Scottish Air Quality Maps

Pollutant modelling for 2010 and projected concentrations for 2015, 2020, 2025, and 2030: 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 km x 1 km grid) and roadside air pollutant concentrations for urban road links throughout Scotland.

The air pollutant maps and projected (future) air pollutant concentrations discussed in this report utilise the Pollution Climate Mapping (PCM) air pollutant concentration modelling and mapping methodology developed for the UK. This provides air pollution maps for the Scottish Government, Defra, and the other Devolved Administrations 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 was therefore identified as an area that may not conform as well as other areas to the general calibration performed for the UK as a whole. This has provided the need for the more detailed Scotland-specific study undertaken within the Scottish Air Quality Database project. Here the Pollution Climate Mapping methodology has been applied to provide pollution maps of Scotland for the Scottish Government for 2010 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}.

2010 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 2010 Scottish PM_{10} monitoring data (FDMS, Partisol and VCM corrected TEOM data). 2010 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 10-12 air quality monitoring sites were used to calibrate the model, depending on pollutant, whilst a smaller number, 1-6 sites, were used to verify the model output.

The 2010 annual mean background air pollutant concentration maps combined Scottish air pollutant measurements with spatially disaggregated emissions information. Scottish air pollutant emissions were based on the UK's National Atmospheric Emissions Inventory (NAEI) and the most recently updated (as of January 2012) National energy usage statistics (UEP43). The Scotland-specific model included the most recently revised (as of January 2012) NO_X emission factors for road transport emissions, taken from COPERT4 v8.1, and ANPR/DVLA-scaled data, to represent the most up-to-date vehicle fleet information in Scotland.

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 background concentrations of NO_X, NO_2, and PM_{10}, for 2015, 2020, 2025, and 2030, 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.

In previous years, the Scotland-specific model has not identified any exceedances of the Scottish annual mean NO_2 objective of 40 µg m^{-3} at background locations. The 2010 Scotland-specific model identified six, 1 km^2 grid squares where the Scottish annual mean NO_2 objective was exceeded. Four of the six grid squares were located in north-east Scotland, in and around Aberdeen, and were believed to be due to NO_2 emissions from maritime sources. These exceedances were believed to be due to better understanding and parameterisation of maritime emissions, e.g., from ships, in recent years. The other two grid squares were located in central Glasgow and at the junction of the M8 and M9 near Edinburgh, respectively.

Exceedances of the Scottish annual mean PM_{10} objective of 18 µg m^{-3} were modelled at six, 1 km^2 grid squares in Scotland. Two grid squares were located around the junction of the M8 and M9, and three to the east of this junction, along the M8 in the direction of Livingston. The sixth grid square was located where the A8 joins the M8 on the outskirts of Glasgow.

The 2010 Scotland-specific model identified 226 road links (317 km of road) which exceeded the Scottish NO_2 annual mean air quality objective. For PM_{10}, the Scotland-specific model identified 322 road links (472 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 2015, 2020, 2025, and 2030 based on the 2010 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 2015, 2020, 2025, and 2030 based on the 2010 Scotland-specific model maps show a progressive decrease in the background annual mean gravimetric PM_{10} concentration between 2010 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 20 years, based on current emissions estimates.

In summary, the results of the 2010 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.
- Exceedances of the Scottish NO_2 air quality objective were modelled by the Scotland-specific background NO_2 model at six background locations.
- Exceedances of the Scottish PM_{10} air quality objective were modelled by the Scotland-specific background PM_{10} model at six background locations. On the whole the extent of the exceedance of the Scottish PM_{10} air quality objective modelled in the six exceeding grid squares was typically of the order of 1 µg m^{-3}, but was as high as

2.5 µg m^{-3} in one grid square. The range of potential PM_{10} sources in the grid square with the highest exceedance were quiet diverse.

- Exceedances of both the Scottish annual mean NO_2 and PM_{10} air quality objectives were modelled at roadside locations. The majority of exceedances of the Scottish NO_2 and PM_{10} air quality objectives were modelled to occur in urban areas, at roadside locations with high volumes of traffic, such as Edinburgh and Glasgow. The number of roadside exceedances of the Scottish PM_{10} air quality objective was approximately 1.5 times the number modelled for NO_2.
- Maps of (future) projected concentrations show a steady decrease in the concentrations of background NO_2 and PM_{10}. The accuracy of the forward projection maps is closely dependent on the future emission projections used to scale the NAEI emissions.

In recent years the Scottish Government put significant effort into increasing the number of sites in the SAQD. These efforts have contributed to the production of robust pollutant maps for NO_X, NO_2, and PM_{10} for Scotland for 2010 based on Scottish air quality measurements and Scottish meteorology. Due to the Scottish-specific nature of the data, it is more appropriate for anyone undertaking air quality studies in Scotland to use the Scottish background maps rather than data from the UK maps. The Scottish Government therefore expects Scottish local authorities to use the Scottish-specific modelling for LAQM purposes. Other organisations undertaking air quality studies in Scotland are directed to the Scottish-specific background modelled data.

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Appendices

1 Introduction

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

The maps and projections discussed in this report utilise the air pollutant concentration mapping methodology developed for the UK Pollution Climate Mapping (PCM) model[1]. This provides air pollution concentration maps for the Scottish Government, Defra, and the other Devolved Administrations[1]. Air pollutant concentration maps are produced annually in order to supplement data from the national monitoring networks and to satisfy the EU Air Quality Directive[2] reporting requirements. The UK PCM model is calibrated using data from the national networks (chiefly the Automatic Urban and Rural Network, AURN) and is 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 was identified as an area that may not conform as well as other areas to the general calibration performed for the UK as a whole. This provided the need for the more detailed Scotland-specific study undertaken within the Scottish Air Quality Database project. Here the PCM methodology has been applied to provide pollution maps of Scotland for the Scottish Government for 2010 using measurements exclusively from Scottish air quality monitoring sites and Scottish meteorology in order to reflect these differences. The maps provide spatial representation of the annual mean concentrations of:

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

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

The air pollutant measurements used in the mapping work presented here, for 2010, use NO_X, NO_2 and appropriately scaled PM_{10} monitoring data (FDMS, Partisol and VCM corrected TEOM data) in conjunction with Scottish meteorology data (from RAF Leuchars) to create and run a Scotland-specific model for NO_X, NO_2, and PM_{10} for 2010. 2010 Scottish PM_{10} measurements from Beta Attenuation Monitors (BAMs) were only used for model verification. The model results have been compared with the measured air pollutant

[1] Brookes, D.M., Stedman, J.R., Grice, S.E., Kent, A.J., Walker, H.L., Cooke, S.L., Vincent, K.J., Lingard, J.J.N., Bush, T.J., and Abbott, J. (2011). UK modelling under the Air Quality Directive (2008/50/EC) for 2010 covering the following air quality pollutants: SO_2, NO_X, NO_2, PM_{10}, $PM_{2.5}$, lead, benzene, CO, and ozone. Report to The Department for Environment, Food and Rural Affairs, Welsh Assembly Government, the Scottish Government and the Department of the Environment for Northern Ireland, AEAT/ENV/R/3215 Issue 1. http://www.scottishairquality.co.uk/documents/reports2/352120809_AQD2010mapsrep_master_v0.pdf

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

concentrations in Scotland. An assessment has been made of area, population, number of roads and road length exposed to specific concentrations above the Objective values adopted by the Scottish Government for NO_2 and PM_{10}.

Projected annual mean concentrations of NO_X, NO_2, and PM_{10} for 2015, 2020, 2025, and 2030, from a base year of 2010, 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 2010, these were prepared using Scotland-specific data. The Scotland-specific model uses the same approach as the UK model to project the component source sector contributions to ambient air pollutant concentrations forward to 2030. Any differences in the source apportionment between the Scottish and UK mapping for 2030 will consequently be carried forward into the projections.

In recent years, analyses[3] conducted for the Scottish Government, Defra and the other Devolved Administrations of historical UK air quality monitoring data measurements have identified a disparity between measured ambient concentrations of NO_X and NO_2 and the projected decline in their concentrations associated with emissions forecasts. The modelled air pollutant concentrations and maps presented here are based on Scottish air pollutant emissions from UK's National Atmospheric Emissions Inventory (NAEI) and the most recently updated (as of January 2012) National energy usage statistics (UEP43). The Scotland-specific model includes the most recently revised (as of January 2012) NO_X emission factors for road transport emissions, taken from COPERT4 v8.1, and ANPR/DVLA-scaled data, to represent the most up-to-date vehicle fleet information in Scotland. Overall, the accuracy of the forward projection maps presented here is closely dependent on the future emission projections used to prepare the background air pollutant maps. 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.

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

2 Methodology

Detailed description of the UK PCM modelling methodology can be found in the annual report to the Scottish Government, Defra and the other Devolved Administrations for 2010[1] and can be downloaded from the Technical Reports Section of the Air Quality in Scotland website (http://www.scottishairquality.co.uk/reports.php?n_action=report2). A brief overview of the modelling methodology is presented here, including a summary of model revisions for 2010, and the specific aspects of the model that have been tailored to provide a Scotland-specific output are detailed below.

The modelled maps of ambient air pollutant concentrations were calculated from NAEI data using a dispersion modelling approach, which was calibrated using air pollutant measurements from the national monitoring networks. These modelled maps were verified against independent monitoring data held by 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 measurements from Scottish monitoring sites only (as shown in Figure 2.1) were used in the model calibration, and
- the dispersion kernel applied to area source emissions was derived using Scottish meteorology data obtained for RAF Leuchars in Fife (Grid Ref: NO467205).

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

2.2 Air quality monitoring sites used for model calibration and verification

In recent years, the Scottish Government has invested significant effort into increasing the number of sites in the Scottish Air Quality Database (SAQD). For 2010, as for the 2009, both calibration and verification of the Scotland specific-model was undertaken. The additional sites funded by the Scottish Government and placed on the SAQD were ratified in equivalent manner to air pollutant measurements from the AURN. Table 2.1 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, 2010.

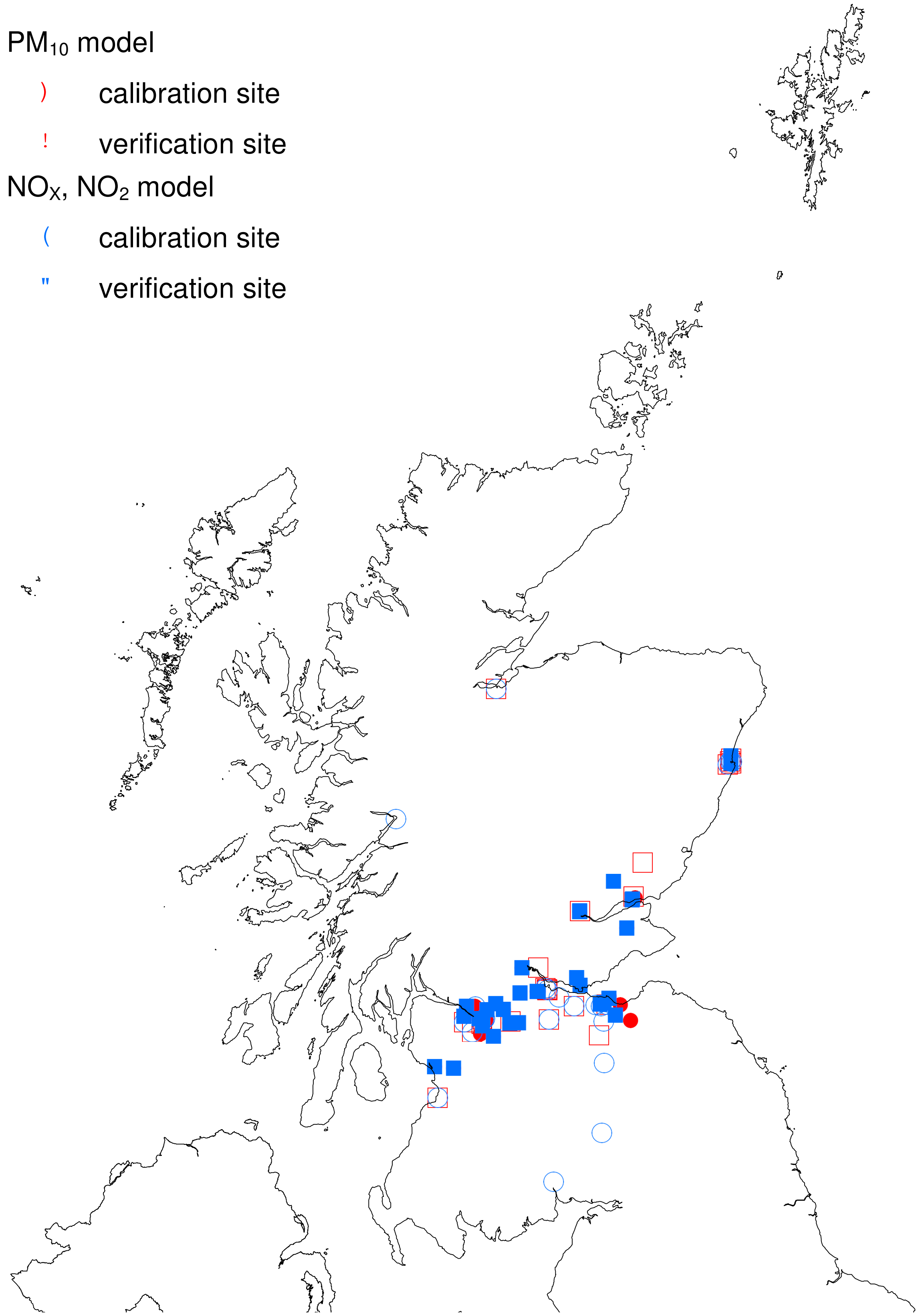


Table 2.1 Scottish background air quality monitoring sites used to calibrate and verify the output of the 2010 Scottish pollutant model.

Pollutant	Calibration site name	Verification site name	Total+
NO_X, NO_2	Bush Estate Edinburgh St Leonards Eskdalemuir Falkirk Grangemouth MC Fort William Glasgow Centre Glasgow City Chambers Glasgow Waulkmillglen Reservoir Grangemouth Peebles West Lothian Whitburn	Paisley Glasgow Airport	12 (19)
PM_{10}‡	Aberdeen (FDMS) Auchencorth Moss (FDMS) Dundee Mains Loan (TEOM VCM) Edinburgh St Leonards (FDMS) Falkirk Grangemouth MC (TEOM VCM) Glasgow Anderston (TEOM VCM) Glasgow Waulkmillglen Reservoir (TEOM VCM) Grangemouth (FDMS) Grangemouth Moray Scottish Government (TEOM VCM) N Lanarkshire Coatbridge Whifflet (TEOM VCM) West Lothian Whitburn (FDMS)	None	11 (12)

+ 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 2010 Scottish pollutant model.

Pollutant	Calibration site name	Verification site name	Total⁺
NO_X, NO_2	Aberdeen Anderson Drive Aberdeen Market Street 2 Aberdeen Union Street Roadside Dumfries East Dunbartonshire Bearsden Edinburgh Gorgie Road Edinburgh St John's Road Inverness Paisley Gordon Street South Ayrshire Ayr High Street West Lothian Broxburn West Lothian Linlithgow High Street	Aberdeen King Street East Ayrshire Kilmarnock John Finnie Street East Dunbartonshire Bearsden East Lothian Musselburgh North High Street Fife Rosyth North Lanarkshire Shawhead Coatbridge	17 (52)
PM_{10}‡	Aberdeen Anderson Drive (TEOM VCM) Aberdeen Union Street (TEOM VCM) Aberdeen Wellington Road (TEOM VCM) Alloa (TEOM VCM) Angus Forfar (FDMS) Glasgow Nithsdale Road (FDMS) Inverness (Partisol) Paisley Gordon Street (FDMS) Perth Atholl Street (TEOM VCM) South Ayrshire Ayr High Street (FDMS) West Lothian Broxburn (FDMS)	Aberdeen King Street (Unheated BAM) East Ayrshire Kilmarnock John Finnie Street (Unheated BAM) East Dunbartonshire Bearsden (Heated BAM) East Lothian Musselburgh North High Street (Unheated BAM) Fife Rosyth (FDMS) North Lanarkshire Shawhead Coatbridge (Unheated BAM)	17 (50)

⁺ 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 2010 at background and roadside locations. Modelled annual mean NO_2 concentrations were calculated from modelled NO_X concentrations using a calibrated version of the updated oxidant-partitioning model[4,5]. This model is discussed in more detail in the 2010 UK mapping report**Error! Bookmark not defined.** 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 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 2010 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.

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

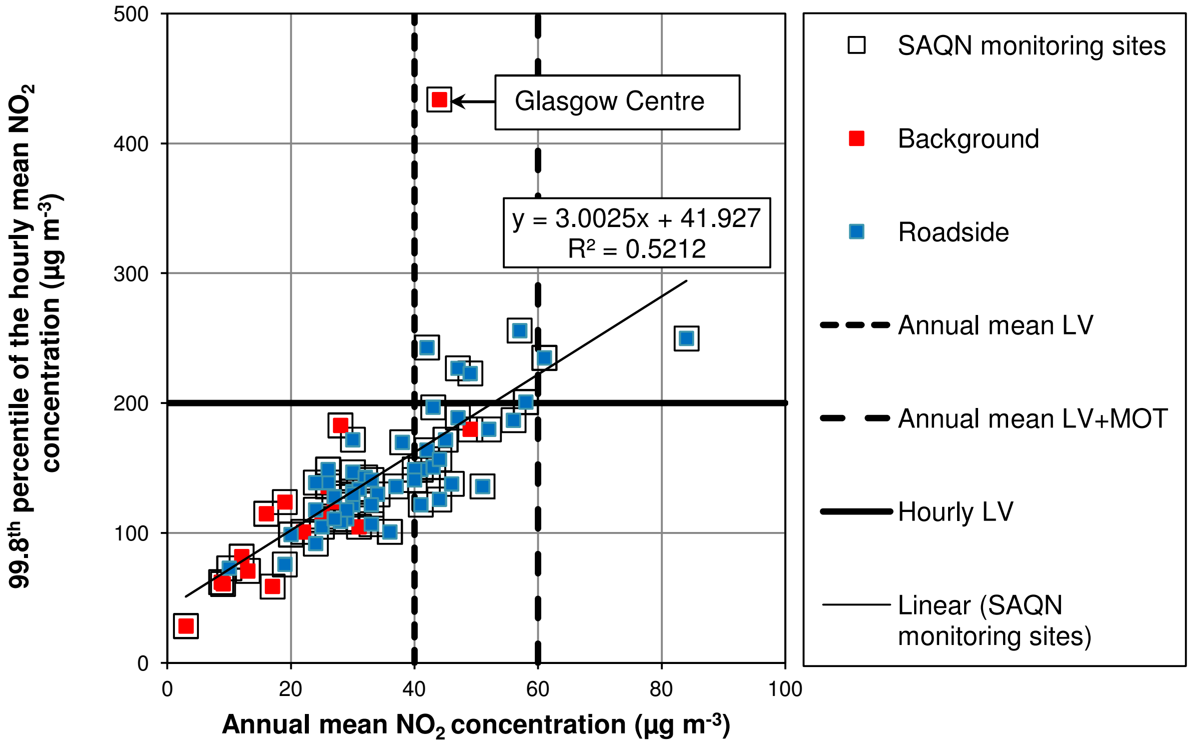
[5] Murrells, T., Cooke, S., Kent, A., Grice, S., Derwent, R., Jenkin, M., Pilling, M., Rickard, A., and Redington, A. (2008). Modelling of tropospheric ozone: first annual report. AEA Report AEAT/ENV/R/2567. http://www.airquality.co.uk/archive/reports/cat07/0804291542_ED48749_Ann_Rep1_2007_tropospheric_ozone_final_AQ03508.pdf

Scottish AQOs for ambient NO_2 concentrations are based on EU limit values set out in the Air Quality Directive[9]. These have been specified for the protection of human health 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 exceedances each year.

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

Figure 2.2 Plot of annual mean against 99.8th percentile hourly NO_2 concentrations in 2010 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[6]. This is illustrated in Figure 2.2 which shows the 2010 annual mean NO_2 concentrations at all Scottish air quality monitoring sites (with an annual %dc ≥75%) plotted against the 99.8th percentile (equivalent to 18 exceedances) hourly mean 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

2010 annual mean concentrations of PM_{10} were modelled for Scotland at background and roadside locations. The modelling methodology used to calculate the annual mean PM_{10} concentrations is broadly similar to that used last year. On the whole, measurements from

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

appropriately scaled PM_{10} monitoring sites (FDMS, Partisol and VCM corrected TEOM[7,8]) measurements 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[9]. 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 2015, 2020, 2025, and 2030, from a base year of 2010, are presented for the purpose of forward projection assessment following a scoping exercise using 2008 PM_{10} measurements undertaken by AEA, on behalf of The Scottish Government, involving four Scottish local authorities[10].

The projected background annual mean concentrations for 2015, 2020, 2025, and 2030 were produced using Scottish specific data within the UK methodology and by appropriately scaling forward:

- 2009 UK NAEI emissions for NO_X, NO_2, and PM_{10}
- 2009 UK road usage statistics split by region,
- 2009 PM_{10} emissions due to brake and tyre wear (BTW),
- 2009 PM_{10} emissions due to road abrasion (RAB),
- 2010 Scottish annual mean NO_X, NO_2, and PM_{10} concentrations, and
- 2010 Scottish meteorology data.

This allows calculation of the background annual mean concentrations of NO_X, NO_2, and PM_{10} in 2015, 2020, 2025, and 2030. Intermediate years background pollutant concentrations were calculated via linear interpolation between the projected years.

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

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

[9] Council Directive 2008/50/EC, of 21 May 2008 on ambient air quality and cleaner air for Europe (The Air Quality Directive). The Official Journal of the European Communities, 11.6.2008, En Series, L152/1.

[10] 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

3 Model calibration

Calibration of the 2010 background NO_X and PM_{10} Scotland-specific model were undertaken using measurements from air quality monitoring stations situated within a range of background (airport, rural, suburban, urban background, urban centre and urban industrial) locations. Similarly, the roadside calibration was undertaken using air quality monitoring measurements from roadside (roadside and kerbside) sites. As noted in Section 2.2, only Scottish air quality monitoring data from background and roadside sites with an annual % data capture (%dc) ≥75% were used to prepare the calibration plots and to verify the 2010 Scotland-specific model, as discussed in Section 5. The 2010 background and roadside calibration factors produced for the Scotland-specific model for NO_X were greater than the equivalent UK values. The 2010 Scotland-specific background PM_{10} calibration factor was less than the UK value, which reflects the lower measured ambient PM_{10} mass concentrations in Scotland. On the other hand the Scotland-specific roadside PM_{10} calibration factor was almost double the UK value. The NO_X, NO_2 and PM_{10} area source and roadside calibration procedures are presented below.

3.1 NO_X contributions from area sources

An ADMS 4.2 dispersion kernel was used to calculate the contribution of area sources to ambient NO_X concentrations at a central receptor location, from area source emissions within a 33 km x 33 km square, surrounding each monitoring site. This provided the modelled Scotland-specific NO_X uncalibrated calibrated area source contribution for each air quality monitoring station. 2010 hourly sequential meteorological observations from RAF Leuchars were used to construct the dispersion kernels. The modelled uncalibrated area source contribution for each source sector were subsequently multiplied by the Scotland-specific NO_X area source calibration coefficient to calculate the calibrated area source contribution for each grid square in Scotland. The point source contributions and regional rural concentrations were then added, resulting in a map of background annual mean NO_X concentrations for Scotland for 2010 as shown in Figure 5.2. A detailed description of this approach can be found in Appendix 3 of the 2010 UK modelling report**Error! Bookmark not defined.**.

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[11]. All ground level aircraft emissions have been included as given in the NAEI 2009. Appendix 4 of the 2010 UK mapping report describes the methodology used to estimate the contribution of aircraft emission to ground-level NO_X emissions.

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

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 2010 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 concentration to calculate the calibration coefficient 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 2010. The measurements from these twelve sites were used to calibrate the model (as shown in Table 2.1); one site was used to verify the model output.

Figure 3.1 Calibration plot for the 2010 Scotland-specific background NO_X model.

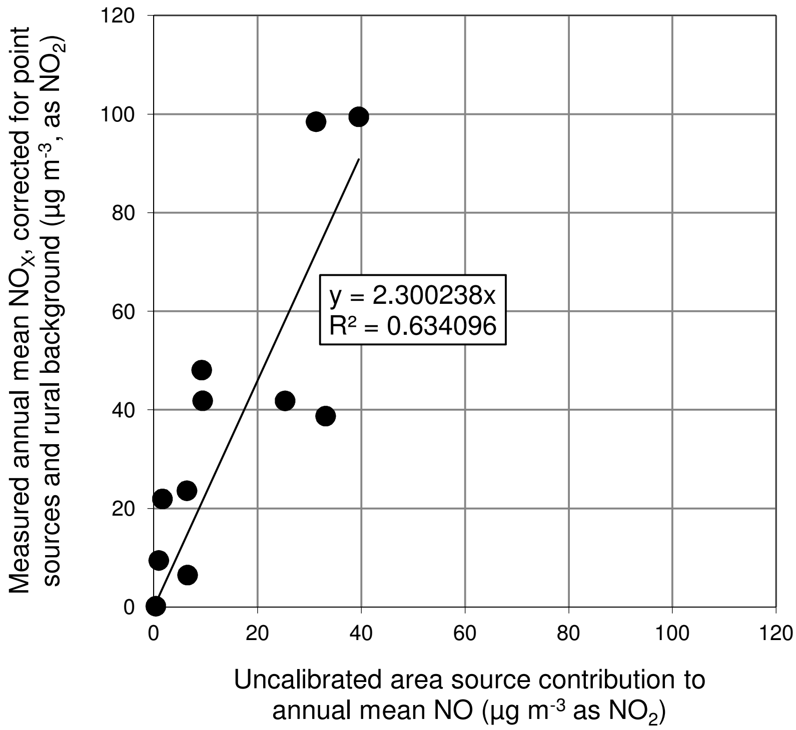


Figure 3.1 shows that the gradient the line of best fit forced through the origin was 2.3002. This value was used as the Scotland-specific NO_X area source calibration coefficient. The regression line has been forced through the origin to provide a reasonable model output without imposing an unrealistic 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 3.1 Background model calibration coefficients applied in the Scotland-specific and UK models for NO_X for 2008-2010.

Model	Pollutant	Year	Calibration coefficient
Scotland-specific	NO_X	2010	2.3002
UK	NO_X	2010	1.9505
Scotland-specific	NO_X	2009	1.5662
UK	NO_X	2009	1.2486
Scotland-specific	NO_X	2008	2.2921
UK	NO_X	2008	2.4547

Table 3.1 provides a comparison of the 2010 Scotland-specific and UK background NO_X calibration coefficients. The 2008 and 2009 Scotland-specific and UK background PM_{10} calibration coefficients are also presented to demonstrate the year-on-year variation in: (1) the Scotland-specific background NO_X calibration coefficient; and, (2) the extent to which these values vary in both models. From Table 3.1 it can be seen that the 2010 Scotland-specific background NO_X calibration coefficient was slightly higher than the equivalent value used in the UK model in 2010. The map of the 2010 background annual mean NO_X concentration 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 are made-up of two components: the background concentrations (as described above) and a roadside increment:

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

The NAEI provides estimates of NO_X emissions for major road links in Scotland for 2009[12] and these have been adjusted to provide estimates of emissions in 2010. 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

[12] Passant, N.R., Murrells, T.P., Misra, A., Pang, Y., Walker, H.L., Whiting, R., Walker, C., Webb, N.C.J. and MacCarthy, J. (2010). UK Informative Inventory Report (1980 to 2010). National Atmospheric Emissions Inventory. http://uk-air.defra.gov.uk/reports/cat07/1203221052_UK_IIR_2012_final.pdf

- 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[13] 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.

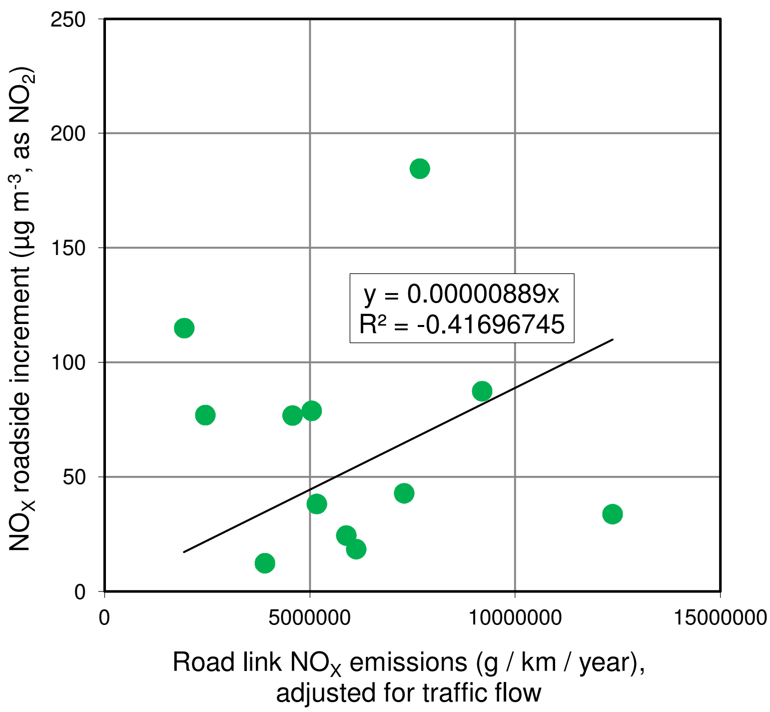
Twelve of the fifty-two roadside NO_X monitoring sites within the Scottish network had sufficient data capture for NO_X in 2010 and were located on urban major road links and adjacent to censusid points at which the traffic flow along the road was measured in 2009. The roadside NO_X measurements from these sites were used to calibrate the model. Scottish NO_X air quality monitoring data from nine roadside sites was used to verify the model output.

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

- on a modelled urban major road link, or
- sufficiently close to a road traffic censusid point.

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

Figure 3.2 Calibration plot for the 2010 Scotland-specific roadside NO_X model.



13 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

Table 3.2 Roadside model calibration coefficients applied in the Scotland-specific and UK models for NO_X for 2008-10.

Model	Pollutant	Year	Calibration coefficient
Scotland-specific	NO_X	2010	0.000 008 89
UK	NO_X	2010	0.000 008 34
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 3.2 provides a comparison of the 2010 Scotland-specific and UK roadside NO_X calibration coefficients. The 2008 and 2009 Scotland-specific and UK roadside NO_X calibration coefficients are also presented. From Table 3.2 it can be seen that the 2010 Scotland-specific roadside NO_X calibration coefficient was marginally higher than the value used in the 2010 UK model. It is therefore anticipated that the 2010 Scotland-specific roadside NO_X, and hence the roadside NO_2 model, may predict a higher number of NO_2 roadside exceedances for Scottish road links when compared to the 2010 UK model. It should be noted that the effect of the higher Scottish roadside NO_X calibration coefficient may be ameliorated by the meteorological terms (dispersion kernels) applied in the model.

3.3 NO_2 modelling

Maps of the estimated 2010 annual mean background and roadside Scottish NO_2 concentrations were calculated from the modelled NO_X concentrations using a calibrated version of the updated oxidant-partitioning model[4,5]. This model uses representative equations to account for the chemical coupling of O_3, NO and NO_2 within the atmosphere. A key advantage of this approach for modelling NO_2 concentrations is that different emission scenarios can be addressed by varying regional oxidant levels and/or primary NO_2 emissions.

This approach is discussed in detail in Section 2.3 of the 2010 UK modelling report**Error! Bookmark not defined.**. Briefly, the oxidant-partitioning model[4] enables NO_2 concentrations to be calculated using the following equations (concentrations in ppb[14]):

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

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

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

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, or volume ratio, 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.

[14] 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, an ADMS 4.2 dispersion kernel was used to calculate the contribution of area sources to ambient PM_{10} concentrations at a central receptor location, from area source emissions within a 33 km x 33 km square, surrounding each monitoring site. This provided the modelled Scotland-specific PM_{10} uncalibrated calibrated area source contribution for each air quality monitoring station. 2010 hourly sequential meteorological observations from RAF Leuchars were used to construct the dispersion kernels. A detailed description of this approach can be found in Appendix 3 of the 2010 UK modelling report**Error! Bookmark not defined.**.

The modelled uncalibrated area source contribution for each source sector were subsequently multiplied by the Scotland-specific PM_{10} area source calibration coefficient to calculate the calibrated area source contribution for each grid square in Scotland. The modelled large point and small point sources, secondary inorganic aerosol (SIA), secondary organic aerosol (SOA), iron and calcium-rich dust, long range transport (LRT), primary PM_{10}, sea salt and the residual concentrations have been subtracted from the measured annual mean PM_{10} concentrations at background sites and compared with the modelled area source contribution to annual mean PM_{10} concentrations. A residual concentration of 1 µg m^{-3} was found to provide the best fit to the monitoring data. This approach is consistent with that used in the 2010 UK mapping. The 2010 background annual mean PM_{10} concentration for Scotland is shown in Figure 4.5.

Eleven of the background PM_{10} monitoring sites within the Scottish network were used to calibrate the model, as reported in Table 2.1. Figure 3.3 shows that the gradient the line of best fit forced through the origin was 1.7049. 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 2010 Scotland-specific background PM_{10} model.

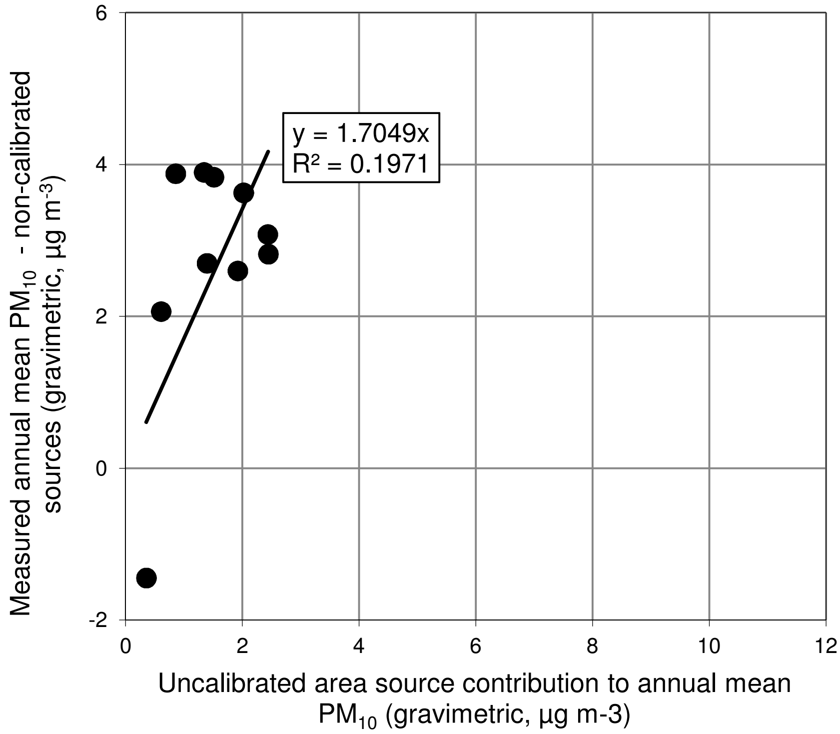


Table 3.3 Background model calibration coefficients applied in the Scotland-specific and UK models for PM_{10} for 2008-10.

Model	Pollutant	Year	Calibration coefficient
Scotland-specific	PM_{10}	2010	1.7049
UK	PM_{10}	2010	2.5992
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 3.3 provides a comparison of the 2010 Scotland-specific and UK background PM_{10} calibration coefficients. The 2008 and 2009 Scotland-specific and UK background PM_{10} calibration coefficients are also presented to demonstrate the year-on-year variation in: (1) the Scotland-specific background PM_{10} calibration coefficient; and, (2) the extent to which these values vary in both models.

From Table 3.3 it can be seen that the 2008-10 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 in Scotland when compared to the UK as a whole due to the more rural nature of Scotland. The 2010 Scotland-specific background PM_{10} calibration coefficient was lower than that used previous years. Consequentially, the 2010 modelled Scottish background PM_{10} concentrations may be slightly lower than those modelled previously. 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

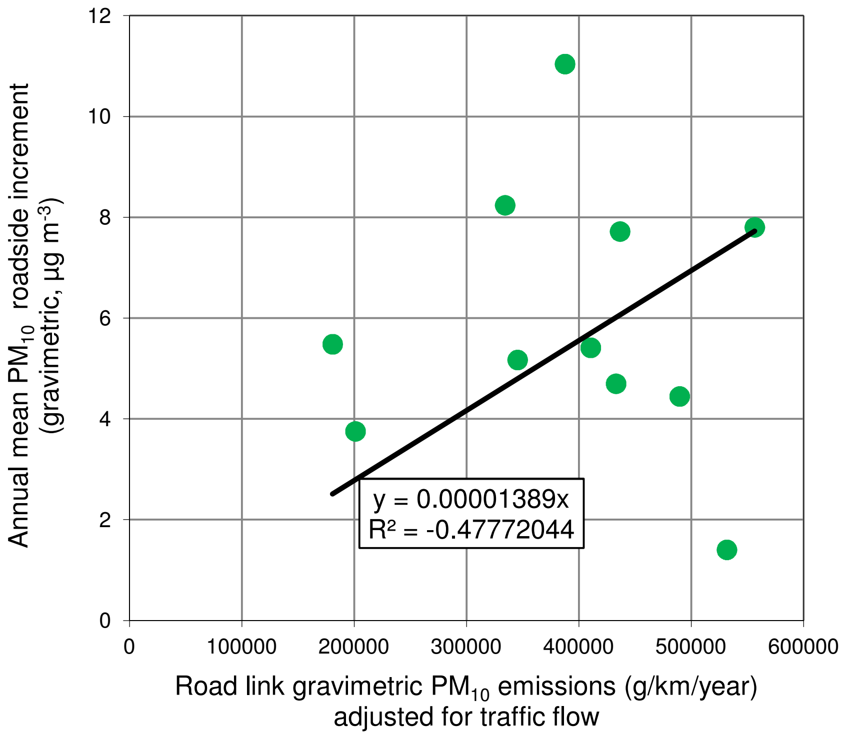
As for NO_X, it is assumed that the annual mean PM_{10} concentration at roadside locations is made-up of two components: the background concentration (as described above) and a roadside increment:

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 2009[12] and these have been adjusted to provide estimates of emissions in 2010. 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.

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 2.2.6 of the 2010 UK modelling report**Error! Bookmark not defined.**. 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.

Figure 3.4 Calibration plot for the 2010 Scotland-specific roadside PM_{10} model.



Eleven of the fifty roadside PM_{10} monitoring sites within the Scottish network had sufficient data capture for PM_{10} in 2010 and were located on urban major road links. PM_{10} measurements from a further six sites were used to verify the output of the roadside model. The roadside PM_{10} measurements from these sites were used to calibrate the model. Measurements from eight roadside sites were excluded on the basis of low annual data capture. Roadside PM_{10} measurements from twenty-five roadside sites were excluded because the sites were not located:

- on a modelled urban major road link, or

- sufficiently close to a road traffic censusid point.

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

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

Model	Pollutant	Year	Calibration coefficient
Scotland-specific	PM_{10}	2010	0.000 013 89
UK	PM_{10}	2010	0.000 006 11
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 3.4 provides a comparison of the 2010 Scotland-specific and UK roadside PM_{10} calibration coefficients. The 2008 and 2009 Scotland-specific and UK roadside PM_{10} calibration coefficients are also presented. From Table 3.4 it can be seen that for 2008 and 2010 Scotland-specific model roadside PM_{10} calibration coefficients were higher, by a least a third, than their equivalent UK values. Comparison of the 2010 Scotland-specific roadside calibration coefficient with the equivalent UK coefficient shows that the Scottish roadside PM_{10} increment was twice that of the equivalent road link PM_{10} emissions in the UK.

It is therefore anticipated that the 2010 Scotland-specific roadside PM_{10} model may predict a higher number of PM_{10} roadside exceedances for Scottish road links when compared to those predicted by the 2010 UK model, however this effect may be ameliorated by the meteorological terms (dispersion kernels) applied in the model. The resulting map of roadside annual mean PM_{10} concentrations for Scotland is shown in Figure 5.12.

4 Model Verification

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

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

The UK model is verified annually against independent air quality monitoring data available from sites located throughout the UK, which have not been used in the model calibration. These are typically air quality monitoring sites used for the purposes of LAQM, e.g., Local Authority sites located at roadside sites or in air pollutant hot-spot areas. In 2010, a small number of Scottish air quality monitoring sites, between one and six, were used to verify the output of the Scotland-specific model, as noted in Section 2.2. The number of sites available for verification of the Scotland-specific model was limited and greatly dependent on the air pollutant and site type (background or roadside). 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. These lines represent the Data Quality Objectives (DQOs) specified in the EU Air Quality Directive[2] for modelled NO_2 concentrations used for national reporting purposes. The plots show that the modelled values provide reasonable agreement with the measured annual mean concentrations, with some sites lying outside the DQOs.

Model verification was performed separately for background and roadside sites. Summary statistics are presented in Table 4.1 and Table 4.2 for NO_X and NO_2, respectively, for the Scotland-specific model. The summary statistics presented in Table 4.1 and Table 4.2 include the:

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

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

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

NO_X Background					
Model output	**Measured annual mean (µg m^{-3})**	**Modelled annual mean (µg m^{-3})**	**R^2**	**% outside data quality objectives**	**Number of sites in assessment**
Scotland-specific calibration	43	38	0.69	73	11
Scotland-specific verification	61	50	-	-	1

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	104	91	0.09	67	11
Scotland-specific verification	105	104	0.08	33	6

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	21	19	0.70	45.5	11
Scotland-specific verification	28	26	N/A	0.0	1

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	41	39	0.15	41.7	12
Scotland-specific verification	42	43	0.02	33.3	6

4.2 PM_{10} model verification

The model verification plots are presented in Figure 4.5 and Figure 4.6. Lines at ±50% are shown on the model verification plots and represent the DQOs specified for modelled PM_{10} concentrations in the EU Air Quality Directive[2]. The plots show that the modelled annual mean concentrations provide good agreement with the measured annual mean concentrations and on the whole fall within the DQO specified by the Directive.

Model verification was performed separately for background and roadside sites. Summary statistics are presented in Table 4.3 including the mean of the annual measured concentrations, the mean of the corresponding modelled estimates, the number of sites included in the analysis for each metric, the R^2 of the relationship between monitored and modelled data, and the number of sites within the DQOs.

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

PM_{10} Background					
Model output	**Measured annual mean (μg m^{-3})**	**Modelled annual mean (μg m^{-3})**	**R^2**	**% outside data quality objectives**	**Number of sites in assessment**
Scotland-specific calibration	14	13	0.60	0	11
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	19	18	0.19	0	11
Scotland-specific verification	19	18	0.38	17	6

Figure 4.1 Annual mean background NO_X model verification, 2010.

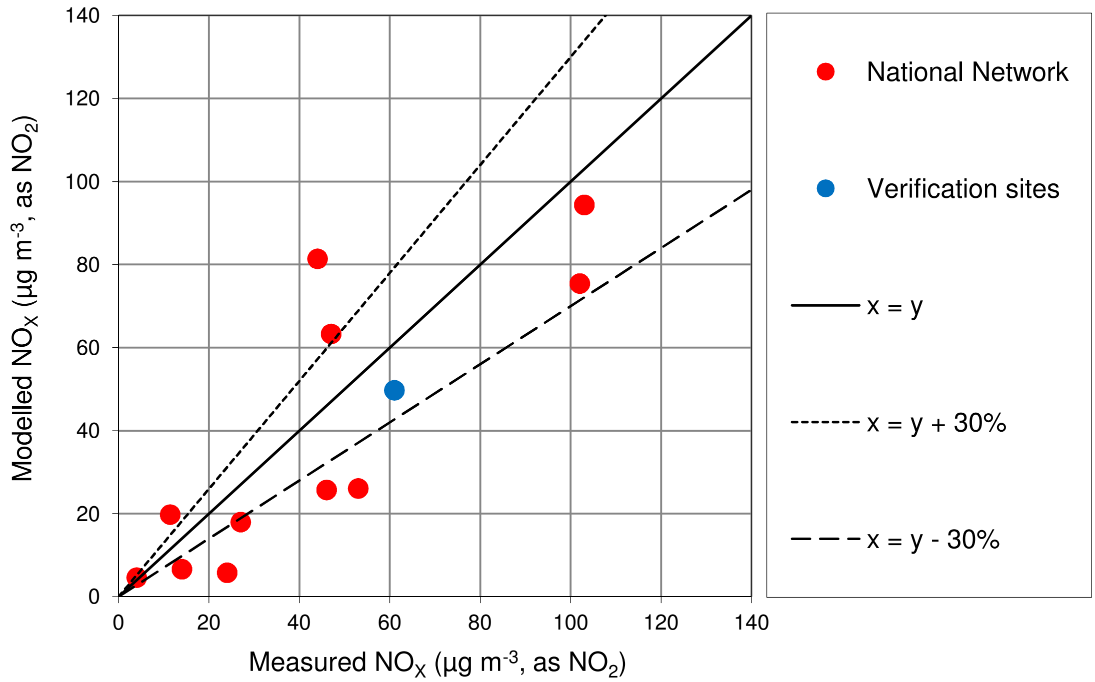


Figure 4.2 Annual mean roadside NO_X model verification, 2010.

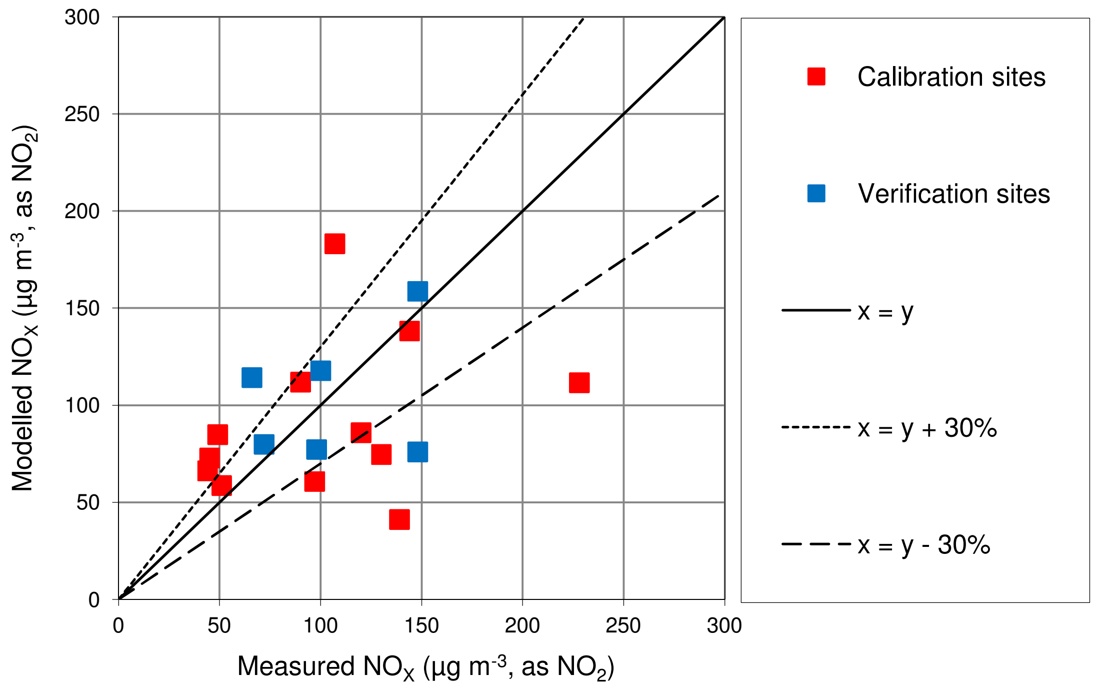


Figure 4.3 Annual mean background NO_2 model verification, 2010.

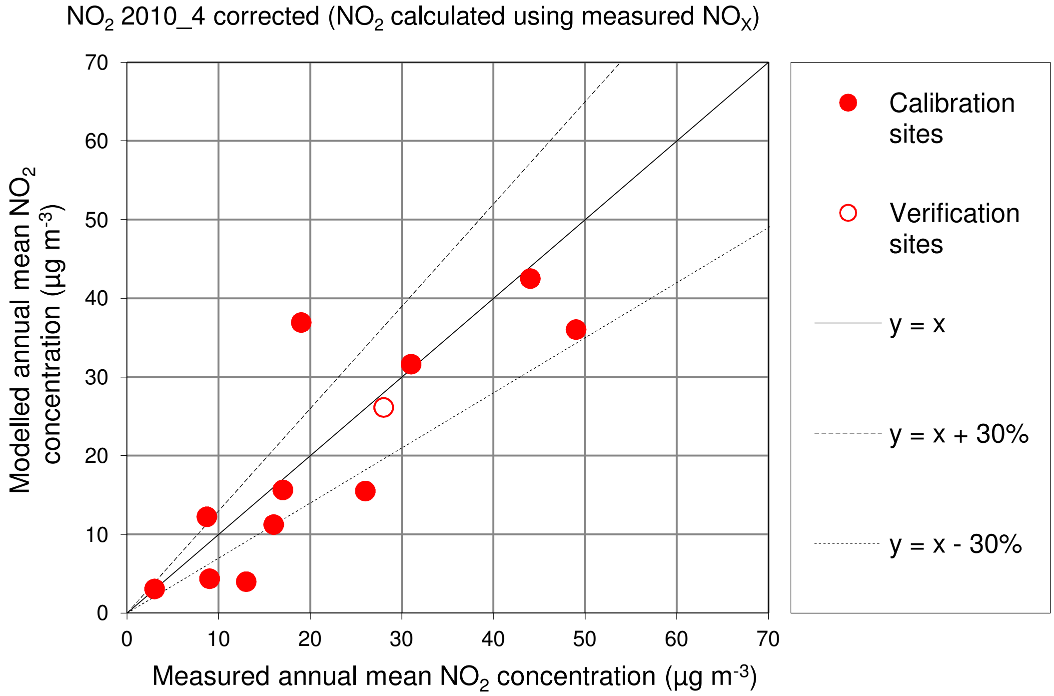


Figure 4.4 Annual mean roadside NO_2 model verification, 2010.

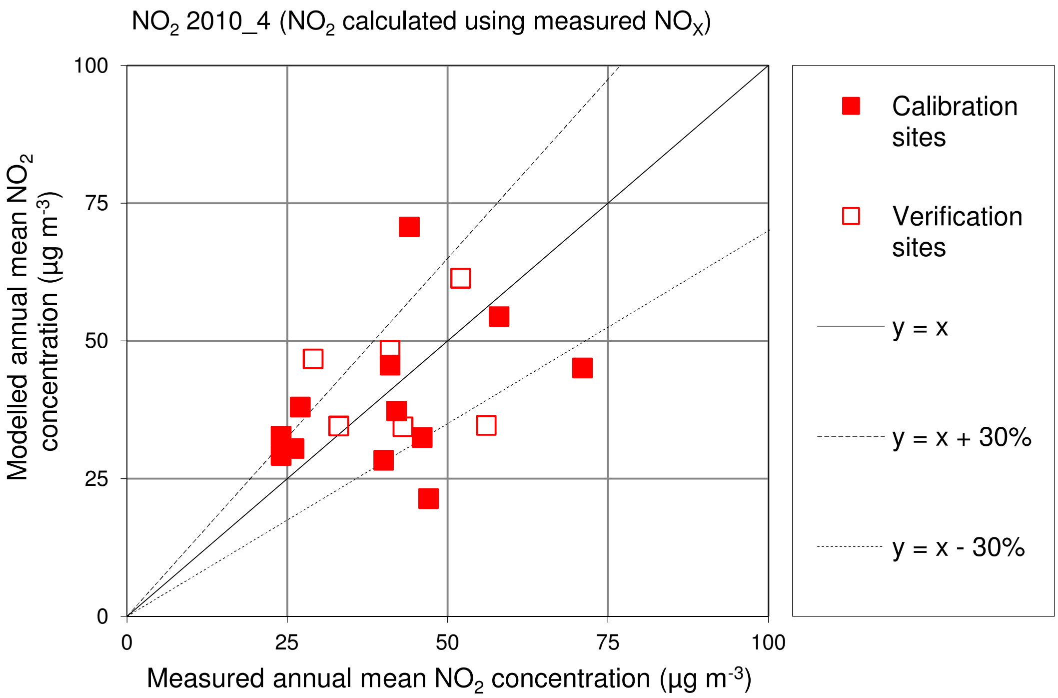


Figure 4.5 Annual mean background PM_{10} model verification, 2010.

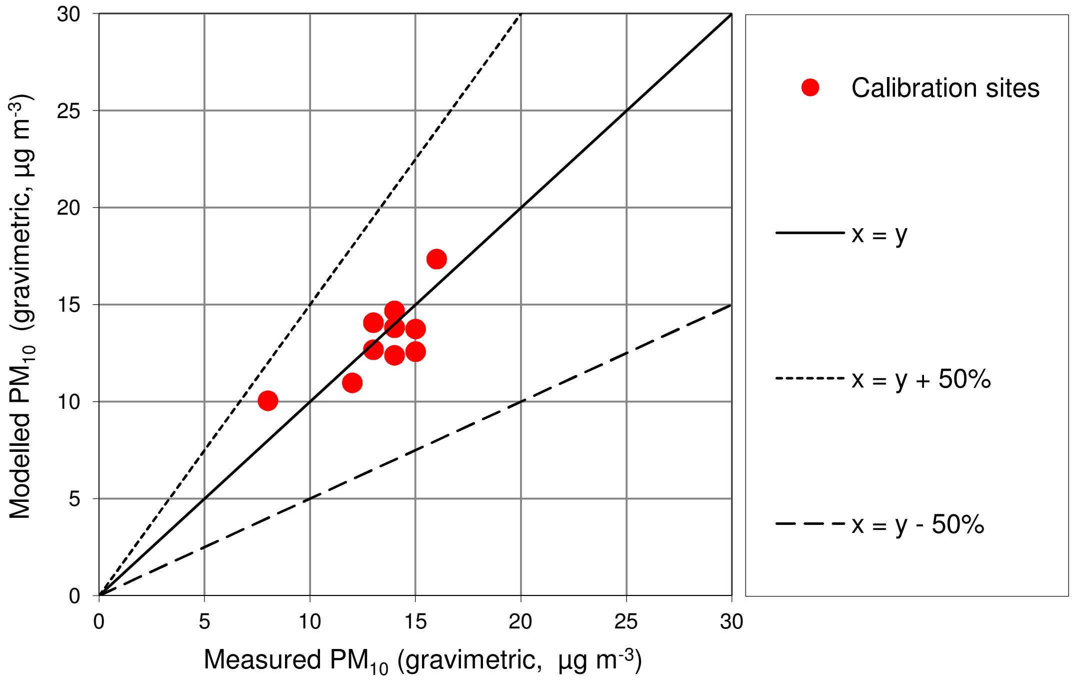
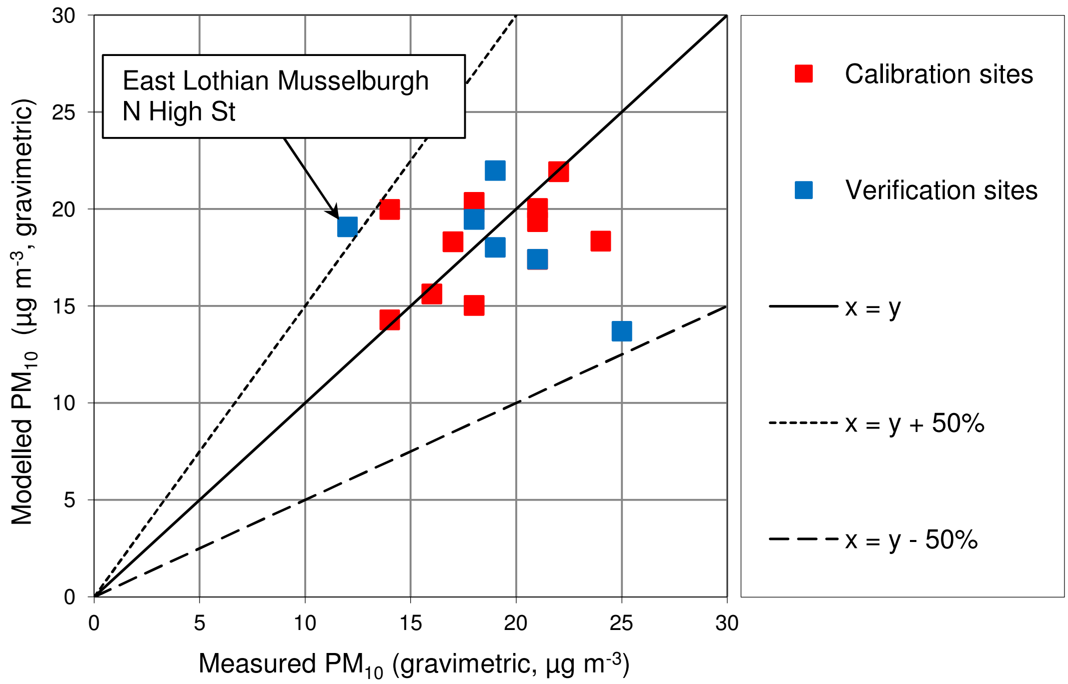


Figure 4.6 Annual mean roadside PM_{10} model verification, 2010.



5 2010 Scottish pollutant maps and results

5.1 Scottish annual mean NO_X and NO_2 maps

The 2010 Scottish annual mean background NO_X concentrations were modelled and are shown in Figure 5.2. The 2010 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 2010. 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 2010. Detailed maps showing the roadside annual mean PM_{10} concentration maps are presented in Figures 5.13 to 5.18 on the basis of the four zones (Highland, North East Scotland, Central Scotland, and the Scottish Borders) and two agglomerations (Edinburgh Urban Area and Glasgow Urban Area) in Scotland as shown in Figure 5.1.

5.3 Exceedance statistics (Scotland-specific model)

5.3.1 Background and roadside NO_2

Figure 5.3 presents the mapped annual mean background NO_2 concentrations for 2010 from the Scotland-specific model. Table 5.1 shows six modelled exceedances (1 km^2 grid squares) of the Scottish annual mean NO_2 objective of 40 $\mu g\ m^{-3}$ at background locations. Four of the six grid squares were located in north-east Scotland, in and around Aberdeen, and were believed to be due to NO_2 emissions from maritime sources. These exceedances were believed to be due to better understanding and parameterisation of maritime emissions, e.g., from ships, in recent years. The other two grid squares were located in central Glasgow and at the junction of the M8 and M9 near Edinburgh, respectively.

Table 5.2 shows that the Scotland-specific model predicted that the Scottish annual mean NO_2 air quality objective of 40 $\mu g\ m^{-3}$ was exceeded along 226 road links (317 km of road). The majority of the modelled exceedances were predicted to occur in the Glasgow Urban Area where exceedances of the Scottish annual mean NO_2 air quality objective was modelled for 136 road links (183 km of road). Overall exceedances of the Scottish annual mean NO_2 air quality objective were modelled in four of the six zones and agglomerations in Scotland. In the other three Scottish zones and agglomerations there were approximately thirty road links where exceedances of the Scottish annual mean NO_2 air quality objective were modelled, effecting 40-50 km of roads. No roadside exceedances of the Scottish annual mean NO_2 air quality objective were modelled in the more rural zones and agglomerations of Scotland, i.e., the Highlands and Scottish Borders. Detailed maps showing the roadside annual mean NO_2 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.

Unlike previous years, there was margin of tolerance (MOT)[15] applicable in 2010. Table 5.3 shows that there were no modelled exceedances of the Scottish annual mean NO_2 air quality objective for + the maximum margin of tolerance (20 µg m^{-3}, 50% of the NO_2 limit value) in 2010.

Table 5.4 shows that exceedances the Scottish annual mean NO_2 air quality objective for + the maximum margin of tolerance (20 µg m^{-3}, 50% of the NO_2 limit value) were modelled on 23 road links (40 km of road) in 2010. Half of the exceedances occurred within the Glasgow Urban area, with 5 exceedances were modelled within the Edinburgh Urban Area, 4 in Central Scotland, and 2 in North East Scotland, effecting 8, 7 and 3 km of road links, respectively.

Table 5.1 Annual mean exceedance statistics for background NO_2 in Scotland based on the Scotland-specific model, 2010.

Zone or agglomeration	Total		>40 µg m^{-3}	
	Area (km^2)	Population	Area (km^2)	Population
Glasgow Urban Area	367	1078339	1	1547
Edinburgh Urban Area	131	439170	0	0
Central Scotland	9895	1870327	1	29
North East Scotland	18991	1049642	4	4017
Highland	43197	368926	0	0
Scottish Borders	11375	254652	0	0
Total	**83956**	**5061056**	**6**	**559**

Table 5.2 Annual mean exceedance statistics for roadside NO_2 in Scotland based on the Scotland-specific model, 2010.

Zone or agglomeration	Total		>40 µg m^{-3}	
	Road links	Length (km)	Road links	Length (km)
Glasgow Urban Area	326	219	136	183
Edinburgh Urban Area	102	60	29	51
Central Scotland	338	208	28	41
North East Scotland	234	133	33	42
Highland	35	10	0	0
Scottish Borders	47	35	0	0
Total	**1083**	**665**	**226**	**317**

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

Table 5.3 Annual mean exceedance statistics for background NO_2 + MOT in Scotland based on the Scotland-specific model, 2010.

Zone or agglomeration	Total		>60 µg m^{-3}	
	Area (km^2)	Population	Area (km^2)	Population
Glasgow Urban Area	367	1078339	0	0
Edinburgh Urban Area	131	439170	0	0
Central Scotland	9895	1870327	0	0
North East Scotland	18991	1049642	0	0
Highland	43197	368926	0	0
Scottish Borders	11375	254652	0	0
Total	**83956**	**5061056**	**0**	**0**

Table 5.4 Annual mean exceedance statistics for roadside NO_2 + MOT in Scotland based on the Scotland-specific model, 2010.

Zone or agglomeration	Total		>60 µg m^{-3}	
	Roads links	Length (km)	Roads links	Length (km)
Glasgow Urban Area	326	219	12	22
Edinburgh Urban Area	102	60	5	8
Central Scotland	338	208	4	7
North East Scotland	234	133	2	3
Highland	35	10	0	0
Scottish Borders	47	35	0	0
Total	**1083**	**665**	**23**	**40**

5.3.2 Background and roadside PM_{10}

Figure 5.11 presents the mapped annual mean background PM_{10} concentrations for 2010 from the Scotland-specific model. Table 5.5 shows exceedances of the Scottish annual mean PM_{10} objective of 18 µg m^{-3} were modelled within six, 1 km^2 grid squares in Scotland. Two grid squares were located around the junction of the M8 and M9. 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 Scotland-specific model predicted similar exceedances of the annual mean PM_{10} concentration in this cluster of grid squares in previous years.

Three further exceedances were modelled in grid squares located to the east of the M8-M9 junction, along the M8 in the direction of Livingston. The sixth grid square was located where the A8 joins the M8 on the outskirts of Glasgow. On the whole the extent of the exceedance of the Scottish PM_{10} air quality objective modelled in the six exceeding grid squares was typically of the order of 1 µg m^{-3}, but was as high as 2.5 µg m^{-3} in one grid square.

The 2010 Scotland-specific model identified 322 road links (472 km of road) exceeding the Scottish annual mean PM_{10} air quality objective. Around half (153 road links, 210 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 exceedances predicted by the 2010 Scotland-specific roadside model for NO_2. A further 73 road links (113 km of road) in Central

Scotland and 46 road links in the Edinburgh Urban Area (82 km of road) exceeded the Scottish annual mean PM_{10} air quality objective. No roadside exceedances of the Scottish PM_{10} objective were identified by the model in the Highlands, though an exceedance was modelled on 1 road link (2 km of road) in Scottish Borders. Detailed maps showing the roadside annual mean PM_{10} concentration maps are presented in Figures 5.13 to 5.18 on the basis of the four zones (Highland, North East Scotland, Central Scotland, and the Scottish Borders) and two agglomerations (Edinburgh Urban Area and Glasgow Urban Area) in Scotland as shown in Figure 5.1.

Table 5.5 Annual mean exceedance statistics for background PM_{10} in Scotland based on the Scotland-specific model, 2010.

Zone or agglomeration	Total		>18 µg m^{-3}	
	Area (km^2)	Population	Area (km^2)	Population
Glasgow Urban Area	367	1078339	1	104
Edinburgh Urban Area	131	439170	0	0
Central Scotland	9895	1870327	5	206
North East Scotland	18991	1049642	0	0
Highland	43197	368926	0	0
Scottish Borders	11375	254652	0	0
Total	**83956**	**5061056**	**6**	**310**

Table 5.6 Annual mean exceedance statistics for roadside PM_{10} in Scotland based on the Scotland-specific model, 2010.

Zone or agglomeration	Total		>18 µg m^{-3}	
	Road links	Length (km)	Road links	Length (km)
Glasgow Urban Area	326	219	153	210
Edinburgh Urban Area	102	60	46	82
Central Scotland	338	208	73	113
North East Scotland	234	133	49	64
Highland	35	10	0	0
Scottish Borders	47	35	1	2
Total	**1083**	**665**	**322**	**472**

No exceedances 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 2010 Scotland-specific model. This is consistent with modelling in previous years. **Error! Not a valid bookmark self-reference.** shows that 52 exceedances (78 km of road) were predicted at roadside locations, half of which (35 road links, 71 km of road) lie in the Glasgow Urban Area.

Table 5.7 Annual mean exceedance statistics for background PM_{10} in Scotland based on the Scotland-specific model, 2010.

Zone or agglomeration	Total		>22 µg m^{-3}	
	Area (km^2)	Population	Area (km^2)	Population
Glasgow Urban Area	367	1078339	0	0
Edinburgh Urban Area	131	439170	0	0
Central Scotland	9895	1870327	0	0
North East Scotland	18991	1049642	0	0
Highland	43197	368926	0	0
Scottish Borders	11375	254652	0	0
Total	**83956**	**5061056**	**0**	**0**

Table 5.8 Annual mean exceedance statistics for roadside PM_{10} in Scotland based on the Scotland-specific model, 2010.

Zone or agglomeration	Total		>22 µg m^{-3}	
	Road links	Length (km)	Road links	Length (km)
Glasgow Urban Area	326	219	35	51
Edinburgh Urban Area	102	60	8	12
Central Scotland	338	208	6	8
North East Scotland	234	133	3	6
Highland	35	10	0	0
Scottish Borders	47	35	0	0
Total	**1083**	**665**	**52**	**78**

5.4 Population-weighted mean calculations for 2010

Calculations of the population-weighted mean were performed on the modelled background maps. These provide a measure of the health impact of modelled pollutant concentrations. Table 5.9 provides a summary of the 2010 Scottish NO_2 and PM_{10} population-weighted mean concentration from the Scotland-specific model.

Table 5.9 2010 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	12.0	14.8

Figure 5.1 Zones and agglomerations in Scotland, 2010.

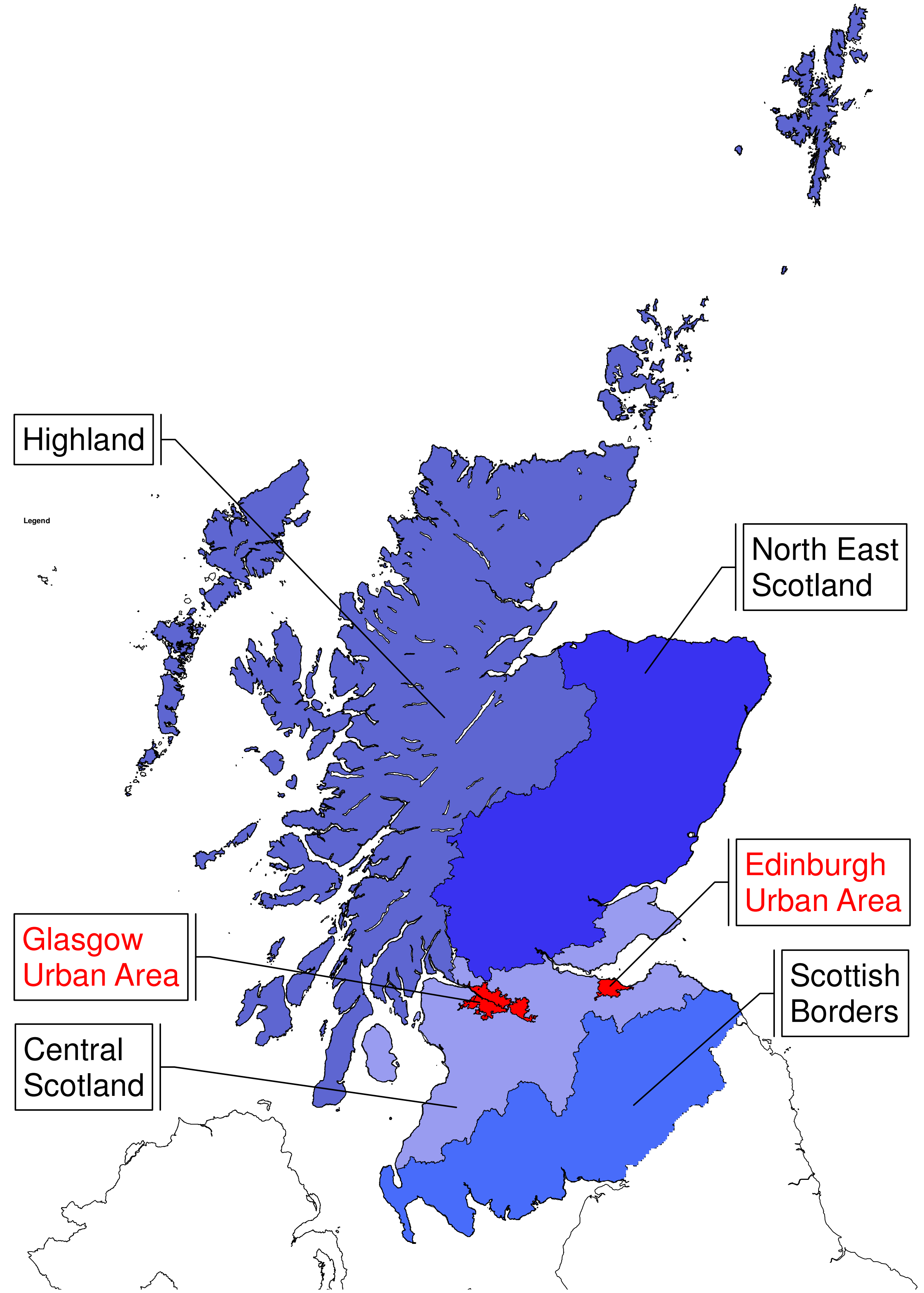


Figure 5.2 Background NO_X map for 2010, µg m^{-3} (Scotland-specific model).

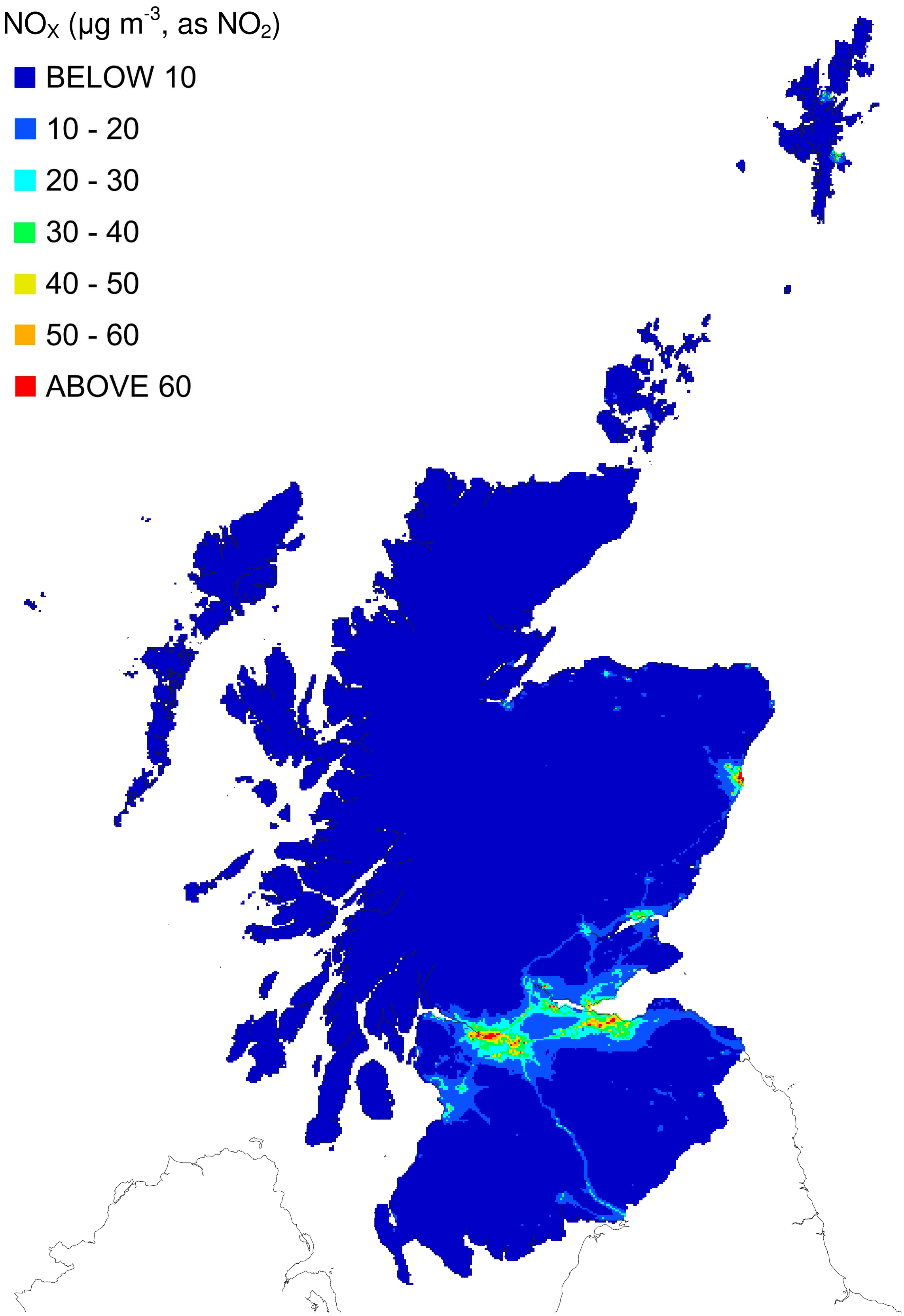


Figure 5.3 Background NO_2 map for 2010, µg m^{-3} (Scotland-specific model).

NO_2 (µg m^{-3})

- BELOW 10
- 10 - 20
- 20 - 30
- 30 - 40
- 40 - 50
- 50 - 60
- ABOVE 60

Figure 5.4 Roadside NO_2 map for 2010, µg m^{-3} (Scotland-specific model).

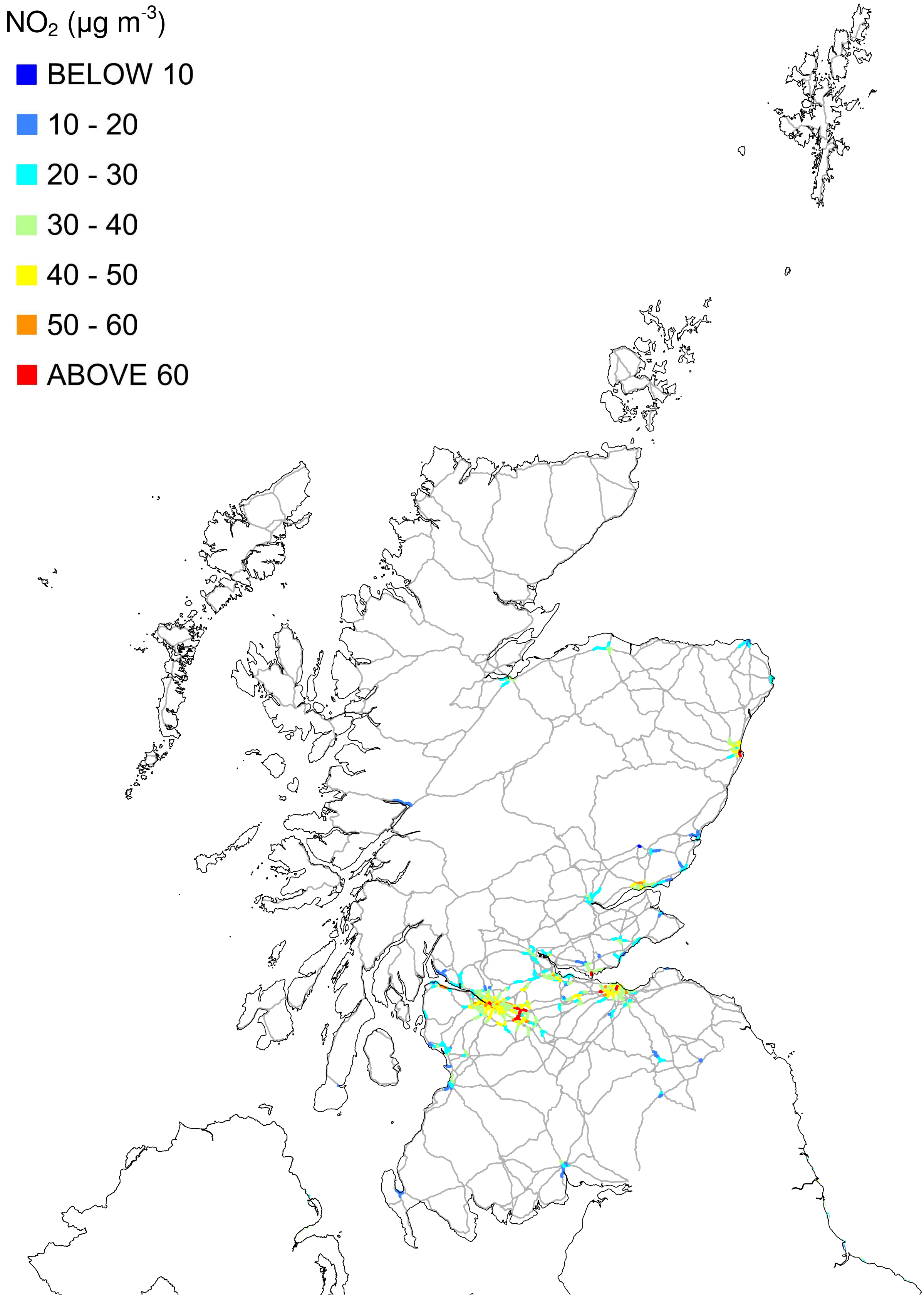
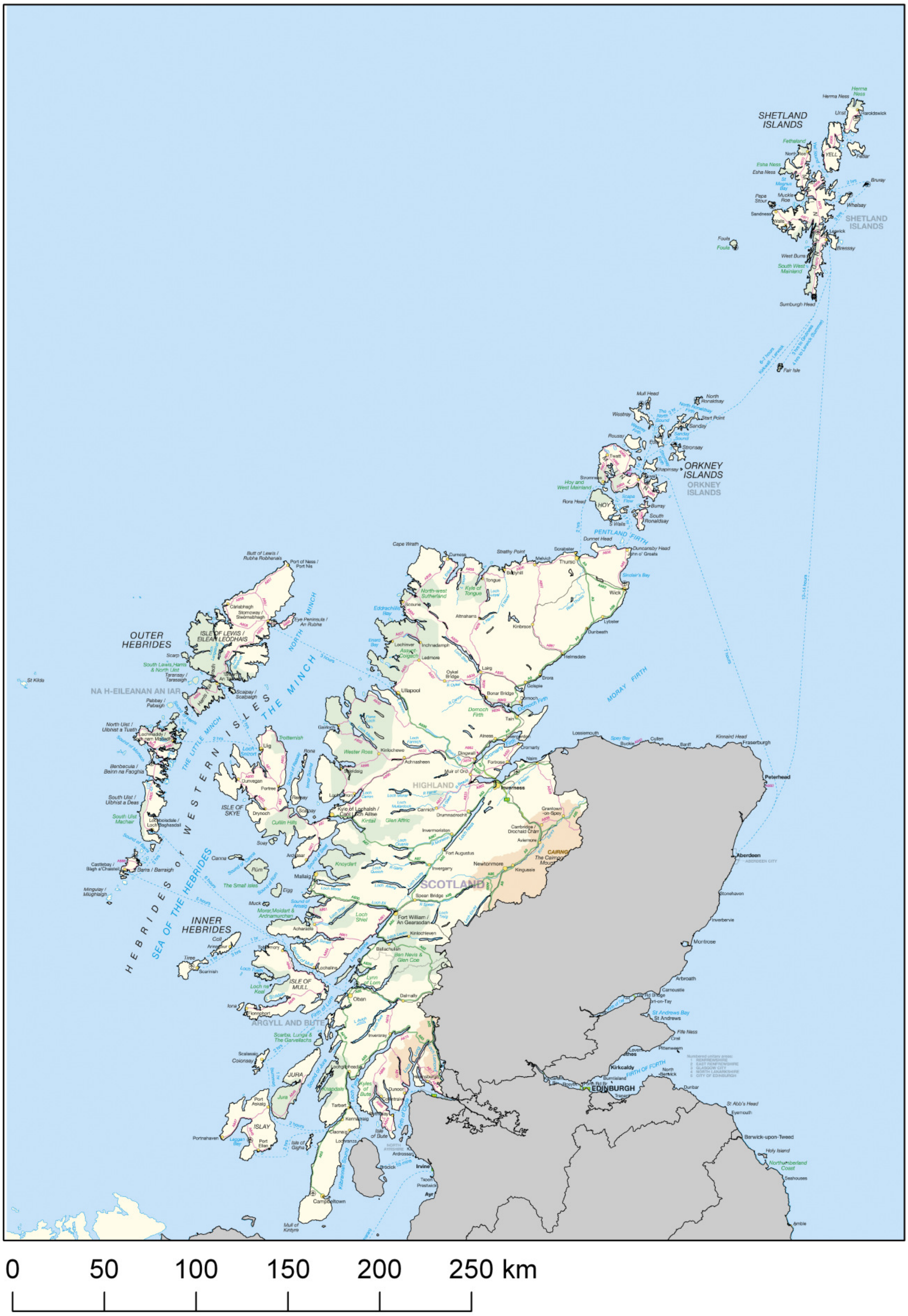


***Figure 5.5** Detailed roadside NO_2 map for 2010, µg m^{-3} showing the road-link concentrations in the Highlands (Scotland-specific model).*



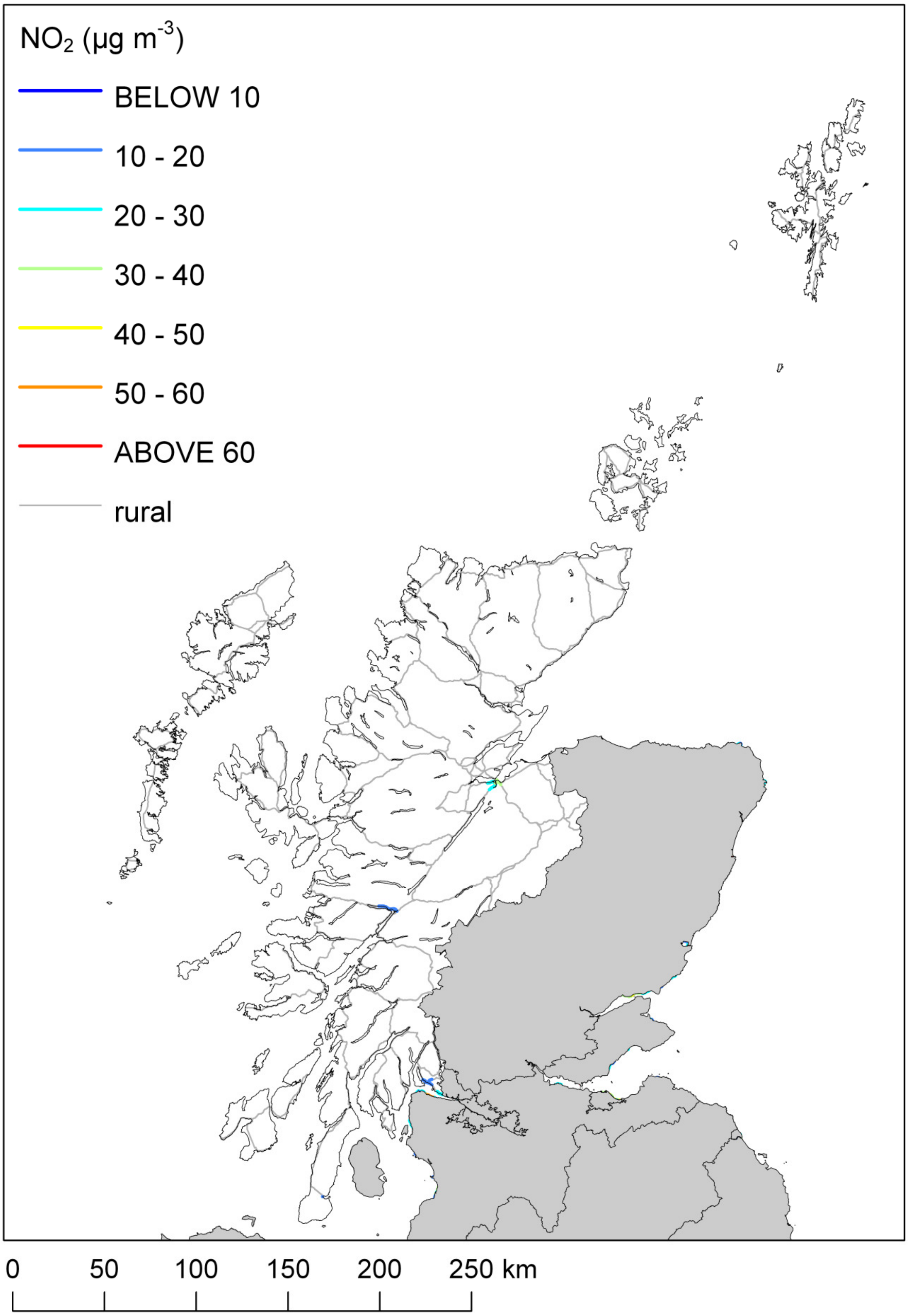
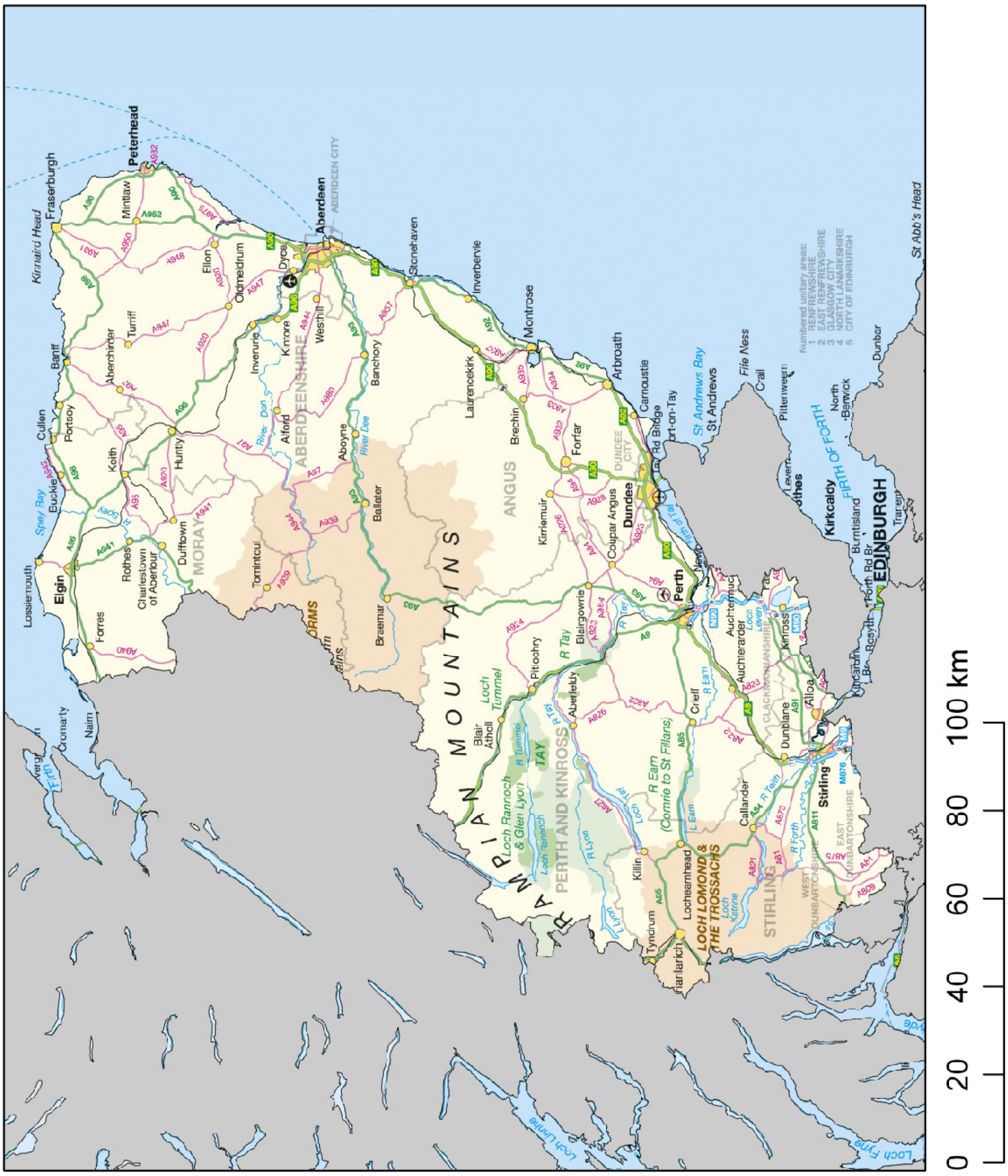

NO_2 (µg m^{-3})
BELOW 10
10 - 20
20 - 30
30 - 40
40 - 50
50 - 60
ABOVE 60
rural
0
50
100
150
200
250 km

Figure 5.6 Detailed roadside NO_2 map for 2010, µg m^{-3} showing the road-link concentrations in North East Scotland (Scotland-specific model).



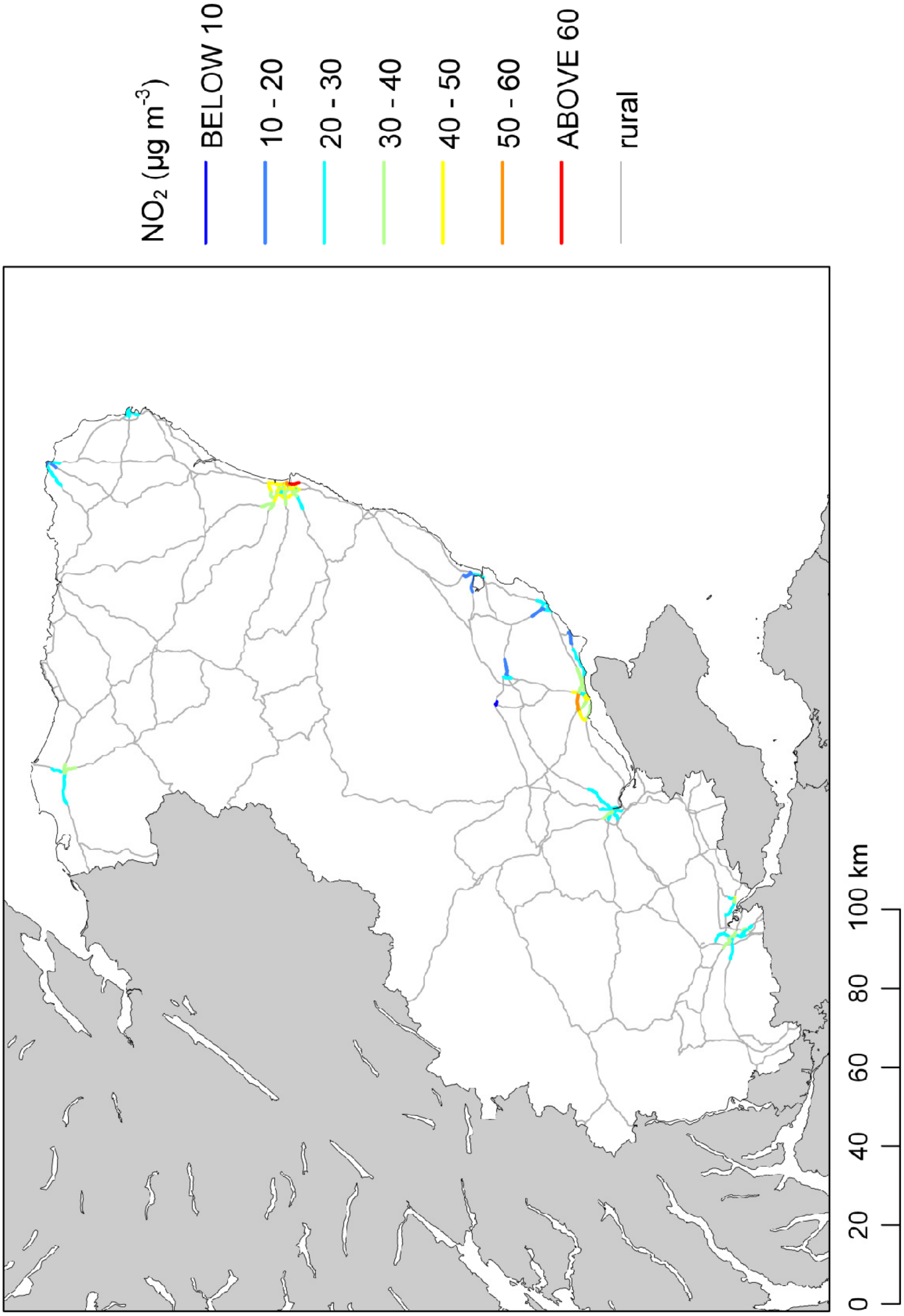
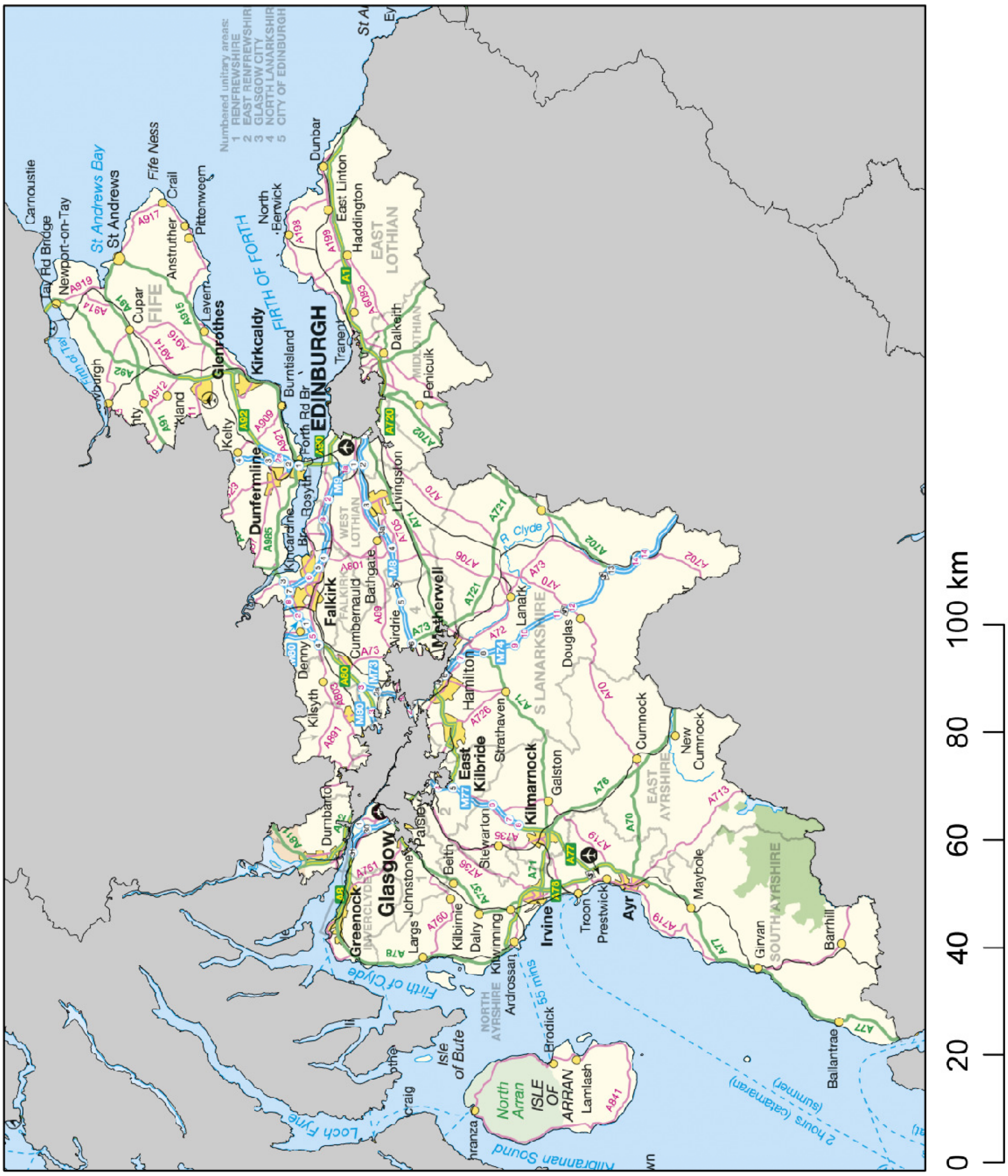

NO2 (µg m-3)
BELOW 10
10 - 20
20 - 30
30 - 40
40 - 50
50 - 60
ABOVE 60
rural
0
20
40
60
80
100 km

Figure 5.7 Detailed roadside NO_2 map for 2010, µg m^{-3} showing the road-link concentrations in Central Scotland (Scotland-specific model).



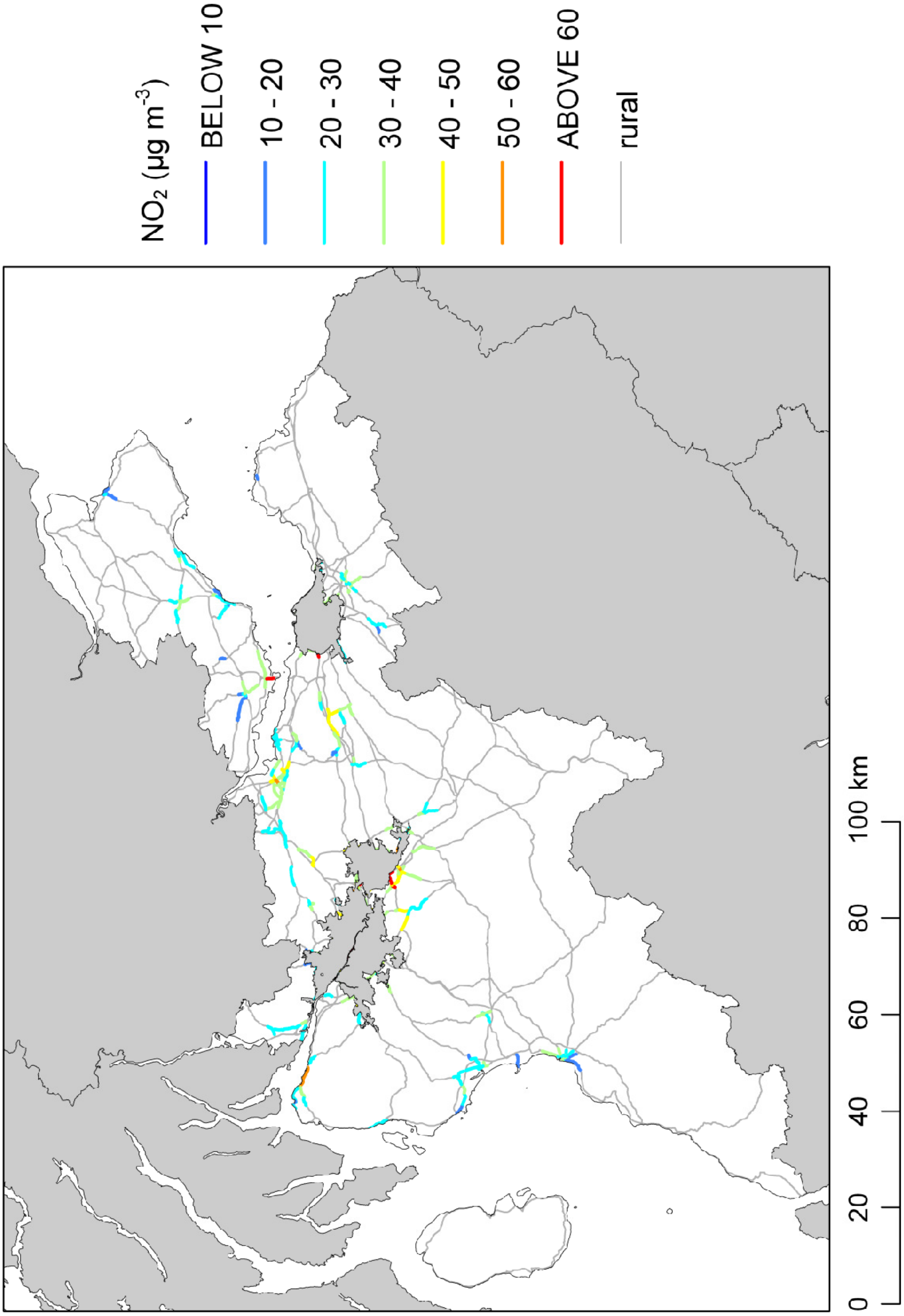
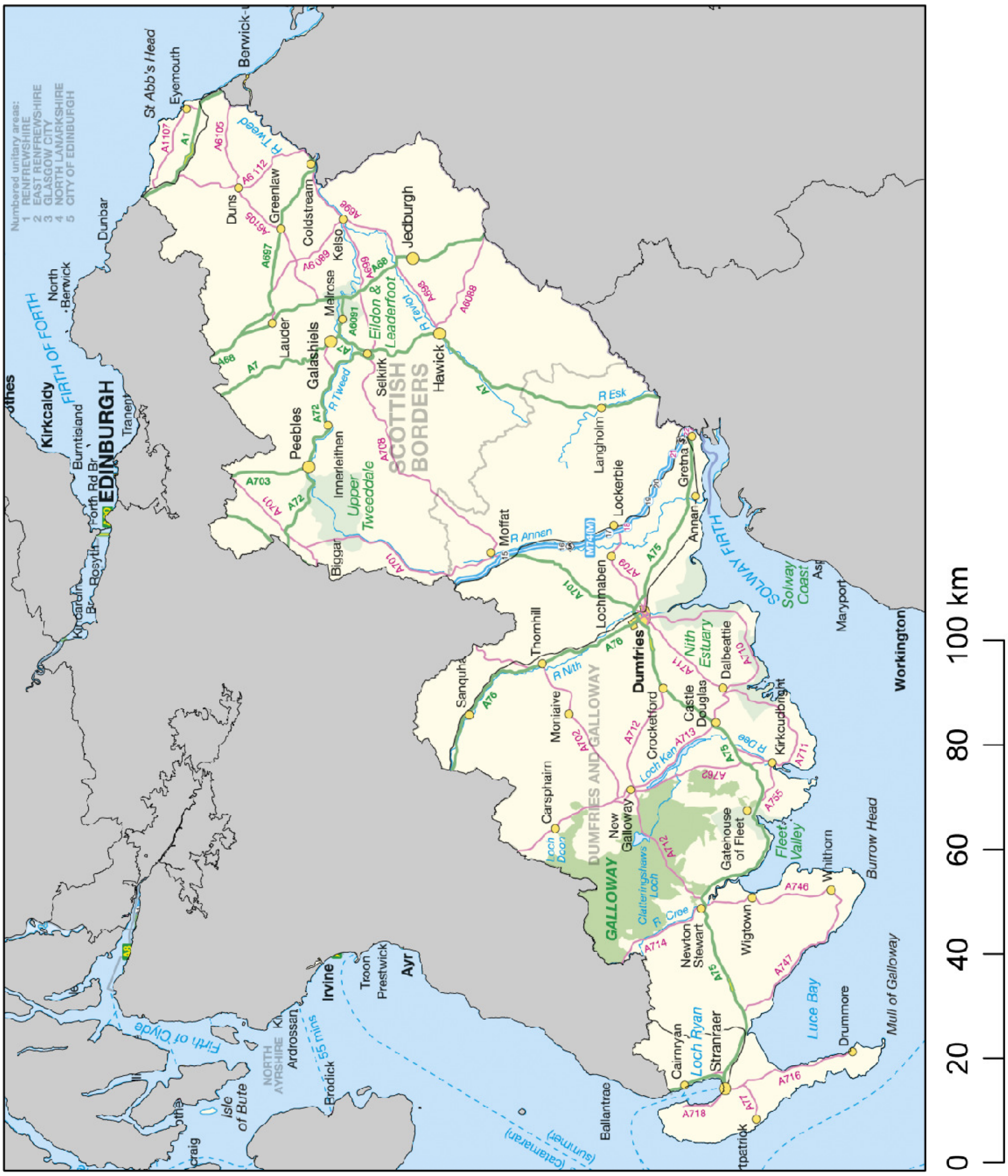

NO2 (µg m-3)
BELOW 10
10 - 20
20 - 30
30 - 40
40 - 50
50 - 60
ABOVE 60
rural
0
20
40
60
80
100 km

***Figure 5.8** Detailed roadside NO_2 map for 2010, µg m^{-3} showing the road-link concentrations in the Scottish Borders (Scotland-specific model).*



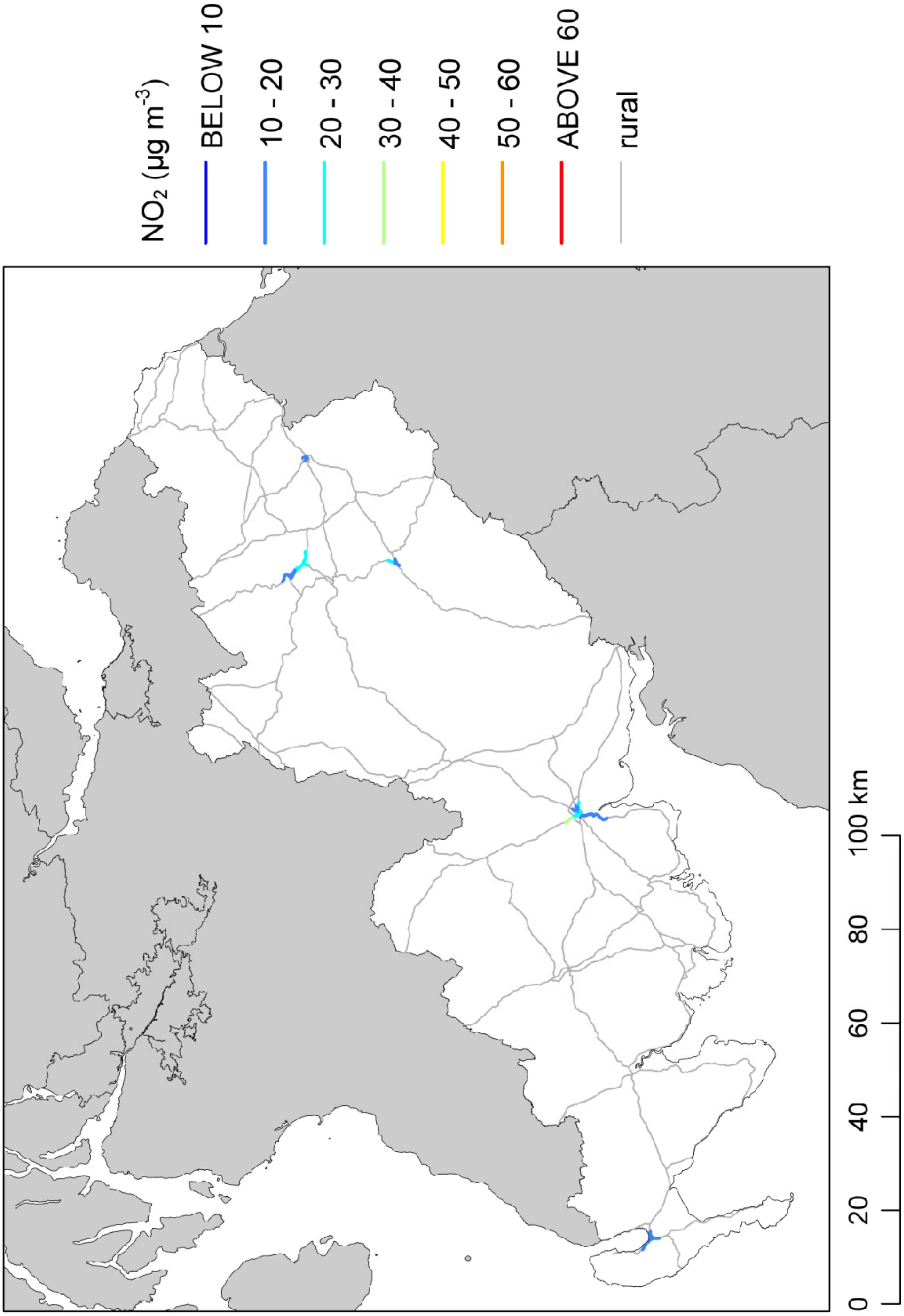
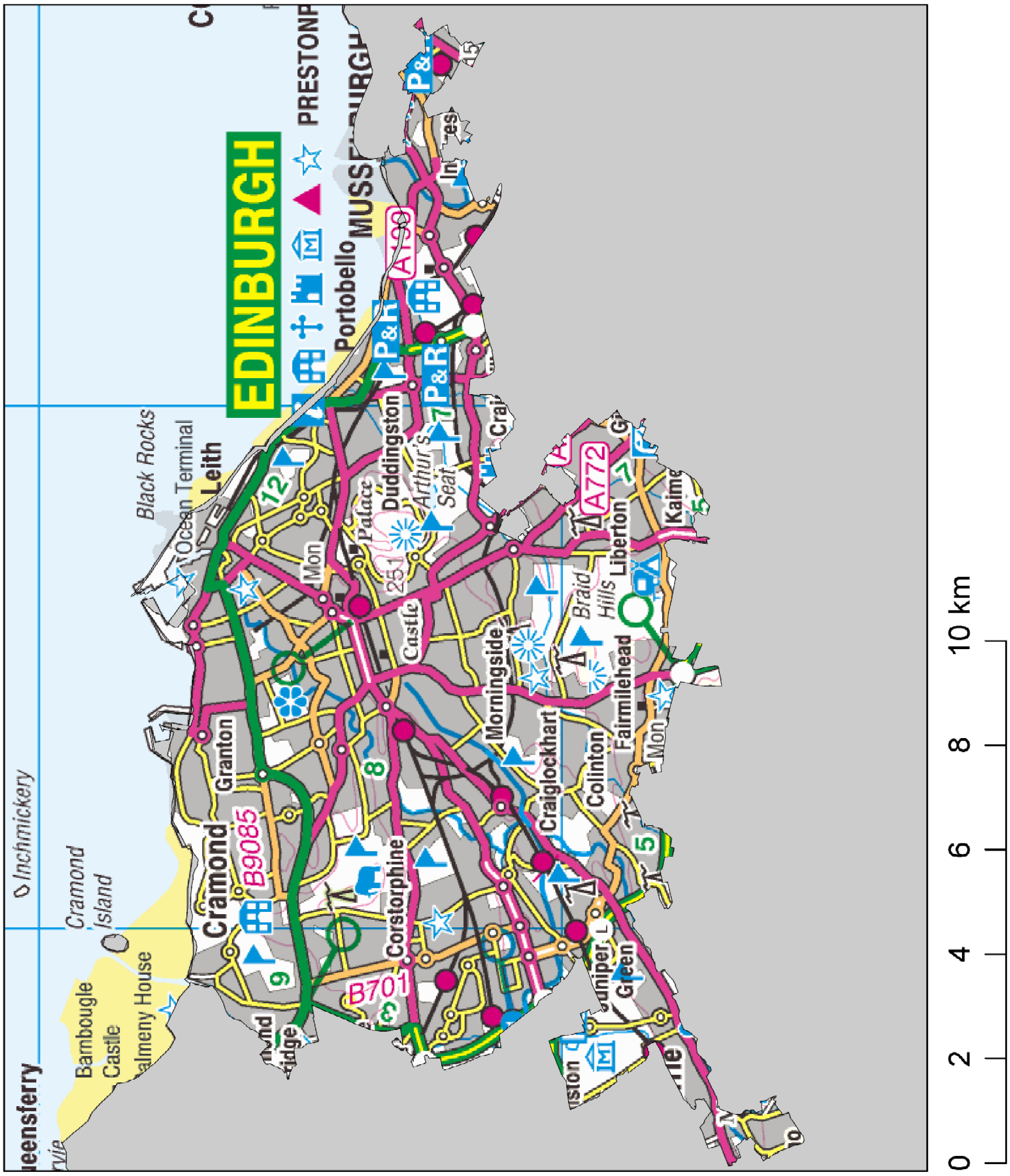

NO_2 (µg m^{-3})
BELOW 10
10 - 20
20 - 30
30 - 40
40 - 50
50 - 60
ABOVE 60
rural
0
20
40
60
80
100 km

***Figure 5.9** Detailed roadside NO_2 map for 2010, µg m^{-3} showing the road-link concentrations in the Edinburgh Urban Area (Scotland-specific model).*



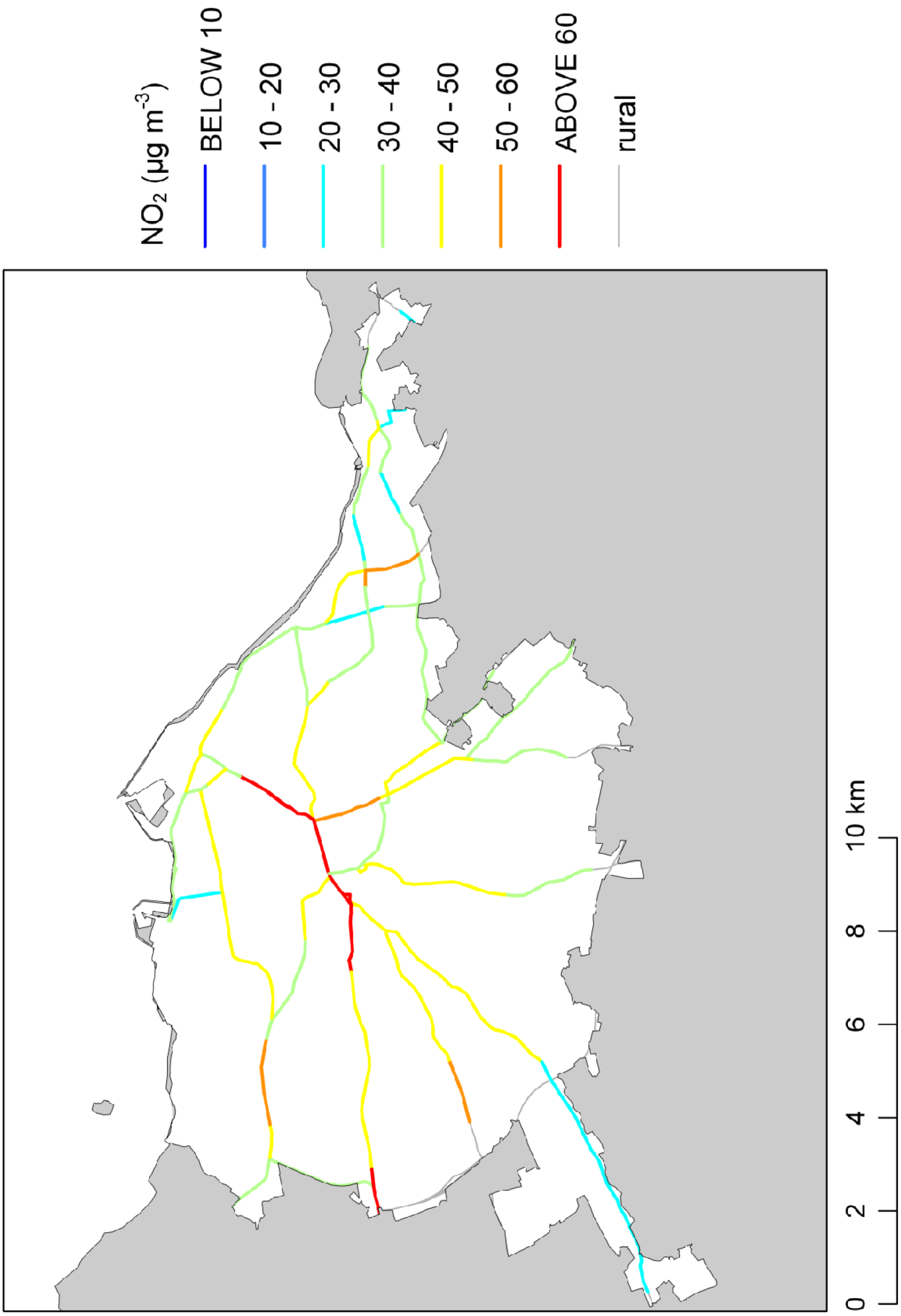
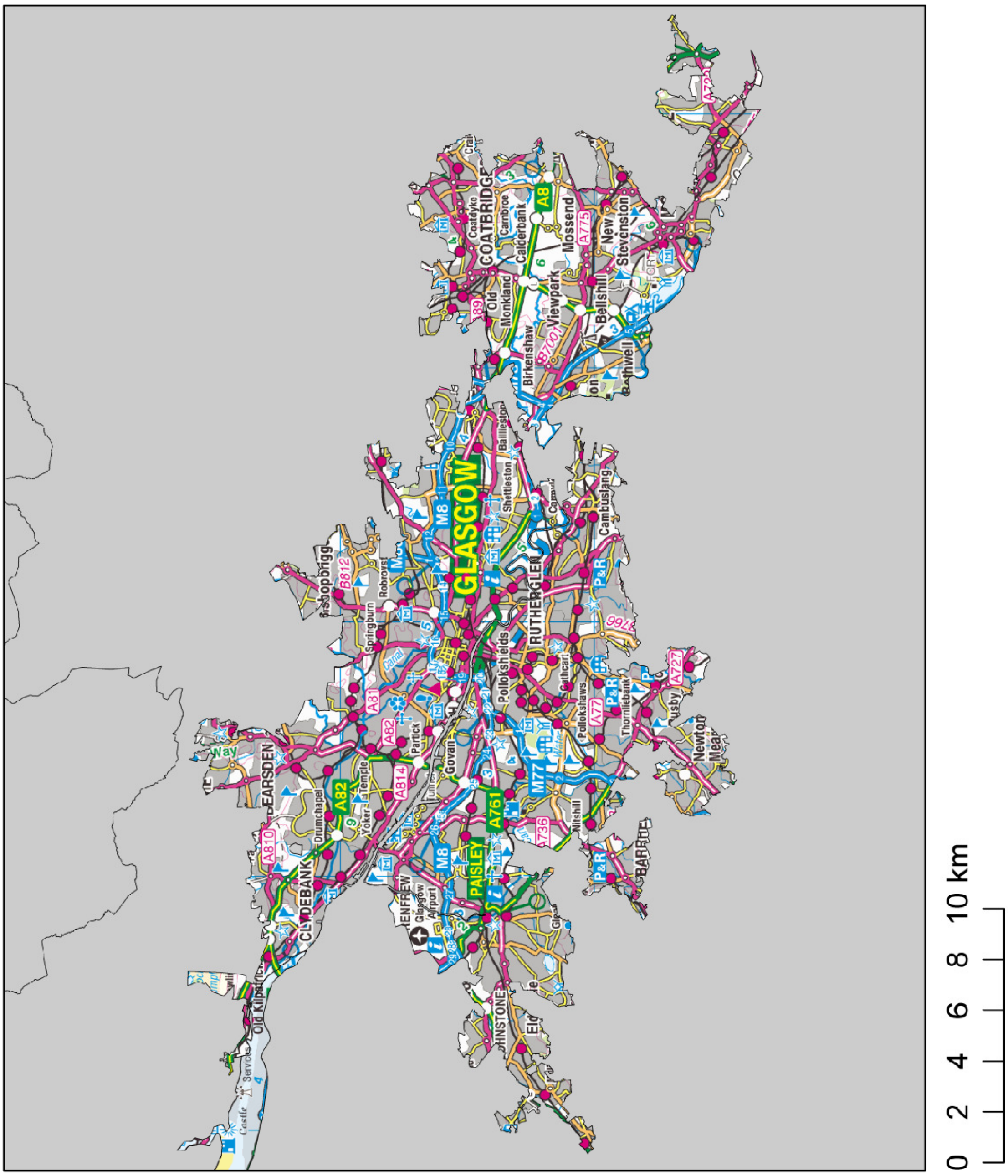

NO_2 (µg m^{-3})
BELOW 10
10 - 20
20 - 30
30 - 40
40 - 50
50 - 60
ABOVE 60
rural
0
2
4
6
8
10 km

Figure 5.10 Detailed roadside NO_2 map for 2010, µg m^{-3} showing the road-link concentrations in the Glasgow Urban Area (Scotland-specific model).



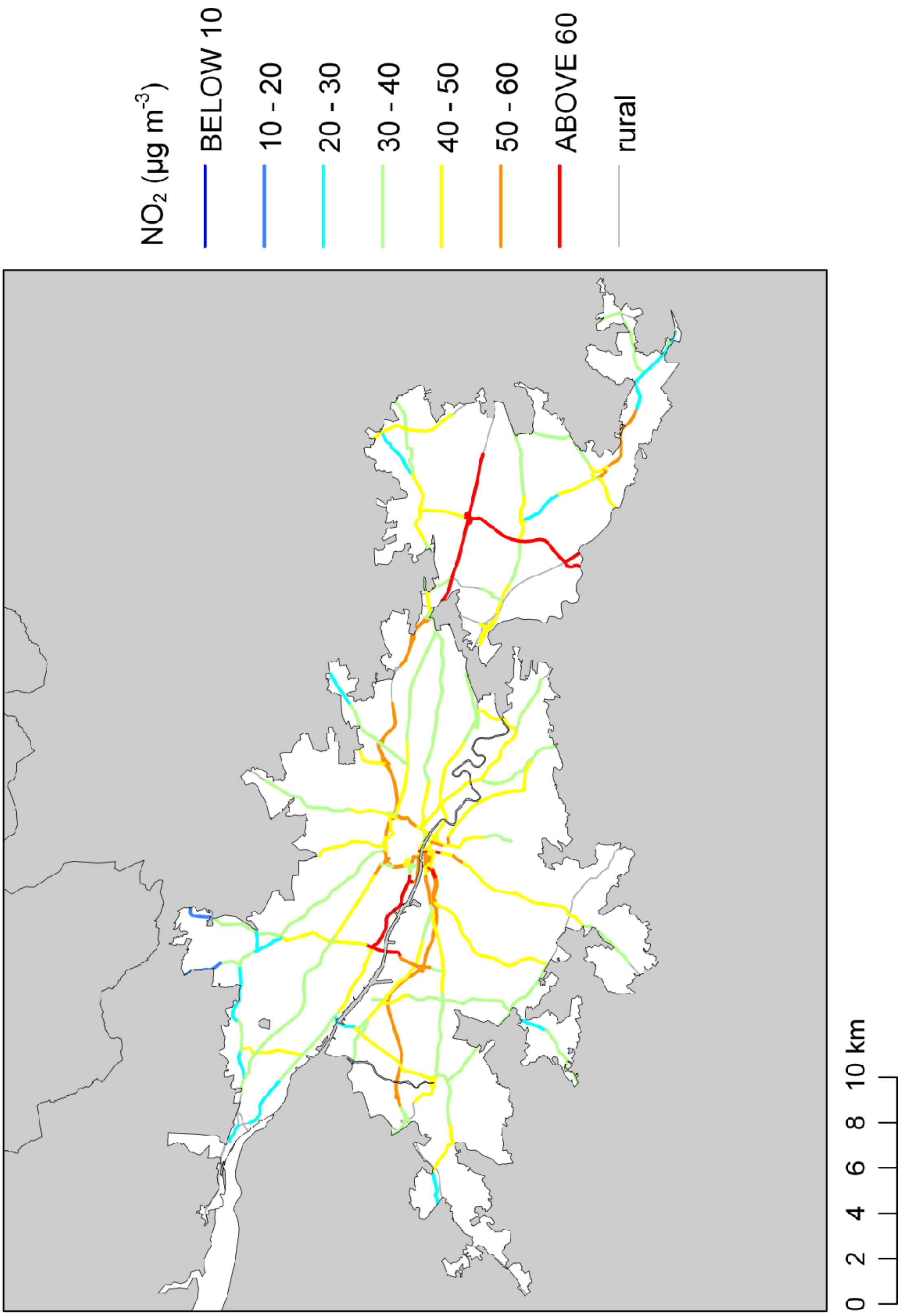

NO$_2$ (μg m^{-3})
BELOW 10
10 - 20
20 - 30
30 - 40
40 - 50
50 - 60
ABOVE 60
rural
0
2
4
6
8
10 km

Figure 5.11 Background PM_{10} map for 2010, µg m^{-3} (Scotland-specific model).

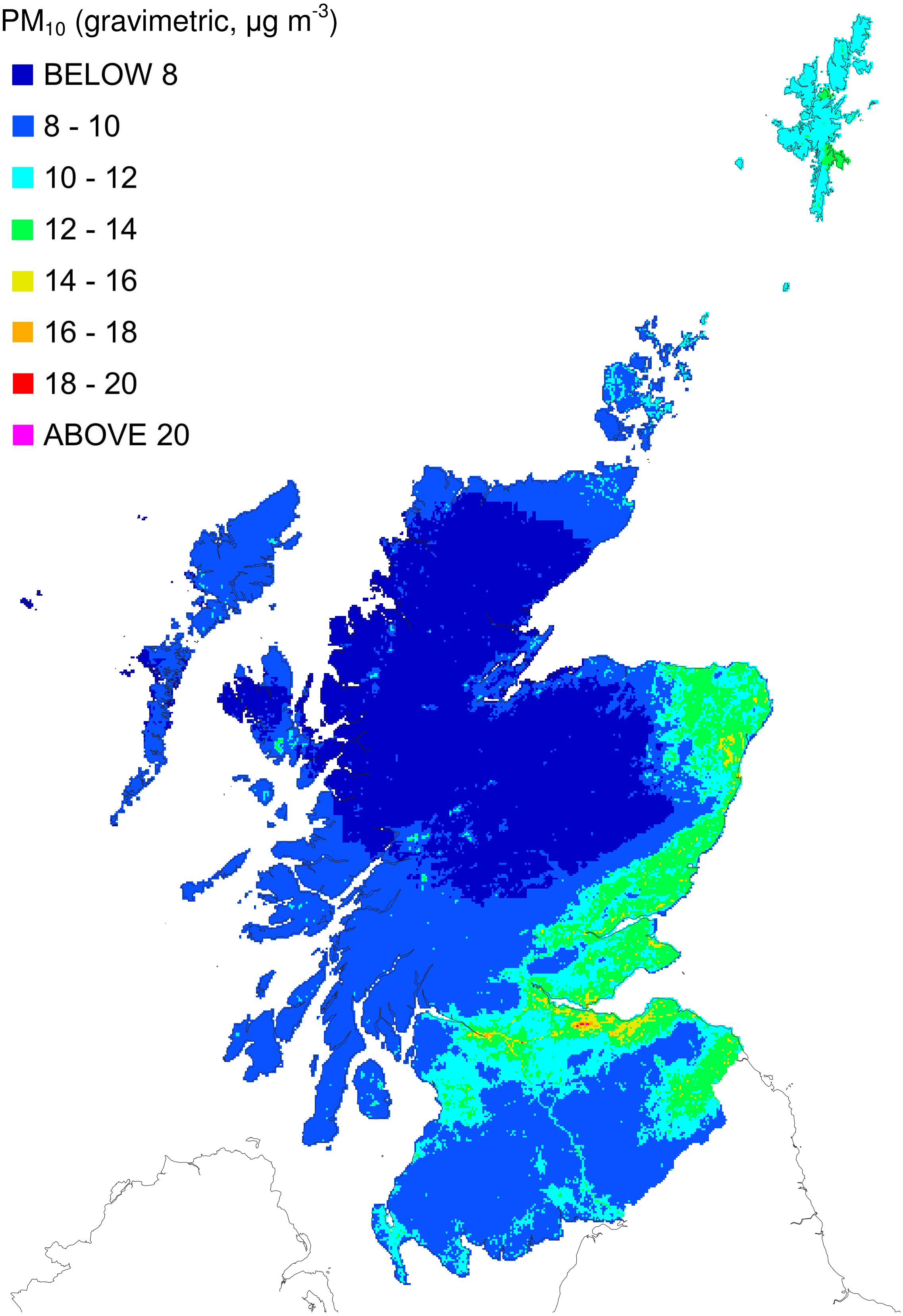


Figure 5.12 Roadside PM_{10} map for 2010, µg m^{-3} (Scotland-specific model).

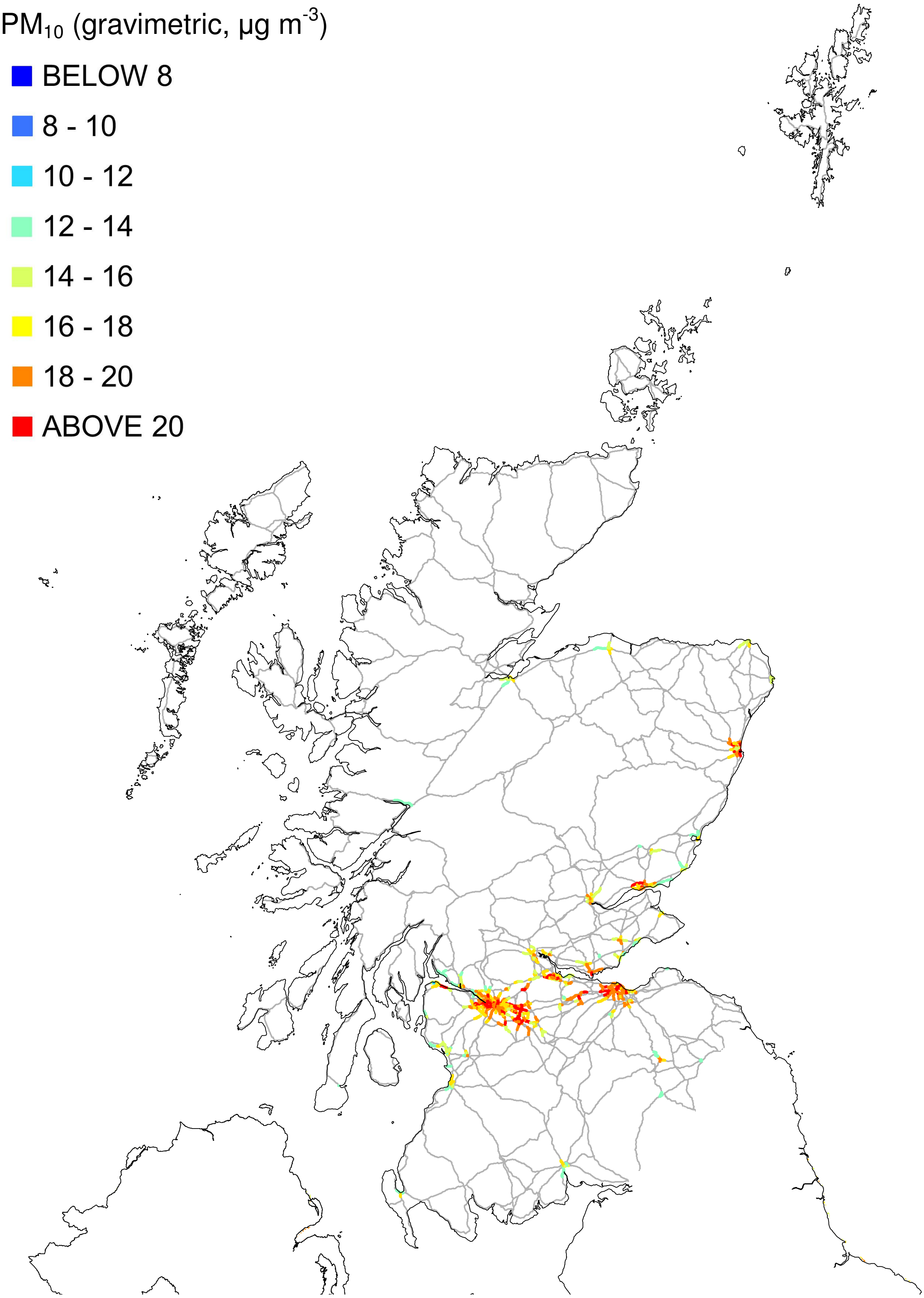
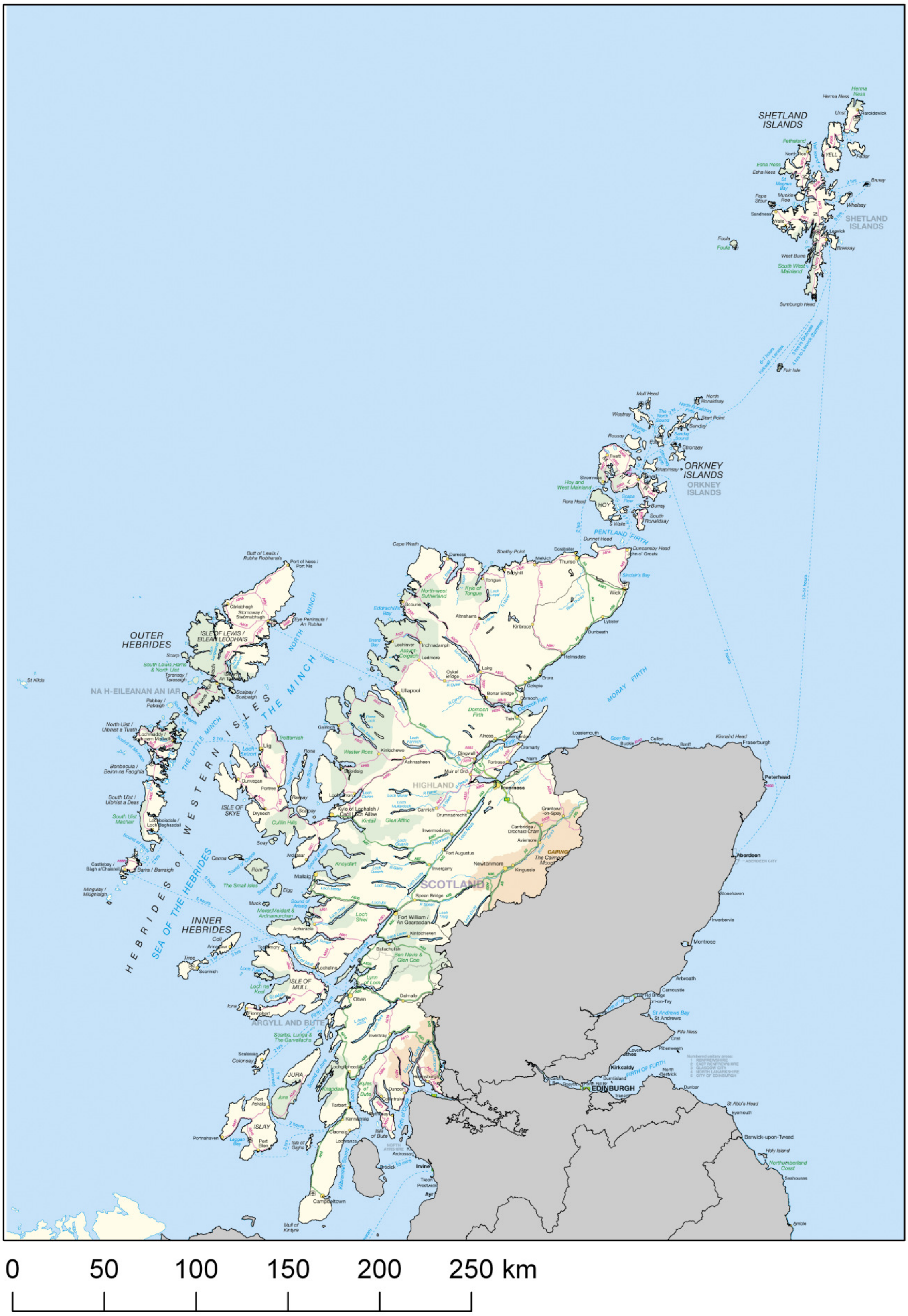


Figure 5.13 Detailed roadside PM_{10} map for 2010, µg m^{-3} showing the road-link concentrations in the Highlands (Scotland-specific model).



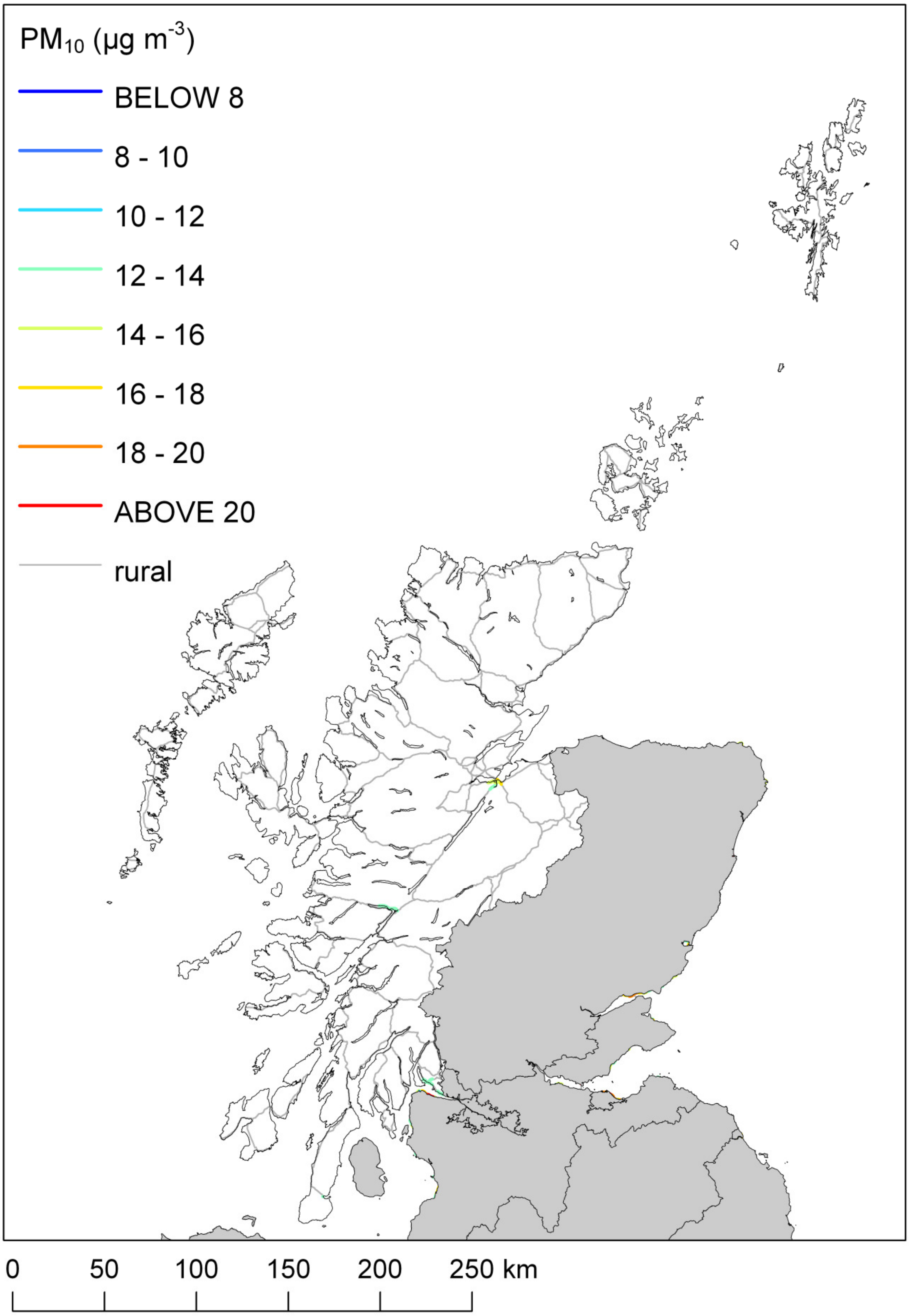
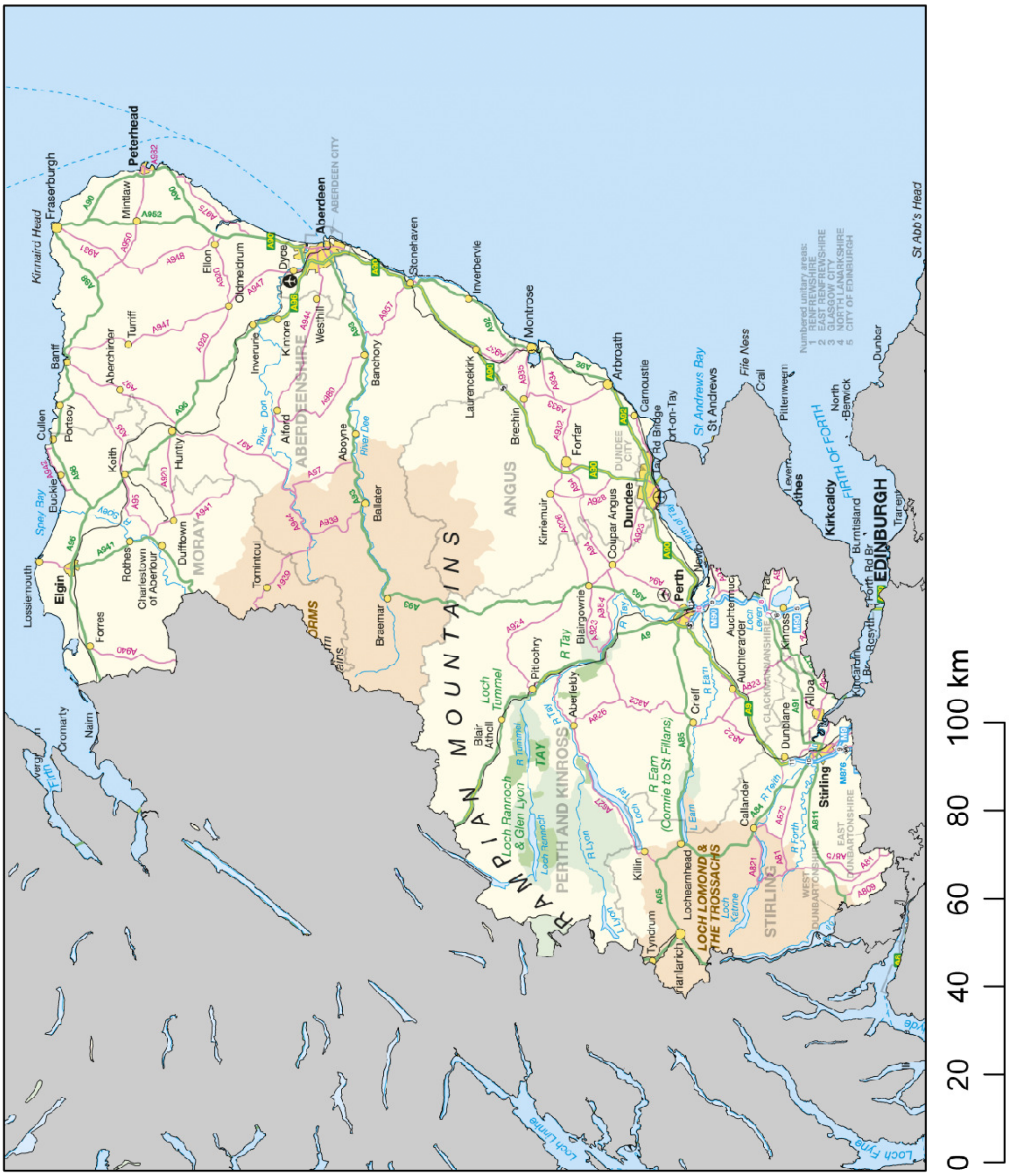

PM10 (µg m-3)
BELOW 8
8 - 10
10 - 12
12 - 14
14 - 16
16 - 18
18 - 20
ABOVE 20
rural
0
50
100
150
200
250 km

Figure 5.14 ***Detailed roadside PM_{10} map for 2010, µg m^{-3} showing the road-link concentrations in North East Scotland (Scotland-specific model).***



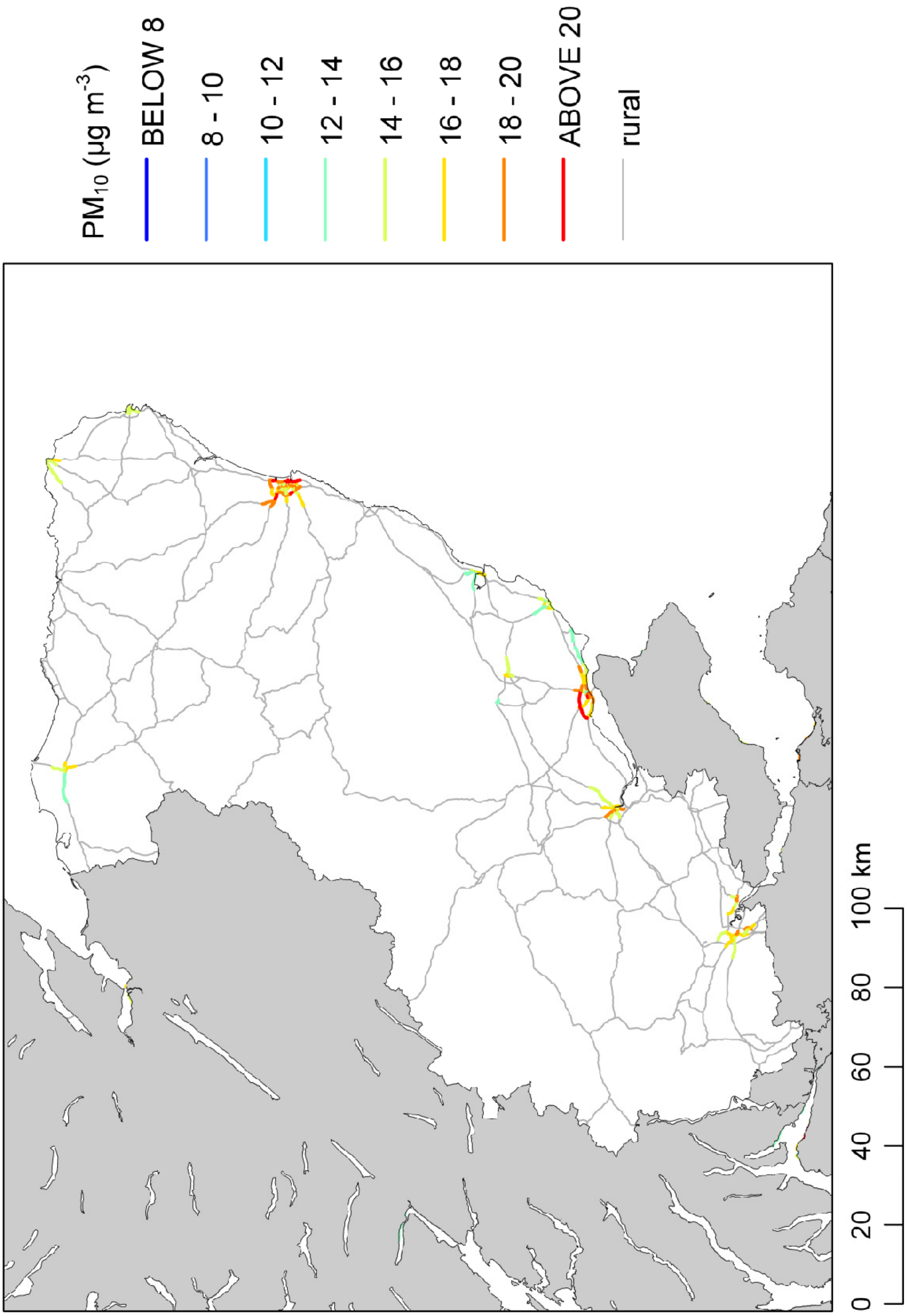
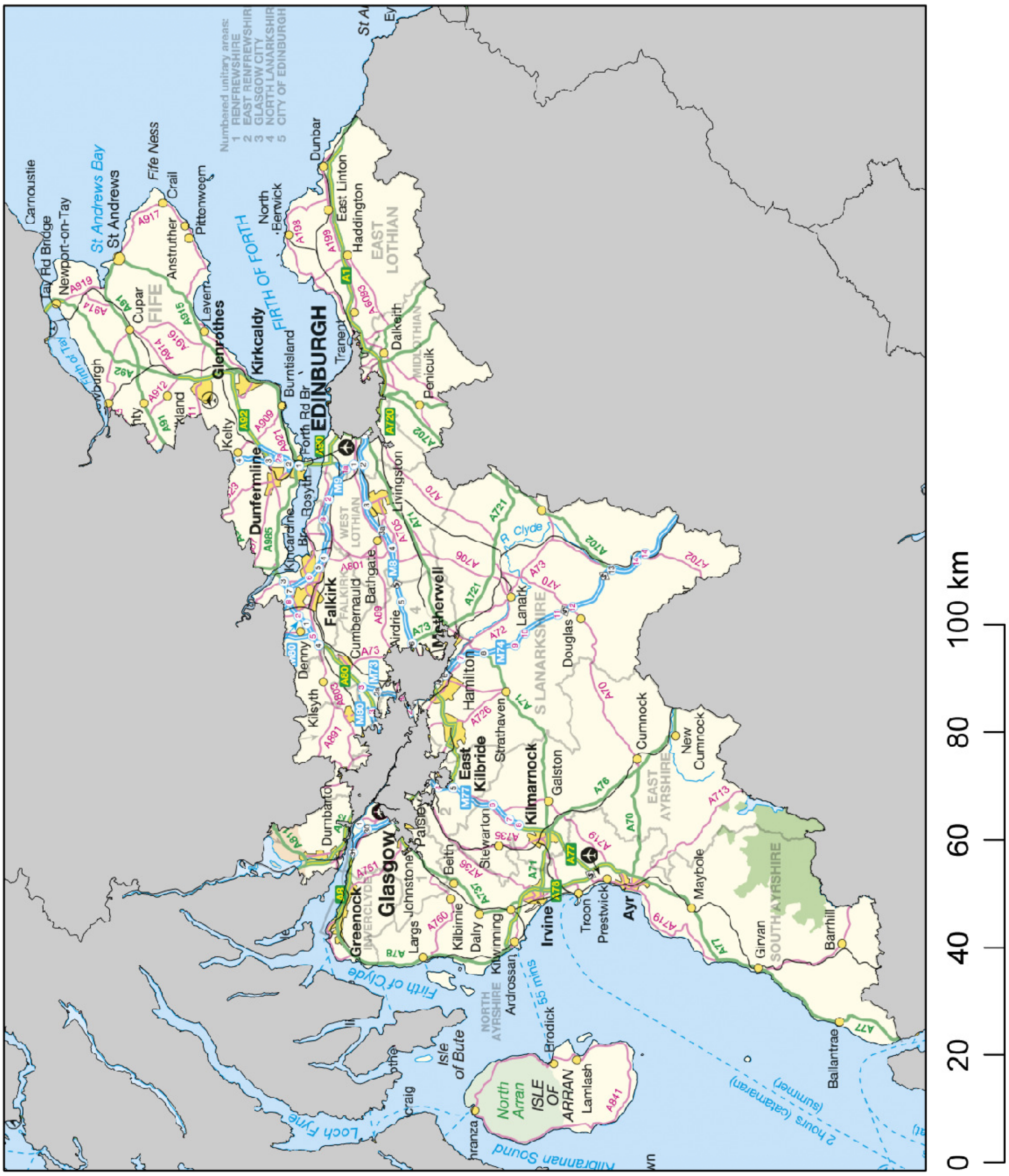

PM10 (μg m-3)
BELOW 8
8 - 10
10 - 12
12 - 14
14 - 16
16 - 18
18 - 20
ABOVE 20
rural
0
20
40
60
80
100 km

Figure 5.15 Detailed roadside PM_{10} map for 2010, µg m^{-3} showing the road-link concentrations in Central Scotland (Scotland-specific model).



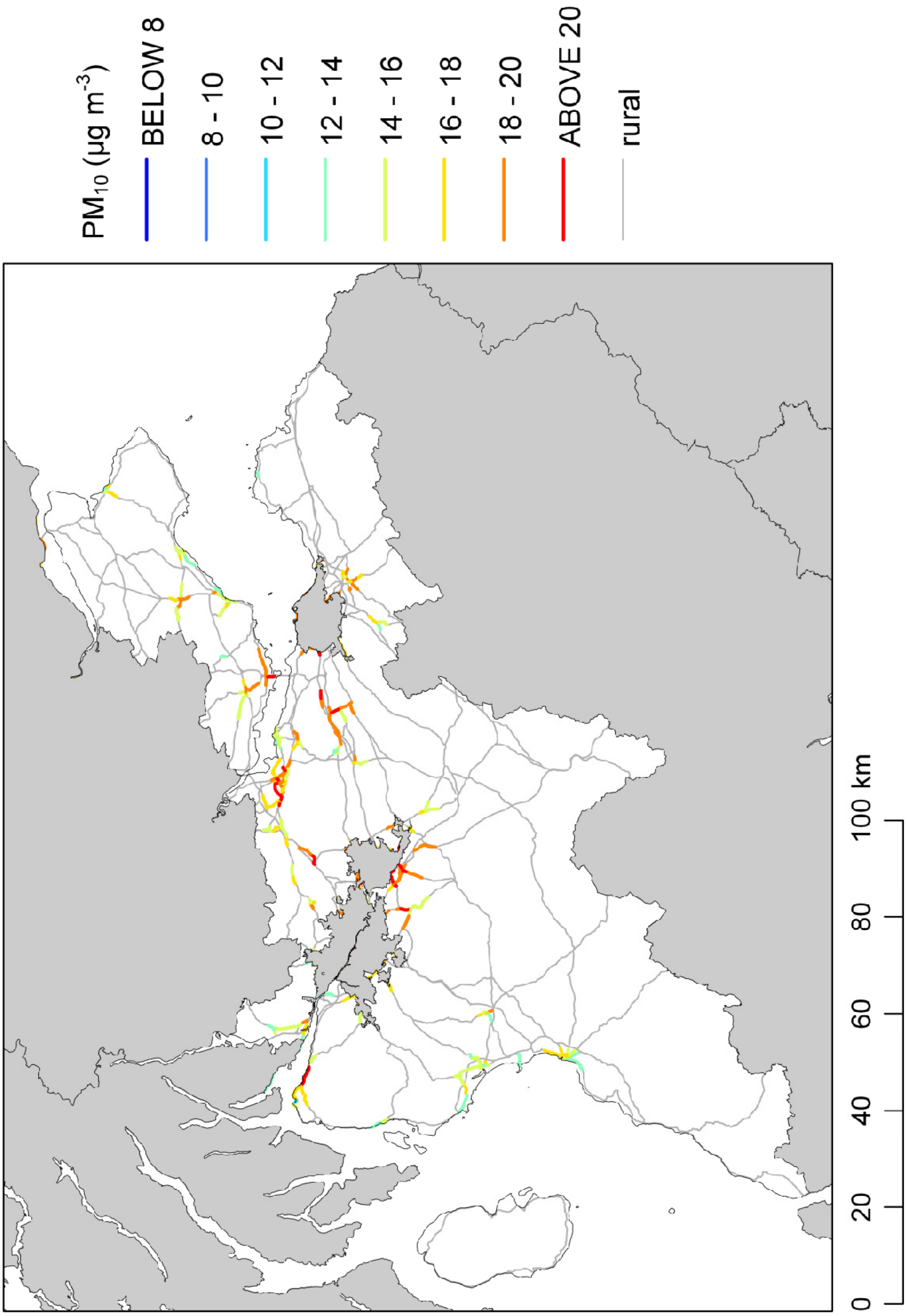
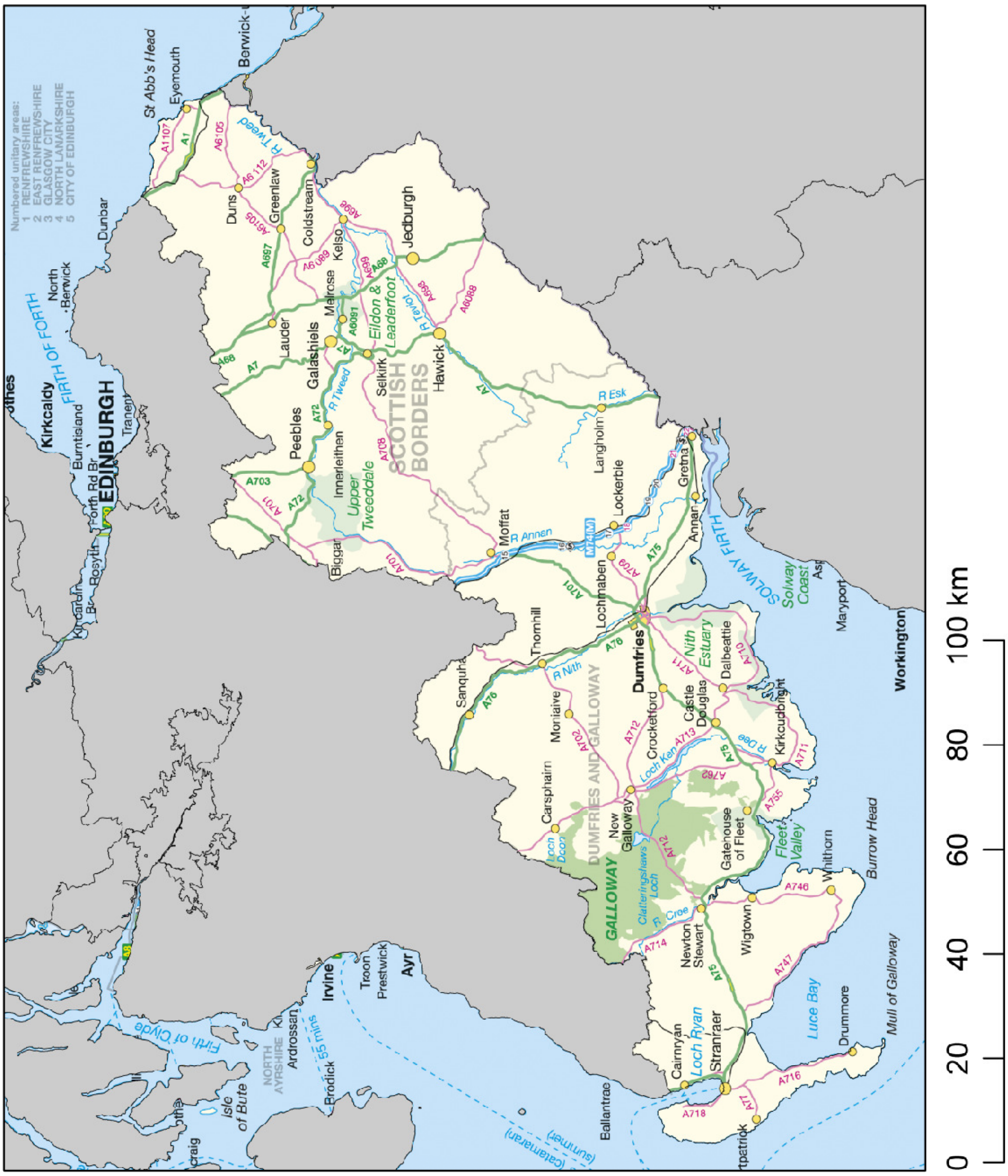

PM_{10} (µg m^{-3})
BELOW 8
8 - 10
10 - 12
12 - 14
14 - 16
16 - 18
18 - 20
ABOVE 20
rural
0
20
40
60
80
100 km

Figure 5.16 Detailed roadside PM_{10} map for 2010, $\mu g\ m^{-3}$ showing the road-link concentrations in the Scottish Borders (Scotland-specific model).



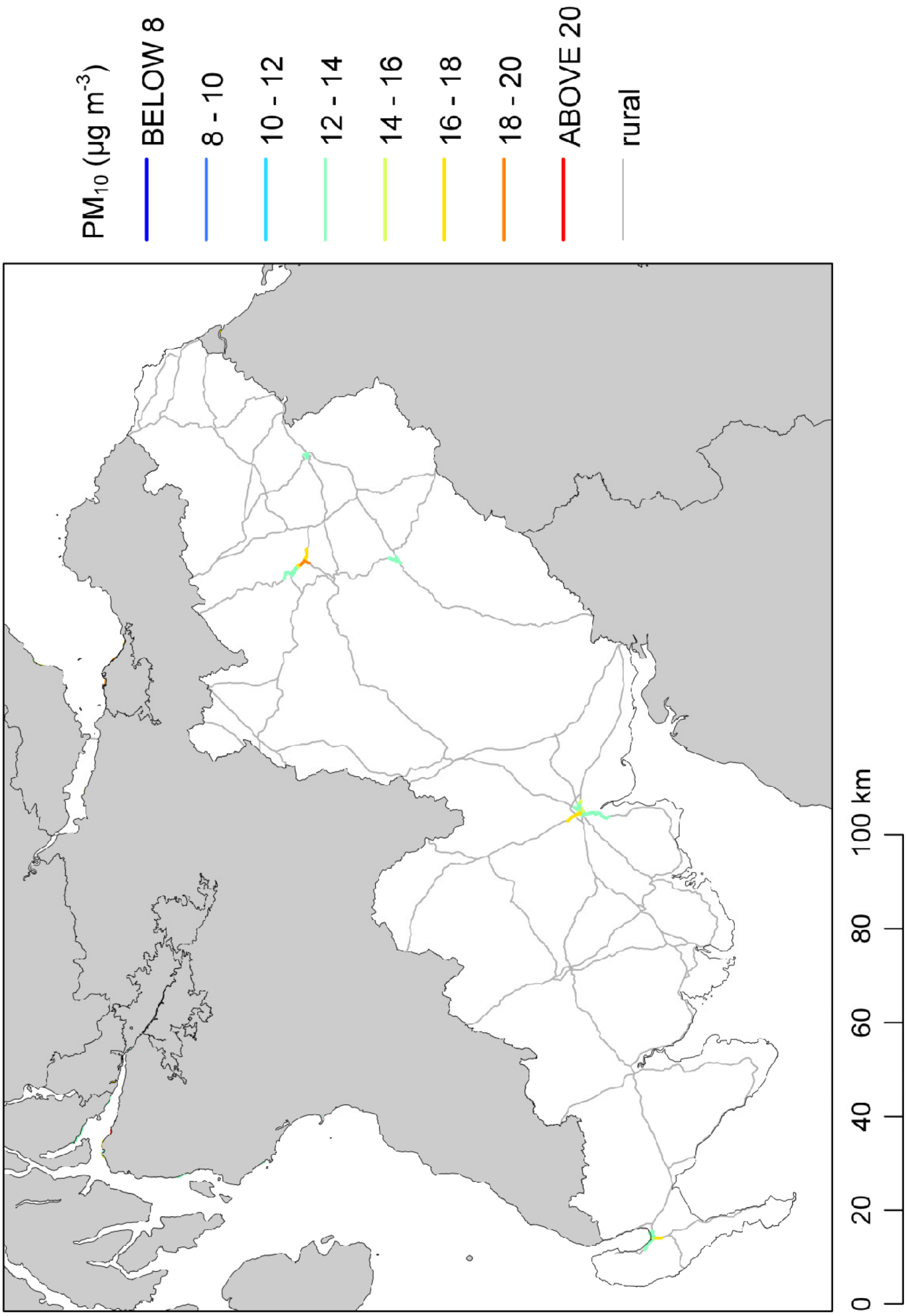
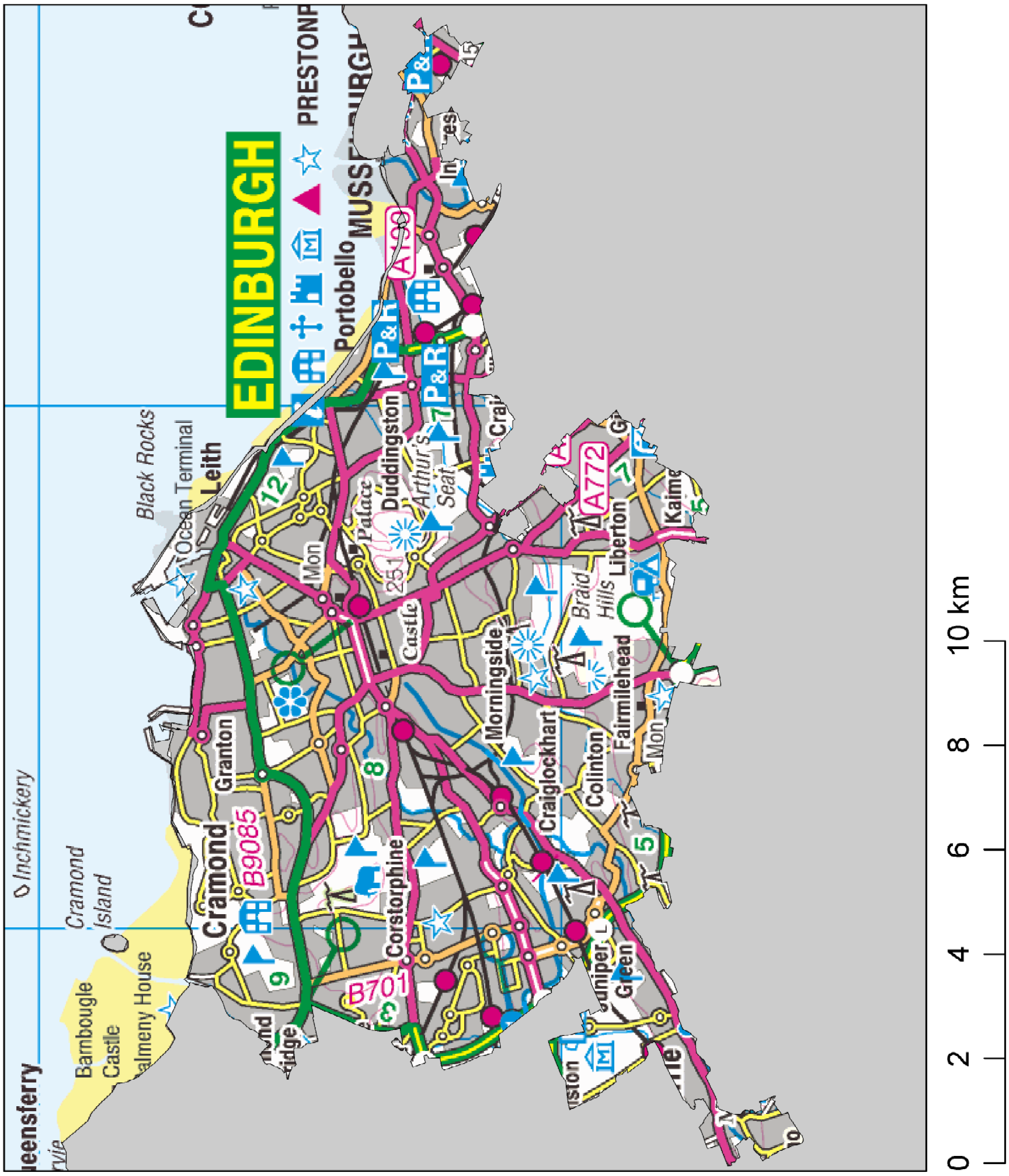

PM10 (µg m-3)
BELOW 8
8 - 10
10 - 12
12 - 14
14 - 16
16 - 18
18 - 20
ABOVE 20
rural
0
20
40
60
80
100 km

Figure 5.17 Detailed roadside PM_{10} map for 2010, µg m^{-3} showing the road-link concentrations in the Edinburgh Urban Area (Scotland-specific model).



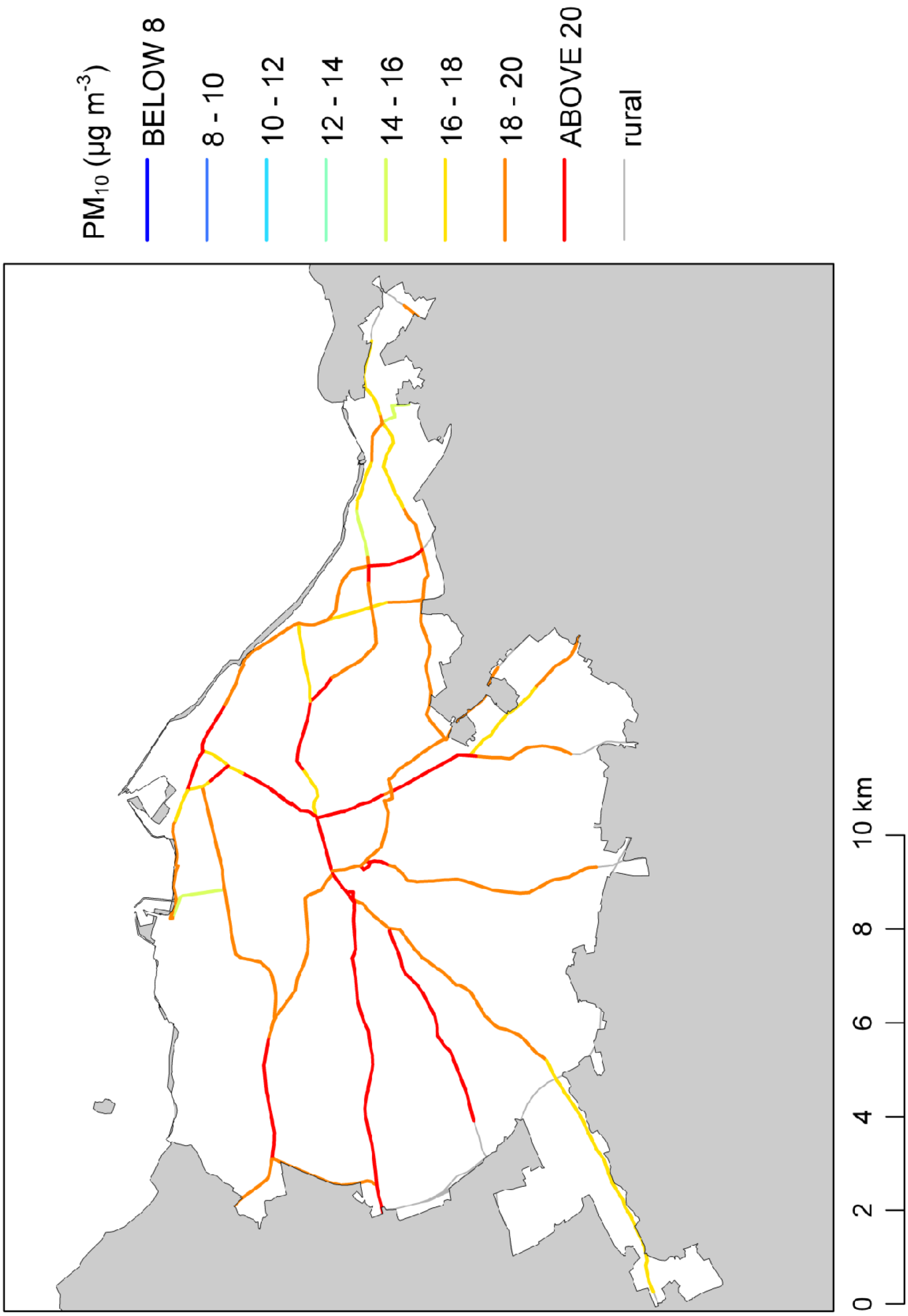
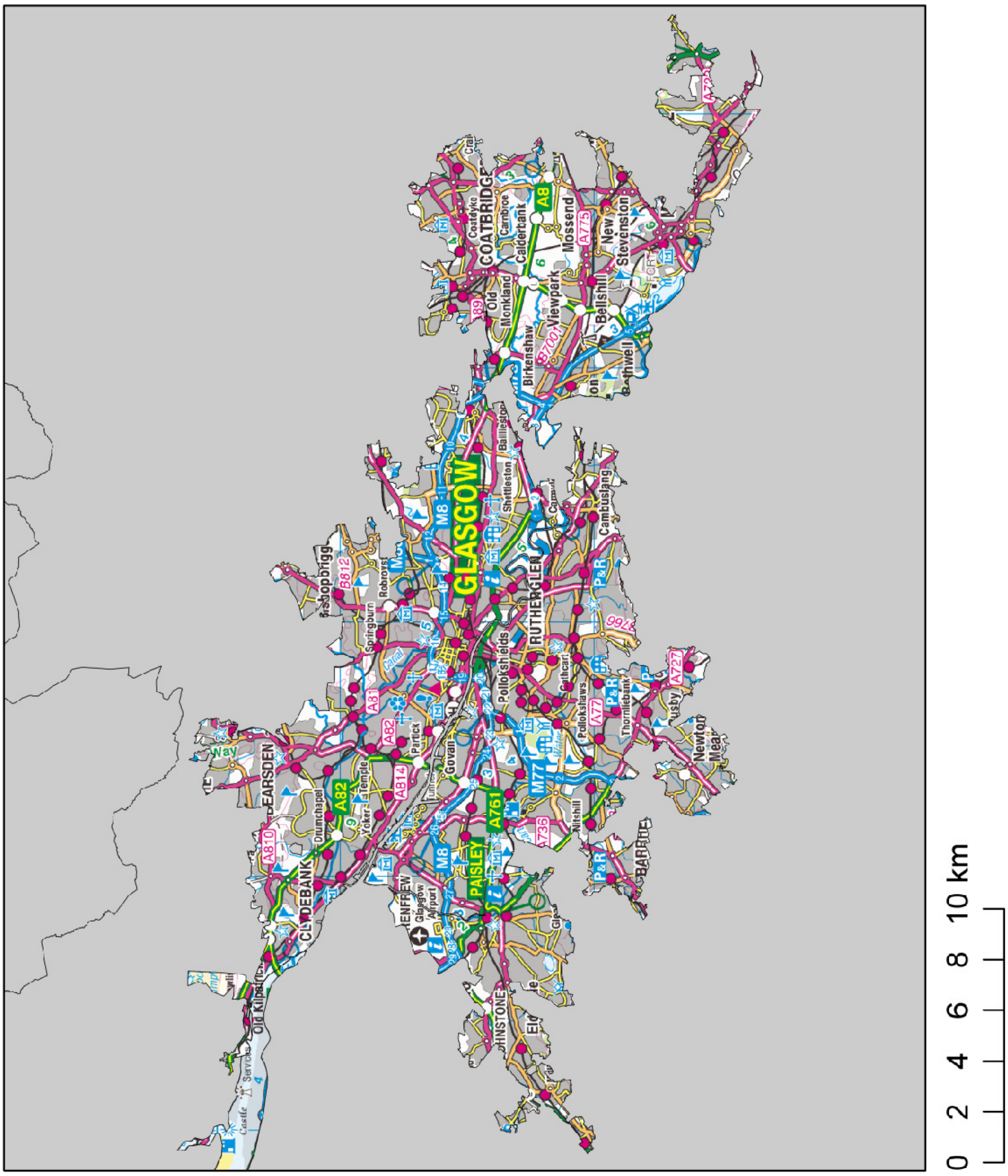
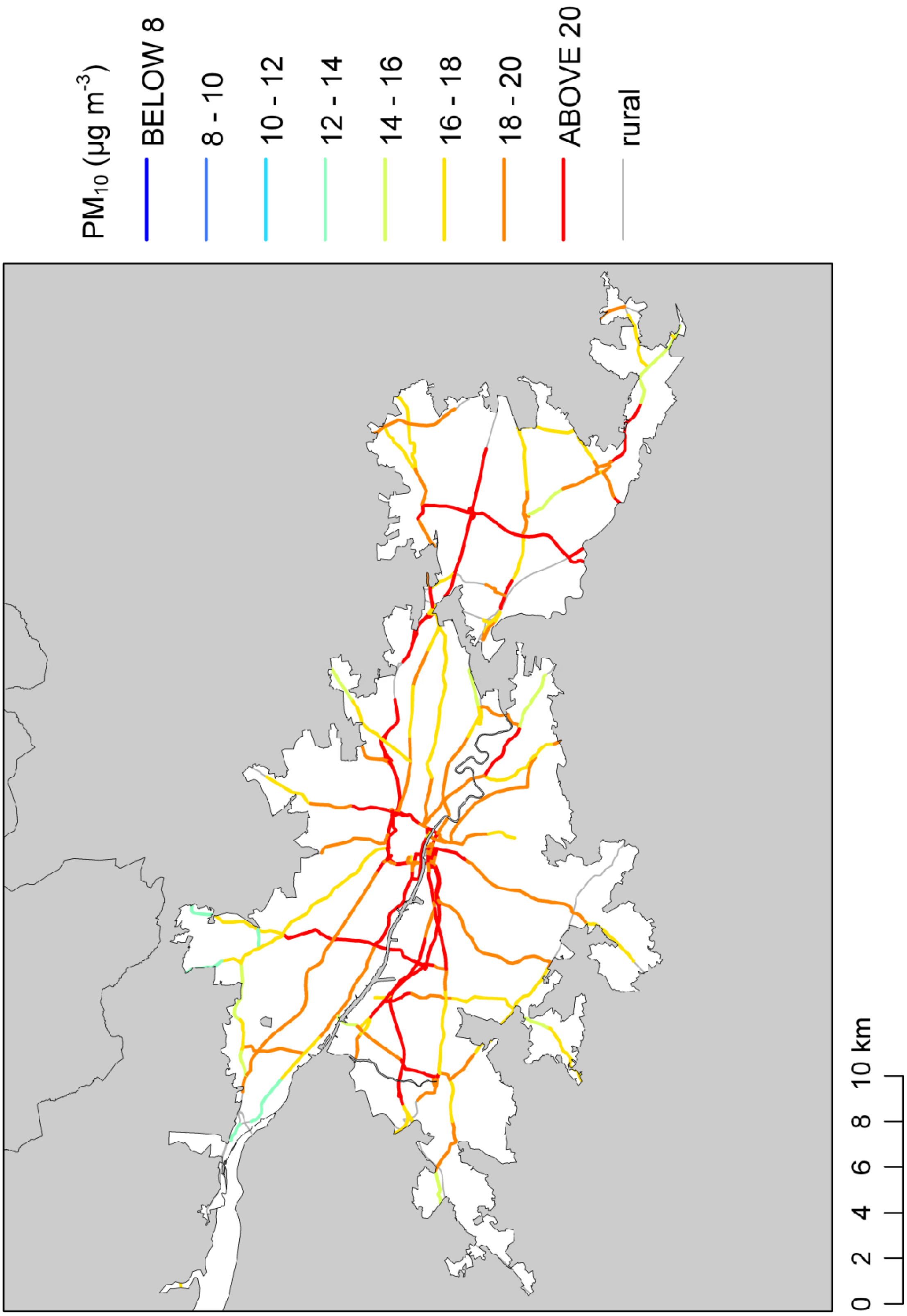

PM$_{10}$ (µg m^{-3})
BELOW 8
8 - 10
10 - 12
12 - 14
14 - 16
16 - 18
18 - 20
ABOVE 20
rural
0
2
4
6
8
10 km

Figure 5.18 Detailed roadside PM_{10} map for 2010, µg m^{-3} showing the road-link concentrations in the Glasgow Urban Area (Scotland-specific model).




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

6 Scotland-specific pollutant projections for 2015, 2020, 2025, and 2030

Projected annual mean concentrations of NO_2 and PM_{10} for 2015, 2020, 2025, and 2030, from a base year of 2010, 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 2010, these were prepared using Scotland-specific data.

The accuracy of the forward projection maps presented here (for both pollutants considered: NO_2 and PM_{10}) are closely dependent on the future emission projections used to prepare the background pollutant maps. As noted previously in this report, the 2010 annual mean background air pollutant concentration maps combined Scottish air pollutant measurements with spatially disaggregated emissions information. Scottish air pollutant emissions were based on the UK's National Atmospheric Emissions Inventory (NAEI) and the most recently updated (as of January 2012) National energy usage statistics (UEP43). The Scotland-specific model included the most recently revised (as of January 2012) NO_X emission factors for road transport emissions, taken from COPERT4 v8.1, and ANPR/DVLA-scaled data, to represent the most up-to-date vehicle fleet information in Scotland. 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 2015, 2020, 2025, and 2030

Figure 6.1 to 6.3 provide background maps of projected annual mean NO_2 concentrations for 2015, 2020, 2025, and 2030 based on the 2010 Scotland-specific model. The projected background maps for NO_2 show a progressive decrease in the background annual mean concentration between 2010 and 2030 due to the predicted reduction in primary NO_X and oxidant emissions, which contribute to the formation of NO_2.

6.2 Scotland-specific background maps of projected annual mean PM_{10} concentrations for 2015, 2020, 2025, and 2030

Figure 6.5 to 6.6 provide background maps of projected annual mean PM_{10} concentrations for 2015, 2020, 2025, and 2030 based on the 2010 Scotland-specific model. The projected background maps show a progressive decrease in the background annual mean PM_{10} concentrations to below 8 µg m^{-3} between 2010 and 2030 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 (around 12-18 µg m^{-3}) PM_{10} concentrations were projected to persist along 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 2010-2030 were 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 2015, µg m^{-3} (Scotland-specific model).

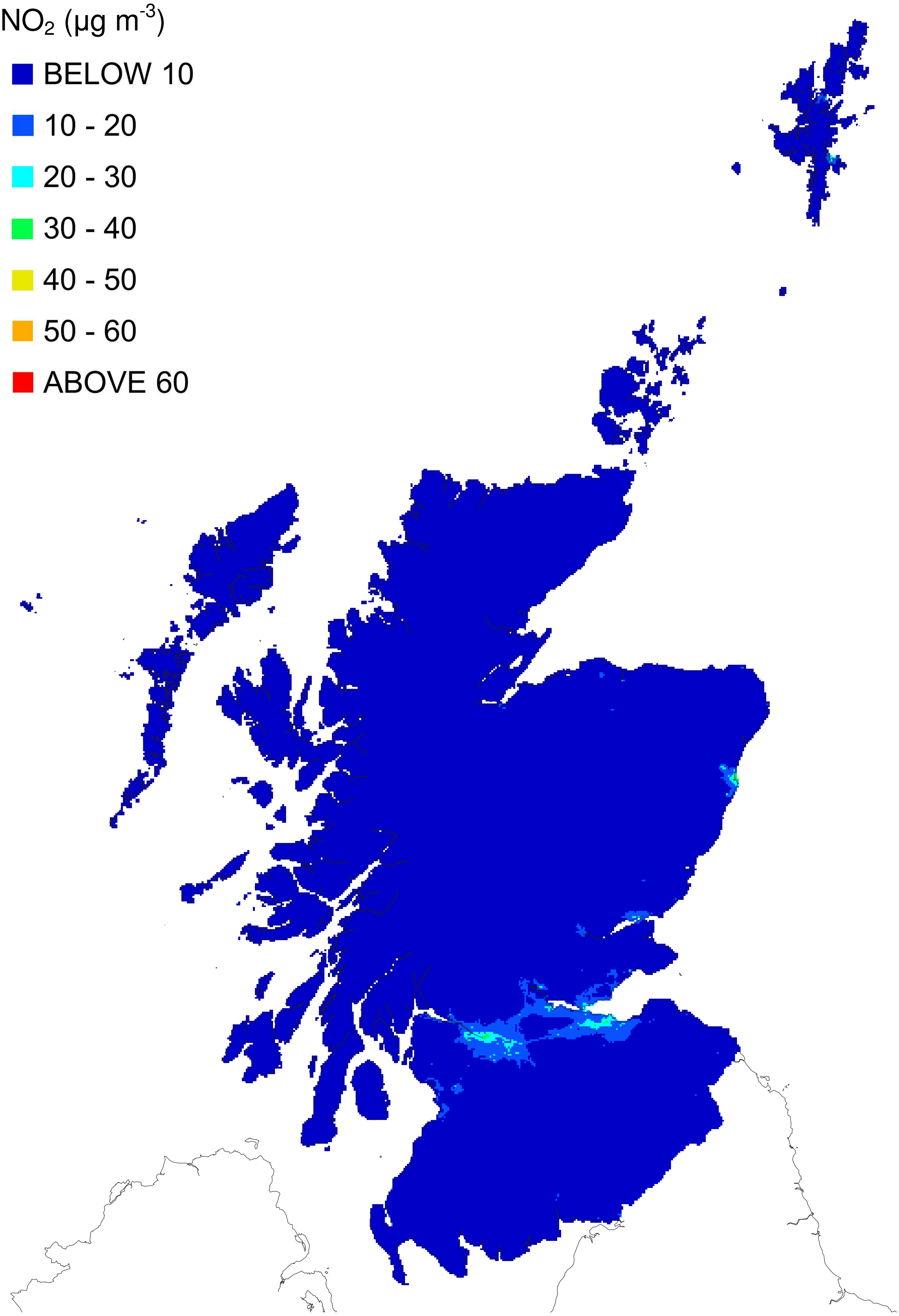


Figure 6.2 Background NO_2 map for 2020, µg m^{-3} (Scotland-specific model).

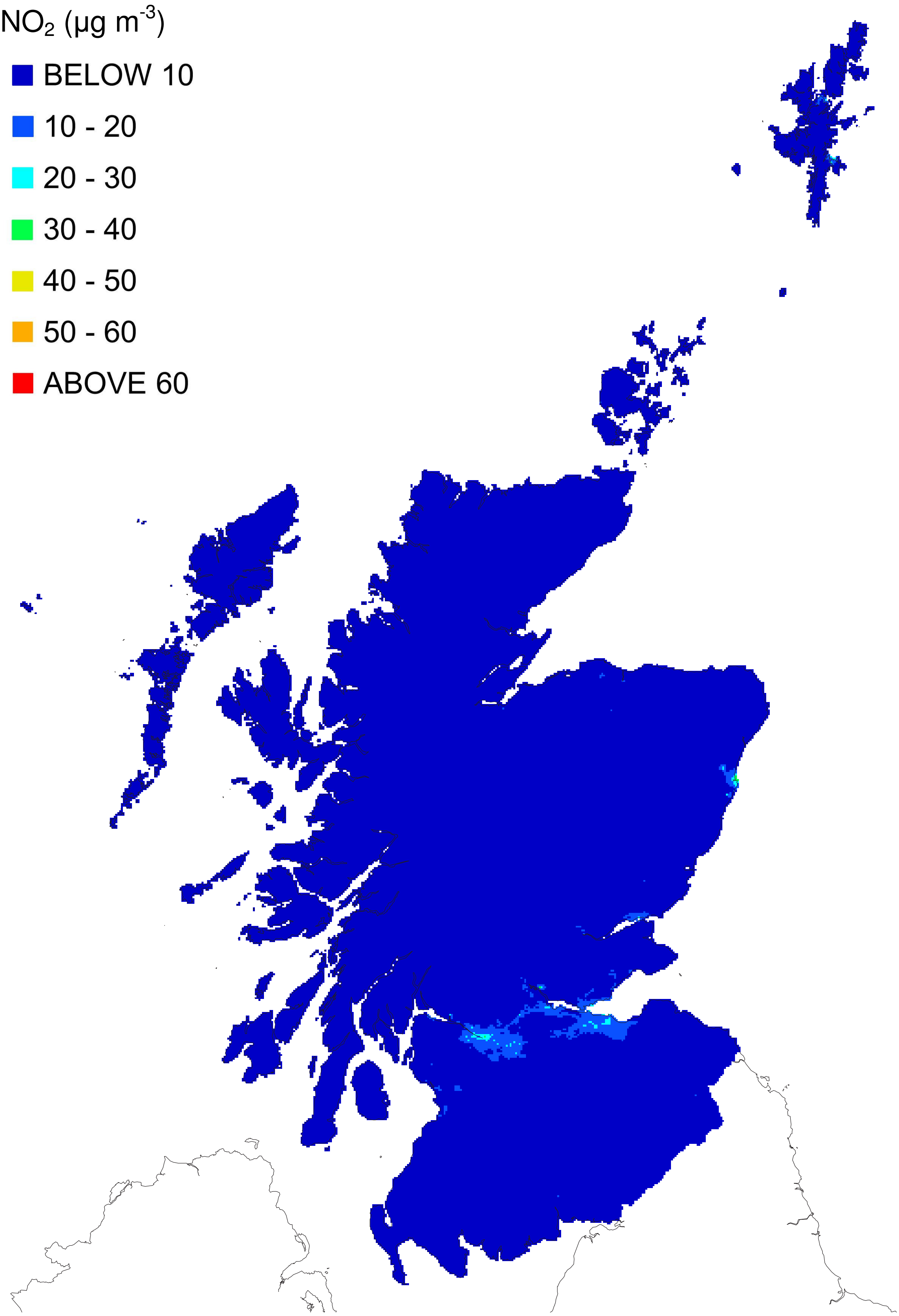


Figure 6.3 Background NO_2 map for 2025, µg m^{-3} (Scotland-specific model).

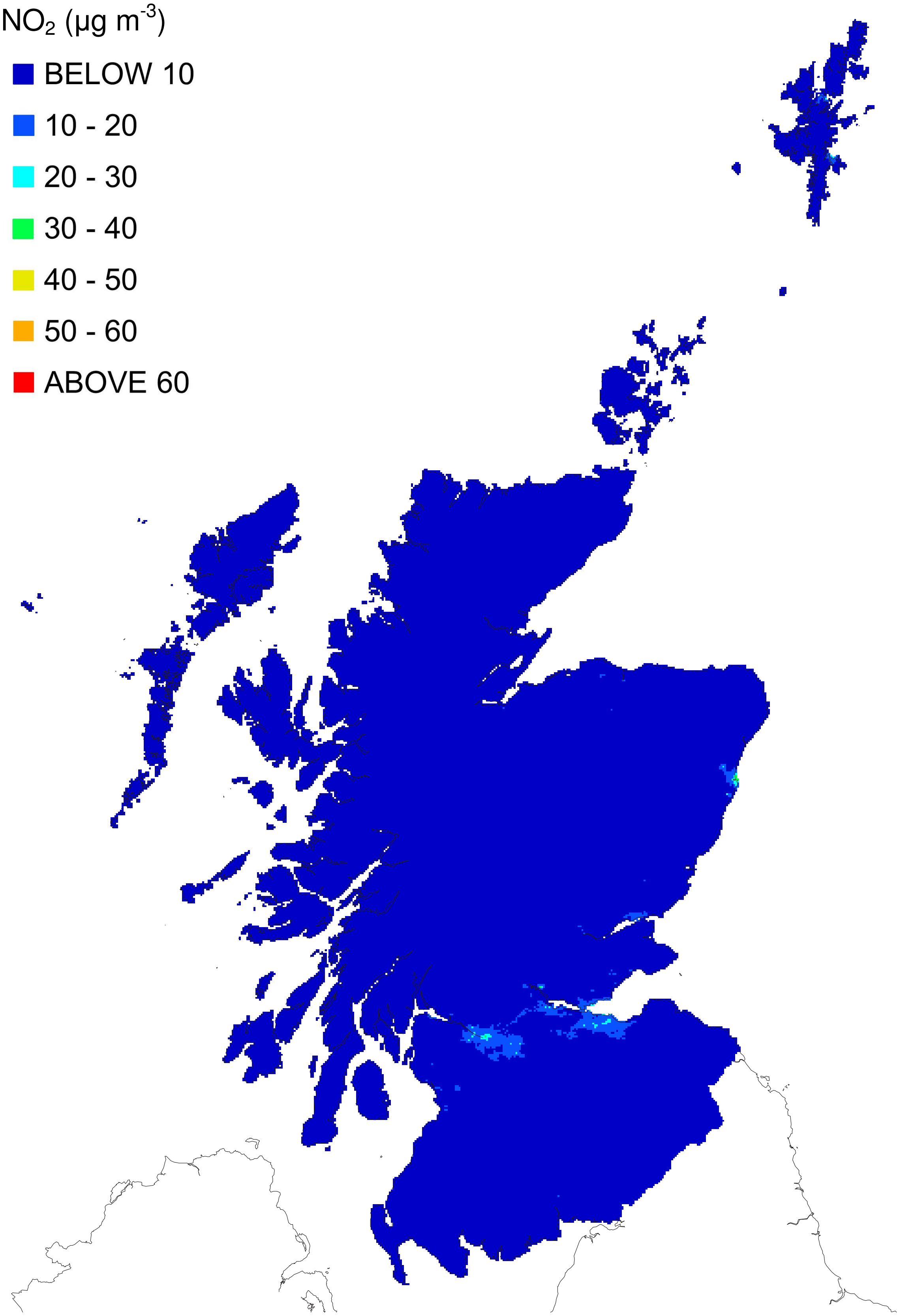


Figure 6.4 Background NO_2 map for 2030, µg m^{-3} (Scotland-specific model).

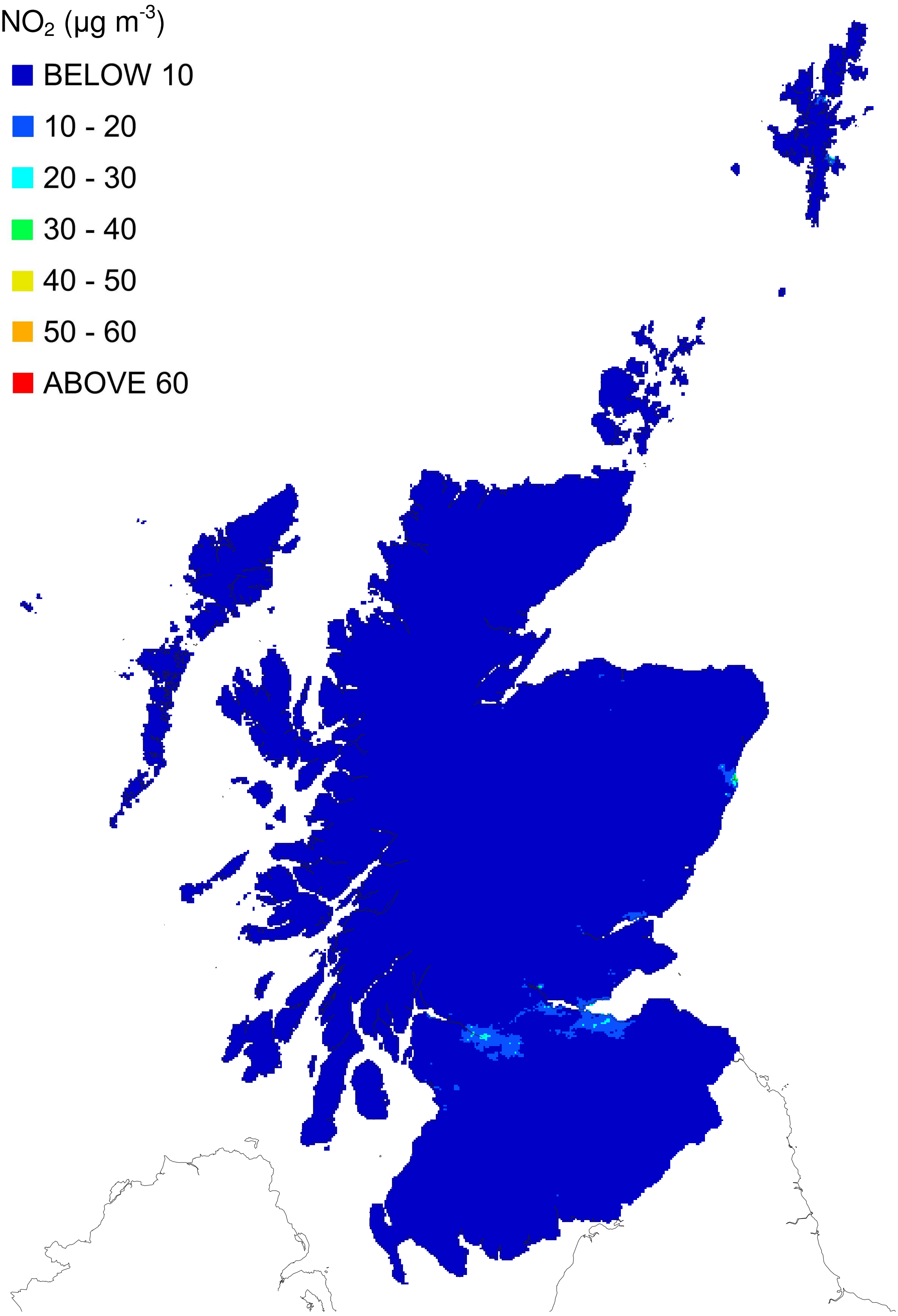


Figure 6.5 Background PM_{10} map for 2015, µg m-3 (Scotland-specific model).

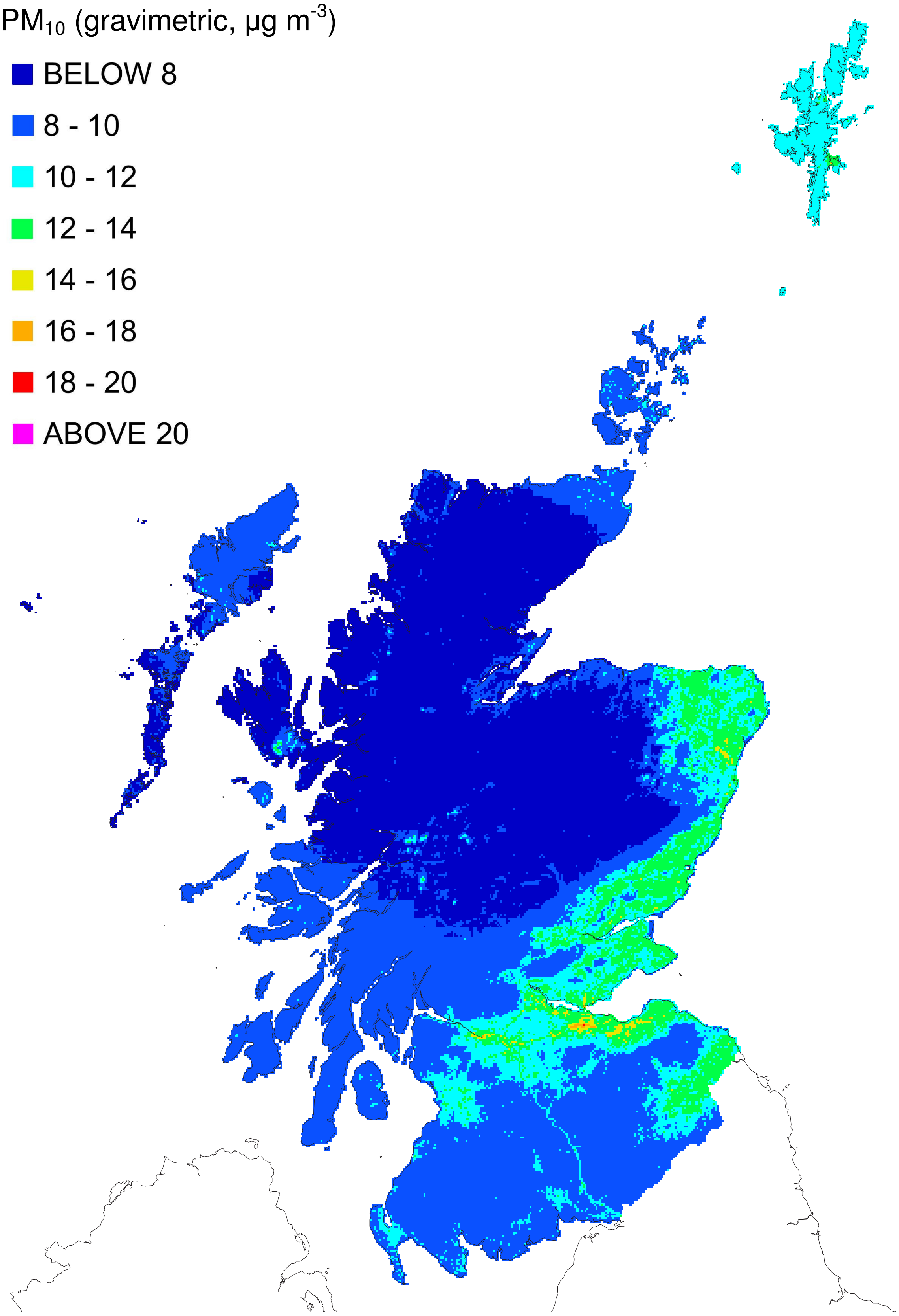


Figure 6.6 Background PM_{10} map for 2020, µg m^{-3} (Scotland-specific model).

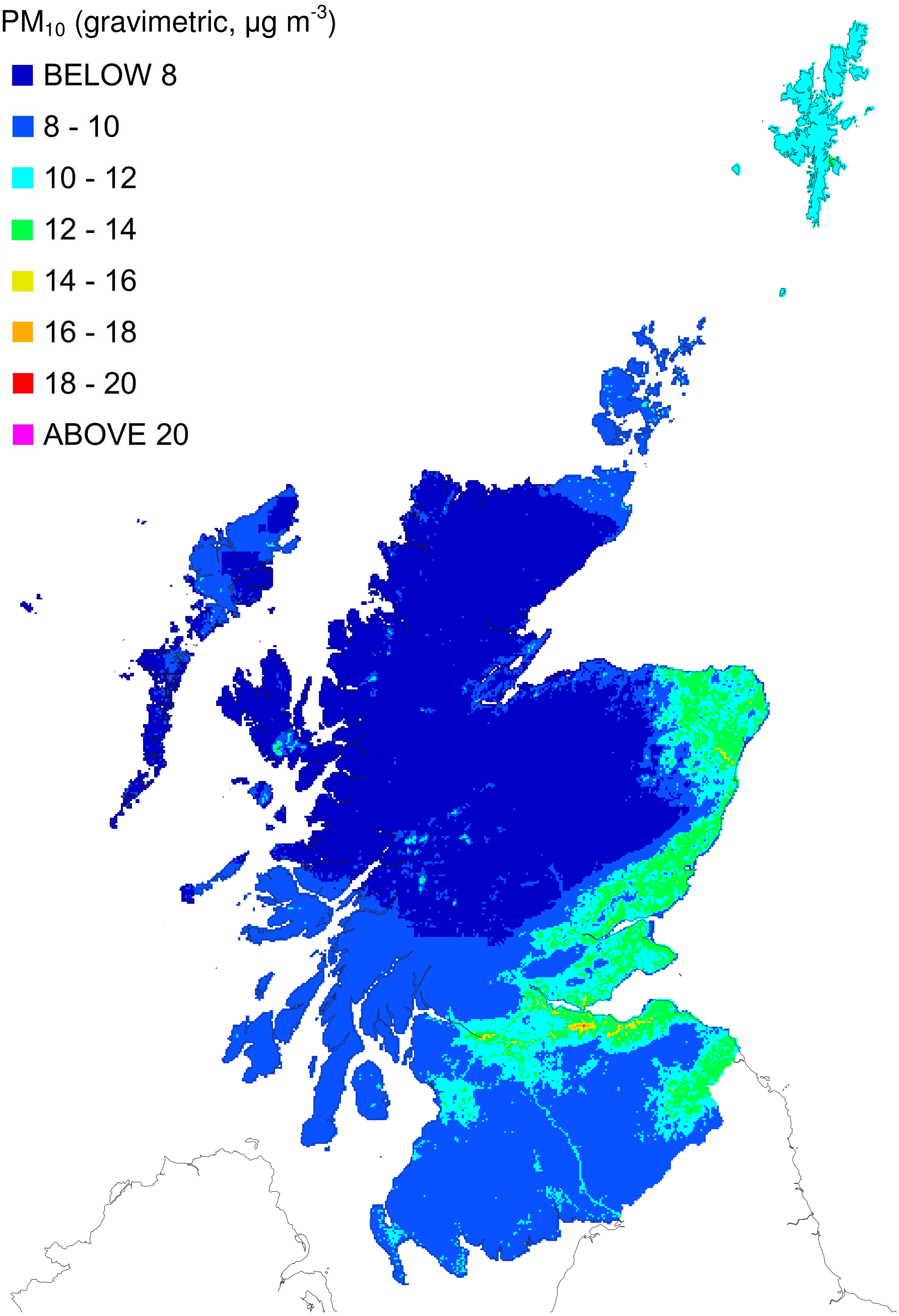


Figure 6.7 Background PM_{10} map for 2025, µg m^{-3} (Scotland-specific model).

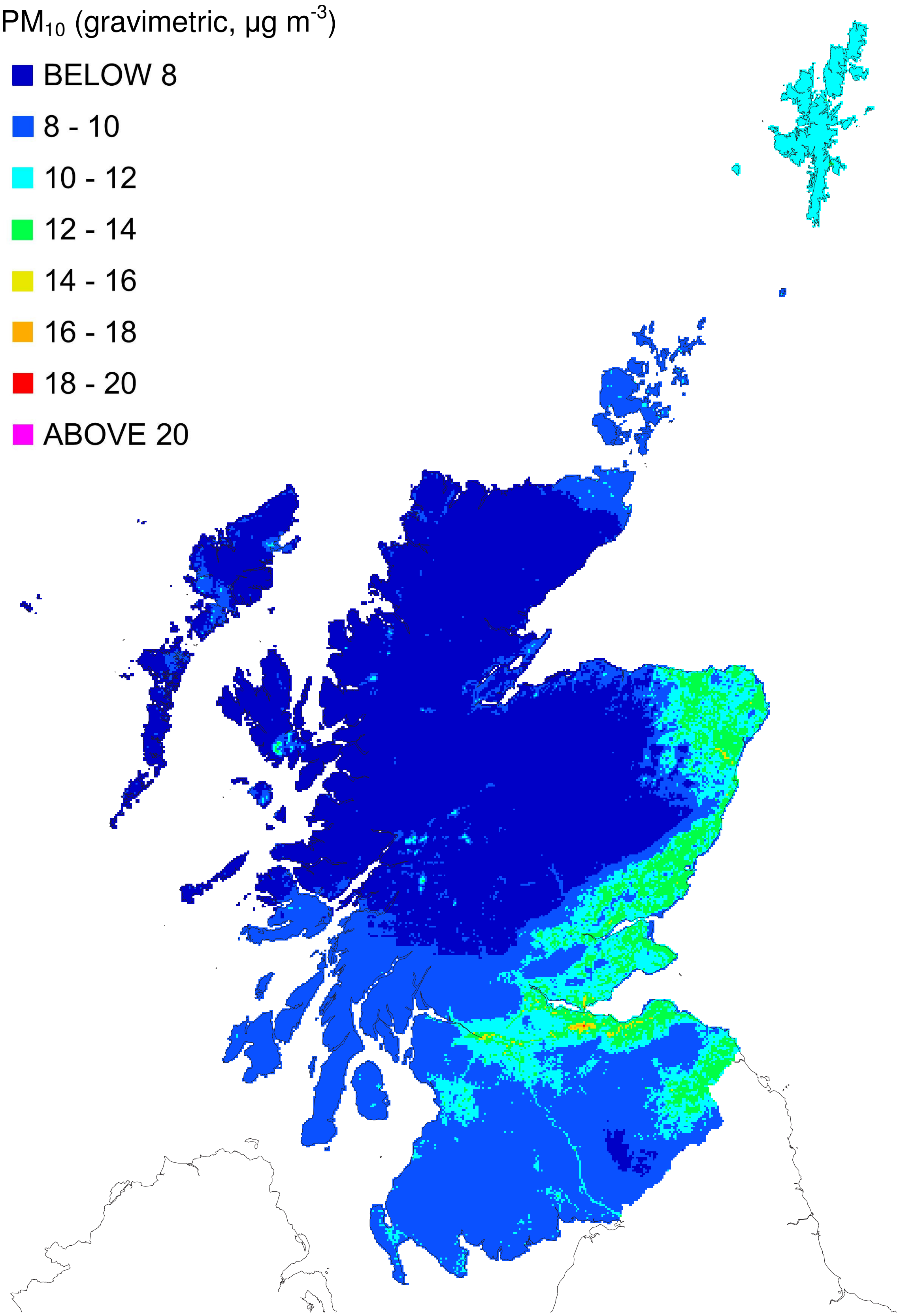
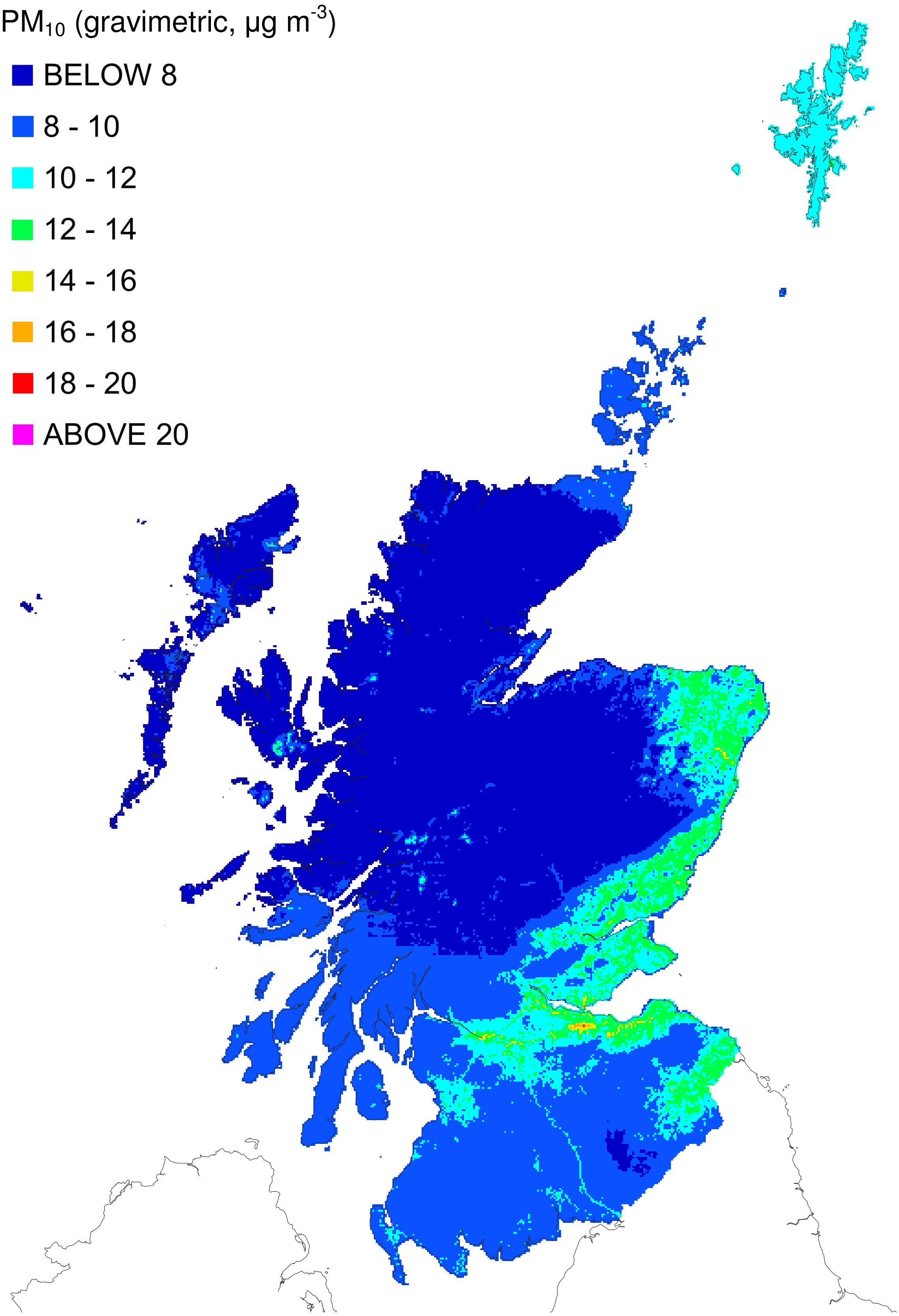


Figure 6.8 Background PM_{10} map for 2030, µg m^{-3} (Scotland-specific model).



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 2010 using measurements from Scottish air quality monitoring sites and Scottish meteorology. Future projection maps for 2015, 2020, 2025, and 2030 have also been prepared along with annual projections of pollutant concentrations by source sector for each grid square, and are available in CSV format.

Scottish air pollutant emissions were based on the UK's National Atmospheric Emissions Inventory (NAEI) and the most recently updated (as of January 2012) National energy usage statistics (UEP43). The Scotland-specific model included the most recently revised (as of January 2012) NO_X emission factors for road transport emissions, taken from COPERT4 v8.1, and ANPR/DVLA-scaled data, to represent the most up-to-date vehicle fleet information in Scotland. In summary, the results of the 2010 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.
- The 2010 Scotland-specific model identified six, 1 km^2 grid squares where the Scottish annual mean NO_2 objective of 40 µg m^{-3} was exceeded. Four of the six grid squares were located in north-east Scotland, in and around Aberdeen, and were believed to be due to NO_2 emissions from maritime sources. These exceedances were believed to be due to better understanding and parameterisation of maritime emissions, e.g., from ships, in recent years. The other two grid squares were located in central Glasgow and at the junction of the M8 and M9 near Edinburgh, respectively.
- Exceedances of the Scottish annual mean PM_{10} objective of 18 µg m^{-3} were modelled at six, 1 km^2 grid squares in Scotland. Two grid squares were located around the junction of the M8 and M9, and three to the east of this junction, along the M8 in the direction of Livingston. The sixth grid square was located where the A8 joins the M8 on the outskirts of Glasgow. The extent of the exceedance modelled in these two grid squares was typically of the order of 1 µg m^{-3}, but was around 2.5 µg m^{-3} in one grid square.
- Exceedances of both the Scottish annual mean NO_2 and PM_{10} air quality objectives were modelled at roadside locations. The majority of exceedances of the Scottish NO_2 and PM_{10} air quality objectives were modelled to occur in urban areas, at roadside locations with high volumes of traffic, such as Edinburgh and Glasgow. The number of roadside exceedances of the Scottish PM_{10} air quality objective was approximately 1.5 times the number modelled for NO_2.
- Maps of (future) projected concentrations show a steady decrease in the concentrations of background NO_2 and PM_{10}. 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 10-12 air quality monitoring sites were used to calibrate the model, depending on pollutant, whilst a smaller number, 1-6 sites, were used to verify the model output. The Scottish Government has invested 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 2010 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 2011, it is hoped that a more rigorous verification of the model outputs can be undertaken in future years.

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

From 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}. 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 quiet variable: Scottish meteorology, Scottish air pollutant concentrations determined from air quality monitoring measurements and scaled emissions projections. The scaling factors applied to the pollutant emissions presented here were based on current understanding of the future variations in emissions and pollutant concentrations, which may result in revisions in subsequent years.

Appendices

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

Appendix 1

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

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

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 ($\mu g\ m^{-3}$)	Metric	Permissible exceedances	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 $\mu g\ m^{-3}$ 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 exceedances per year = 7/365 = 2%) of the daily mean concentration. This relationship was based on UK AURN PM_{10} air quality monitoring data as 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 $\mu g\ m^{-3}$, which was based on UK AURN PM_{10} air quality monitoring data measured between 1992 and 2007, 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 1992-2010. 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 to 2010, but overall the values are broadly consistent. The application of a Scottish annual mean PM_{10} equivalent value of 22 $\mu g\ m^{-3}$ 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 $\mu g\ m^{-3}$ based on Scottish AURN PM_{10} air quality monitoring data measurements from 1992 to 2010 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 1992-2010.

	Model area		
	Scotland (Figure A.1)	UK (Figure A.2)	Scotland (Figure A.3)
Source of air quality monitoring	All UK AURN air quality monitoring sites	All UK AURN air quality monitoring sites	Scottish **only** AURN monitoring sites
Data range	1992-2010	1992-2010	1992-2010
Objective value ($\mu g\ m^{-3}$)	50	50	50
Metric	Daily mean	Daily mean	Daily mean
Permissible exceedances	7	35	7
Percentile equivalent	98^{th}	90^{th}	98^{th}
2007 equivalent daily mean value ($\mu g\ m^{-3}$)	22.0 (0.72)†	31.5 (0.90)†	N/A
2008 equivalent daily mean value ($\mu g\ m^{-3}$)	21.0 (0.72)†	31.9 (0.90)†	20.0 (0.75)†
2009 equivalent daily mean value ($\mu g\ m^{-3}$)	21.0 (0.69)†	32.0 (0.85)†	20.1 (0.78)†
2010 equivalent daily mean value ($\mu g\ m^{-3}$)	21.0 (0.70)†	32.0 (0.86)†	20.1 (0.80)†

† R^2 values given in parentheses

Figure A.1 Relationship between the UK annual mean PM_{10} concentration and the 98^{th} percentile of the UK daily mean PM_{10} concentration (1992-2010).

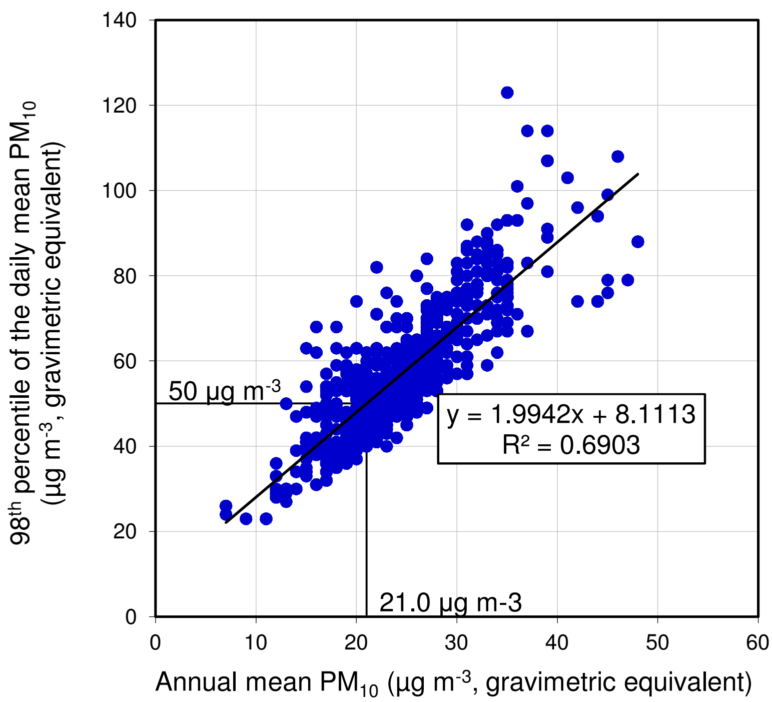


Figure A.2 Relationship between the UK annual mean PM_{10} concentration and the 90^{th} percentile of the UK daily mean PM_{10} concentration (1992-2010).

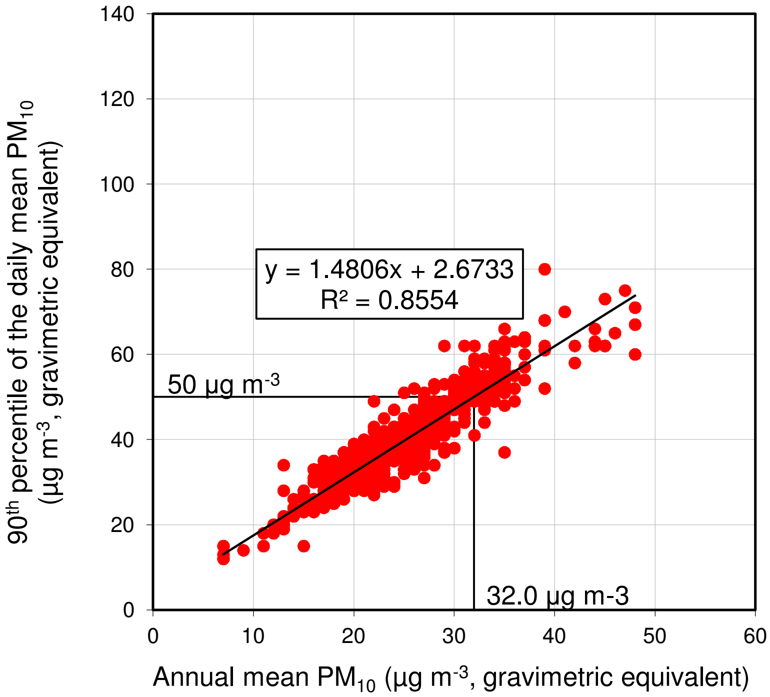
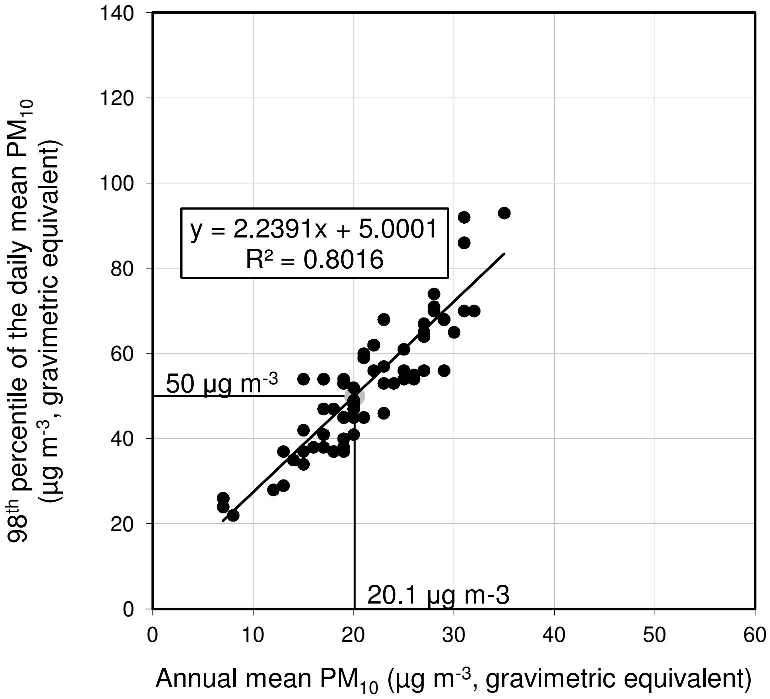


Figure A.3 Relationship between the Scottish annual mean PM_{10} concentration and the 98^{th} percentile of the Scottish daily mean PM_{10} concentration (1992-2010).



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