction at the met mast location. The model projects the wind direction up to the free wind height and calculates back down to the localised variation at ground height within each modelled grid. The data is contained within the model configuration file as spot height data at 100m x 100m resolution.

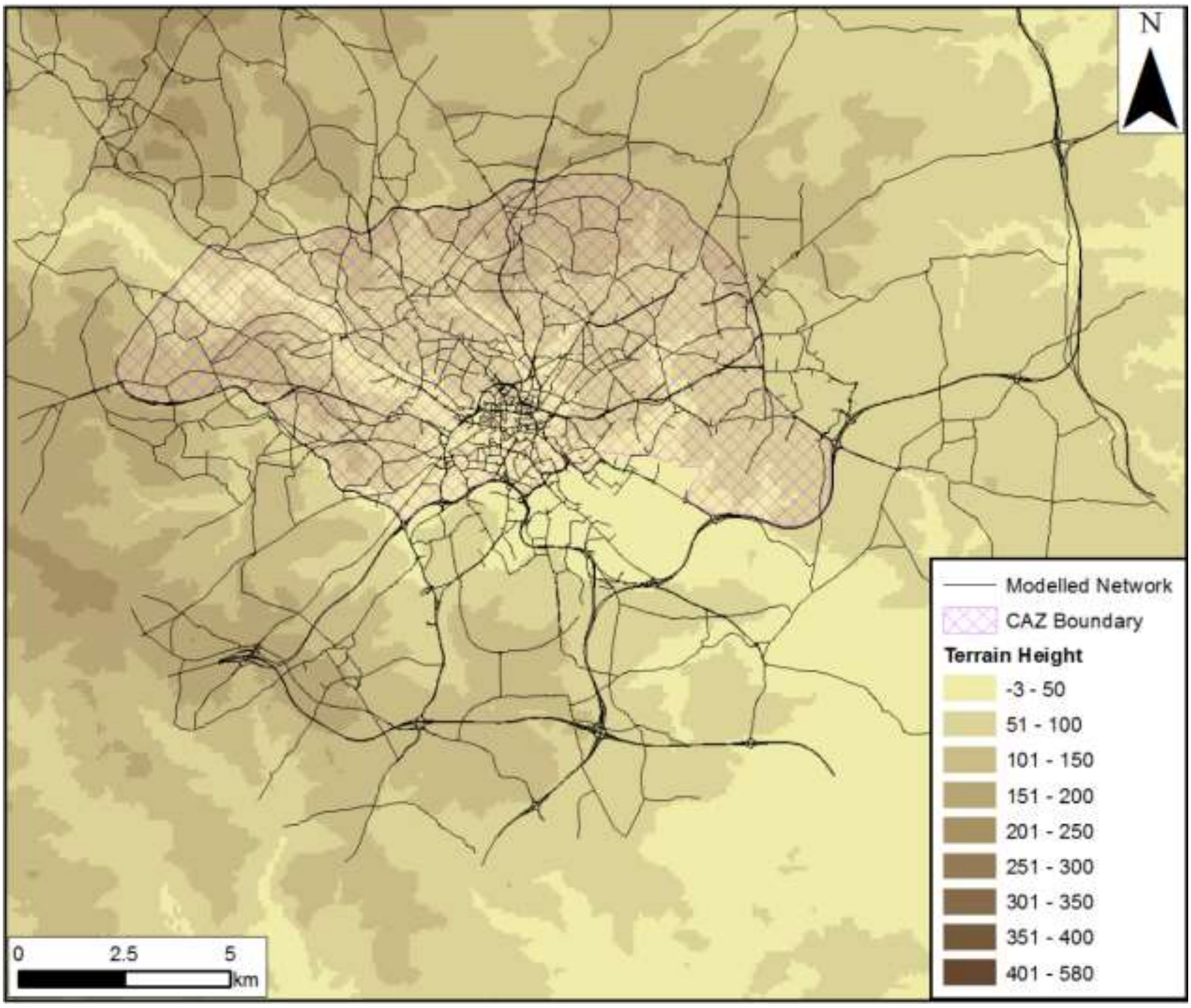



Figure A71.2 Depiction of the Underlying Land Height data used within the Airvro Wind Model

Figure A7.1.3 depicts the underlying surface roughness index used within the Airviro wind model. The index is calculated based on the combination of land use data and separate building height data. Each 100m x 100m grid within the modelled domain is allocated a percentage of each land use type contained within it which is combined with the average building height data for the same grid to dictate what surface roughness index is used within the wind speed calculation.

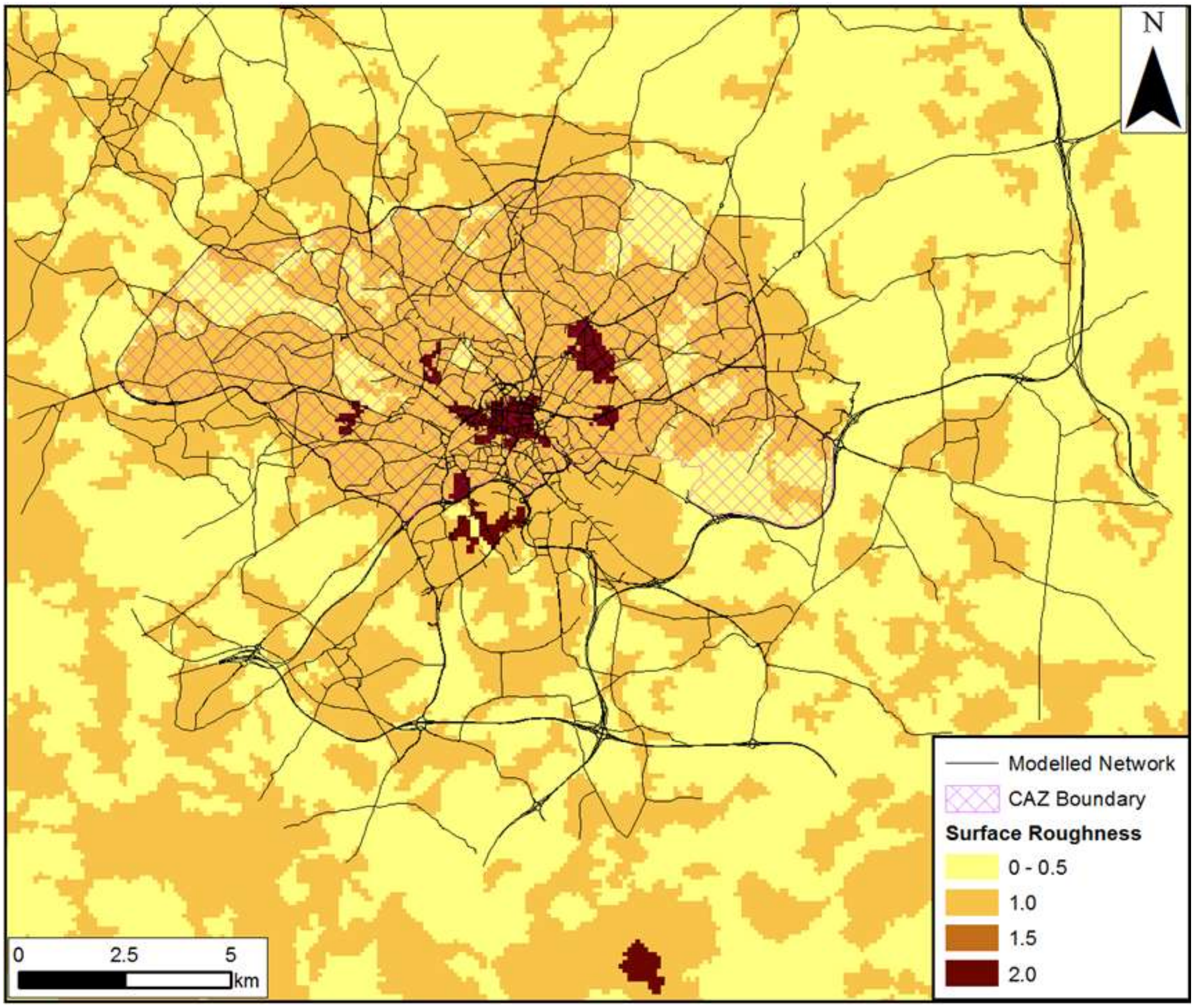



Figure A71.3 Depiction of the Underlying Surface Roughness Index used within the Airvro Wind Model

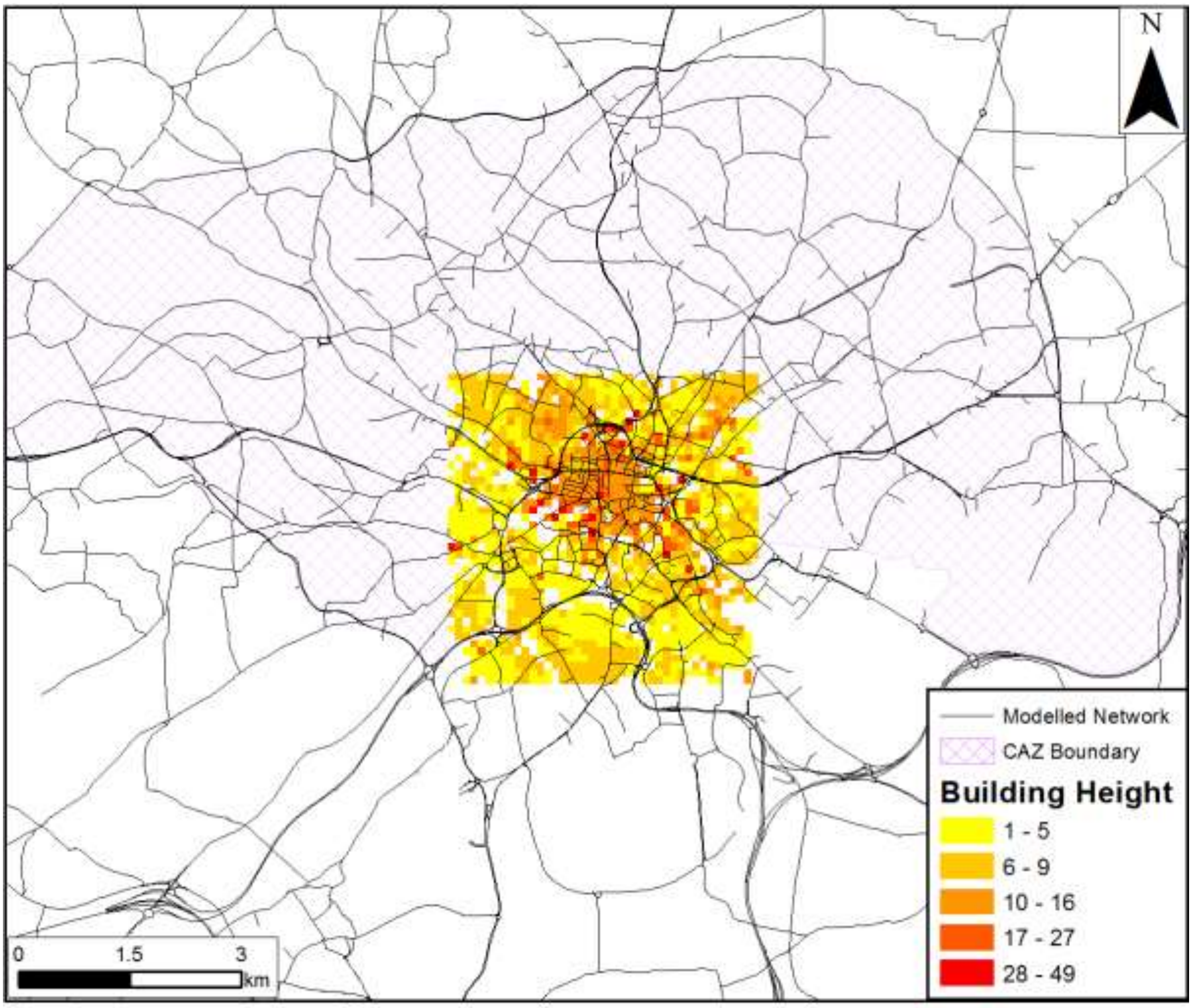
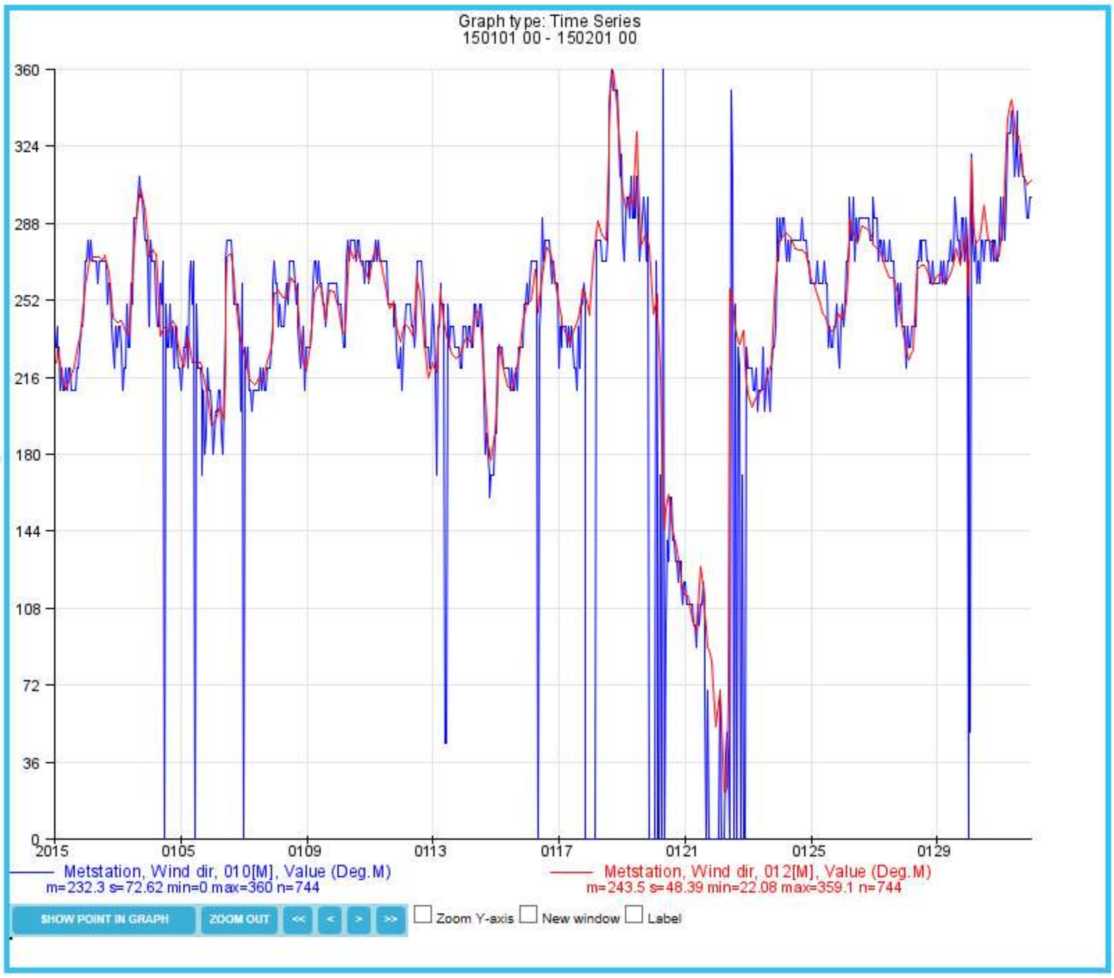



Figure A71.4 Depiction of Building Height used within the Airvro Wind Model

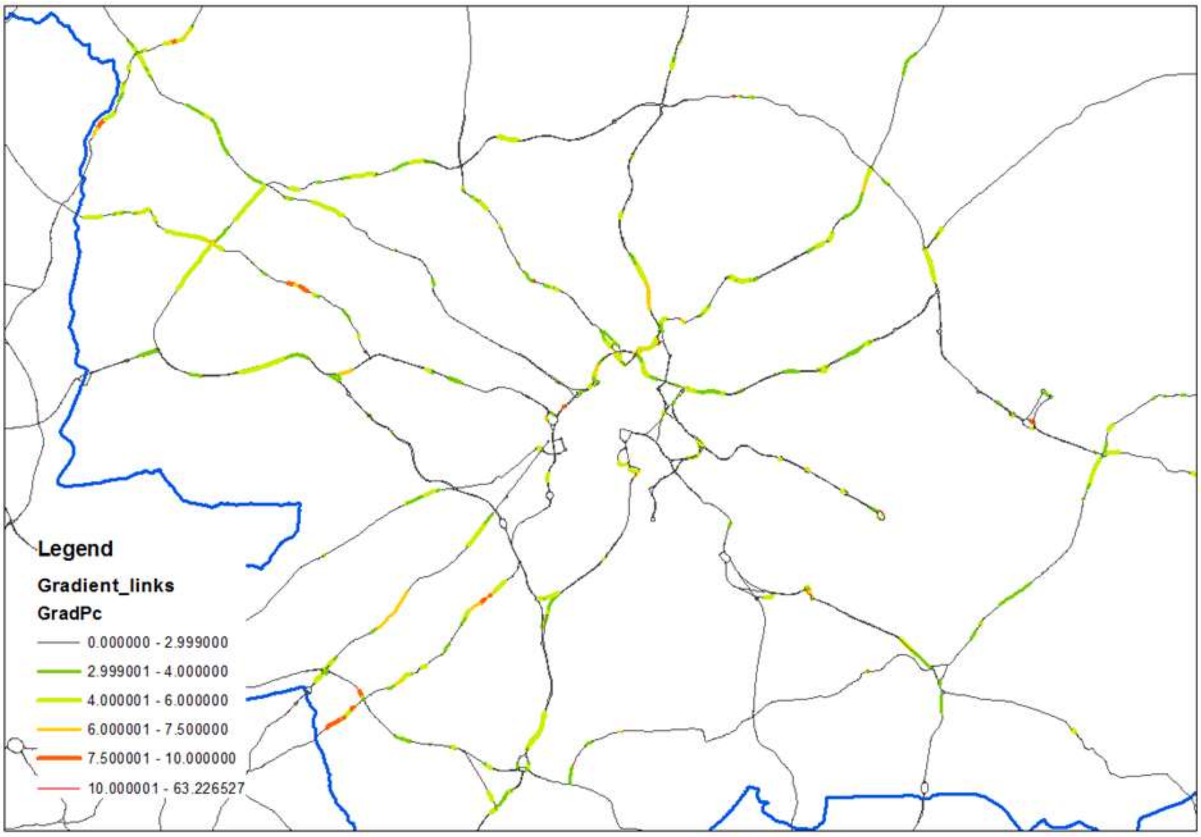
## A7.2 Meteorological data projected from Leeds Bradford Airport to the Leeds Meteorological Station.

The graph below depicts the hourly average wind direction data generated by SMHI for January 2015 (in red) compared against the wind data collected by the Meteorological mast close to Leeds City Centre (in blue) which is normally used as input data for dispersion calculations. The drop outs in data collected by the meteorological mast can be clearly seen in the flat peaks and excessive northerly directions indicating periods of suspicious data which led Leeds City Council to request SMHI to generate a new Meteorological data set from other local weather stations. The graph otherwise shows a good similarity between locally monitored direction and the projected wind direction calculated from data collected at the nearby Leeds Bradford International Airport and gives additional assurance in the process providing a robust local dataset for the purpose of dispersion modelling.



## A7.3 Gradients

The figure below depicts the gradient of links included within the national PCM model (excluding motorways) which have been estimated via interpolation of spot height matched ITN road network data. A number of issues were encountered when assessing how this data could be used appropriately within the emission modelling process.




Problems with the resulting data were identified such as locations close to bridges and flyovers picking up spot heights from different road sections and calculating unrealistically steep gradients.

Another issue of concern was that the road network modelled within the Leeds model has many more road links included within it for which gradient was not readily useable to isolate the relevant links. To include the gradient correction calculations for all roads in the Leeds model would have been prohibitive in terms of time and resources constraints. It was considered that if some roads had gradient corrections applied in the emission calculation stage which were close to the monitoring locations and/or other complexities had gradient corrections applied, this would have an impact on the eventual modelled road NOx correction factors calculated within the verification exercise. This in turn could lead to further uncertainties when the factors were applied to links where gradient corrections had not been included in the emission calculations.

Under TG16, Gradient correction factors are not applied to Euro VI HDV's. which partly led to the decision that using the correction factors based on validation against the monitoring which already included some local impact of gradients and other complex situations would most likely introduce a conservative approach to the future year scenarios. This would particularly be the case for the CAZ scenarios which include a much greater number of Euro VI HDVs than the base year data which was used to determine the correction factors.

## A7.4 Canyons and Flyovers

This section examines some typical examples of the complex situations which exist in the modelled area and discusses the potential conflict between the way they have been reflected in the model and how it this may compare with the reality of the situation.  Each location has individual complexities which are difficult to replicate with in a Gaussian dispersion model. Without very local monitoring to test the effect introducing correction factors or localised canyon models, it was judged that further uncertainties could be introduced to the results as it would not be possible to apply a single correction technique to all such situations.

### A7.4.1 Inner Ring Road A64 to A65

**Marsh Lane / A64 junction** - the flyover takes the A64 over the top of Marsh Lane (IRR) with the EB/off slip emerging as a tunnel mouth under the flyover to the left. On and off slip roads with gradients are to the right.

There is monitoring to the North East corner (Haslewood Close AQMA) adjacent to the up-hill on-slip. The roads are all modelled at grade with no gradient corrections or other adjustments to account for the tunnel mouth and flyover. The area was calibrated as a stand-alone verification zone and validated reasonably well against the monitored concentrations but slightly over predicted.

### A7.4.2 A64(M) on flyover over the A61 north of the bus station.

The off slip in both directions are downhill with no on-slips. It is therefore expected that modelling at grade will overestimate the impact locally. There is monitoring located at properties immediately to the South of the A64 at the Ladybeck Close AQMA, which is set below the level of the flyover and set back behind the buildings which face on to the A64. These monitoring locations were considered unsuitable for influencing a wider modelled area and were not included in the verification exercise. The situation as it is modelled is likely to over-estimate the influence of the flyover in the immediate vicinity especially down wind of the prevailing wind direction.

### A7.4.3 Off slip from A64(M) on to North street intersection

The North Street intersection is located on a long bridge over the A64(M) – the receptor representing this section of the Inner Ring Road link is located to the left to reflect the public access criteria of the car park on the left which is represented by receptor TD58230, which returned the highest predicted $NO_2$ concentrations for the CAZ-B scenarios in respect of all the receptors relevant to the air quality directive.


The main through traffic flow on the A64(M) is high in volume but is set down in a cutting bounded by vertical concrete walls between the slip road on the left and New York Road on the right. Just to the East, before the slip road, the main A64 is set above the New York Road on a flyover over the A61 discussed above.

There are no gradient effects modelled on the slip road, however it is most likely that vehicles will generally be slowing down and not under load at this location until they become stationary at the junction. The junction is not prone to excessive queueing on a prolonged basis. Overall, it is concluded that the modelling of this location as “at grade” is more likely to be overestimating than underestimating the overall impact of the localised emissions.

Although there are few buses which use the main section of the ring road, the roads immediately up wind of the prevailing wind and slip roads have significant bus movements and explains why a CAZ B does has such a positive effect at the receptor which represents the A64(M) Inner Ring Road.

### A7.4.4 A58(M) Inner Ring Road

Looking East


Looking West


The section of the A58(M) Inner Ring Road between the A65 and A58 is characterised by a series of long and short tunnelled sections bounded by vertical concrete retaining walls within 2m of the carriageway on both sides. There are occasional on and off-slip roads which are generally characterised by the off-slips being up-hill or at grade and the on-slips being down-hill or at grade.

No permitted public access exists within the bounds of the IRR retaining walls. The traffic flow on this section of road is substantial and there are almost certainly some piston effects. It is uncertain where the pollution is ultimately dispersed more widely than the confines of the retaining walls from. Monitoring has previously shown that pollutant concentrations above the retaining walls are lower than predicted concentrations when modelled at grade with no canyon effects.

A58(M) looking South/West from under the A65 / Headrow interchange.


The on-slip from the A65 Eastbound can be seen emerging from the tunnelled section on the right within the cutting to join the A58(M) as it enters a short tunnelled section under the interchange. The cutting is formed by the off-slip running from A58(M) up on to the Headrow/ A65 junction which passes over the top of the A65 on-slip to the right and the A65 west bound running down from the Headrow to the left parallel to the A58(M)

The off-slip from the A58(M) as it goes over the top of the A65 on slip shown above to join the Headrow.

The footway shown to the left represents the public access within 15m of the main carriageway of the A58(M) Inner Ring Road reported as receptor TD18451. The slip road is on a gradient, but is an off slip and therefore vehicles are likely to be slowing down with their engines not under load. The roads are all modelled at grade with no tunnel impacts which gives the potential for over-estimating the predicted concentrations at this location.