Scottish Air Quality Maps

Pollutant modelling for 2009 and projected concentrations for 2010, 2015 and 2020: annual mean NO_X, NO_2, and PM_{10}.

Report for The Scottish Government

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Executive summary

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

The maps and projections discussed in this report utilise the air pollutant concentration mapping methodology developed for the UK Pollution Climate Mapping (PCM) contract. This provides air pollution maps for the Scottish Government, Defra, and the other Devolved Administrations (DAs) in order to supplement data from the national monitoring networks, and to satisfy the EU Air Quality Directive reporting requirements. The models are calibrated using data from the national networks (chiefly the Automatic Urban and Rural Network, AURN) and are verified using independent monitoring data 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 has therefore been 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 2009 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}.

2009 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 2009 Scottish PM_{10} monitoring data (FDMS, Partisol and VCM corrected TEOM data). 2009 Scottish PM_{10} measurements from Beta Attenuation Monitors (BAMs) were only used for model verification. The pollutant monitoring data was 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 8-16 air quality monitoring sites were used to calibrate the model, depending on pollutant, whilst a smaller number, 3-5 sites, were used to verify the model output.

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}. Projected annual mean concentrations of NO_X, NO_2, and PM_{10}, for 2010, 2015 and 2020, from a base year of 2009, are presented for the purpose of forward projection assessment. The projected background annual mean concentrations were produced by applying the UK methodology using Scottish monitoring and meteorological data.

No exceedences of the Scottish annual mean NO_2 objective of 40 µg m^{-3} were modelled at background locations. Two exceedences of the Scottish annual mean objective for PM_{10} of

18 µg m^{-3} were modelled at two background locations. The 2009 Scotland-specific model identified 250 road links (368 km of road) which exceeded the Scottish NO_2 annual mean air quality objective. For PM_{10}, the Scotland-specific model identified 133 road links (179 km of road) along which the Scottish annual mean PM_{10} air quality objective of 18 µg m^{-3} was exceeded.

The projected background maps of the annual mean NO_2 concentrations for 2010, 2015 and 2020 based on the 2009 Scotland-specific model show a progressive decrease in the background annual mean NO_2 concentration due to the predicted reduction in primary NO_2 and oxidant emissions, which contribute to the formation of NO_2. Likewise, projected background maps of the Scottish annual mean gravimetric PM_{10} concentrations for 2010, 2015 and 2020 based on the 2009 Scotland-specific model maps show a progressive decrease in the background annual mean gravimetric PM_{10} concentration between 2009 and 2020 for the majority of Scotland. This reduction is due to the projected reduction in primary PM_{10} emissions, and a subsequent reduction in secondary PM_{10}, due to the reduction in precursor emissions, over the next 12 years based on current emissions estimates.

Recent analyses[2] conducted for the Scottish Government, Defra and the other DAs of historical air quality monitoring data from throughout the UK 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 precise reason for this disparity is not fully understood, and is currently under investigation. It is thought that the discrepancy may be related to air pollutant emissions calculated on the basis of Euro engine standards and actual on-road emissions under real-world driving conditions, particularly for Diesel road vehicles (LDV and HDV). The accuracy of the forward projection maps presented here is closely dependent on the future emission projections used to prepare the background pollutant maps. Future emissions projections were based on current, published "year-adjustment" factors for NO_X and NO_2 concentrations for all years up until 2020.

The disparity in the historical data highlights the uncertainty of future year projections of both NO_X and NO_2, but at this stage there is no robust evidence upon which to base any revised future year projections. Further advice will be provided once the additional research being undertaken by the Scottish Government, Defra and the other DAs is completed. New "year-adjustment" factors will be incorporated in future updates of the National Atmospheric Emissions Inventory (NAEI) and consequently will be reflected in future annual updates of the forward projected maps presented to the Scottish Government.

In summary, the results of the 2009 Scotland-specific modelling exercise show:

- The modelled annual mean background NO_2 concentrations from the Scotland-specific model provided good agreement with the annual mean measured background NO_2 concentrations. Less agreement 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.
- 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.
- No exceedences of the Scottish air quality objectives for NO_2 at background locations were modelled by the Scotland-specific background NO_2 model.
- Two exceedences of the Scottish air quality objectives for PM_{10} at background locations were modelled by the Scotland-specific background PM_{10} model. The two exceedences were modelled to occur in two adjacent grid squares in Central Scotland. The extent of the exceedence modelled in these two grid squares was of the order of 1 µg m^{-3}.

- Exceedences of both the Scottish annual mean NO_2 and PM_{10} air quality objectives were modelled at roadside locations. The majority of exceedences were modelled to occur in urban areas, at roadside locations with high traffic volumes, such as Edinburgh and Glasgow. The numbers of roadside exceedences of the Scottish NO_2 air quality objective were almost twice the number modelled for PM_{10}.
- Future projection maps show a steady decrease in the concentrations of background NO_2 and PM_{10}. However, as noted above, the accuracy of the forward projection maps is closely dependent on the future emission projections used to scale the NAEI emissions.

The Scottish Government has put significant effort into increasing the number of sites in the SAQD in recent years. These efforts have contributed to the production of robust pollutant maps for NO_X, NO_2, and PM_{10} for Scotland for 2009 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 Scotland-specific data rather than data from the UK maps. The Scottish Government therefore expects Scottish local authorities to use the Scottish-specific data for LAQM purposes and also that other organisations undertaking air quality studies in Scotland are directed to the Scottish-specific background data.

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Appendices

1 Introduction

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

The maps and projections discussed in this report utilise the air pollutant concentration mapping methodology developed for the UK Pollution Climate Mapping (PCM) contract. This provides air pollution maps for the Scottish Government, Defra, and the other Devolved Administrations[1], in order to supplement data from the national monitoring networks, and to satisfy the EU Air Quality Directive reporting requirements. The models are calibrated using data from the national networks (chiefly the Automatic Urban and Rural Network, AURN) and are verified using independent monitoring data 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 has been 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 2009 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 pollutant data used in the mapping work presented here, for 2009, uses 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 2009. 2009 Scottish PM_{10} measurements from Beta Attenuation Monitors (BAMs) were only used for model verification. The model results have been compared with the measured pollutant concentrations in Scotland. An assessment has been made of area, population, number of roads and road

[1] Grice, S.E., Lingard, J.J.N., Stedman, J.R., Cooke, S.L., Yap F.W., Kent, A.J., Bush, A.J., Vincent, K.V., and Abbott, J. (2010). UK air quality modelling for annual reporting 2008 on ambient air quality assessment under Council Directives 96/62/EC, 1999/30/EC and 2000/69/EC. AEAT/ENV/R/2859 Issue 1. http://uk-air.defra.gov.uk/reports/cat09/1101250943_dd122008mapsrep_v4.pdf

length exposed to specific concentrations above the Objective values adopted by the Scottish Government for NO_2 and PM_{10}.

Projected annual mean concentrations of NO_X, NO_2, and PM_{10} for 2010, 2015 and 2020, from a base year of 2009, are presented for the purpose of forward projection assessment. The projected background annual mean concentrations were produced using the UK methodology, but as with the modelled Scottish annual mean concentrations for 2009, these were prepared using Scotland-specific data. The same methods were used to project the various contributions to ambient pollutant concentrations forward to 2020 as were used in the UK models. Any differences in the source apportionment between the Scottish and UK mapping for 2009 will consequently be carried forward into the projections.

Recent analyses[2] conducted for the Scottish Government, Defra and the other DAs of historical air quality monitoring data from throughout the UK 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 accuracy of the forward projection maps presented here is closely dependent on the future emission projections used to prepare the background pollutant maps. Future emissions projections were based on current, published "year-adjustment" factors for NO_X and NO_2 concentrations for all years up until 2020. Further advice will be provided once the additional research being undertaken by the Scottish Government, Defra and the other DAs is completed. New "year-adjustment" factors will be incorporated in future updates of the NAEI and consequently will be reflected in future annual updates of the forward projected maps presented to the Scottish Government.

[2] 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

A brief overview of the modelling methodology is presented here. A summary of model revisions for 2009 and the specific aspects of the model that have been tailored to provide a Scotland-specific output are detailed below. Detailed description of the UK PCM modelling methodology can be found in the annual report to the Scottish Government, Defra and the other DAs for 2008[1] and can be downloaded from the UK AIR website (http://uk-air.defra.gov.uk/). The updated version of the report detailing the modelling undertaken for 2009 is currently under review and will be published on the website following approval by the Scottish Government, Defra and the other DAs.

The modelled maps of ambient concentrations are calculated from National Atmospheric Emissions Inventory (NAEI) data using a dispersion modelling approach, which is calibrated using monitored data from the national monitoring networks. These modelled maps are typically verified against independent monitoring data held by AEA (from ad-hoc monitoring campaigns, 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 data 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 PM_{10} and NO_2. 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 have put significant effort into increasing the number of sites in the SAQD and 2009 is the first year both calibration and verification of the Scotland specific-model has been attempted. The additional sites funded by the Scottish Government and placed on the SAQD are AURN equivalent. Table 2.1 and Table 2.2 list 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 calibrate or verify the model output. Typically between 10 and 12 sites are required to calibrate the pollutant model, with residual sites being used to verify the model output. In the case of the roadside NO_X, NO_2 and PM_{10} monitoring sites there were sufficient sites to allow limited verification of the model output. However, in the case of PM_{10} background model (Table 2.1) all the available PM_{10} air quality monitoring sites were used to calibrate the model therefore no sites could be used to verify the model output.

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, 2009.

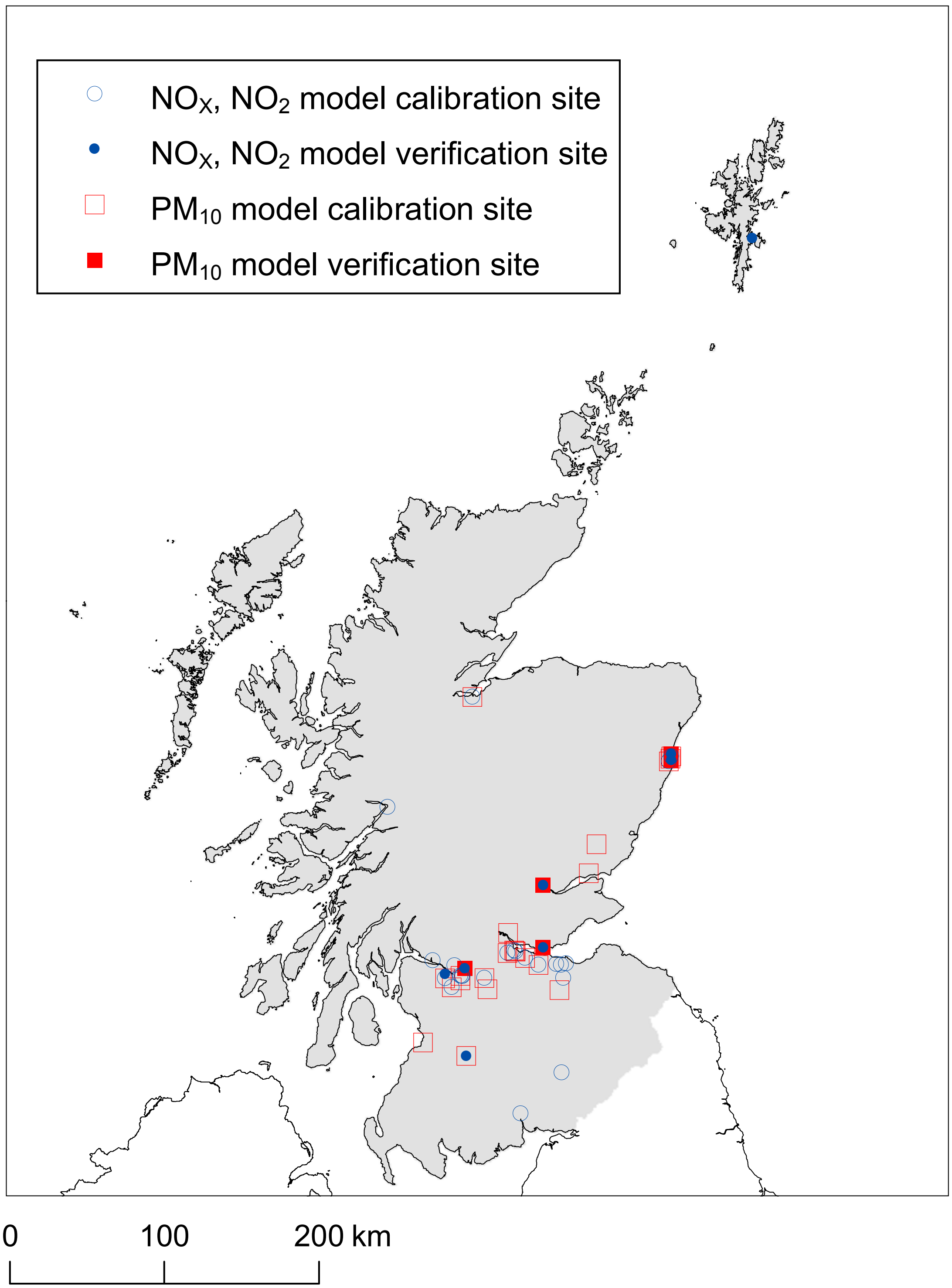


Table 2.1 Scottish background air quality monitoring sites used to calibrate and verify the output of the 2009 Scottish pollutant model.

Pollutant	Calibration site name	Verification site name	Total[+]
NO_X, NO_2	Aberdeen Bush Estate Edinburgh St Leonards Eskdalemuir Falkirk Grangemouth MC Fort William Glasgow Anderston Glasgow Centre Glasgow City Chambers Glasgow Waulkmillglen Reservoir Grangemouth N Lanarkshire Coatbridge Whifflet	East Ayrshire New Cumnock Lerwick Staney Hill Paisley Glasgow Airport	15 (19)
PM_{10}[‡]	Aberdeen (FDMS) Dundee Mains Loan (VCM corrected TEOM) Falkirk Grangemouth MC (VCM corrected TEOM) Glasgow Anderston (VCM corrected TEOM) Glasgow Waulkmillglen Reservoir (VCM corrected TEOM) Grangemouth (FDMS) Grangemouth Moray Scot Gov (VCM corrected TEOM) N Lanarkshire Coatbridge Whifflet (VCM corrected TEOM)	None	8 (15)

[+] Total number of Scottish background pollutant monitoring sites given in parentheses.

[‡] PM_{10} sampler type given in parentheses.

Table 2.2 Scottish roadside air quality monitoring sites used to calibrate and verify the output of the 2009 Scottish pollutant model.

Pollutant	Calibration site name	Verification site name	Total+
NO_X, NO_2	Aberdeen Anderson Dr Dumfries East Dunbartonshire Bearsden Edinburgh Gorgie Road Edinburgh St Johns Road Falkirk Hope St Inverness Paisley Gordon Street West Dunbartonshire Glasgow Road West Lothian Broxburn West Lothian Linlithgow High Street	Aberdeen King Street Aberdeen Wellington Road East Dunbartonshire Bishopbriggs Fife Rosyth Perth Atholl Street	16 (49)
PM_{10}‡	Aberdeen Anderson Dr (VCM corrected TEOM) Aberdeen Union St (VCM corrected TEOM) Angus Forfar (FDMS) Falkirk Hope St (VCM corrected TEOM) Glasgow Nithsdale Road (FDMS) Inverness (Partisol) N Lanarkshire Motherwell (VCM corrected TEOM) Paisley Gordon Street (FDMS) South Ayrshire Ayr High St (FDMS) West Lothian Broxburn (FDMS) West Lothian Linlithgow High Street (FDMS)	Aberdeen Wellington Road (VCM corrected TEOM) East Dunbartonshire Bishopbriggs (Heated BAM) Fife Rosyth (FDMS) Perth Atholl Street (VCM corrected TEOM)	15 (49)

+ Total number of Scottish roadside 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 2009 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[3,4]. This model is discussed in more detail in the 2008 UK mapping report[1] and the references herein. 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

[3] 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.

[4] 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

emission scenarios to be addressed by varying regional oxidant levels and/or primary NO_2 emissions.

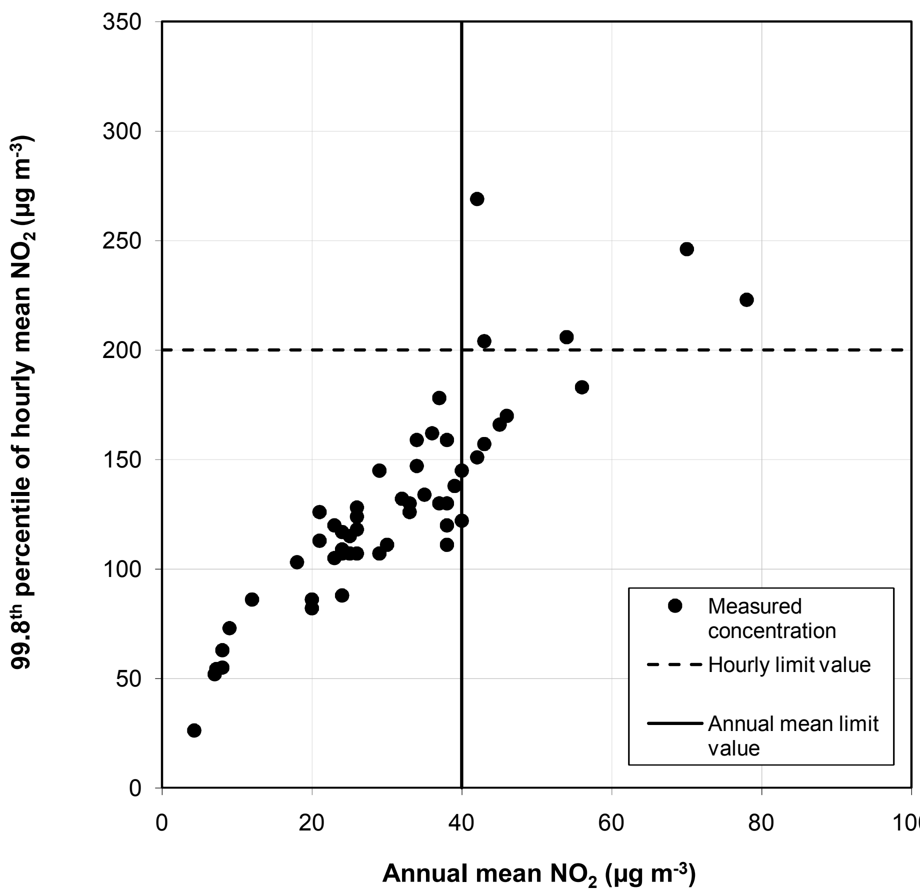
The modelling of the annual mean Scottish NO_X and NO_2 concentrations for 2009 were undertaken using Scotland-specific changes to the UK PCM model noted in Section 2.1. The regional oxidant component of the NO_X-NO_2 model remains unchanged for the Scottish modelling as this is not affected by the Scotland-specific changes to the UK PCM model noted in Section 2.1.

Scottish AQOs for ambient NO_2 concentrations are based on EU limit values set out in the Air Quality Directive[8]. These have been specified for the protection of human health and came into force on 01/01/2010. 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 exceedences each year.

For the hourly objective, it is appropriate to have an allowed number of **exceedences** 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 can affect concentrations).

Figure 2.2 Plot of annual mean against 99.8th percentile hourly NO_2 concentrations in 2009 for all Scottish air quality monitoring sites (%dc ≥75%).



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[5]. This is

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

illustrated in Figure 2.2 which shows the 2009 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 exceedences) hourly mean concentration for the same year. The plot shows a significantly higher number of sites exceeding the annual mean limit value of 40 µg m^{-3} than the 200 µg m^{-3} hourly limit value.

2.4 PM_{10} modelling

Annual mean concentrations of PM_{10} have been modelled for Scotland for 2009 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[6,7]) data were used to calibrate the model. Measurements from Beta Attenuation Monitors (BAMs) in Scotland were 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 (e.g., soot particles from biomass burning)
- sea salt aerosol, and
- iron and calcium-based dusts.

Scottish AQOs for ambient PM_{10} concentrations for 2010 are more stringent than the EU limit values set out in the Air Quality Directive[8]. In Scotland the PM_{10} objectives are:

- An hourly 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

Projected annual mean concentrations of NO_X, NO_2, and PM_{10} for 2010, 2015 and 2020, from a base year of 2009, are presented for the purpose of forward projection assessment following a scoping exercise using 2008 data undertaken by AEA, on behalf of The Scottish Government, involving four Scottish LAs[9].

The projected background annual mean concentrations for 2010, 2015 and 2020 were produced using Scottish specific data within the UK methodology and by appropriately scaling forward:

- 2008 UK NAEI emissions for NO_X, NO_2, and PM_{10}

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[6] 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

[7] 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

[8] 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.

[9] Stevenson, K., Kent, A. and Stedman, J. (2010). Investigation of the possible effect of the use of Scottish specific air quality maps in the LAQM process in four selected Local Authorities. AEA Report AEAT/ENV/R/2948. http://www.scottishairquality.co.uk/documents/reports2/258100203_LA_mapping_Report_Issue_1_FINAL.PDF

- 2008 UK road usage statistics, and vehicle, brake and tyre wear (BTW) emissions, split by region
- 2009 Scottish annual mean NO_X, NO_2, and PM_{10} concentrations,
- 2009 Scottish meteorology data.

This allows calculation of the background annual mean concentrations of NO_X, NO_2, and PM_{10} in 2010, 2015 and 2020. As noted earlier in this report the future emissions projections presented here were based on current, published “year-adjustment” factors for NO_X and NO_2 concentrations up until 2020. New “year-adjustment” factors will be incorporated in future updates of the NAEI as, and when, they become available, and consequently will be reflected in future annual updates of the forward projected maps presented to the Scottish Government.

3 Model calibration

The background model calibrations for NO_X and PM_{10} for the 2009 Scotland-specific model were undertaken using air quality monitoring measurements from a range of background (airport, rural, suburban, urban background, urban centre and urban industrial) sites. 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 %dc ≥75% were used to prepare the calibration plots and to verify the 2009 Scotland-specific model, as discussed in Section 5. The 2009 background and roadside calibration factors produced for the Scotland-specific model for NO_X were greater than the equivalent UK values. The 2009 Scotland-specific background PM_{10} calibration factor was less than the UK value, but the Scotland-specific roadside PM_{10} calibration factor was greater than the UK value. The area source and roadside calibration procedures for NO_X, NO_2 and PM_{10} are presented below.

3.1 NO_X contributions from area sources

The Scotland-specific NO_X modelled uncalibrated area source contribution was calculated by applying an ADMS 4.2 derived dispersion kernel to calculate the contribution to ambient concentrations at a central receptor location from area source emissions within a 33 km x 33 km square surrounding each monitoring site. 2009 hourly sequential meteorological observations from RAF Leuchars were used to construct the dispersion kernels.

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[10]. All ground level aircraft emissions have been included as given in the NAEI 2008. Appendix 5 of the 2008 UK mapping report[1] describes the methodology used to estimate the contribution of aircraft emission to ground-level NO_X emissions.

A new method for calculating shipping emissions was used in the NAEI 2008. In the area source model, a cap of 90 tonnes was applied to the total emissions from any given grid square to avoid calculating the equivalent of dock side concentrations in grid squares which are meant to be representative of the entire 1 km x 1 km square. Details of how this cap has been selected are given in Appendix 5 of the 2008 UK mapping report[1].

As part of the calibration process, concentration caps were applied to certain sectors. This is because the use of surrogate statistics for mapping area source emissions sometimes results in unrealistically large concentrations in some grid squares for a given sector. The concentration caps applied are given in Table 3.1.

The modelled area source contributions for each sector were 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 for 2009 as shown in Figure 4.1.

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

Table 3.1 Concentration caps applied to NO_X sector grids.

SNAP code	Description	Cap applied ($\mu g\ m^{-3}$)*
SNAP 1	Combustion in energy production & transformation	12
SNAP 3	Combustion in industry	24
SNAP 4	Production process	12
SNAP 8 (industrial offroad machinery only)	Other transport & mobile machinery	36
SNAP 8 (shipping only)	Other transport & mobile machinery	24

*Caps listed are for calibrated concentrations.

Figure 3.1 shows the calibration of the Scotland-specific NO_X area source model. The modelled concentrations from all point sources and corrected rural NO_X concentrations were subtracted from the 2009 measured annual mean NO_X concentrations measured at the Scottish background air quality monitoring sites. This corrected background concentration was compared with the modelled area source contribution to annual mean Scottish NO_X to calculate the calibration coefficients used in the area source modelling. Twelve of the nineteen background NO_X monitoring sites within the Scottish network had sufficient data capture (%dc ≥75%) for NO_X in 2009 to be used to calibrate the model (as shown in Table 2.1); three sites were used to verify the model output.

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

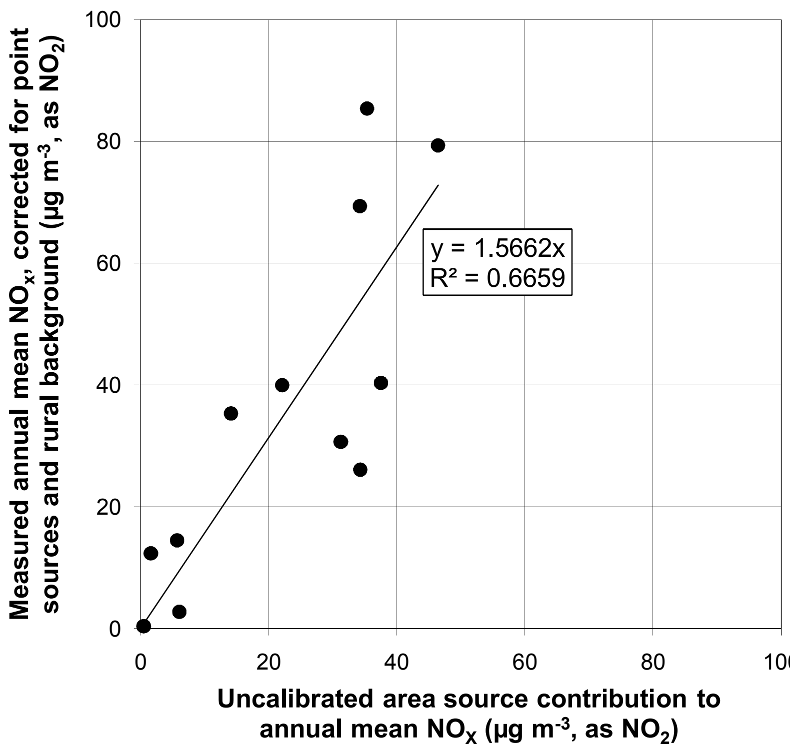


Figure 3.1 shows that the gradient the line of best fit forced through the origin was 1.5662. This value was used as the Scotland-specific NO_X area source calibration coefficient. The regression line has been forced through the origin to provide a reasonable model output without imposing an unrealistic 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 the country. The point source contributions and regional rural concentrations were then added resulting in a map of background annual mean NO_X concentrations for Scotland.

Table 3.2 Background model calibration coefficients applied in the Scotland-specific and UK models for NO_X for 2009 and 2008.

Model	Pollutant	Year	Calibration coefficient
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 3.2 provides a comparison of the 2009 Scotland-specific and UK background NO_X calibration coefficients. The 2008 Scotland-specific and UK background NO_X calibration coefficients are also presented for reference. From Table 3.2 it can be seen that the 2009 Scotland-specific background NO_X calibration coefficient was slightly higher, by about 25%, than the equivalent value used in the UK model in 2009. The map of the 2009 background annual mean NO_X concentrations for Scotland is shown in Figure 5.2.

3.2 Roadside NO_X concentrations

It is assumed that the annual mean NO_X concentrations at roadside locations is made-up of two parts: 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 2008[11] and these have been adjusted to provide estimates of emissions in 2009. Figure 3.2 shows the roadside increment of annual mean NO_X concentrations plotted against NO_X emission estimates adjusted for traffic flow for the individual road links alongside which these sites were located. The background NO_X component at these roadside monitoring sites is taken from the background map described in Section 3.1.

The calibration coefficient derived is then used to calculate the roadside increment on each road link by multiplying it by an adjusted road link emission (see Figure 3.2). 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.

The dispersion of emissions from vehicles travelling along an urban road is influenced by a number of factors. These factors generally contribute to make the dispersion of emissions less efficient on urban roads with lower flows. Factors include:

- traffic speed (urban roads with lower flows are more likely to have slower moving traffic and thus cause less initial dispersion due to mechanical and thermal turbulence)
- road width (dispersion will tend to be more efficient on wider roads, such as motorways than on smaller roads in town centres), and
- proximity of buildings to the kerbside (urban roads with lower flows are more likely to have with buildings close to the road, giving a more confined setting and reduced dispersion).

Urban roads are only considered here because the model does not cover rural roads.

Detailed information on the dispersion characteristics of each urban major road link within the NAEI is not available. An approach similar to that used within the DMRB Screening Model[12]

[11] Murrells, T.P., Passant, N.R., Thistlethwaite, G. and Wagner, A. (2009). UK Emissions of Air Pollutants 1970 to 2007. National Atmospheric Emissions Inventory, AEA Technology. Report AEAT/ENV/R/2856. http://www.naei.org.uk/reports.php

[12] Boulter, P.G., Hickman, A.J. and McCrae, I.S. (2003). The DMRB air quality screening method (version 1.02): calibration report. Transport Research Laboratory (TRL) (2003). Transport Research Laboratory (TRL) Limited. Report PA/SE/4029/03. http://www.trl.co.uk/files/general/DMRB1.pdf

was adopted and adjustment factors were applied to the estimated emissions. These adjustment factors depend on the total traffic flow on each link and are higher for the roads with the lowest flow and lower for roads with the highest flow. Thus the traffic flow is used as a surrogate for road width and other factors influencing dispersion. Motorways are generally wider than A-roads and the emissions have therefore been adjusted accordingly.

Eleven of the forty-nine roadside NO_X monitoring sites within the Scottish network had sufficient data capture for NO_X in 2009 and were located on urban major road links and adjacent to censusid points at which the traffic flow along the road was measured in 2008. The roadside NO_X measurements from these sites were used to calibrate the model. Scottish NO_X air quality monitoring data from five roadside sites was used to verify the model output.

Ten roadside NO_X monitoring sites were excluded on the basis of low annual data capture (annual %dc <75%). The twenty-three roadside sites that were not used to calibrate the Scotland-specific roadside model were excluded because they were not located:

- on an 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.

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

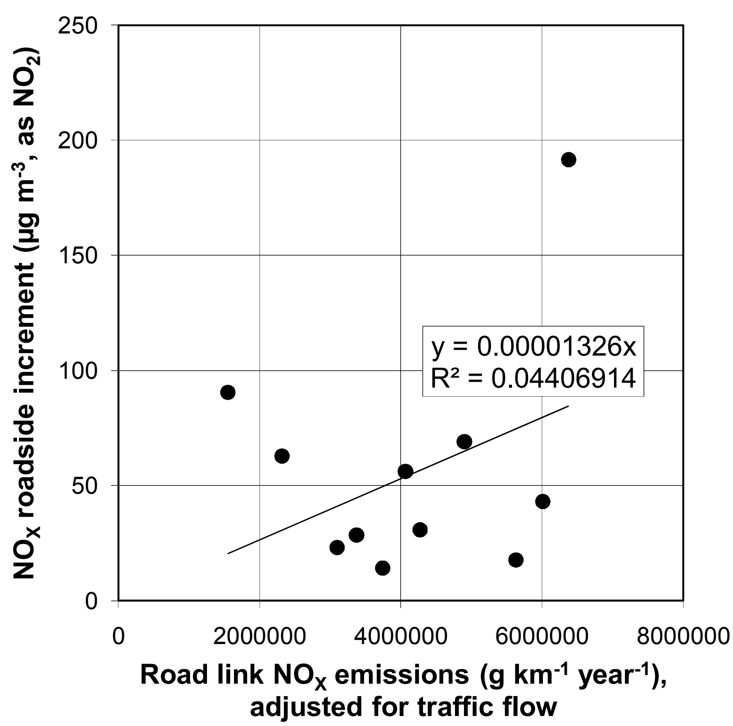


Table 3.3 Roadside model calibration coefficients applied in the Scotland-specific and UK models for NO_X for 2009 and 2008.

Model	Pollutant	Year	Calibration coefficient
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

Table 3.3 provides a comparison of the 2009 Scotland-specific and UK roadside NO_X calibration coefficients. The 2008 Scotland-specific and UK roadside NO_X calibration coefficients are also presented. From Table 3.3 it can be seen that the 2009 Scotland-specific roadside NO_X calibration coefficient was higher, by about 40%, than the value used in the 2009 UK model, and almost double the value used in the 2008 UK model. It is therefore anticipated that the 2009 Scotland-specific roadside NO_X model may predict a higher number of NO_X roadside exceedences for Scottish road links when compared to those predicted by the 2008 and 2009 UK models. It should be noted that this effect may be ameliorated by the meteorological terms (dispersion kernels) applied in the model.

3.3 NO_2 modelling

Maps of the estimated 2009 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[3,4]. 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 3.3 of the 2008 UK modelling report[1]. Briefly, the oxidant-partitioning model[3] enables NO_2 concentrations to be calculated using the following equations (concentrations in ppb[13]):

$$[NO_2] = [OX].([NO_2]/[OX]) , \qquad \text{(i)}$$

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

$$[NO_2]/[OX] = f[NO_X]. \qquad \text{(iii)}$$

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 of NO_X emitted directly as NO_2), and B is the regional oxidant. $[NO_2]/[OX]$ is a function of $[NO_X]$ denoted by $f[NO_X]$. 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. 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.

[13] 1 ppb of NO_2 = 1.91 $\mu g\ m^{-3}$ of NO_2, NO_X concentrations are expressed as NO_2, so the conversion factor is the same. 1 ppb of O_3 = 2 $\mu g\ m^{-3}$ of O_3.

3.4 PM_{10} contributions from area sources

As for NO_X, the Scotland-specific PM_{10} uncalibrated area source contribution was modelled by applying an ADMS 4.2 derived dispersion kernel to calculate the contribution to ambient concentrations at a central receptor location from area source emissions within a 33 km x 33 km square surrounding each monitoring site. Further information on this approach can be found in Appendix 3 of the 2008 UK modelling report[1]. 2009 hourly sequential meteorological observations from RAF Leuchars were used to construct the dispersion kernels.

Eight of the background PM_{10} monitoring sites within the Scottish network were used to calibrate the model, as reported in Table 2.1. PM_{10} measurements from one site (East Ayrshire New Cumnock) were excluded on the basis that they were made using an unheated BAM. Measurements from Auchencorth Moss were also excluded because the measured annual mean minus non-calibrated sources was negative. This was due to the pristine nature of the monitoring site at Auchencorth Site which is located in open moorland in a remote rural location ~20 km south of Edinburgh. Inclusion of a negative value would skew the calibration plot. Five sites were excluded due to low data capture (annual %dc <75%).

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 concentration of 1 $\mu g\ m^{-3}$ was found to provide the best fit to the monitoring data. This approach is consistent with that used in the 2009 UK mapping.

As part of the calibration process, concentration caps were applied to certain sectors. This is because the use of surrogate statistics for mapping area source emissions sometimes results in unrealistically large concentrations in some grid squares for a given sector. The concentration caps applied are given in Table 3.4.

Table 3.4 Concentration caps applied to PM_{10} sector grids.

SNAP code	Description	Cap applied ($\mu g\ m^{-3}$)*
SNAP 1	Combustion in energy production & transformation	3
SNAP 2 (excludes domestic)	Combustion in Commercial, Institutional & residential & agriculture	3
SNAP 2 (domestic only)	Combustion in Commercial, Institutional & residential & agriculture	3
SNAP 3	Combustion in industry	3
SNAP 4 (excludes quarrying and construction)	Production processes	3
SNAP 4 (quarrying)	Production processes	2
SNAP 4 (construction)	Production processes	3
SNAP 6	Solvent use	3
SNAP 8 (industrial offroad machinery only)	Other transport & mobile machinery	3
SNAP 8 (other offroad mobile machinery)	Other transport & mobile machinery	3
SNAP 8 (shipping only)	Other transport & mobile machinery	2
SNAP 8 (rail only	Other transport & mobile machinery	3
SNAP 8 (aircraft only)	Other transport & mobile machinery	3
SNAP 10	Agriculture forestry & land use change	2
SNAP 11	Nature	3

*Caps listed are for calibrated concentrations.

Figure 3.3 shows that the gradient the line of best fit forced through the origin was 1.9196. 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 Scotland-specific background PM_{10} model.

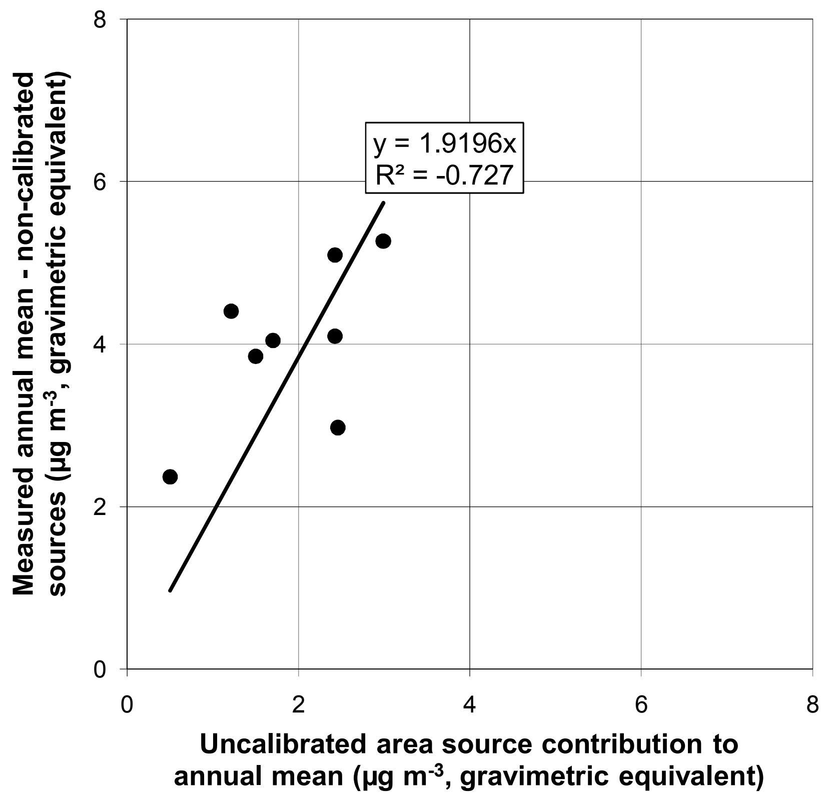


Table 3.5 Background model calibration coefficients applied in the Scotland-specific and UK models for PM_{10} for 2009 and 2008.

Model	Pollutant	Year	Calibration coefficient
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 3.5 provides a comparison of the 2009 Scotland-specific and UK background PM_{10} calibration coefficients. The 2008 Scotland-specific and UK background PM_{10} calibration coefficients are also presented to allow assessment of 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 3.5 it can be seen that the 2008 and 2009 Scotland-specific background PM_{10} calibration coefficients were lower than their equivalent UK values. This is a reflection of the relatively lower background PM_{10} concentrations when compared to the UK as a whole due to the more rural nature of Scotland. The 2009 Scotland-specific background PM_{10} calibration coefficient was lower than that used in the 2008 modelling. Consequentially, the 2009 modelled Scottish background PM_{10} concentrations may be slightly lower than those modelled in 2008, however it is important to note that this effect may be ameliorated by the meteorological terms (dispersion kernels) applied in the model.

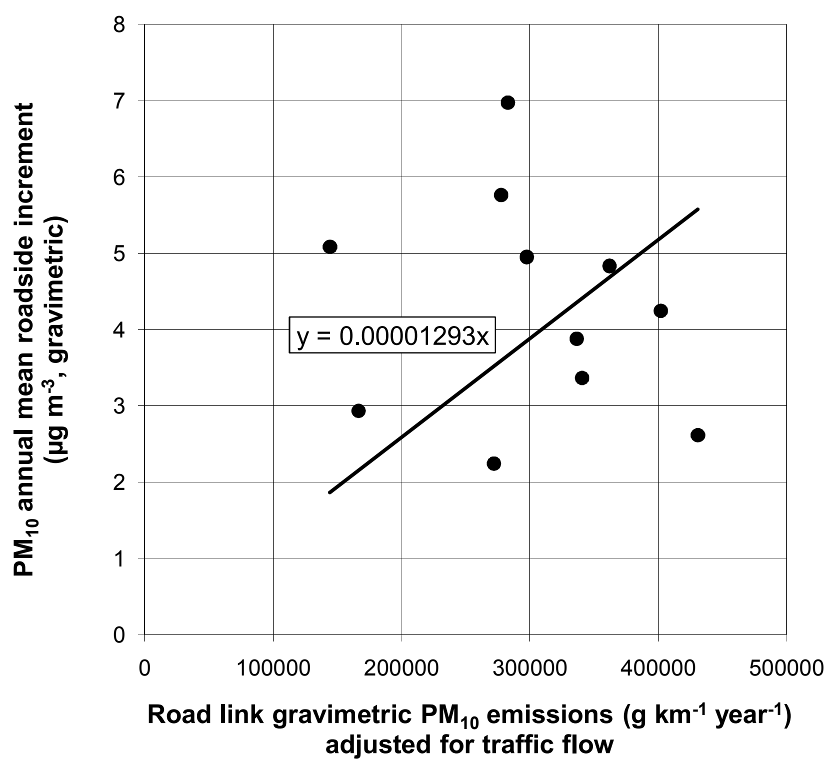
3.5 Roadside PM_{10} concentrations

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 2008[11] and these have been adjusted to provide estimates of emissions in 2009. Figure 3.4 shows a comparison of the roadside increment of annual mean PM_{10} concentrations (i.e., measured roadside PM_{10} concentration – modelled background PM_{10} concentration) at Scottish roadside or kerbside monitoring sites plotted against PM_{10} emission estimates adjusted for traffic flow for the individual road links alongside which these sites were located. The background PM_{10} component at these roadside monitoring sites is taken from the background map described in Section 3.4.

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



As for the area source calibration coefficient (described in Section 3.4), 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 3.2.5 of the 2008 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.

Fifteen of the forty-nine roadside PM_{10} monitoring sites within the Scottish network had sufficient data capture for PM_{10} in 2009 and were located on urban major road links. The roadside PM_{10} measurements from these sites were used to calibrate the model. Eleven sites were excluded on the basis of low annual data capture. Roadside PM_{10} measurements from twenty-two roadside sites were excluded because the sites were not located:

- on an 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. Measurements from Alloa were discounted due to a large discrepancy (of around 2 µg m^{-3}) between the measured and modelled PM_{10} concentration at this site.

Table 3.6 Roadside model calibration coefficients applied in the Scotland-specific and UK models for PM_{10} for 2009 and 2008.

Model	Pollutant	Year	Calibration coefficient
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

Table 3.6 provides a comparison of the 2009 Scotland-specific and UK roadside PM_{10} calibration coefficients. The 2008 Scotland-specific and UK roadside PM_{10} calibration coefficients are also presented to allow assessment of year-on-year variation in: (1) the Scotland-specific roadside PM_{10} calibration coefficient; and, (2) the extent to which these values vary in both models.

From Table 3.6 it can be seen that for 2008 and 2009 Scotland-specific model roadside PM_{10} calibration coefficients were higher than their equivalent UK values. Comparison of the Scotland-specific and UK roadside calibration coefficients shows that the Scottish roadside PM_{10} increment was greater than that for equivalent road link PM_{10} emissions in the UK. Therefore the Scottish roadside PM_{10} calibration coefficient is more sensitive to traffic flow, and the associated PM_{10} roadside increment, on each Scottish road link, when compared to the PM_{10} roadside calibration coefficient used in the 2009 UK model.

It is therefore anticipated that the 2009 Scotland-specific roadside PM_{10} model may predict a higher number of PM_{10} roadside exceedences for Scottish road links when compared to those predicted by the 2009 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 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 data being used to compare against the model result have also been used in the model calibration process. 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 2009, a small number of Scottish air quality monitoring sites, around three to five, as noted in Section 2.2, were used to verify the model output. The number of sites available for model verification was dependent on air pollutant and site type (background or roadside). Ideally the number of sites used to verify the model output should be equal to the number of sites used to calibrate the model.

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 and represent the DQOs specified for NO_2 in the EU Air Quality Directive. 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 for NO_X, and Table 4.2 for NO_2, for the Scotland-specific model. The summary statistics presented in Table 4.1 and Table 4.2 include 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 4.1 and Table 4.2 also provide the equivalent measured and modelled annual mean NO_X and NO_2 concentrations from the 2009 UK model for the sites used in the Scotland-specific models, for comparison. 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	41.4	40.1	0.67	58.3	12
Scotland-specific verification	24.7	24.5	0.99	0.0	3

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	85.7	83.3	0.20	72.7	11
Scotland-specific verification	100.8	112.6	0.01	80.0	5

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	22.3	21.4	0.75	27.3	11
Scotland-specific verification	13.3	15.3	0.88	33.3	3

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	33.8	35.6	0.19	36.4	11
Scotland-specific verification	38.6	46.2	0.01	60.0	5

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 data quality objectives (DQOs) specified for PM_{10} in the EU Air Quality Directive. The plots show that the modelled annual mean concentrations provide good agreement with the measured annual mean concentrations and 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 also provides the equivalent measured and modelled annual mean PM_{10} concentrations from the 2009 UK model for the sites used in the Scotland-specific models, for comparison.

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	13.6	13.3	0.77	0	8
Scotland-specific verification	N/A	N/A	N/A	N/A	N/A

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	16.5	16.2	0.24	0	11
Scotland-specific verification	19.5	12.4	0.09	0	4

Figure 4.1 Annual mean background NO_X model verification, 2009.

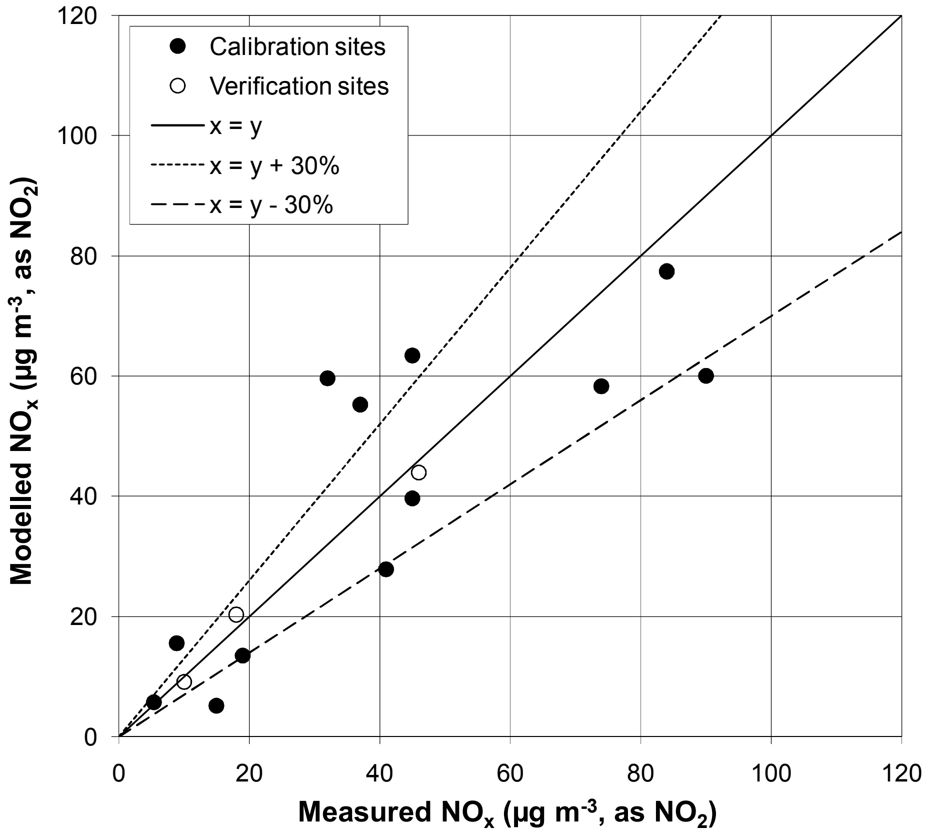


Figure 4.2 Annual mean roadside NO_X model verification, 2009.

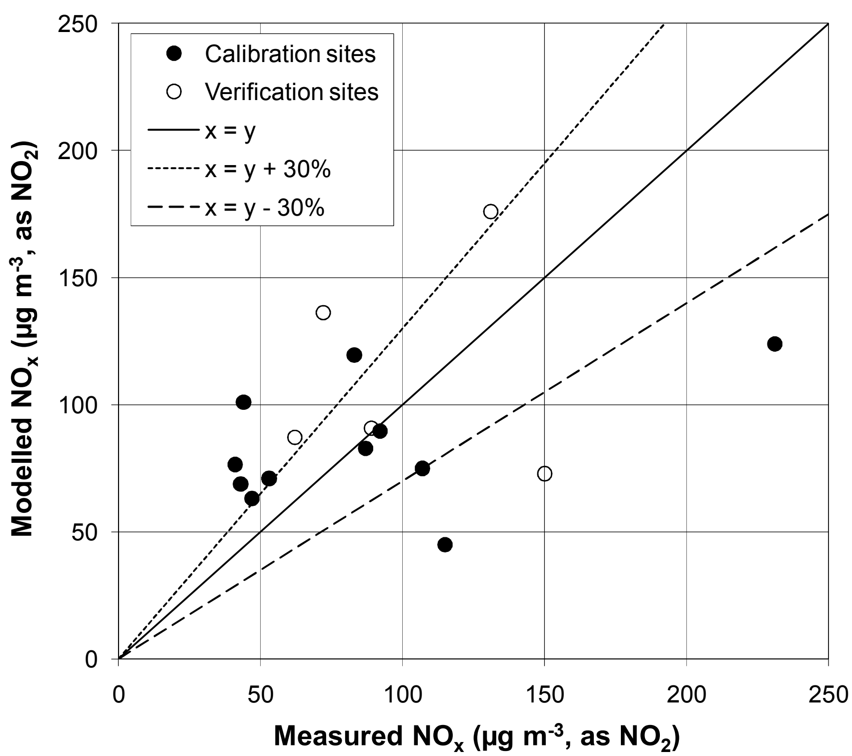


Figure 4.3 Annual mean background NO_2 model verification, 2009.

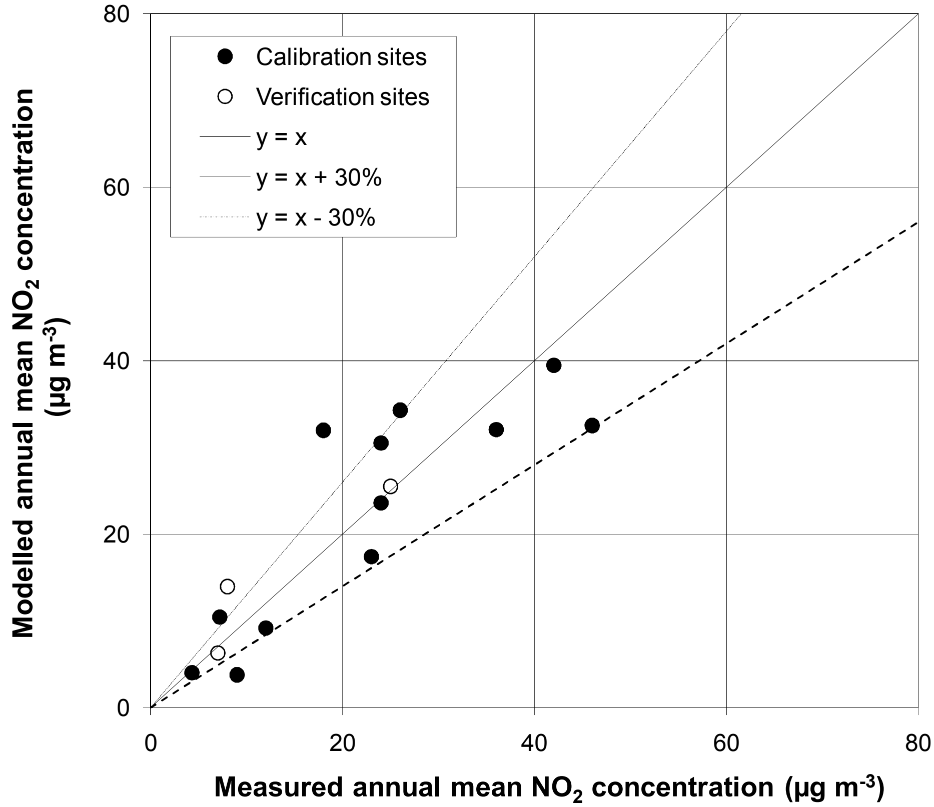


Figure 4.4 Annual mean roadside NO_2 model verification, 2009.

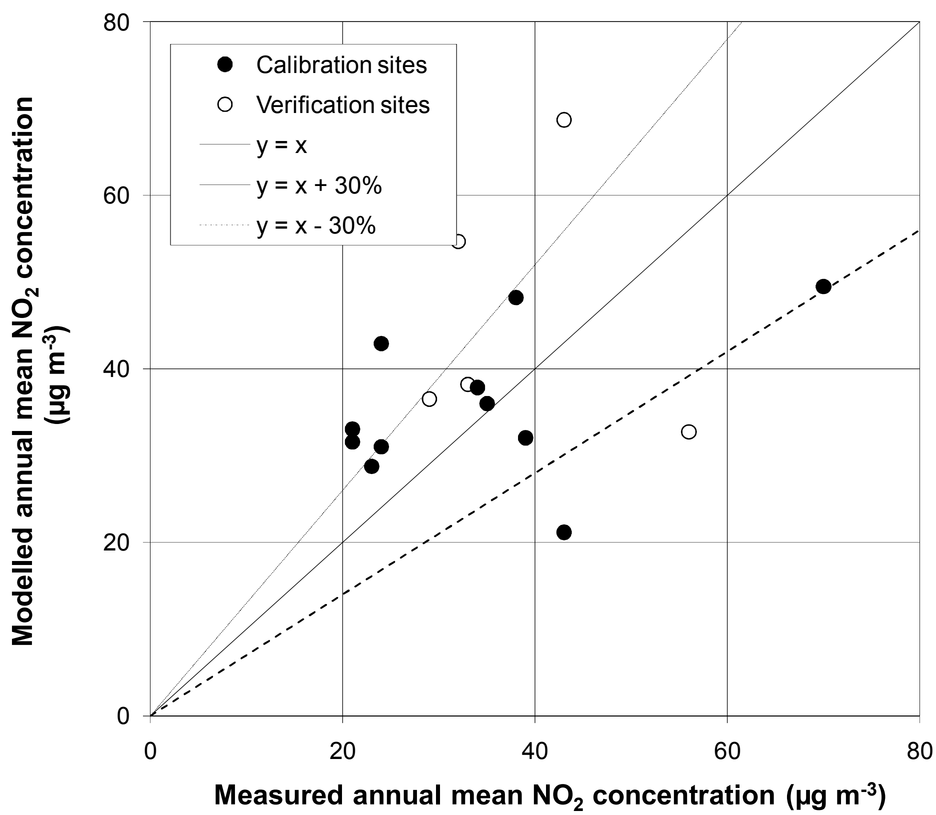


Figure 4.5 Annual mean background PM_{10} model verification, 2009.

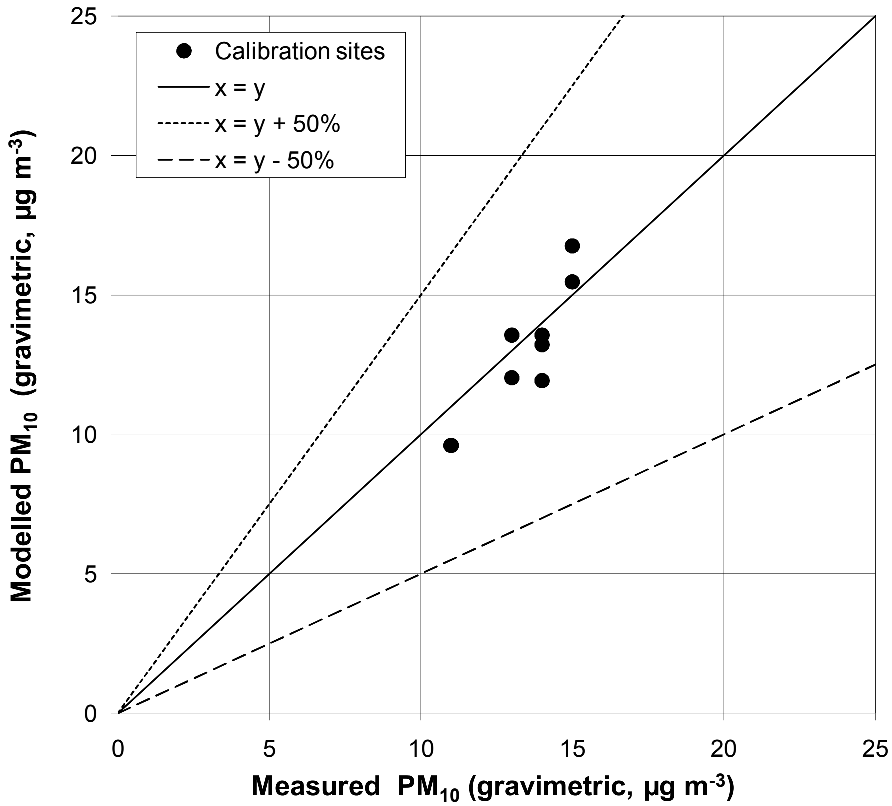
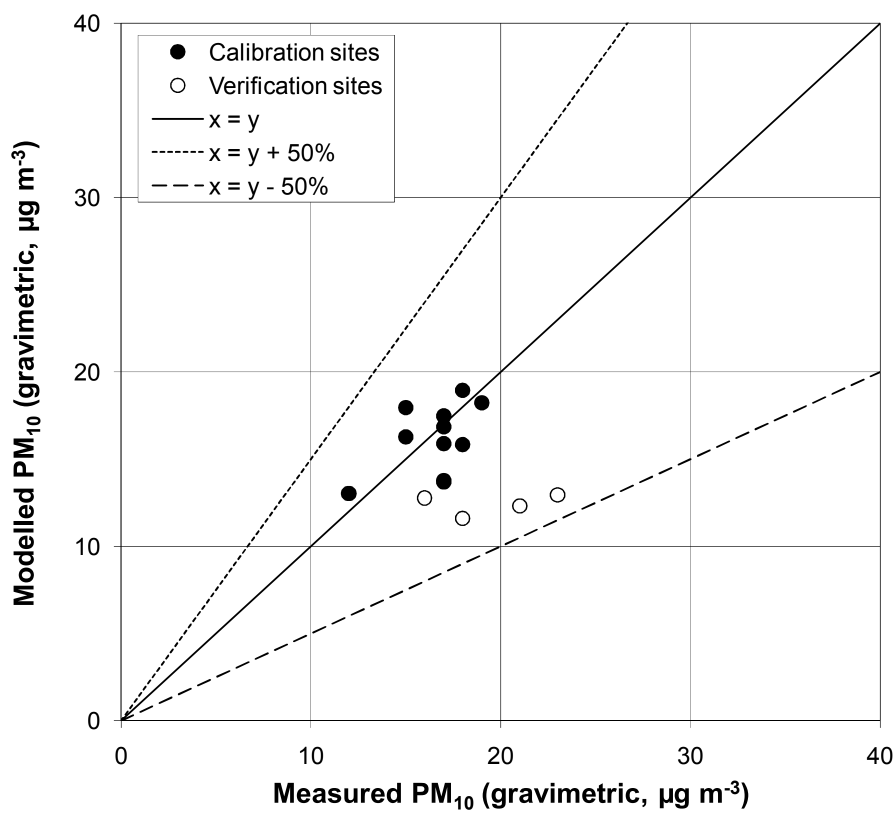


Figure 4.6 Annual mean roadside PM_{10} model verification, 2009.



5 2009 Scottish pollutant maps and results

5.1 Scottish annual mean NO_X and NO_2 maps

The 2009 Scottish annual mean background NO_X concentrations were modelled and are shown in Figure 5.2. The 2009 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 2009. More 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 (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.

5.2 Scottish annual mean PM_{10} maps

The annual mean PM_{10} concentrations were modelled for Scotland for 2009 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 2009. More 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 Exceedence 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 2009 from the Scotland-specific model. Table 5.1 showed no modelled exceedence of the Scottish annual mean NO_2 objective of 40 μg m^{-3} at any background locations.

The Scotland-specific model predicted that the Scottish annual mean NO_2 air quality objective of 40 μg m^{-3} was exceeded along 250 road links (368 km of road). The majority of the modelled exceedences were predicted to occur in the Glasgow Urban Area where exceedences of the Scottish annual mean NO_2 air quality objective was modelled for 135 road links (192 km of road). Overall exceedences of the Scottish annual mean NO_2 air quality objective were modelled in five of the six zones and agglomerations in Scotland, including one exceedence (affecting 3 km of road) in the Highlands. No roadside exceedences of the Scottish annual mean NO_2 air quality objective were identified by the model in the Scottish Borders.

Table 5.3 shows the number of modelled roadside exceedences of the Scottish annual mean NO_2 air quality objective + the margin of tolerance (MOT, 2 μg m^{-3}) in 2009. Table 5.4 shows the number of modelled roadside exceedences of the Scottish annual mean NO_2 air quality objective for + the maximum margin of tolerance (20 μg m^{-3}) in 2009. Table 5.3 shows that 220 roads out of the 250 exceeding Scottish annual mean air quality objective for NO_2, exceed the Scottish annual mean air quality objective for NO_2 + the margin of tolerance. Table 5.4 shows that 55 roads out of the 250 exceeding Scottish annual mean air quality objective for NO_2, exceed the Scottish annual mean air quality objective for NO_2 + the maximum margin of tolerance.

Table 5.1 Annual mean exceedence statistics for background NO_2 in Scotland based on the Scotland-specific model, 2009.

Zone or agglomeration	Total		>40 µg m^{-3}	
	Area (km^2)	**Population**	**Area (km^2)**	**Population**
Glasgow Urban Area	366	1083323	0	0
Edinburgh Urban Area	128	432414	0	0
Central Scotland	9615	1916281	0	0
North East Scotland	18837	1001550	0	0
Highland	43603	372608	0	0
Scottish Borders	11375	253305	0	0
Total	**83924**	**5059482**	**0**	**0**

Table 5.2 Annual mean exceedence statistics for roadside NO_2 in Scotland based on the Scotland-specific model, 2009.

Zone or agglomeration	Total		>40 µg m^{-3}	
	Roads	**Length (km)**	**Roads**	**Length (km)**
Glasgow Urban Area	219	326	135	192
Edinburgh Urban Area	60	102	32	56
Central Scotland	213	345	41	63
North East Scotland	129	227	41	54
Highland	10	35	1	3
Scottish Borders	35	47	0	0
Total	**666**	**1083**	**250**	**368**

Table 5.3 Annual mean exceedence statistics for roadside NO_2 in Scotland based on the Scotland-specific model, 2009.

Zone or agglomeration	Total		>42 µg m^{-3}	
	Roads	**Length (km)**	**Roads**	**Length (km)**
Glasgow Urban Area	219	326	119	172
Edinburgh Urban Area	60	102	29	51
Central Scotland	213	345	33	54
North East Scotland	129	227	38	48
Highland	10	35	1	3
Scottish Borders	35	47	0	0
Total	**666**	**1083**	**220**	**329**

Table 5.4 Annual mean exceedence statistics for roadside NO_2 in Scotland based on the Scotland-specific model, 2009.

Zone or agglomeration	Total		>60 µg m^{-3}	
	Roads	**Length (km)**	**Roads**	**Length (km)**
Glasgow Urban Area	219	326	36	67
Edinburgh Urban Area	60	102	6	10
Central Scotland	213	345	8	21
North East Scotland	129	227	5	10
Highland	10	35	0	0
Scottish Borders	35	47	0	0
Total	**666**	**1083**	**55**	**107**

5.3.2 Background and roadside PM_{10}

Figure 5.11 presents the mapped annual mean background PM_{10} concentrations for 2009 from the Scotland-specific model. Two exceedences of the Scottish annual mean PM_{10} objective, of 18 µg m^{-3} were identified by the Scotland-specific model in Central Scotland as shown in Table 5.5. Examination of the Scotland-specific model results showed that the modelled annual mean PM_{10} concentrations exceeded the Scottish annual mean PM_{10} objective in two adjacent grid squares by up to 1 µg m^{-3} located in Central Scotland. The cause of the elevated modelled annual mean PM_{10} concentrations in these grid squares was difficult to apportion precisely due to the difficulties in resolving the source from a mix of modelled and measured air quality monitoring data. Examination of the grid squares revealed a complex situation with several potential contributory sources: fugitive PM_{10} emissions combined with PM_{10} emissions from a range of transport sources. The 2008 Scotland-specific model predicted a similar exceedence of the annual mean PM_{10} concentration in one of the two grid squares.

The 2009 Scotland-specific model identified 133 road links (179 km of road) exceeding the Scottish annual mean PM_{10} air quality objective. Just over half (76 road links, 97 km of road) of the road links were in the Glasgow Urban Area, as shown in Table 5.6, which corresponds well with the number and location of exceedences predicted by the 2009 Scotland-specific roadside model for NO_2. A further 23 road links (33 km of road) in Central Scotland and 11 road links in the Edinburgh Urban Area (16 km of road) exceeded the Scottish annual mean PM_{10} air quality objective. No roadside exceedences of the Scottish PM_{10} objective were identified by the model in the Highland or Scottish Borders zones.

No exceedences of the Scottish annual mean equivalent value of the Scottish daily mean PM_{10} air quality objective of 22 µg m^{-3} (22 µg m^{-3} is the annual mean equivalent of the 98th percentile of the Scotland daily mean PM_{10} objective of 50 µg m^{-3} as described in Appendix 1) were predicted at background locations by the 2009 Scotland-specific model. Table 5.7 shows that thirteen exceedences were predicted at roadside locations, half of which (7 road links, 13 km of road) lie in the Glasgow Urban Area.

Table 5.5 Annual mean exceedence statistics for background PM_{10} in Scotland based on the Scotland-specific model, 2009.

Zone or agglomeration	Total		>18 µg m^{-3}	
	Area (km^2)	**Population**	**Area (km^2)**	**Population**
Glasgow Urban Area	366	1083323	0	0
Edinburgh Urban Area	128	432414	0	0
Central Scotland	9615	1916281	2	114
North East Scotland	18837	1001550	0	0
Highland	43603	372608	0	0
Scottish Borders	11375	253305	0	0
Total	**83924**	**5059482**	**2**	**114**

Table 5.6 Annual mean exceedence statistics for roadside PM_{10} in Scotland based on the Scotland-specific model, 2009.

Zone or agglomeration	Total		>18 µg m^{-3}	
	Roads	**Length (km)**	**Roads**	**Length (km)**
Glasgow Urban Area	219	326	76	97
Edinburgh Urban Area	60	102	11	16
Central Scotland	213	345	23	33
North East Scotland	129	227	23	33
Highland	10	35	0	0
Scottish Borders	35	47	0	0
Total	**666**	**1083**	**133**	**179**

Table 5.7 Annual mean exceedence statistics for roadside PM_{10} in Scotland based on the Scotland-specific model, 2009.

Zone or agglomeration	Total		>22 µg m^{-3}	
	Roads	**Length (km)**	**Roads**	**Length (km)**
Glasgow Urban Area	219	326	7	13
Edinburgh Urban Area	60	102	1	2
Central Scotland	213	345	4	7
North East Scotland	129	227	1	1
Highland	10	35	0	0
Scottish Borders	35	47	0	0
Total	**666**	**1083**	**13**	**22**

5.4 Population-weighted mean calculations for 2009

Calculations of the population-weighted mean were performed on the modelled background maps. Both pollutants and people are clustered in Scotland, calculating the population weighted mean is therefore a useful way to quantify pollution exposure and provide a measure of the health impact of modelled pollutant concentrations. Table 5.8 provides a summary of the 2009 Scottish NO_2 and PM_{10} population-weighted mean concentration from the Scotland-specific model.

Table 5.8 2009 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	11.18	14.25

Figure 5.1 Zones and agglomerations in Scotland in 2009.

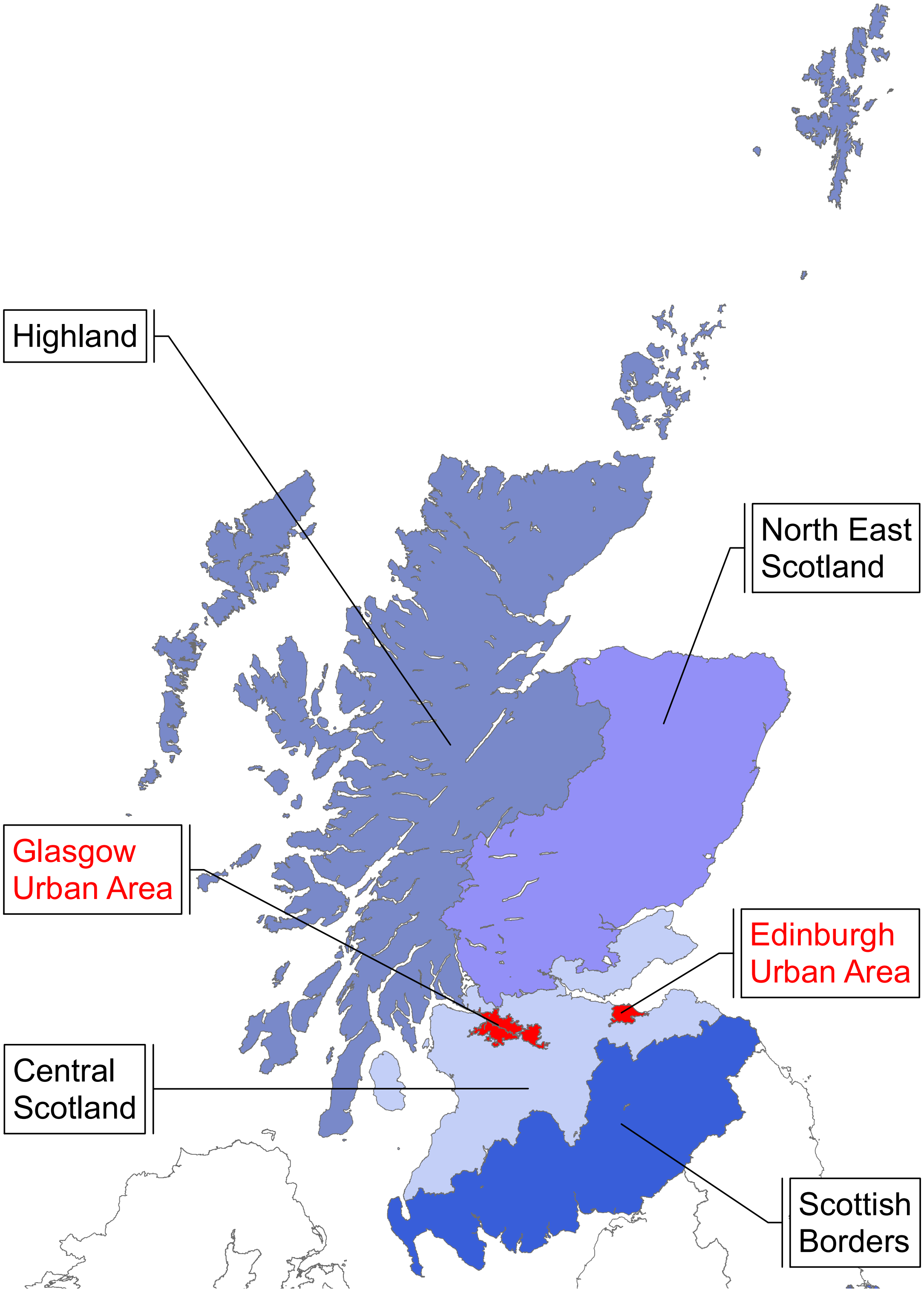


Figure 5.2 Background NO_X map for 2009, µg m^{-3} (Scotland-specific model).

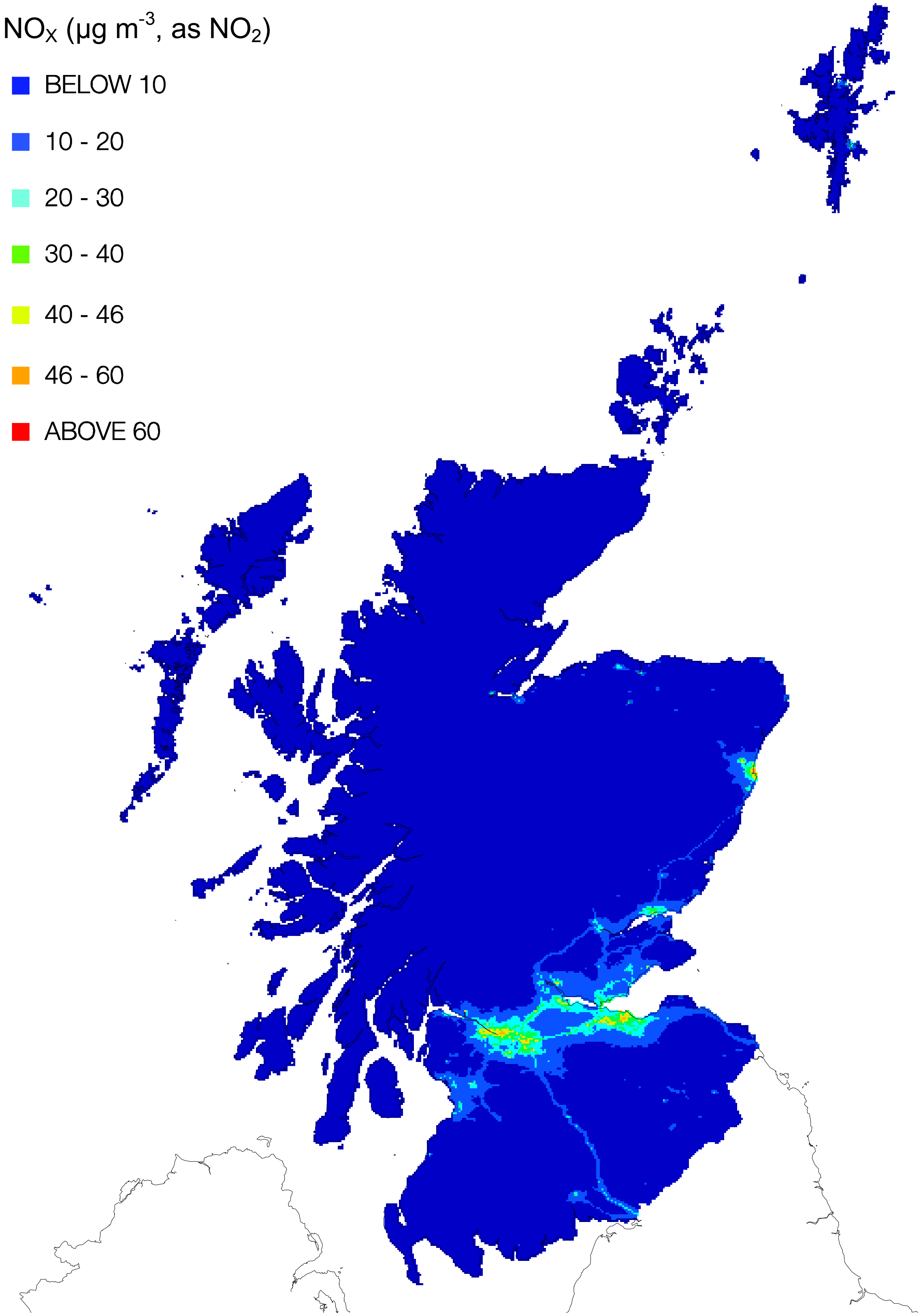


Figure 5.3 Background NO_2 map for 2009, µg m^{-3} (Scotland-specific model).

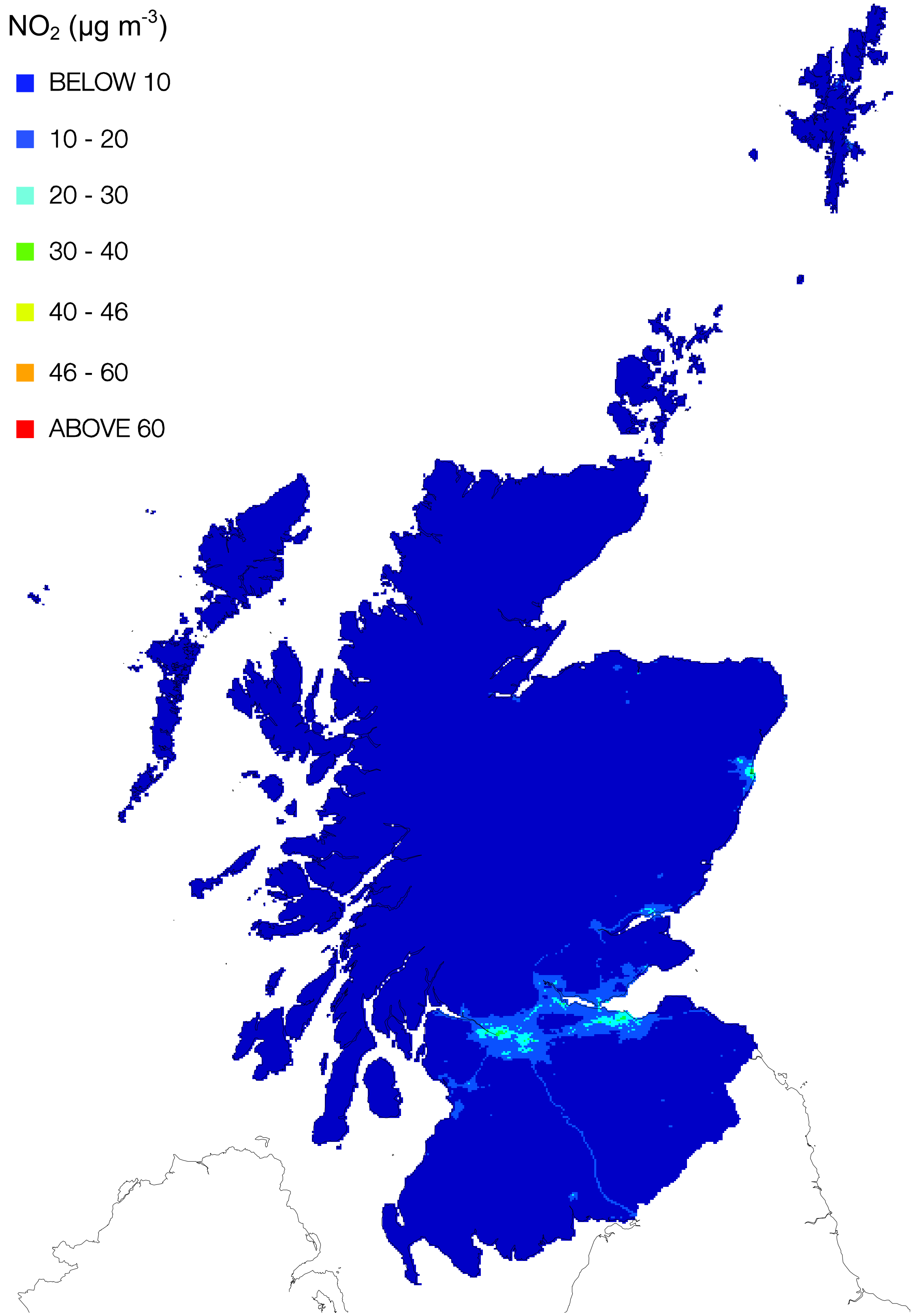


Figure 5.4 Roadside NO_2 map for 2009, µg m^{-3} (Scotland-specific model).

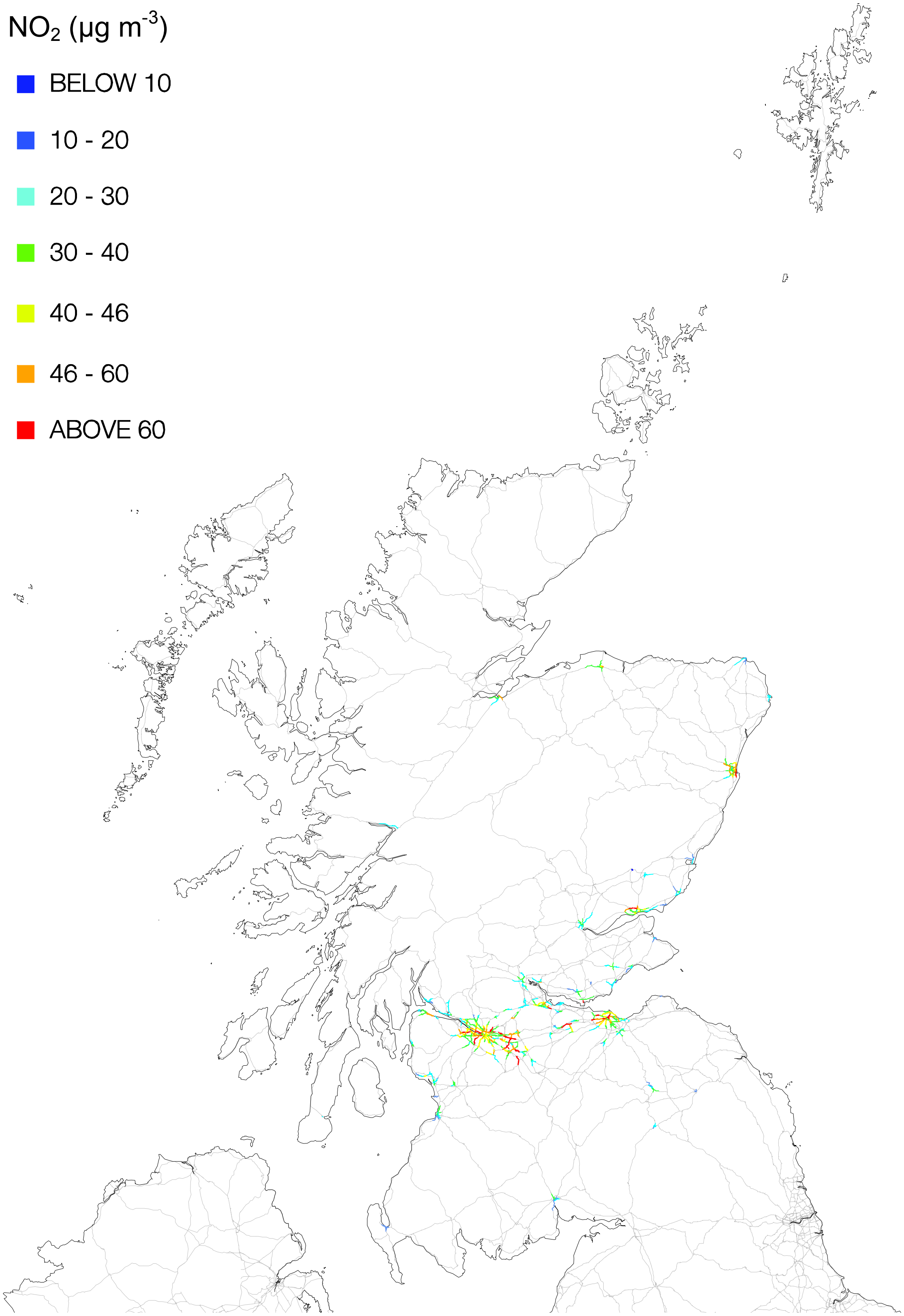
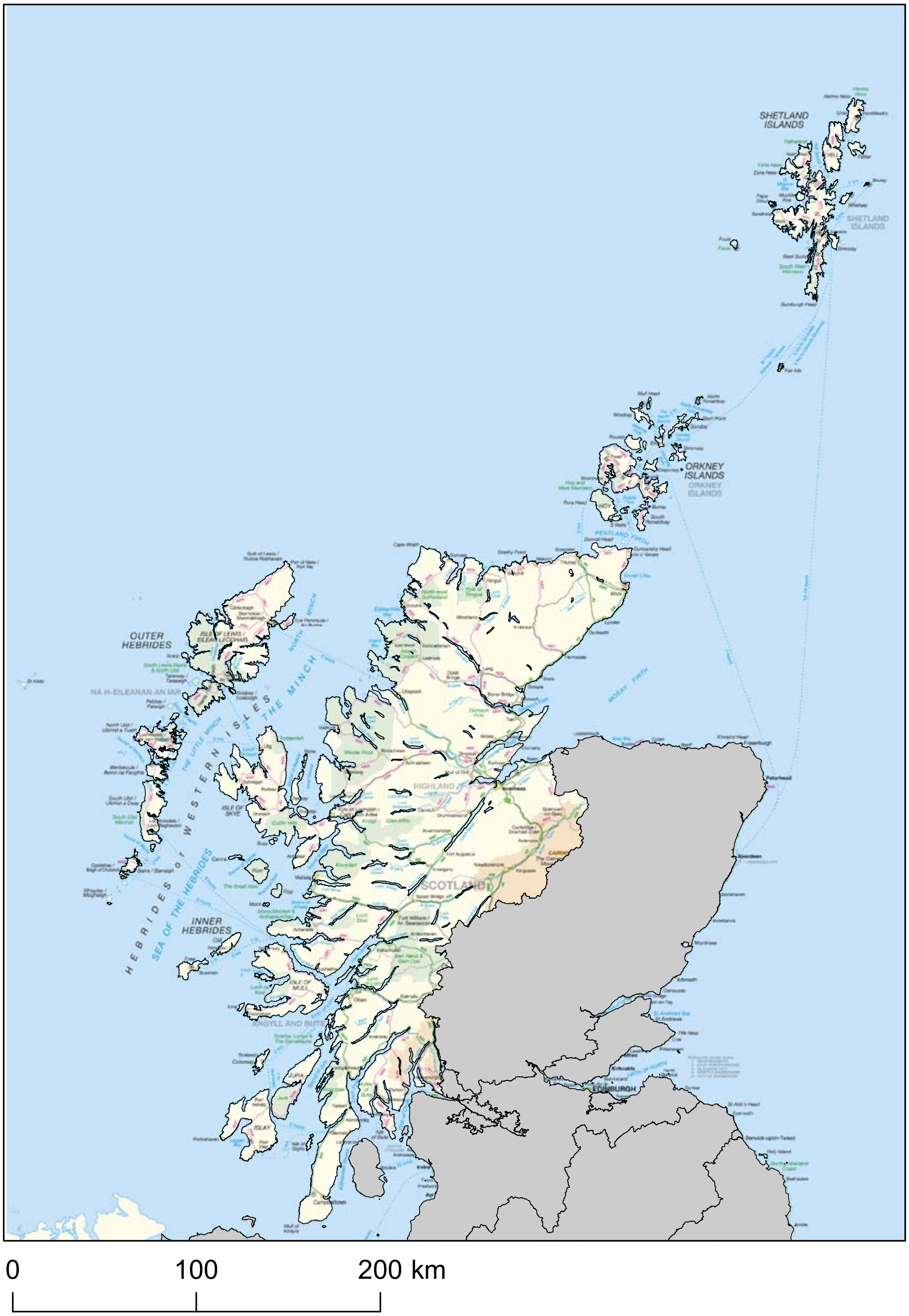


Figure 5.5 Detailed roadside NO_2 map for 2009, µg m^{-3} showing the road-link concentrations in the Highlands (Scotland-specific model).



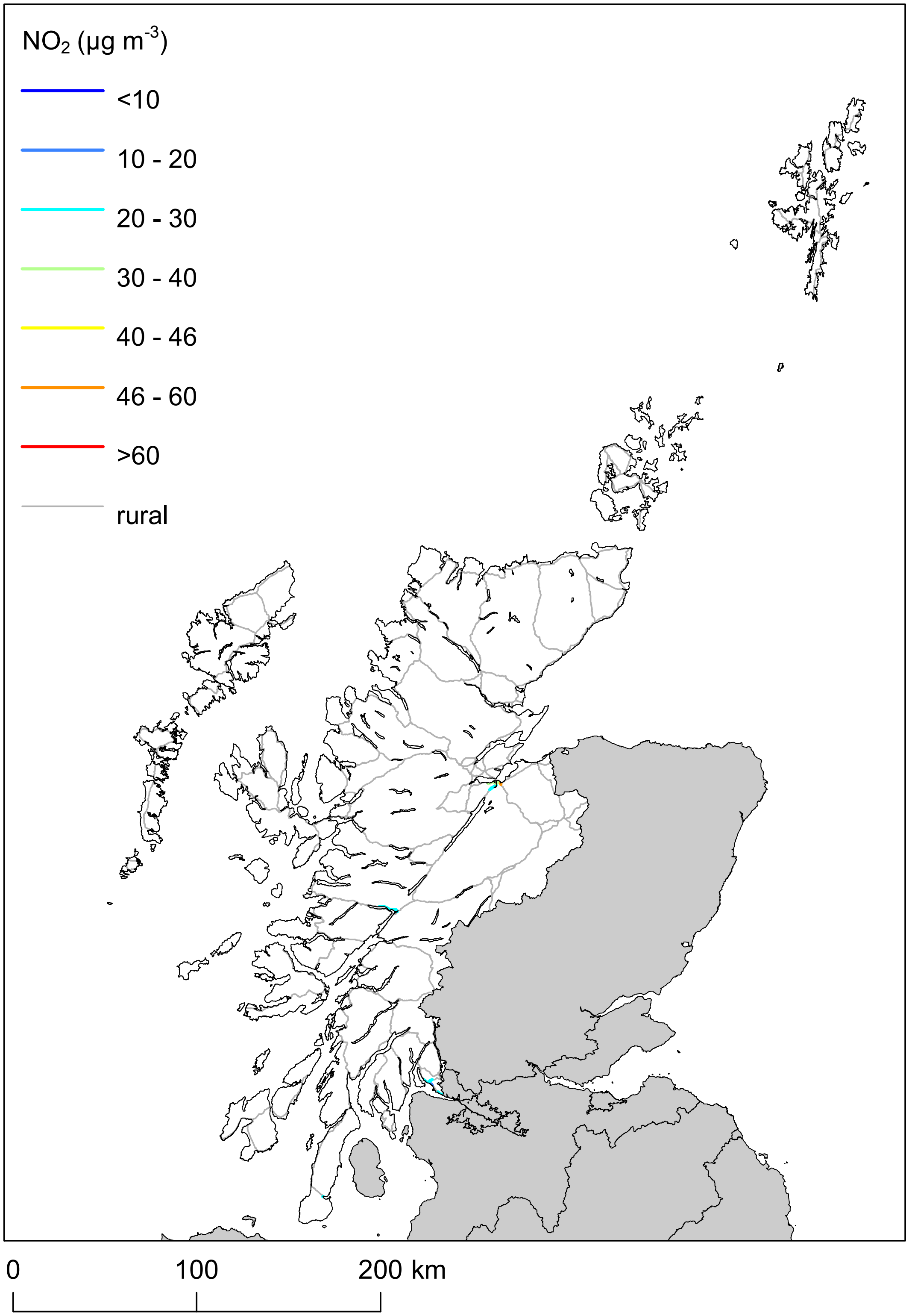
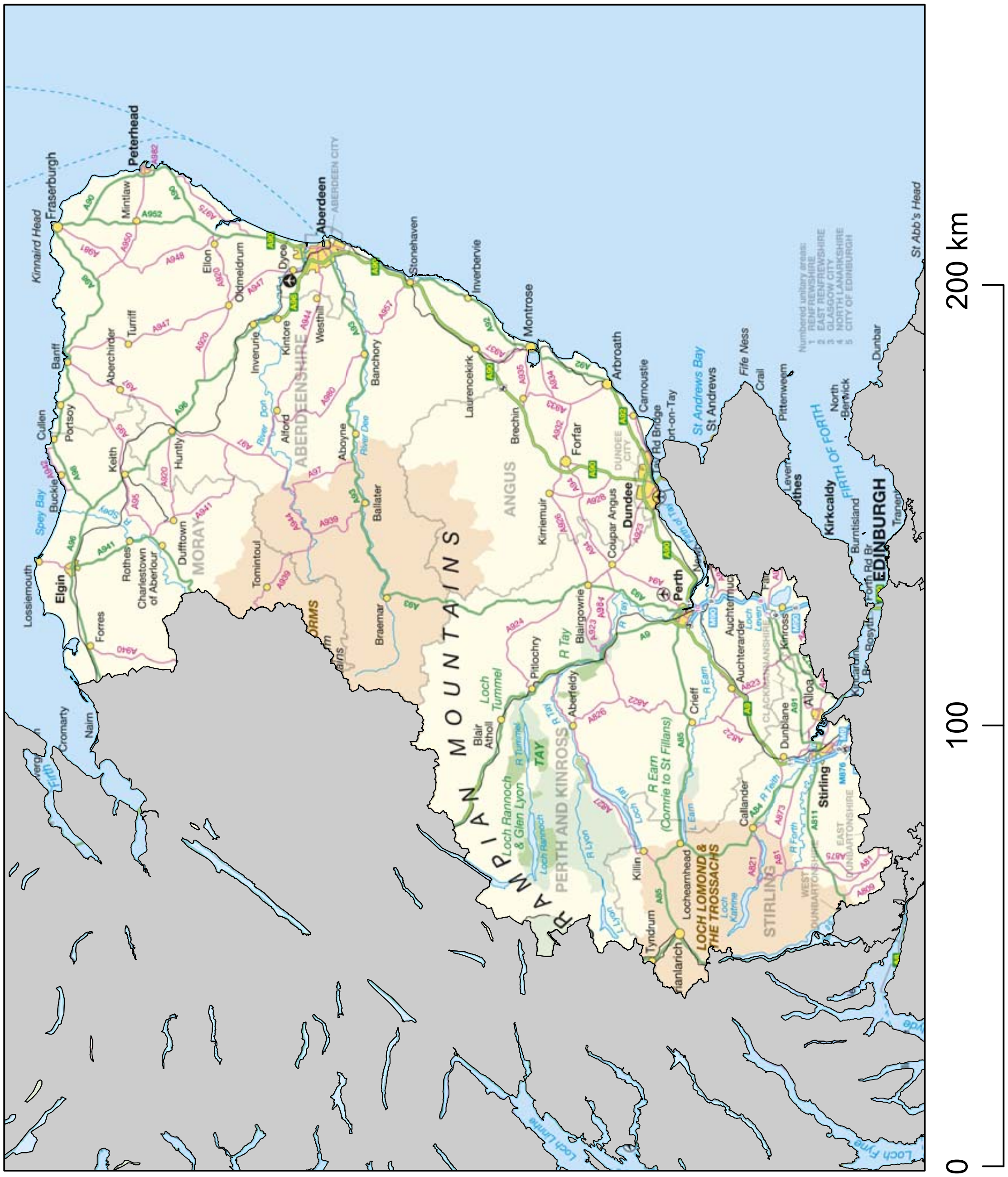

NO2 (µg m-3)
<10
10 - 20
20 - 30
30 - 40
40 - 46
46 - 60
>60
rural
0
100
200 km

Figure 5.6 Detailed roadside NO_2 map for 2009, µg m^{-3} showing the road-link concentrations in North East Scotland (Scotland-specific model).



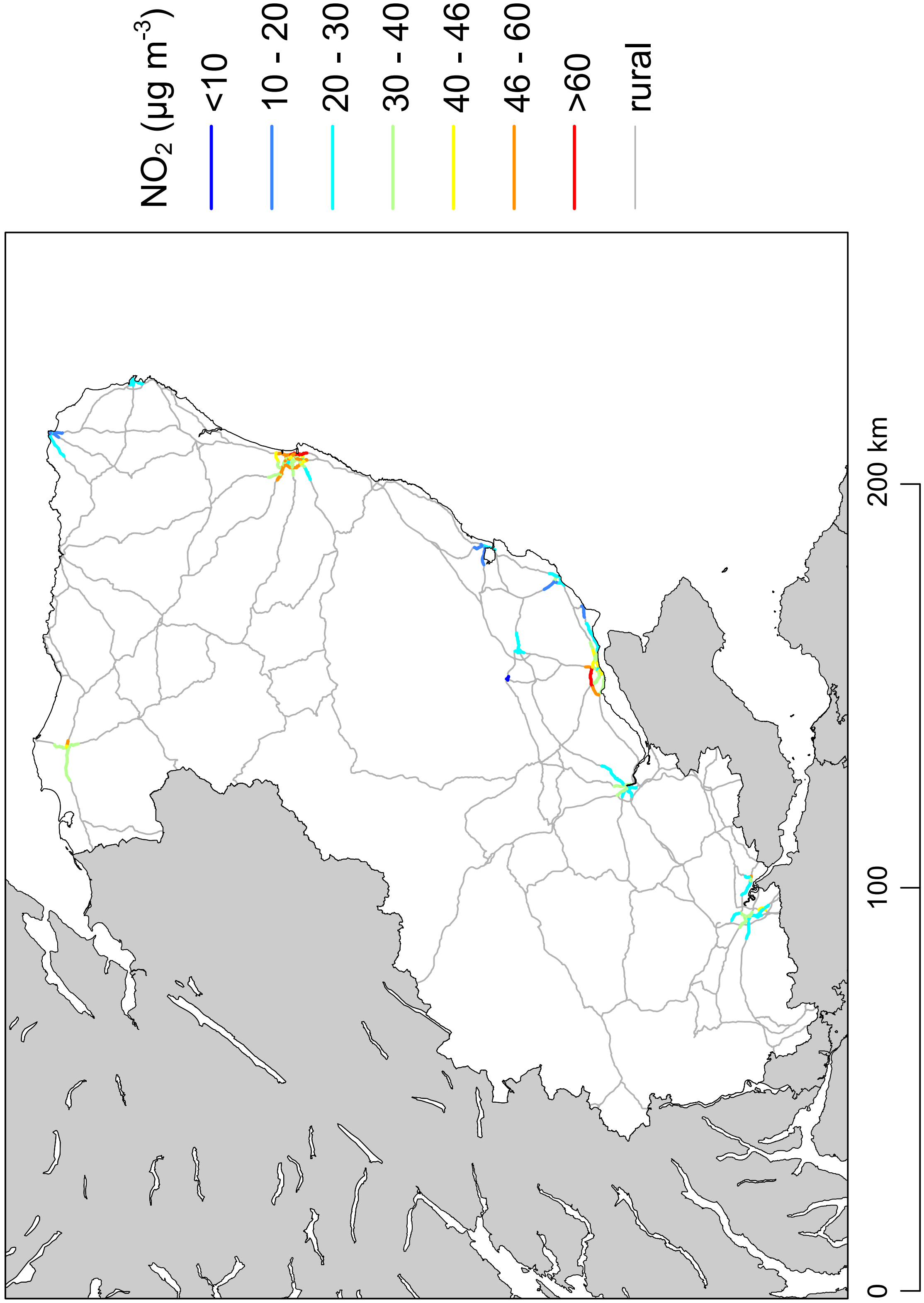
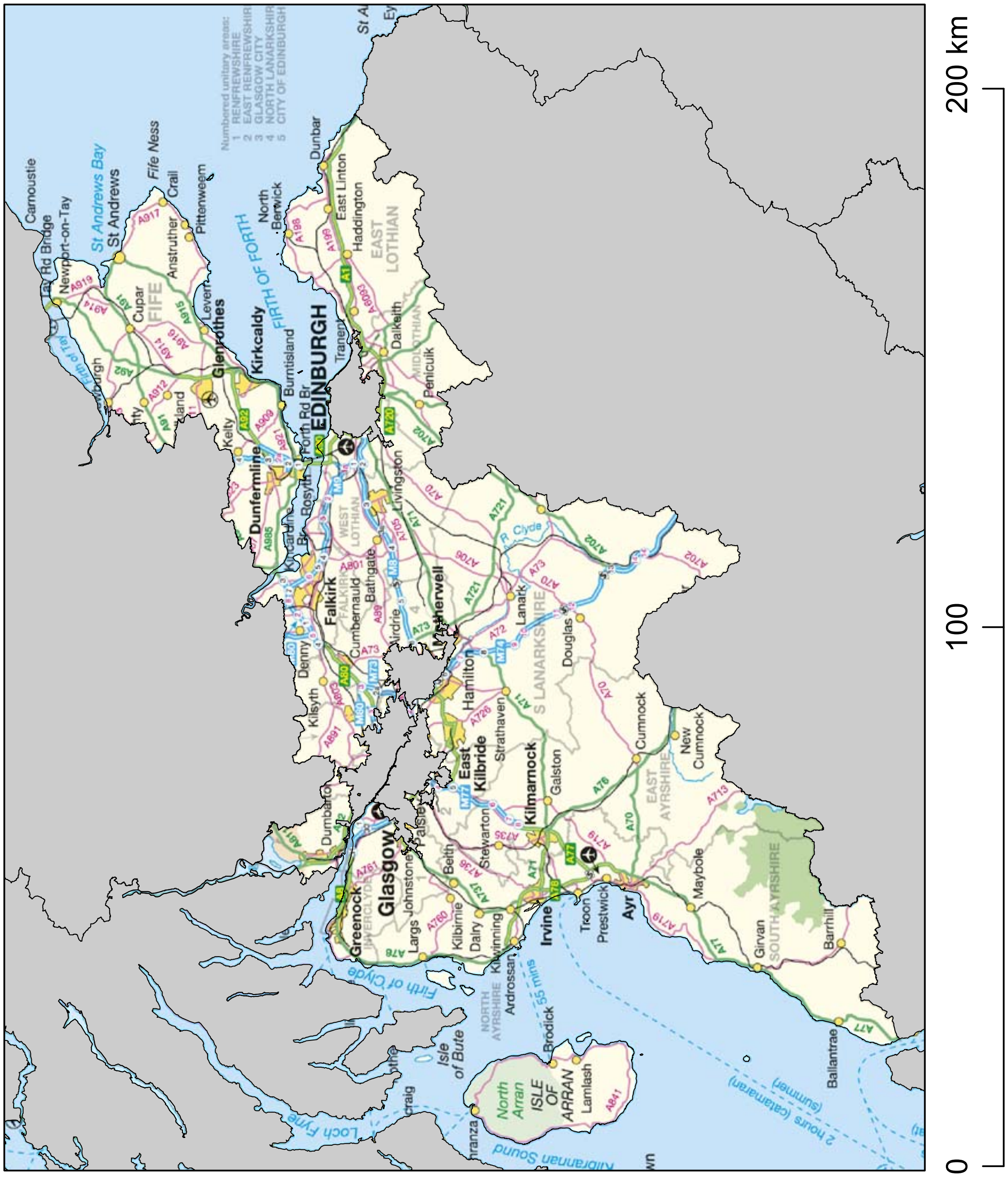

NO_2 ($\mu g\ m^{-3}$)
<10
10 - 20
20 - 30
30 - 40
40 - 46
46 - 60
>60
rural
0
100
200 km

Figure 5.7 Detailed roadside NO_2 map for 2009, µg m^{-3} showing the road-link concentrations in Central Scotland (Scotland-specific model).



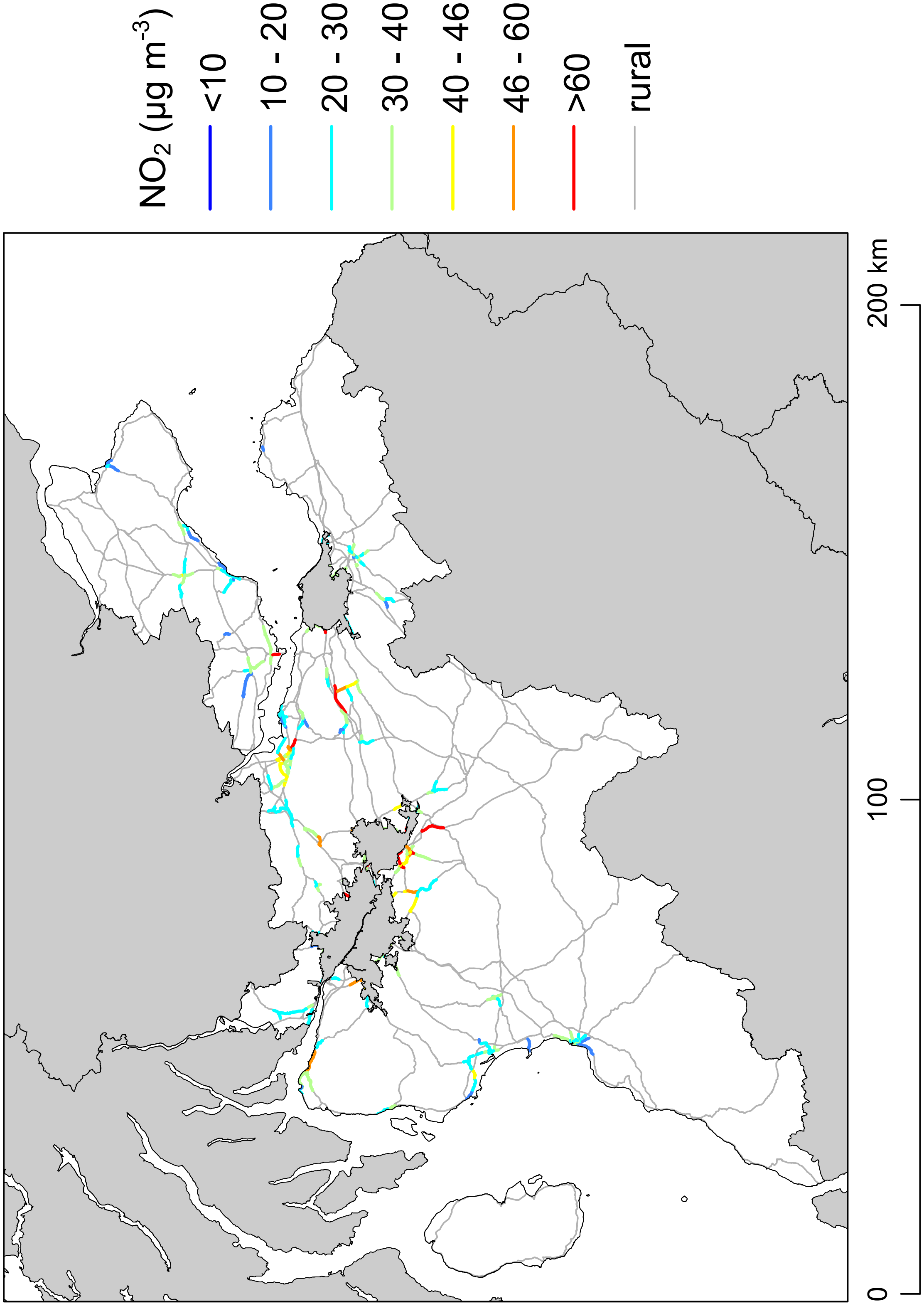
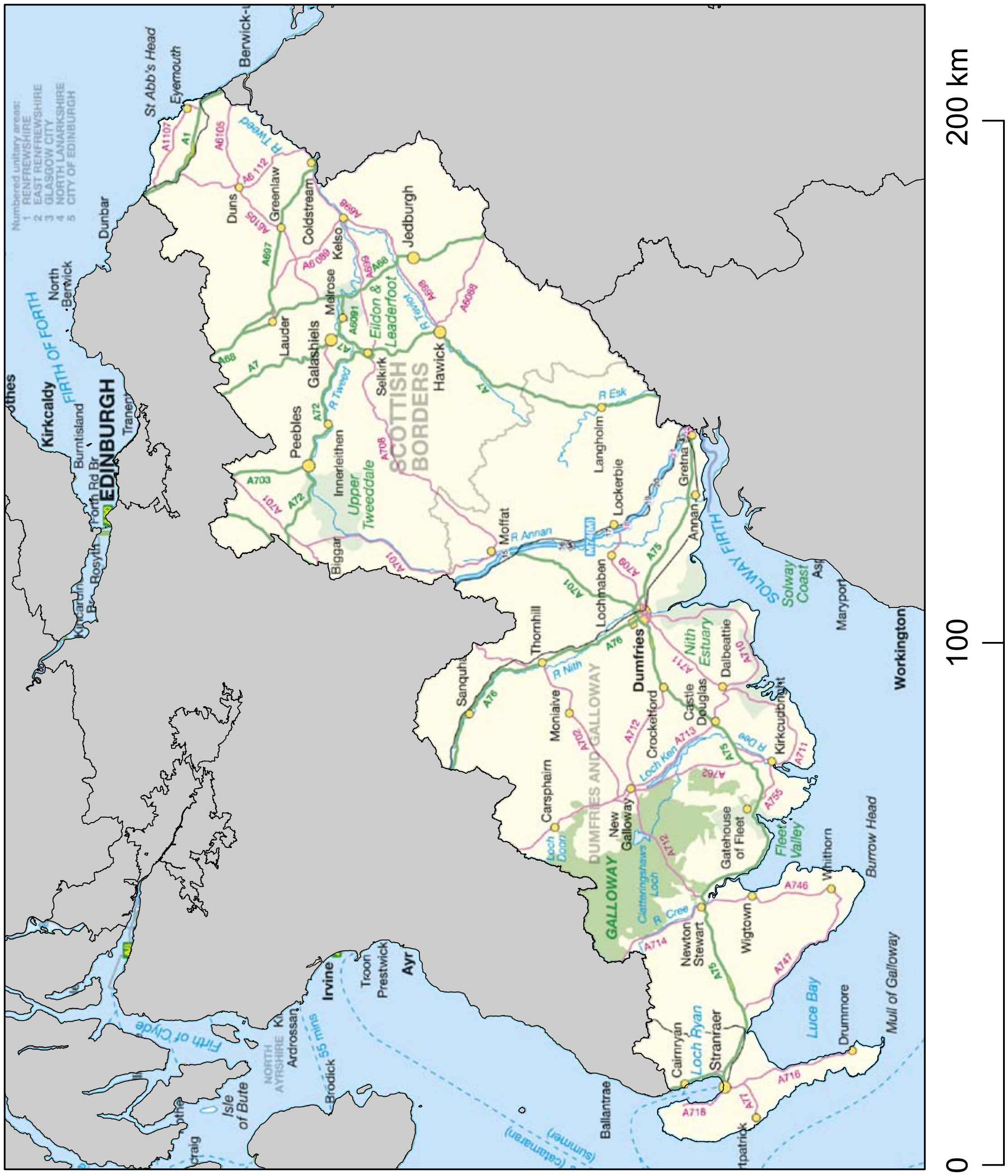
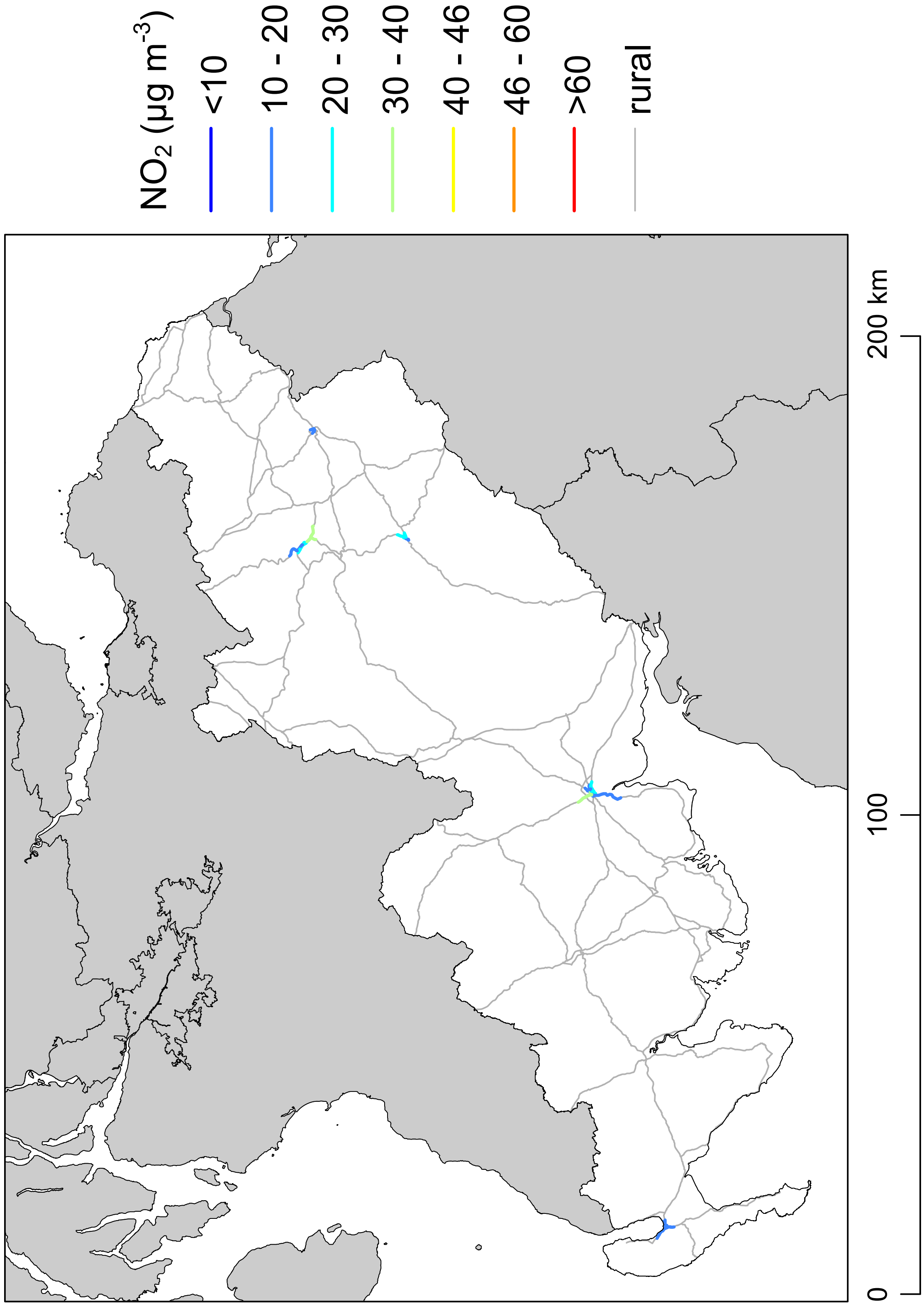

NO2 (µg m-3)
<10
10 - 20
20 - 30
30 - 40
40 - 46
46 - 60
>60
rural
0
100
200 km

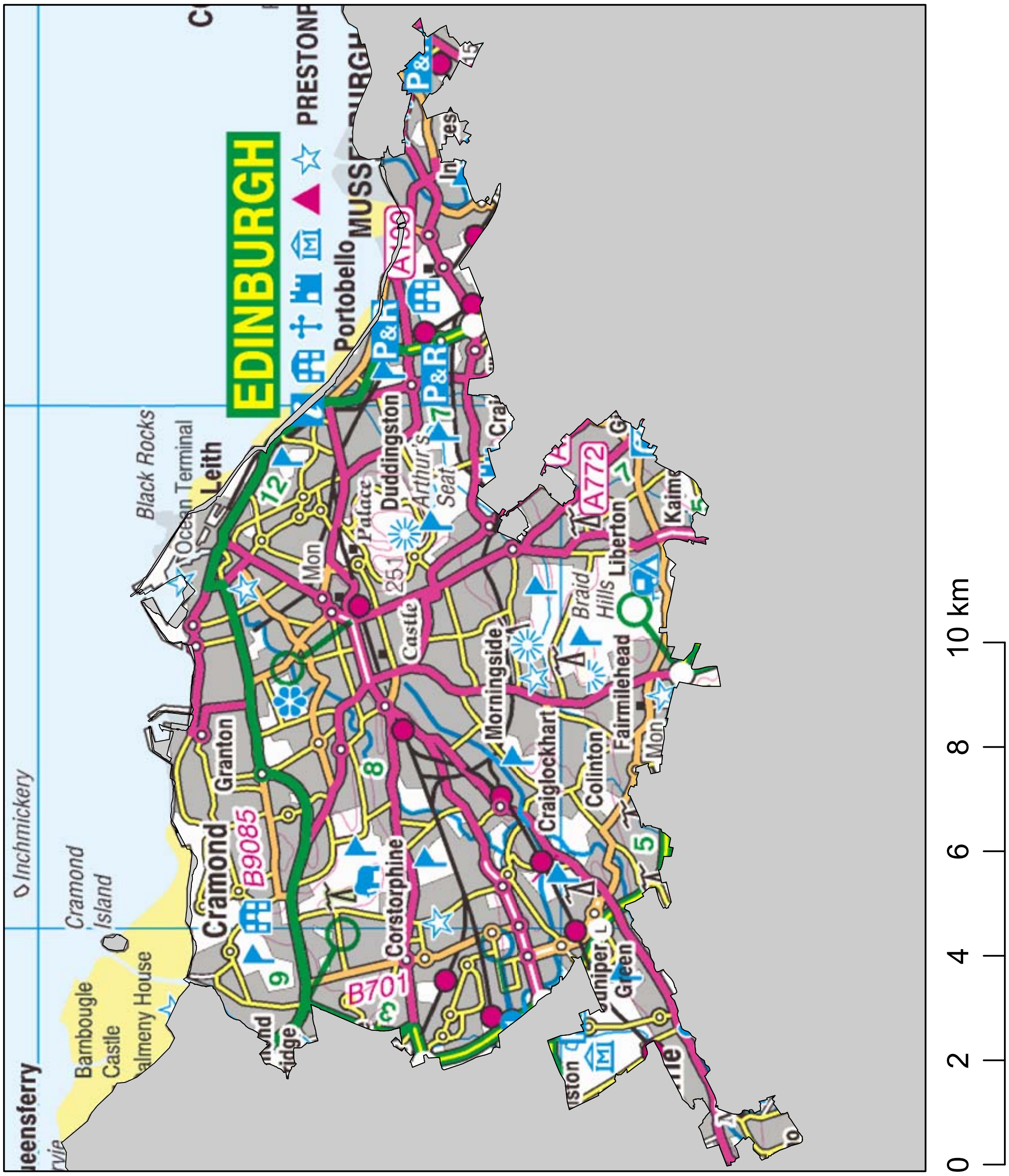
Figure 5.8 Detailed roadside NO_2 map for 2009, µg m^{-3} showing the road-link concentrations in the Scottish Borders (Scotland-specific model).





NO_2 (µg m^{-3})
<10
10 - 20
20 - 30
30 - 40
40 - 46
46 - 60
>60
rural
0
100
200 km

Figure 5.9 Detailed roadside NO_2 map for 2009, µg m^{-3} showing the road-link concentrations in the Edinburgh Urban Area (Scotland-specific model).



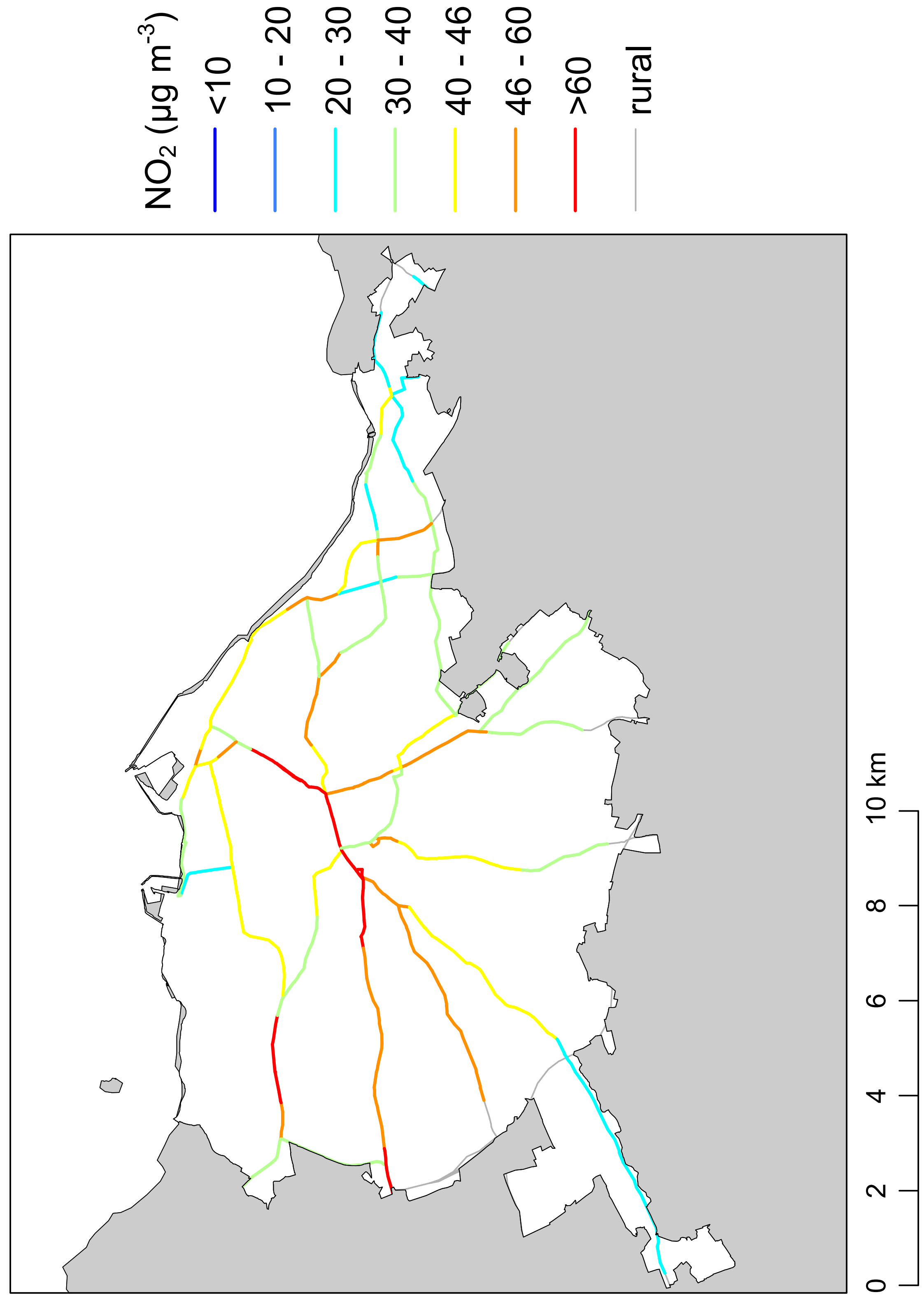
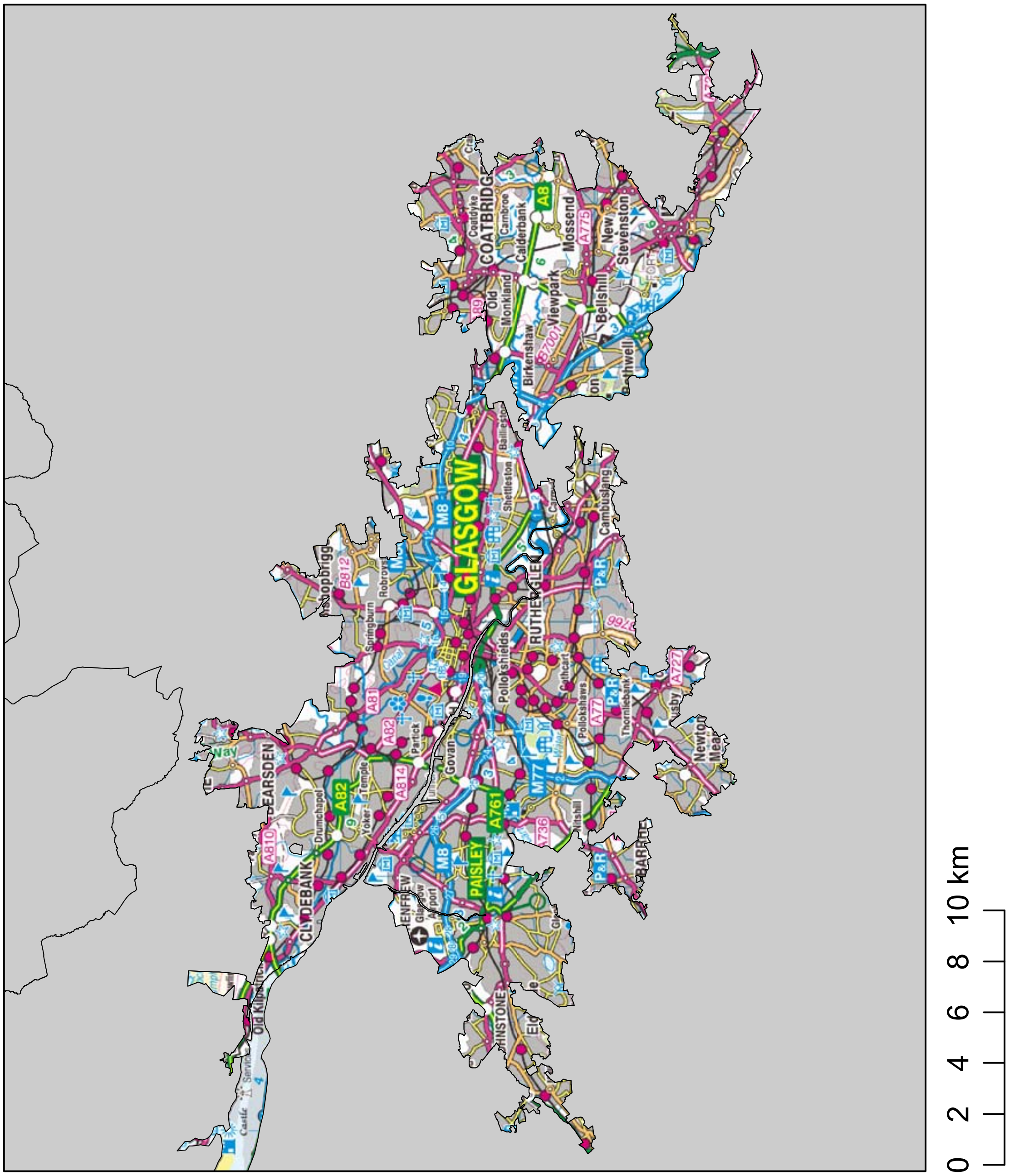

NO2 (µg m-3)
<10
10 - 20
20 - 30
30 - 40
40 - 46
46 - 60
>60
rural
0
2
4
6
8
10 km

Figure 5.10 Detailed roadside NO_2 map for 2009, μg m^{-3} showing the road-link concentrations in the Glasgow Urban Area (Scotland-specific model).



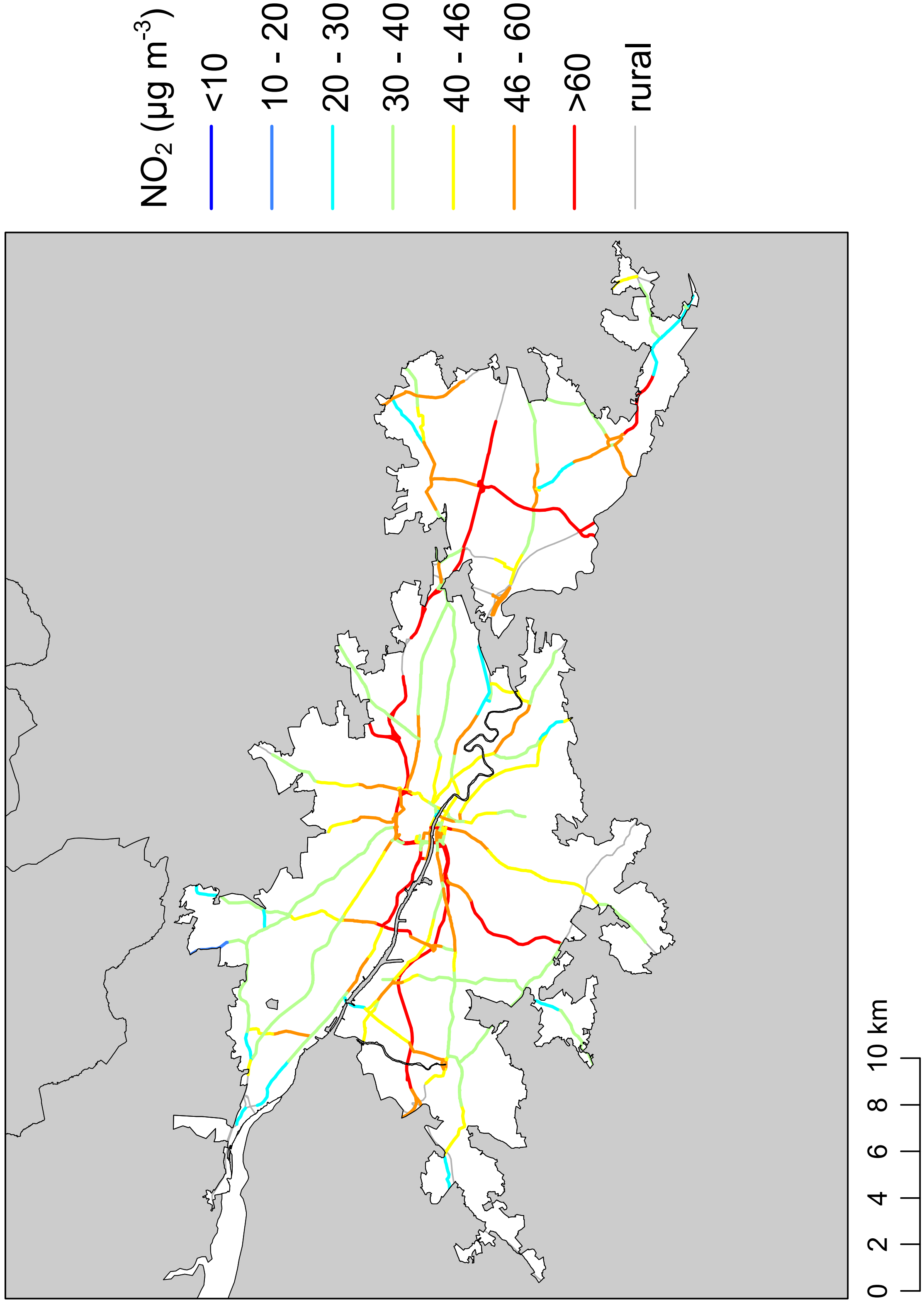

NO2 (µg m-3)
<10
10 - 20
20 - 30
30 - 40
40 - 46
46 - 60
>60
rural
0 2 4 6 8 10 km

Figure 5.11 Background PM_{10} map for 2009, µg m^{-3} (Scotland-specific model).

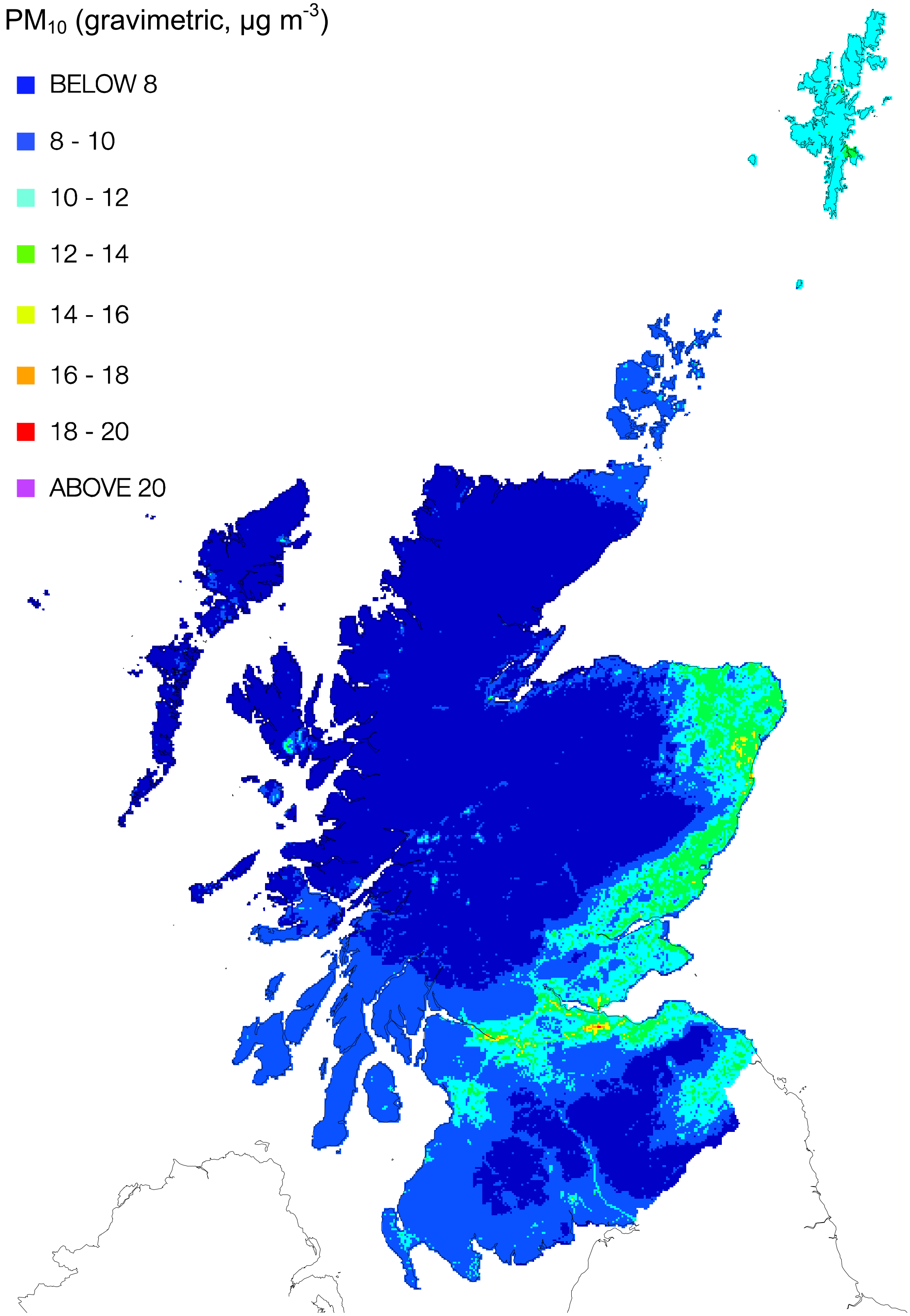


Figure 5.12 Roadside PM_{10} map for 2009, $\mu g\ m^{-3}$ (Scotland-specific model).

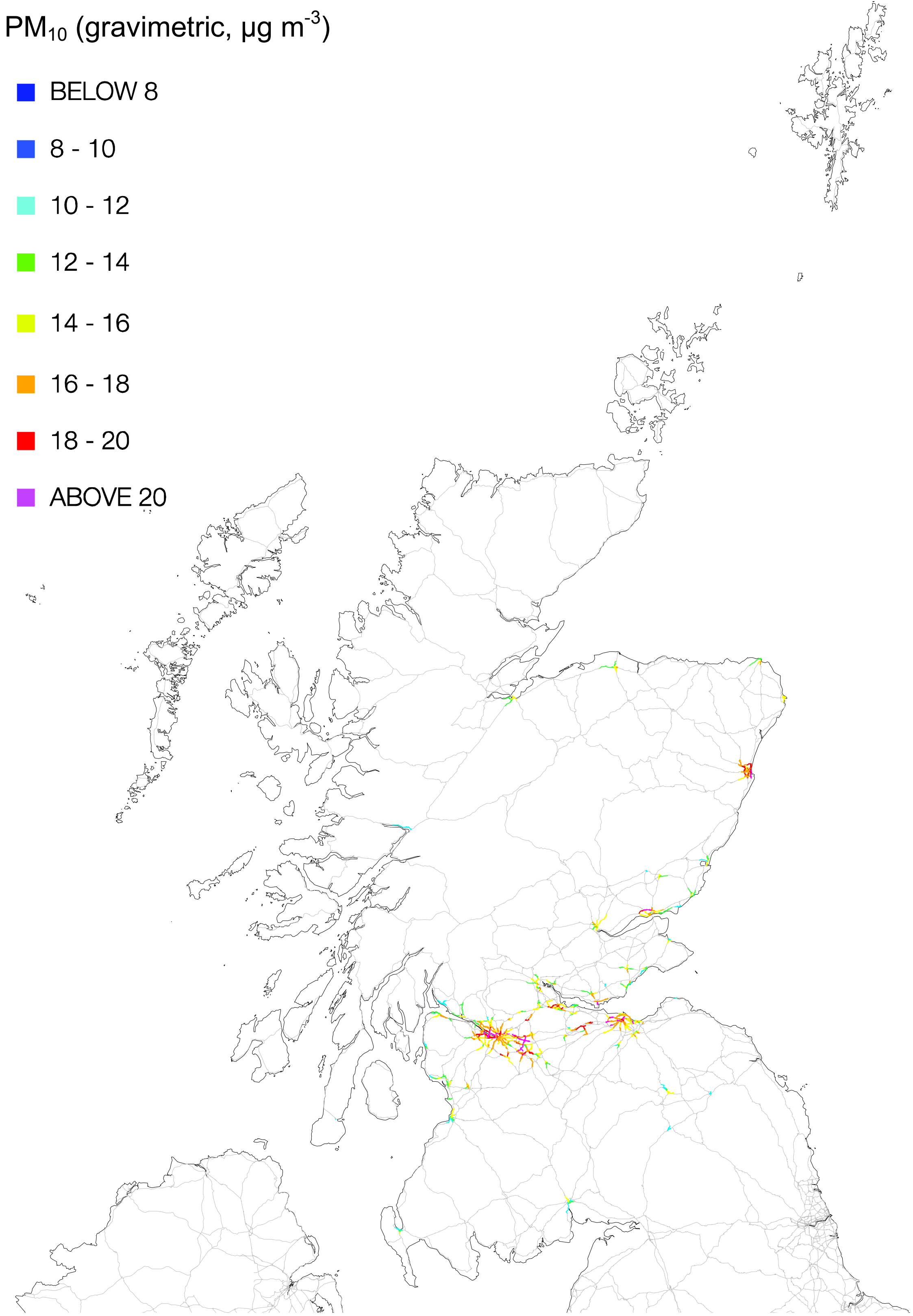
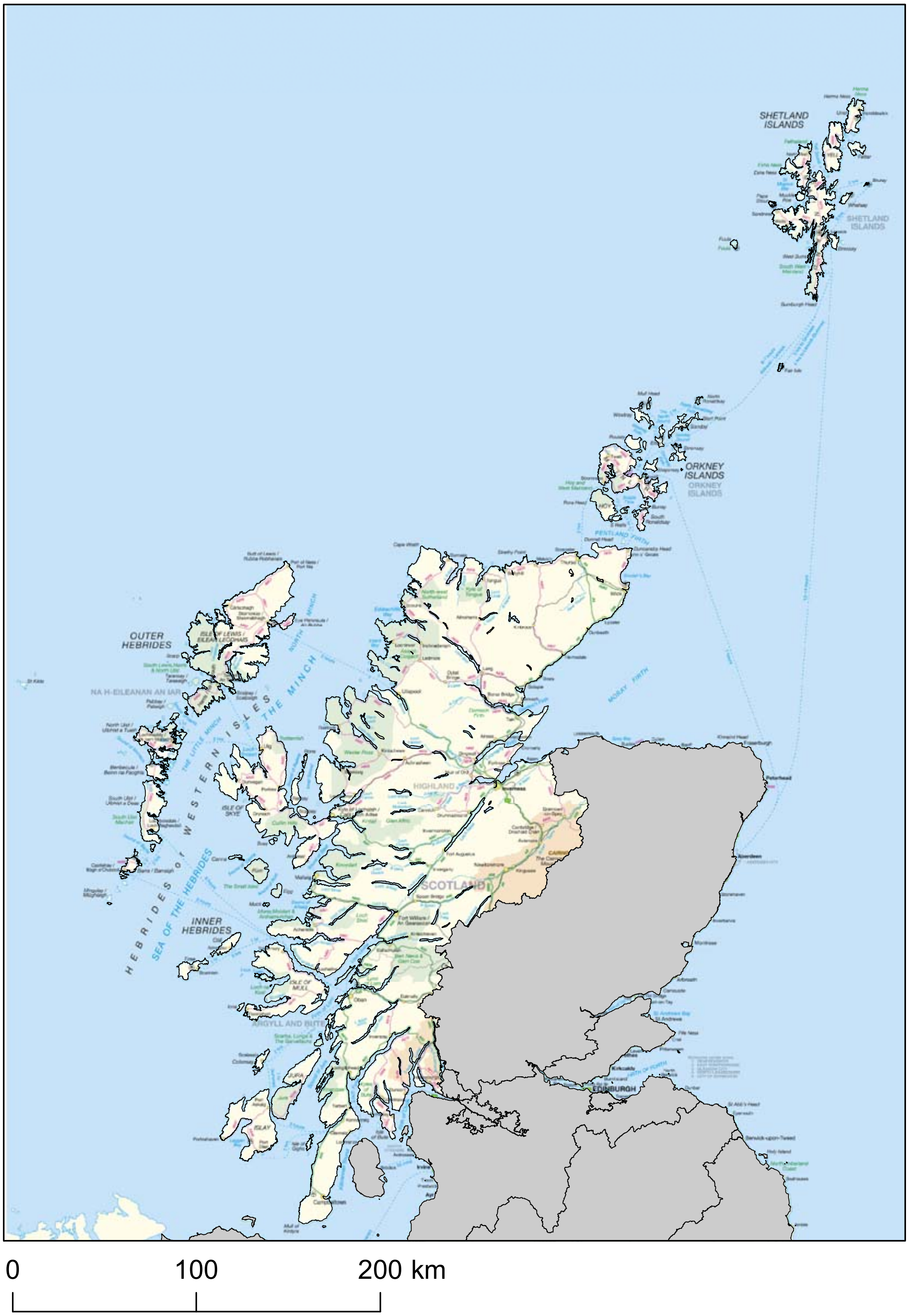
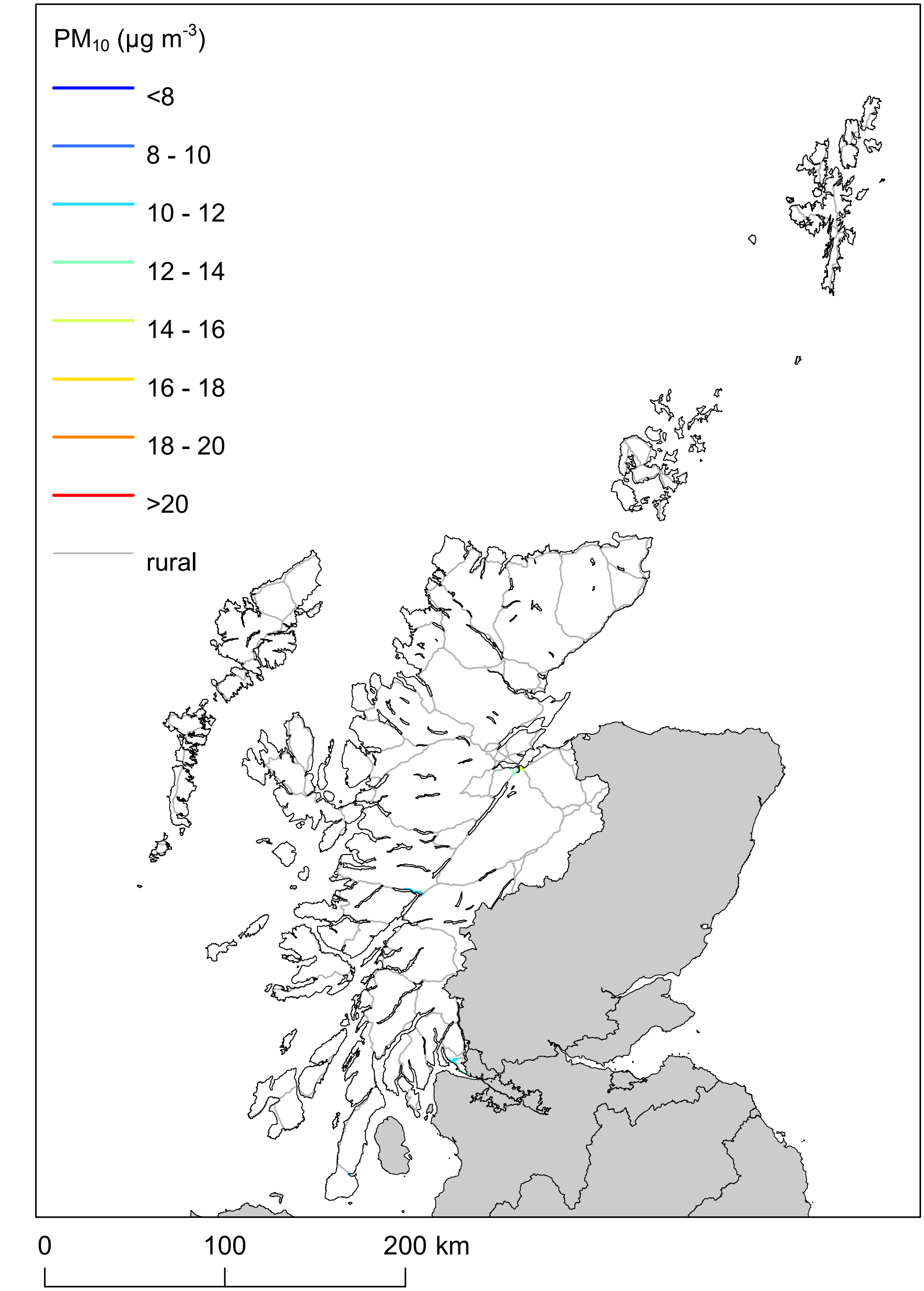


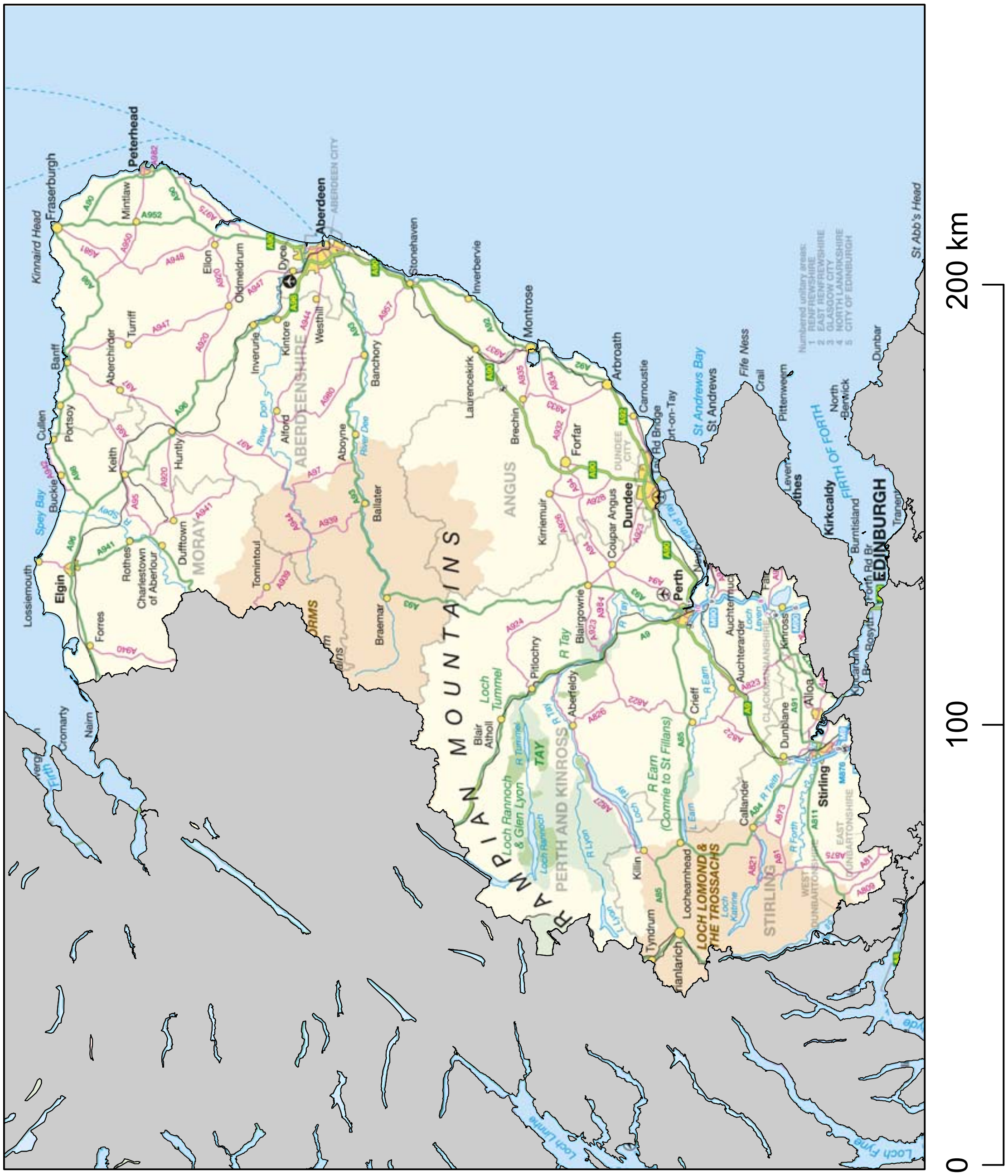
Figure 5.13 Detailed roadside PM_{10} map for 2009, µg m^{-3} showing the road-link concentrations in the Highlands (Scotland-specific model).





PM10 (µg m-3)
<8
8 - 10
10 - 12
12 - 14
14 - 16
16 - 18
18 - 20
>20
rural
0
100
200 km

Figure 5.14 Detailed roadside PM_{10} map for 2009, µg m^{-3} showing the road-link concentrations in North East Scotland (Scotland-specific model).



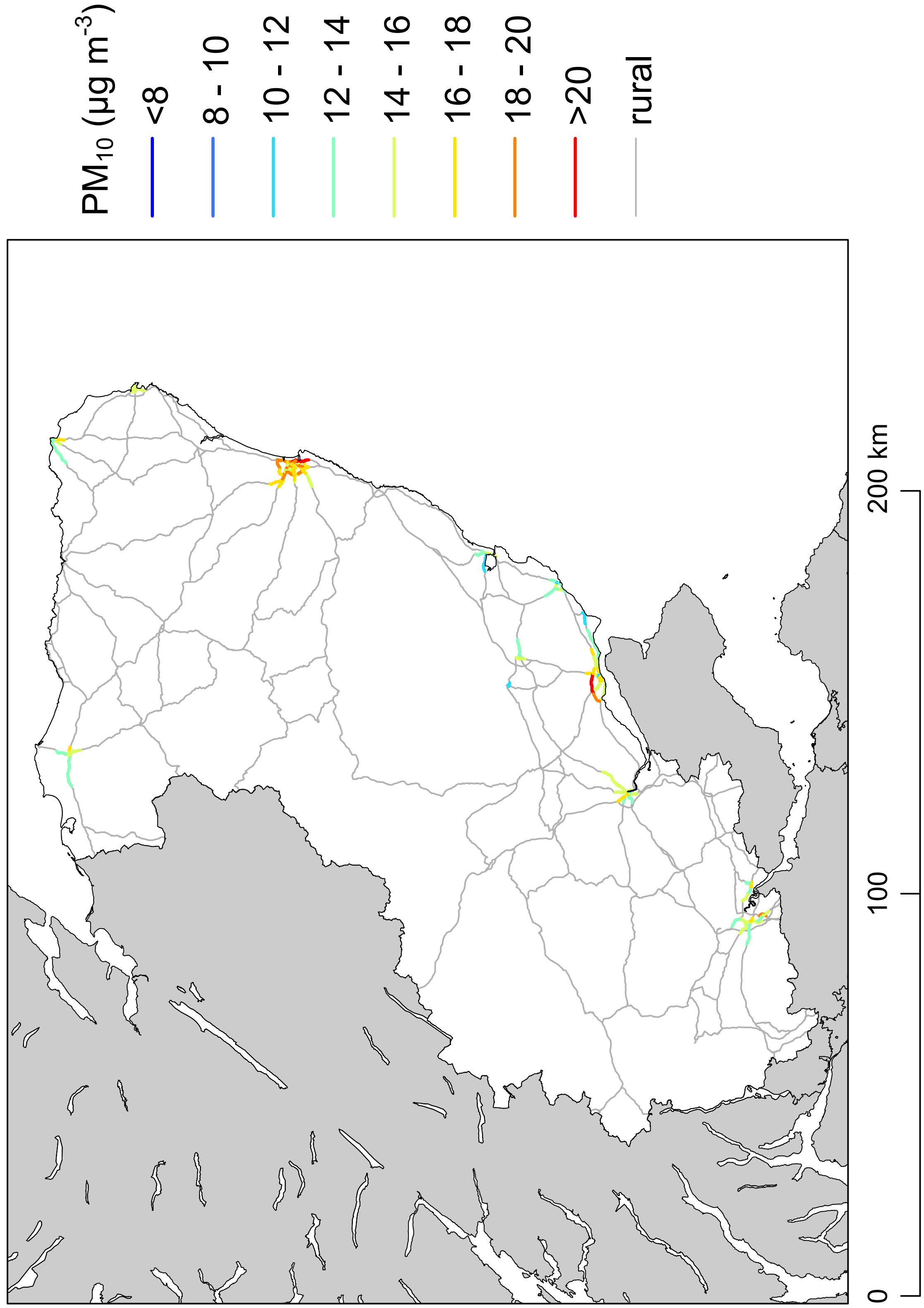
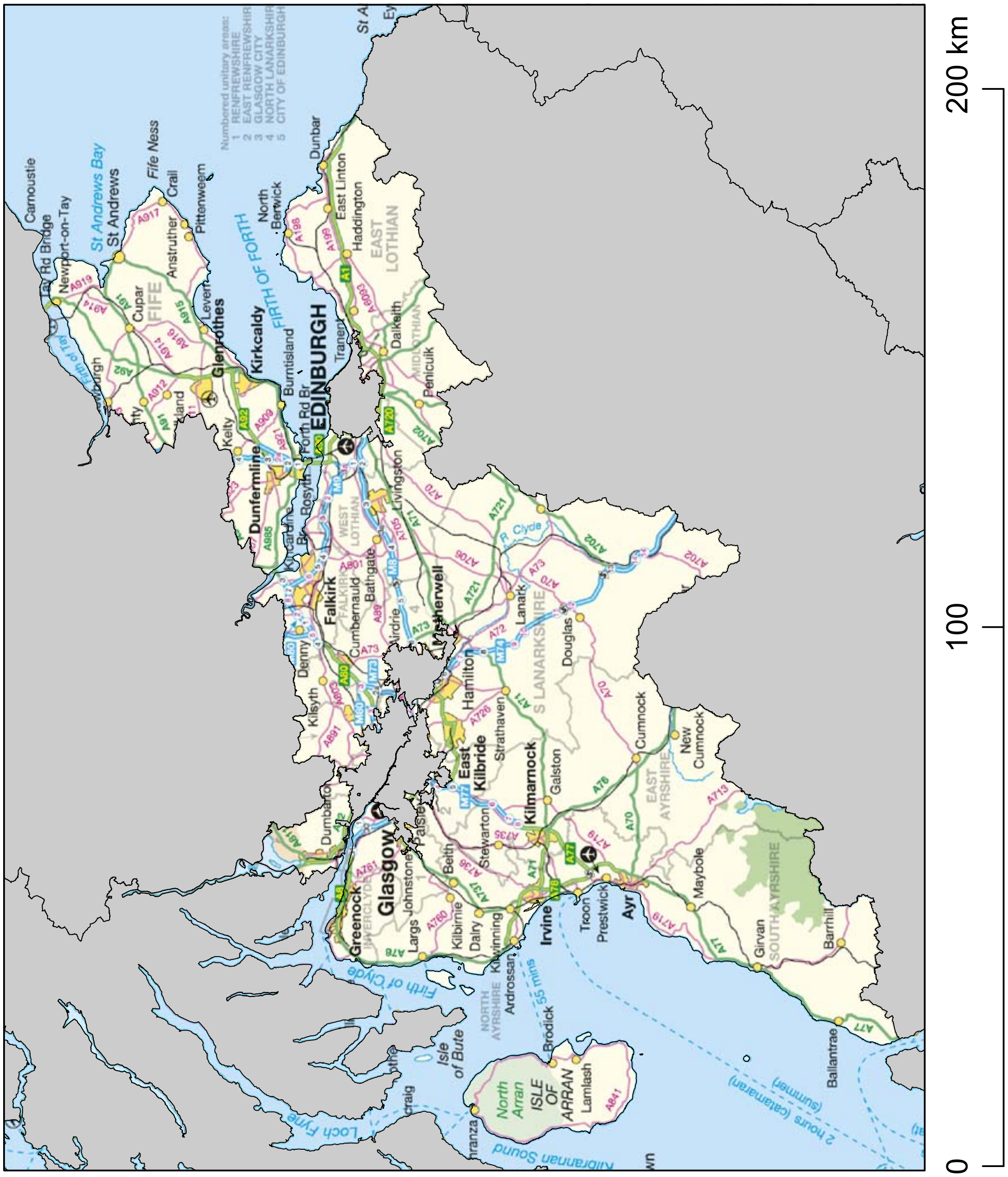

PM10 (µg m-3)
<8
8 - 10
10 - 12
12 - 14
14 - 16
16 - 18
18 - 20
>20
rural
0
100
200 km

Figure 5.15 Detailed roadside PM_{10} map for 2009, µg m^{-3} showing the road-link concentrations in Central Scotland (Scotland-specific model).



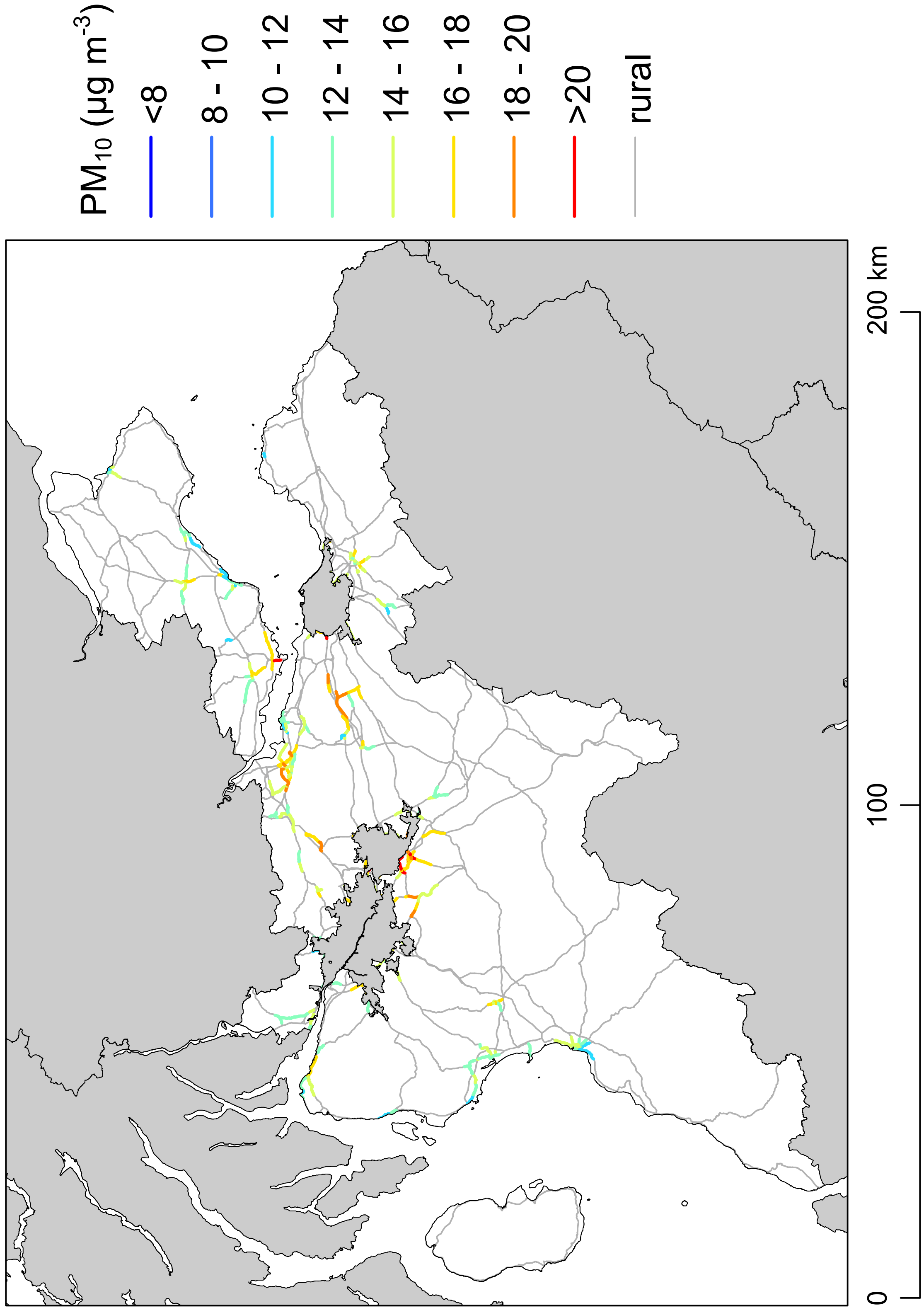
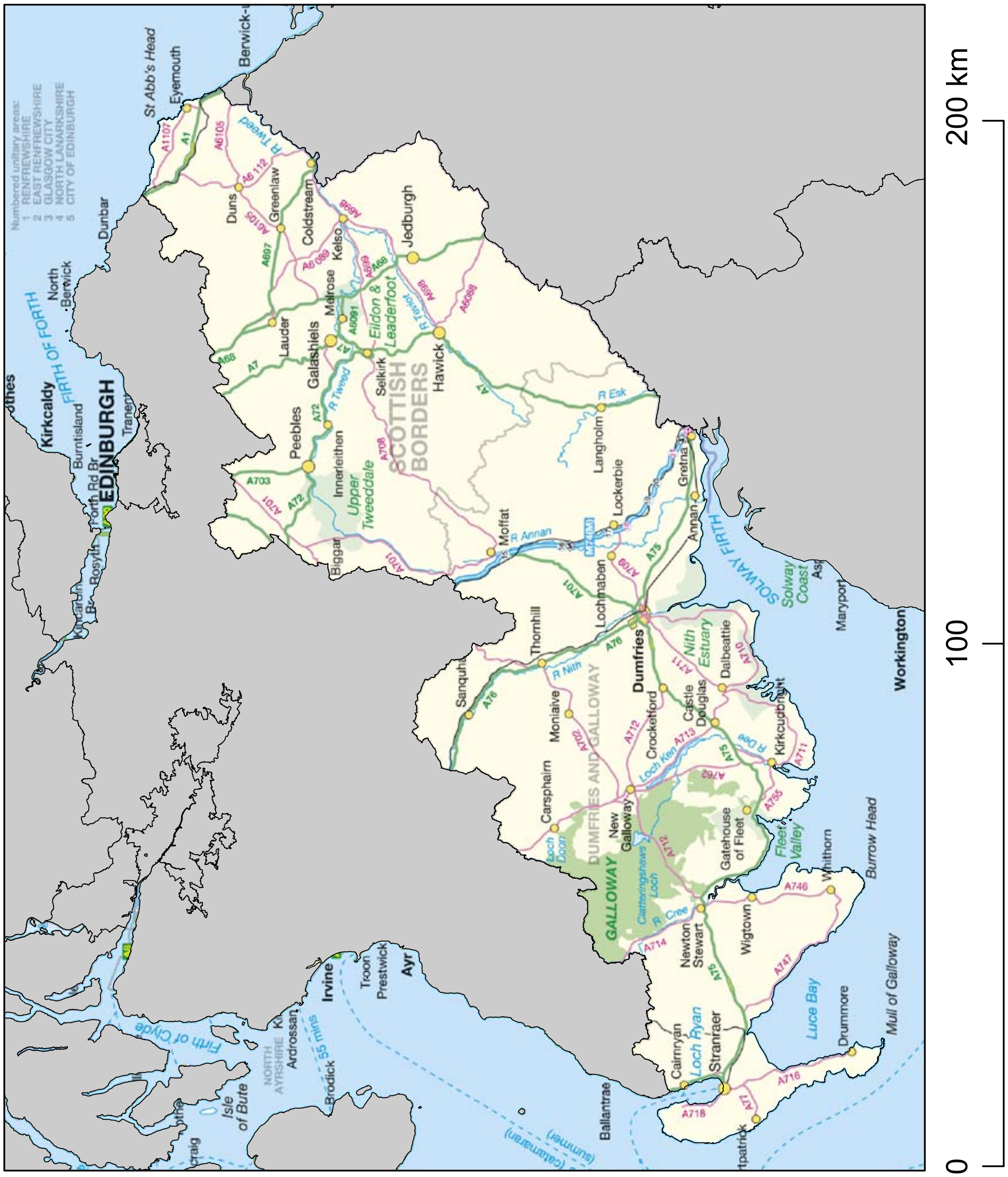

PM10 (µg m-3)
<8
8 - 10
10 - 12
12 - 14
14 - 16
16 - 18
18 - 20
>20
rural
0
100
200 km

Figure 5.16 Detailed roadside PM_{10} map for 2009, µg m^{-3} showing the road-link concentrations in the Scottish Borders (Scotland-specific model).



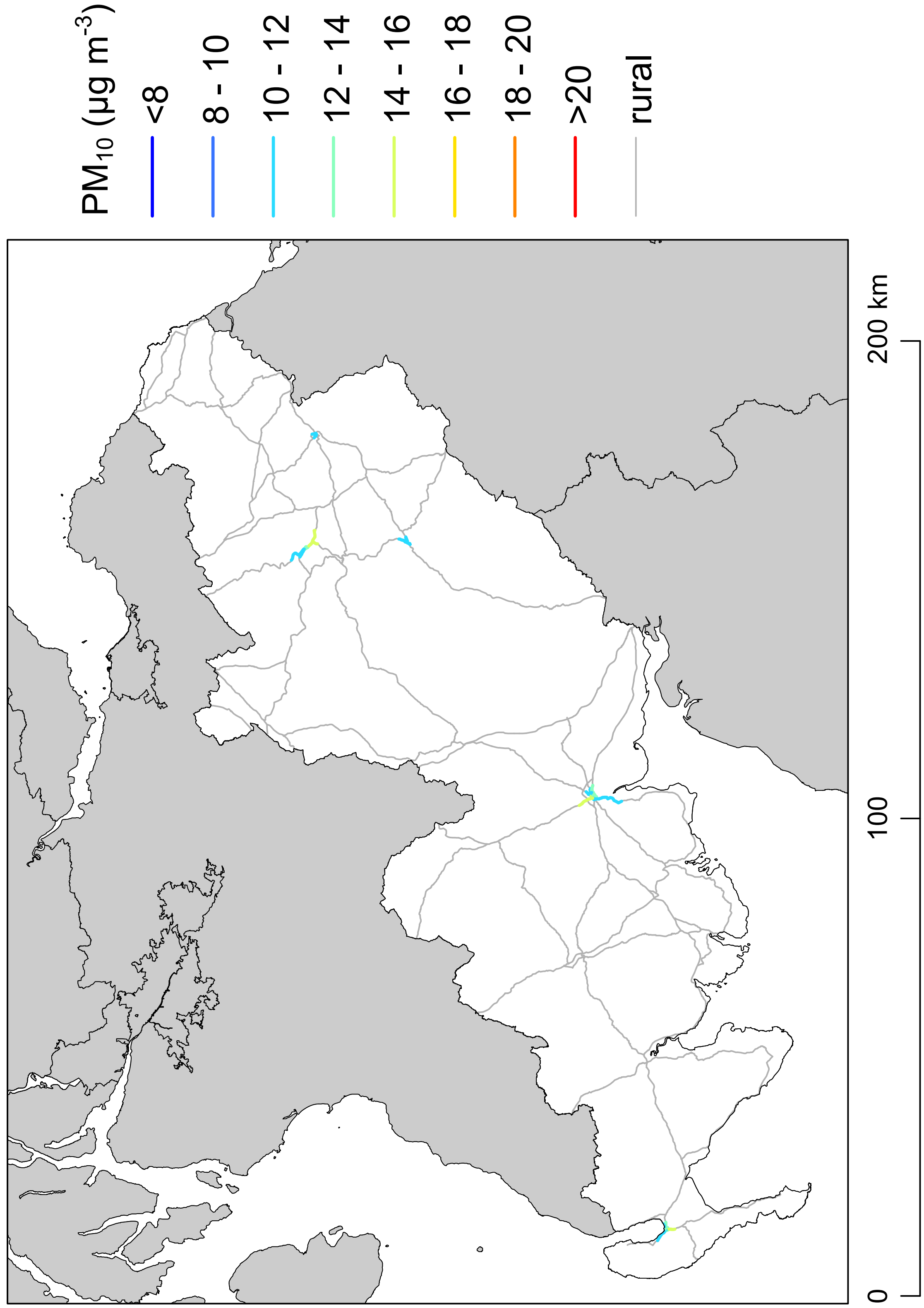
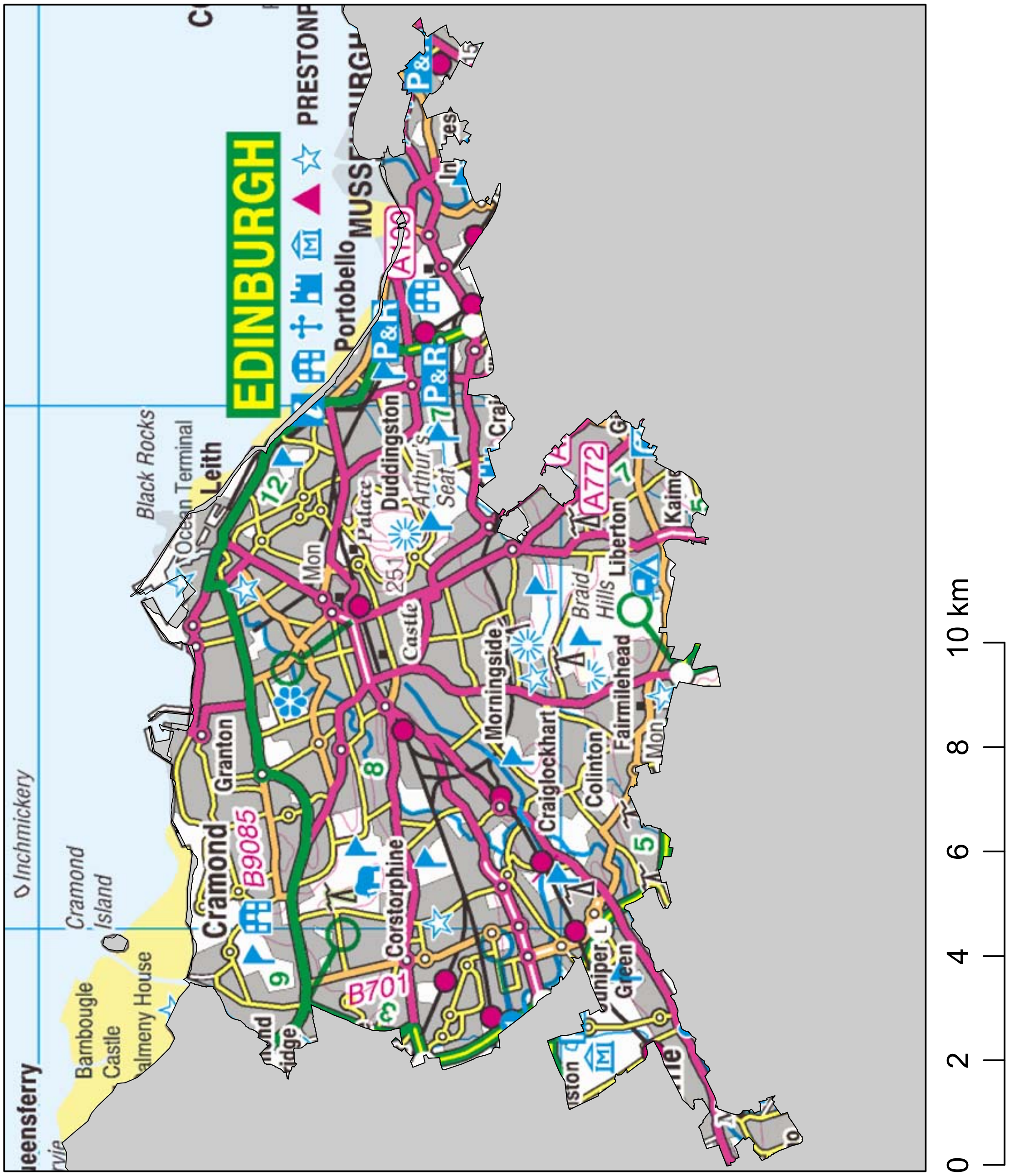

PM$_{10}$ (µg m^{-3})
<8
8 - 10
10 - 12
12 - 14
14 - 16
16 - 18
18 - 20
>20
rural
0
100
200 km

Figure 5.17 Detailed roadside PM_{10} map for 2009, μg m^{-3} showing the road-link concentrations in the Edinburgh Urban Area (Scotland-specific model).



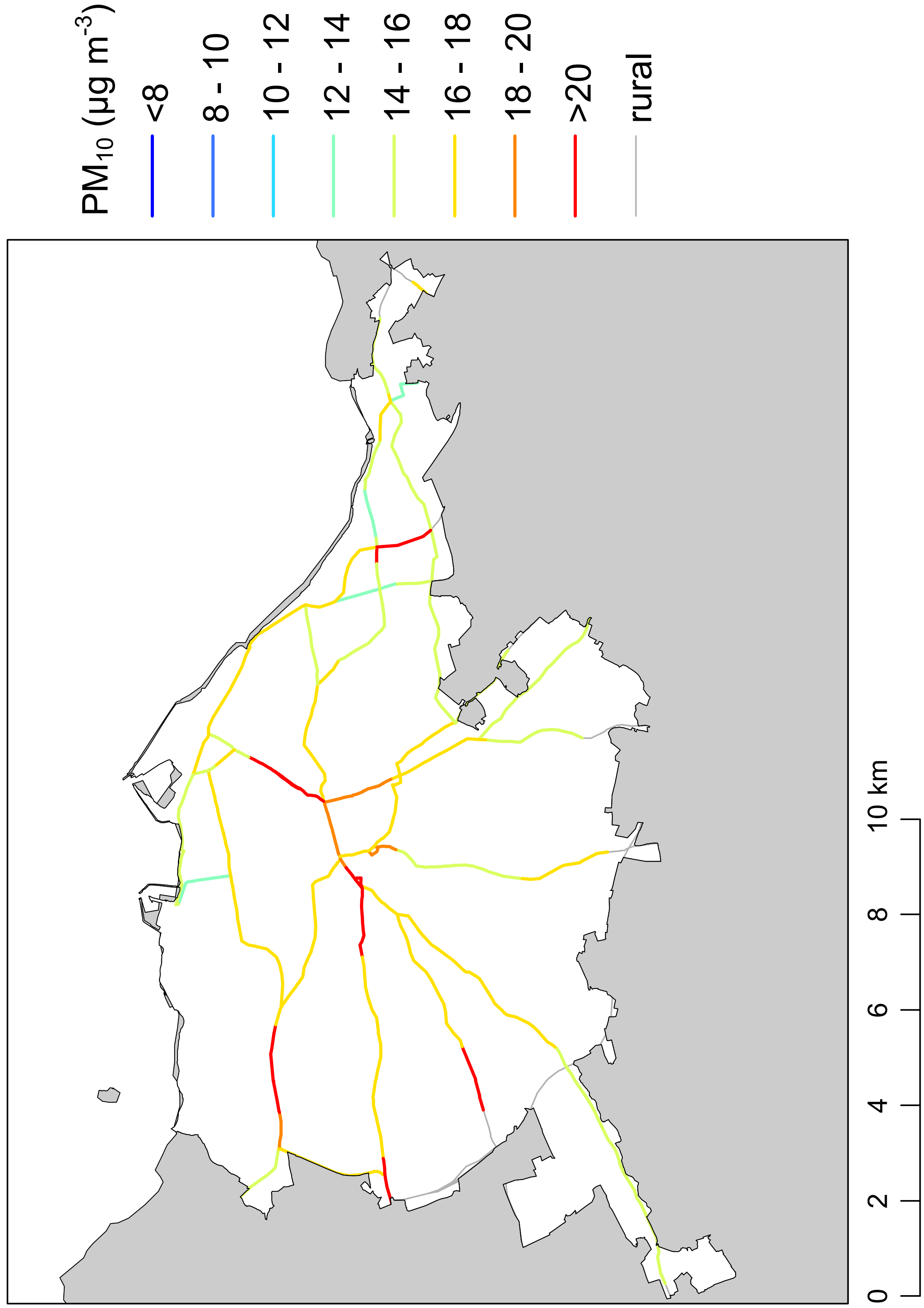
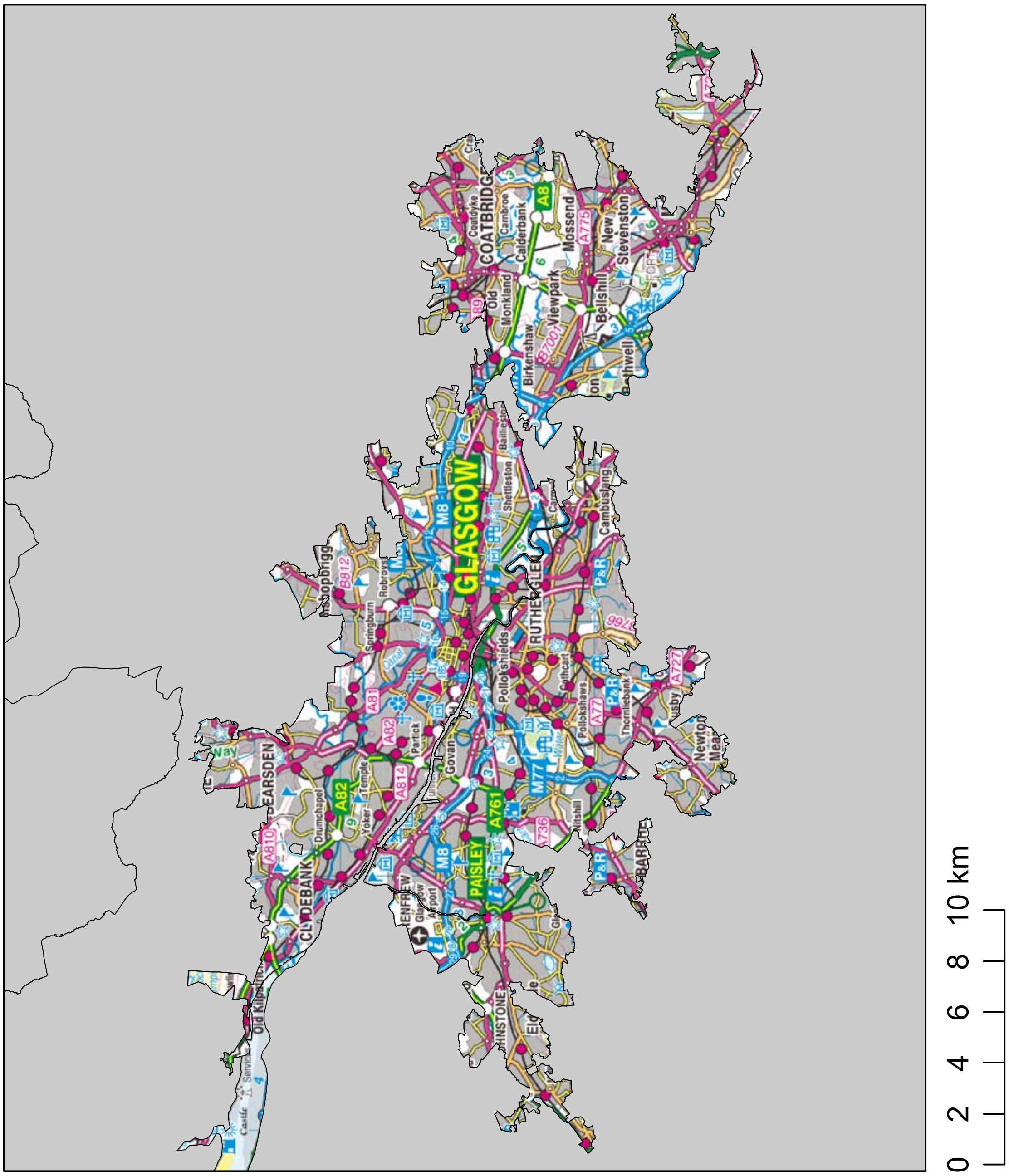
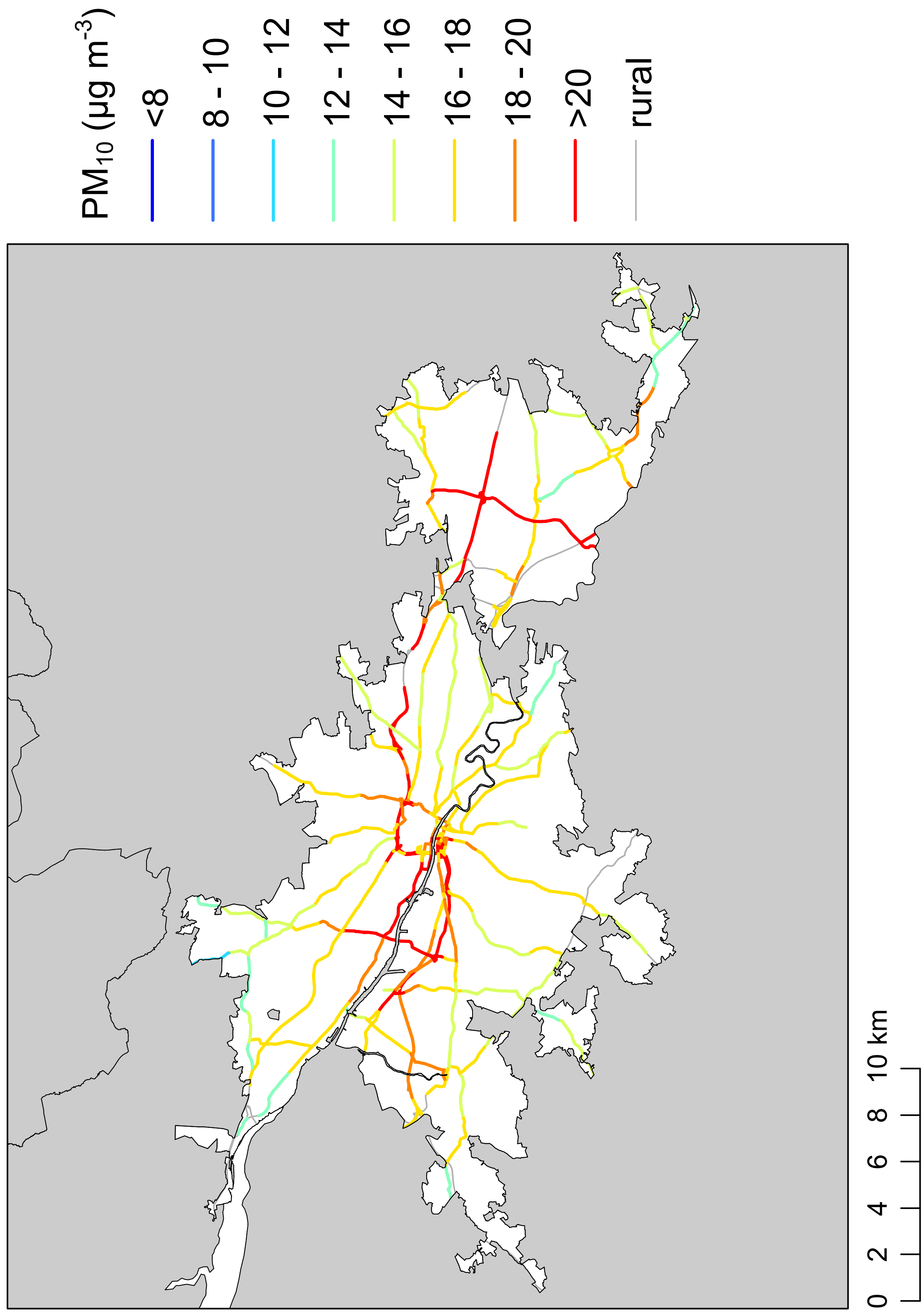

PM10 (µg m-3)
<8
8 - 10
10 - 12
12 - 14
14 - 16
16 - 18
18 - 20
>20
rural
0
2
4
6
8
10 km

Figure 5.18 Detailed roadside PM_{10} map for 2009, µg m^{-3} showing the road-link concentrations in the Glasgow Urban Area (Scotland-specific model).




PM_{10} ($\mu g\ m^{-3}$)
<8
8 - 10
10 - 12
12 - 14
14 - 16
16 - 18
18 - 20
>20
rural
0
2
4
6
8
10 km

6 Scotland-specific pollutant projections for 2010, 2015 and 2020

Projected annual mean concentrations of NO_2 and PM_{10} for 2010, 2015 and 2020, from a base year of 2009, are presented here for the purpose of forward projection assessment. The projected background annual mean concentrations were produced using the UK methodology, but as with the modelled Scottish annual mean concentrations for 2009, these were prepared using Scotland-specific data.

Recent analyses[2] conducted for the Scottish Government, Defra and the other DAs of historical air quality monitoring data from throughout the UK 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 accuracy of the forward projection maps presented here is closely dependent on the future emission projections used to prepare the background pollutant maps. Future emissions projections were based on current, published "year-adjustment" factors for NO_X and NO_2 concentrations for all years up until 2020. Further advice will be provided once the additional research being undertaken by the Scottish Government, Defra and the other DAs is completed. New "year-adjustment" factors will be incorporated in future updates of the NAEI and consequently will be reflected in future annual updates of the forward projected maps presented to the Scottish Government.

6.1 Scotland-specific background maps of projected annual mean NO_2 concentrations for 2010, 2015 and 2020

Figure 6.1 to 6.3 provide background maps of projected annual mean NO_2 concentrations for 2010, 2015 and 2020 based on the 2009 Scotland-specific model. The projected background maps for NO_2 show a progressive decrease in the background annual mean concentration between 2009 and 2020 due to the predicted reduction in primary NO_X and oxidant emissions, which contribute to the formation of NO_2. However, as discussed above there is considerable on-going investigation of likely future emissions of NO_X and NO_2.

6.2 Scotland-specific background maps of projected annual mean PM_{10} concentrations for 2010, 2015 and 2020

Figure 6.4 to 6.6 provide background maps of projected annual mean PM_{10} concentrations for 2010, 2015 and 2020 based on the 2009 Scotland-specific model. The projected background maps show a progressive decrease in the background annual mean PM_{10} concentration to below 8 $\mu g\ m^{-3}$ between 2009 and 2020 for the majority of Scotland which is expected due to the predicted reduction in primary PM_{10} emissions, and associated pollutants, e.g., NO_X and SO_2, which contribute to secondary PM_{10} formation, in the form of nitrate and sulphate-based aerosol. Higher (10-16 $\mu g\ m^{-3}$) PM_{10} concentrations were projected to persist for the eastern coast of Scotland. The enhancement in the annual mean background PM_{10} concentration along the east coast is thought to be due to contributions to the overall PM_{10} concentration from wind-blown soil and dust.

6.3 Annual CSV format Scottish Maps for LAQM Review and Assessment

The projected annual mean NO_X, NO_2, and PM_{10} concentrations by source sector for each grid square in Scotland from the Scotland-specific model for 2010, 2015 and 2020 have been prepared in CSV format files. These are analogous to the data already available to local authorities based on the UK PCM mapping for use in Review and Assessment reports for the purposes of LAQM. The data from the Scotland-specific model is available to Scottish local authorities to use in the preparation of their annual Review and Assessment reports (see: http://www.scottishairquality.co.uk/maps.php?n_action=data).

Figure 6.1 Background NO_2 map for 2010, μg m^{-3} (Scotland-specific model).

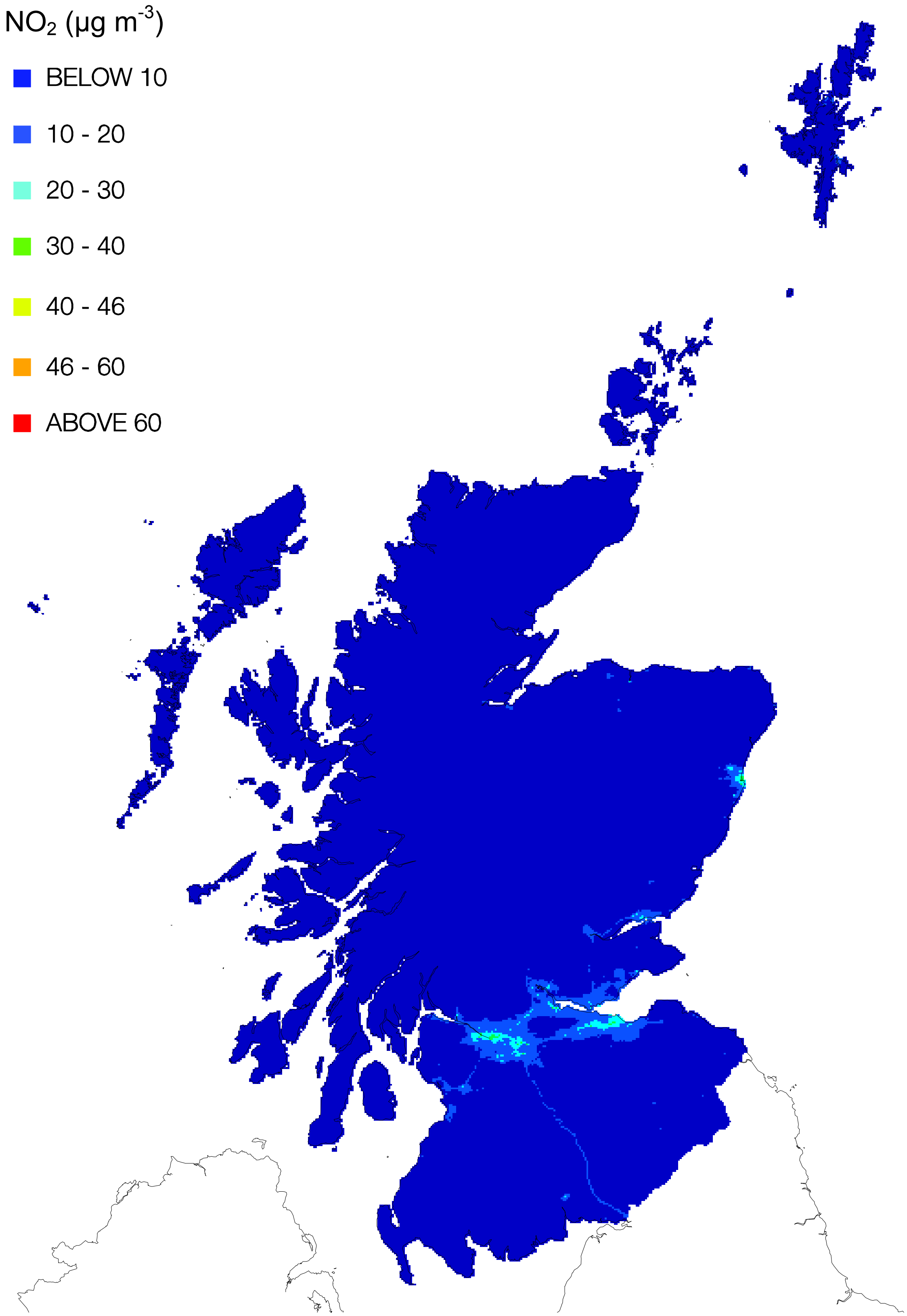


Figure 6.2 Background NO_2 map for 2015, µg m^{-3} (Scotland-specific model).

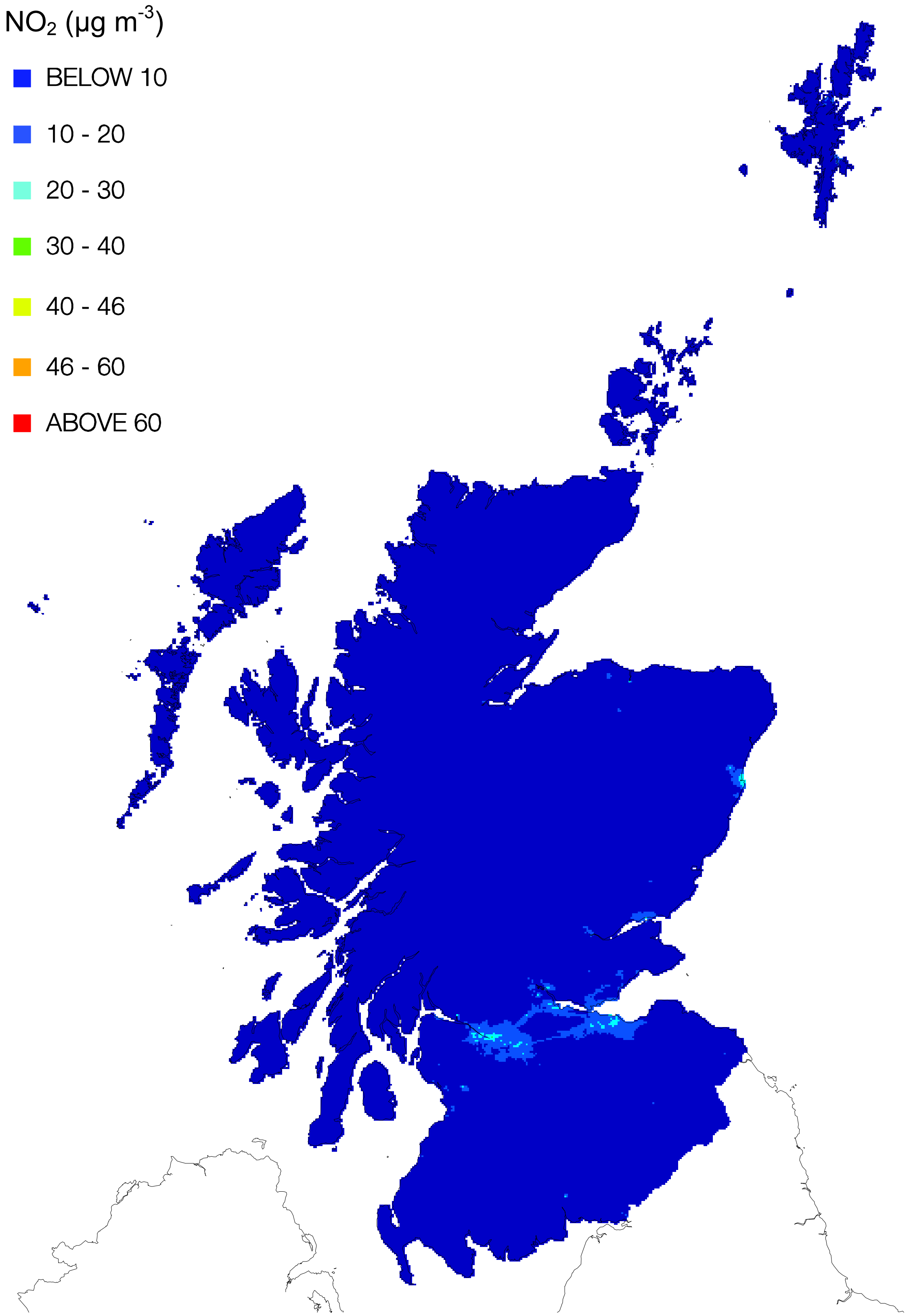


Figure 6.3 Background NO_2 map for 2020, µg m^{-3} (Scotland-specific model).

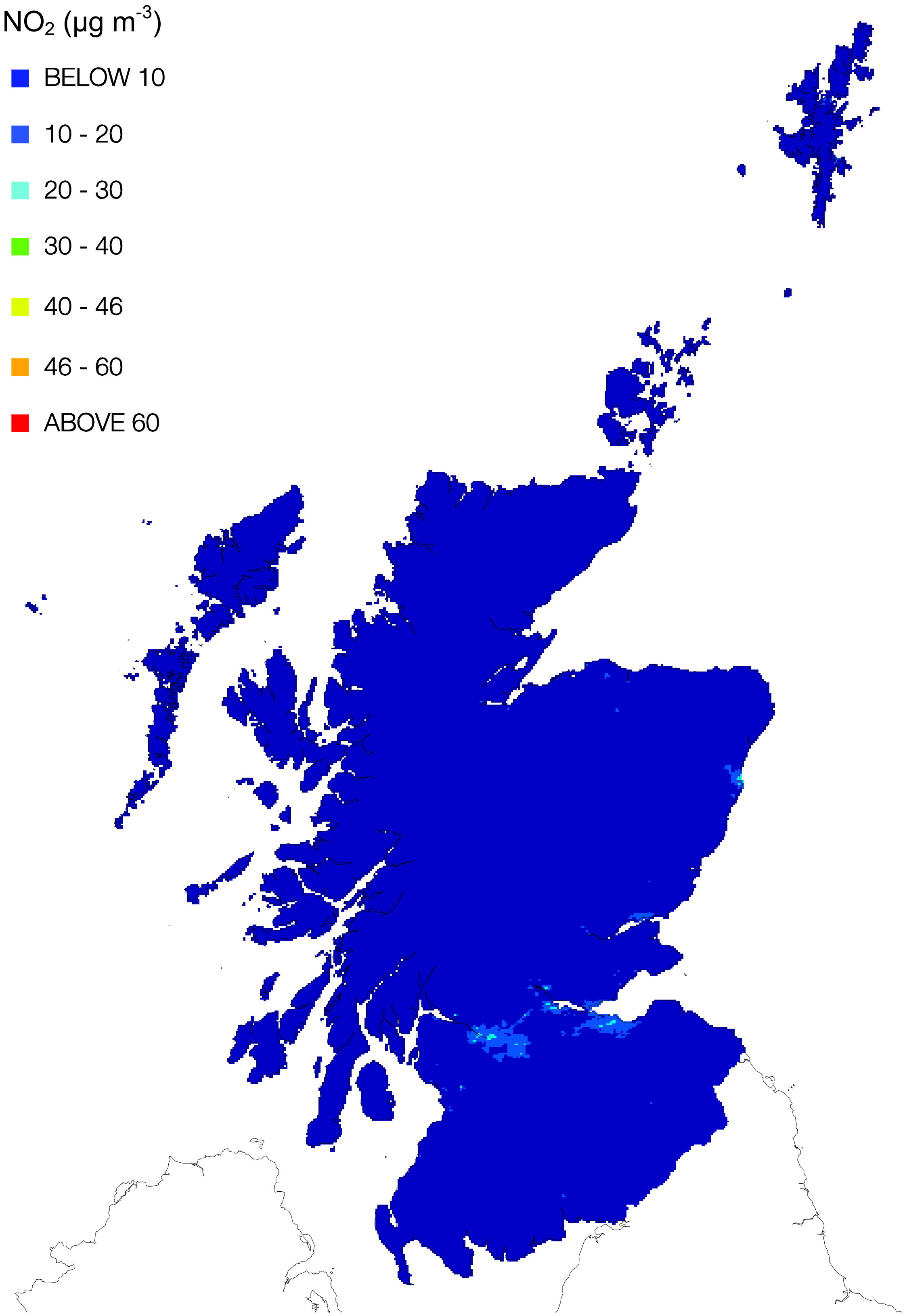


Figure 6.4 Background PM_{10} map for 2010, µg m-3 (Scotland-specific model).

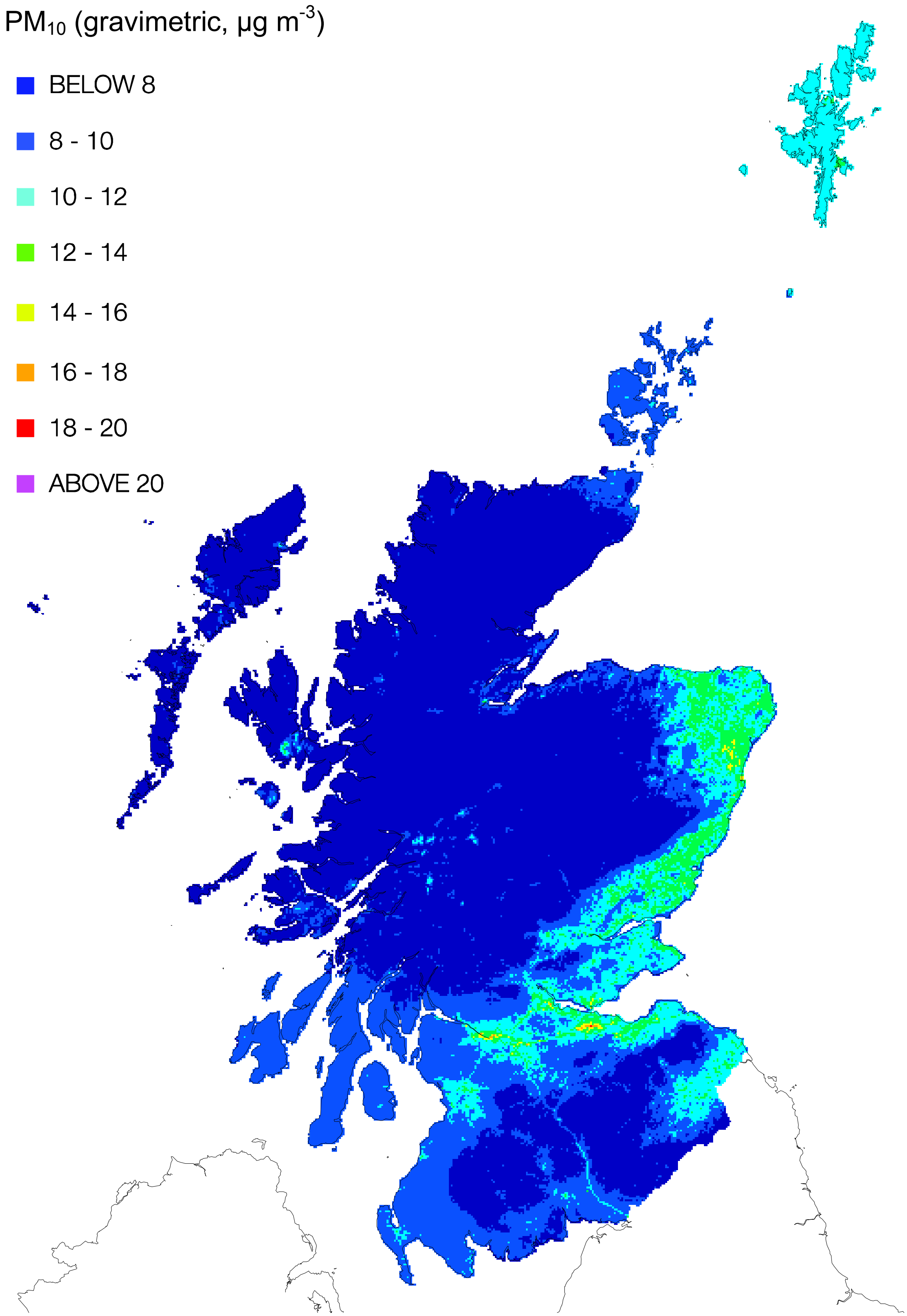


Figure 6.5 Background PM_{10} map for 2015, $\mu g\ m^{-3}$ (Scotland-specific model).

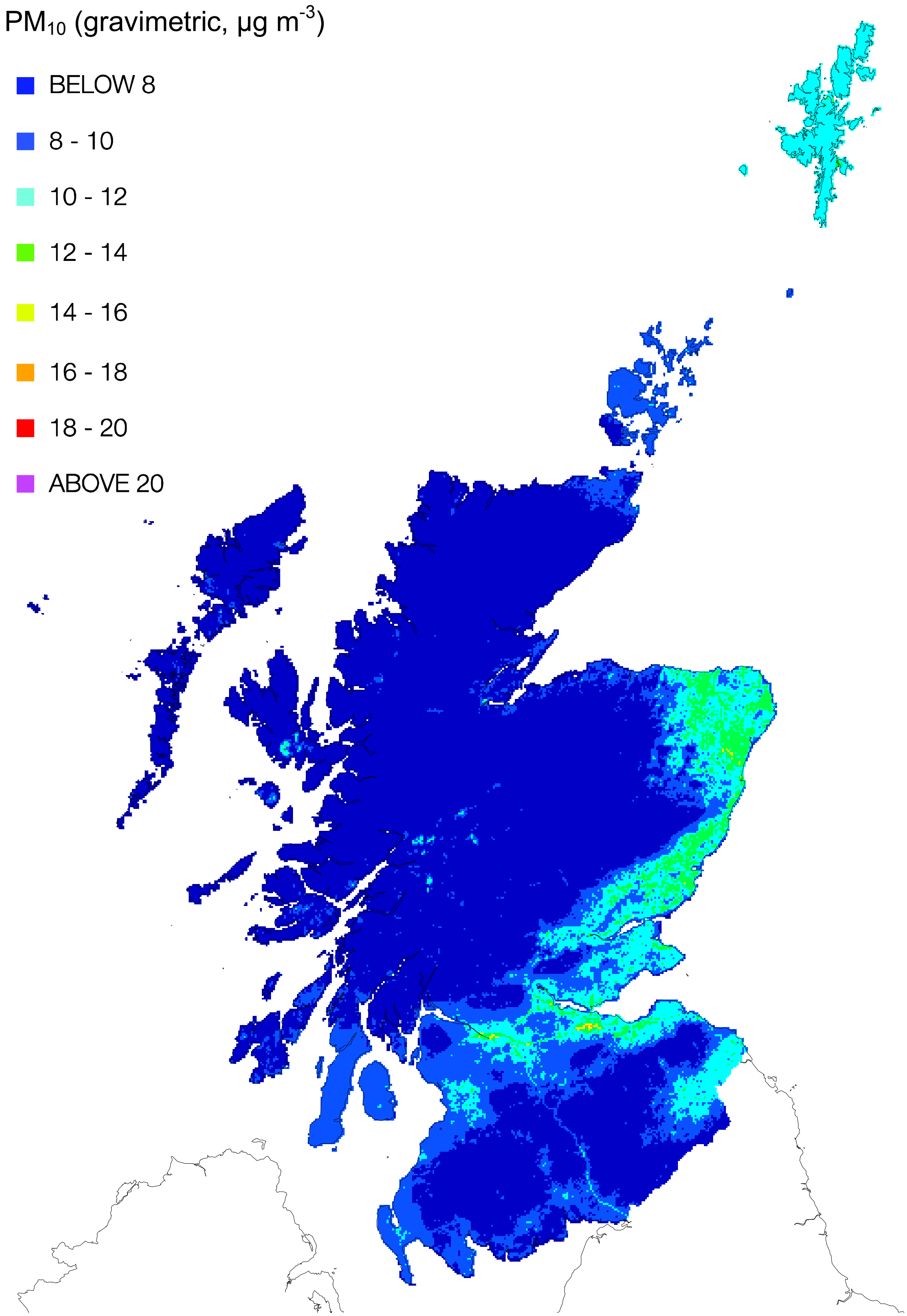
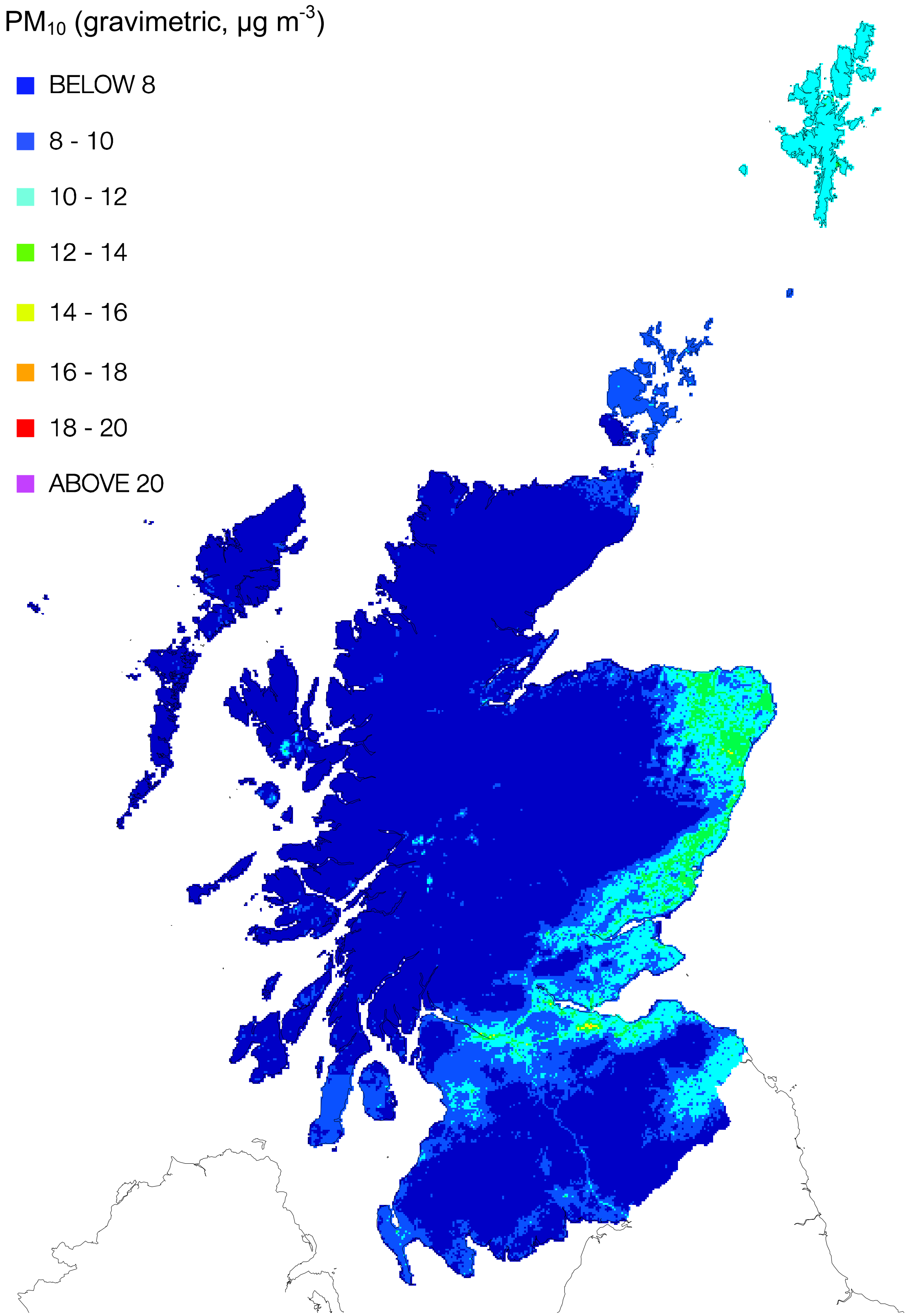


Figure 6.6 Background PM_{10} map for 2020, µg m^{-3} (Scotland-specific model).



7 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 pollutant maps for the Scottish Government for 2009 using measurements from Scottish air quality monitoring sites and Scottish meteorology. Future projection maps for 2010, 2015 and 2020 have also been prepared along with annual projections of pollutant concentrations by source sector for each grid square, and are available in CSV format.

In summary, the results of the 2009 Scotland-specific modelling exercise show:

- The modelled annual mean background NO_2 concentrations from the Scotland-specific model provided good agreement with the annual mean measured background NO_2 concentrations. Less agreement was seen when the modelled annual mean roadside NO_2 concentrations from the Scotland-specific model was compared to the annual mean measured roadside NO_2 concentrations.
- 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.
- No exceedences of the Scottish air quality objectives for NO_2 at background locations were modelled by the Scotland-specific background NO_2 model.
- Two exceedences of the Scottish air quality objectives for PM_{10} at background locations were modelled by the Scotland-specific background PM_{10} model. The two exceedences were modelled to occur in two adjacent grid squares in Central Scotland. The extent of the exceedence modelled in these two grid squares was of the order of 1 $\mu g\ m^{-3}$.
- Exceedences of both the Scottish annual mean NO_2 and PM_{10} air quality objectives were modelled at roadside locations. The majority of exceedences were modelled to occur in urban areas, at roadside locations with high traffic volumes, such as Edinburgh and Glasgow. The numbers of roadside exceedences of the Scottish NO_2 air quality objective were almost twice the number modelled for PM_{10}.
- Future projection maps show a steady decrease in the concentrations of background NO_2 and PM_{10}. However, as noted above, the accuracy of the forward projection maps is closely dependent on the future emission projections used to scale the NAEI emissions.

Currently there are only a limited number of sites available for calibrating and verifying the Scotland-specific model outputs. Ideally there should be two groups of sites: one for model calibration, one for model verification. Each group should contain 10-12 sites chosen based on geographic location, from the available Scottish air quality monitoring sites in order to provide a good representation of the air pollutant mass concentrations measured throughout the modelling extent. This year, for both the background and roadside pollutant models, air pollutant measurements from 8-16 air quality monitoring sites were used to calibrate the model, depending on pollutant, whilst a smaller number, 3-5 sites, were used to verify the model output.

The Scottish Government have put significant effort into increasing the number of sites in the SAQD in recent years. These efforts have contributed to the production of robust pollutant maps for NO_X, NO_2, and PM_{10} for Scotland for 2009 based on Scottish air quality measurements and Scottish meteorology. With improved data capture at the Scottish roadside NO_X/NO_2 and PM_{10} monitoring sites in 2010, it is hoped that a more rigorous verification of the model outputs can be undertaken next year.

From a LAQM 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}. However, it is more appropriate for anyone undertaking air quality studies in Scotland to use the Scotland-specific data rather than data from the UK maps. The Scottish Government expects Scottish local authorities to use the Scottish-specific data for LAQM purposes and also that other organisations undertaking air quality studies in Scotland are directed to the Scottish-specific background data. 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, including Scottish meteorology, Scottish air pollutant concentrations determined from monitoring data and scaled emissions projections. The scaling factors applied to the pollutant emissions are based on current understanding of the future variations in emissions and pollutant concentrations. As demonstrated in the case of roadside NO_2 there exists a considerable degree of uncertainty within the scaling factors, 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 2: Corrigendum for Scottish background and roadside NO_2 maps for 2009, 2010, 2015 and 2020

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 exceedences specified by each objective. The Scottish and UK national air quality objectives for PM_{10} are summarised in Table A.1.

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 exceedences	Percentile equivalent
Scotland	50	Daily mean	7	98^{th}
UK	50	Daily mean	35	90^{th}

An equivalent daily 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 98^{th} percentile (7 exceedences per year = 7/365 = 2%) of the daily mean concentration. This relationship was based on UK AURN PM_{10} air quality monitoring data as until 2008 there were insufficient Scottish PM_{10} monitoring sites to derive a relationship.

In order to test the suitability of the application of the equivalent daily mean PM_{10} concentration of 22 µg m^{-3} based on UK AURN PM_{10} air quality monitoring data measured between 1992 and 2007 year-on-year, the equivalent daily mean PM_{10} concentration is recalculated each mapping year. Table A.2 summarises the equivalent daily mean air quality PM_{10} objective for Scotland (90^{th} percentile, Figure A.1) and the UK (98^{th} percentile, Figure A.2) based on UK AURN PM_{10} air quality monitoring data from 1992-2009. The table includes 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). The table also includes the equivalent daily mean PM_{10} concentrations for 2007 and 2008, which are included for comparison, and were calculated from PM_{10} air quality monitoring data upto the end of those calendar years.

Table A.2 shows that there is a small degree of annual variation in the value of the equivalent daily mean PM_{10} concentration for 2007, 2008 and 2009, but overall the values are broadly consistent. The application of a Scottish annual mean PM_{10} equivalent value of 22 µg m^{-3} based on UK AURN PM_{10} air quality monitoring data measured from 1992 to 2007 is not unreasonable compared to the Scottish annual mean PM_{10} equivalent value of 20.1 µg m^{-3} based on Scottish AURN PM_{10} air quality monitoring data measurements from 1992 to 2009 exclusively.

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 1992-2009.

	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** air quality monitoring sites
Data range	1992-2009	1992-2009	1992-2009
Objective value (µg m^{-3})	50	50	50
Metric	Daily mean	Daily mean	Daily mean
Permissible exceedences	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)†

† 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 (1992-2009).

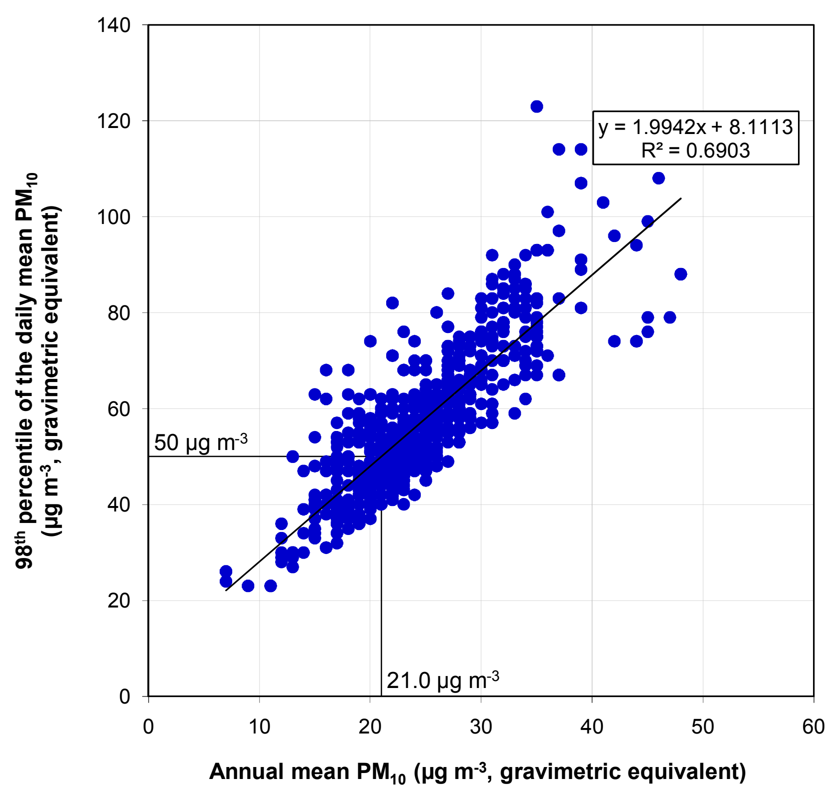


Figure A.2 Relationship between the UK annual mean PM_{10} concentration and the 90^{th} percentile of the UK daily mean PM_{10} concentration (1992-2009).

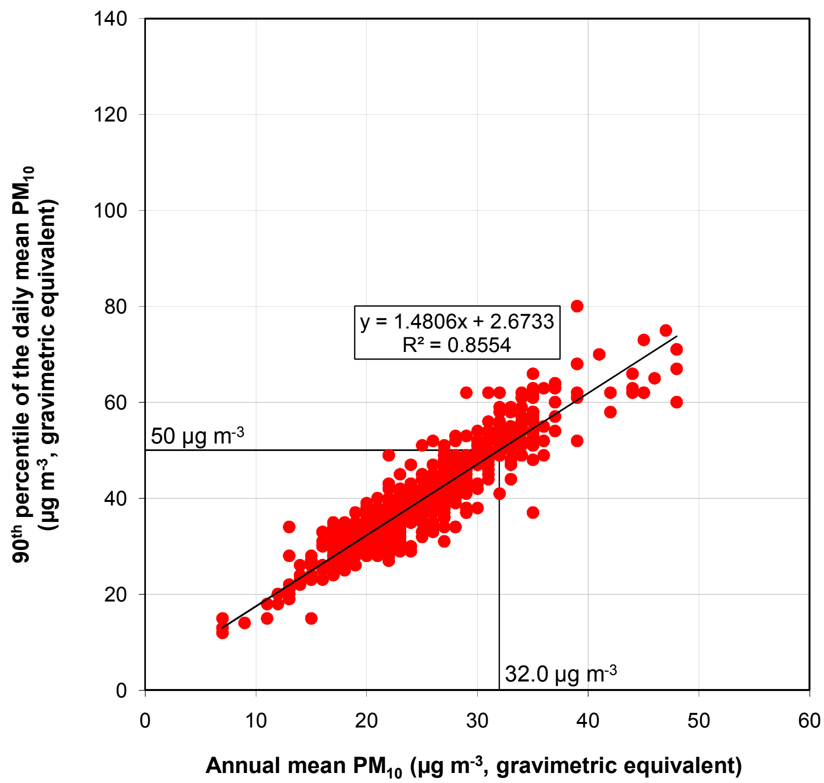
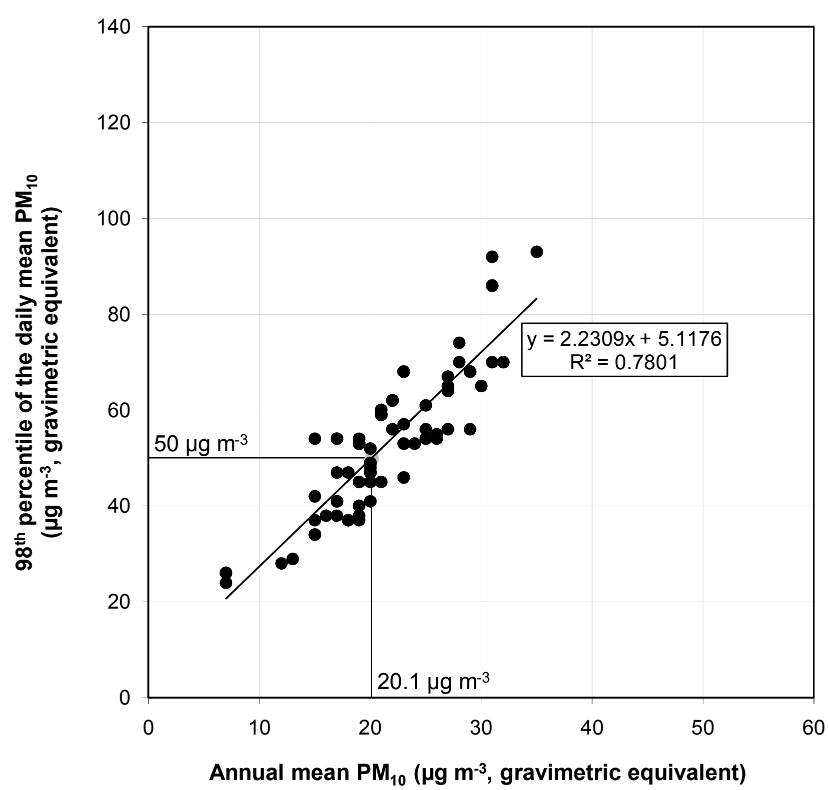


Figure A.3 Relationship between the Scottish annual mean PM_{10} concentration and the 98^{th} percentile of the Scottish daily mean PM_{10} concentration (1992-2009).



Appendix 2

Corrigendum for Scottish background and roadside NO_2 maps for 2009, 2010, 2015 and 2020

Maps of estimated annual mean NO_2 concentrations were calculated from modelled NO_X model uses representative equations to account for the chemical coupling of NO, NO_2, and O_3 within the atmosphere. The modelled background and roadside NO_2 concentration is calculated from background or roadside NO_X concentration using a sixth order polynomial relationship of the form:

$$NO_2 = a[NO_X] + a_2[NO_X]^2 + a_3[NO_X]^3 + \ldots + a_i[NO_X]^i \times [OX]_B + c,$$

where:

i	=	6,
NO_2	=	background or roadside NO_2 concentration (ppb),
$[NO_X]$	=	background or roadside NO_X concentration (ppb),
$[OX]_B$	=	background oxidant concentration (ppb),
a_i, c	=	coefficients.

For the background NO_2 model coefficients a_1 and c are calculated by comparing the measured NO_X to the ratio of the $[NO_2]_{obs}/[NO_2]_{calc}$, whilst for the roadside NO_2 model coefficients a_1, a_2 and c are calculated by comparing the measured NO_X to the ratio of the $[NO_2]_{obs}/[NO_2]_{calc}$. In both cases, these coefficients were incorrectly derived in the original Scotland-specific modelling published in March 2011. The coefficients have been revised and background and roadside NO_2 concentrations for 2009 have subsequently been re-calculated and new maps prepared.

Corrected maps of background NO_2 concentrations for future years (2010, 2015, and 2020) have also been produced. Maps of roadside NO_2 concentrations for future years (2010, 2015, and 2020) are not typically published.

Figures B1 to B.4 show the difference between the original modelled (March 2011) background NO_2 concentrations and the re-modelled (May 2011) concentrations for 2009, 2010, 2015, and 2020, respectively. The purpose of the maps is to indicate the locations where differences exist and the extent of the differences. Examination of the maps shows that the decrease in the background NO_2 concentration between the original modelled and re-modelled values is typically less than 1 µg m^{-3}, but can reach 2 µg m^{-3}. The greatest difference exists in urban conurbations and around major road links due to the high number of sources (vehicle emissions). The lowest differences exist in the north west of Scotland, the Outer Hebrides, Orkney Isles and Shetland Isles.

Figure B.1 Difference between the original modelled (March 2011) background NO_2 concentrations ($\mu g\ m^{-3}$) and the re-modelled (May 2011) concentrations for 2009, for the Scotland-specific model.

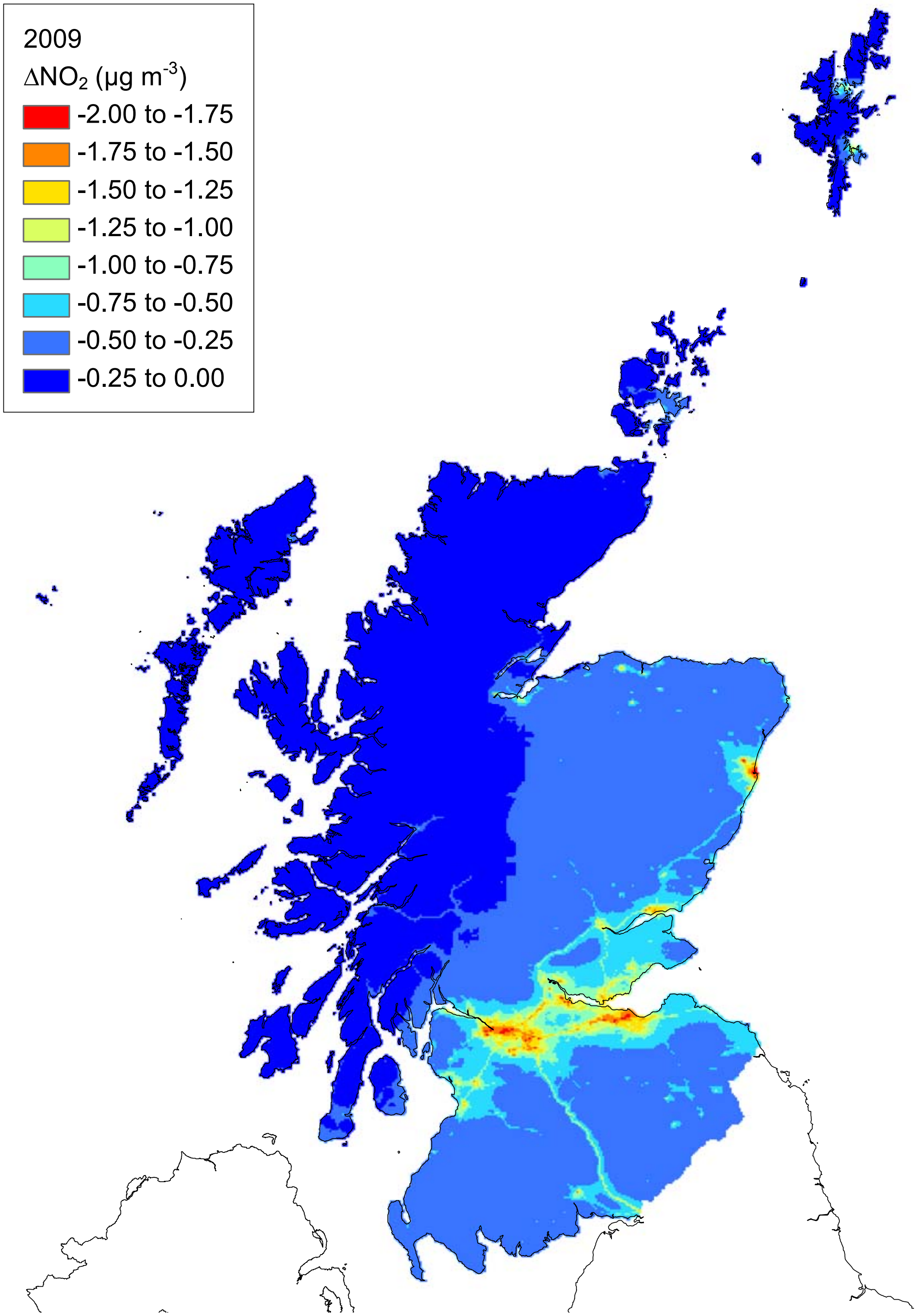


Figure B.2 Difference between the original modelled (March 2011) background NO_2 concentrations ($\mu g\ m^{-3}$) and the re-modelled (May 2011) concentrations for 2010, for the Scotland-specific model.

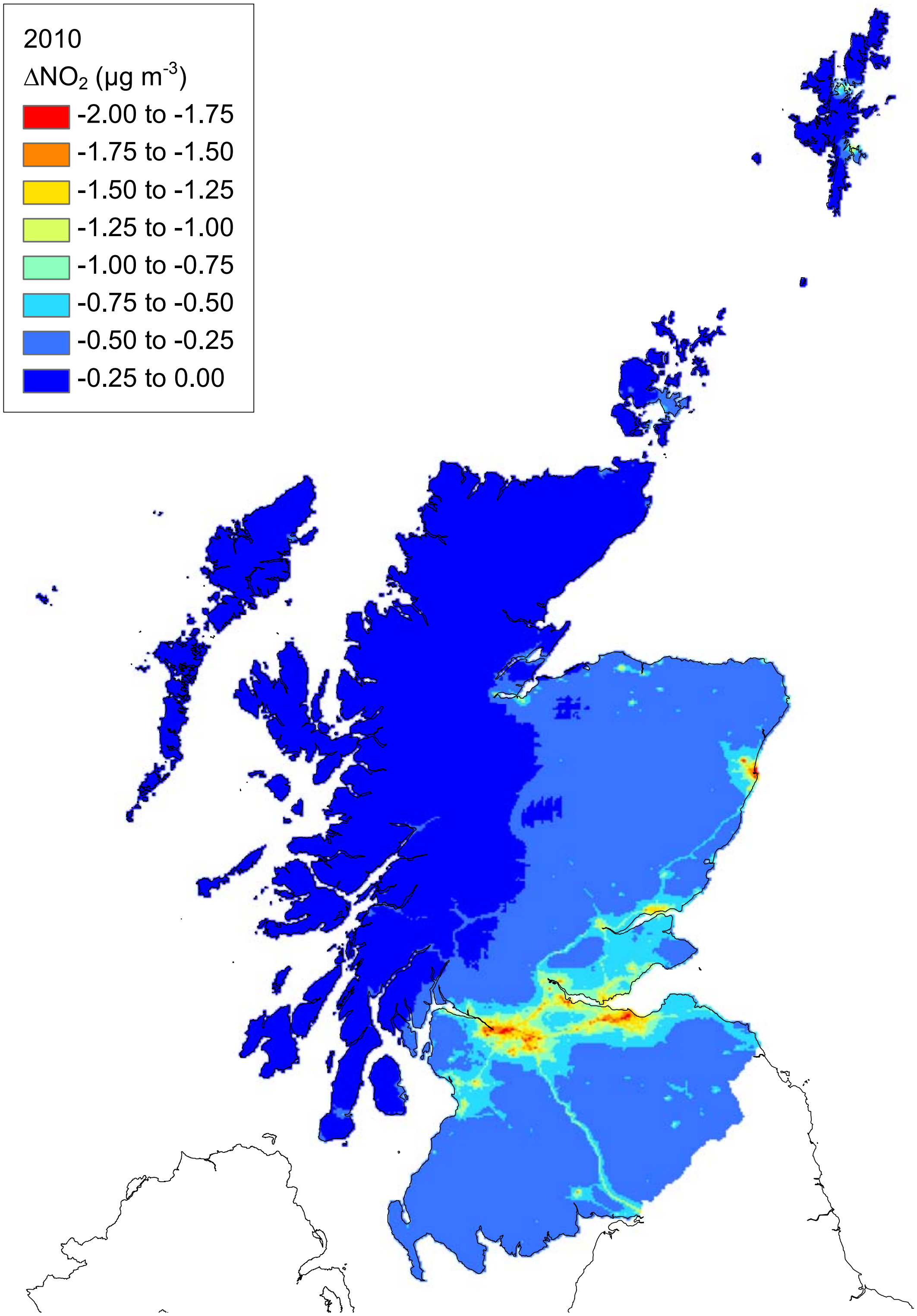


Figure B.3 Difference between the original modelled (March 2011) background NO_2 concentrations ($\mu g\ m^{-3}$) and the re-modelled (May 2011) concentrations for 2015, for the Scotland-specific model.

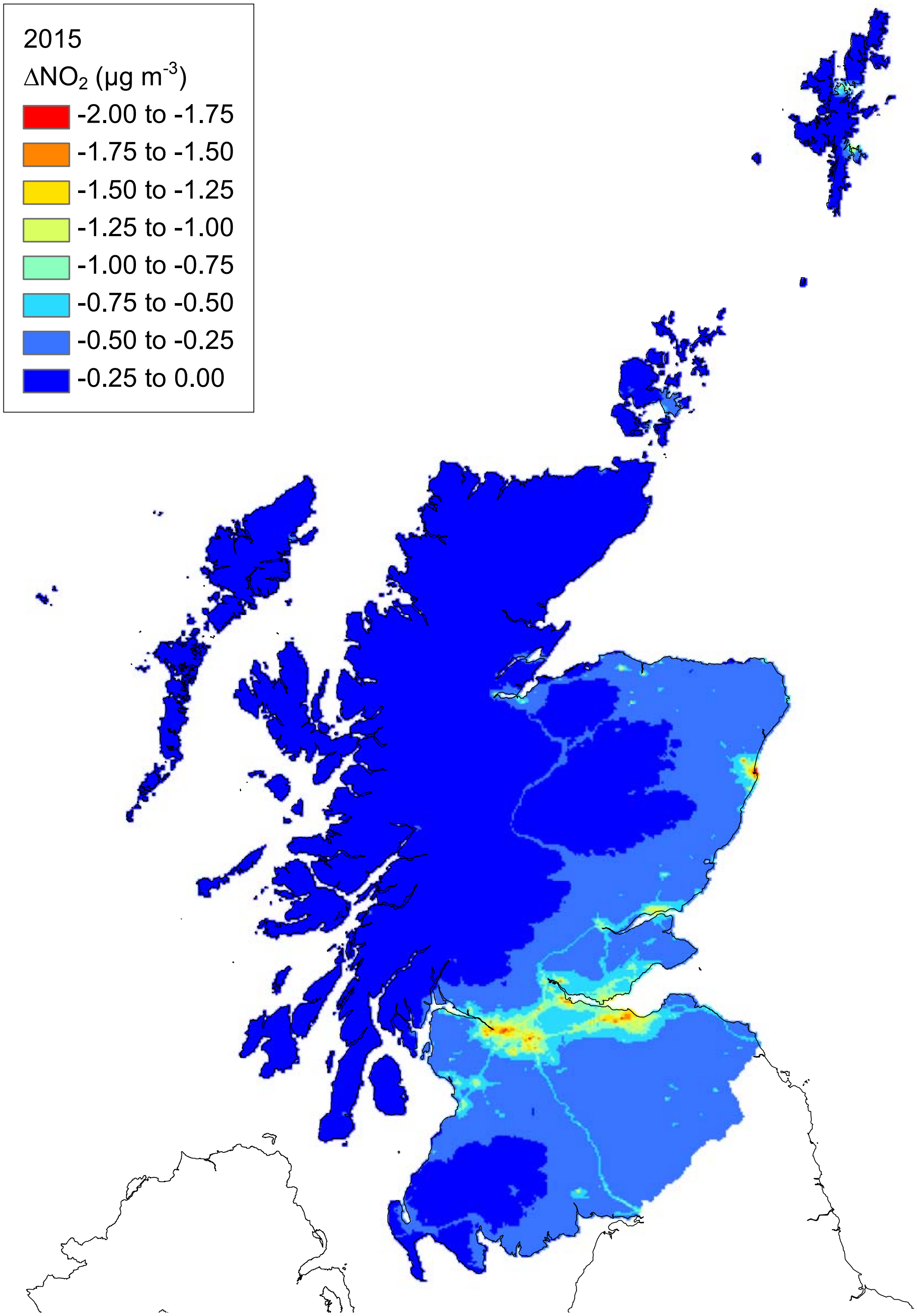
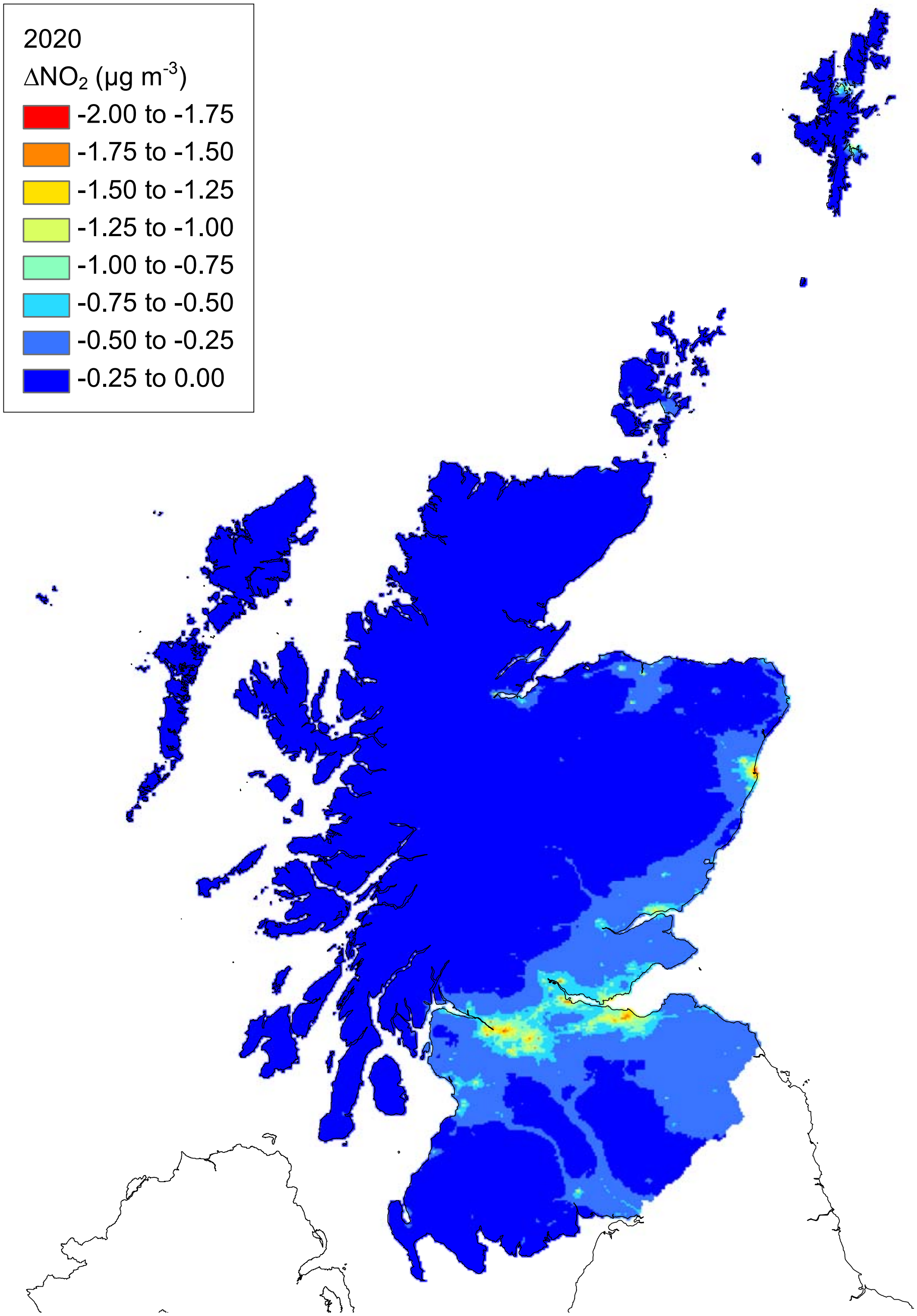


Figure B.4 Difference between the original modelled (March 2011) background NO_2 concentrations ($\mu g\ m^{-3}$) and the re-modelled (May 2011) concentrations for 2020, for the Scotland-specific model.



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