Ricardo Energy & Environment

Scottish Air Quality Maps

Pollutant modelling for 2014: annual mean NO_X, NO_2, and PM_{10}

Report for the Scottish Government

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Contact:

Stuart Sneddon
Ricardo Energy & Environment
Gemini Building, Harwell,
Didcot, OX11 0QR, United Kingdom

t: +44 (0) 1235 75 3015
e:stuart.sneddon@ricardo.com

Ricardo-AEA Ltd is certificated to ISO9001 and ISO14001

Author:

Rose, Rebecca

Approved By:

John Stedman

Date:

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Executive summary

As a component of the Scottish Air Quality Database (SAQD) project, the Scottish Government contracted Ricardo Energy & Environment (previously Ricardo-AEA), to prepare air pollution maps for Scotland showing background air pollutant concentrations on a 1 km^2 basis (1 km x 1 km grid) and roadside air pollutant concentrations for urban road links throughout Scotland.

The air pollutant maps and concentrations discussed in this report utilise the Pollution Climate Mapping (PCM) modelling and mapping methodology developed for the UK. This approach provides air pollution maps for the Scottish Government, Defra, and the other Devolved Administrations in order to supplement measurements from the national monitoring networks, and to satisfy the EU Air Quality Directive reporting requirements. The models are calibrated using measurements from the national air quality networks (chiefly the Automatic Urban and Rural Network, AURN) and are verified using independent air pollutant measurements from local authorities and ad-hoc monitoring campaigns that have been quality assured to the same standard as the AURN. The UK PCM modelling employs a single set of calibration coefficients to represent the whole of the UK.

The distribution of urban areas in Scotland is different to the rest of the UK as they are clustered in the central belt and north east coast; Scotland also has its own distinct meteorology. Scotland was therefore identified as an area that may not conform as well as other areas to the general calibration performed for the UK as a whole. This has provided the need for the more detailed Scotland-specific study undertaken within the Scottish Air Quality Database project. Here the Pollution Climate Mapping methodology has been applied to provide pollution maps of Scotland for the Scottish Government for 2014 using measurements exclusively from Scottish air quality monitoring sites and Scottish meteorology in order to reflect these differences. The maps provide spatial representation of the annual mean concentration of:

- NO_X and NO_2, and
- Gravimetric equivalent PM_{10}.

2014 Scottish automatic NO_X and NO_2 measurements were used for the Scotland-specific NO_X and NO_2 maps. Likewise, Scotland-specific PM_{10} maps were produced using appropriately scaled 2014 Scottish PM_{10} monitoring data (FDMS, Partisol and VCM corrected TEOM data). 2014 Scottish PM_{10} measurements from Beta Attenuation Monitors (BAMs) were only used for model verification. The air pollutant measurements were used in conjunction with Scottish meteorology data (from RAF Leuchars) to create and run Scotland-specific models for both pollutants. The model results have been compared with the measured air pollutant concentrations in Scotland.

This year, for both the background and roadside pollutant models, air pollutant measurements from between 7 and 13 air quality monitoring sites were used to calibrate the model, depending on pollutant (NO_X/NO_2 or PM_{10}), and model (background or roadside), whilst between 3 and 11 sites, were used to verify the model outputs.

The 2014 annual mean background air pollutant concentration maps combined Scottish air pollutant measurements with spatially disaggregated emissions information. Scottish air pollutant emissions were based on the UK's 2013 National Atmospheric Emissions Inventory (NAEI) and Updated energy and emissions projections 2014. The 2014 (base-year) Scotland-specific model included the most recently revised (as of December 2015) NO_X (diesel cars and LGV) and PM_{10} emission factors from COPERT4 v11.0, combined with ANPR/DVLA-scaled data, to represent the most up-to-date vehicle fleet information in Scotland. Jenkin (2012) reported that short term variability in NO_X concentrations is a major cause of the scatter in the relationship between $[NO_2]/[OX]$ and $[NO_X]$. The 2014 Scotland-specific NO_X/NO_2 model uses this updated relationship of the oxidant partitioning modelling.

An assessment has been made of area, population, number of road links and road length exposed to specific concentrations above the Objective values adopted by the Scottish Government for NO_2 and PM_{10}. In summary, the results of the 2014 Scotland-specific modelling exercise show:

- The modelled annual mean background NO_2 concentrations from the Scotland-specific model provided reasonable agreement with the annual mean measured background NO_2 concentrations. A similar degree of variability was seen when the modelled annual mean roadside NO_2 concentrations from the Scotland-specific model were compared to the annual mean measured roadside NO_2 concentrations.

- Exceedances of the Scottish annual mean NO_2 objective of 40 µg m^{-3} at background locations were modelled at three 1 km^2 background grid squares in Central Scotland. All exceedances were located close to Aberdeen Harbour and are related to emissions from shipping. The modelled annual mean background PM_{10} concentrations from the Scotland-specific model provided good agreement with the annual mean measured background concentrations. Similar agreement was seen with the modelled annual mean roadside PM_{10} concentrations provided by the Scotland-specific model.

- Exceedances of the Scottish PM_{10} air quality objective of 18 µg m^{-3} were modelled at seventy one background locations. Twenty nine of which were located in Central Scotland zone, forty one in North East Scotland zone and one in Scottish borders zone (Scotland is split into 6 zones for the purposes of air pollution monitoring, in accordance with EC Directives (96/62/EC)). No background exceedances of the Scottish annual mean PM_{10} air quality objective were modelled in Edinburgh Urban Area, Glasgow Urban Area or the Scottish Borders. The causes of modelled exceedances were varied. The extent of modelled exceedances of the Scottish PM_{10} air quality objective was up to 5 µg m^{-3}.

- Exceedances of both the Scottish annual mean NO_2 and PM_{10} air quality objectives were modelled at roadside locations. The 2014 Scotland-specific model identified 54 road links (62.7 km of road) which exceeded the Scottish NO_2 annual mean air quality objective. For PM_{10}, the Scotland-specific model identified 72 road links (84.0 km of road) along which the Scottish annual mean PM_{10} air quality objective of 18 µg m^{-3} was exceeded. The majority of exceedances of the Scottish NO_2 and PM_{10} air quality objectives were modelled to occur in urban areas, at roadside locations with high volumes of traffic, such as Edinburgh and Glasgow. No exceedances of the Scottish annual mean NO_2 or PM_{10} air quality objective were modelled for roads in the Highlands or the Scottish Borders zones.
- In recent years the Scottish Government put significant effort into increasing the number of sites in the SAQD. These efforts have contributed to the production of robust pollutant maps for NO_X, NO_2, and PM_{10} for Scotland for 2014 based on Scottish air quality measurements and Scottish meteorology. Due to the Scottish-specific nature of the data, it is more appropriate for anyone undertaking air quality studies in Scotland to use the Scottish background maps rather than data from the UK maps. The Scottish Government therefore expects Scottish local authorities to use the Scottish-specific modelling for LAQM purposes. Other organisations undertaking air quality studies in Scotland are directed to the Scottish-specific background modelled data.

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1 Introduction

As a component of the Scottish Air Quality Database (SAQD) project, The Scottish Government contracted Ricardo Energy & Environment, previously Ricardo AEA, to prepare air pollution maps for Scotland showing background air pollutant concentrations on a 1 km^2 basis (1 km x 1 km grid) and roadside air pollutant concentrations for urban road links throughout Scotland.

The maps discussed in this report utilise the air pollutant concentration mapping methodology developed for the UK Pollution Climate Mapping (PCM) model[1]. This approach provides air pollution concentration maps for the Scottish Government, Defra, and the other Devolved Administrations. Air pollutant concentration maps are produced annually in order to supplement measurements from the national monitoring networks and to satisfy the EU Air Quality Directive[2] reporting requirements. The UK PCM model is calibrated using measurements from the national networks (chiefly the Automatic Urban and Rural Network, AURN) and is verified using independent air pollutant measurements from local authorities and ad-hoc monitoring campaigns that have been quality assured to the same standard as the AURN. The UK PCM modelling employs a single set of calibration coefficients to represent the whole of the UK.

Due to the limited number of urban areas in Scotland and the distinct Scottish meteorology, Scotland was identified as an area that may not conform as well as other areas to the general calibration performed for the UK as a whole. This provided the need for the more detailed Scotland-specific study undertaken within the Scottish Air Quality Database project. Here the PCM methodology has been applied to provide pollution maps of Scotland for the Scottish Government for 2014 using measurements exclusively from Scottish air quality monitoring sites and Scottish meteorology in order to reflect these differences. The maps provide spatial representation of the annual mean concentrations of:

- NO_X and NO_2, and
- Gravimetric equivalent PM_{10}.

Previous mapping and modelling efforts on behalf of The Scottish Government concentrated on developing a more Scotland-specific air quality model by incorporating a Scottish meteorological data set (from RAF Leuchars) and a Scotland-specific model calibration. The resulting Scotland-specific model for 2004 and 2005 suggested that there was little improvement in the model performance resulting from these changes. The limited improvement in the Scotland-specific modelled values was believed to due to the removal of meteorological variations by the calibration process. The lack of suitable monitoring sites in Scotland made calibration and verification of the model difficult, particularly for PM_{10}, for which only a small number of monitoring sites existed. In 2007 the Scottish Government instigated an extensive upgrade programme to increase the number PM_{10} analysers (Partisol instruments) in the Scottish air quality network. For the first time this allowed maps of the annual mean spatial concentrations of PM_{10} to be prepared.

The air pollutant measurements used in the mapping work presented here, for 2014, use NO_X, NO_2 and appropriately scaled PM_{10} monitoring data (FDMS, Partisol and VCM corrected TEOM data) in conjunction with Scottish meteorology data (from RAF Leuchars) to create and run a Scotland-specific model for NO_X, NO_2, and PM_{10} for 2014. 2014 Scottish PM_{10} measurements from Beta Attenuation Monitors (BAMs) were only used for model verification. The model results have been compared with the measured air pollutant concentrations in Scotland. An assessment has been made of area, population, number of roads and road length exposed to specific concentrations above the Objective values adopted by the Scottish Government for NO_2 and PM_{10}.

[1] Brookes, D.M., Stedman, J.R., Kent, A.J., Morris, R.J., Cooke, S.L., Lingard, J.J.N., Rose, R.A., Vincent, K.J., Bush, T.J., and Abbott, J. (2015). Technical report on UK supplementary assessment under the Air Quality Directive (2008/50/EC), the Air Quality Framework Directive (96/62/EC) and Fourth Daughter Directive (2004/107/EC) for 2014. Report for The Department for Environment, Food and Rural Affairs, Welsh Government, the Scottish Government and the Department of the Environment for Northern Ireland, Ricardo-Energy & Environment/R/3459., unpublished <Link needs updating>

[2] Directive 2008/50/EC (CAFE Directive), http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32008L0050:EN:NOT.

In recent years, analyses[3] conducted for the Scottish Government, Defra and the other Devolved Administrations of historical UK air quality monitoring data measurements have identified a disparity between measured ambient concentrations of NO_X and NO_2 and the projected decline in their concentrations associated with emissions forecasts. The modelled air pollutant concentrations and maps presented here are based on Scottish air pollutant emissions from UK's 2013 National Atmospheric Emissions Inventory (NAEI) and updated energy and emissions projections 2014. The 2014 (base-year) Scotland-specific model included NO_X (diesel cars and LGV) and PM_{10} emission factors from COPERT4 v11.0, combined with ANPR/DVLA-scaled data, to represent the most up-to-date vehicle fleet information in Scotland. Jenkin (2012) reported that short term variability in NO_X concentrations is a major cause of the scatter in the relationship between [NO_2]/[OX] and [NO_X]. The 2014 Scotland-specific NO_X/NO_2 model uses this updated relationship of the oxidant partitioning modelling.

As for 2012 and 2013 base years, no forward projections of air pollutant concentrations in future years are presented in this report.

[3] Carslaw, D., Beevers, S., Westmoreland, E., Williams, M., Tate, J., Murrells, T., Stedman, J., Li, Y., Grice, S., Kent, A., and Tsagatakis, I. (2011). Trends in NO_X and NO_2 emissions and ambient measurements in the UK. 3rd March 2011. Draft for Comment. http://uk-air.defra.gov.uk/reports/cat05/1103041401_110303_Draft_NOx_NO2_trends_report.pdf

2 Methodology

Detailed description of the UK PCM modelling methodology can be found in the annual report to the Scottish Government, Defra and the other Devolved Administrations for 2014[1]. A copy of this report can be downloaded from the Technical Reports Section of the SAQD website (http://www.scottishairquality.co.uk/news/reports?view=technical&id=496). A brief overview of the modelling methodology is presented here, including a summary of model revisions for 2014, and the specific aspects of the model that have been tailored to provide a Scotland-specific output are detailed below.

The modelled maps of ambient air pollutant concentrations were calculated from NAEI data using a dispersion modelling approach, which was calibrated using air pollutant measurements from the national monitoring networks. These modelled maps were verified against independent monitoring data held by Ricardo Energy & Environment (from airport authorities and local authorities).

2.1 The Scotland-specific model

The standard UK PCM model was used as the template and was tailored to produce a Scotland-specific model by incorporating two significant changes:

- Air quality monitoring measurements from Scottish monitoring sites only (as shown in

- Figure 2.1) were used in the model calibration, and
- The dispersion kernel applied to area source emissions was derived using Scottish meteorology data obtained for RAF Leuchars in Fife (Grid Ref: NO467205).

No attempt has been made to model hourly concentrations for comparison with the Scottish hourly or daily AQOs in this report for NO_2 and PM_{10}. This is due to the considerable uncertainties involved in modelling at such a fine temporal scale.

2.2 Air quality monitoring sites used for model calibration and verification

In recent years, the Scottish Government has invested significant effort into increasing the number of sites in the Scottish Air Quality Database (SAQD). For 2014, as for previous years, both calibration and verification of the Scotland specific-model was undertaken. The additional sites funded by the Scottish Government and placed on the SAQD were ratified in equivalent manner to air pollutant measurements from the AURN. Table 2.1 lists the Scottish air quality monitoring sites used to calibrate and verify the background and roadside NO_X, NO_2 and PM_{10} models.

Annual means from sites with a percentage data capture (%dc) less than 75% were not used to calibrate or verify the model output. Typically 7-13 sites are required to calibrate the pollutant model, with residual sites being used to verify the model output. In the case of the background NO_X, NO_2 and PM_{10} there were between three and eleven air quality monitoring sites remaining with sufficient data capture, in 2014. This permitted limited verification of the model output, as shown in Table 2.1. There were generally more (seven to thirteen) air quality monitoring sites available to verify the roadside NO_X, NO_2 and PM_{10} models.

Measurements from AURN sites were used for model calibration in-line with UK-based model. Measurements from non-AURN air quality sites were split between sites for model calibration and model verification. The non-AURN air quality sites were partitioned on the basis of their location in order to provide a reasonable geographical spread of sites and thereby limit local source effects.

Figure 2.1 Location of Scottish air quality monitoring sites used to produce Scotland-specific background and roadside NO_X, NO_2, and PM_{10} maps, 2014.

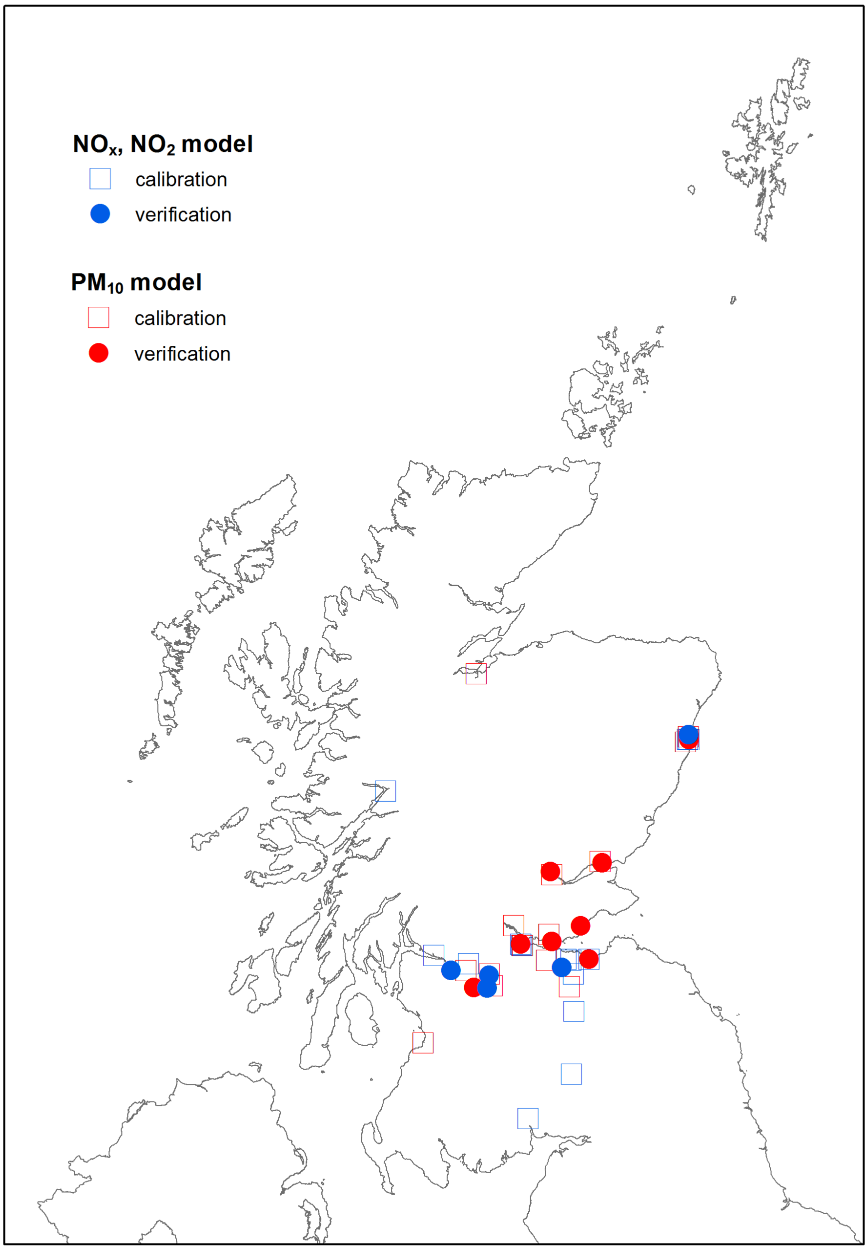


Table 2.1 Scottish air quality monitoring sites used to calibrate and verify the output of the 2014 Scotland-specific model.

Background sites			
Pollutant	Calibration site name	Verification site name	Total+
NO_X, NO_2	Aberdeen Bush Estate Eskdalemuir Falkirk Grangemouth MC Fort William Glasgow Townhead Grangemouth Moray Grangemouth Peebles	Dundee Mains Loan Edinburgh Currie Glasgow Waulkmillglen Reservoir Paisley Glasgow Airport	9 (13)
PM_{10}‡	Aberdeen (TEOM) Dundee Mains Loan (VCM) Glasgow Townhead (FDMS) Grangemouth (FDMS) Auchencorth Moss (Partisol) Perth Muirton (FDMS) N Lanarkshire Coatbridge Whifflet (VCM)	Edinburgh Currie (VCM) Falkirk Grangemouth MC (VCM) Dundee Broughty Ferry Road (VCM)	7 (10)
Roadside			
NO_X, NO_2	Aberdeen Market Street 2 Aberdeen Anderson Dr Aberdeen Union Street Roadside South Ayrshire Ayr High St West Lothian Broxburn Dumbarton Roadside Dumfries Fife Dunfermline Edinburgh St John's Road Edinburgh Gorgie Road East Dunbartonshire Bishopbriggs Inverness East Lothian Musselburgh N High St	Aberdeen King Street Edinburgh Queensferry Road South Lanarkshire East Kilbride Falkirk Hope St Fife Kirkcaldy N Lanarkshire Shawhead Coatbridge Paisley Gordon Street Perth Atholl Street Renfrew Cockels Loan Fife Rosyth South Lanarkshire Hamilton	13 (24)
PM_{10}‡	Aberdeen Anderson Dr (VCM) Alloa (VCM) South Ayrshire Ayr High St (FDMS) Fife Dunfermline (FDMS) N Lanarkshire Motherwell (VCM) Perth Atholl Street (VCM) Inverness (Patrisol)	Aberdeen Market Street 2 (heated BAM) Aberdeen King Street (unheated BAM) South Lanarkshire East Kilbride (FDMS) Fife Kirkcaldy (FDMS) East Lothian Musselburgh N High St (unheated BAM_ Fife Rosyth (FDMS) South Lanarkshire Hamilton (FDMS)	7 (14)

+ Total number of Scottish pollutant monitoring sites given in parentheses. ‡ PM_{10} sampler type given in parentheses.

2.3 NO_X and NO_2 modelling

Annual mean concentrations of NO_X were modelled for Scotland for 2014 at background and roadside locations. Modelled annual mean NO_2 concentrations were calculated from modelled NO_X concentrations using a calibrated version of the updated oxidant-partitioning model[4,5]. This model is discussed in more detail in the 2014 UK mapping report[1] and the references therein. Briefly, the oxidant-partitioning model uses representative equations to account for the chemical coupling of O_3, NO and NO_2 within the atmosphere. A key advantage of this approach for modelling NO_2 concentrations is that it allows different emission scenarios to be addressed by varying regional oxidant levels and/or primary NO_2 emissions.

The modelling of the annual mean Scottish NO_X and NO_2 concentrations for 2014 were undertaken using Scotland-specific changes to the UK PCM model noted in Section 2.1. The regional oxidant component of the NO_X-NO_2 model remains unchanged for the Scottish modelling as this is not affected by the Scotland-specific changes to the UK PCM model noted in Section 2.1.

Scottish air quality objectives (AQOs) for ambient NO_2 concentrations are based on EU limit values set out in the Air Quality Directive[9]. These have been specified for the protection of human health. The limit values are:

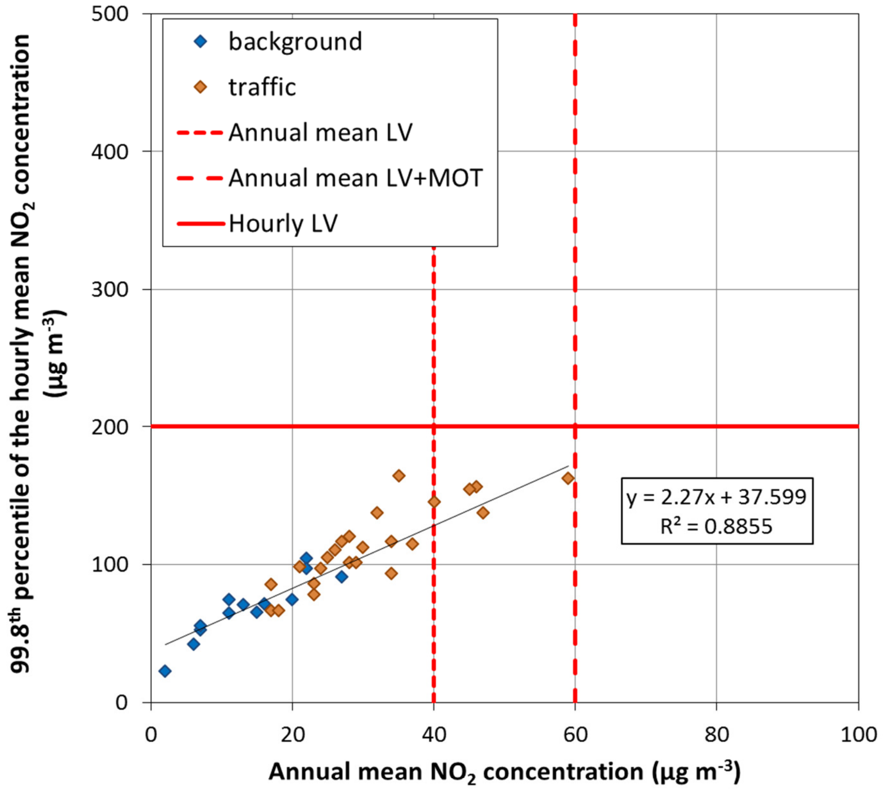
- An annual mean concentration of 40 µg m^{-3}, and
- An hourly concentration of 200 µg m^{-3}, with 18 permitted exceedances each year.

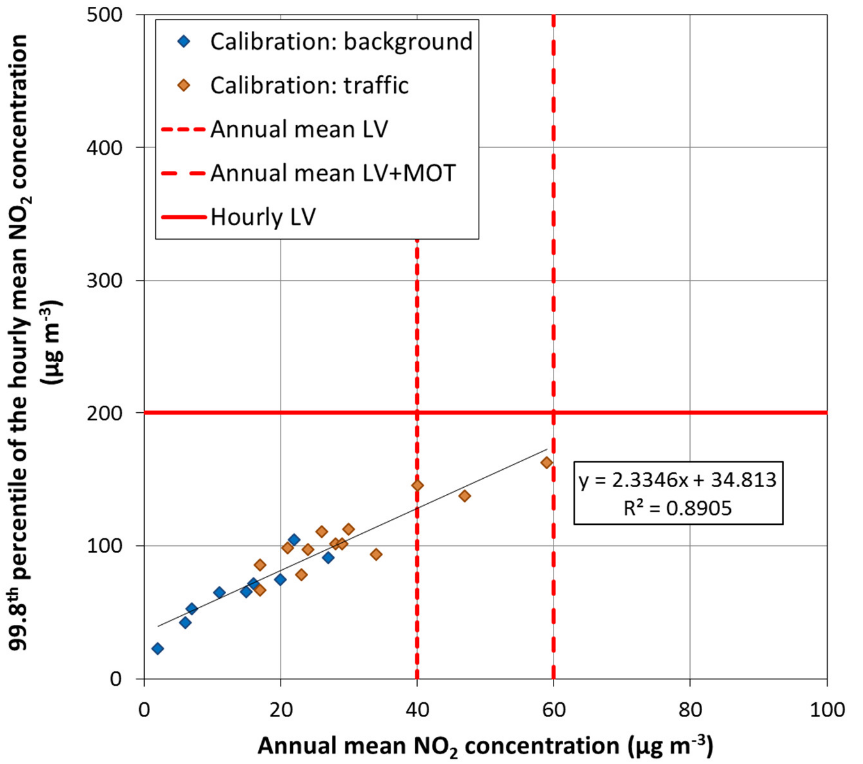
For the hourly objective, it is appropriate to have an allowed number of exceedances for the objective. This allows for situations where it is not practical to expect hourly average concentrations to always be within the allowed limit (for example, where bad weather conditions affect concentrations).

Figure 2.2 Plot of annual mean against 99.8th percentile hourly NO_2 concentrations in 2014 for all Scottish air quality monitoring sites (%dc ≥75%).

[4] Jenkin, M.E. (2004). Analysis of sources and partitioning of oxidant in the UK-Part 1: the NO_X-dependence of annual mean concentrations of nitrogen dioxide and ozone. *Atmospheric Environment*, **38**, 5117-5129.

[5] Murrells, T., Cooke, S., Kent, A., Grice, S., Derwent, R., Jenkin, M., Pilling, M., Rickard, A., and Redington, A. (2008). Modelling of tropospheric ozone: first annual report. AEA Report AEAT/ENV/R/2567. http://www.airquality.co.uk/archive/reports/cat07/0804291542_ED48749_Ann_Rep1_2007_tropospheric_ozone_final_AQ03508.pdf





Compliance with the annual mean limit value is considered to be more stringent than achieving compliance with the 1-hour limit value in the majority of situations[6]. This is illustrated in Figure 2.2 which shows the 2014 annual mean NO_2 concentrations at all Scottish air quality monitoring sites (with an annual %dc ≥75%) plotted against the 99.8th percentile (equivalent to 18 exceedances) hourly mean

[6] Air Quality Expert Group (AQEG, 2004). Nitrogen Dioxide in the United Kingdom. http://www.defra.gov.uk/environment/airquality/publications/nitrogen-dioxide/index.htm

concentration for the same year. The plot shows four sites exceeding the annual mean limit value of 40 µg m^{-3} but no sites exceeding the 200 µg m^{-3} hourly limit value.

2.4 PM_{10} modelling

2014 annual mean concentrations of PM_{10} were modelled for Scotland at background and roadside locations. The modelling methodology used to calculate the annual mean PM_{10} concentrations is broadly similar to that used last year. On the whole, measurements from appropriately scaled PM_{10} monitoring sites (FDMS, Partisol and VCM corrected TEOM[7,8]) measurements were used to calibrate the model. Typically measurements from Beta Attenuation Monitors (BAMs) in Scotland are only used for model verification.

It should be noted that many of the chemical components of the PM_{10} model are not affected by the Scotland-specific changes to the UK PCM model noted in Section 2.1. This includes the contribution to the total PM_{10} mass from the following components:

- Secondary inorganic aerosols (e.g., sulphate, nitrate, ammonium-based particles, SIA)
- Secondary organic aerosols (SOA)
- Primary particles from long-range transport
- Sea salt aerosol, and
- Iron and calcium-rich dusts.

Scottish AQOs for ambient PM_{10} concentrations for 2014 are more stringent than the EU limit values set out in the Air Quality Directive[9]. In Scotland the PM_{10} objectives are:

- A 24-hour mean concentration of 50 µg m^{-3}, not to be exceeded more than 7 times a year, and
- An annual mean value of 18 µg m^{-3}.

2.5 Forward projections

As for Scottish specific modelling for a base year of 2012 and 2013, no forward projections of air pollutant concentrations in future years are presented in this report. Projections from a base year of 2011 were published previously.

[7] Green, D., Baker, T. and Fuller, G. (2007). The King's College London Volatile Correction Model for PM_{10}: development, testing and application. Environmental Research Group, King's College London. http://www.airquality.co.uk/archive/reports/cat13/0711261345_KCL_Volatile_Correction_Model_for_PM10.pdf

[8] Green, D., Baker, T. and Fuller, G. (2008). Volatile Correction Model (VCM) for PM_{10} Application to hourly time resolution and AURN FDMS purge measurements. Environmental Research Group, King's College London. http://www.airquality.co.uk/reports/cat13/0902231025VCM_Application_to_Hourly_and_AURN_FDMS_Purge_Measurements.pdf

[9] Council Directive 2008/50/EC, of 21 May 2008 on ambient air quality and cleaner air for Europe (The Air Quality Directive). The Official Journal of the European Communities, 11.6.2008, En Series, L152/1. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:152:0001:0044:EN:PDF

3 Model calibration

3.1 Overview

Calibration of the 2014 background NO_X and PM_{10} Scotland-specific model were undertaken using measurements from air quality monitoring stations situated within a range of background (airport, rural, suburban, urban background, urban centre and urban industrial) locations. Similarly, the roadside calibration was undertaken using air quality monitoring measurements from roadside (roadside and kerbside) sites. As noted in Section 2.2, only Scottish air quality monitoring data from background and roadside sites with an annual % data capture (%dc) ≥75% were used to prepare the calibration plots and to verify the 2014 Scotland-specific model, as discussed in Section 5.

The 2014 calibration factor produced for the Scotland-specific background NO_X model was lower than the equivalent UK value. The 2014 calibration factor produced for the Scotland-specific roadside NO_X model was lower than the equivalent UK value, as shown in Table 3.2.

The 2014 Scotland-specific background PM_{10} calibration factor was less than the UK value, which reflects the lower measured ambient PM_{10} mass concentrations in Scotland, as shown in Table 3.4. The Scotland-specific roadside PM_{10} calibration factor was approximately a third greater than the UK value, as shown in Table 3.5. The NO_X, NO_2 and PM_{10} area source and roadside calibration procedures are presented below.

3.2 NO_X modelling

3.2.1 NO_X contributions from area sources

An ADMS 5.0 dispersion kernel was used to calculate the contribution of area source emissions to ambient NO_X concentrations at a central receptor location, from area source emissions within a 33 km x 33 km square, surrounding each monitoring site. This provided the modelled Scotland-specific NO_X uncalibrated area source contribution for each air quality monitoring station. 2014 hourly sequential meteorological observations from RAF Leuchars were used to construct the dispersion kernels. The modelled uncalibrated area source contribution for each source sector were subsequently multiplied by the Scotland-specific NO_X area source calibration coefficient to calculate the calibrated area source contribution for each grid square in Scotland. The point source contributions and regional rural concentrations were then added, resulting in a map of background annual mean NO_X concentrations for Scotland for 2014 as shown in Figure 5.2. A detailed description of this approach can be found in Appendix 3 of the 2014 UK modelling report[1].

Figure 3.1 shows the calibration plot for the Scotland-specific NO_X area source model. The measurements from nine background NO_X monitoring sites within the Scottish network were used to calibrate the model (as shown in Table 2.1); four sites were used to verify the model output.

Figure 3.1 shows that the gradient of the line of best fit forced through the origin was 2.2875. This value was used as the Scotland-specific NO_X area source calibration coefficient. The regression line has been forced through the origin to provide a reasonable model output without imposing an unrealistic high residual to the area source calibration coefficient. The modelled area source contribution was multiplied by the coefficient to calculate the calibrated area source contribution for each grid square in Scotland. The point source contributions and regional rural concentrations were then added resulting in a map of background annual mean NO_X concentrations for Scotland.

Figure 3.1 Calibration plot for the 2014 Scotland-specific background NO_X model.

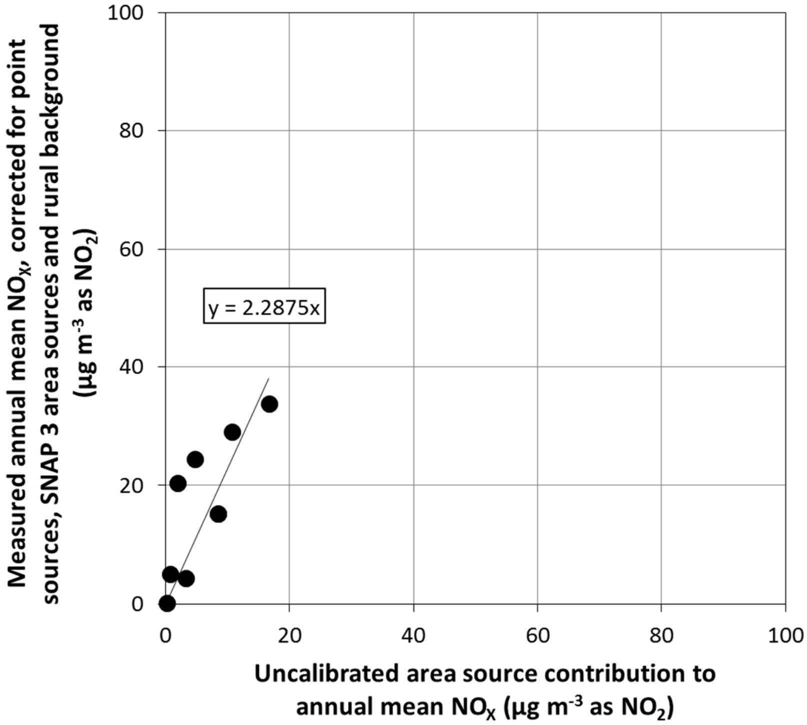


Table 3.1 Background model calibration coefficients applied in the Scotland-specific and UK models for NO_X for 2008-2014.

Model	Pollutant	Year	Calibration coefficient
Scotland-specific	NO_X	2014	2.2875
UK	NO_X	2014	2.3314
Scotland-specific	NO_X	2013	1.6308
UK	NO_X	2013	1.9955
Scotland-specific	NO_X	2012	2.1175
UK	NO_X	2012	2.0187
Scotland-specific	NO_X	2011	2.1596
UK	NO_X	2011	1.9413
Scotland-specific	NO_X	2010	2.3002
UK	NO_X	2010	2.2025
Scotland-specific	NO_X	2009	1.5662
UK	NO_X	2009	1.2486
Scotland-specific	NO_X	2008	2.2921
UK	NO_X	2008	2.4547

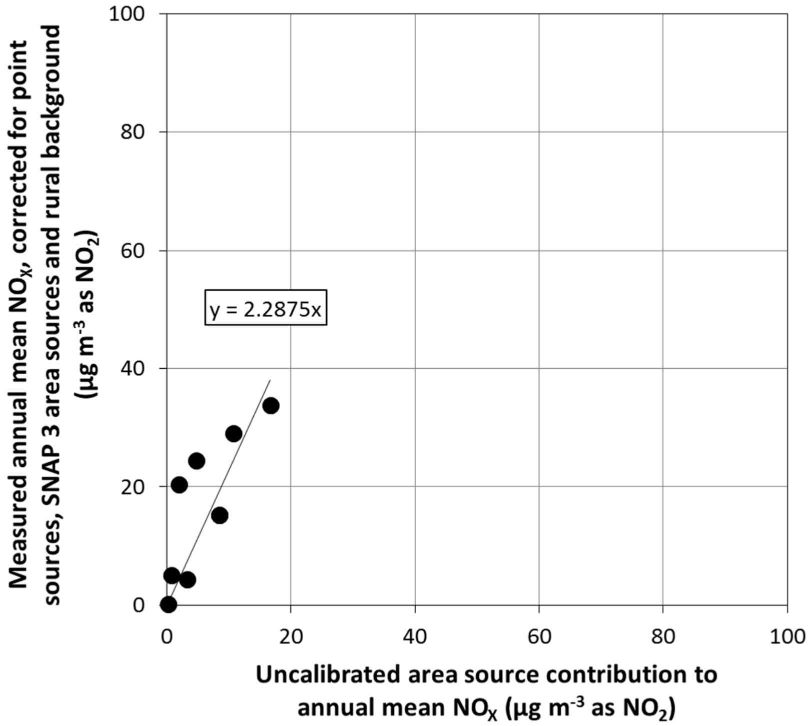


Table 3.1 provides a comparison of the 2014 Scotland-specific and UK background NO_X calibration coefficients. The Scotland-specific and UK background NO_X calibration coefficients from 2008 to 2014 are also presented to demonstrate the year-on-year variation in: (1) the Scotland-specific background NO_X calibration coefficient; and, (2) the extent to which these values vary in both models. From

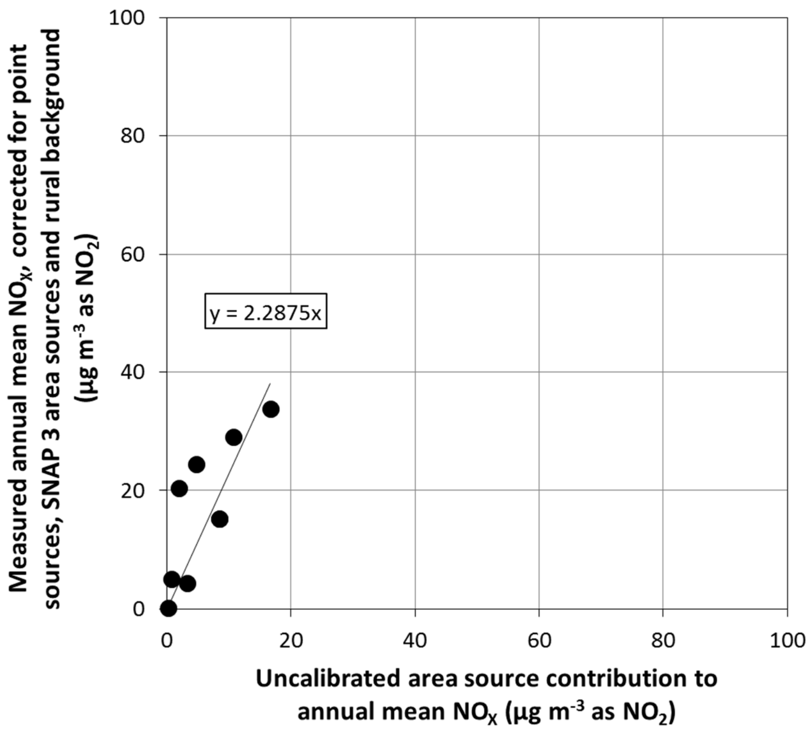


Table 3.1 it can be seen that the 2014 Scotland-specific background NO_X calibration coefficient was a little lower than the equivalent value used in the UK model in 2014 due to the different mix of sites included in the UK national and Scotland specific models and the different meteorology. The map of the 2014 background annual mean NO_X concentration for Scotland is shown in Figure 5.2.

3.2.2 Roadside NO_X concentrations

It is assumed that the annual mean NO_X concentrations at roadside locations are made-up of two components: the background concentrations (as described above) and a roadside increment:

roadside NO_X concentration = background NO_X concentration + NO_X roadside increment.

The NAEI provides estimates of NO_X emissions for major road links in Scotland for 2013[10] and these have been adjusted to provide estimates of emissions in 2014. In 2014 the roadside increment was calculated using the PCM Roads Kernel Model (PCM-RKM) which was introduced into the UK PCM model in 2014. The PCM-RKM uses ADMS-Roads dispersion model (version 4.0) to calculate roadside concentrations of PM_{10} on urban major roads. Individual model runs were carried out for approximately 730 census points covering urban major roads in Scotland. Each model run is parameterised using specific input data for the census point:

- Road geometry
- Traffic speeds, emissions and traffic counts
- Meteorology
- Receptor locations

The input data used for this Scotland specific modelling is consistent with the data used for UK modelling and is described in detail in Appendix 5 of the 2014 UK modelling report[1]. This is with the exception of meteorological data for which observations from RAF Leuchars are included in the modelling. Modelled concentrations were derived from the ADMS-Roads model outputs at a distance of 4 m from the kerb, averaged across each site of the road for all road links modelled. The PCM-RKM represents a more process-based approach than the previous empirical method. It provides a more robust assessment, whilst retaining the link with measurement data provided by the use of measurement data to calibrate this component of the model.

The PCM-RKM model is calibrated by comparison with an empirically calculated roadside increment (measured roadside NOx concentration – modelled background NOx concentration) at Scottish roadside or kerbside monitoring sites. Calibration of the PCM-RKM is shown in Figure 3.2. The background NO_X component at these roadside monitoring sites is taken from the background map described in the previous Section.

The calibration coefficient derived is then applied to the roadside increment calculated using the PCM-RKM for each road link. Only roadside concentrations for urban major road links (A-roads and motorways) which are reported annually to the EU for the UK as a whole are included in this report.

Thirteen of the sixty six roadside NO_X monitoring sites within the Scottish network had sufficient data capture for NO_X (and NO_2) in 2014 and were located on modelled major road links and adjacent to censusid points at which the traffic flow along the road was measured. The roadside NO_X measurements from these sites were used to calibrate the model. Scottish NO_X air quality monitoring data from eleven roadside sites was used to verify the model output.

Eleven roadside NO_X monitoring sites were excluded on the basis of low annual data capture (annual %dc ≤75%). Thirty-one roadside sites, with sufficient data capture, were excluded because they were not located on a modelled urban major road link.

These air quality monitoring sites are typically installed at kerbside or roadside locations in order to measure air pollutant concentrations in pollution 'hotspots', i.e., locations where the highest concentrations are expected, typically for AQMA purposes.

Figure 3.2 Calibration plot for the 2014 Scotland-specific roadside NO_X model.

[10] Misra, A., Passant, N.R., Murrells, T.P., Pang, Y., Thistlethwaite, G.,, Walker, C., Broomfield, M., Wakeling, D., del Vento, S., Pearson, B (2015). UK Informative Inventory Report (1990 to 2013). National Atmospheric Emissions Inventory http://uk-air.defra.gov.uk/assets/documents/reports/cat07/1508131403_GB_IIR_2015_Final_v20.1_resubmission.pdf

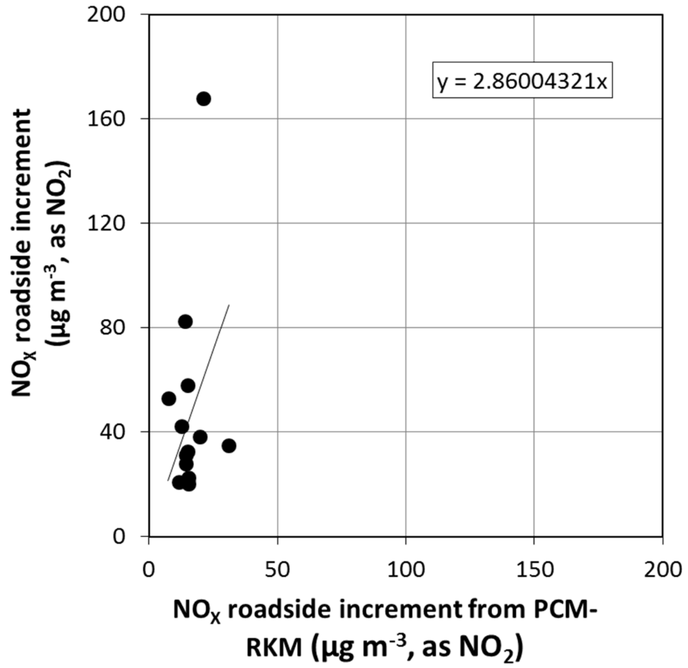


Table 3.2 Roadside model calibration coefficients applied in the Scotland-specific and UK models for NO_X for 2008-14.#

Model	Pollutant	Year	Calibration coefficient
Scotland-specific	NO_X	2014	2.8600
UK	NO_X	2014	3.3358
Scotland-specific	NO_X	2013	0.000 008 77
UK	NO_X	2013	0.000 008 14
Scotland-specific	NO_X	2012	0.000 009 30
UK	NO_X	2012	0.000 008 48
Scotland-specific	NO_X	2011	0.000 007 65
UK	NO_X	2011	0.000 007 99
Scotland-specific	NO_X	2010	0.000 008 89
UK	NO_X	2010	0.000 011 52
Scotland-specific	NO_X	2009	0.000 013 26
UK	NO_X	2009	0.000 009 35
Scotland-specific	NO_X	2008	0.000 007 94
UK	NO_X	2008	0.000 007 22

Calibration coefficients for 2014 and 2008-13 are not directly comparable as the roads modelling methodology for 2014 used the new PCM-RKM method.

Table 3.2 provides a comparison of the 2014 Scotland-specific and UK roadside NO_X calibration coefficients. The Scotland-specific and UK roadside NO_X calibration coefficients from 2008 to 2013 are also presented. From Table 3.2 it can be seen that the 2014 Scotland-specific roadside NO_X calibration coefficient a little lower than the value used in the 2014 UK model. It is therefore anticipated that the 2014 Scotland-specific roadside NO_X, and hence the roadside NO_2 model, may predict a lower number of NO_2 roadside exceedances for Scottish road links when compared to the 2014 UK model. However, it should be noted that this effect may be ameliorated by the meteorological terms (dispersion kernels) applied in the model.

3.2.3 NO_2 modelling

Maps of the estimated 2014 annual mean background and roadside Scottish NO_2 concentrations were calculated from the modelled NO_X concentrations using a calibrated version of the updated oxidant-partitioning model[4,5]. This model uses representative equations to account for the chemical coupling of O_3, NO and NO_2 within the atmosphere. A key advantage of this approach for modelling NO_2 concentrations is that different emission scenarios can be addressed by varying regional oxidant levels and/or primary NO_2 emissions.

This approach is discussed in detail in Section 3.4 of the 2014 UK modelling report[1]. Briefly, the oxidant-partitioning model[4] enables NO_2 concentrations to be calculated using the following equations (concentrations in ppb[11]):

$$[NO_2] = [OX].([NO_2]/[OX]) \qquad (i)$$

$$[OX] = f\text{-}NO_2.[NO_X] + [OX]_B \qquad (ii)$$

Where OX is the total oxidant (the sum of NO_2 and O_3), f-NO_2 is the primary NO_2 emission fraction (defined as the proportion, or volume ratio, of NO_X emitted directly as NO_2), and $[OX]_B$ is the regional oxidant. The regional oxidant component of the NO_X-NO_2 model remains unchanged for the Scottish modelling as this is not affected by the Scotland-specific changes to the UK PCM model noted in Section 2.1. NO_X, NO_2, O_3 and OX are all expressed as ppb in these equations: 1 ppb of O_3 = 2 µg m^{-3}; 1 ppb of NO_2 = 1.91 µg m^{-3}. By convention when NO_X is expressed in µg m^{-3} it is expressed as "µg m^{-3} as NO_2" therefore 1 ppb of NO_X = 1.91 µg m^{-3} of NO_X as NO_2.

In Jenkin (2004), $[NO_2]/[OX]$ was calculated using two equations, one of which represented background locations and the other roadside locations. Updated equations for $[NO_2]/[OX]$ were subsequently developed in (Murrells et al., 2008). More recently, Jenkin (2012)[12] found that short term variability in NO_X concentrations is a major cause of the scatter in the relationship between $[NO_2]/[OX]$ and $[NO_X]$. The ratio of the upper to the lower quartile of hourly concentrations is a good indicator of this variability and this ratio increases with decreasing NO_X concentrations at roadside and background sites. This dependence has been used to interpolate between equations based on a constant NO_X quartile ratio. This led to two equations for calculating $[NO_2]/[OX]$, one of which represents background locations and the other roadside locations. These are the equations that are currently used in the modelling. These are an improvement over the equations presented in Murrells et al. (2008) because the background equation requires less adjustment in the background adjustment calibration and the roadside equation enables linear calibration adjustment for roadside locations.

Jenkin (2012) presented two equations for calculating $[NO_2]/[OX]$ as a function of $[NO_X]$. These are:

- One background relationship, which has been derived using data from background sites.

One roadside relationship, which has been derived using data from roadside sites. The two relationships are presented below in

[11] 1 ppb of NO_2 = 1.91 µg m^{-3} of NO_2, NO_X concentrations are expressed as NO_2, so the conversion factor is the same. 1 ppb of O_3 = 2 µg m^{-3} of O_3.
[12] Jenkin, M.E. (2012). Investigation of the NO_X-dependence of oxidant partitioning at UK sites using annual mean data 1991-2011. Report 05-12. Atmospheric Chemistry Services, Okehampton, Devon, UK. Available upon request.

- Table 3.3:

Table 3.3 The two relationships in the updated oxidant-partitioning model (Jenkin, 2012).

PCM category	Relationship (where y = $[NO_2]/[OX]$ and x = $[NO_X$, in ppb)
Background	$y = -2.5124 \times 10^{-13}x^6 + 1.5805 \times 10^{-10}x^5 - 4.1429 \times 10^{-8}x^4 + 5.8239 \times 10^{-6}x^3 - 4.8076 \times 10^{-4}x^2 + 2.5916 \times 10^{-2}x$
Roadside	$y = -2.0901 \times 10^{-13}x^6 + 1.5001 \times 10^{-10}x^5 - 4.2894 \times 10^{-8}x^4 + 6.2659 \times 10^{-6}x^3 - 5.0720 \times 10^{-4}x^2 + 2.5322 \times 10^{-2}x$

Detailed description of how this approach is applied, namely:

- Calculation of the map of regional oxidant in the UK
- Calculation of the local oxidant background and roadside locations
- Calculation of $[NO_2]/[OX]$ in the PCM model, and
- How the updated oxidant-partitioning model has been applied in the UK to background and roadside locations

can be found in the annual report to the Scottish Government, Defra and the other Devolved Administrations for 2014[1]. The resultant maps of background and roadside annual mean NO_2 concentrations for Scotland are shown in

Figure 5.3 and

Figure 5.4, respectively.

3.2.4 Aircraft emissions

The NAEI aircraft emissions total for NO_X includes all emissions up to 1000 m above ground level. To avoid over-estimating area source contributions from aircraft to ground level NO_X concentrations, a factor of 0.5 was applied to take-off and landing emissions. All other non-ground level aircraft emissions were excluded. The factor of 0.5 has been chosen on the basis of findings from detailed studies[13]. All ground level aircraft emissions have been included as given in the NAEI 2013. Appendix 5 of the 2014 UK mapping report describes the methodology used to estimate the contribution of aircraft emission to ground-level NO_X emissions.

3.2.5 Shipping emissions

Entec[14] developed a detailed gridded ship emissions inventory for UK waters using recent information on ship movements, vessel engine characteristics and emission factors to quantify atmospheric emissions from shipping sources (Entec, 2010). The methodology developed was based on guidance from the EMEP/CORINAIR Atmospheric Emission Inventory Guidebook (2006) and relies on the following information, which largely dictates the emissions from a vessel:

- Installed engine power
- Type of fuel consumed
- Vessel speed and the distance travelled (or the time spent travelling at sea)
- Time spent in port
- Installed emission abatement technologies

Emissions and fuel consumption estimates were calculated at a 5 km x 5 km grid resolution (based on the EMEP grid) for an emissions domain extending 200 miles from the UK coastline. The emissions were subsequently re-mapped to a 1 km x 1 km grid based on the OSGB grid system. This produced mapped total NO_X shipping emissions within the UK's territorial waters (within 12 nautical miles of the coastline). A detailed distribution of emissions by historical NAEI shipping sectors (coastal shipping, international shipping and naval shipping) is not currently available.

The 1 km x 1 km emission maps generated from the 5 km x 5 km grid resolution were found to provide better agreement with measurements than the emission distribution grids previously used. The comparison revealed that NO_X concentrations were previously over-estimated by the model close to some ports. This is thought to be caused by the uncertainties associated with disaggregating the 5 km x 5 km gridded emissions estimates based on the EMEP grid to the 1 km x 1 km grid squares required for the NAEI maps. This is particularly the case in port areas where the 5 km x 5 km grid may include a large proportion of land.

A review of 2007 monitoring data recorded at sites close to UK ports was used to inform where, if any, emission caps should be applied:

- The 2007 measured annual mean NO_X concentration recorded at Dover Docks, a site located within the dock area, very close to shipping emission sources (within ~100m), was 135 µg m^{-3} (as NO_2);
- The 2007 measured annual mean NO_X concentration recorded at Castle Point 1 Town Centre, approximately 3km from significant shipping emissions, was 34 µg m^{-3} (as NO_2), and;
- The 2007 measured annual mean NO_X concentration recorded at Southampton Centre AURN site, approximately 2 km from significant shipping emissions, was 67 µg m^{-3} (as NO_2).

The high concentrations recorded at Dover Docks were close to the source of emissions, while Castle Point 1 Town Centre and Southampton Centre were away from the emission source. The monitoring results suggest that a contribution of up to 30 µg m^{-3} of NO_X (as NO_2) is a reasonable concentration to be modelled for a grid square average with significant emissions. The NO_X shipping emission maps were therefore capped to ensure that the modelled contribution from this source was not greater than

[13] Personal communication from Brian Underwood, AEA (2009). AEA Technology, Harwell, UK.

[14] Entec (2010). UK Ship Emissions Inventory. Retrieved from http://uk-air.defra.gov.uk/reports/cat15/1012131459_21897_Final_Report_291110.pdf.

30 µg m^{-3}. The PM_{10} cap was calculated using the ratio of total UK shipping emissions for each pollutant to the total UK NO_X shipping emissions.

3.3 PM_{10} modelling

3.3.1 PM_{10} contributions from area sources

As for NO_X, an ADMS 5.0 dispersion kernel was used to calculate the contribution of area source emissions to ambient PM_{10} concentrations at a central receptor location, from area source emissions within a 33 km x 33 km square, surrounding each monitoring site. This provided the modelled Scotland-specific PM_{10} uncalibrated calibrated area source contribution for each air quality monitoring station. 2014 hourly sequential meteorological observations from RAF Leuchars were used to construct the dispersion kernels. A detailed description of this approach can be found in Appendix 4 of the 2014 UK modelling report[1].

The modelled uncalibrated area source contribution for each source sector was subsequently multiplied by the Scotland-specific PM_{10} area source calibration coefficient to calculate the calibrated area source contribution for each grid square in Scotland. The modelled large point and small point sources, secondary inorganic aerosol (SIA), secondary organic aerosol (SOA), iron and calcium-rich dust, long range transport (LRT), primary PM_{10}, sea salt and the residual concentrations have been subtracted from the measured annual mean PM_{10} concentrations at background sites and compared with the modelled area source contribution to annual mean PM_{10} concentrations. A residual PM_{10} concentration of 1.5 µg m^{-3} was found to provide the best fit to the monitoring data. This approach is consistent with that used in the 2014 UK mapping. The 2014 background annual mean PM_{10} concentration for Scotland is shown in Figure 4.5.

Seven background PM_{10} monitoring sites within the Scottish network were used to calibrate the model, as reported in Table 2.1.

Figure 3.3 shows that the gradient the line of best fit forced through the origin was 2.8990. This value was used as the Scotland-specific PM_{10} area source calibration coefficient. The regression line has been forced through the origin to provide a reasonable model output without imposing an unrealistic high residual to the area source calibration coefficient.

The modelled area source contribution was multiplied by the empirically-derived calibration coefficient in order to calculate the calibrated area source contribution for each grid square in Scotland. The area source contribution was then added to the contributions from secondary organic and inorganic particles, from small and large point sources, from regional primary particles, from sea salt, from calcium and iron rich dusts and the residual, resulting in a map of background annual mean PM_{10} concentrations for Scotland is shown in

Figure 5.11.

Figure 3.3 Calibration plot for the 2014 Scotland-specific background PM_{10} model.

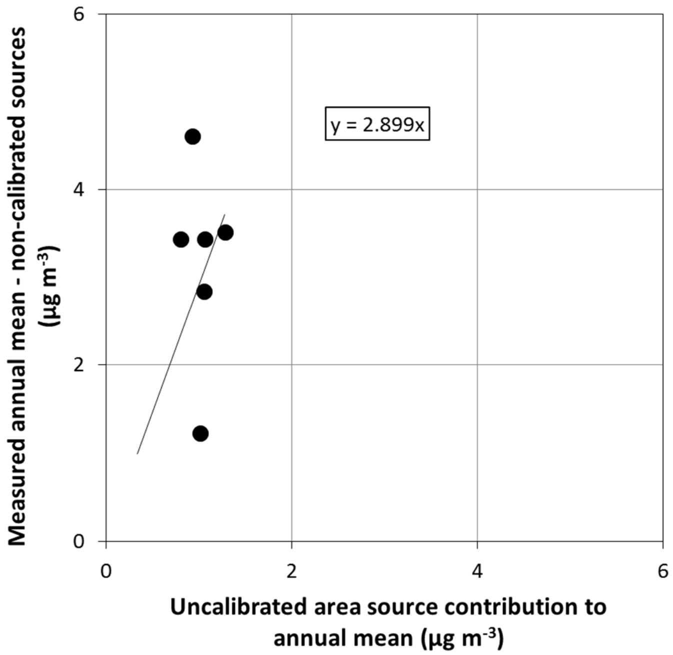


Table 3.4 Background model calibration coefficients applied in the Scotland-specific and UK models for PM_{10} for 2008-14.

Model	Pollutant	Year	Calibration coefficient
Scotland-specific	PM_{10}	2014	2.8990
UK	PM_{10}	2014	3.3703
Scotland-specific	PM_{10}	2013	3.2466
UK	PM_{10}	2013	2.9107
Scotland-specific	PM_{10}	2012	1.9918
UK	PM_{10}	2012	2.1525
Scotland-specific	PM_{10}	2011	2.8473
UK	PM_{10}	2011	3.2142
Scotland-specific	PM_{10}	2010	1.7049
UK	PM_{10}	2010	2.6164
Scotland-specific	PM_{10}	2009	1.9196
UK	PM_{10}	2009	1.9744
Scotland-specific	PM_{10}	2008	2.8091
UK	PM_{10}	2008	3.3916

Table 3.4 provides a comparison of the 2014 Scotland-specific and UK background PM_{10} calibration coefficients. The Scotland-specific and UK background PM_{10} calibration coefficients for 2008 to 2013 are also presented to demonstrate the year-on-year variation in: (1) the Scotland-specific background PM_{10} calibration coefficient; and, (2) the extent to which these values vary in both models.

From Table 3.4 it can be seen that the 2014 Scotland-specific background PM_{10} calibration coefficient is lower than the equivalent UK value. This is similar to previous model years for which the Scotland-specific PM_{10} background calibration coefficient, with the exception of 2013 where the Scotland-specific calibration coefficient was higher than the UK calibration coefficient.

3.3.2 Roadside PM_{10} concentrations

As for NO_X, it is assumed that the annual mean PM_{10} concentration at roadside locations is made-up of two components: the background concentration (as described above) and a roadside increment:

roadside PM_{10} concentration = background PM_{10} concentration + roadside PM_{10} increment.

The NAEI provides estimates of PM_{10} emissions for major road links in Scotland for 2013 and these have been adjusted to provide estimates of emissions in 2014. In 2014 the roadside increment was calculated using the PCM Roads Kernel Model (PCM-RKM) which was introduced into the PCM model for UK modelling in 2014. The PCM-RKM uses ADMS-Roads dispersion model (version 4.0) to calculate roadside concentrations of PM_{10} on urban major roads. Individual model runs were carried out for approximately 730 census points covering urban major roads in Scotland. Each model run is parameterised using specific input data for the census point:

- Road geometry
- Traffic speeds, emissions and traffic counts
- Meteorology (meteorological observations from RAF Leuchars)
- Receptor locations

Modelled concentrations were derived from the ADMS-Roads model outputs at a distance of 4 m from the kerb, averaged across each site of the road for all road links modelled. The PCM-RKM represents a more process-based approach than the previous empirical method. It provides a more robust assessment, whilst retaining the link with measurement data provided by the use of measurement data to calibrate this component of the model. A full description of the PCM-RKM is described in Appendix 5 of the 2014 UK modelling report[1].

The PCM-RKM model is calibrated by comparison with an empirically calculated roadside increment (measured roadside PM_{10} concentration – modelled background PM_{10} concentration) at Scottish roadside or kerbside monitoring sites. Calibration of the PCM-RKM is shown in Figure 3.4. The background PM_{10} component at these roadside monitoring sites is taken from the background map described in Section 3.3.1.

As for the area source calibration coefficient (described in Section 3.3.1), the regression line has been forced through the origin to provide a reasonable model output without imposing an unrealistic high residual to the roadside increment. Emissions were adjusted for annual average daily traffic flow using the method described in Section 3.3.6 of the 2014 UK modelling report[1]. Only roadside concentrations for urban major road links (A-roads and motorways) (which are reported annually to the EU for the UK as a whole) are included in this report.

Seven of the sixty-three roadside PM_{10} monitoring sites within the Scottish network had sufficient data capture for PM_{10} in 2014 and were located on modelled major road links. The roadside PM_{10} measurements from these sites were used to calibrate the model. PM_{10} measurements from a further seven sites were used to verify the output of the roadside model. Measurements from seventeen roadside sites were excluded on the basis of low annual data capture. Roadside PM_{10} measurements from thirty-one roadside sites were excluded because the sites were not located:

- On a modelled urban major road link, or
- Sufficiently close to a road traffic censusid point.

These air quality monitoring sites are typically installed at kerbside or roadside locations in order to measure air pollutant concentrations in pollution 'hotspots', i.e., locations where the highest concentrations are expected, typically for AQMA purposes. One further site was excluded as it exhibited a very low roadside increment.

Figure 3.4 Calibration plot for the 2014 Scotland-specific roadside PM_{10} model.

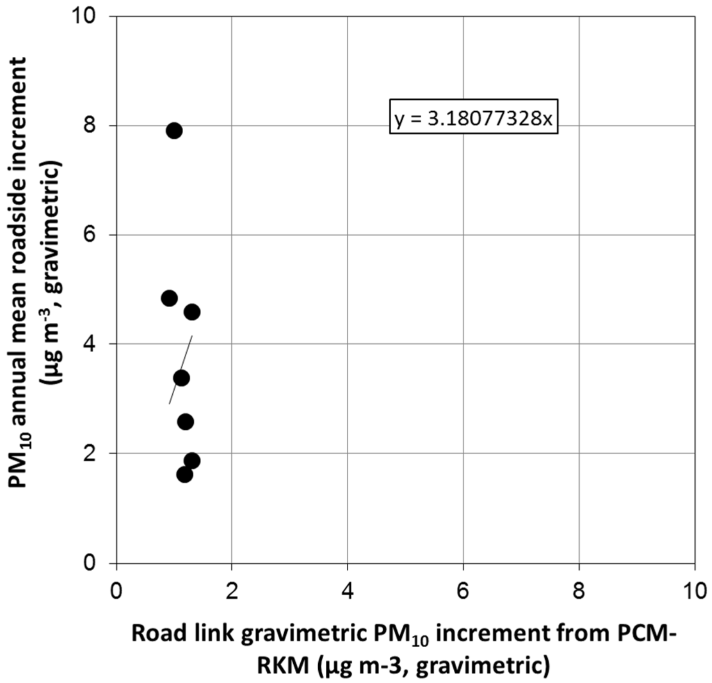


Table 3.5 Roadside model calibration coefficients applied in the Scotland-specific and UK models for PM_{10} for 2008-14.#

Model	Pollutant	Year	Calibration coefficient
Scotland-specific	PM_{10}	2014	3.1808
UK	PM_{10}	2014	1.9928
Scotland-specific	PM_{10}	2013	0.000 010 556
UK	PM_{10}	2013	0.000 006 265
Scotland-specific	PM_{10}	2012	0.000 010 77
UK	PM_{10}	2012	0.000 008 21
Scotland-specific	PM_{10}	2011	0.000 010 79
UK	PM_{10}	2011	0.000 007 55
Scotland-specific	PM_{10}	2010	0.000 013 89
UK	PM_{10}	2010	0.000 007 67
Scotland-specific	PM_{10}	2009	0.000 012 93
UK	PM_{10}	2009	0.000 009 08
Scotland-specific	PM_{10}	2008	0.000 012 77
UK	PM_{10}	2008	0.000 008 40

Calibration coefficients for 2014 and 2008-13 are not directly comparable as the roads modelling methodology for 2014 used the new PCM-RKM method.

Table 3.5 provides a comparison of the 2014 Scotland-specific and UK roadside PM_{10} calibration coefficients. The Scotland-specific and UK roadside PM_{10} calibration coefficients for 2008 to 2013 are also presented. From Table 3.5 it can be seen that for 2008 to 2014 Scotland-specific model roadside PM_{10} calibration coefficients were higher, by a least a third, than their equivalent UK values.

It is therefore anticipated that the 2014 Scotland-specific roadside PM_{10} model may predict a higher number of PM_{10} roadside exceedances for Scottish road links when compared to those predicted by the 2014 UK model, however this effect may be ameliorated by the meteorological terms (dispersion kernels) applied in the model. The resulting map of roadside annual mean PM_{10} concentrations for Scotland is shown in Figure 5.12.

4 Model Verification

The modelled background Scottish annual mean pollutant concentrations were extracted for each of the relevant 1 km x 1 km grid square and plotted against the pollutant concentration measured at the background Scottish air quality monitoring sites in order to provide a measure of the model performance. For roadside sites, the corresponding modelled road link was used to ascertain a modelled roadside concentration rather than the modelled background concentration.

It should be noted that this process is not a true indication of model performance because the majority of the data points, against which the model performance is being compared against, were used to calibrate the model. A good agreement between the measured concentrations and the model outputs from the Scotland-specific model indicates that the calibration has worked well and there were no underlying problems with the model components, but it cannot provide confidence in the model result as a whole.

The UK model is verified annually against independent air quality monitoring data available from sites located throughout the UK, which have not been used in the model calibration. These are typically air quality monitoring sites used for the purposes of LAQM, e.g., Local Authority sites located at roadside sites or in air pollutant hot-spot areas. In 2014, a small number of Scottish air quality monitoring sites, between three and eleven, were used to verify the output of the Scotland-specific model, as noted in Section 2.2. The number of sites available for verification of the Scotland-specific model was limited and greatly dependent on the air pollutant and site type (background or roadside).

4.1 NO_X and NO_2 model verification

The model verification plots are presented in Figure 4.1 and Figure 4.2 for background and roadside NO_X, respectively. Figure 4.3 and Figure 4.4 show the verification plots for background and roadside NO_2, respectively. Lines at ±30% are shown on the model verification plots. These lines represent the Data Quality Objectives (DQOs) specified in the EU Air Quality Directive[2] for modelled NO_2 concentrations used for national reporting purposes. The plots show that the modelled values provide reasonable agreement with the measured annual mean concentrations, with some sites lying outside the DQOs.

Model verification was performed separately for background and roadside sites. Summary statistics are presented in

Table 4.1 and Table 4.2 for NO_X and NO_2, respectively, for the Scotland-specific model. The summary statistics presented in

Table 4.1 and Table 4.2 include the:

a) annual mean measured concentrations,
b) corresponding modelled mean estimates,
c) number of sites included in the analysis for each metric, and
d) R^2 (the squared Pearson's correlation coefficient) of the relationship between monitored and modelled data, and the number of sites within the DQOs.

The percentage of monitoring sites for which the modelled annual mean concentration fell outside the data quality objectives was greater for NO_X than for NO_2. This is to be expected because NO_2 concentrations show a lower dynamic range than NO_X concentrations and were less strongly influenced by very local sources.

Table 4.1 Comparison of the modelled and measured annual mean concentration of NO_X at background and roadside sites, µg m^{-3} (Scotland-specific model).

NO_X Background					
Model output	**Measured annual mean (µg m^{-3})**	**Modelled annual mean (µg m^{-3})**	**R^2**	**% outside data quality objectives**	**Number of sites in assessment**
Scotland-specific calibration	22.1	19.6	0.70	44.4	9
Scotland-specific verification	19.8	21.7	0.55	50.0	4

NO_X Roadside					
Model output	**Measured annual mean (µg m^{-3})**	**Modelled annual mean (µg m^{-3})**	**R^2**	**% outside data quality objectives**	**Number of sites in assessment**
Scotland-specific calibration	76.5	73.7	0.26	53.8	13
Scotland-specific verification	77.5	72.9	0.13	36.4	11

Table 4.2 Comparison of the modelled and measured annual mean concentration of NO_2 at background and roadside sites, µg m^{-3} (Scotland-specific model).

NO_2 Background					
Model output	**Measured annual mean (µg m^{-3})**	**Modelled annual mean (µg m^{-3})**	**R^2**	**% outside data quality objectives**	**Number of sites in assessment**
Scotland-specific calibration	14.0	12.5	0.82	33.3	9
Scotland-specific verification	13.3	14.0	0.68	25.0	4

NO_2 Roadside					
Model output	**Measured annual mean (µg m^{-3})**	**Modelled annual mean (µg m^{-3})**	**R^2**	**% outside data quality objectives**	**Number of sites in assessment**
Scotland-specific calibration	30.4	30.3	0.36	30.8	13
Scotland-specific verification	31.8	30.7	0.23	9.1	11

4.2 PM_{10} model verification

The model verification plots are presented in Figure 4.5 and Figure 4.6. Lines at ±50% are shown on the model verification plots and represent the DQOs specified for modelled PM_{10} concentrations in the EU Air Quality Directive2. The plots show that the modelled annual mean concentrations provide good agreement with the measured annual mean concentrations and on the whole fall within the DQO specified by the Directive.

Model verification was performed separately for background and roadside sites. Summary statistics are presented in

Table 4.3 including the mean of the annual measured concentrations, the mean of the corresponding modelled estimates, the number of sites included in the analysis for each metric, the R^2 of the relationship between monitored and modelled data, and the number of sites within the DQOs.

Table 4.3 Comparison of the modelled and measured annual mean concentration of PM_{10} at background and roadside sites, µg m^{-3} (Scotland-specific model).

PM_{10} Background					
Model output	**Measured annual mean (µg m^{-3})**	**Modelled annual mean (µg m^{-3})**	**R^2**	**% outside data quality objectives**	**Number of sites in assessment**
Scotland-specific calibration	11.9	12.0	0.85	0	7
Scotland-specific verification	13.7	11.8	0.92	0	3

PM_{10} Roadside					
Model output	**Measured annual mean (µg m^{-3})**	**Modelled annual mean (µg m^{-3})**	**R^2**	**% outside data quality objectives**	**Number of sites in assessment**
Scotland-specific calibration	15.1	14.9	0.18	0	7
Scotland-specific verification	17.4	16.8	0.89	0	7

Figure 4.1 Annual mean background NO_X model verification, 2014. Sites with <75% data capture have been included in addition to calibration and verification sites.

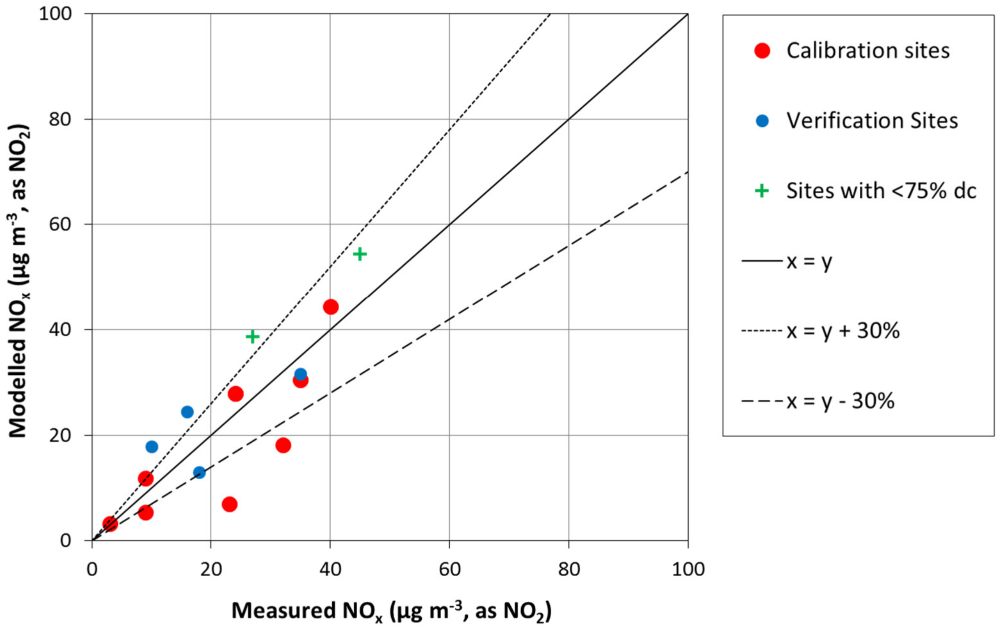


Figure 4.2 Annual mean roadside NO_X model verification, 2014. Sites with <75% data capture have been included in addition to calibration and verification sites.

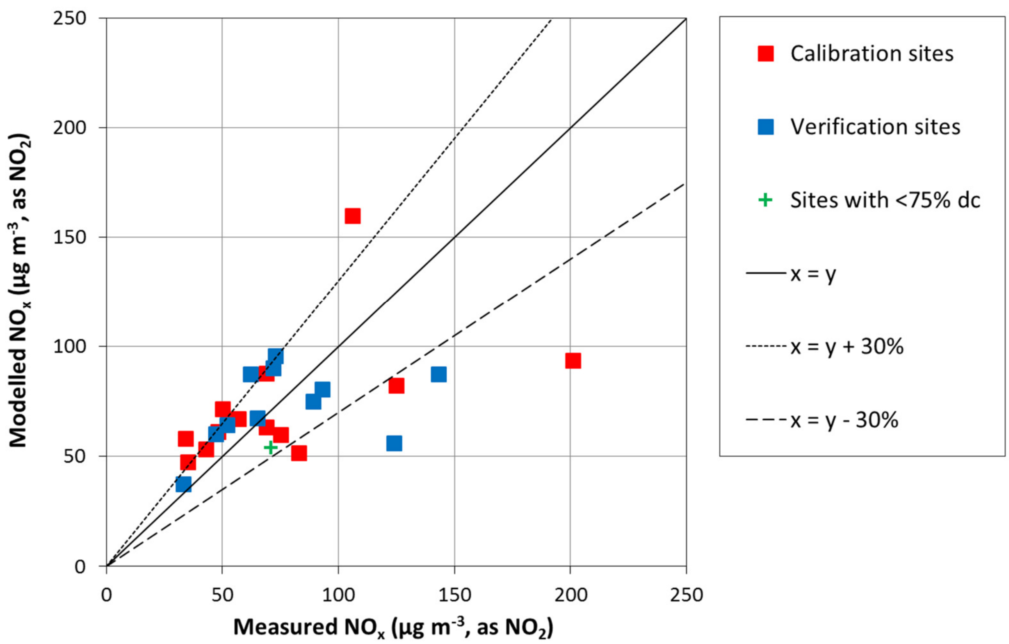


Figure 4.3 Annual mean background NO_2 model verification, 2014. Sites with <75% data capture have been included in addition to calibration and verification sites.

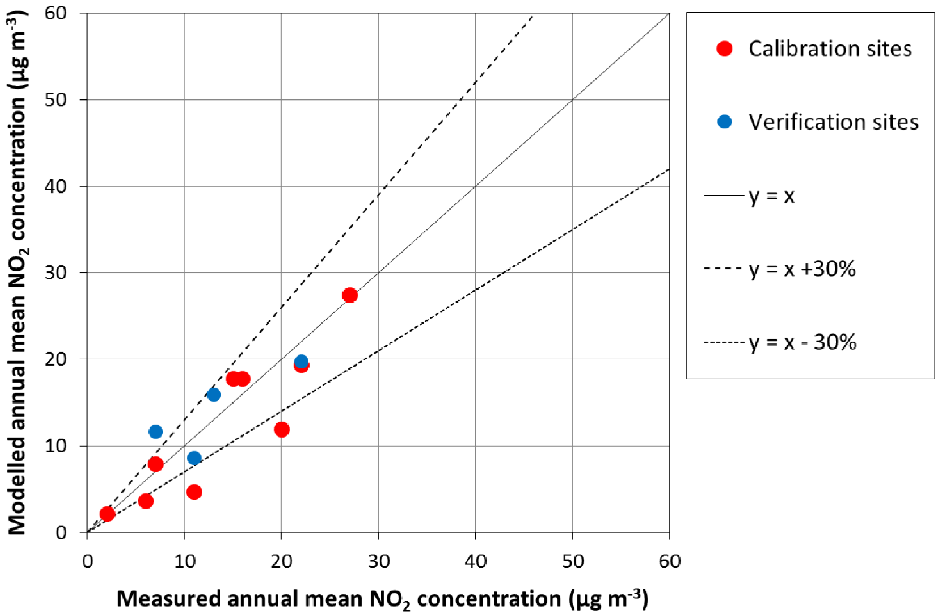


Figure 4.4 Annual mean roadside NO_2 model verification, 2014. Sites with <75% data capture have been included in addition to calibration and verification sites.

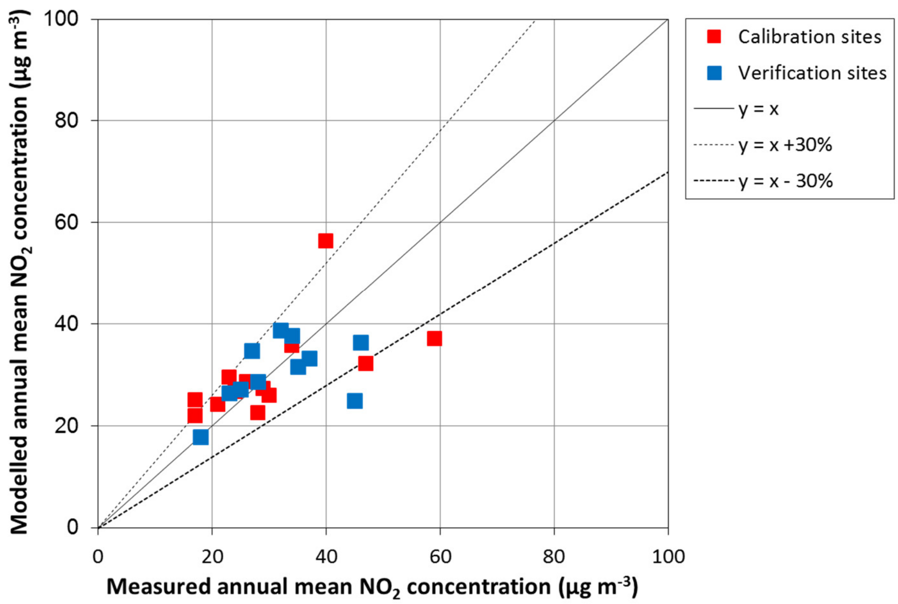


Figure 4.5 Annual mean background PM_{10} model verification, 2014. Sites with <75% data capture have been included in addition to calibration and verification sites.

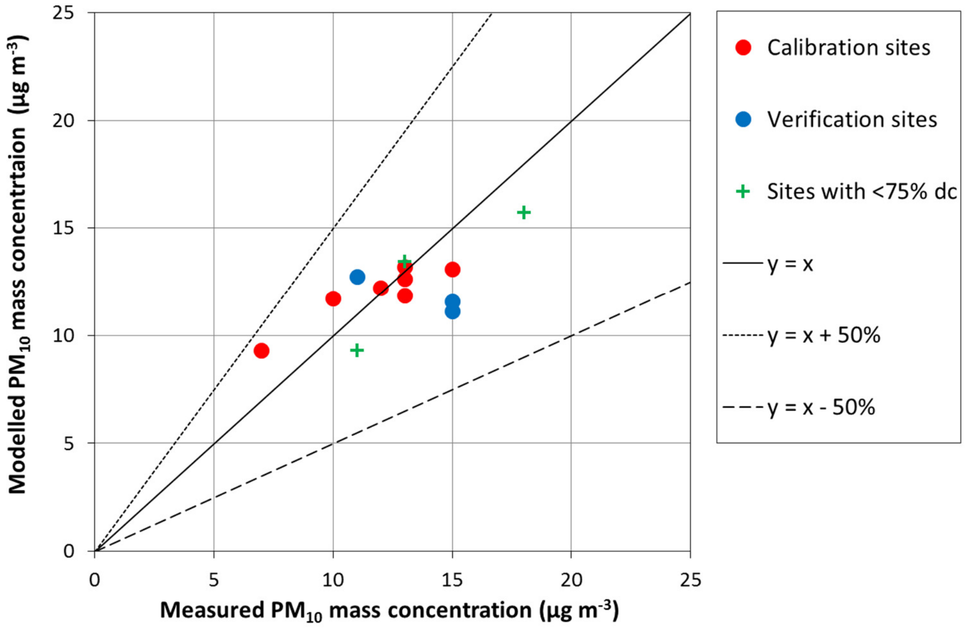
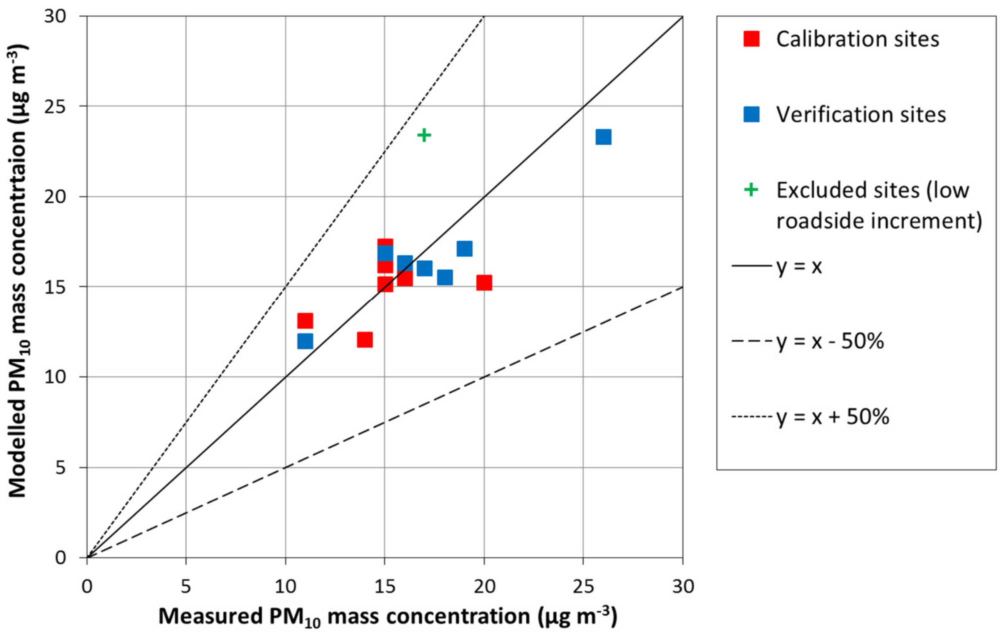


Figure 4.6 Annual mean roadside PM_{10} model verification, 2014. Sites with <75% data capture have been included in addition to calibration and verification sites.



5 2014 Scottish pollutant maps and results

5.1 Scottish annual mean NO_X and NO_2 maps

For the purposes of assessing compliance to air quality limit values, Scotland is divided into four zones (Highland, North East Scotland, Central Scotland, and the Scottish Borders) and two agglomerations (Edinburgh Urban Area and Glasgow Urban Area), as shown in Figure 5.1.The 2014 Scottish annual mean background NO_X concentrations were modelled and are shown in Figure 5.2. Following derivation of the mapped 2014 Scottish annual mean background NO_X concentrations the Scottish annual mean NO_2 concentrations were modelled for background and roadside locations.

Figure 5.3 and

Figure 5.4 present maps of annual mean NO_2 for these locations in 2014. Detailed maps showing the roadside annual mean NO_2 concentration maps are presented in Figures 5.5 to 5.10 on the basis of the four zones and two agglomerations in Scotland.

5.2 Scottish annual mean PM_{10} maps

The annual mean PM_{10} concentrations were modelled for Scotland for 2014 at background and roadside locations.

Figure 5.11 and Figure 5.12, respectively, present maps of annual mean PM_{10} concentrations for these area types in 2014. Detailed maps showing the roadside annual mean PM_{10} concentration maps are presented in Figures 5.13 to 5.18 on the basis of the four zones (Highland, North East Scotland, Central Scotland, and the Scottish Borders) and two agglomerations (Edinburgh Urban Area and Glasgow Urban Area) in Scotland as shown in Figure 5.1.

5.3 Exceedance statistics (Scotland-specific model)

5.3.1 Background and roadside NO_2

Figure 5.3 presents the mapped annual mean background NO_2 concentrations for 2014 from the Scotland-specific model. Table 5.1 shows that three square kilometres in North East Scotland were modelled to exceed the Scottish NO_2 AQS objective of 40 µg m^{-3}. These three exceedances are located close to Aberdeen Harbour and are linked to emissions from shipping. Table 5.2 shows that the Scotland-specific model predicted that the Scottish annual mean NO_2 air quality objective was exceeded along 54 road links (62.7 km of road). The majority of exceedances were predicted to occur in the Glasgow Urban area where exceedances were modelled for 34 road links (41.0 km of road). Overall exceedances of the Scottish annual mean NO_2 air quality objective were modelled in four of the six zones and agglomerations in Scotland. In each of the other three Scottish zones and agglomerations there were no more than 10 road links where exceedances of the Scottish annual mean NO_2 air quality objective were modelled, representing 5-9 km of roads. No roadside exceedances of the Scottish annual mean NO_2 air quality objective were modelled in the more rural zones and agglomerations of Scotland, i.e. the Highlands and Scottish Borders. Detailed maps showing the roadside annual mean NO_2 concentrations are presented in Figure 5.5 to 5.10 on the basis of the four zones (Highland, North East Scotland, Central Scotland, and the Scottish Borders) and two agglomerations (Edinburgh Urban Area and Glasgow Urban Area) in Scotland as shown in Figure 5.1.

Prior to 2010 there existed a margin of tolerance (MOT)[15] applicable to the Scottish NO_2 Limit Value. Although MOT are no longer applicable in air quality assessments the modelled NO_2 concentrations are routinely assessed against the annual mean NO_2 air quality objective (40 µg m^{-3}) + the maximum MOT (20 µg m^{-3}, 50% of the NO_2 limit value) as this provides an indication of locations where large exceedances may exist. There were no modelled background exceedances of the Scottish NO2 annual mean air quality objective + maximum margin of tolerance in 2014. Table 5.4 shows that exceedances of the Scottish annual mean NO_2 air quality objective + the maximum margin of tolerance (20 µg m^{-3}, 50% of the NO_2 limit value) were modelled on four road links (10 km of road) in 2014. The exceedances occurred within the Glasgow Urban Area agglomeration. No exceedances of the MOT were reported in any other zones or agglomerations.

Table 5.1 Annual mean exceedance statistics for background NO_2 in Scotland based on the Scotland-specific model, 2014.

Zone or agglomeration	Total		>40 µg m^{-3}	
	Area (km^2)	**Population**	**Area (km^2)**	**Population**
Glasgow Urban Area	367	1105095	0	0
Edinburgh Urban Area	134	468399	0	0
Central Scotland	9984	1942272	0	0
North East Scotland	19024	1121019	3	8450
Highland	43514	393586	0	0
Scottish Borders	11400	265466	0	0
Total	**84423**	**5295838**	**3**	**8450**

Table 5.2 Annual mean exceedance statistics for roadside NO_2 in Scotland based on the Scotland-specific model, 2014.

Zone or agglomeration	Total		>40 µg m^{-3}	
	Road links	**Length (km)**	**Road links**	**Length (km)**
Glasgow Urban Area	283	339.6	34	41.0

[15] Council Directive 1999/30/EC (relating to limit values for sulphur dioxide, nitrogen dioxide and oxides of nitrogen, particulate matter and lead in ambient air, http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:1996:296:0055:0063:EN:PDF) defines 'margin of tolerance' as the percentage of the limit value by which this value may be exceeded subject to the conditions laid down in Directive 96/62/EC. MOTs were annually decreasing values applied in addition to the LV, to ensure compliance with the LV by a specific date (whereupon the MOT would be equal to 0). In previous years, if an air pollution value fell between the LV and the MOT, it was expected that the LV would be attained in due time with existing pollution reduction measures. If the value was above the MOT, however, authorities are expected to produce specific plans detailing how LVs would be met.

Edinburgh Urban Area	60	99.5	6	7.4
Central Scotland	238	353.0	10	9.0
North East Scotland	133	233.4	4	5.3
Highland	11	36.6	0	0.0
Scottish Borders	36	47.1	0	0.0
Total	**761**	**1109.3**	**99**	**125.0**

Table 5.3 Annual mean exceedance statistics for background NO_2 >60 µgm^{-3} in Scotland based on the Scotland-specific model, 2014.

Zone or agglomeration	Total		>60 µg m^{-3}	
	Area (km^2)	**Population**	**Area (km^2)**	**Population**
Glasgow Urban Area	367	1117379	0	0
Edinburgh Urban Area	134	469052	0	0
Central Scotland	9922	1929140	0	0
North East Scotland	19023	1120962	0	0
Highland	43571	393901	0	0
Scottish Borders	11399	265338	0	0
Total	**84416**	**5295772**	**0**	**0**

Table 5.4 Annual mean exceedance statistics for roadside NO_2 >60 µgm^{-3} in Scotland based on the Scotland-specific model, 2014.

Zone or agglomeration	Total		>60 µg m^{-3}	
	Roads links	**Length (km)**	**Roads links**	**Length (km)**
Glasgow Urban Area	283	339.6	4	9.9
Edinburgh Urban Area	60	99.5	0	0.0
Central Scotland	238	353.0	0	0.0
North East Scotland	133	233.4	0	0.0
Highland	11	36.6	0	0.0
Scottish Borders	36	47.1	0	0.0
Total	**761**	**1109.3**	**4**	**9.9**

5.3.2 Background and roadside PM_{10}

Figure 5.11 presents the mapped annual mean background PM_{10} concentrations for 2014 from the Scotland-specific model. Table 5. shows exceedances of the Scottish annual mean PM_{10} objective of 18 µg m^{-3} were modelled at seventy one 1 km^2 grid squares in Scotland.

Twenty nine exceedances in background concentrations of PM_{10} occur in the vicinity of Edinburgh. The majority of these are located on the western outskirts of Edinburgh close to Edinburgh airport and the M8 corridor. This location contains various industrial and traffic sources which are believed to contribute to the elevated modelled PM_{10} concentrations in this area. The Scotland specific model has predicted similar exceedances in the annual mean PM_{10} concentration in this cluster of grid squares in previous years, however, modelled concentrations in this area for 2013 were lower than those reported here for 2014. Additional isolated exceedances on the outskirts of Edinburgh and are related to industry and agriculture.

Forty one exceedances are located close to Aberdeen. The causes of exceedances modelled in these areas are varied and relate to a combination of quarrying and industry, the contribution of road transport emissions to background, or shipping close to Aberdeen Harbour. One further isolated exceedance is located in the Scottish borders and is related to emissions of PM_{10} from agriculture.

On the whole the extent of the exceedance of the Scottish PM_{10} air quality objective was typically of the order of 1 to 2 µg m^{-3}, but was as high as 5 µg m^{-3} in one grid square.

Table 5.5 Annual mean exceedance statistics for background PM_{10} in Scotland based on the Scotland-specific model, 2014.

Zone or agglomeration	Total		>18 µg m^{-3}	
	Area (km^2)	**Population**	**Area (km^2)**	**Population**
Glasgow Urban Area	367	1105095	0	0
Edinburgh Urban Area	134	468399	0	0
Central Scotland	9984	1942272	29	21560
North East Scotland	19024	1121019	41	7614
Highland	43514	393586	0	0
Scottish Borders	11400	265466	1	0
Total	**84423**	**5295838**	**71**	**29175**

Table 5.5 Annual mean exceedance statistics for roadside PM_{10} in Scotland based on the Scotland-specific model, 2014.

Zone or agglomeration	Total		>18 µg m^{-3}	
	Road links	**Length (km)**	**Road links**	**Length (km)**
Glasgow Urban Area	290	338.7	36	37.0
Edinburgh Urban Area	60	99.5	9	12.8
Central Scotland	239	352.5	12	9.5
North East Scotland	133	233.4	15	24.7
Highland	11	36.6	0	0.0
Scottish Borders	36	47.1	0	0.0
Total	769	1107.8	**72**	**84.0**

The 2014 Scotland-specific model identified 72 road links (84.0 km of road) exceeding the Scottish annual mean PM_{10} air quality objective. 36 road links (37.0 km of road) were in the Glasgow Urban Area, as shown in Table 5.5.

Exceedances of the Scottish annual mean PM_{10} objective were modelled on 15 road links (24.7 km of road) in North East Scotland, 12 road links (9.5 km of road) in Central Scotland and 9 road links in the Edinburgh Urban Area (12.8 km of road). No roadside exceedances of the Scottish PM_{10} objective were modelled in the Highlands or Scottish Borders. Detailed maps showing the roadside annual mean PM_{10} concentration maps are presented in Figures 5.13 to 5.18 on the basis of the four zones (Highland, North East Scotland, Central Scotland, and the Scottish Borders) and two agglomerations (Edinburgh Urban Area and Glasgow Urban Area) in Scotland as shown in Figure 5.1.

To assess against the PM_{10} 24 hour limit value an annual mean PM_{10} equivalent value is defined which establishes an annual mean PM_{10} concentration for comparison with the daily mean PM_{10} objective, the derivation of this value is described in detail in Appendix 1. For 2014, a Scottish annual mean PM_{10} equivalent value of 20.6 µg m^{-3} was used. This value was based on Scottish only AURN PM_{10} air quality monitoring measurements from 1993 to 2014. In 2014, the UK annual mean PM_{10} equivalent value, based on measurements from 1992 to 2014, was 30.5 µg m^{-3}.

Table 5.7 shows there were seventeen modelled exceedance of the Scottish annual mean equivalent value of the Scottish daily mean PM_{10} air quality objective of 20.6 µg m^{-3} at background locations (20.6 µg m^{-3} is the annual mean equivalent of the 98^{th} percentile of the Scotland daily mean PM_{10} objective of 50 µg m^{-3} as described in Appendix 1).

Table 5.7 shows that 13 exceedances (21.4 km of road) were predicted at roadside locations.

Table 5.6 Annual mean exceedance (>20.6) statistics for background PM_{10} in Scotland based on the Scotland-specific model, 2014.

Zone or agglomeration	Total		>20.6 µg m^{-3}	
	Area (km^2)	**Population**	**Area (km^2)**	**Population**
Glasgow Urban Area	367	1105095	0	0
Edinburgh Urban Area	134	468399	0	0
Central Scotland	9984	1942272	10	10404
North East Scotland	19024	1121019	7	443
Highland	43514	393586	0	0
Scottish Borders	11400	265466	0	0
Total	**84423**	**5295838**	**17**	**10847**

Table 5.7 Annual mean exceedance (>20.6) statistics for roadside PM_{10} in Scotland based on the Scotland-specific model, 2014.

Zone or agglomeration	Total		>20.6 µg m^{-3}	
	Road links	**Length (km)**	**Road links**	**Length (km)**
Glasgow Urban Area	283	339.6	5	10.7
Edinburgh Urban Area	60	99.5	1	0.8
Central Scotland	238	353.0	5	6.6
North East Scotland	133	233.4	2	3.2
Highland	11	36.6	0	0.0
Scottish Borders	36	47.1	0	0.0
Total	**761**	**1109.3**	**13**	**21.4**

5.4 Population-weighted mean calculations for 2014

Calculations of the population-weighted mean were performed on the modelled background maps. These provide a measure of the health impact of modelled pollutant concentrations. Table 5.8 provides a summary of the 2014 Scottish NO_2 and PM_{10} population-weighted mean concentration from the Scotland-specific model.

Table 5.8 2014 Scottish NO_2 and PM_{10} population-weighted mean concentration from the Scotland-specific model.

Model	PM_{10} (µg m^{-3})	NO_2 (µg m^{-3})
Scotland-specific	11.3	11.6

Figure 5.1 Zones and agglomerations in Scotland, 2014.

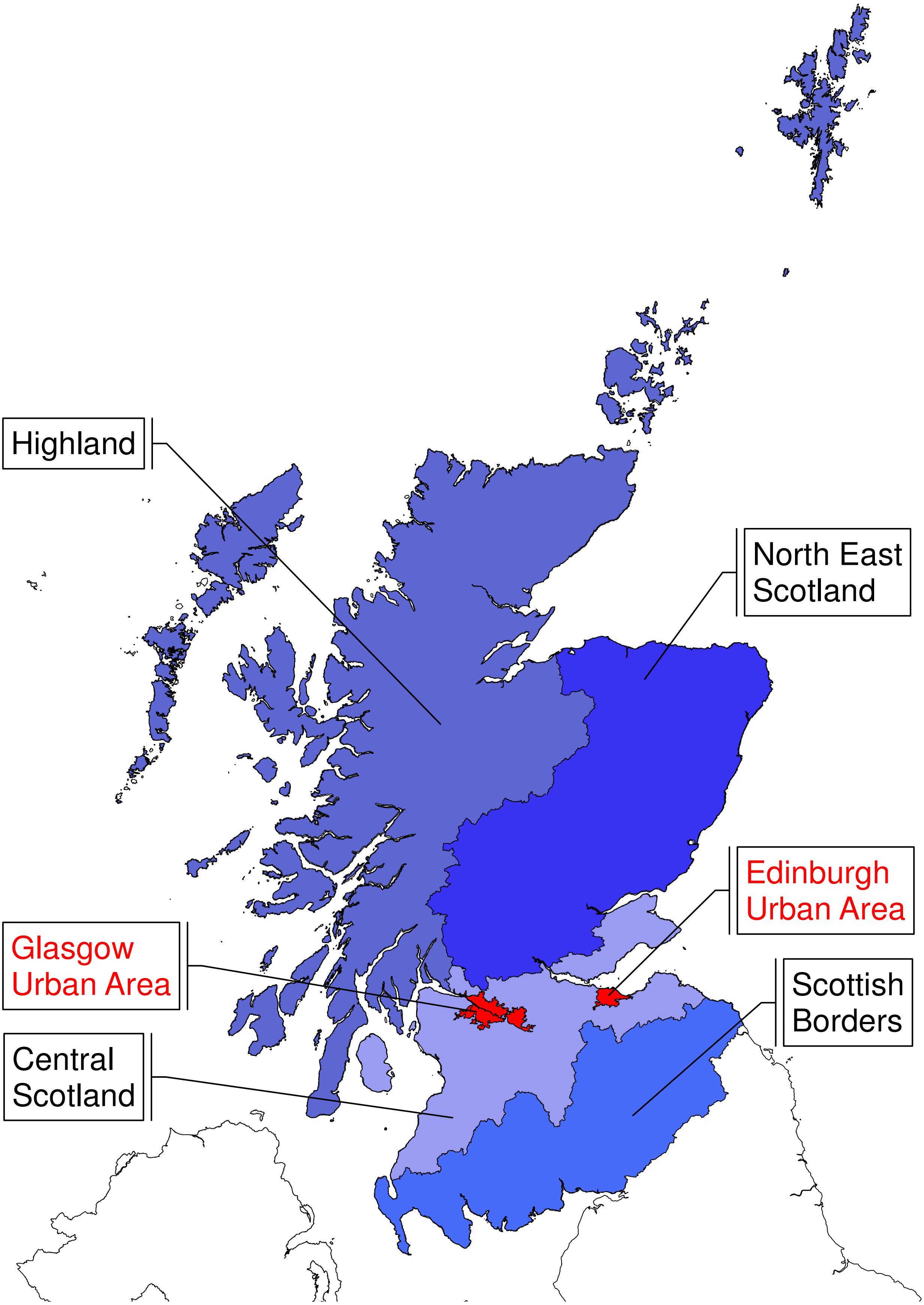


Figure 5.2 Background NO_X map for 2014, µg m^{-3} (Scotland-specific model).

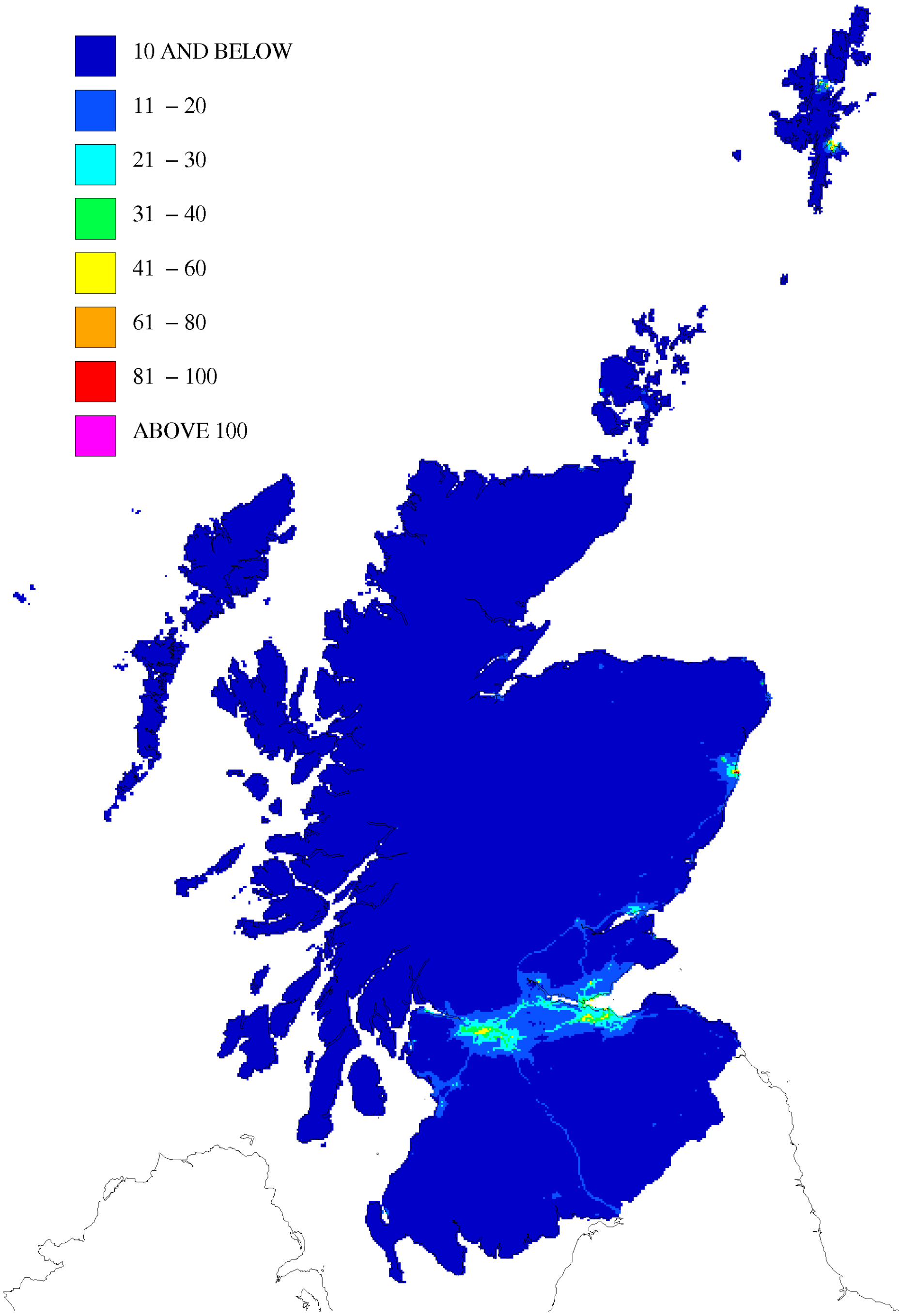


Figure 5.3 Background NO_2 map for 2014, µg m^{-3} (Scotland-specific model).

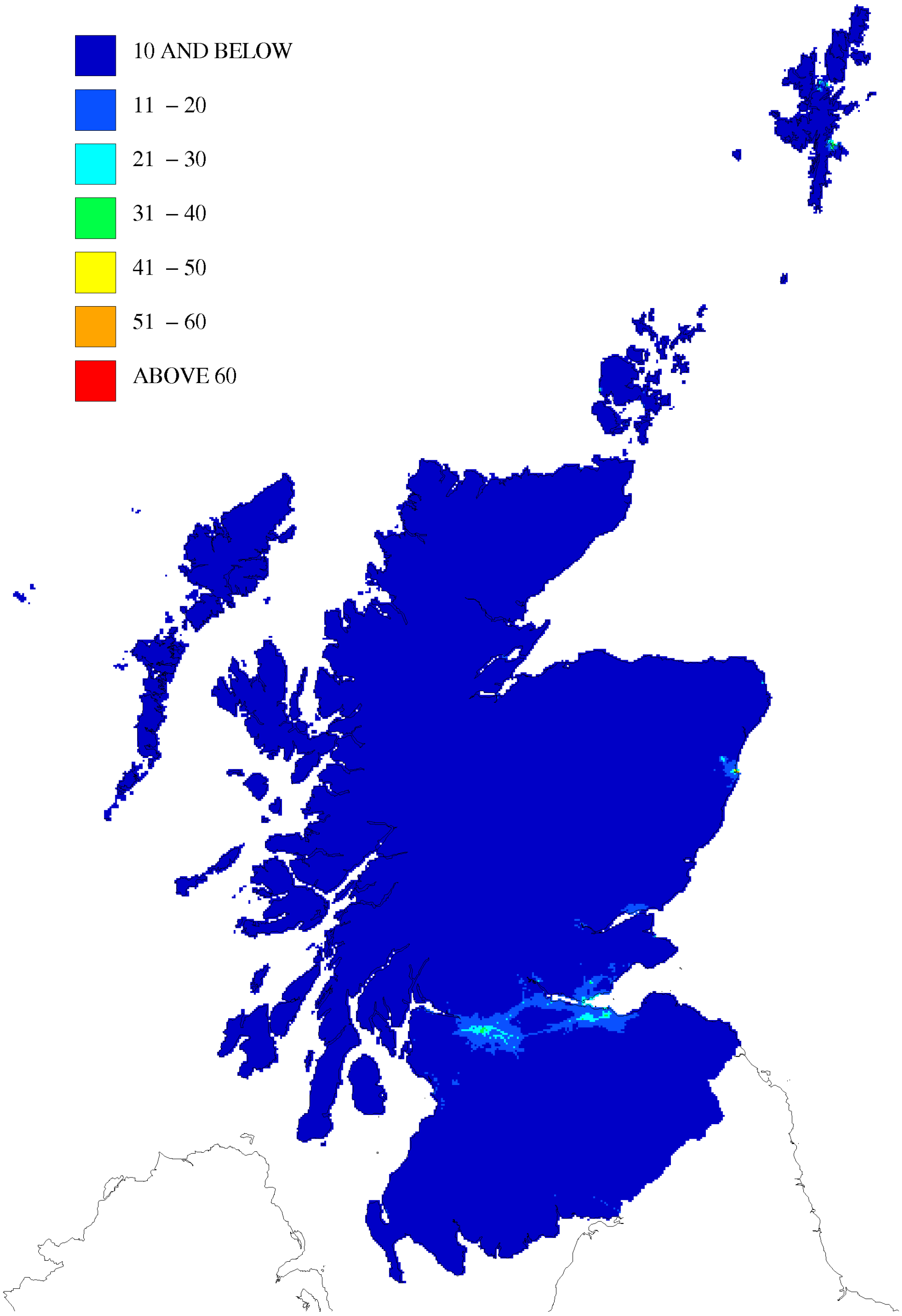


Figure 5.4 Roadside NO_2 map for 2014, µg m^{-3} (Scotland-specific model).

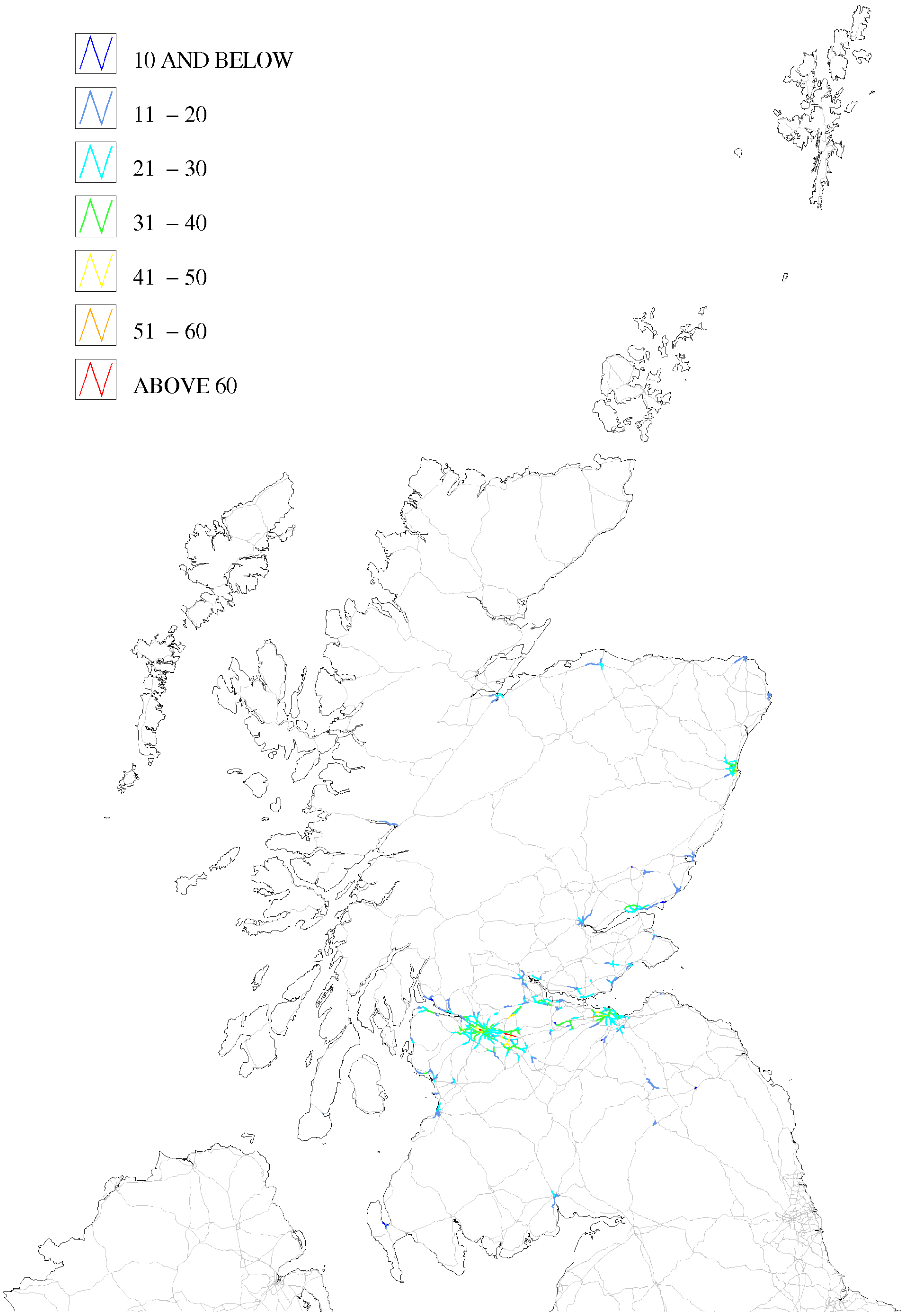
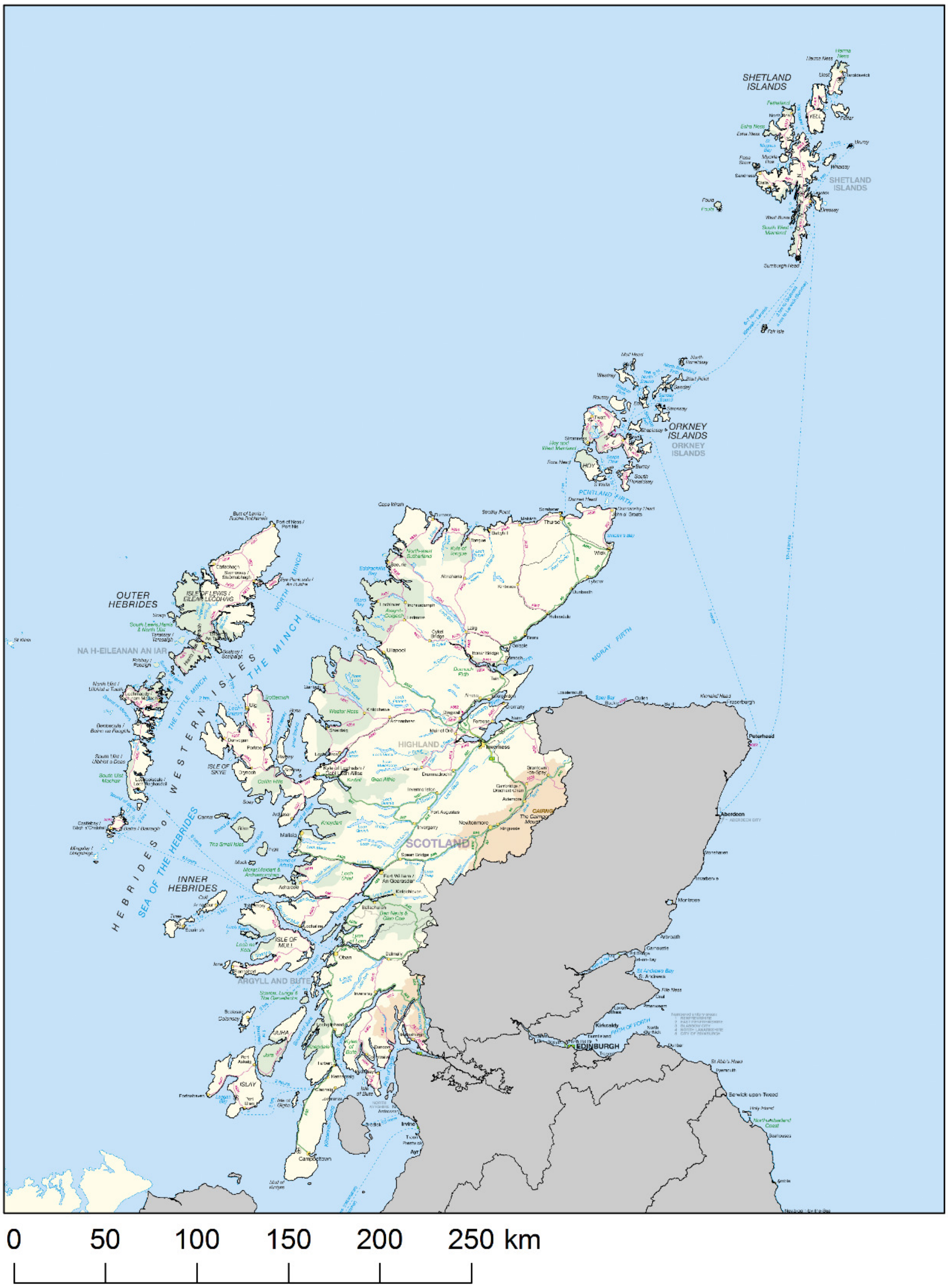
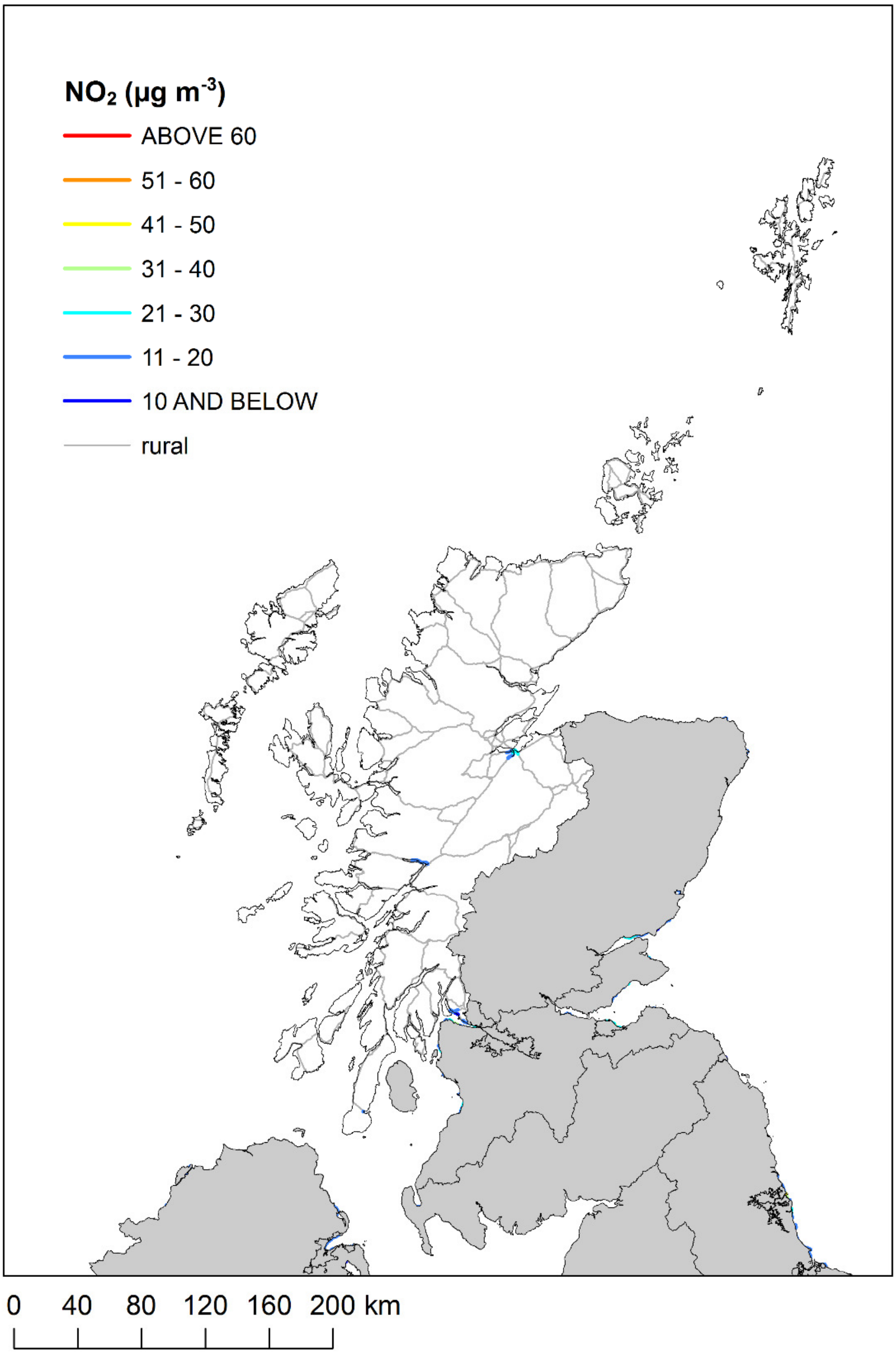


Figure 5.5 2014 detailed roadside NO_2, showing the road-link concentrations in the Highlands of Scotland, µg m^{-3} (Scotland-specific model).





NO_2 (µg m^{-3})
ABOVE 60
51 - 60
41 - 50
31 - 40
21 - 30
11 - 20
10 AND BELOW
rural
0 40 80 120 160 200 km

Figure 5.6 2014 detailed roadside NO_2, showing the road-link concentrations in North East Scotland, µg m^{-3} (Scotland-specific model).

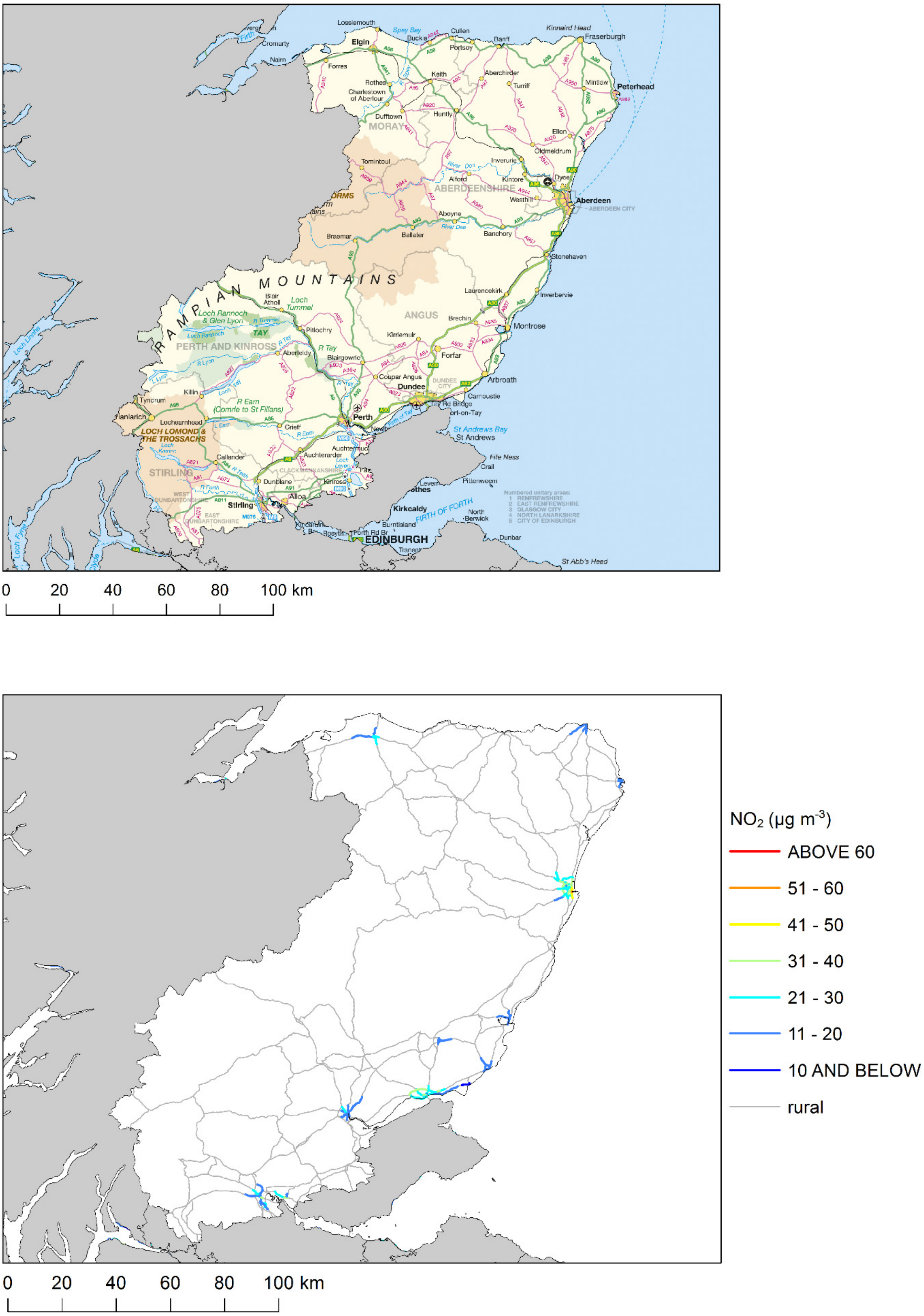
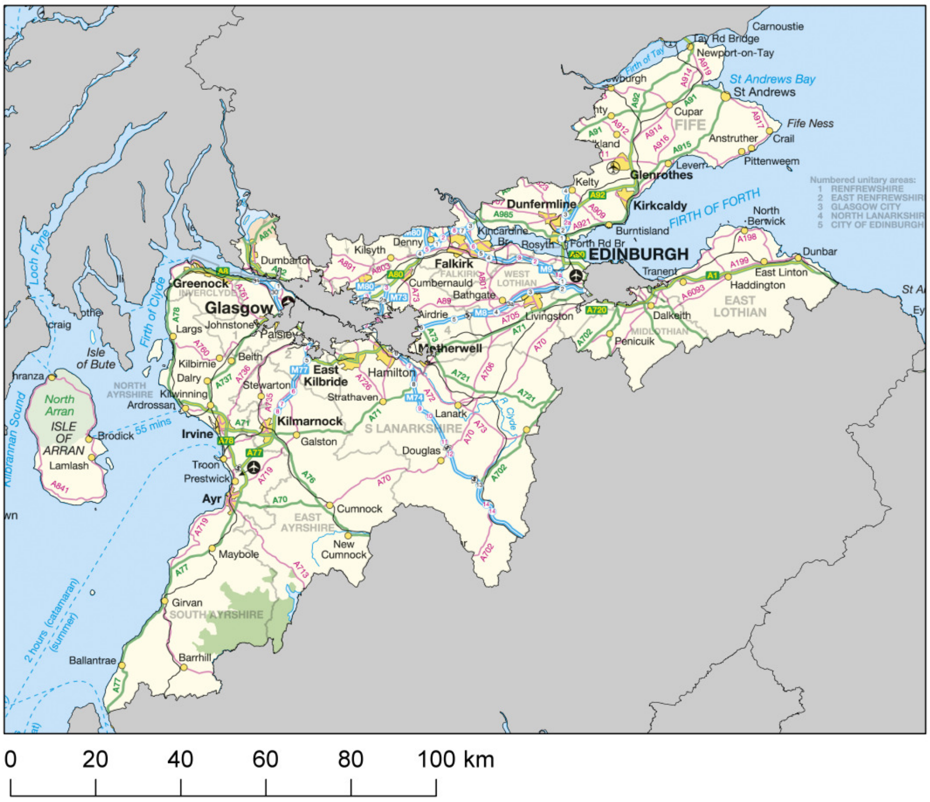


Figure 5.7 2014 detailed roadside NO_2, showing the road-link concentrations in Central Scotland, µg m^{-3} (Scotland-specific model).



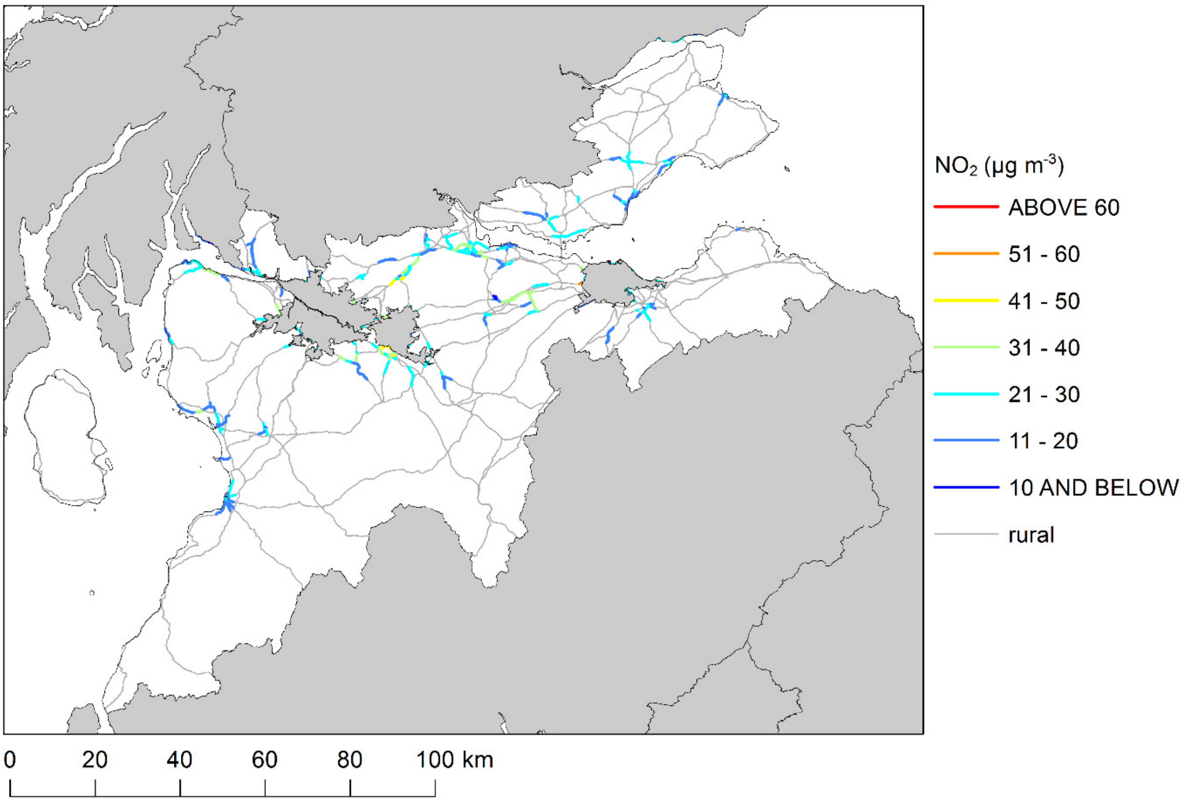


Figure 5.8 2014 detailed roadside NO_2, showing the road-link concentrations in the Scottish Borders, µg m^{-3} (Scotland-specific model).

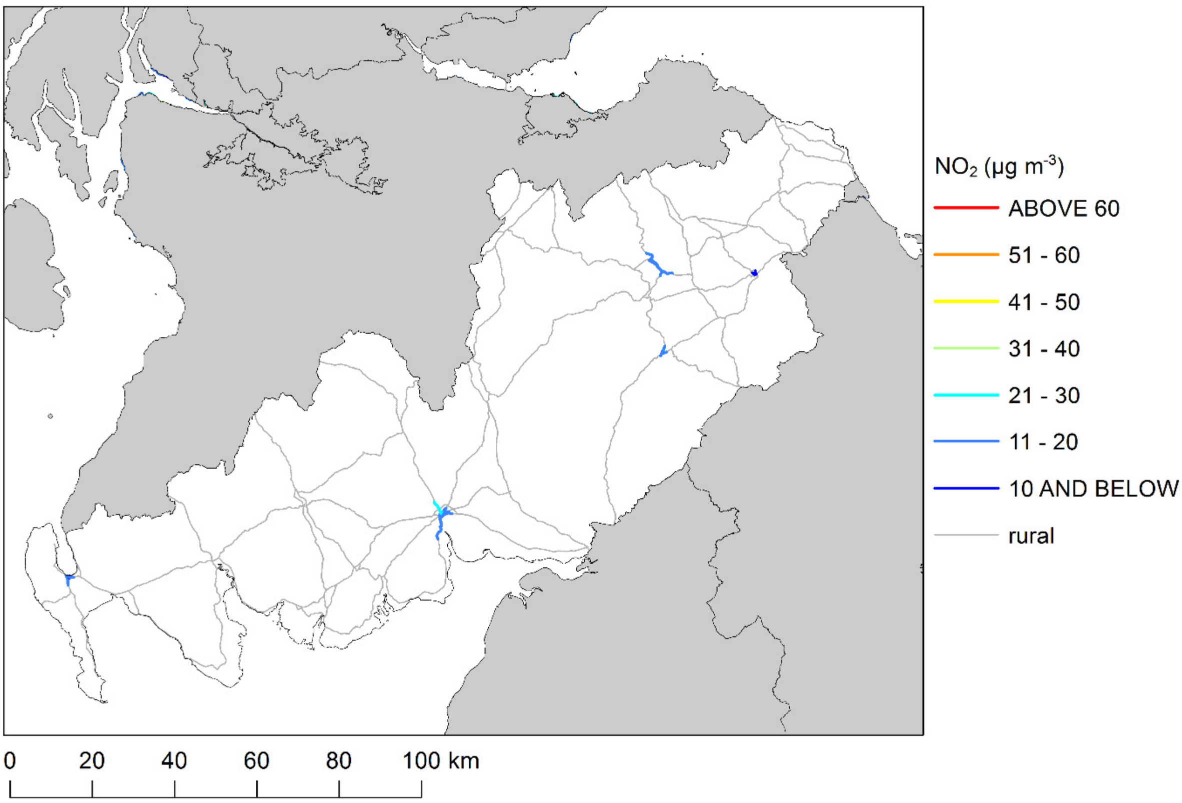


Figure 5.9 2014 detailed roadside NO_2, showing the road-link concentrations in the Edinburgh Urban Area, µg m^{-3} (Scotland-specific model).

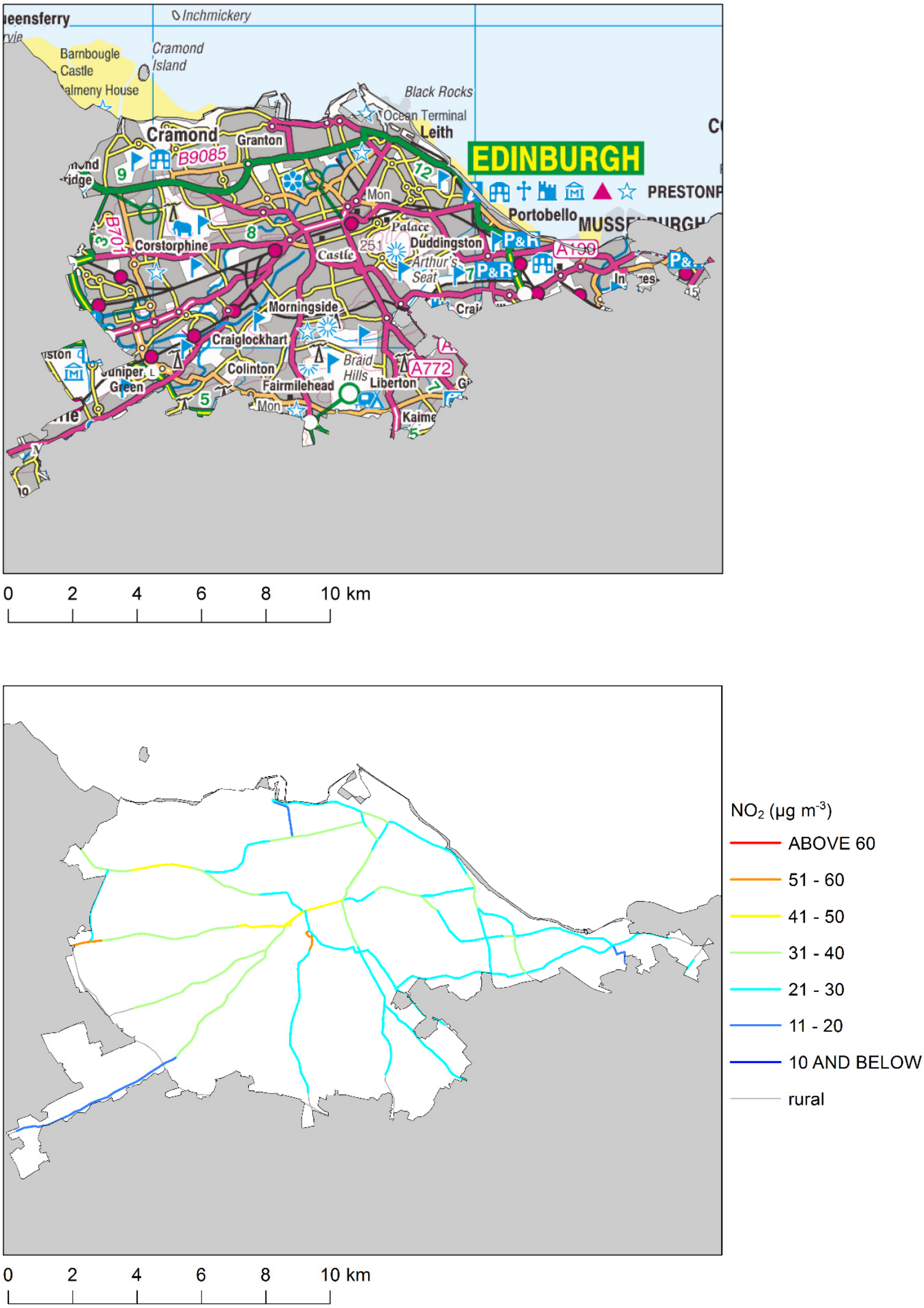


Figure 5.10 2014 detailed roadside NO_2, showing the road-link concentrations in the Glasgow Urban Area, μg m^{-3} (Scotland-specific model).

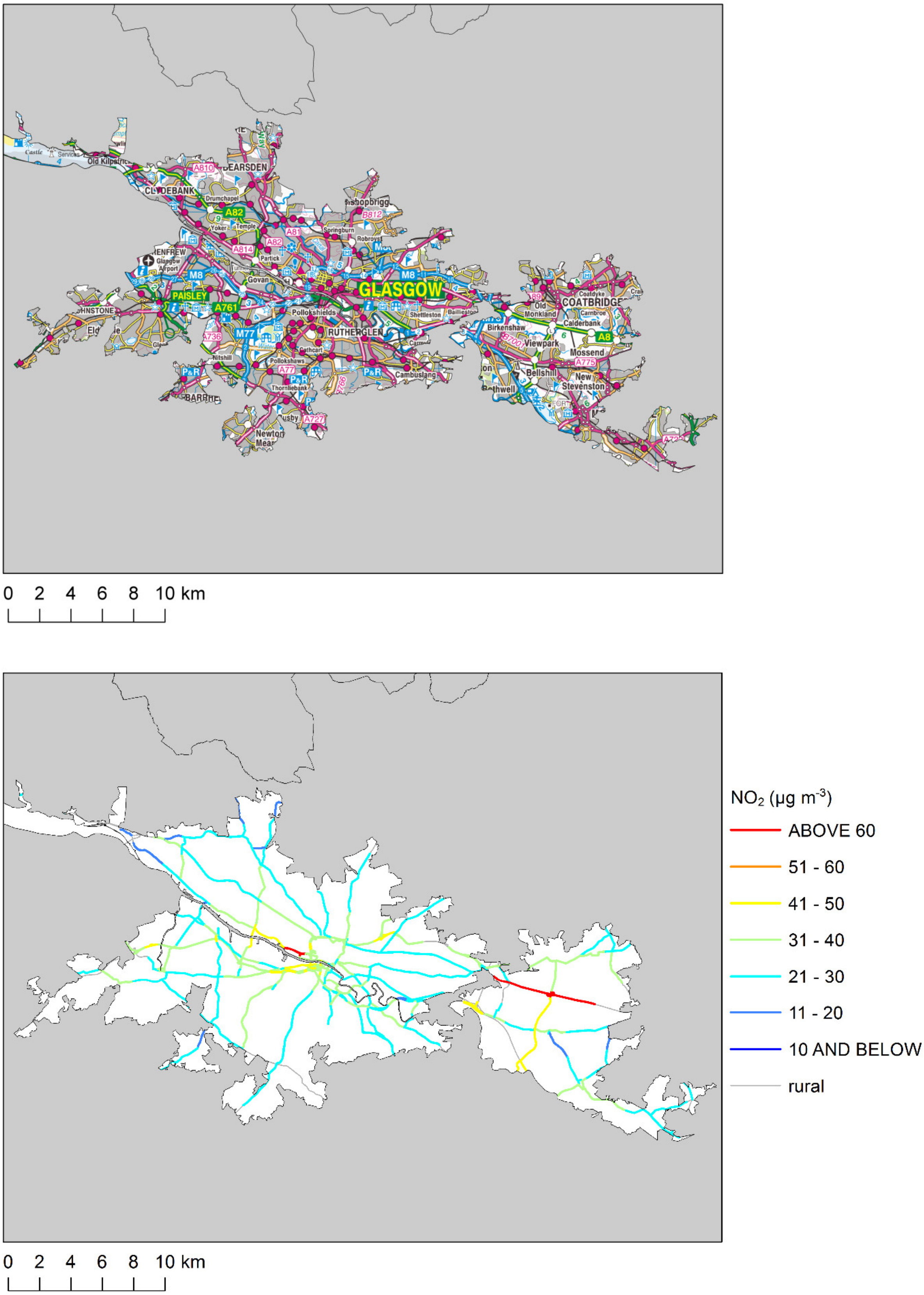


Figure 5.11 Background PM_{10} map for 2014, µg m^{-3} (Scotland-specific model).

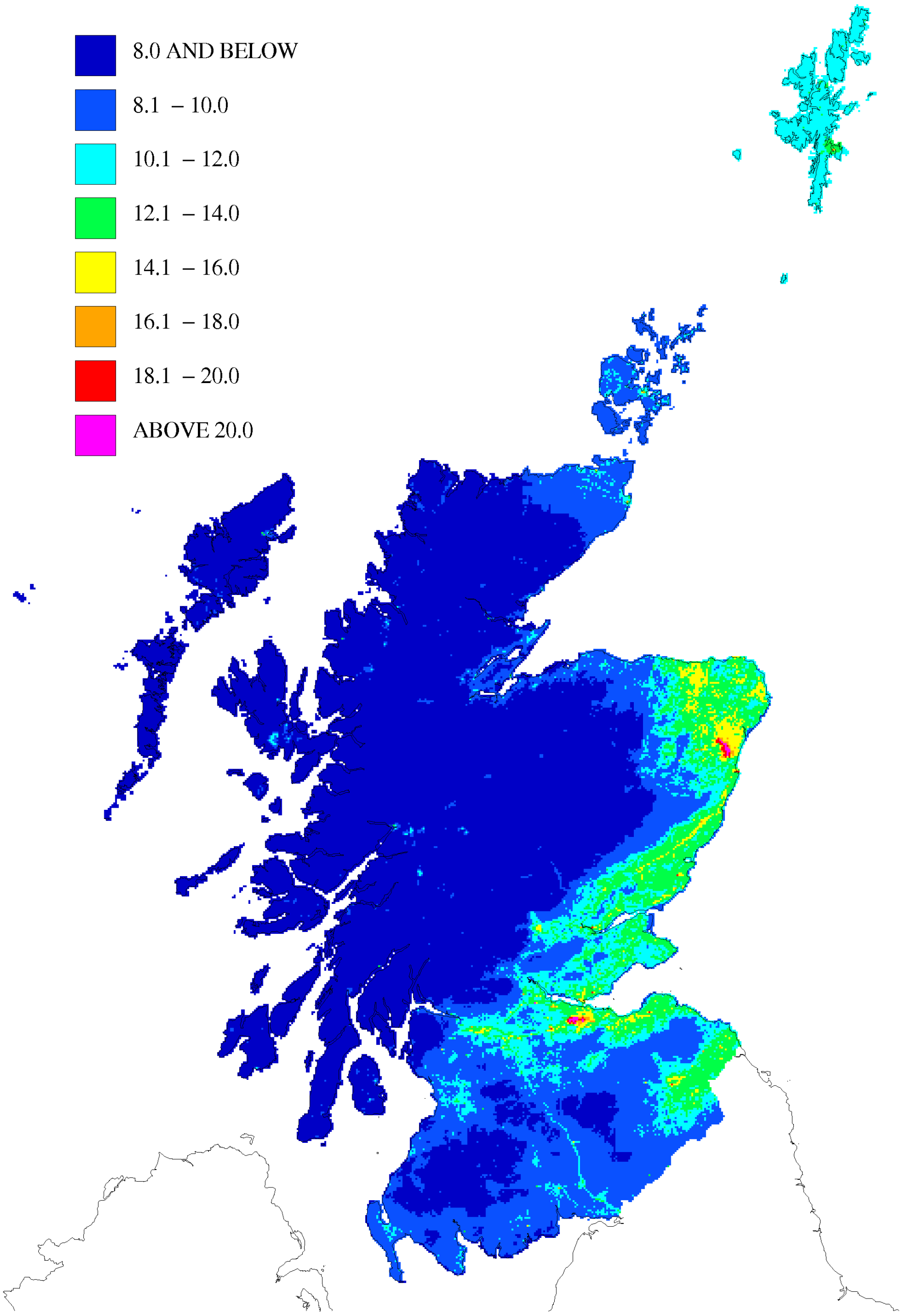


Figure 5.12 Roadside PM_{10} map for 2014, µg m^{-3} (Scotland-specific model).

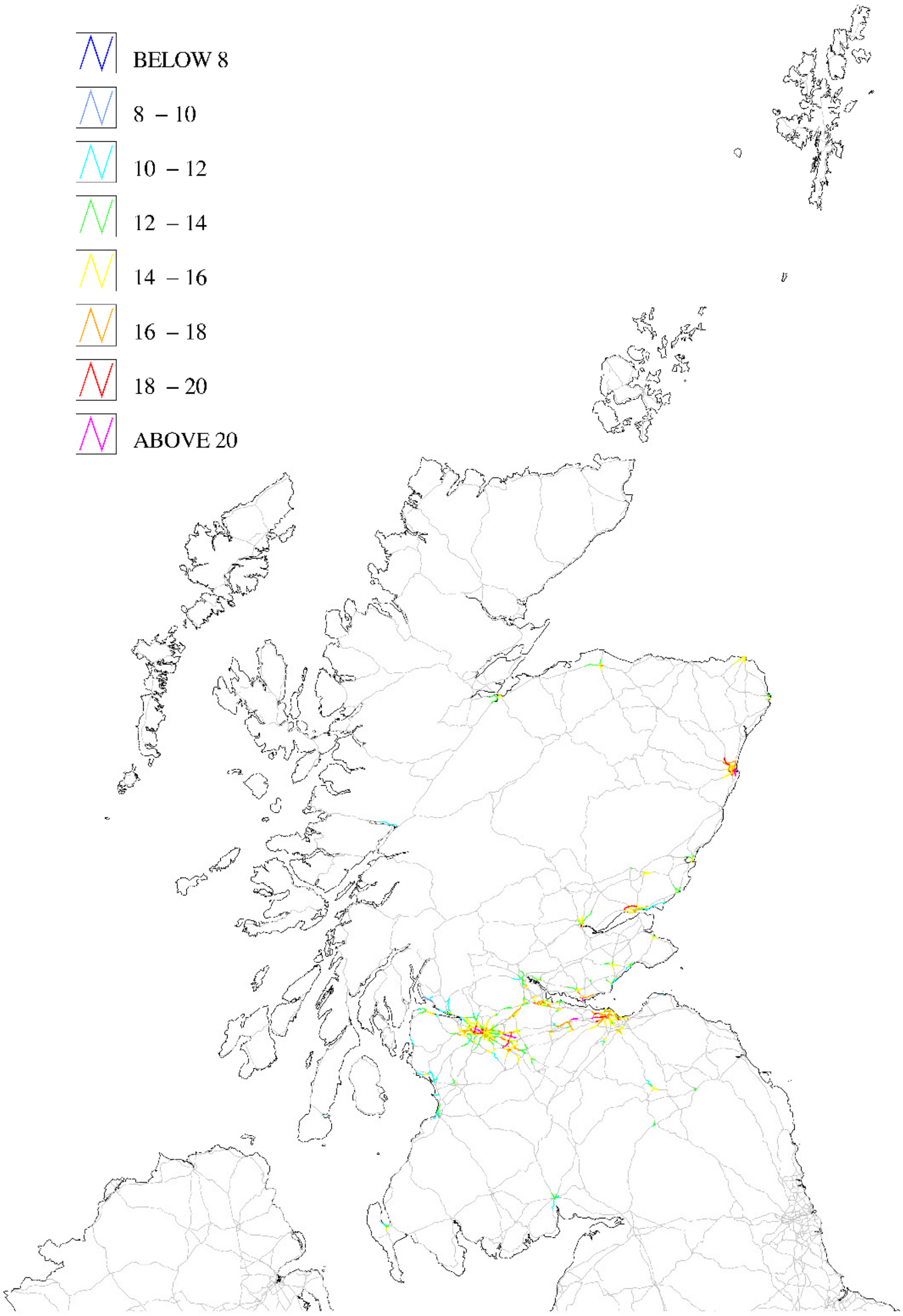
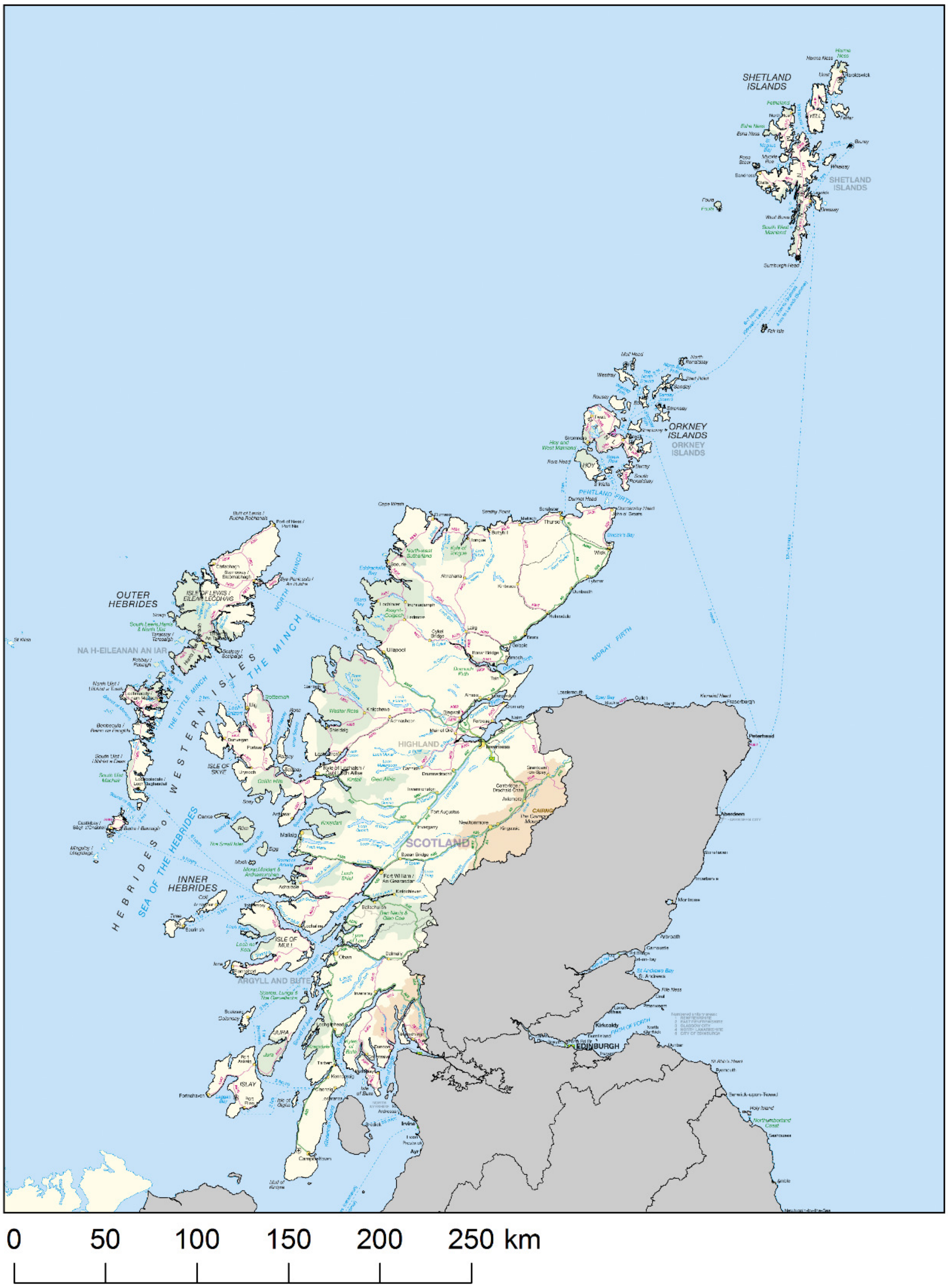


Figure 5.13 2014 detailed roadside PM_{10}, showing the road-link concentrations in the Highlands of Scotland, µg m^{-3} (Scotland-specific model).


SHETLAND ISLANDS
ORKNEY ISLANDS
OUTER HEBRIDES
NA H-EILEANAN AN IAR
THE MINCH
NORTH MINCH
THE LITTLE MINCH
WESTERN ISLES
HEBRIDES
SEA OF THE HEBRIDES
INNER HEBRIDES
ISLE OF SKYE
ISLE OF MULL
ARGYLL AND BUTE
ISLAY
JURA
HIGHLAND
SCOTLAND
MORAY FIRTH
PENTLAND FIRTH
HOY
EDINBURGH
0
50
100
150
200
250 km

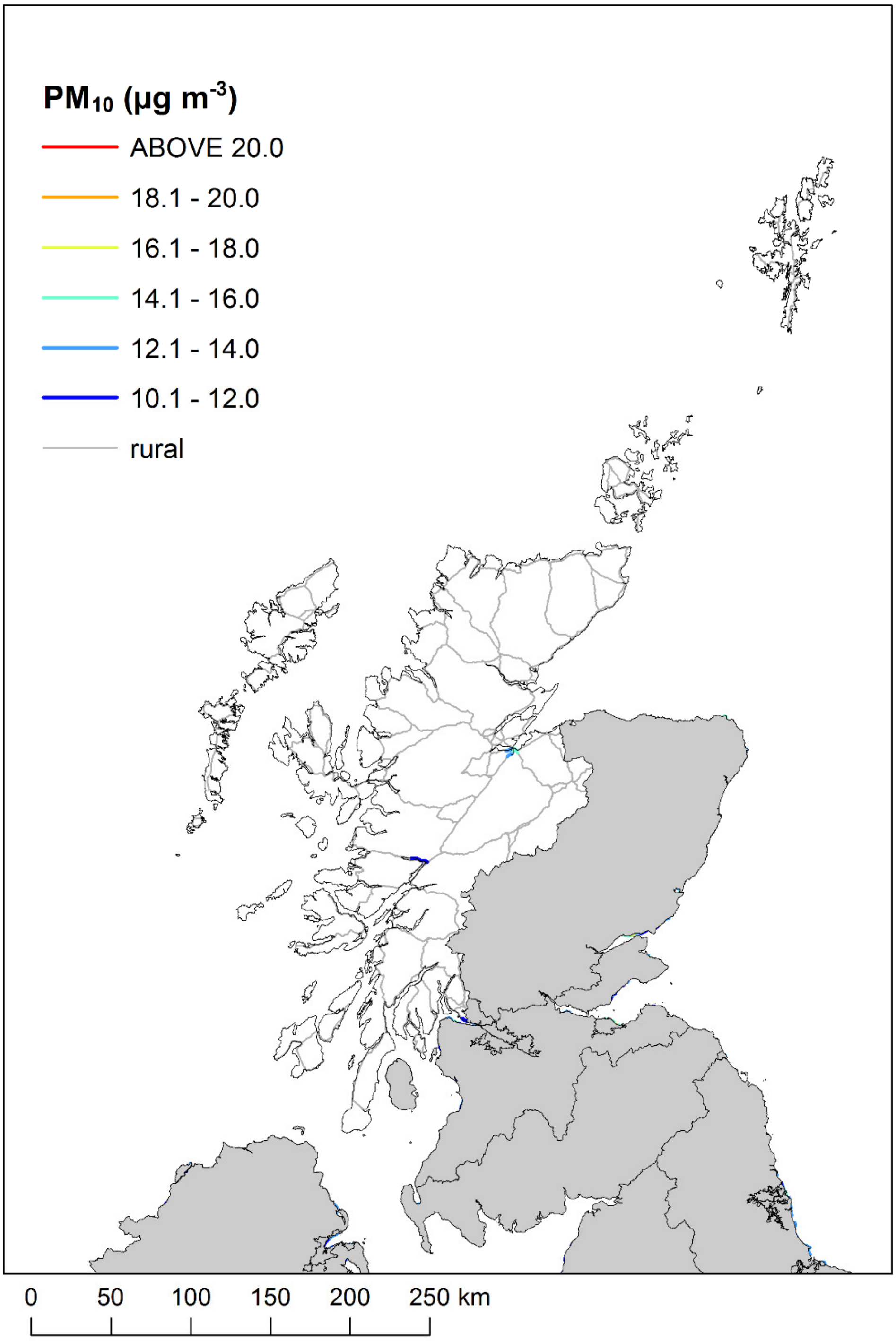
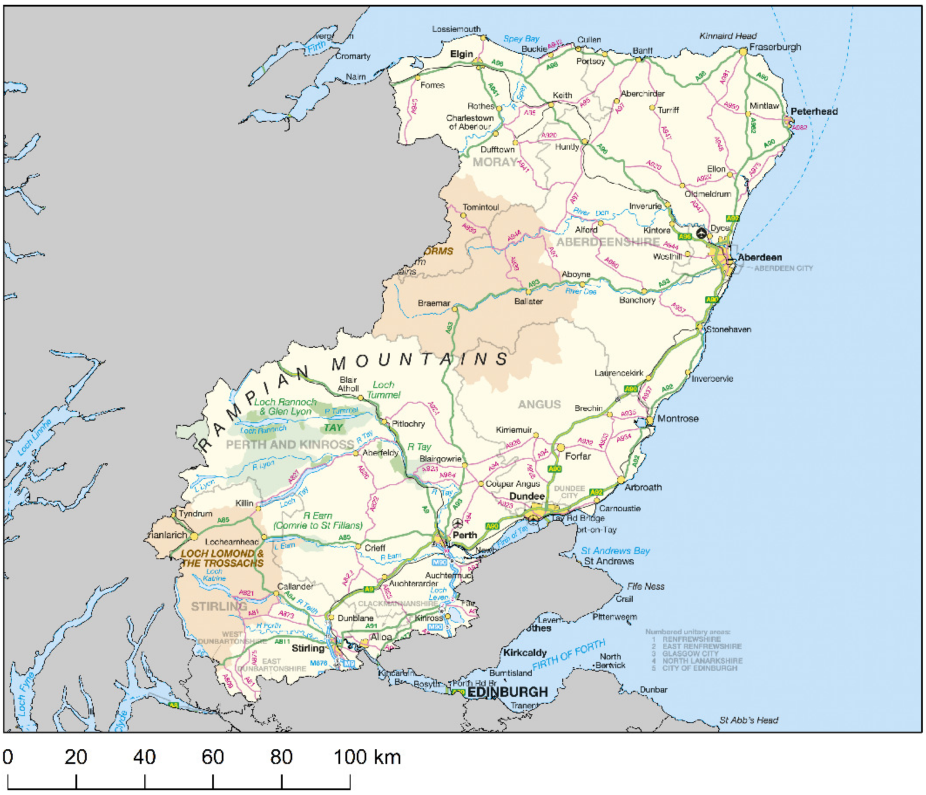

PM10 (µg m-3)
ABOVE 20.0
18.1 - 20.0
16.1 - 18.0
14.1 - 16.0
12.1 - 14.0
10.1 - 12.0
rural
0
50
100
150
200
250 km

Figure 5.14 2014 detailed roadside PM_{10}, showing the road-link concentrations in North East Scotland, µg m^{-3} (Scotland-specific model).



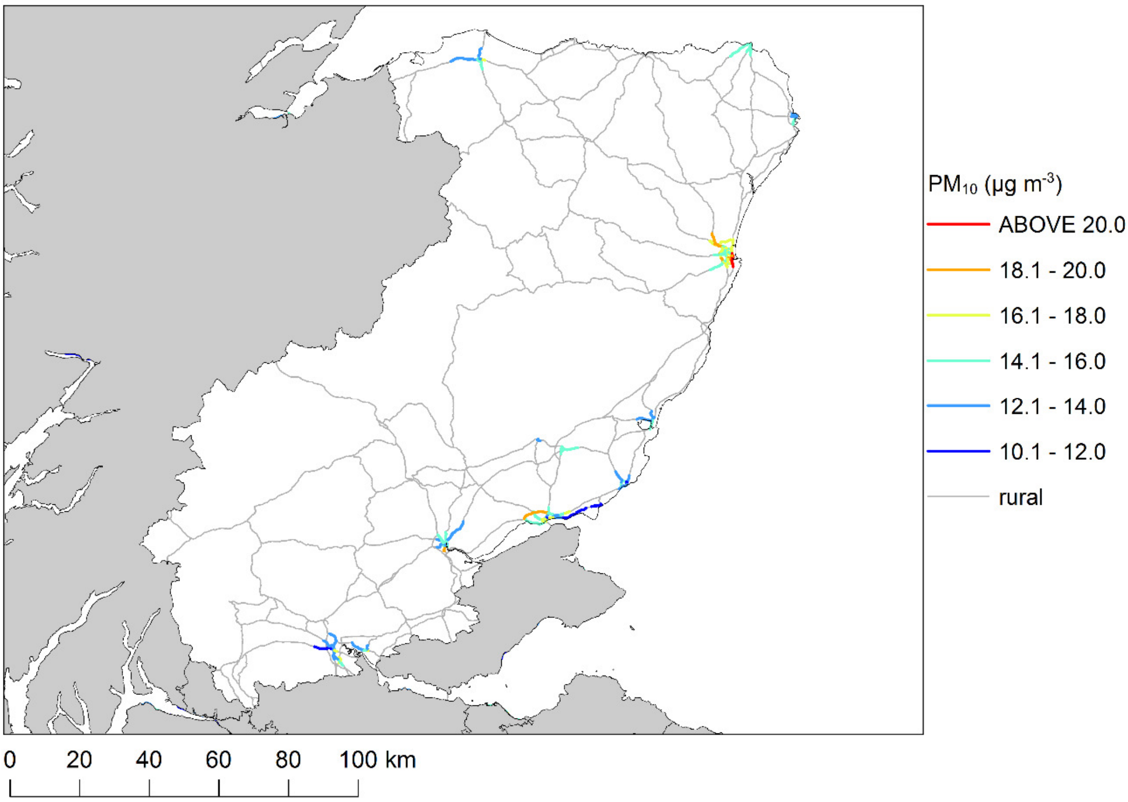


Figure 5.15 2014 detailed roadside PM_{10}, showing the road-link concentrations in Central Scotland, μg m^{-3} (Scotland-specific model).

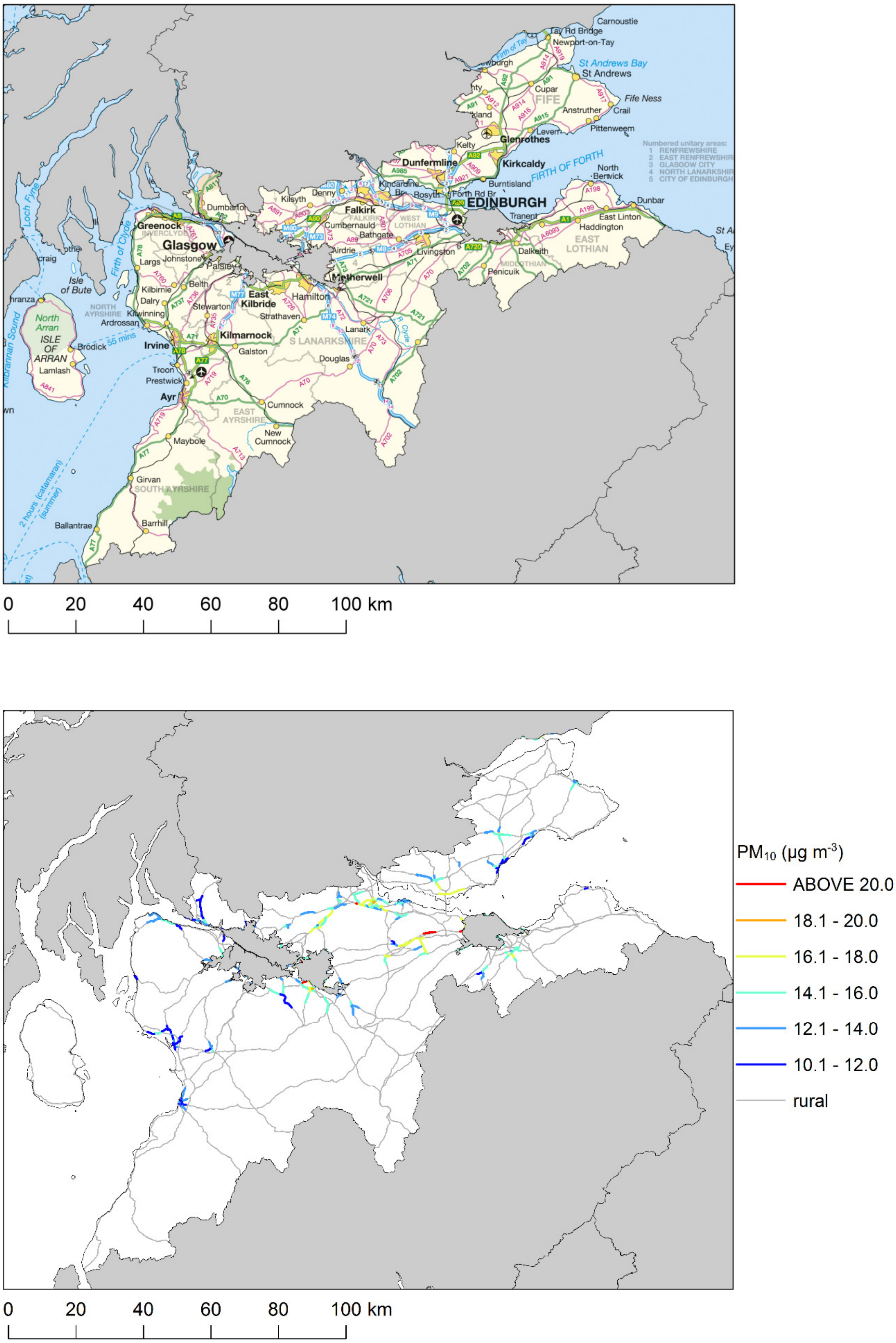


Figure 5.16 2014 detailed roadside PM_{10}, showing the road-link concentrations in the Scottish Borders, µg m^{-3} (Scotland-specific model).

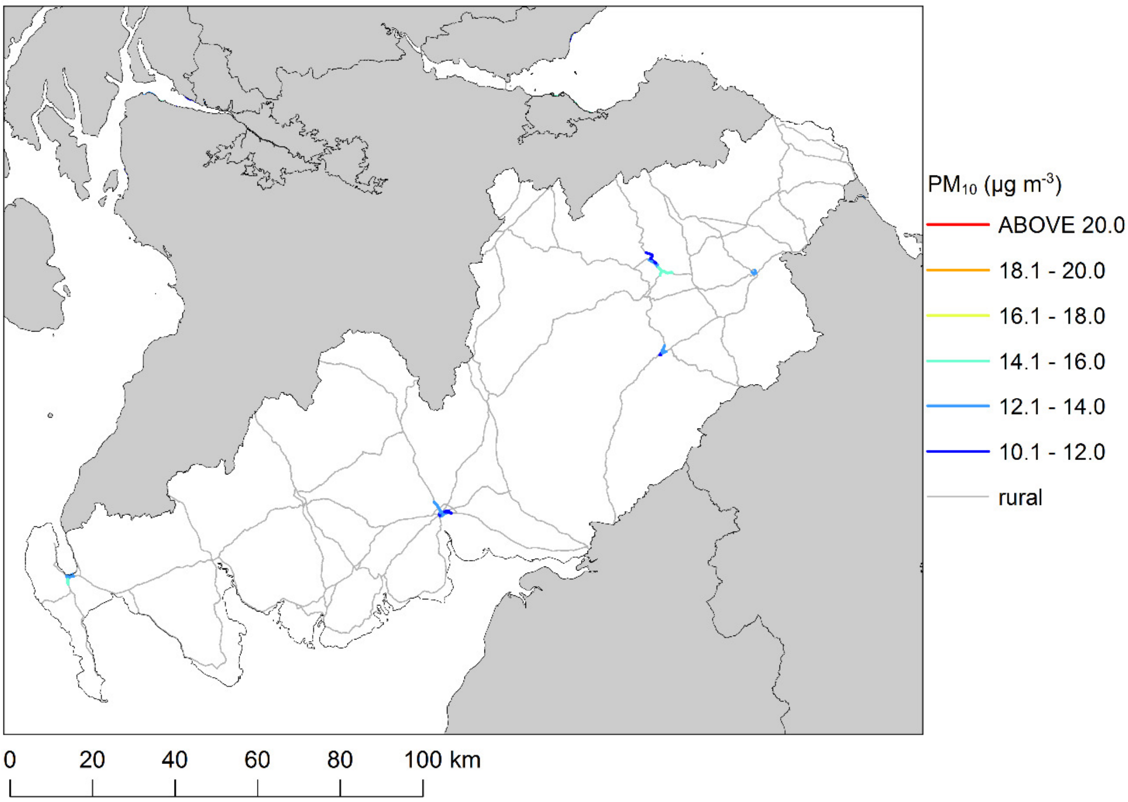
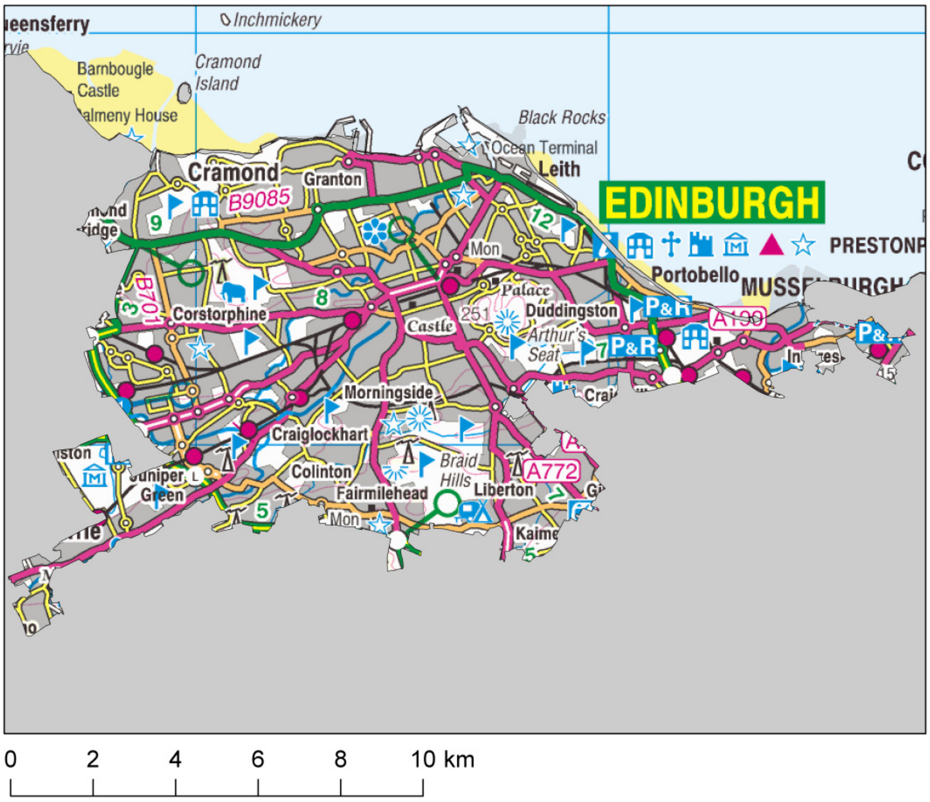


Figure 5.17 2014 detailed roadside PM_{10}, showing the road-link concentrations in the Edinburgh Urban Area, μg m^{-3} (Scotland-specific model).



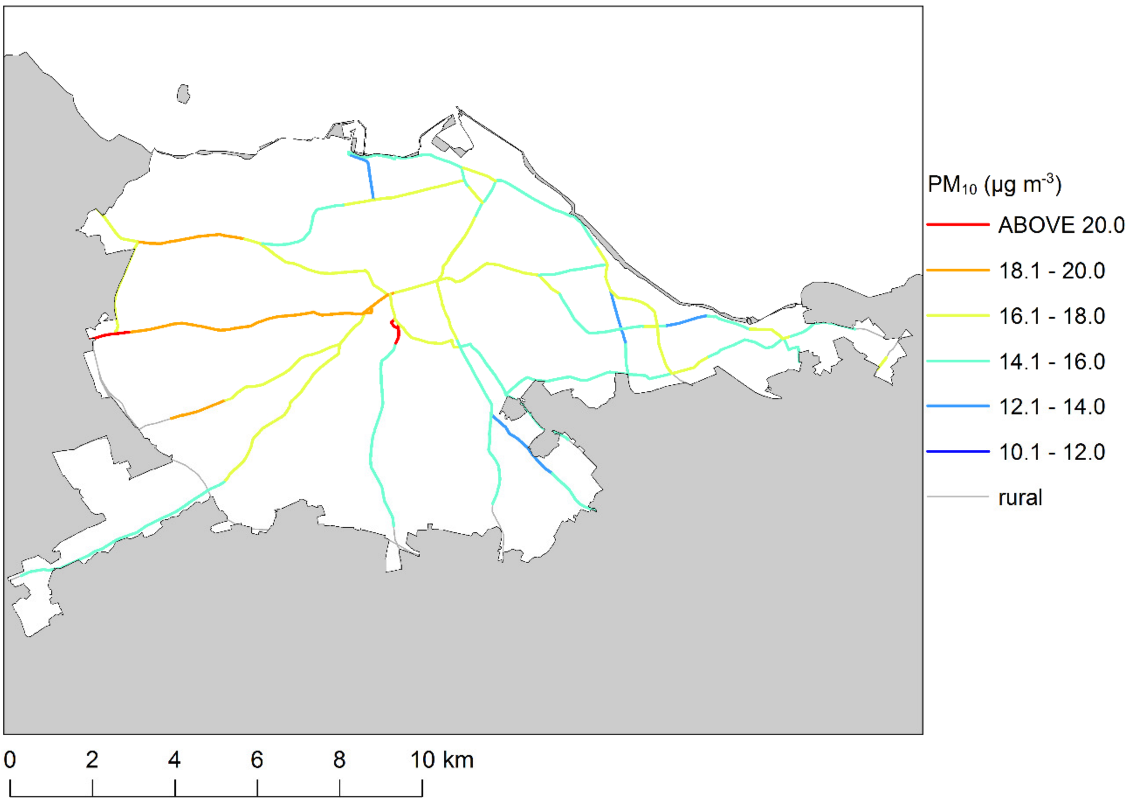
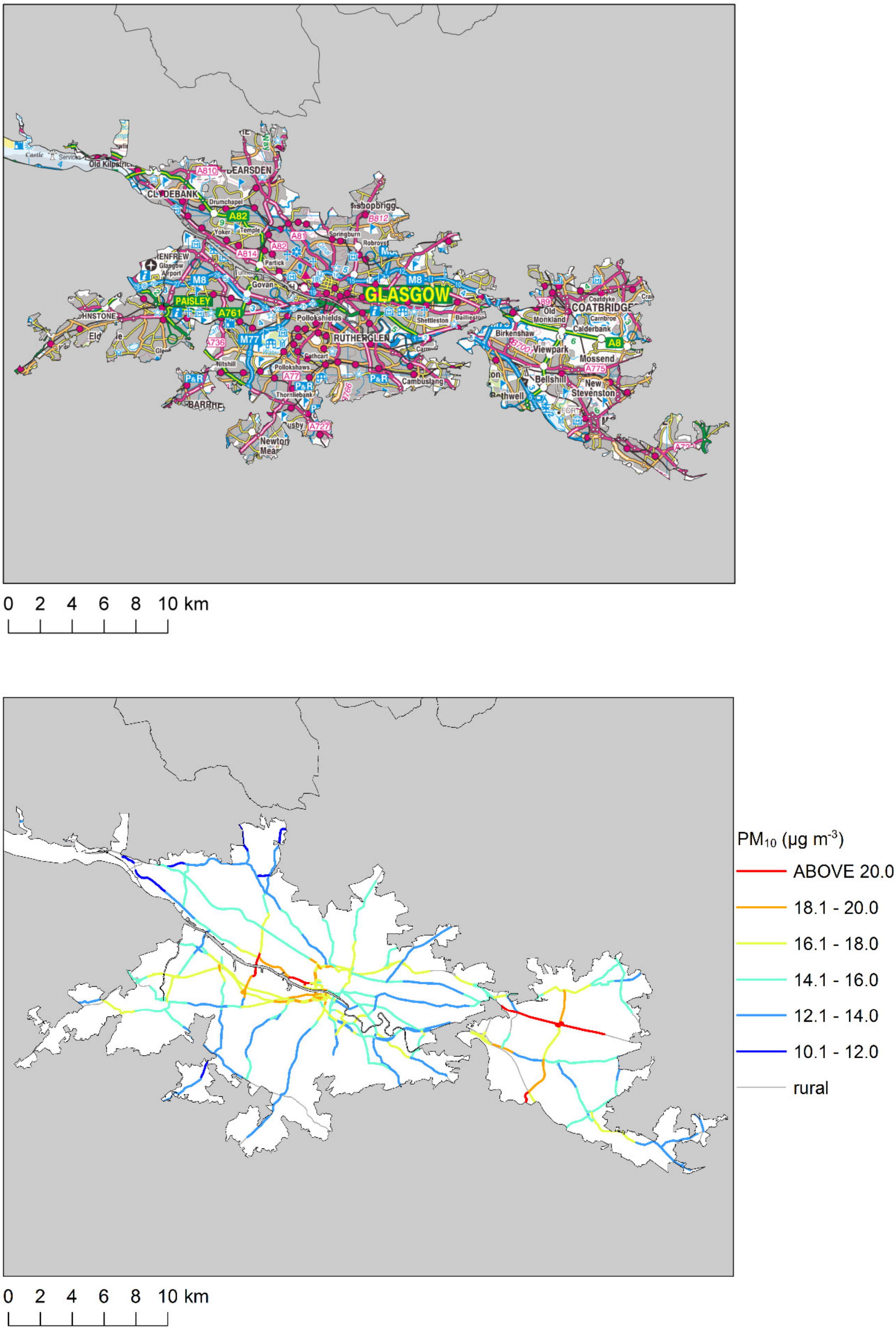


Figure 5.18 2014 detailed roadside PM_{10}, showing the road-link concentrations in the Glasgow Urban Area, µg m^{-3} (Scotland-specific model).



6 Conclusions and recommendations

There are now sufficient monitoring sites in the SAQD for mapping to be undertaken for NO_X, NO_2 and PM_{10} for Scotland. The UK PCM methodology has been applied to provide Scotland-specific air pollutant maps of annual mean background and roadside NO_X, NO_2 and PM_{10} concentrations for the Scottish Government for 2014 using measurements from Scottish air quality monitoring sites and Scottish meteorology.

Scottish air pollutant emissions were based on the UK's 2013 National Atmospheric Emissions Inventory (NAEI) and updated National energy usage statistics (EEP2014). The 2014 (base-year) Scotland-specific model included the most recently revised (as of December 2015) NO_X (diesel cars and LGV) and PM_{10} emission factors from COPERT4 v11.0, combined with ANPR/DVLA-scaled data, to represent the most up-to-date vehicle fleet information in Scotland. A recent study by Jenkin (2012) reported that short term variability in NO_X concentrations is a major cause of the scatter in the relationship between $[NO_2]/[OX]$ and $[NO_X]$. The 2014 Scotland-specific NO_X/NO_2 model uses this updated relationship of the oxidant partitioning modelling. In summary, the results of the 2014 Scotland-specific modelling exercise show:

- The modelled annual mean background NO_2 concentrations from the Scotland-specific model provided reasonable agreement with the annual mean measured background NO_2 concentrations. A similar degree of variability was seen when the modelled annual mean roadside NO_2 concentrations from the Scotland-specific model were compared to the annual mean measured roadside NO_2 concentrations.
- Three exceedances of the Scottish NO_2 air quality objective were modelled by the 2014 Scotland-specific background NO_2 model at background locations.
- The modelled annual mean background PM_{10} concentrations from the Scotland-specific model provided good agreement with the annual mean measured background concentrations. Similar agreement was seen with the modelled annual mean roadside PM_{10} concentrations provided by the Scotland-specific model.
- Exceedances of the Scottish PM_{10} air quality objective of 18 $\mu g\ m^{-3}$ were modelled at seventy one background locations. Twenty nine of which were located in Central Scotland zone, forty one in North East Scotland zone and one in Scottish borders zone (Scotland is split into 6 zones for the purposes of air pollution monitoring, in accordance with EC Directives (96/62/EC)). No background exceedances of the Scottish annual mean PM_{10} air quality objective were modelled in Edinburgh Urban Area, Glasgow Urban Area or the Scottish Borders. The extent of modelled exceedances of the Scottish PM_{10} air quality objective was up to 5 $\mu g\ m^{-3}$.
- Exceedances of both the Scottish annual mean NO_2 and PM_{10} air quality objectives were modelled at roadside locations. The majority of exceedances of the Scottish NO_2 and PM_{10} air quality objectives were modelled to occur in urban areas, at roadside locations with high volumes of traffic, such as Edinburgh and Glasgow. No exceedances of the Scottish annual mean NO_2 or PM_{10} air quality objective were modelled for roads in the Highlands or the Scottish Borders zones. Overall, there were a greater number modelled roadside exceedances of the annual mean Scottish air quality PM_{10} objective than exceedances of the NO_2 air quality objective.

Due to the Scottish-specific nature of the data, it is more appropriate for anyone undertaking air quality studies in Scotland to use the Scottish background maps rather than data from the UK maps. The Scottish Government therefore expects Scottish local authorities to use the Scottish-specific modelling for LAQM purposes. Other organisations undertaking air quality studies in Scotland are directed to the Scottish-specific background modelled data.

From an air quality perspective it would be difficult to state that the use of Scotland-specific model results would lead to a change in the number of AQMAs declared for NO_2 and PM_{10}. The maps of modelled pollutant concentrations presented here are designed as an indicative, rather than absolute, measure of the annual mean NO_2 and PM_{10} concentration at background and roadside locations. It should be noted that the modelling used to produce the maps is based on a range of inputs, some of which are quite variable: Scottish meteorology, Scottish air pollutant concentrations determined from air quality monitoring measurements and scaled emissions projections. The scaling factors applied to the pollutant emissions presented here were based on current understanding of the future variations in emissions and pollutant concentrations, which may result in revisions in subsequent years.

Appendices

Appendix 1: Calculation of the Scottish Annual Mean Equivalent Value of the Scottish Daily Mean Air Quality Objective for PM_{10}

Appendix 1

Calculation of the Scottish Annual Mean Equivalent Value of the Scottish Daily Mean Air Quality Objective for PM_{10}

The models used to calculate air quality concentrations for this study, and for national assessments in the UK, produce an annual mean metric as a standard output. Therefore a mechanism is required to establish an *annual mean PM_{10} concentration* for comparison with the *daily mean PM_{10} objective*. The percentile concentrations correspond to the number of permissible daily exceedances specified by each objective. The Scottish and UK national air quality objectives for PM_{10} are summarised in Table A.1.

Previously, an equivalent annual mean PM_{10} concentration of 22 µg m^{-3} was calculated for Scotland based on UK AURN PM_{10} air quality monitoring data measured between 1992 and 2007 by plotting the measured annual mean concentration against the measured 98th percentile (7 exceedances per year = 7/365 = 2%) of the daily mean concentration. This relationship was based on UK AURN PM_{10} air quality monitoring data as before 2008 there were insufficient Scottish PM_{10} monitoring sites to derive a relationship.

This equivalent daily mean PM_{10} concentration of 22 µg m^{-3} was used to relate modelled annual mean concentrations to the daily PM_{10} objective in Scottish mapping prior to 2012 mapping. During the 2012 Scottish mapping study a new approach was recommended.[16] This approach used ***Scottish only*** AURN PM_{10} air quality monitoring measurements from 1993 to 2012 to calculate the relationship between the measured annual mean concentration and the 98th percentile of the daily mean concentration.

Lingard (2014)[16] showed that there is a small degree of annual variation in the value of the equivalent daily mean PM_{10} concentration for each calendar year from 2007 to 2012, but overall the values are broadly consistent. This is shown in Table A.2 which summarises the equivalent daily mean PM_{10} concentrations for the UK and Scotland from 2007 to 2014 based on air quality monitoring data. The table also includes the equivalent daily mean air quality PM_{10} objective for the UK (98th percentile,

[16] Lingard, JNN, Scottish Air Quality. Pollutant modelling for 2012: annual mean NO_x,NO_2 and PM_{10}, (2014) to be published.

Figure A.1) and Scotland (90th percentile, Figure A.2) based on UK AURN PM_{10} air quality monitoring data from 1992-2014 and the equivalent annual mean air quality objective for PM_{10} for Scotland based on Scottish AURN PM_{10} air quality monitoring data exclusively (

Figure A.3).

Table A.2 shows that since 2007, the UK annual mean PM_{10} equivalent value has fallen from 22 µg m^{-3} to below 21 µg m^{-3}. The annual mean PM_{10} equivalent values based on measurements from Scottish only AURN PM_{10} air quality monitoring measurements are consistently lower than the equivalent values based the full set of UK AURN measurements which is attributed to the pristine nature of the Scottish environment. The trends seen for 2007 to 2013 are continued in 2014. Therefore an annual mean PM_{10} equivalent value of 20.6 µg m^{-3} based on Scottish only AURN measurements from 1993 to 2014 was used for the 2014 Scottish mapping work.

Table A.1 Summary of the daily mean air quality objective for PM_{10} and equivalent percentiles for Scotland and the UK.

Model area	Objective value (µg m^{-3})	Metric	Permissible exceedances	Percentile equivalent
Scotland	50	Daily mean	7	98^{th}
UK	50	Daily mean	35	90^{th}

Table A.2 Summary of the annual mean equivalent air quality objective for PM_{10} for the UK and Scotland based on air quality monitoring data 1992-2014.

	Model area		
	Scotland (Figure A.1)	**UK** (Figure A.2)	**Scotland** (Figure A.3)
Source of air quality monitoring	All UK AURN air quality monitoring sites	All UK AURN air quality monitoring sites	Scottish **only** AURN monitoring sites
Data range	1993-2014	1993-2014	1993-2014
Objective value (µg m^{-3})	50	50	50
Metric	Daily mean	Daily mean	Daily mean
Permissible exceedances	7	35	7
Percentile equivalent	98th	90th	98th
2007 equivalent daily mean value (µg m^{-3})	22.0 (0.72)†	31.5 (0.90)†	N/A
2008 equivalent daily mean value (µg m^{-3})	21.0 (0.72)†	31.9 (0.90)†	20.0 (0.75)†
2009 equivalent daily mean value (µg m^{-3})	21.0 (0.69)†	32.0 (0.85)†	20.1 (0.78)†
2010 equivalent daily mean value (µg m^{-3})	21.0 (0.70)†	32.0 (0.86)†	20.1 (0.80)†
2011 equivalent daily mean value (µg m^{-3})	21.1 (0.71)†	31.7 (0.90)†	20.6 (0.85)†
2012 equivalent daily mean value (µg m^{-3})	20.8 (0.71)†	31.7 (0.91)†	20.5 (0.86)†
2013 equivalent daily mean value (µg m^{-3})	20.8 (0.71)†	31.7 (0.91)†	20.6 (0.86)†
2014 equivalent daily mean value (µg m^{-3})	20.8 (0.71)†	31.7 (0.91)†	20.6 (0.87)

† R^2 values given in parentheses

Figure A.1 Relationship between the UK annual mean PM_{10} concentration and the 98th percentile of the UK daily mean PM_{10} concentration (1992-2014).

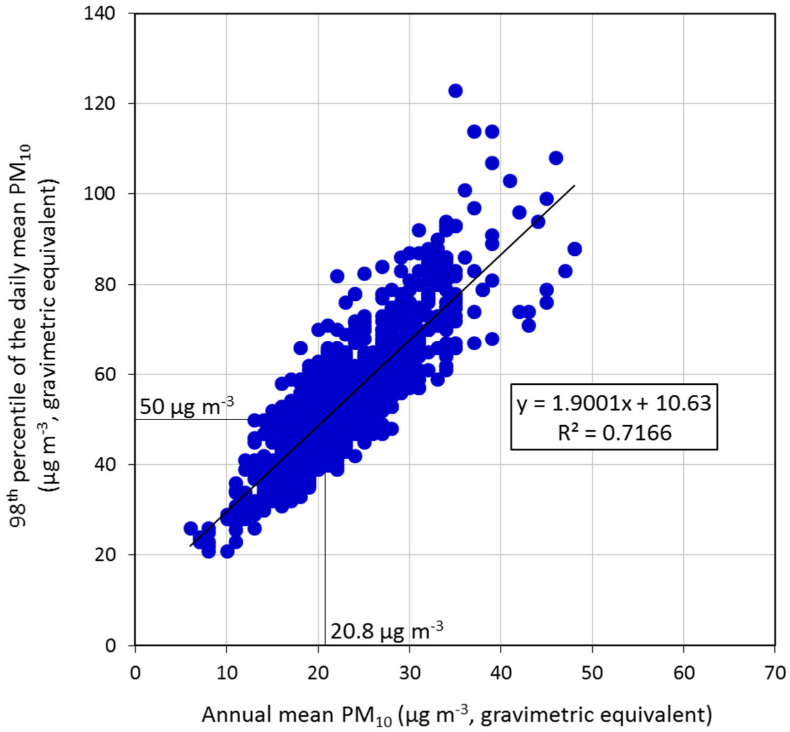


Figure A.2 Relationship between the UK annual mean PM_{10} concentration and the 90th percentile of the UK daily mean PM_{10} concentration (1992-2014).

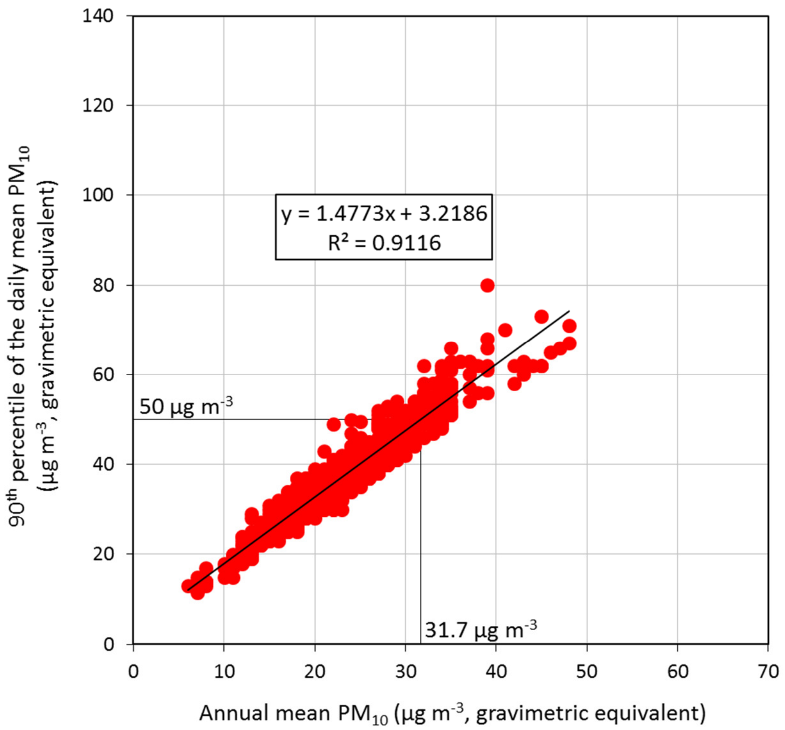
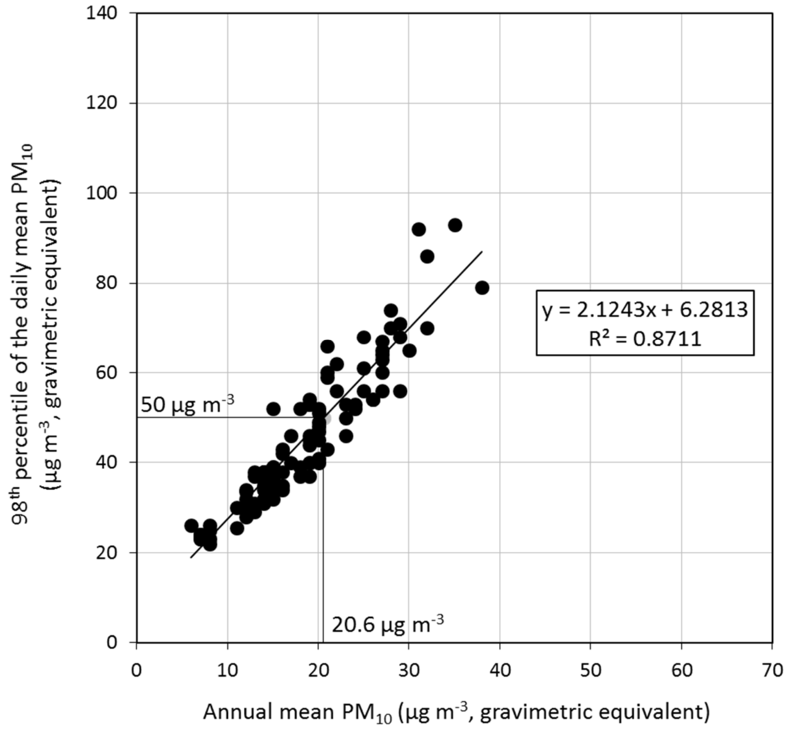


Figure A.3 Relationship between the Scottish annual mean PM_{10} concentration and the 98th percentile of the Scottish daily mean PM_{10} concentration (1992-2014).



Ricardo
Energy & Environment

The Gemini Building
Fermi Avenue
Harwell
Didcot
Oxfordshire
OX11 0QR
United Kingdom

t: +44 (0)1235 753000
e: enquiry@ricardo.com

ee.ricardo.com