Ricardo Energy & Environment

Derby Air Quality Modelling Methodology Report (AQ2)

Report for Derby City Council

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1 Introduction and outline modelling scope

Derby City Council (DCC) is one of the initial five cities that were required to carry out a Feasibility Study by the Government for non-compliance with the nitrogen dioxide (NO_2) limit values. This report sets out the Air Quality modelling methodology used for this study.

1.1 Background

Derby, like many other urban areas in the UK, has some locations where Nitrogen Dioxide (NO_2) concentrations are in excess of national and European air quality standards. To date, Derby City Council has declared two Air Quality Management Areas (AQMAs) as a result of exceedances of the UK NO_2 annual mean objective. A map showing the locations of each AQMA is presented in Figure 1. The associated Local Air Quality Management (LAQM) assessment work has concluded that these exceedances are mainly attributable to emissions from road traffic.

Derby City Council was identified in the 2015 National Air Quality Plan as one of five councils required to introduce a Clean Air Zone (CAZ) by the end of 2019. However, under a revision to the national plans released in May 2017, an NO_2 compliance plan is required, which may include a mandatory charging-based CAZ or a range of alternative measures able to deliver the same NO_2 reductions as a charging-based CAZ.

The key areas identified by the DEFRA plan that were modelled to exceed NO_2 limits in 2020 are at Eastgate and Holms Bridge as shown in Figure 2. Derby City Council has noted in their recent annual LAQM report[1] that

> *"the locations highlighted in the national plans as areas of potential exceedance are not areas which have been highlighted as areas of concern under the LAQM regime. The apparent disparity between the national and local results has arisen primarily because of marked differences between the assessment methodologies described under the EU Directive versus the LAQM regime.'*
>
> *The road links highlighted as exceedance points using DEFRA's national modelling results (namely Eastgate and Holms Bridge) are not within influencing distance of receptors considered relevant to the LAQM standards i.e. residential dwellings, schools or care/residential homes. The only public exposure at these locations are footpaths/cycleways, which DEFRA have deemed are relevant to the EU Directive's standards."*

[1] 2016 Updating and Screening Assessment and Progress Report for Derby City Council

Figure 1 Derby Air Quality Management Areas (AQMAs)

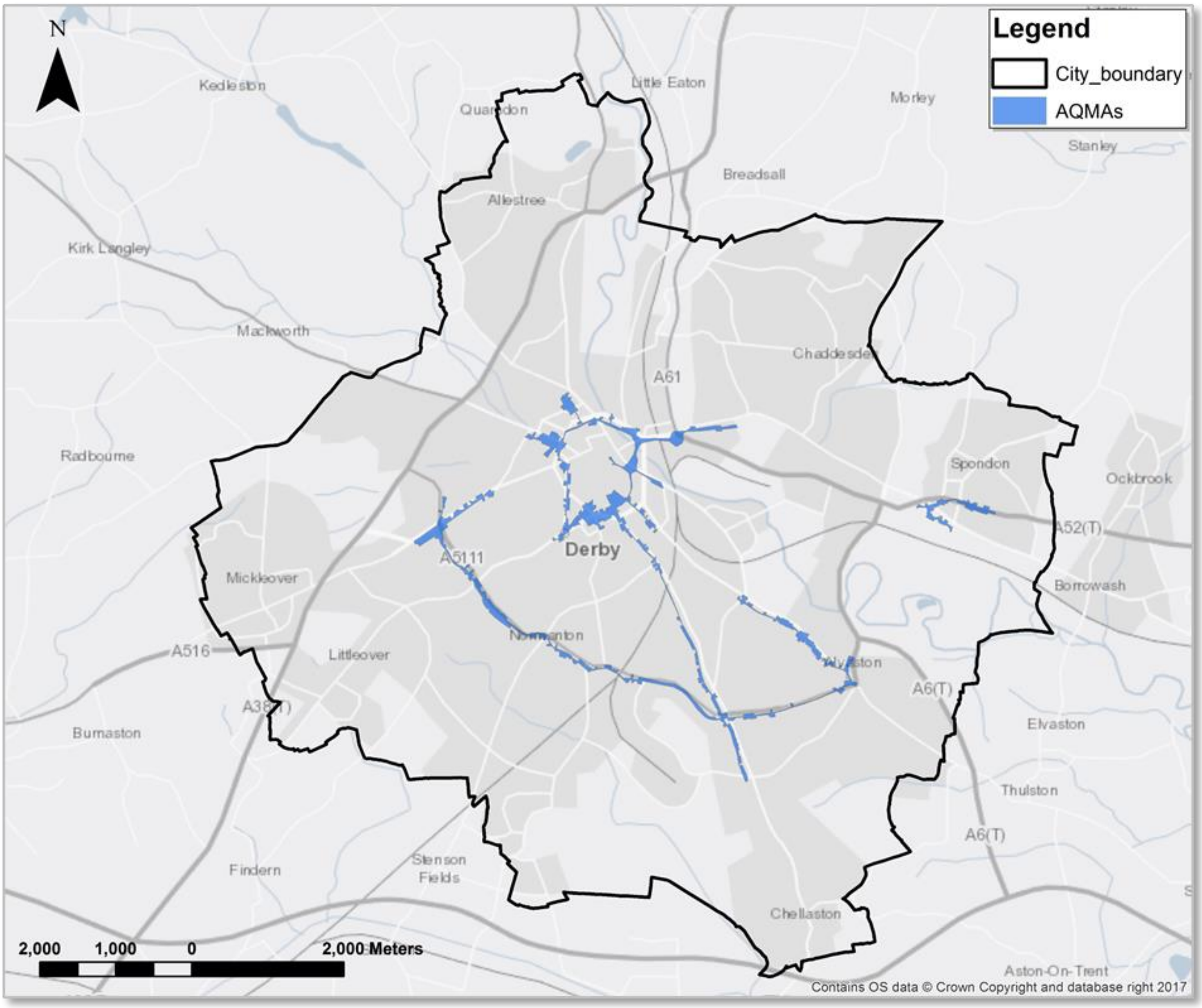
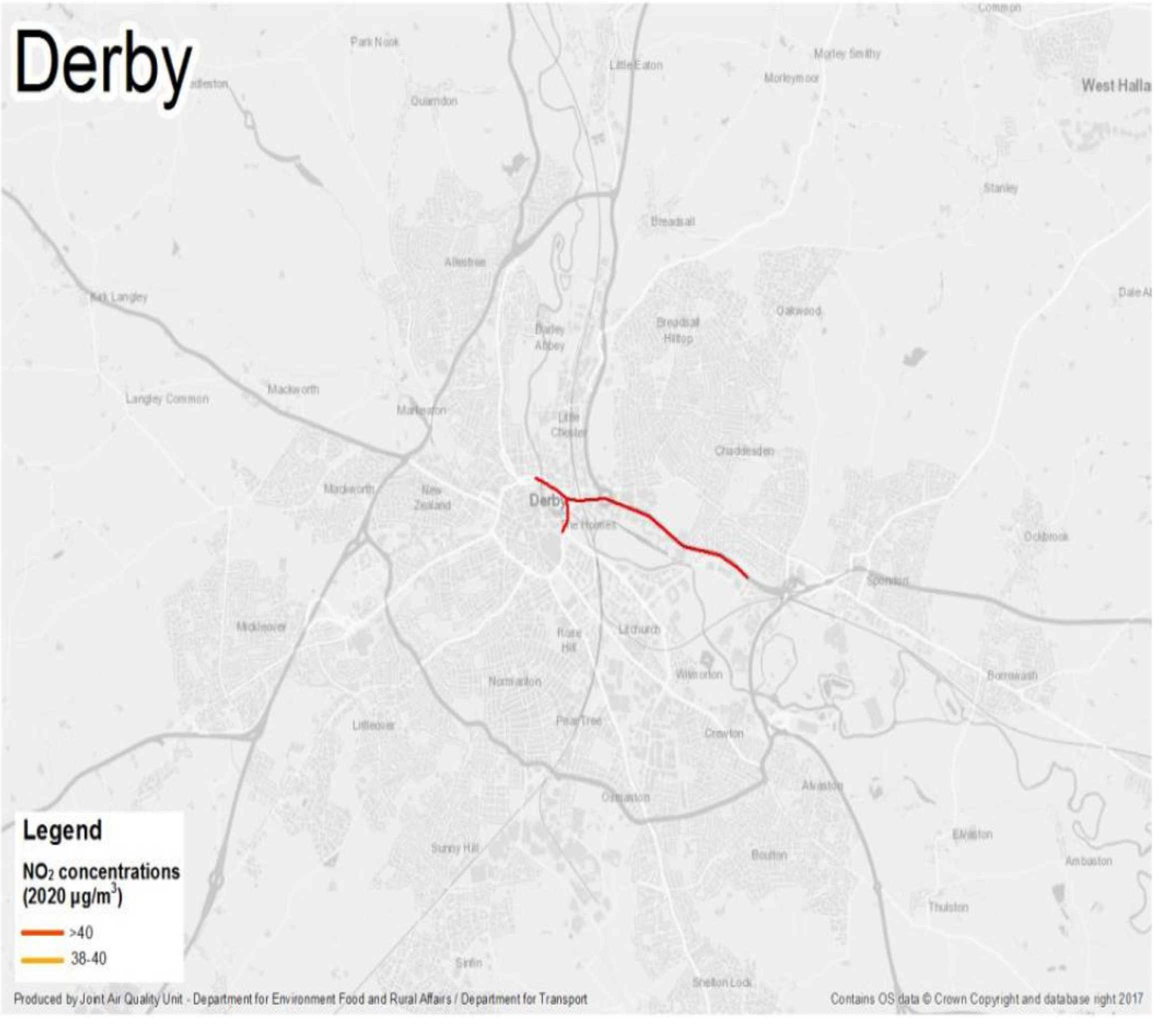


Figure 2 Areas of NO_2 exceedances identified in the National Plan



1.2 Outline scheme options

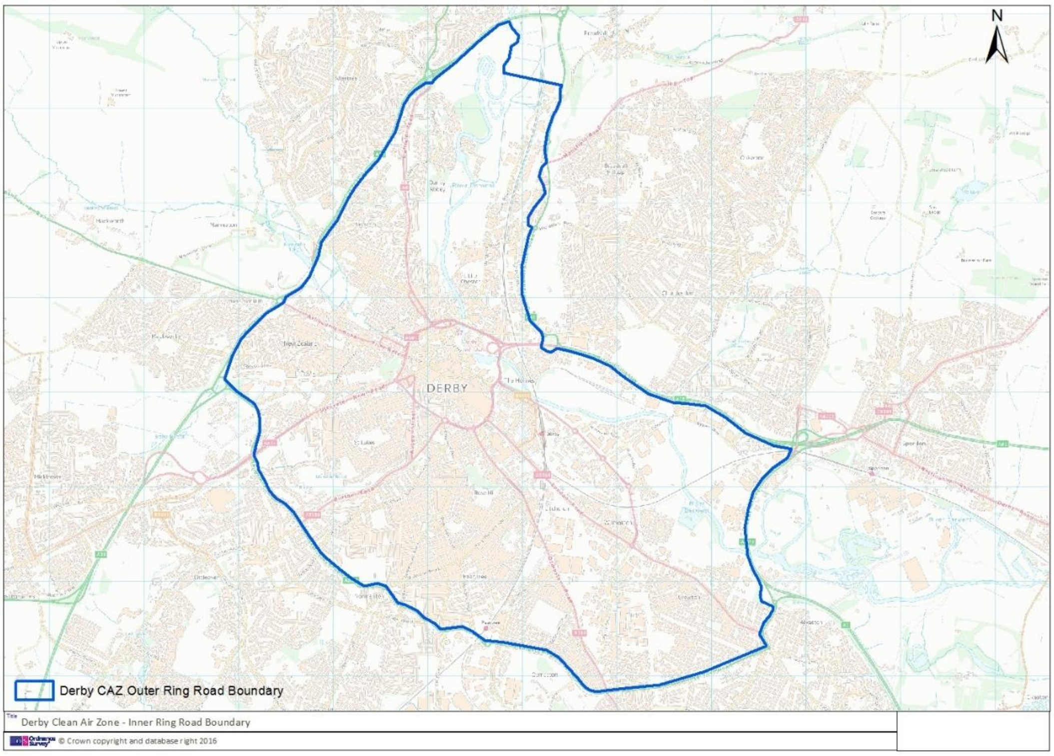
DCC is determining the nature and extent of available measures to address the roadside NO_2 issue. In doing so the council has assessed the feasibility and effectiveness of introducing a charging CAZ, in line with the government's requirements for a benchmark charging CAZ to be considered as one of the options. This has enabled careful consideration of the options to ascertain whether there are other measures, or packages of measures that are just as effective or more effective, at addressing the principle aim of the project, which is to achieve compliance with roadside NO_2 limits in the shortest possible time period. The assessment has been conducted in tandem with the preparation of a draft Low Emissions Strategy (LES) which has helped inform the range of alternative measures able to deliver the same, or more effective, reductions in NO_2 concentrations as a charging-based CAZ.

Following this wider assessment work four future scenarios for 2020 have been modelled for the Full Business Case as part of the CAZ feasibility study and covering the following:

- *Test 1 – business as usual (BAU):* this is the standard baseline assessment using the transport model results for 2020 and the projected fleet mix for 2020 based on local ANPR data. This provided the results for the formal 'target determination' process.
- *Test 2 – do minimum:* this scenario accounts for measures that have already received funding approval from government but were not in the original BAU baseline in test 1.
- *Test 3 – Stafford Street traffic management and wider network management scheme:* this is a targeted set of traffic management measures designed to specifically tackle the exceedance problem identified on Stafford Street.
- *Test 4 – A benchmark Class D charging CAZ access restriction*: this scheme would apply to all vehicles entering the area within the outer ring-road. The scheme boundary is illustrated in Figure 3.

In addition, a further test has been carried out for a 2025 reference year which includes the completion of the A38 three junctions upgrade works.

Figure 3 Derby outer ring road boundary



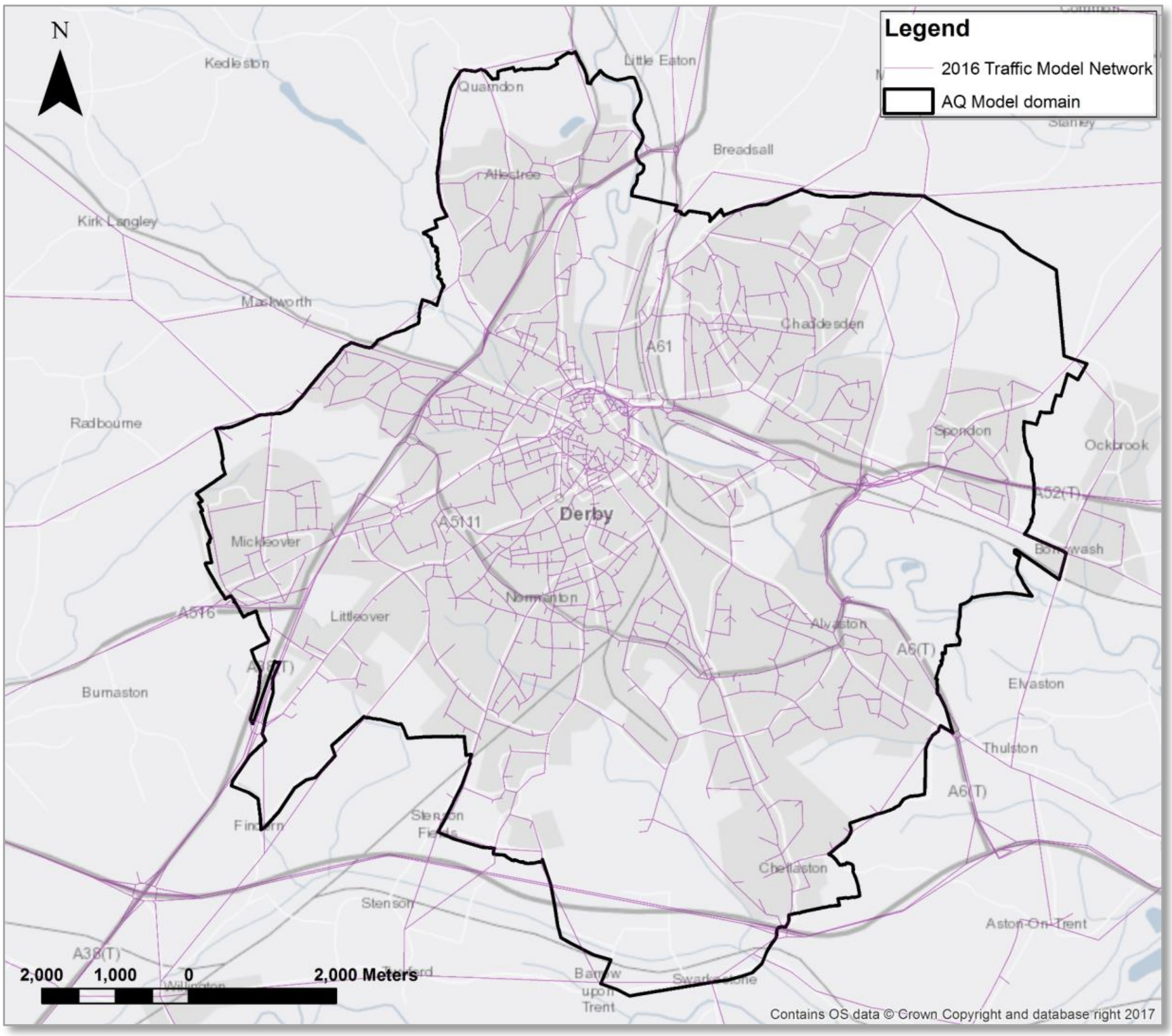
1.3 Model domain

To assess the transport and air quality impacts of the scheme, a model domain is required that covers the potential scheme options, relevant AQMAs and possible diversion routes. The model domain used is shown in Figure 4 and has been chosen to cover the following:

- All of the AQMAs in Derby
- The main areas of concern identified in the national modelling assessment at Eastgate and Holms Bridge
- The wider transport network covered by the Derby Area Transport Model (DATM3), see the Transport Model documentation[2] contained in T1 to T5 of this series of reports to JAQU for further details.

Further details in relation to the model domain are presented in section 2.

Figure 4 Proposed model domain



2 'T2 Local Plan Transport Model Validation Report V5.1', SYSTRA 2017

1.4 Modelling years

There are two key years used in the modelling work, as set out in Table 1 below, plus an additional future reference year. The baseline modelling year is 2016 as this allows use of the latest air quality and transport data. The future baseline is modelled for the assumed implementation year in 2020. Any interim years required will be generated through interpolation rather than direct model tests. For Derby, modelling of a later future reference year in 2025 is also being carried out to allow for the major upgrade to the A38 to be fully implemented and reflected in the results.

Table 1: Model years

Year	Description
2016	**Base year** – using latest available data on air quality and traffic.
2020	**Implementation year** – latest date when the scheme is assumed to be in place, if it is required in Derby.
2025	**Post implementation year** – reference case including the completion of the A38 upgrade works.

1.5 Background modelling

The primary cause of the localised air pollution problems in Derby are related to road traffic emissions. As such the focus of the modelling study is road traffic emissions. However, one background source that was considered as significant and was investigated specifically in the modelling work was a new 200,000 tonnes-per-annum municipal waste incinerator along Sinfin Lane.

The incinerator came into operation between the 2016 baseline and the 2020 target year and so has been added to the 2020 background maps. The details of how this has been modelled and its relation to the wider background is described in section 5.2

2 Details of the Modelling Domain

The core air quality model domain covers the Derby city boundary. It also extends beyond the city boundary to include sections of the A38 and A50 trunk roads. The air quality model domain matches the area of influence assessed in the associated transport modelling. As stated in the Transport Model review document[3], the traffic model area of influence contains all major roads and junctions that could potentially be included in a Derby Clean Air Zone. Displacement of traffic due to the implementation of CAZ measures is not expected to occur beyond the proposed model domain.

A map showing the extent of the air quality model domain relative to the associated traffic model network was presented above in Figure 4. A map showing the model domain relative to roads included in the national Pollution Climate Mapping (PCM) model is presented in Figure 5. All road links in the PCM model within the Derby City Boundary are included in the model domain specification.

Derby City Council has two current Air Quality Management Areas (AQMAs), both of which are entirely within the proposed model domain. A map showing the locations of the AQMAs relative to the model domain is presented earlier in this report (see Figure 1).

[3] 'Derby T2 Local Plan Transport Model Validation Report', SYSTRA 2017

Derby City Council's 2016 NO_2 roadside measurements have been used in the air quality modelling assessment to verify the model outputs, assuming data capture and QA/QC are satisfactory for the 2016 baseline year. A map showing the sites at which NO_2 concentrations were measured during 2016 is presented in Figure 6.

Figure 5: PCM model road links within the CAZ study domain 2015

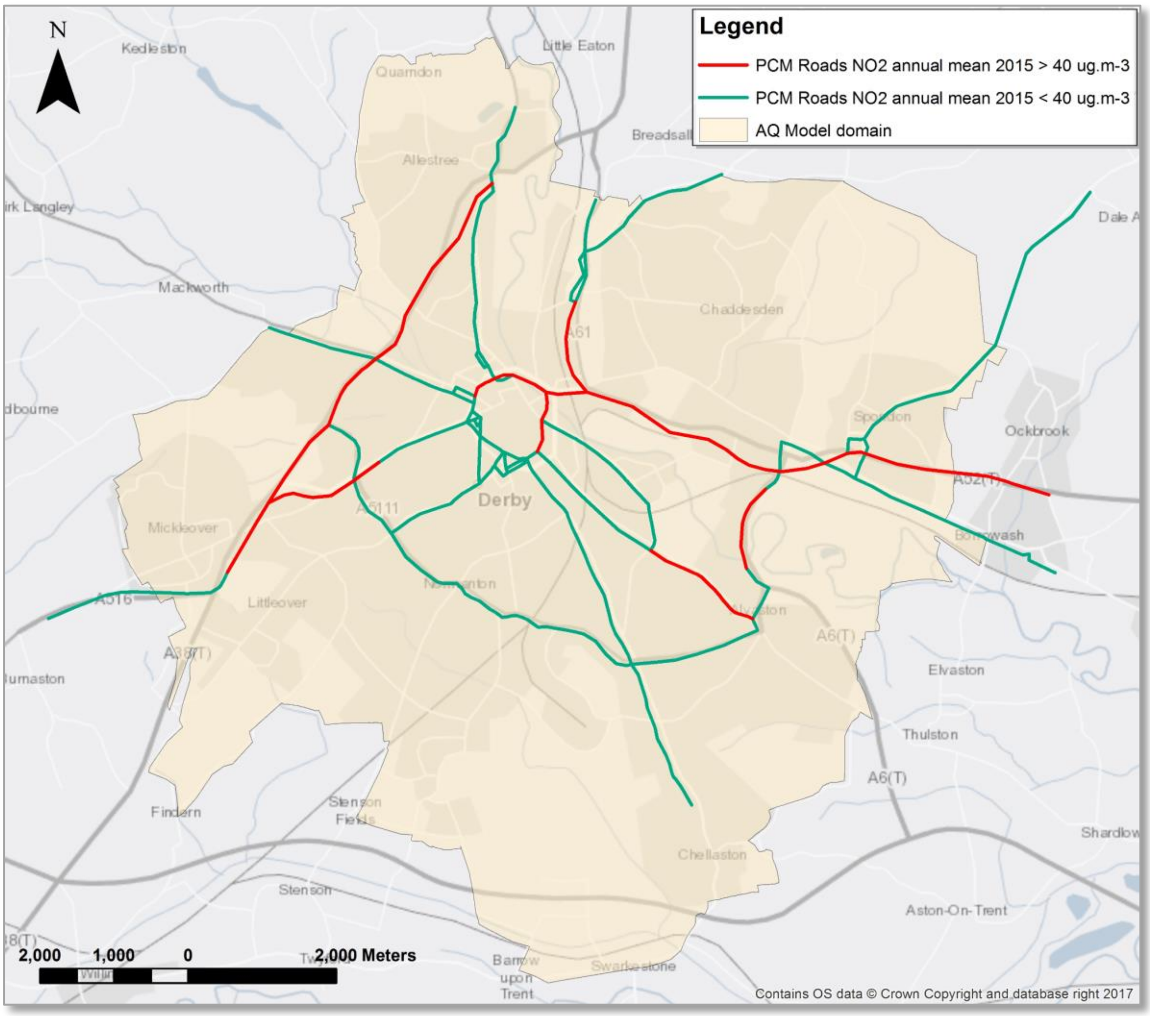
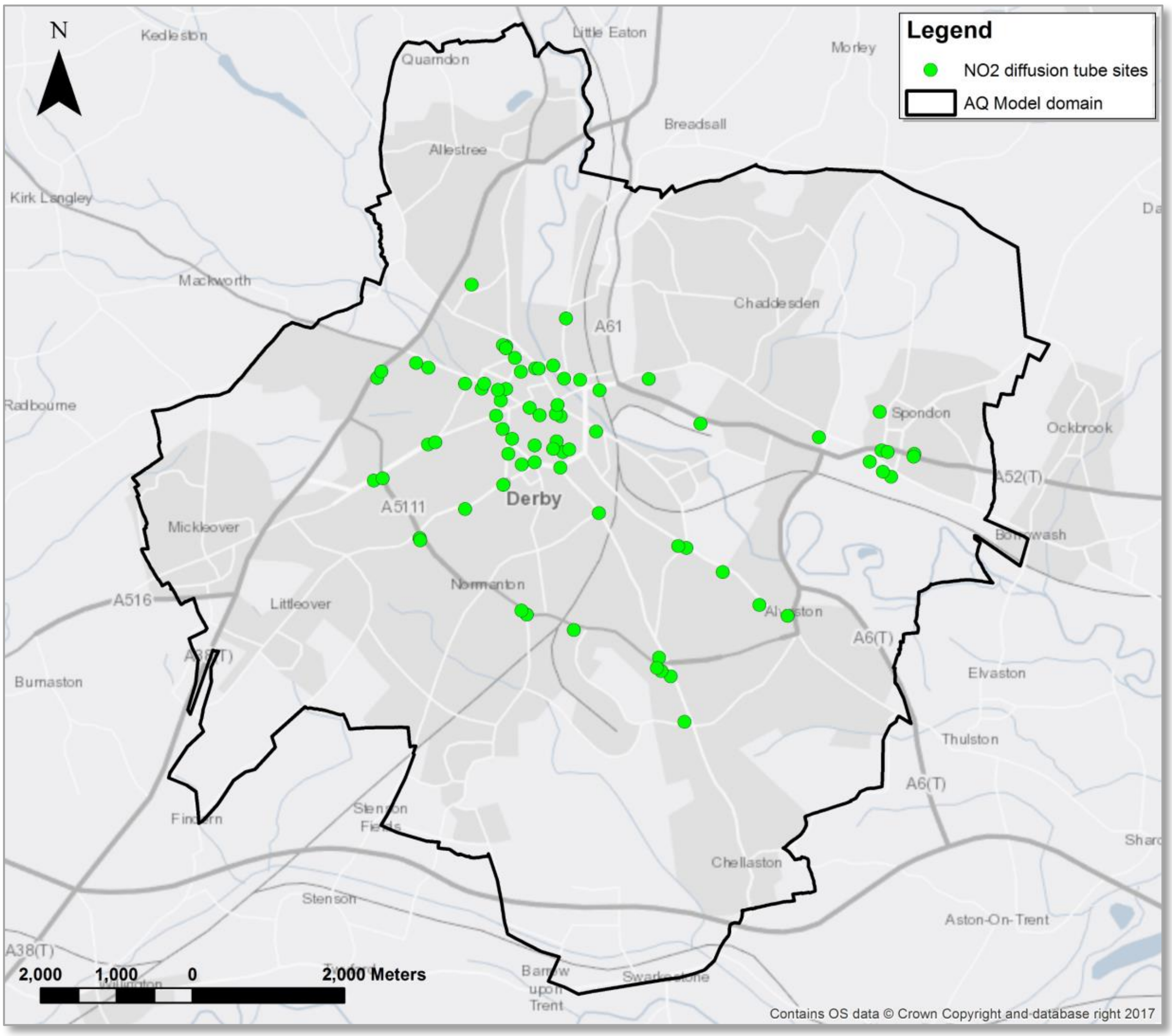


Figure 6 Derby City Council NO_2 monitoring sites 2016



3 Model and receptor location selection

3.1 Model selection

The RapidAir© dispersion modelling system has been used for the study. This is Ricardo Energy & Environment's proprietary modelling system developed for urban air pollution assessment. Information regarding compliance with the JAQU technical requirements is set out in AQ1 the Air Quality Modelling Tracking Table with further description of the model also provided here.

The model is based on convolution of an emissions grid with dispersion kernels derived from the USEPA AERMOD[4] model. The physical parameterisation (release height, initial plume depth and area source configuration) closely follows guidance provided by the USEPA in their statutory road transport dispersion modelling guidance[5]. AERMOD provides the algorithms which govern the dispersion of the emissions and is an accepted international model for road traffic studies (it is one of only two

[4] https://www3.epa.gov/ttn/scram/dispersion_prefrec.htm#aermod
[5] https://www.epa.gov/state-and-local-transportation/project-level-conformity-and-hot-spot-analyses

mandated models in the US and is widely used overseas for this application). The combination of an internationally recognised model code and careful parameterisation matching international best practice makes RapidAir demonstrably fit for purpose for this study.

The USEPA have very strict guidelines on use of dispersion models and in fact the use of AERMOD is written into federal law in 'Appendix W' of the Guideline on Air Quality Models[6]. The RapidAir model uses AERMOD at its core and is therefore based on sound principles given the pedigree of the core model.

The model produces high resolution concentration fields at the city scale (1 to 3m scale) so is ideal for spatially detailed compliance modelling. A validation study has been conducted in London using the same datasets as the 2011 Defra inter-comparison study[7]. Using the LAEI 2008 data and the measurements for the same time period the model performance is consistent (and across some metrics performs better) than other modelling solutions currently in use in the UK. A RapidAIR model validation paper has also recently been published with our partners at Strathclyde Universit in the well known Environmental Modelling and Software journal[8].

3.2 Core aspects of the modelling

3.2.1 Chemistry, meteorology and topology

NOx to NO_2 chemistry was modelled using the Defra NOx/NO_2 calculator. Modelled annual mean road NOx concentrations were combined with background NOx and a receptor specific (i.e. at each receptor) fNO_2 fraction to calculate NO_2 annual mean concentrations. The receptor specific fNO_2 fraction was calculated by dividing the modelled road NO_2 by modelled road NOx (total road NOx) at each receptor. Further information on this is presented in Section 4.3.3.

3.2.2 Meteorology

Modelling was conducted using the 2016 annual surface meteorological dataset measured at Nottingham/Watnall. The dataset was processed in house using our own meteorological data gathering and processing system. We use freely available overseas meteorological databases which hold the same observations as supplied by UK meteorological data vendors. Our RapidAir model also takes account of upper air data which is used to determine the strength of turbulent mixing in the lower atmosphere; this was obtained from the closest radiosonde site and process with the surface data in the USEPA AERMET model. We have utilised data filling where necessary following USEPA guidance which sets out the preferred hierarchy of routines to account for gaps (persistence, interpolation, substitution). AERMET processing was conducted following the USEPA guidance. To account for difference between the meteorological site and the dispersion site, surface parameters at the met site were included as recommended in the guidance and the urban option specified for the dispersion site. Land use parameters were accessed from the CORINE land cover datasets[9].

A uniform surface roughness value of 1.0 m was modelled to represent a typical city/urban environment.

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[6] 40 CFR Part 51 Revision to the Guideline on Air Quality Models: Adoption of a Preferred General Purpose (Flat and Complex Terrain) Dispersion Model and Other Revisions; Final Rule, Environmental Protection Agency, 2005

[7] https://uk-air.defra.gov.uk/research/air-quality-modelling?view=intercomparison

[8] Masey, Hamilton, Beverland (2018) Development and evaluation of the RapidAir® dispersion model, including the use of geospatial surrogates to represent street canyon effects

[9] EEA (2018) https://www.eea.europa.eu/publications/COR0-landcover

3.2.3 Canyon modelling

The platform includes two very well-known street canyon algorithms with significant pedigree in the UK and overseas. The first replicates the functionality of the USEPA 'STREET' model. The code was developed by the Office of Mobile Source Air Pollution Control at the USEPA and published in a series of technical articles aimed at operational dispersion modellers in the regulatory community[10,11]. The STREET model has been used for many years and has been adopted in dispersion modelling software such as AirViro. The USEPA canyon model algorithms are essentially the same as those recommended by the European Environment Agency for modelling canyons in compliance assessment[12].

The RapidAir model also includes the AEOLIUS model which was developed by the UK Met Office in the 1990s. The AEOLIUS model was originally developed as a nomogram procedure[13]. The scientific basis for the model is presented in a series of papers by the Met Office[14,15,16,17,18.] The model formulation shares a high level of commonality with the Operational Street Pollution Model[1920] (OSPM) which in turn forms the basis of the basic street canyon model included in the ADMS-Roads software. Therefore, the AEOLIUS based canyon suite in RapidAir aligns well with industry standards for modelling dispersion of air pollutants in street canyons. The systems of equation used in each street canyon model are provided in Appendix 1.

Using available information on building heights and road widths, candidate locations for street canyons were identified. These locations were then checked using Google Street View to confirm the presence of a street canyon. For roads assigned as street canyons, the required information for the AEOLIUS street canyon model was populated – this includes building height, emissions and number of vehicles per hour. Further details on the model parameters required are provided in the equations in Appendix 3. The canyon model is only turned on if the wind is blowing parallel across the canyon (± 5 degrees) i.e. the wind must be between 40 and 50 degrees from the orientation of the canyon. For each hour in the meteorological data (same as that described in 3.2.2**Error! Reference source not found.**) with wind direction matching the criteria to turn the street canyon on, the leeward, windward and parallel street canyon concentrations were calculated. To provide annual street canyon concentrations, the sum of the data contained within each of leeward, windward and parallel was calculated.

The results from the street canyon module were combined with the concentrations modelled in the dispersion step of RapidAir. The annual leeward and annual windward concentrations were added together, then this was added to the dispersion modelled road NO_x. The concentrations from the parallel contribution of the street canyon model were not included as including this would result in double counting of the road NOx when combined with the dispersion NO_x.

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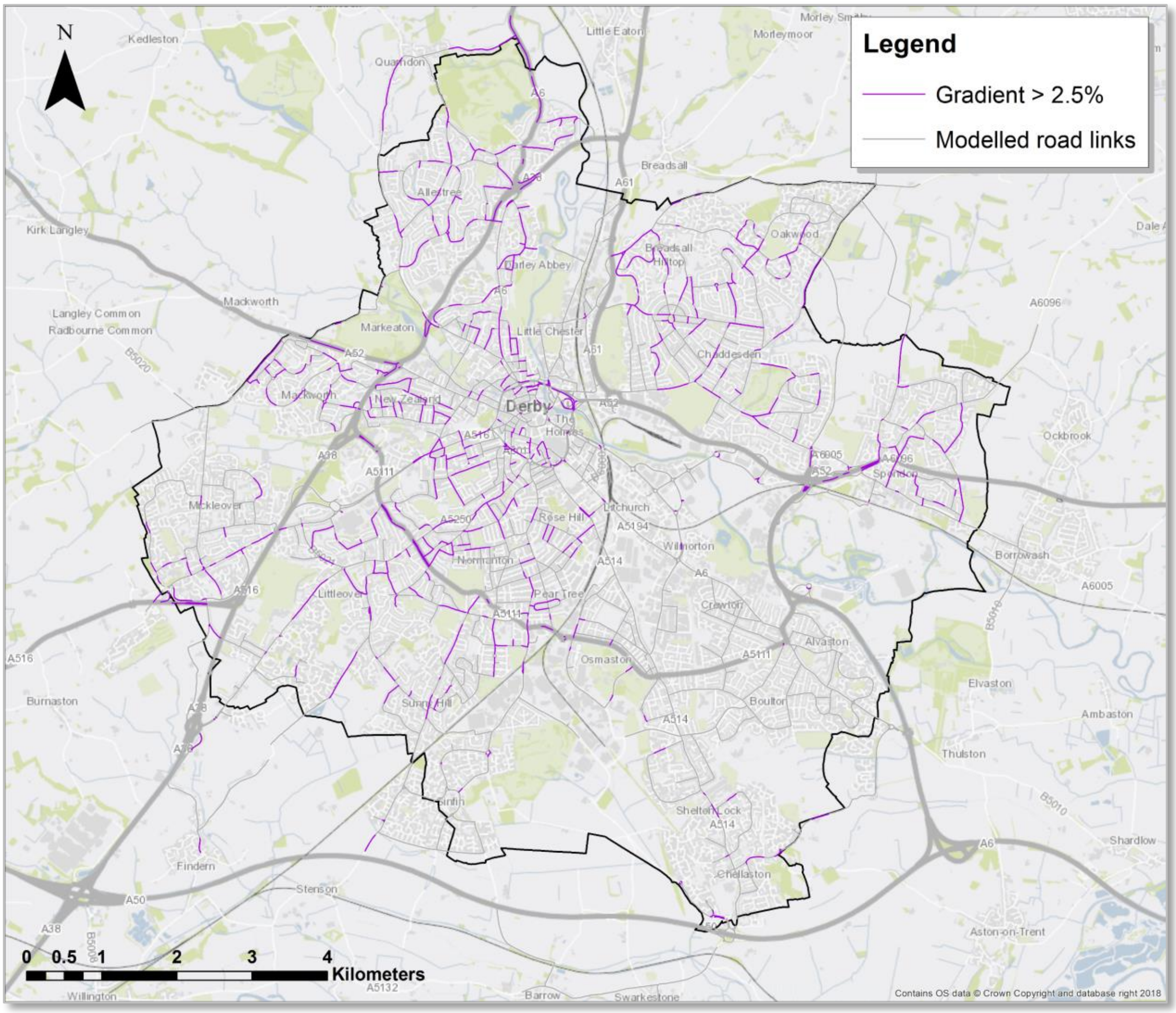
[10] Ingalls., M. M., 1981. Estimating mobile source pollutants in microscale exposure situations. US Environmental Protection Agency. EPA-460/3-81-021
[11] USEPA Office of Air Quality Planning and Standards., 1978. Guidelines for air quality maintenance planning and analysis, Volume 9: Evaluating indirect sources. EPA-450/4-78-001
[12] http://www.eea.europa.eu/publications/TEC11a/page014.html
[13] Buckland AT and Middleton DR, 1999, Nomograms for calculating pollution within street canyons, Atmospheric Environment, 33, 1017-1036.
[14] Middleton DR, 1998, Dispersion Modelling: A Guide for Local Authorities (Met Office Turbulence and Diffusion Note no 241: ISBN 0 86180 348 5), (The Meteorological Office, Bracknell, Berks).
[15] Buckland AT, 1998, Validation of a street canyon model in two cities, Environmental Monitoring and Assessment, 52, 255-267.
[16] Middleton DR, 1998, A new box model to forecast urban air quality, Environmental Monitoring and Assessment, 52, 315-335.
[17] Manning AJ, Nicholson KJ, Middleton DR and Rafferty SC, 1999, Field study of wind and traffic to test a street canyon pollution model, Environmental Monitoring and Assessment, 60(2), 283-313.
[18] Middleton DR, 1999, Development of AEOLIUS for street canyon screening, Clean Air, 29(6), 155-161, (Nat. Soc for Clean Air, Brighton, UK).
[19] Hertel O and Berkowicz R, 1989, Modelling pollution from traffic in a street canyon: evaluation of data and model development (Report DMU LUFT A129), (National Environmental Research Institute, Roskilde, Denmark).
[20] Berkowicz R, Hertel O, Larsen SE, Sørensen NN and Nielsen M, 1997, Modelling traffic pollution in streets, (Ministry of Environment and Energy, National Environmental Research Institute, Roskilde, Denmark).

3.2.4 Gradient, tunnels and flyovers

Gradient effects have been included for relevant road links during emissions calculations. LIDAR Composite Digital Terrain Model (DTM) datasets at 1m and 2m resolution are available over the model domain[21]. Link gradients across the model domain can be calculated by extracting start and end node elevations for road links of known length from the LIDAR DTM datasets.

The TG(16) guidance[22] provides a method of adjusting road link emission rates for gradients greater than 2.5%; it is applicable to broad vehicle categories for heavy vehicles only. As per the guidance and clarification provided by JAQU this adjustment has been applied to all pre Euro VI HGVs and buses. Figure 7 shows the roads where gradient effects were included during emissions calculations.

Figure 7: Locations where gradient effects have been included during emission calculations



No modelling of tunnels or flyovers was included as the RapidAir kernel approach applies the same source height across the model domain. If modelling of flyovers was considered to be beneficial for

[21] http://environment.data.gov.uk/ds/survey/#/survey

[22] Defra & the devolved administrations (2018) Part IV of the Environment Act 1995; Environment (Northern Ireland) Order 2002 Part III; Local Air Quality Management Technical Guidance (TG16); February 2018

this assessment, we could have modelled road links at a higher elevation using a dispersion kernel created with a different source height in AERMOD. It was not however considered beneficial for this assessment.

3.3 Air quality model receptor locations

Derby has a wide network of monitoring locations comprised of passive diffusion tube samplers. All available NO_2 measurements conducted in 2016 have been specified as receptors in the model; and where relevant, used for model verification and calculating model performance statistics. A map of the monitoring locations is presented above in Figure 6.

A set of gridded results with a resolution of at least 10m x10m is required by the JAQU guidance. For this study RapidAir was used to model at 1m grid resolution. The model can comfortably deal with up to 500 million gridded receptor points which allows for over 20,000 cells in the ‘x’ and ‘y’ axes. The model is therefore capable of modelling an urban area the size of the Derby domain at 1m resolution. The canyon model is set to the same resolution as the grid model so that they align spatially.

As RapidAir produces concentration grids (in raster format), modelled NO_2 concentrations can be extracted at receptor locations anywhere on the 1m resolution model output grid. For comparison with the PCM model results, annual mean concentrations at a distance of 4m from the kerb and at 2m height have been extracted from the RapidAir model outputs. This provides an assessment of compliance at relevant roadside locations where there may be public access as specified in the Air Quality Directive (AQD) requirements Annex III A, B, and C3. These results are presented later in this report.

Annex III of the AQD specifies that macroscale siting of sampling points should be representative of air quality for a street segment of no less than 100 m length at traffic-orientated sites. To provide results for roadside locations, where there is public access and the Directive therefore applies, road links with exceedances of the NO_2 annual mean objective stretching over link lengths of 100m or greater have been extracted and presented as a separate GIS layer of model results.

Annex III of the AQD also specifies that microscale sampling should be at least 25 m from the edge of major junctions. Therefore, when reporting model results relevant to compliance with the AQD, locations up to 25m from the edge of major junctions in the model domain have been excluded.

4 Base year modelling

4.1 Base year and meteorological dataset

As described in section 1.4 we have modelled a baseline year of 2016. We have used the 2016 annual surface meteorological dataset measured at Nottingham/Watnall which has been processed in house using our own meteorological data gathering and processing system. We use open overseas meteorological databases which hold the same observations as supplied by UK meteorological data vendors. Our RapidAir model also takes account of upper air data which is used to determine the strength of turbulent mixing in the lower atmosphere; we have derived this from the closest radiosonde site and processed with the surface data using the USEPA AERMET model. Where necessary we have utilised data filling following USEPA guidance which sets out the preferred hierarchy of routines to account for gaps (persistence, interpolation, substitution). A map showing the location and a wind rose for the 2016 Nottingham/Watnall met dataset are presented in

Figure 8 and Figure 9 respectively.

Figure 8: Nottingham/Watnall meteorological measurement site location

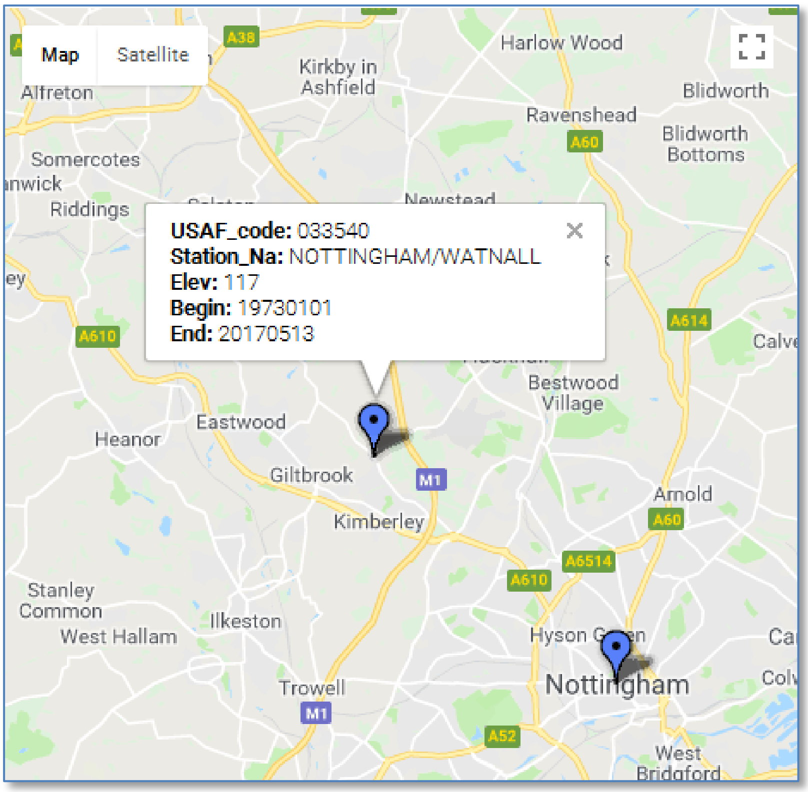
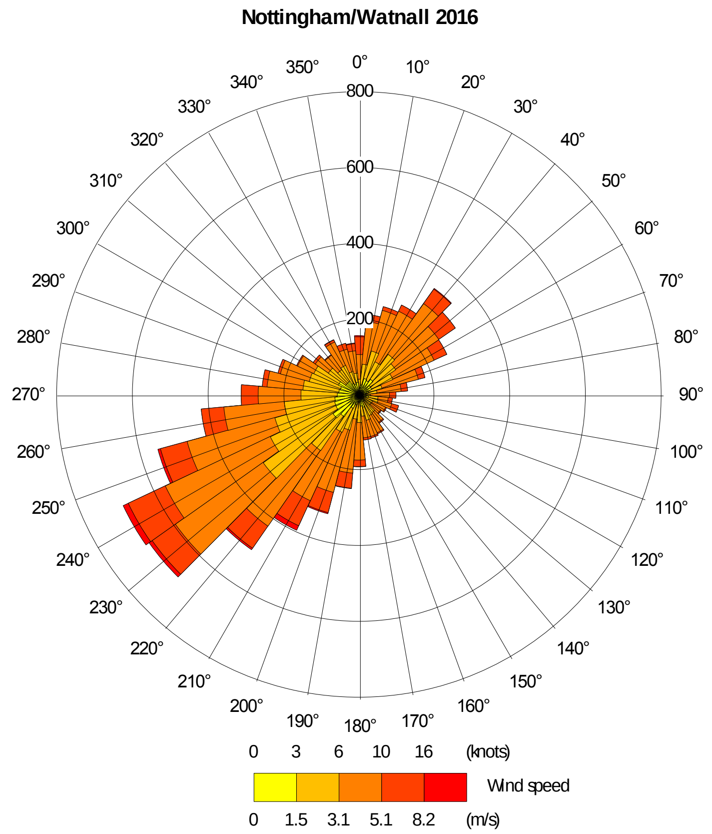


Figure 9: Windrose

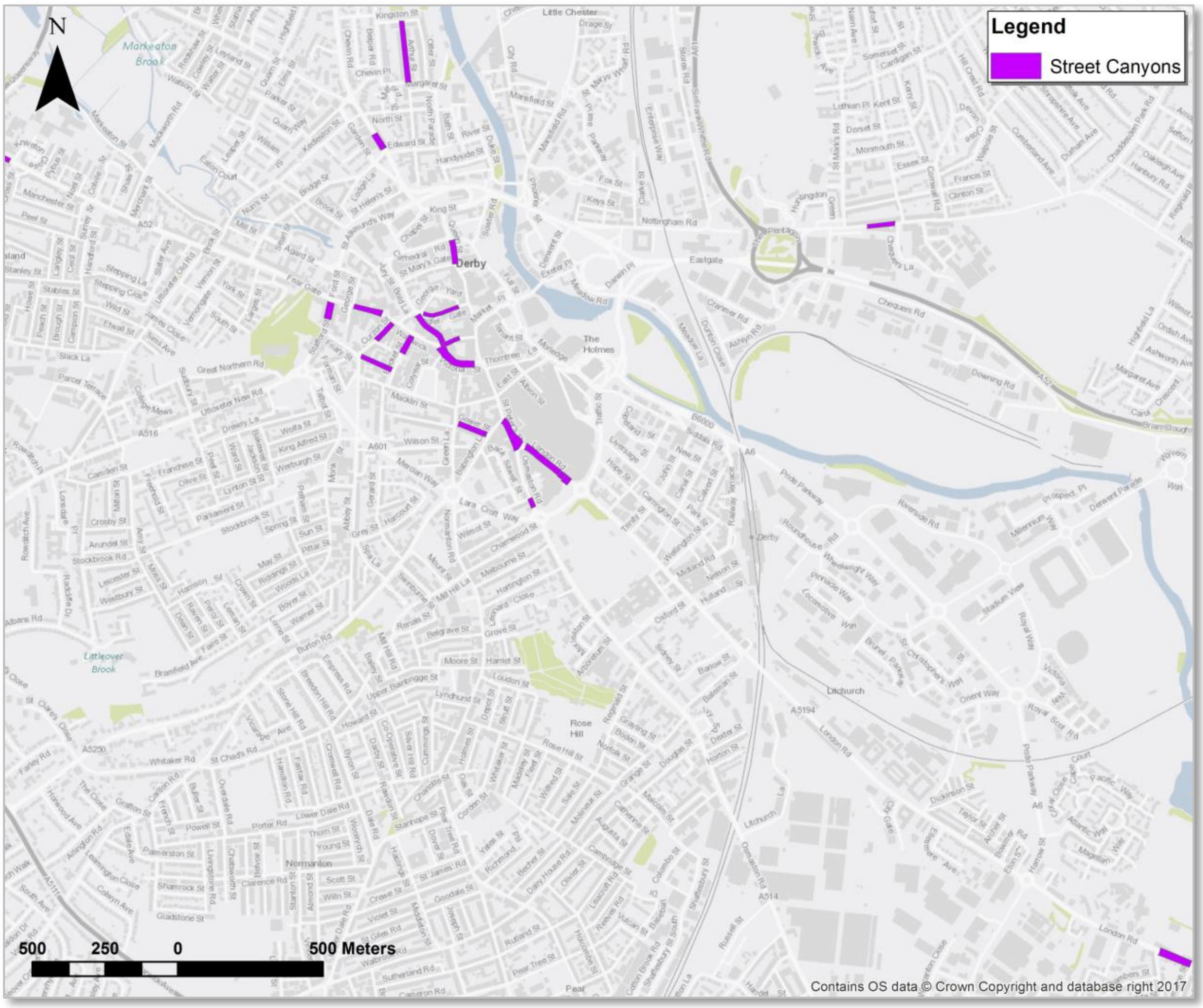


4.2 Representation of road locations and canyons

A realistic representation of road locations has been modelled by assigning emissions to the road links represented in the Ordnance Survey ITN Roads GIS dataset; it contains spatially accurate road centreline locations for various road categories e.g. Motorway, A road, B road, minor road, local street etc. Link gradients across the model domain were calculated using LIDAR DTM datasets.

A map showing the locations where canyon effects were modelled is presented in Figure 10.

Figure 10: Locations where street canyons effects were modelled



4.3 Road traffic modelling

4.3.1 Average daily vehicle flow and speeds

Baseline and future year annual average daily traffic (AADT) link flows for each model link have been provided by SYSTRA using outputs from the Derby Area Transport Model (DATM3) which has a detailed representation of the transport networks and demand within the Derby Principal Urban Area (PUA).

Baseline daily average link speeds have been calculated using the DfT Traffic Master GPS measured journey time datasets cross referenced with the Ordnance Survey ITN roads GIS dataset. This provided observed average speed data over defined road links at an appropriate spatial resolution. It should also provide a reasonable representation of the change in emissions at locations where typical vehicle speeds are reduced e.g. approaching junctions. A typical UK week day diurnal profile[23] was assumed and applied as time varying emissions in AERMOD when creating the RapidAir dispersion kernel

4.3.2 Vehicle fleet composition

Vehicle emission rates for the vehicle categories buses, taxis, coaches, rigid HGVs, articulated HGVs, LGVs, cars and motorcycles have been calculated using the latest COPERT v5 NOx emission functions.

The traffic model has provided vehicle flows for five highway user classes which are: Car, taxi, HGV, LGV and Buses. A further breakdown of the HGV into rigid and articulated categories has been conducted using local traffic count data and ANPR data, and was defined separately for two model zones: city centre (within the inner ring road) and rest of city. The taxi fleet was also split between private hire (which were modelled as standard cars) and hackney cab (which are modelled as LGVs).

Emission calculations for each vehicle category are based on vehicle age split by Euro classification. Information on the baseline Euro standard mix (traffic composition & age) was collected during ANPR surveys conducted over two days in October 2016. An average distribution of Euro classifications calculated from the complete ANPR dataset can either be applied across the entire model domain or more localised splits at a zonal level. An assessment of the ANPR data suggested that for both light and heavy duty vehicles the Euro class distribution was reasonably consistent across the survey locations. Based on this, a common distribution of fuel types and euro classifications was used across the whole model domain for each vehicle type.

Modelling coach emissions

When using the EFT or our in-house equivalent road traffic emissions calculator RapidEms; the assumed fraction of coaches in the bus fleet is 28%. This is the coach fraction specified for Urban/rural UK roads (outside London) in the 2013 and 2015 base year NAEI rtp fleet projections[24]. We are however aware that coach movements were not included in the traffic model outputs so all bus movements would be passenger service vehicles. To account for this when calculating bus emissions, we used an identical local euro fleet breakdown for both the bus and coach vehicle categories. This will however mean that emissions from the additional bus/coach AADT not represented in the traffic model have not been included.

[23] 2015
[24] NAEI (2014) rtp_fleet_projection_Base2013_v3.0_final -

4.3.3 NOx/NO_2 emissions assumptions

Link specific NOx emission factors have been calculated using the COPERT v5 emission functions for all vehicles up to and including Euro 6/VI. Emission rates have been calculated using our in-house emission calculation tool RapidEms as agreed by JAQU, which is fully consistent with COPERT v5 and links directly to our RapidAir dispersion modelling system.

JAQU recommend the use of data on primary NO_2 emissions (fNO_2) by vehicle type which is available via the NAEI website (based on 2014 NAEI) to provide a more detailed breakdown than provided by the LAQM NOx to NO_2 convertor. This approach uses road link specific f-NO_2 emission estimates.

Based on this requirement, the RapidEms road emissions calculation tool now includes additional functionality to calculate fNO_2 emission rates for each road link. Link specific fNO_2 fractions can then be calculated for each link by dividing fNO_2 by total road NOx emission rate.

Calculating link specific fNO_2 emission rates also facilitates dispersion modelling of both road NOx and fNO_2 across the entire model domain to produce separate concentration rasters, which can then be combined with background concentrations to calculate NO_2 concentrations in each grid cell.

The recently updated version (5.3) of the LAQM NO_x to NO_2 conversion spreadsheet has been used to convert road NOx, fNO_2 and background NOx into NO_2 concentrations where results at discrete receptor locations are required. This currently includes all NO_2 monitoring site locations and receptors placed at 4m from the PCM road links.

The citywide domain has been modelled at 1m resolution, with modelled concentration grid rasters having approximately 182 million cells. The JAQU guidance note for assigning fNO_2 when calculating NO_2 acknowledges that for large model domains and high-resolution models, use of the spreadsheet tool is not practical because the calculator is limited to a maximum of 64.6K lines in the excel spreadsheet. The guidance note recommends the use of the NOx to NO_2 calculator to define statistical relationships between NO_2 concentrations and the input parameters and use these relationships to calculate NO_2. This approach is being used to calculate the full set of gridded NO_2 results at the 1 m resolution.

In this case the statistical relationship was derived using an ordinary least squares (OLS) regression model. The OLS model was derived by defining background NOx, road NOx and road fNO_2 as the independent variables, and total NO_2 as the dependent variable.

4.4 Non-road transport modelling and background concentrations

For the 2016 baseline year we have used the 2015 base year LAQM background maps available to download from the Defra UK air web page. The contribution from local road transport sources sectors that have been modelled explicitly were subtracted from the background maps.

4.5 Measurement data for model calibration

Derby City Council's 2016 diffusion tube annual mean NO_2 measurements from roadside sites were used for model verification. Information on monitoring data QA/QC, diffusion tube bias adjustment factors etc. will be as presented in the Derby City Council 2017 LAQM Annual Status Report[25].

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[25] Derby CC (2017) Derby City Council Air Quality Annual Status Report (ASR); July 2017.

5 Projected future year scenario modelling

5.1 Road transport future year baseline

Future year baseline scenarios have currently been modelled in the year 2020 as described in section 1.4.

The main modelling issues for the future year baseline scenarios are:

- **AADT flows for future baseline years** have been provided from the SYSTRA Derby Area Transport Model (DATM3). Further information on how these traffic flows were derived and how local growth in traffic will be calculated is presented in the 'T4 Local Plan Transport Model Forecasting Report' (SYSTRA, 2019)

- **Projected fleet split (vehicle type):** All future year scenarios have scenario specific vehicle fleet splits for each traffic model link, using the same categories as provided in the 2016 base year traffic model. The further split of HGVs into artic and rigid used the same ratios as derived for the 2016 baseline.

- **Projected fleet age composition (Euro class):** The locally observed 2016 baseline Euro fleet composition (from ANPR surveys) has been adjusted to account for turnover in the local fleet in the future baseline years being modelled. This has been done using the draft methodology provided by JAQU which recommends deriving future scaling factors from the national NAEI data, applying these to the local ANPR results and then normalising to 100%. This gives an evolution of the local fleet that is slightly behind the national fleet.

- **Future year scenarios average vehicle speed data:** Average link speeds for all future year scenarios have been estimated by adjusting the observed baseline speed data (Traffic Master) by the ratio of the 2016 baseline vs future baseline journey times calculated in the traffic model.

- **Projected vehicle NOx emission rates** have been calculated using the latest COPERT v5 NOx emission functions applied to the projected average flows, average speeds, fleet and vehicle age composition for the future year being modelled.

5.2 Non-road transport projections

For the 2020 baseline year we have used the relevant future year LAQM background maps dataset with the relevant road traffic sector contributions discounted to avoid double counting of emissions.

In addition to this we have modelled emissions from a new municipal waste incinerator located at Sinfin Lane using stack and emission parameters from the planning application for the site. NOx concentrations attributable to emissions from the incinerator were modelled at 10m resolution using AERMOD, then combined with the 2020 future year background maps using raster addition.

5.3 Scheme option modelling projections

Four future scenarios have been tested for 2020 as set out in section 1.2 above, along with a 2025 reference year when all other major traffic schemes in the area are expected to be completed. In addition, a set of sensitivity tests have been carried as described in section 6 below. The basic components of these scenarios and the primary modelling assumptions are shown below in Table 2.

Table 2 Final list of scenarios for assessment

Option	Components	Modelling approach
Business as usual – 2020	Reference traffic model run for 2020 National background NO_2 maps and local point sources.	Reference traffic model data is used for traffic activity. Detailed fleet composition is generated from ANPR data in 2016 and projected to 2020. Non-transport concentrations provided by the national background maps, plus local modelling of the Sinfin incinerator.
Do Minimum baseline – 2020	Reference traffic and non-transport activity	As per business as usual scenario above
	Clean Bus Technology Fund (CBTF)	All non-Euro VI buses retrofitted to Euro VI (total of 152 buses), so have set bus fleet to all Euro VI in the model
Traffic management scenario – 2020	CBTF	Same modelling assumption as Do Minimum above.
	Stafford Street traffic management and wider network measures	Traffic management measures modelled in traffic model and then used as traffic activity data for the AQ model.
City Wide Charging CAZ D – 2020	Benchmark City Wide Charging CAZ D	A City -wide CAZ D, using upgrade assumptions provided by JAQU, is run through the transport model to assess behaviour of non-complaint vehicles. The compliant and non-compliant fleet are then modelled in the AQ model
2025 reference case	Reference traffic model run for 2025 CBTF assumed to be in place	Reference traffic model data is used for traffic activity. Detailed fleet composition is generated from ANPR data in 2016 and projected to 2025. Non-transport concentrations provided by the national background maps, plus local modelling of the Sinfin incinerator.

Further detail on the future scenarios and how they have been modelled is included in the Air Quality Modelling Report (AQ3).

6 Sensitivity testing

In any type of modelling there is always a level of uncertainty related to how well the model reflects reality. When setting up the air quality and transport models this general uncertainty is managed to some degree by validating the models to existing air quality measurement data and traffic data. The validation of the air quality model is described in the Air Quality Modelling Report (AQ3) with the level of model performance defined in terms of the Root Mean Squared Error (RMSE). The performance of the transport model is described the Transport Model Validation Report (T2).

When forecasting forward, further uncertainty is introduced in relation to the forecast activity levels and assumptions made about the measures being assessed. To explore the impact of these uncertainties on the robustness of the results and the conclusions drawn, a series of sensitivity tests have been performed. These have been carried out on the forecast ‘do minimum’ baseline, the options modelling and some wider tests related to emissions and fleet forecasting.

Some general guidance on the sensitivity tests to be carried out has been provided by JAQU. The details of the tests carried out for Derby, taking account of this guidance, are set out below in Table 3.

Table 3 Air Quality modelling sensitivity tests

Area of uncertainty	Sensitivity testing suggested by JAQU	Sensitivity test adopted	Which modelling options is test applied to?
Level of uptake of CBTF by bus operators	Consider a lower level of uptake to assess impact on traffic management scheme.	Worst case adopted by removing CBTF from the traffic management option.	Traffic management option.
Behavioural response to charging	0% upgrade response with other responses either determined by a travel demand model or scaled accordingly.	Apply test as proposed	City wide charging CAZ D test
Future emissions standards	Low scenario: Euro 6d-temp emissions equivalent to Euro 6d High scenario: Euro 6d-temp emissions halfway between Euro 6 & Euro 6d-temp and Euro 6d emissions halfway between Euro 6d-temp and Euro 6d	Adjust LDV Euro 6 fleet mix to all Euro 6a as worst-case scenario and re-run emissions and dispersion models	Assessed for 2020 baseline line and traffic management scheme to assess impact on compliance
Projecting f-NO_2	Lower f-NO_2 values in projected year by 40%.	Apply test as proposed	Apply to all future scenario results
Gradient based emission factors	Remove the effect of gradients (if modelled), add the effect of gradients (if not modelled).	Gradients are not present along areas of concern so this test is not necessary.	Not applied at all
Canyon effects	Use canyon module (if not used in 'central'	The canyon effect is key aspect of exceedance on Stafford Street. Including the canyon here provides	Not applied at all

Area of uncertainty	Sensitivity testing suggested by JAQU	Sensitivity test adopted	Which modelling options is test applied to?
	modelling), use separate calibration for canyon road links (if not done in ‘central’ modelling). Alternatively, cite information provided by JAQU.	good agreement with monitoring data. Removing the canyon is likely to remove the exceedance but then the model would not replicate actual monitoring data. As such this test was deemed inappropriate.	
Emissions at low speeds	Low scenario: Emissions factors for HDVs used to speeds recommended in COPERT 4. High scenario: Emissions factors for HDVs used to 5kph.	Provide comments justifying approach used in modelling and discussing the extent of the difference this could make.	For this and all below provide a discussion. Discussion done in relation to baseline as all these will affect all options equally.
Zonal vs full model domain calibration	Full model domain calibration (if zonal applied), zonal calibration (if full model domain applied).		
Background NO_2 calibration	Calibrate background NO_2 (if uncalibrated background maps used), remove background NO_2 calibration (if calibrated background maps used).		
f-NO_2 and calibration	Calibrate NOx using chemiluminescence monitors only (or cite information provided by		

Area of uncertainty	Sensitivity testing suggested by JAQU	Sensitivity test adopted	Which modelling options is test applied to?
	JAQU).		
Surface roughness length	High and low surface roughness values (to be discussed with JAQU on a case by case basis).		
Meteorology	Model in projected year using alternative years of meteorological data (or cite information provided by JAQU).		

Appendix 1 - RapidAir street canyon equations

The formulations for both models are described below.

USEPA STREET model

The STREET model assumes that the concentration of pollutants within a street canyon location consist of the urban background concentrations and a concentration from vehicle emissions within the street being modelled. The recommendation by the USEPA is to use the concentration from the model at 3m height as background concentrations at the actual receptor height being modelled. Since the canyons are expected to be well mixed over longer averaging periods it is sensible that we use the RapidAir kernel model to provide boundary conditions to the STREET model. Concentrations on the leeward (CL) and windward (CW) side of the canyon are calculated in this method, using the equations below:

$$CL = \frac{K * Q}{(U + 0.5) * \left[(x^2 + z^2)^{1/2} + L_0\right]}$$

$$CW = \frac{K * Q * (H - z)}{W * (U + 0.5) * H}$$

Where K is an empirical constant (usually set between 10 and 14); Q is the emission rate (g/m/s); U is the wind speed (m/s); L_0 is the length of individual vehicles (set to 3 m in this case); W is the width of the canyon (m); H is the average building height of the canyon (m); x is the distance from emission source to receptor (m); and z is the receptor height.

AEOLIUS/OSPM

There are three principal contributions in the AEOLIUS model, a direct contribution from the source to the receptor, a recirculating component within a vertex caused by winds flowing across the top of the canyon, and the urban background. The RapidAir model only take the recirculating component from the canyon and sums this with the kernel derived concentrations.

The RapidAir implementation of AEOLIUS is written in python 2.7 and uses the same equations described in the referenced Met Office papers.

During the coding of the canyon model we tested the outputs of our code with calibration data provided with the FORTRAN version of AEOLIUS. Our implementation agrees almost (R^2 = 0.97) perfectly with the version supplied by the Met Office (which is in any case now out of circulation).

The AEOLIUS model is more complex than the STREET model. Concentrations are calculated for the windward and leeward sides of the road using the equations detailed below (based on equations from the Met Office). The leeward and windward concentrations described below are only calculated for streets that were perpendicular to the direction of the wind. Concentrations calculated in ppb, and for NOx/NO_2 models are converted to µg/m^3 by multiplication by 1.91. The system of equations in RapidAir's implementation of the AEOLIUS model are shown below.

<u>Inputs</u>:

Emission rates (Q, µg/m/s); traffic speeds (v_t, mph), traffic density (f, vehicles per hour), % of cars and heavy good vehicles (f_c and f_h respectively), wind speed at roof level (u_r, m/s), street canyon width (w, m), street canyon height (h, m), and angle of street (θ).

Leeward concentrations:

The leeward concentrations = sum(C_{dlee} + C_{rec}) where C_{dlee} is the direct contribution from vehicles and C_{rec} is the pollution associated with recirculation.

Direct contribution (C_{dlee}):

$$Recirculation\ zone\ (l_r) = \min(w, l_v * \sin(\theta)) \quad \text{(meters)}$$

Where:

$$vortex\ length\ (l_v) = 2 * r * h \quad \text{(meters)}$$

And r = wind speed dependence factor = 1 if u_r > 2 m/s and = u_r/2 otherwise.

If the recirculation zone is greater than the width of the canyon:

$$C_{dlee} = \sqrt{\frac{2}{\pi} * \frac{Q}{(w * \sigma_w)} * \ln\left[\left(\frac{\sigma_w * w}{h_o * u_s}\right) + 1\right]}$$

Where:

σ_w = mechanical turbulence from wind and traffic (m/s) = $\sqrt{(\lambda * u_s)^2 + {\sigma_{wo}}^2}$

λ = constant for removal at the top of the canyon = 0.1

σ_{wo} = traffic-created turbulence (m/s) = $b * \sqrt{\frac{v_t * f_c * s_c + v_t * f_h * s_h}{w}}$

where s_c = mean surface area of cars (4 m^2), s_h = mean surface area of heavy vehicles (16 m^2) and b = aerodynamic constant (0.18)

u_s = wind speed at street level (m/s) = $u_r \left(\frac{\ln\left(\frac{h_o}{z_o}\right)}{\ln\left(\frac{h}{zo}\right)}\right)(1 - d * \sin(\theta))$

h_o = effective height of emissions (2 m)

z_o = effective roughness length (0.6 m)

d = model dependence (0.45)

If the recirculation zone is less than the width of the canyon:

$$C_{dlee} = \sqrt{\frac{2}{\pi}} \frac{Q}{(w * \sigma_w)} \left[ln\left[\left(\frac{\sigma_w * d_1}{h_o * u_s}\right) + 1\right] + R * \ln\left(\frac{h_o + \sigma_w * \frac{d_6}{u_s}}{\frac{\sigma_w * l_r}{u_s} + h_o}\right) + \frac{\sigma_w}{\omega_t}\left[1 - e^{\left(\frac{-\omega_t d_7}{u_s h}\right)}\right] \right]$$

Where:

d_1 (m) = min(w, l_r)

R = max(0, C_{ang})

C_{ang} = cos(2*r* θ)

d_6 (m)= min(max(l_{max}, l_r), x_1)

l_{max} = w/sin(θ)

x_1 = vertical distance (m) at which pollutants can escape canyon = $\frac{u_s(h - h_o)}{\sigma_w}$

ω_t = removal at top of the canyon (m/s) = $\sqrt{(\lambda * u_r)^2 + 0.4(\sigma_{wo})^2}$

d_7 (m) = max(l_{max}, x_1)-x_1

Recirculation contribution (C_{rec}):

$$C_{lee} = \frac{\left[\left(\frac{Q}{w}\right) d_1\right]}{\omega_t * d_2 + \omega_s * d_3}$$

Where

d_2 (m) = min(w, 0.5*l_r)

d_3 (m) = $l_s \left(\max(0, \frac{2w}{l_r} - 1\right)$

l_s (m) = $\sqrt{(0.5 * l_r)^2 + h^2}$

ω_s = removal speed at the side of the canyon (m/s) = $\sqrt{{u_s}^2 + {\sigma_{wo}}^2}$

Windward concentrations (C_{dwind}):

Final windward concentrations = C_{dwind} + C_{rec}. C_{dwind} = 0 if l_r ≥ w, else:

$$C_{dwind} = \sqrt{\frac{2}{\pi}} \frac{Q}{w * \sigma_w} \left[ln\left(\frac{\sigma_w + d_4}{u_s + h_o} + 1\right) + \frac{\sigma_w}{\omega_t}\left[1 - e^{\left(\frac{-\omega_t d_5}{u_s h}\right)}\right]\right]$$

d_4 (m) = min[(w – l_r), x_1]

d_5 (m) = [max[(w – l_r),x_1]]-x_1

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