Scottish air quality modelling for 2008 and projected concentrations for 2010, 2015 and 2020: annual mean PM_{10}, NO_X and NO_2

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Executive summary

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

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

Due to the limited number of urban areas in Scotland and the distinct Scottish meteorology, Scotland has been identified as an area that may not conform as well as other areas to the general calibration performed for the UK as a whole. This has provided the need for the more detailed Scotland-specific study undertaken within the Scottish Air Quality Database project. Here the Pollution Climate Mapping methodology has been applied to provide pollution maps of Scotland for the Scottish Government for 2008 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:

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

The pollutant data used in the mapping work presented here uses 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 PM_{10} concentrations. Automatic monitoring data for NO_X and NO_2 in 2008 are used for the Scotland-specific NOx and NO_2 maps. The model results have been compared with the measured concentrations in Scotland and with the UK model outputs.

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 PM_{10} and NO_2. Projected annual mean concentrations of PM_{10}, NO_X and NO_2 for 2010, 2015 and 2020, from a base year of 2008, 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 2008, these were prepared using Scotland-specific data.

The outputs from the 2008 Scotland-specific and UK models have been compared in terms of their performance in representing measured concentrations (verification plots and summary statistics) and in terms of the modelled exceedences of the Scottish Air Quality Objectives (AQOs). The Scottish annual mean objective for gravimetric equivalent PM_{10} of 18 µg m^{-3} was exceeded at one background location. No exceedence of the Scottish annual mean objective for NO_2 of 40 µg m^{-3} was identified for background locations. These results were consistent with the 2008 UK model outputs.

The 2008 Scotland-specific model identified 128 km of road (101 road links) exceeding the Scottish annual mean PM_{10} air quality objective. The number of exceedences of the Scottish annual mean PM_{10} objective at roadside locations in Scotland from the UK model were lower than those predicted by the Scotland-specific model (66 km of road or 48 road links), though the relative proportions of roads in each zone or agglomeration where exceedences were predicted were broadly similar between the two models. Differences between UK and Scottish pollutant maps are to be expected given the complexity of both measurement and modelling of pollutant concentrations over such a large spatial extent.

For NO_2, overall the 2008 Scotland-specific roadside exceedence statistics were similar to those produced by the UK model. The Scotland-specific model predicted that the Scottish annual mean air

quality objective for NO_2 of 40 $\mu g\ m^{-3}$ was exceeded along 123 km of road (80 road links) compared to 132 km of road (85 road links) predicted by the 2008 UK model.

Projected background maps of the Scottish annual mean gravimetric PM_{10} concentrations for 2010, 2015 and 2020 based on the 2008 Scotland-specific model maps show a progressive decrease in the background annual mean gravimetric PM_{10} concentration between 2008 and 2020 for the majority of Scotland. This reduction is due to the projected reduction in primary PM_{10} emissions, and a subsequent reduction in secondary PM_{10}, due to the reduction in precursor emissions, over the next 12 years based on current emissions estimates. The projected background maps of the annual mean NO_2 concentrations for 2010, 2015 and 2020 based on the 2008 Scotland-specific model showed a similar 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.

Recent analyses conducted for Defra and the DAs of historical air quality monitoring data from throughout the UK have identified a disparity between the measured concentrations of NO_X and/or NO_2 and the projected decline in concentrations associated with emissions forecasts. The precise reason for this disparity is not known, and is currently under investigation, but may be related to the actual on-road performance of diesel road vehicles (LDV and HDV) when compared with calculations based on the Euro standards. The accuracy of the forward projection maps presented here is closely dependent on the future emission projections used to prepare the background pollutant maps. Future emissions projections were based on current, published "year-adjustment" factors for NO_X and NO_2 concentrations for all years up until 2020.

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

In summary, the results of the 2008 Scotland-specific modelling exercise show:

- The modelled annual mean background PM_{10} concentration from the Scotland-specific model provided good agreement with the annual mean measured background concentration. Similar agreement was seen with the modelled annual mean roadside PM_{10} concentration provided by the Scotland-specific model.
- The modelled annual mean background NO_2 concentration from the Scotland-specific model provided good agreement with the annual mean measured background NO_2 concentration. Less agreement was seen when the modelled annual mean roadside NO_2 concentration from the Scotland-specific model was compared to the annual mean measured roadside NO_2 concentration.
- At background locations, the Scottish maps indicate no exceedences of the Scottish air quality objectives for both PM_{10} and NO_2, except for a possible exceedence of the PM_{10} objective in one grid square in central Scotland.
- At roadside locations, exceedences of both the PM_{10} and NO_2 objectives are likely, with the majority of exceedences occurring in urban areas, particularly in Glasgow.
- Future projection maps show a steady decrease in concentrations of both PM_{10} and NO_2. However, as noted above, the accuracy of the forward projection maps is closely dependent on the future emission projections used to scale the NAEI emissions.

The UK model is verified annually against independent monitoring data available from sites throughout the UK, which have not been used in the model calibration. All available Scottish air quality monitoring measurements were used for model calibration within the mapping process and therefore none were available for independent model verification.

The Scottish Government have put significant effort into increasing the number of sites in the SAQD in recent years. These efforts have contributed to the production of robust pollutant maps for PM_{10}, NO_X and NO_2 for Scotland for 2008 based on Scottish air quality measurements and Scottish meteorology. It is anticipated that additional sites available in 2009 or in future years will allow for independent verification of mapped concentrations produced.

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Appendices

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

1 Introduction

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

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

Due to the limited number of urban areas in Scotland and the distinct Scottish meteorology, Scotland has been identified as an area that may not conform as well as other areas to the general calibration performed for the UK as a whole. This has provided the need for the more detailed Scotland-specific study undertaken within the Scottish Air Quality Database project. Here the Pollution Climate Mapping methodology has been applied to provide pollution maps of Scotland for the Scottish Government for 2008 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:

- gravimetric equivalent PM_{10} concentration (hereafter simply referred to as PM_{10}), and
- NO_X and NO_2.

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 concentration of PM_{10} (and $PM_{2.5}$) to be prepared.

The pollutant data used in the mapping work presented here, for 2008, uses 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 PM_{10}, NO_X and NO_2 for 2008. The model results have been compared with the measured concentrations in Scotland and with the UK model outputs. 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 PM_{10} and NO_2.

Projected annual mean concentrations of PM_{10}, NO_X and NO_2 for 2010, 2015 and 2020, from a base year of 2008, 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 2008, these were prepared using Scotland-specific data. The same methods were used to project the various contributions to ambient concentrations forward to 2020 as has been used in the UK models. Any differences in the source apportionment between the Scottish and UK mapping for 2008 will consequently be carried forward into the projections.

[1] Grice, S.E., Cooke, S.L., Stedman, J.R., Bush, T.J., Vincent, K.J., Hann, M., Abbott, J. and Kent, A.J. (2009). UK air quality modelling for annual reporting 2007 on ambient air quality assessment under Council Directives 96/62/EC, 1999/30/EC and 2000/69/EC. Report to the Department for Environment, Food and Rural Affairs, the Scottish Executive, Welsh Assembly Government and the Department of the Environment in Northern Ireland. AEA report. AEAT/ENV/R/2656 Issue 1. http://www.airquality.co.uk/reports/cat09/0905061048_dd12007mapsr

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

2 Methodology

A brief overview of the modelling methodology is presented here. A summary of model revisions for 2008 and the specific aspects of the model that have been tailored to provide a Scotland-specific output are detailed below. A detailed description of the UK PCM modelling methodology can be found in the annual report to Defra and the DAs for 2007[1] and can be downloaded from the UK Air Quality Archive. The updated version of the report detailing the modelling undertaken for 2008 is currently under review and will be released on the Archive when approved by Defra and the DAs.

The modelled maps of ambient concentrations are calculated from National Atmospheric Emissions Inventory (NAEI) data using a dispersion modelling approach, which is calibrated using monitored data from the national monitoring networks. These modelled maps are typically verified against independent monitoring data held by AEA (from ad-hoc monitoring campaigns, airport authorities and Local Authorities, LAs).

2.1 The Scotland-specific model

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

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

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

2.2 PM_{10} modelling

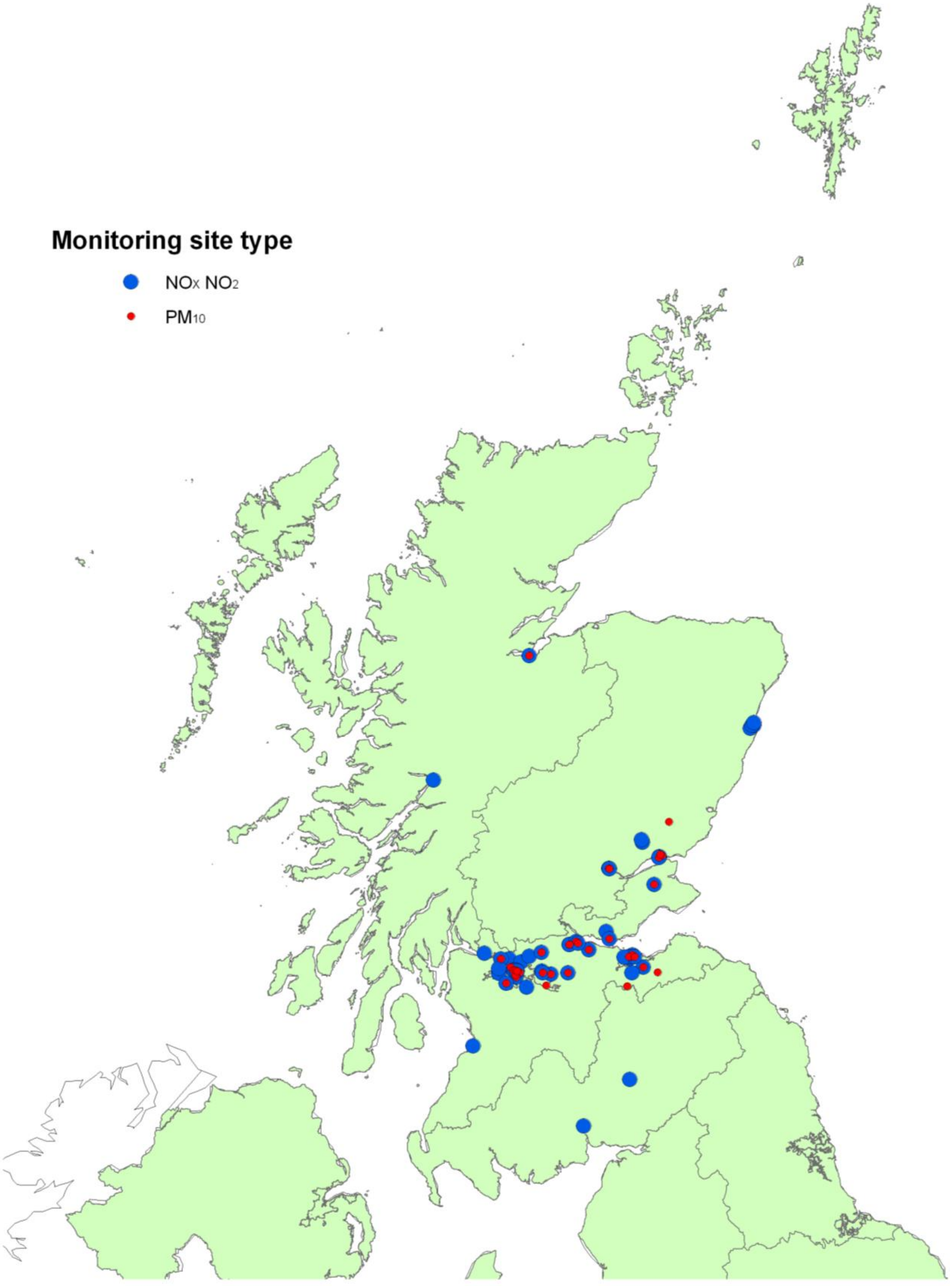
Annual mean concentrations of PM_{10} have been modelled for Scotland for 2008 at background and roadside locations. The modelling methodology used to calculate the annual mean PM_{10} concentration is broadly similar to that used last year. The modelling of the annual mean PM_{10} concentration in 2007 for Scotland proved challenging. By comparison modelling of the annual mean PM_{10} concentration in 2008 for Scotland was more straightforward due to the availability of a larger data set of appropriately scaled PM_{10} monitoring (FDMS, Partisol and VCM corrected TEOM[2,3]) data. Measurements from (four) Beta Attenuation Monitors (BAMs) in Scotland were not used.

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, SIA)
- secondary organic aerosols (SOA)
- long range transport primary component
- sea salt contributions, and
- iron and calcium-associated dusts.

[2] 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
[3] 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

Figure 2.1 Location of Scottish air quality monitoring sites used to produce Scotland-specific background and roadside PM_{10}, NO_X and NO_2 maps, 2008.



Scottish AQOs for ambient PM_{10} concentrations for 2010 are more stringent than the EU limit values set out in the Air Quality Directive[4]. 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}.

2.3 NO_X and NO_2 modelling

Annual mean concentrations of NO_X were modelled for Scotland for 2008 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[5,6]. This model is discussed in more detail in the 2007 UK mapping report[1] and the references herein. Briefly, the oxidant-partitioning model uses representative equations to account for the chemical coupling of O_3, NO and NO_2 within the atmosphere. A key advantage of this approach for modelling NO_2 concentrations is that it allows different 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 2008 were undertaken using Scotland-specific changes to the UK PCM model noted in Section 2.1. The regional oxidant component of the NO_X-NO_2 model remains unchanged for the Scottish modelling as this is not affected by the Scotland-specific changes to the UK PCM model noted in Section 2.1.

Scottish AQOs for ambient NO_2 concentrations are based on EU limit values set out in the Air Quality Directive[4]. These have been specified for the protection of human health and will come into force on 01/01/2010. The limit values are:

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

The annual mean limit value is expected to be more stringent than the 1-hour limit value in the majority of situations[7] . This is illustrated in Figure 2.2 which shows the 2008 annual mean NO_2 concentrations at all Scottish air quality monitoring sites (with an annual percentage data capture ≥75%) plotted against the 99.8th percentile (equivalent to 18 exceedences) hourly mean concentration for the same year. The plot shows a significantly higher number of sites exceeding the annual mean limit value of 40 µg m^{-3} than the 200 µg m^{-3} hourly limit value.

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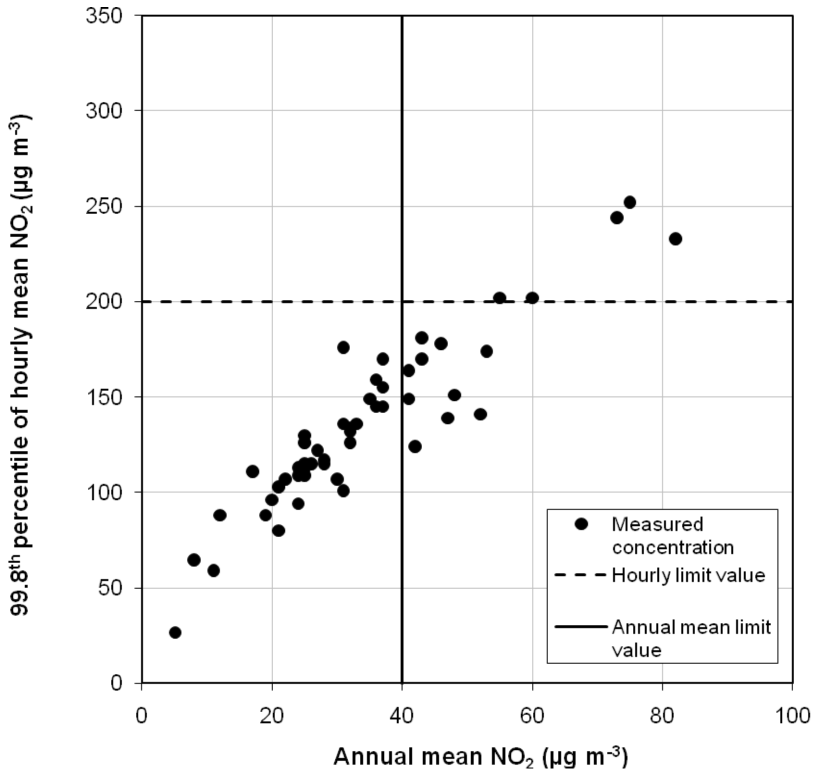
[4] Council Directive 2008/50/EC, of 21 May 2008 on ambient air quality and cleaner air for Europe (The Air Quality Directive). The Official Journal of the European Communities, 11.6.2008, En Series, L152/1.

[5] 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.

[6] 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

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

Figure 2.2 Plot of annual mean against 99.8th percentile hourly NO_2 concentrations in 2008 for all Scottish air quality monitoring sites.



2.4 Forward projections

Projected annual mean concentrations of PM_{10}, NO_X and NO_2 for 2010, 2015 and 2020, from a base year of 2008, are presented for the purpose of forward projection assessment following a recent scoping exercise undertaken by AEA on behalf of The Scottish Government involving four Scottish LAs[8].

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

- 2007 UK NAEI emissions for PM_{10}, NO_X and NO_2
- 2007 UK road usage statistics, and vehicle, brake and tyre wear (BTW) emissions, split by region
- 2008 Scottish annual mean concentrations of PM_{10}, NO_X and NO_2, and
- 2008 Scottish meteorology data.

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

[8] 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

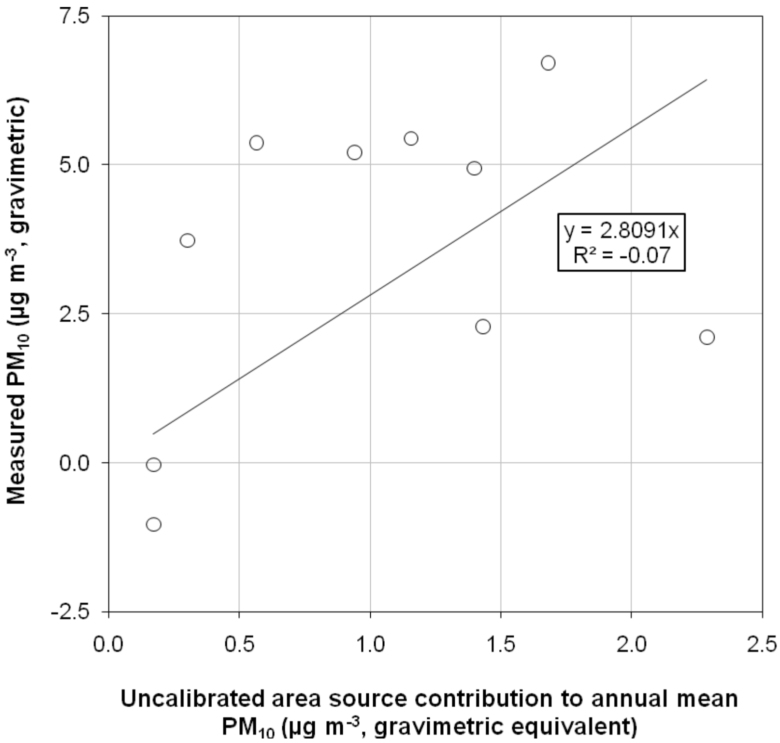
3 Model calibration

The background model calibrations for PM_{10} and NO_X for the 2008 Scotland-specific model were undertaken using air quality monitoring measurements from a range of background (airport, rural, suburban, urban background, urban centre and urban industrial) sites. Similarly, the roadside calibration was undertaken using air quality monitoring measurements from roadside (roadside and kerbside) sites. Only data from background and roadside Scottish air quality monitoring sites with an annual data capture of ≥75% were used to prepare the calibration plots and to measure the performance of the 2008 Scotland-specific model, as discussed in Section 5. Overall, the calibration factors produced for the Scotland-specific model from this process for PM_{10} and NO_X were different, but not unrealistically high, when compared with the calibration values used in the 2008 UK model. The area source and roadside calibration procedures for PM_{10}, NO_X and NO_2 are presented below.

3.1 PM_{10} contributions from area sources

Figure 3.1 shows the calibration of the Scotland-specific PM_{10} area source model. The modelling method utilises an ADMS 4.1 derived dispersion kernel which was used to calculate the contribution to ambient concentrations at a central receptor location from area source emissions within a 33 km x 33 km square surrounding each monitoring site. Further information on this approach can be found in Appendix 3 of the 2007 UK modelling report[1]. Hourly sequential meteorological observations from RAF Leuchars for 2008 were used to construct the dispersion kernels. All ten background PM_{10} monitoring sites within the Scottish network had sufficient data capture for PM_{10} in 2008 to be used to calibrate the model. It should be noted that between ten and twelve sites are required for model calibration. Ideally, a further ten to twelve sites (separate from those used to calibrate the model) are required for model verification.

Figure 3.1 Calibration plot for the Scotland-specific background PM_{10} model.



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} concentration at background sites and compared with the modelled area source contribution to annual mean PM_{10} concentration. A residual concentration of 1 $\mu g\ m^{-3}$ was found to provide the best fit to the monitoring data. This approach is consistent with that used in the 2008 UK mapping.

Figure 3.1 shows that the gradient the line of best fit forced through the origin was 2.8091. 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 5.1.

Table 3.1 Background model calibration coefficients applied in the Scotland-specific and UK models for PM_{10} for 2008 and 2007.

Background model calibration coefficients applied in the Scotland-specific and UK models			
Model	Pollutant	Year	Calibration coefficient
Scotland-specific	PM_{10}	2008	2.8091
UK	PM_{10}	2008	3.3916
Scotland-specific	PM_{10}	2007	2.2838
UK	PM_{10}	2007	3.0598

Table 3.1 provides a comparison of the 2008 Scotland-specific and UK background PM_{10} calibration coefficients. The 2007 Scotland-specific and UK background PM_{10} calibration coefficients are also presented to allow assessment of year-on-year variation in: (1) the Scotland-specific background PM_{10} calibration coefficient; and, (2) the extent to which these values vary in both models.

From Table 3.1 it can be seen that for 2007 and 2008 Scotland-specific background PM_{10} calibration coefficients were lower than their equivalent UK values. This is a reflection of the relatively lower background PM_{10} concentrations when compared to the UK as a whole due to the more rural nature of Scotland. The 2008 Scotland-specific background PM_{10} calibration coefficient was higher than that used in the 2007 modelling. Consequentially, the 2008 modelled Scottish background PM_{10} concentrations may be slightly higher than those modelled in 2007, however it is important to note that this effect may be ameliorated by the meteorological terms (dispersion kernels) applied in the model.

3.2 Roadside PM_{10} concentrations

It is assumed that the annual mean concentration of PM_{10} at a roadside location is made up of two components: the background concentration (as described above) and a roadside increment:

roadside concentration = background concentration + roadside increment.

The NAEI provides estimates of PM_{10} emissions for major road links in Scotland for 2007[9] and these have been adjusted to provide estimates of emissions in 2008. Figure 3.2 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 3.1.

As for the area source calibration coefficient (described in Section 3.1), the regression line has been forced through the origin to provide a reasonable model output without imposing an unrealistic high residual to the roadside increment. Emissions were adjusted for annual average daily traffic flow using the method described in Section 3.2.5 of the 2007 UK modelling report[1]. Only roadside concentrations for urban major road links (A-roads and motorways) (which are reported annually to the EU for the UK as a whole) are included in this report.

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

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

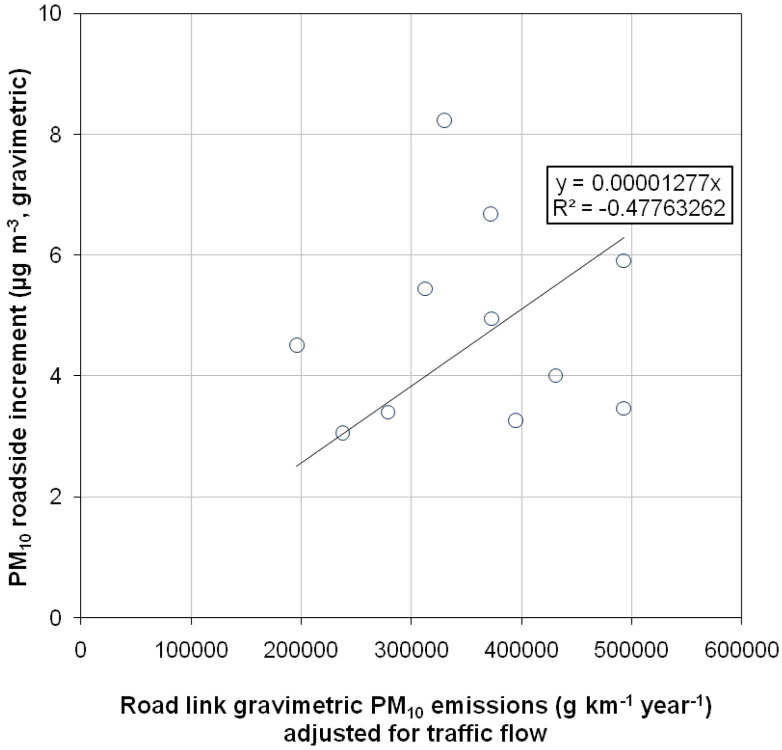
- traffic speed (urban roads with lower flows are more likely to have slower moving traffic and thus cause less initial dispersion due to mechanical and thermal turbulence)
- road width (dispersion will tend to be more efficient on wider roads, such as motorways than on smaller roads in town centres),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

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

Detailed information on the dispersion characteristics of each urban major road link within the NAEI is not available. An approach similar to that used within the DMRB Screening Model[10] was adopted and adjustment factors were applied to the estimated emissions. These adjustment factors depend on the total traffic flow on each link and are higher for the roads with the lowest flow and lower for roads with the highest flow. Thus the traffic flow is used as a surrogate for road width and other factors influencing dispersion. Motorways are generally wider than A-roads and the emissions have therefore been adjusted accordingly.

Eleven of the forty-four roadside PM_{10} monitoring sites within the Scottish network had sufficient data capture for PM_{10} in 2008 and were located on urban major road links. The roadside PM_{10} measurements from these sites were used to calibrate the model. Sixteen roadside sites that were excluded as they were not located on urban major road links and therefore could not used to calibrate the Scotland-specific roadside model. 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. Five roadside sites were excluded as the TEOM measurements could not be corrected using the VCM model: they were out of range (in 2008) of a suitable FDMS instrument against which the correction could be performed. Twelve sites were excluded on the basis of low annual data capture.

Figure 3.2 Calibration plot for the Scotland-specific roadside PM_{10} model.



[10] 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 PM_{10} for 2008 and 2007.

Roadside model calibration coefficients applied in the Scotland-specific and UK models			
Model	Pollutant	Year	Calibration coefficient
Scotland-specific	PM_{10}	2008	0.000 012 77
UK	PM_{10}	2008	0.000 008 40
Scotland-specific	PM_{10}	2007	0.000 006 67
UK	PM_{10}	2007	0.000 005 42

Table 3.2 provides a comparison of the 2008 Scotland-specific and UK background PM_{10} calibration coefficients. The 2007 Scotland-specific and UK background PM_{10} calibration coefficients are also presented to allow assessment of year-on-year variation in: (1) the Scotland-specific roadside PM_{10} calibration coefficient; and, (2) the extent to which these values vary in both models.

From Table 3.2 it can be seen that for 2007 and 2008 Scotland-specific model roadside PM_{10} calibration coefficients were higher than their equivalent UK values. Comparison of the 2008 Scotland-specific and UK roadside calibration plot revealed that in general the Scottish roadside PM_{10} increment was greater than that for the UK for the equivalent road link PM_{10} emission. It is therefore anticipated that the 2008 Scotland-specific roadside PM_{10} model may predict a higher number of PM_{10} roadside exceedences for Scottish road links when compared to those predicted by the 2008 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 5.2.

3.3 NO_X contributions from area sources

As for PM_{10}, contributions from area sources discussed in Section 3.1, the Scotland-specific NO_X modelled uncalibrated area source contribution was calculated by applying an ADMS 4.1 derived dispersion kernel to calculate the contribution to ambient concentrations at a central receptor location from area source emissions within a 33 km x 33 km square surrounding each monitoring site. Hourly sequential meteorological observations from RAF Leuchars for 2008 were used to construct the dispersion kernels.

The NAEI aircraft emissions total for NO_X includes all emissions up to 1000 m above ground level. To avoid over-estimating area source contributions from aircraft to ground level NO_X concentrations, a factor of 0.5 was applied to take-off and landing emissions. All other non-ground level aircraft emissions were excluded. The factor of 0.5 has been chosen on the basis of findings from detailed studies[11]. All ground level aircraft emissions have been included as given in the NAEI 2007. Appendix 5 of the 2008 UK mapping report[12] describes the methodology used to estimate the contribution of aircraft emission to ground-level NO_X emissions.

A new method for calculating shipping emissions was used in the NAEI 2007. In the area source model, a cap of 90 tonnes was applied to the total emissions from any given grid square to avoid calculating the equivalent of dock side concentrations in grid squares which are meant to be representative of the entire 1 km x 1 km square. Details of how this cap has been selected are given in Appendix 5 of the 2008 UK mapping report[12].

Figure 3.3 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 2008 measured annual mean NO_X concentration measured at the Scottish background sites. This corrected background concentration was compared with the modelled area source contribution to annual mean Scottish NO_X to calculate the calibration coefficients used in the area source modelling. Twelve of the thirteen background NO_X monitoring sites within the Scottish network had sufficient data capture for NO_X in 2008 to be used to calibrate the model. The excluded site had an annual data capture <75%.

[11] Personal communication from Brian Underwood, AEA (2009). AEA Technology, Harwell, UK.
[12] Grice, S.E., Lingard, J.J.N., Stedman, J.R., Cooke, S.L., Yap, F.W., Kent, A.J., Bush, T.J., Vincent, K.J. and Abbott, J. (2009). UK air quality modelling for annual reporting 2008 on ambient air quality assessment under Council Directives 96/62/EC, 1999/30/EC and 2000/69/EC. Report to The Department for Environment, Food and Rural Affairs, Welsh Assembly Government, the Scottish Executive and the Department of the Environment for Northern Ireland. Report AEAT/ENV/R/2656 Issue 1.

Figure 3.3 Calibration plot for the Scotland-specific background NO_X model.

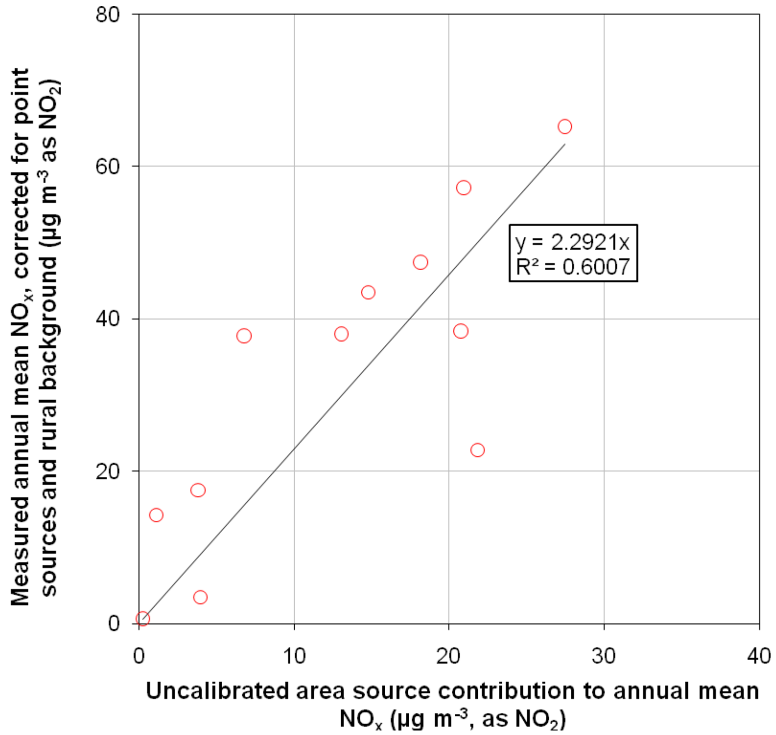


Figure 3.3 shows that the gradient the line of best fit forced through the origin was 2.2921. This value was used as the Scotland-specific NO_X area source calibration coefficient. The regression line has been forced through the origin to provide a reasonable model output without imposing an unrealistic 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 3.3 Background model calibration coefficients applied in the Scotland-specific and UK models for NO_X for 2008 and 2007.

Roadside model calibration coefficients applied in the Scotland-specific and UK models			
Model	Pollutant	Year	Calibration coefficient
Scotland-specific	NO_X	2008	2.2921
UK	NO_X	2008	2.4547
Scotland-specific	NO_X	2007	Not modelled
UK	NO_X	2007	2.3033

Table 3.3 provides a comparison of the 2008 Scotland-specific and UK background NO_X calibration coefficients. The 2007 UK background NO_X calibration coefficients are also presented.

From Table 3.3 it can be seen that the 2008 Scotland-specific background NO_X calibration coefficient was slightly lower than the value used in the UK model. NO_X modelling was not undertaken in 2007 therefore no background calibration coefficient is available for comparison with the UK model value for 2007.

3.4 Roadside NO_X concentrations

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

$$\textit{roadside } NO_X \textit{ concentration} = \textit{background } NO_X \textit{ concentration} + NO_X \textit{ roadside increment}.$$

The NAEI provides estimates of NO_X emissions for major road links in Scotland for 2007[9] and these have been adjusted to provide estimates of emissions in 2008. Figure 3.4 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 3.3.

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 3.4). 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.

Twenty-two of the thirty-nine roadside NO_X monitoring sites within the Scottish network had sufficient data capture for NO_X in 2008 and were located on urban major road links. The roadside NO_X measurements from these sites were used to calibrate the model. The seventeen roadside sites that were not used to calibrate the Scotland-specific roadside model were excluded as they were not located on urban major road links. No roadside NO_X monitoring sites were excluded on the basis of low annual data capture.

Figure 3.4 Calibration plot for the Scotland-specific roadside NO_X model.

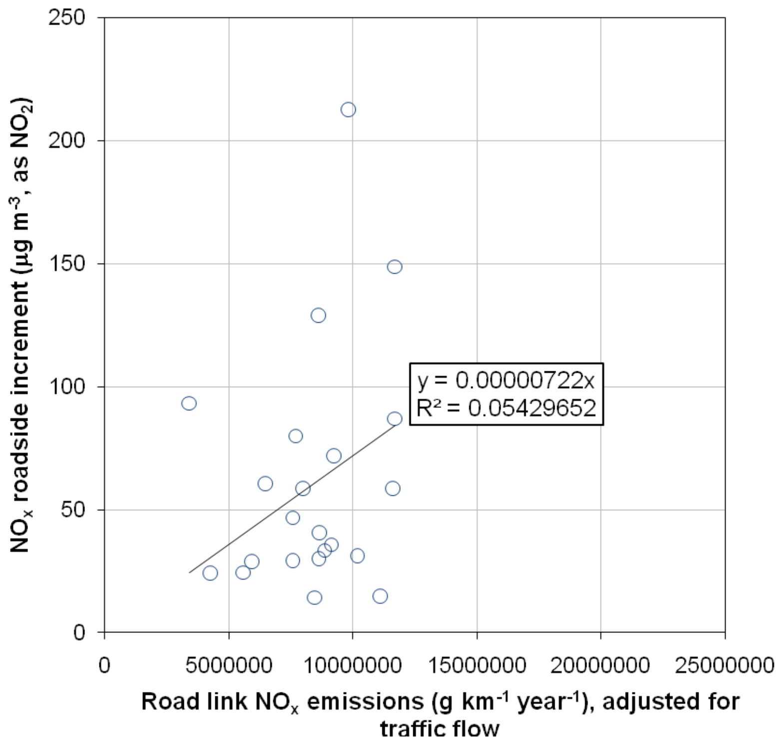


Table 3.4 Roadside model calibration coefficients applied in the Scotland-specific and UK models for NO_X for 2008 and 2007.

Roadside model calibration coefficients applied in the Scotland-specific and UK models			
Model	Pollutant	Year	Calibration coefficient
Scotland-specific	NO_X	2008	0.000 007 94
UK	NO_X	2008	0.000 007 22
Scotland-specific	NO_X	2007	Not modelled
UK	NO_X	2007	0.000 008 74

Table 3.4 provides a comparison of the 2008 Scotland-specific and UK roadside NO_X calibration coefficients. The 2007 UK roadside NO_X calibration coefficients are also presented.

From Table 3.4 it can be seen that the 2008 Scotland-specific roadside NO_X calibration coefficient was slightly higher than the value used in the UK model. NO_X modelling was not undertaken in 2007 therefore no roadside calibration coefficient is available for comparison with the UK model value for 2007.

It is therefore anticipated that the 2008 Scotland-specific roadside NO_X model may predict a higher number of NO_X roadside exceedences for Scottish road links when compared to those predicted by the 2008 UK model, however this effect may be ameliorated by the meteorological terms (dispersion kernels) applied in the model.

3.5 NO_2 modelling

Maps of estimated 2008 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[5,6]. This model uses representative equations to account for the chemical coupling of O_3, NO and NO_2 within the atmosphere. A key advantage of this approach for modelling NO_2 concentrations is that different emission scenarios can be addressed by varying regional oxidant levels and/or primary NO_2 emissions.

This approach is discussed in detail in Section 3.3 of the 2007 UK modelling report[1]. Briefly, the oxidant-partitioning model[5] enables NO_2 concentrations to be calculated using the following equations (concentrations in ppb[13]):

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

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

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

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 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 5.7 and Figure 5.8, respectively.

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

4 Model Verification

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

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

The UK model is verified annually against independent monitoring data available from sites throughout the UK, which have not been used in the model calibration. For 2008, measurements from all available Scottish air quality monitoring were used for model calibration within the mapping process and therefore none were available for independent model verification as noted in Section 3.

In particular, the number of Scottish background PM_{10} and NO_X monitoring site monitoring sites is limited as Local Authority sites are concentrated at roadside or hot-spot areas to fulfil the requirements of LAQM. In 2008 there were ten PM_{10} and thirteen NO_X Scottish background monitoring sites (as noted in Sections 3.1 and 3.3).

In addition, for roadside sites, only roadside located at major urban road links (A-roads and motorways) can be used for the mapping (as noted in Sections 3.2 and 3.4). Roadside measurements made for LAQM review and assessment purposes, or similar, which are reported in the SAQD, are not always indicative of typical background and roadside air pollutant concentration. Rather they tend to be employed to measure atypical air pollutant concentrations in pollution hotspots. Such roadside air quality monitoring sites are not always located adjacent to urban major road links and for this reason were excluded from use in the modelling process (as noted in Section 3.2).

As with all monitoring network, some sites also fail to achieve the required level of data capture in some years.

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. Once partitioned, sites would remain in the same group year-on-year to maintain consistency. This can already be achieved for Scottish roadside NO_X model as there is a sufficient number of air quality monitoring sites in this category. For the 2009 mapping exercise independent verification of the roadside NO_X model will be undertaken. It is also anticipated that there will be sufficient sites to allow independent verification of the roadside PM_{10} model. Independent verification of the background NO_X/NO_2 model may be achievable, but with a much more limited number (approximately six) of verification sites, compared to the ten-twelve sites typically required for a robust, independent verification. Due to the limited number (ten) of background PM_{10} air quality monitoring sites, independent verification of the background PM_{10} will not be practicably achievable.

4.1 PM_{10} model verification and comparison

The model verification plots are presented in Figure 4.1 and Figure 4.2. Lines at ±50% are shown on the model verification plots and represent the data quality objectives (DQOs) specified for PM_{10} in the EU Air Quality Directive. The plots show that the modelled annual mean concentrations provide good agreement with the measured annual mean concentrations and fall within the DQO specified by the Directive.

Table 4.1 Comparison of the modelled and measured annual mean concentration of PM_{10} at background and roadside sites, μg m^{-3} (Scotland-specific and UK models).

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	12.8	12.2	0.42	0	10
UK PCM	12.8	12.2	0.42	0	10
PM_{10} Roadside					
Scotland-specific	16.3	16.4	0.23	0	11
UK PCM roadside	16.3	14.8	0.29	0	11

Summary statistics are presented in Table 4.1 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. The analysis was performed separately for background (non-roadside) and roadside sites. Table 4.1 also provides the equivalent measured and modelled annual mean PM_{10} concentrations from the 2008 UK model for the sites used in the Scotland-specific models, for comparison.

4.2 NO_X and NO_2 model verification and comparison

The model verification plots are presented in Figure 4.3 and Figure 4.4 for background and roadside NO_X, respectively. Figure 4.5 and Figure 4.6 show the verification plots for background and roadside NO_2, respectively. Lines at ±30% are shown on the model verification plots and represent the DQOs specified for NO_2 in the EU Air Quality Directive. The plots show that the modelled values provide reasonable agreement with the measured annual mean concentrations, with some sites lying outside the DQOs.

Summary statistics are presented in Table 4.2 for NO_X and Table 4.3 for NO_2. The analysis was performed separately for background (non-roadside) and roadside sites. 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 4.2 Comparison of the modelled and measured annual mean concentration of NO_X at background and roadside sites (Scotland-specific and UK models).

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	37.5	34.5	0.68	41.7	12
UK PCM	37.5	31.6	0.71	16.7	12
NO_X Roadside					
Scotland-specific	90.2	77.2	0.12	50.0	22
UK PCM	90.2	78.4	0.12	27.3	22

Table 4.3 Comparison of the modelled and measured annual mean concentration of NO_2 at background and roadside sites (Scotland-specific and UK models).

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	20.8	20.2	0.70	25.0	12
UK PCM	20.8	18.8	0.72	16.7	12

NO_2 Roadside					
Scotland-specific	36.6	33.0	0.20	27.3	22
UK PCM	36.6	33.5	0.19	27.3	22

Figure 4.1 Annual mean PM_{10} background model verification, 2008.

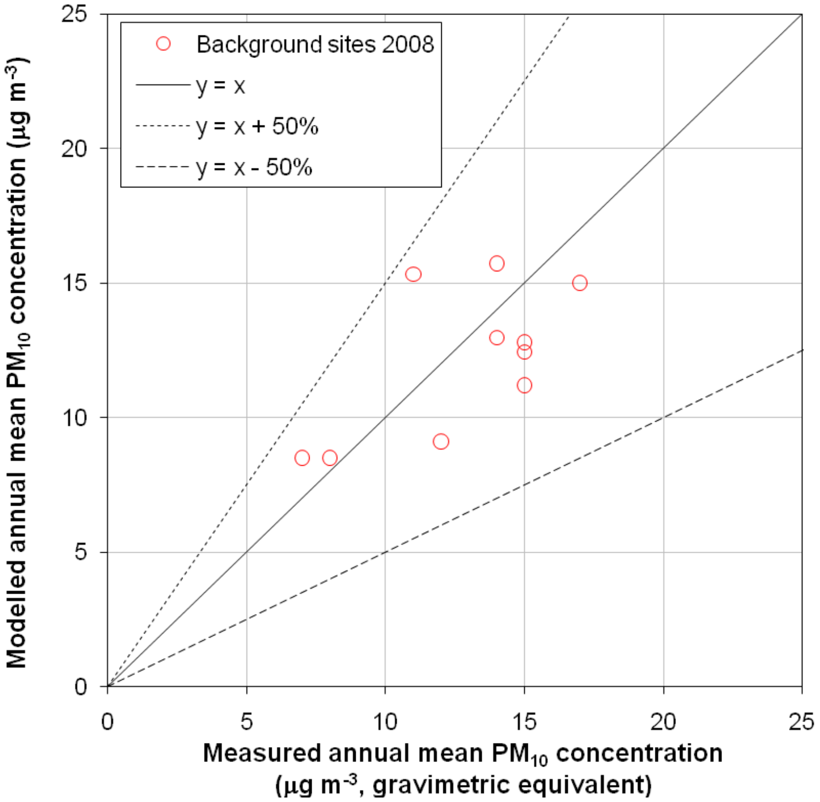


Figure 4.2 Annual mean PM_{10} roadside model verification, 2008.

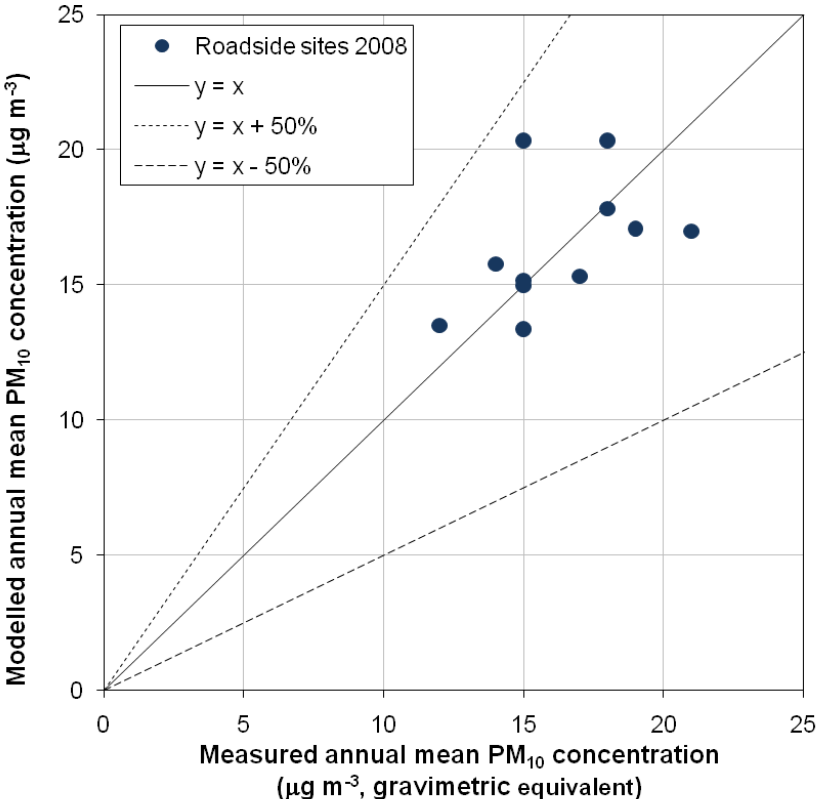


Figure 4.3 Annual mean NO_X background model verification, 2008.

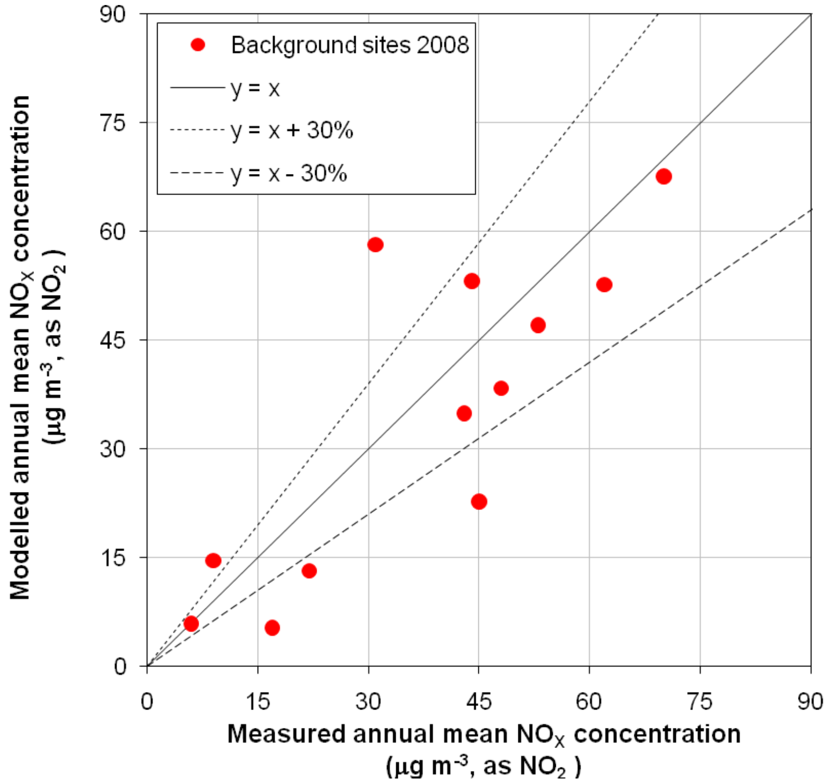


Figure 4.4 Annual mean NO_X roadside model verification, 2008.

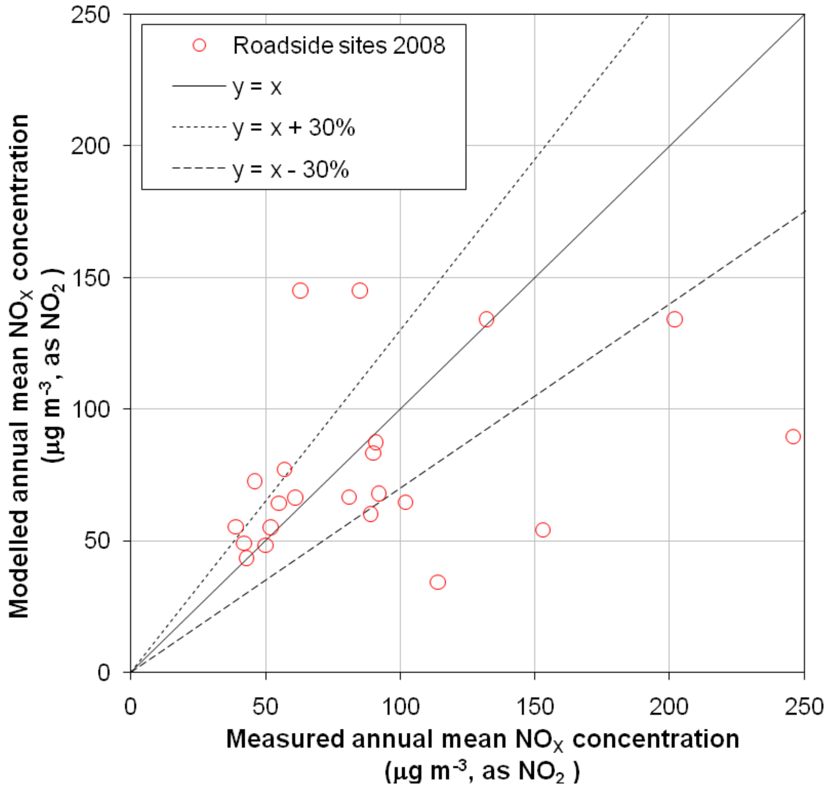


Figure 4.5 Annual mean NO_2 <u>background</u> model verification, 2008.

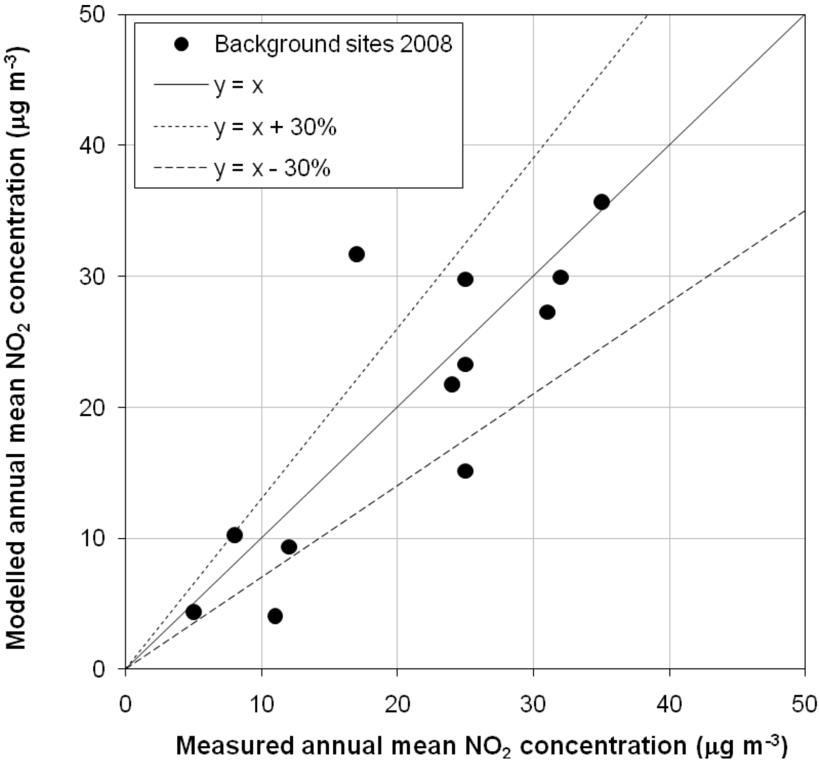
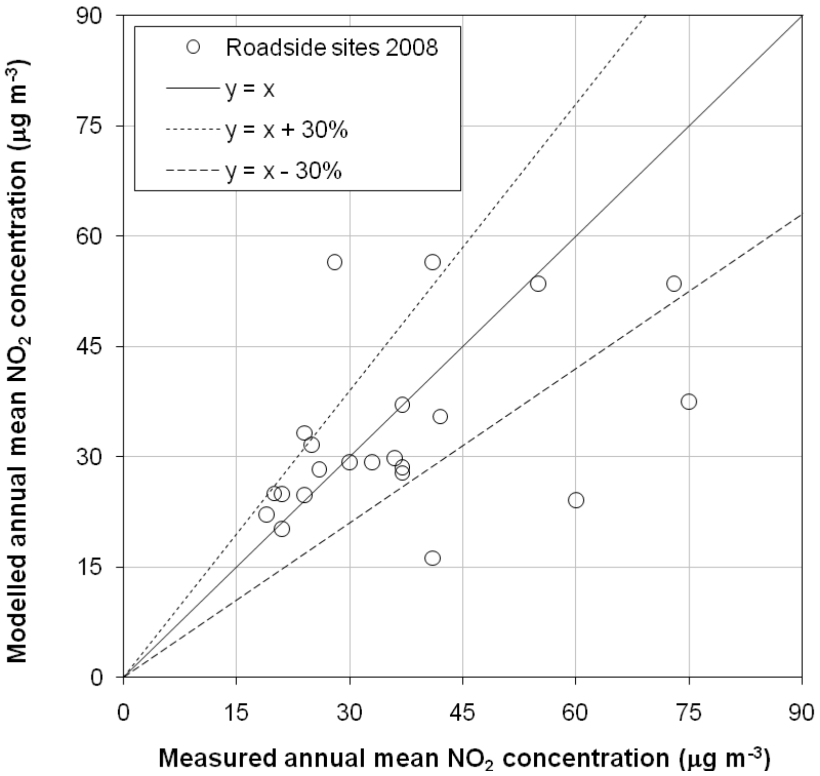


Figure 4.6 Annual mean NO_2 <u>roadside</u> model verification, 2008.



4.3 Comparison of UK and Scotland-specific annual mean roadside model outputs

Comparison of the 2008 Scotland-specific modelled and the UK modelled annual mean roadside concentrations are shown in Figure 4.7 and Figure 4.8 for PM_{10} and NO_2, respectively. The comparison for PM_{10} includes comparison with the Scotland-specific model values from 2007. The 2008 modelled annual mean PM_{10} concentrations from the Scotland-specific model tended to be greater than those from the 2007 Scotland-specific model and 2008 UK model, and fall above the 1:1 line (y = x). By comparison there were only marginal differences between the 2008 modelled annual mean NO_2 concentrations from the Scotland-specific model and the 2008 UK model. Comparison of the two sets of the modelled values showed good agreement with most points falling on or very close to the 1:1 line.

The reason for the difference between the 2007 Scotland-specific model, 2008 UK model and the 2008 Scotland-specific roadside PM_{10} model results can be explained by differences in the roadside calibration coefficients applied in each case as shown in Table 3.2. The 2008 PM_{10} Scotland-specific roadside calibration factor was greater than that applied in the 2008 UK model, and considerably more than that applied in the 2007 Scotland-specific model. By comparison the 2008 Scotland-specific and UK roadside NO_X coefficients were broadly similar in value.

The 2008 Scotland-specific roadside PM_{10} calibration coefficient was based exclusively on the relationship between traffic flow and PM_{10} roadside increment for Scottish major roads (motorways and A-roads). It is therefore more demonstrative of the traffic flow, and the associated PM_{10} roadside increment, on each Scottish road link used when compared to the PM_{10} roadside calibration coefficient used in the 2008 UK model. The UK model utilises a relationship based on the traffic flow and PM_{10} roadside increment for all UK road links and therefore demonstrates no local bias. On one hand this makes it ideal for broadly demonstrating conditions in the UK as a whole, but insensitive to local effects, which could be very important at the Devolved Administration level.

Figure 4.7 Comparison of the 2008 Scotland-specific modelled and the UK modelled annual mean roadside concentrations for PM_{10}. The figure includes comparison with the Scotland-specific model values from 2007.

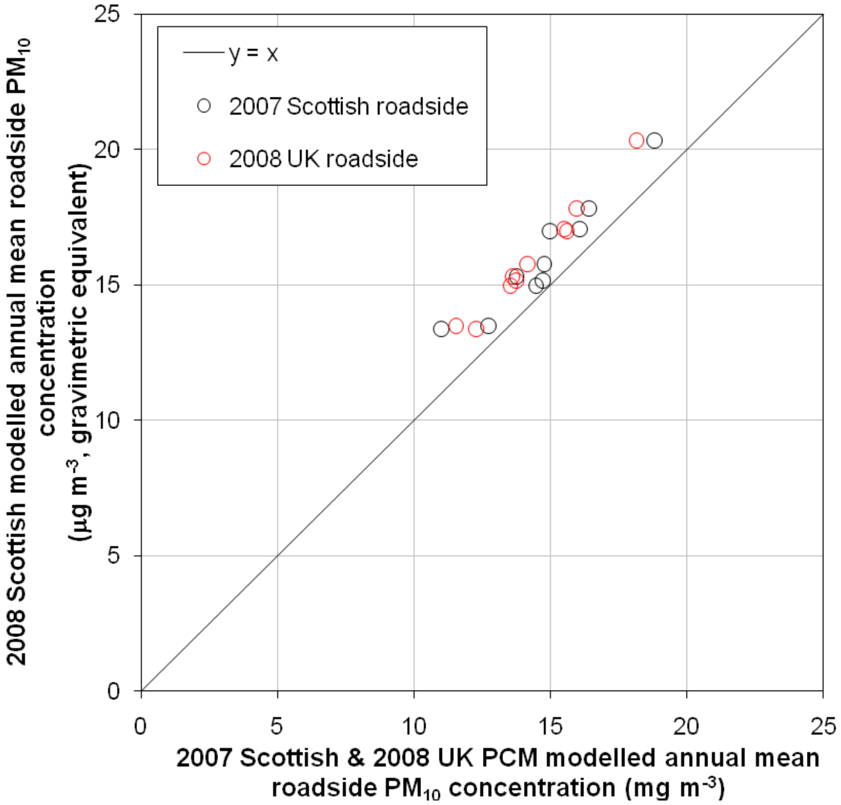
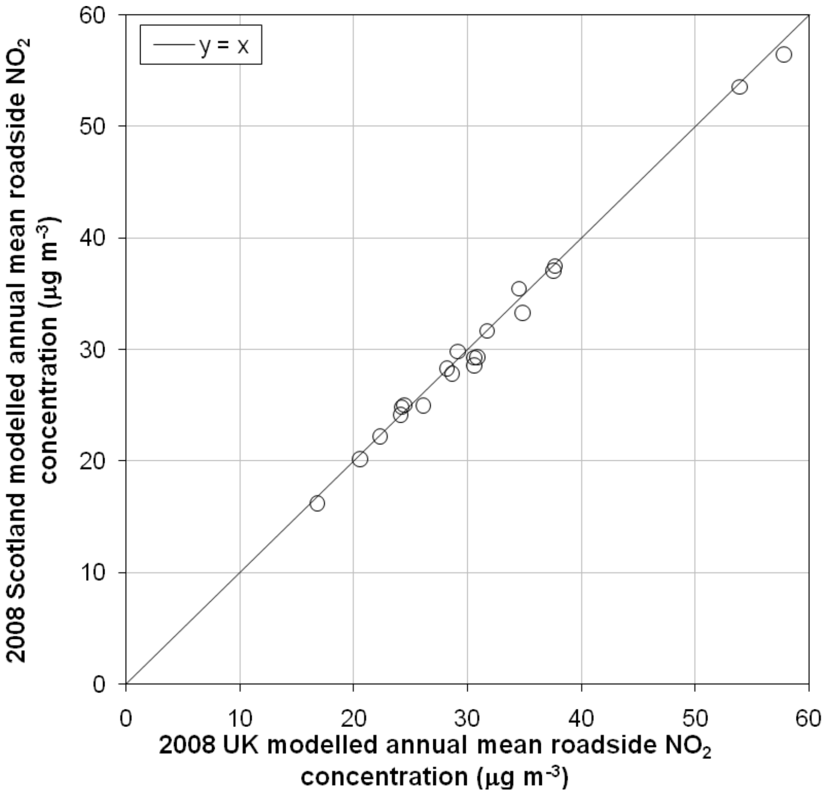


Figure 4.8 Comparison of the 2008 Scotland-specific modelled and the UK modelled annual mean roadside concentrations for NO_2.



5 2008 Scottish pollutant maps and results

5.1 Scottish annual mean PM_{10} maps

The annual mean PM_{10} concentration was modelled for Scotland for 2008 at background and roadside locations. Figure 5.1 and Figure 5.2 present maps of annual mean PM_{10} concentration for these locations in 2008. These maps have been used for comparison with the PM_{10} limit values described above (in Section 2.2) and are the results presented in Section 5.3. More detailed roadside annual mean PM_{10} concentration maps are presented in Figure 5.3, Figure 5.4, Figure 5.5, and Figure 5.6. The maps are presented by region:

- North East Scotland (Thurso and Aberdeen),
- South East Scotland (Dundee, Perth, and Edinburgh),
- South West Scotland (Glasgow), and
- North West Scotland (Fort William, Inverness, Ullapool, Isle of Skye, and the Isle of Lewis).

Maps of the Orkney and Shetland Isles are not presented as the roadside model output only provides roadside annual mean PM_{10} concentrations for urban areas.

5.2 Scottish annual mean NO_2 maps

The annual mean NO_2 concentration was modelled for Scotland for 2008 at background and roadside locations. Figure 5.7 and Figure 5.8 present maps of annual mean NO_2 concentration for these locations in 2008. These maps have been used for comparison with the NO_2 limit values described above (in Section 2.3) and the results are presented in Section 5.3. More detailed roadside annual mean NO_2 concentration maps are presented in Figure 5.9, Figure 5.10, Figure 5.11, and Figure 5.12. The maps are presented by region:

- North East Scotland (Thurso and Aberdeen),
- South East Scotland (Dundee, Perth, and Edinburgh),
- South West Scotland (Glasgow), and
- North West Scotland (Fort William, Inverness, Ullapool, Isle of Skye, and the Isle of Lewis).

Maps of the Orkney and Shetland Isles are not presented as the roadside model output only provides roadside annual mean NO_2 concentrations for urban areas.

5.3 Exceedence statistics (Scotland-specific model)

The model outputs were compared against appropriate AQOs for Scotland to determine the extent of exposure to specific concentrations. As noted in Section 2.2, The Scottish Government has adopted more challenging annual mean targets for PM_{10} for 2010 than the rest of the UK. At background locations the area and population exposed were assessed. At roadside locations, the number of road links and the length of road exposed were assessed.

Figure 5.1 presents the mapped annual mean background PM_{10} concentration for 2008 from the Scotland-specific model. One exceedence of the Scottish annual mean objective for PM_{10} of 18 µg m^{-3} at one background location was identified by the Scotland-specific model in Central Scotland as shown in Table 5.1. Examination of the model results revealed that an annual mean PM_{10} concentration of 19.7 µg m^{-3} was modelled in one grid square in this zone. The cause of the elevated modelled annual mean PM_{10} concentration in this grid square 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 square revealed a complex situation with several potential contributory sources: fugitive PM_{10} emissions combined with PM_{10} emissions from a range of transport sources. The 2008 UK model predicted a similar annual mean PM_{10} concentration in this grid square. Overall, the background annual exceedence statistics for Scotland from the UK model were the same as those produced by the Scotland-specific model.

Table 5.1 Annual mean exceedence statistics for background PM_{10} in Scotland based on Scotland-specific model, 2008.

Annual mean exceedence statistics for Background PM_{10}						
Zone or agglomeration	Total		>18 µg m^{-3}		>22[14] µg m^{-3}	
	Area (km^2)	Population	Area (km^2)	Population	Area (km^2)	Population
Glasgow Urban Area	366	1083323	0	0	0	0
Edinburgh Urban Area	128	432414	0	0	0	0
Central Scotland	9615	1916281	1	29	0	0
North East Scotland	18837	1001550	0	0	0	0
Highland	43603	372608	0	0	0	0
Scottish Borders	11375	253305	0	0	0	0
Total	**83924**	**5059482**	**1**	**29**	**0**	**0**

Table 5.2 Annual mean exceedence statistics for roadside PM_{10} in Scotland based on Scotland-specific model, 2008.

Annual mean exceedence statistics for Roadside PM_{10}						
Zone or agglomeration	Total		>18 µg m^{-3}		>22[14] µg m^{-3}	
	Roads	Length (km)	Roads	Length (km)	Roads	Length (km)
Glasgow Urban Area	201	301	51	68	6	13
Edinburgh Urban Area	60	102	11	16	1	2
Central Scotland	222	361	15	17	4	7
North East Scotland	130	230	24	27	1	2
Highland	9	32	0	0	0	0
Scottish Borders	35	47	0	0	0	0
Total	**657**	**1074**	**101**	**128**	**12**	**22**

The 2008 Scotland-specific model identified 101 road links (128 km of road) exceeding the Scottish PM_{10} air quality objective of which half were in the Glasgow Urban Area as shown in. A further 11 road links in the Edinburgh Urban Area (15.5 km of road) exceeded the Scottish PM_{10} objective. No roadside exceedences of the Scottish PM_{10} objective were identified by the model in the Highland or Scottish Borders zones. No background locations showed an exceedence of 22 µg m^{-3} of PM_{10} (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). The Scotland-specific model identified 6 road links (12 km) in the Glasgow urban area exceeding the annual mean equivalent value of the Scotland daily mean PM_{10} objective.

Examination of the plot of UK annual mean PM_{10} concentration against the 98th percentile of the UK daily mean PM_{10} concentration shown in Figure A.1 (in Appendix 1) shows more scatter than the plot of UK annual mean PM_{10} concentration against the 90th percentile of the UK daily mean PM_{10} concentration shown in Figure A.2 (in Appendix 1). This is merely an artefact of the variability in the range of values in the top 2% (98th percentile) of measurements when compared to those in the top 10% (90th percentile). The annual mean equivalent of the 98th percentile of the Scotland daily mean PM_{10} objective based on measurements from the UK AURN network was originally chosen due to the lack of Scotland-specific data in previous years. The choice of 22 µg m^{-3} as the annual mean equivalent of the 98th percentile of the Scotland daily mean PM_{10} objective (of 50 µg m^{-3} not to be exceeded on more than 7 days) based on measurements from the UK AURN network was not unreasonable. Figure A.3 shows that the annual mean equivalent of the 98th percentile of the Scotland daily mean PM_{10} daily objective based on measurements from the Scottish air quality network from 1992-2008 was 20 µg m^{-3}. At present, we have continued with the value of 22 µg m^{-3} for the annual mean equivalent to the Scottish daily mean PM_{10} objective to maintain consistency.

[14] 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.

Table 5.3 Annual mean exceedence statistics for roadside PM_{10} in Scotland based on UK model, 2008.

Annual mean exceedence statistics for Roadside PM_{10}						
Zone or agglomeration	Total		>18 $\mu g\ m^{-3}$		>22[14] $\mu g\ m^{-3}$	
	Roads	Length (km)	Roads	Length (km)	Roads	Length (km)
Glasgow Urban Area	201	301	28	40	4	10
Edinburgh Urban Area	60	102	3	7	0	0
Central Scotland	222	361	4	7	0	0
North East Scotland	130	230	13	13	0	0
Highland	9	32	0	0	0	0
Scottish Borders	35	47	0	0	0	0
Total	**657**	**1074**	**48**	**66**	**4**	**10**

Table 5.3 shows that the number of exceedences of the Scottish annual mean PM_{10} objective at roadside locations in Scotland from the UK model were lower than those predicted by the Scotland-specific model (48 road links or 66 km of road), though the relative proportions of roads in each zone or agglomeration where exceedences were predicted were broadly similar between the two models. The higher number of roadside exceedences reported by the 2008 Scotland-specific model was due to the higher roadside calibration coefficient used in the Scotland-specific model (as described in Sections 3.2 and 4.3). The higher Scottish roadside calibration coefficient used in the 2008 Scotland-specific model is likely to be more representative of the local PM_{10} increment for each Scottish road link.

Table 5.4 Annual mean exceedence statistics for background NO_2 in Scotland based on the Scotland-specific model, 2008.

Annual mean exceedence statistics for Background NO_2				
Zone or agglomeration	Total		>40 $\mu g\ m^{-3}$	
	Area (km^2)	Population	Area (km^2)	Population
Glasgow Urban Area	366	1083323	0	0
Edinburgh Urban Area	128	432414	0	0
Central Scotland	9615	1916281	0	0
North East Scotland	18837	1001550	0	0
Highland	43603	372608	0	0
Scottish Borders	11375	253305	0	0
Total	**83924**	**5059482**	**0**	**0**

Table 5.5 Annual mean exceedence statistics for roadside NO_2 in Scotland based on the Scotland-specific model, 2008.

Annual mean exceedence statistics for Roadside NO_2				
Zone or agglomeration	Total		>40 $\mu g\ m^{-3}$	
	Roads	Length (km)	Roads	Length (km)
Glasgow Urban Area	201	301	47	68
Edinburgh Urban Area	60	102	9	14
Central Scotland	222	361	13	25
North East Scotland	130	230	11	16
Highland	9	32	0	0
Scottish Borders	35	47	0	0
Total	**657**	**1074**	**80**	**123**

Table 5.6 Annual mean exceedence statistics for roadside NO_2 in Scotland based on the UK model, 2008.

Annual mean exceedence statistics for Roadside NO_2				
Zone or agglomeration	Total		>40 $\mu g\ m^{-3}$	
	Roads	Length (km)	Roads	Length (km)
Glasgow Urban Area	201	301	52	76
Edinburgh Urban Area	60	102	9	14
Central Scotland	222	361	12	24
North East Scotland	130	230	12	18
Highland	9	32	0	0
Scottish Borders	35	47	0	0
Total	**657**	**1074**	**85**	**132**

Figure 5.7 presents the mapped annual mean background NO_2 concentration for 2008 from the Scotland-specific model. Table 5.4 shows that no exceedence of the Scottish annual mean objective for NO_2 of 40 µg m^{-3} was identified in any background zones. The background annual exceedence statistics for Scotland from the 2008 UK model were the same as those produced by the Scotland-specific model. For NO_2, overall the 2008 Scotland-specific roadside exceedence statistics were similar those produced by the UK model as shown in Table 5.5 and Table 5.6, respectively. The Scotland-specific model predicted that the Scottish annual mean air quality objective for NO_2 of 40 µg m^{-3} was exceeded along 80 road links compared to 85 predicted by the 2008 UK model. As for PM_{10}, the majority of exceedences occur in the Glasgow urban area where exceedences of the Scottish annual mean air quality objective for NO_2 was modelled for 47 road links (68 km of road). No roadside exceedences of the Scottish annual mean air quality objective for NO_2 objective were identified by the model in the Highland or Scottish Borders zones.

Figure 5.1 Background PM_{10} map for 2008, $\mu g\ m^{-3}$ (Scotland-specific model).

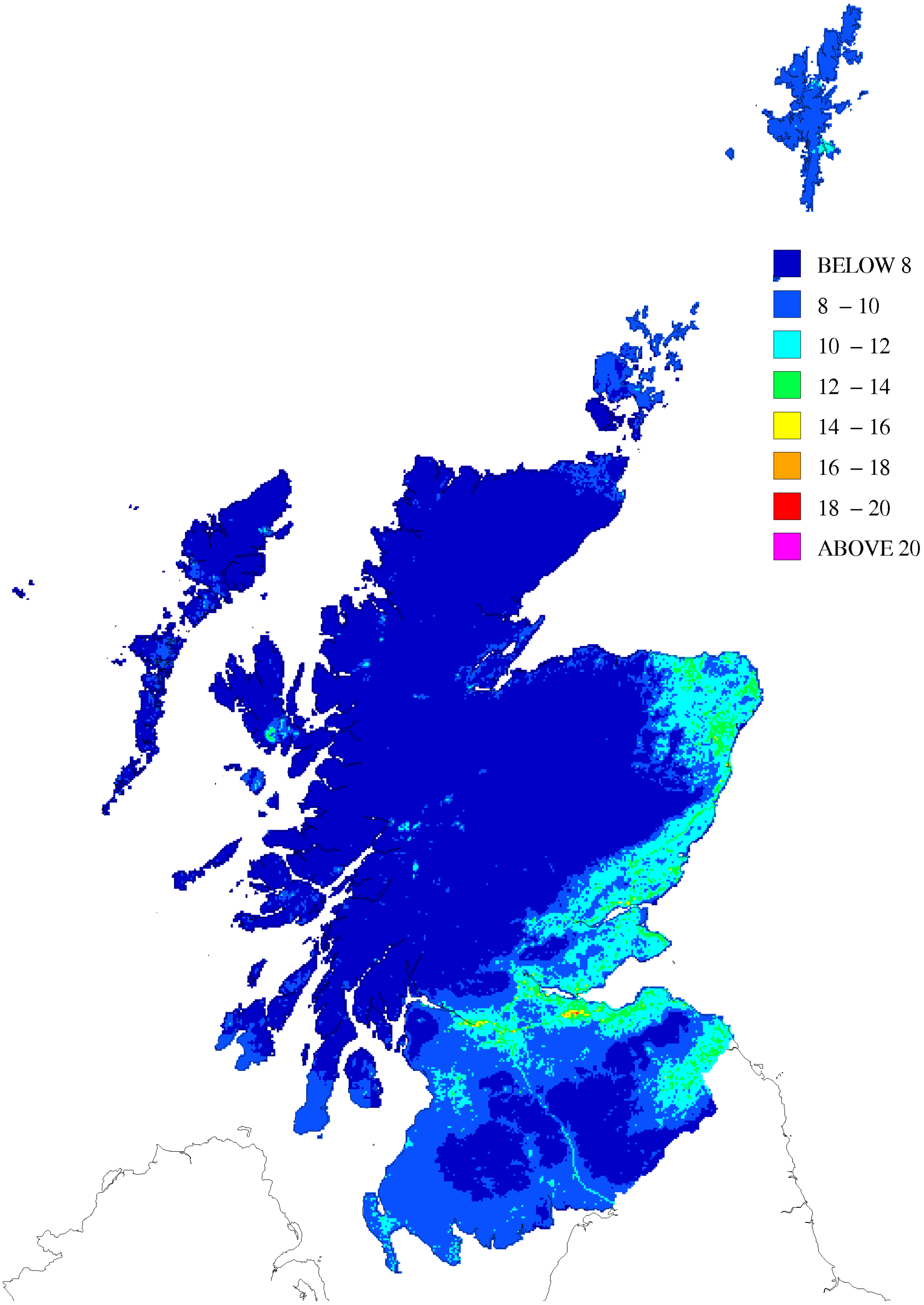


Figure 5.2 Roadside PM_{10} map for 2008, µg m^{-3} (Scotland-specific model).

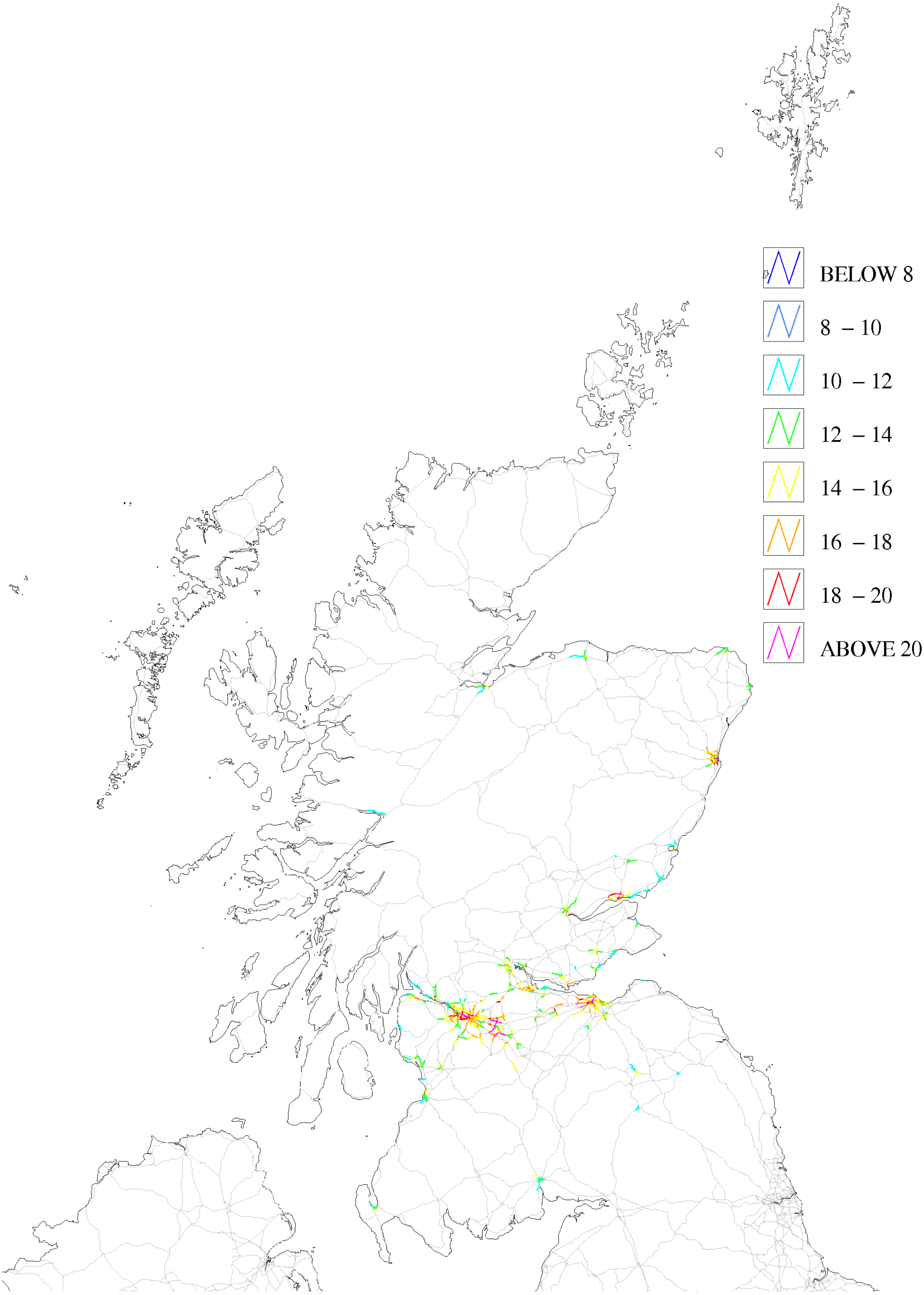


Figure 5.3 Detailed roadside PM_{10} map for 2008, $\mu g\ m^{-3}$ showing road-link emissions in North East Scotland (Scotland-specific model). Figure key as per Figure 5.2.

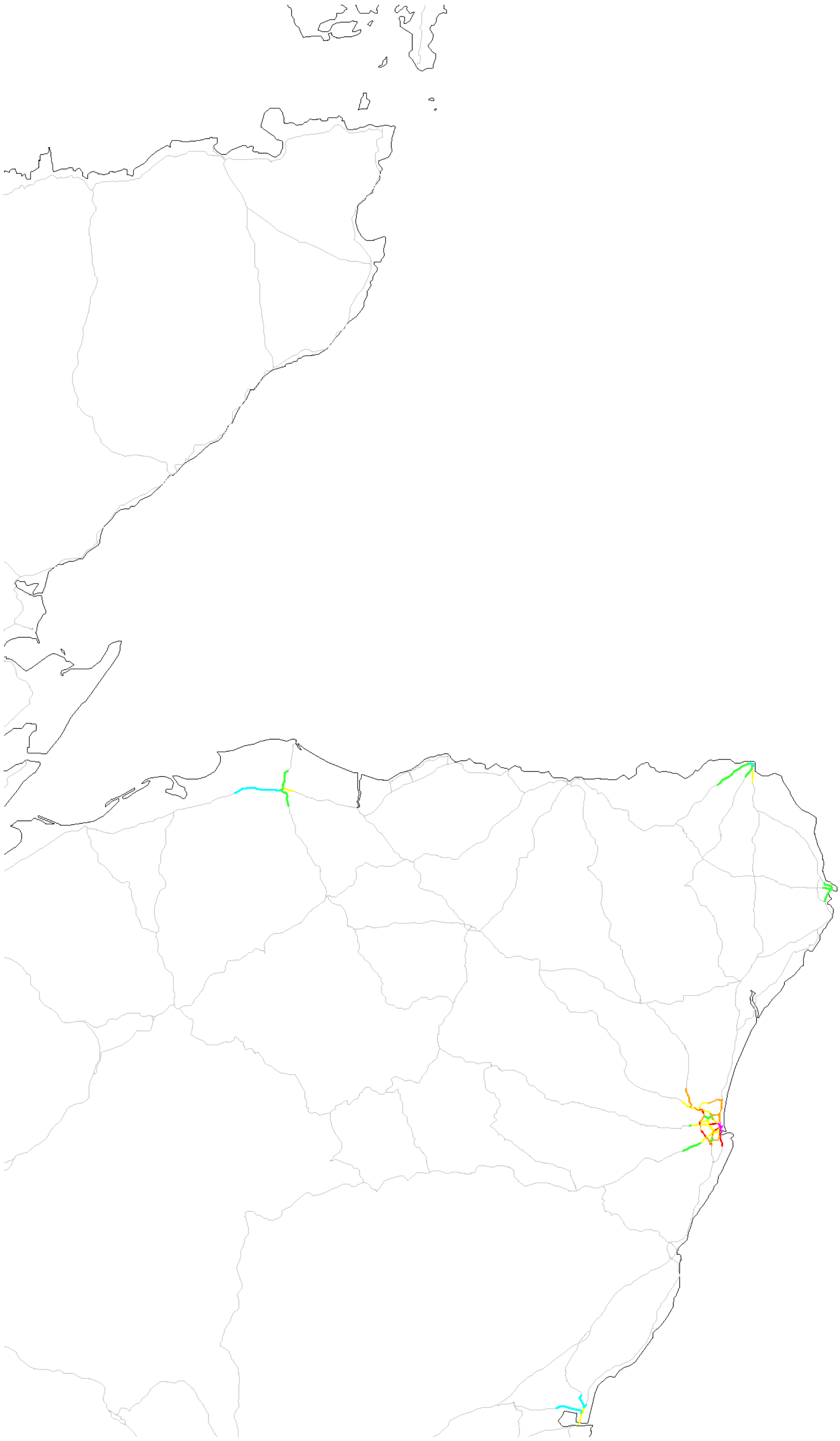


Figure 5.4 Detailed roadside PM_{10} map for 2008, $\mu g\ m^{-3}$ showing road-link emissions in South East Scotland (Scotland-specific model). Figure key as per Figure 5.2.

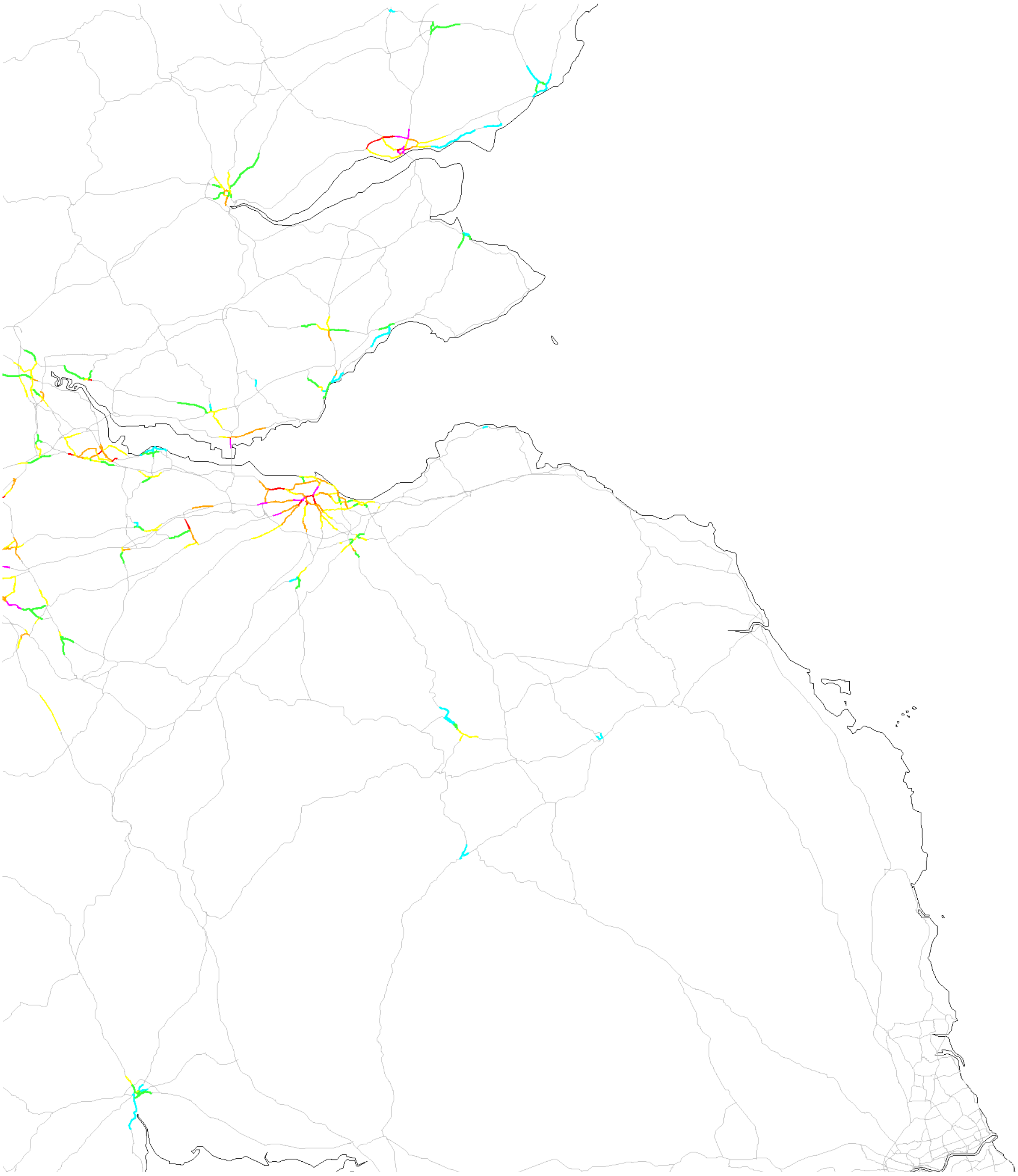


Figure 5.5 Detailed roadside PM_{10} map for 2008, µg m^{-3} showing road-link emissions in South West Scotland (Scotland-specific model). Figure key as per Figure 5.2.

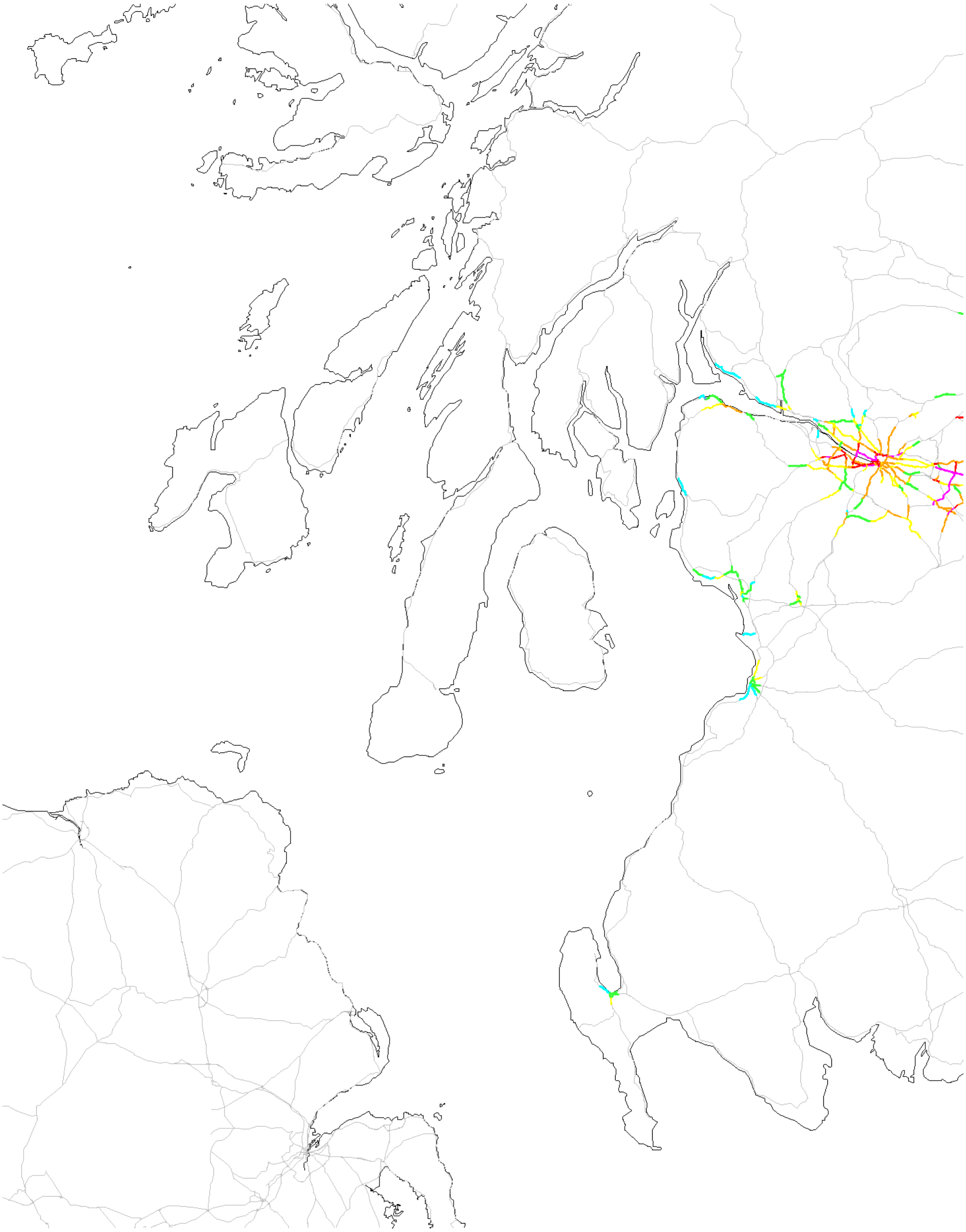


Figure 5.6 Detailed roadside PM_{10} map for 2008, $\mu g\ m^{-3}$ showing road-link emissions in North West Scotland (Scotland-specific model). Figure key as per Figure 5.2.

Figure 5.7 Background NO_2 map for 2008, µg m^{-3} (Scotland-specific model).

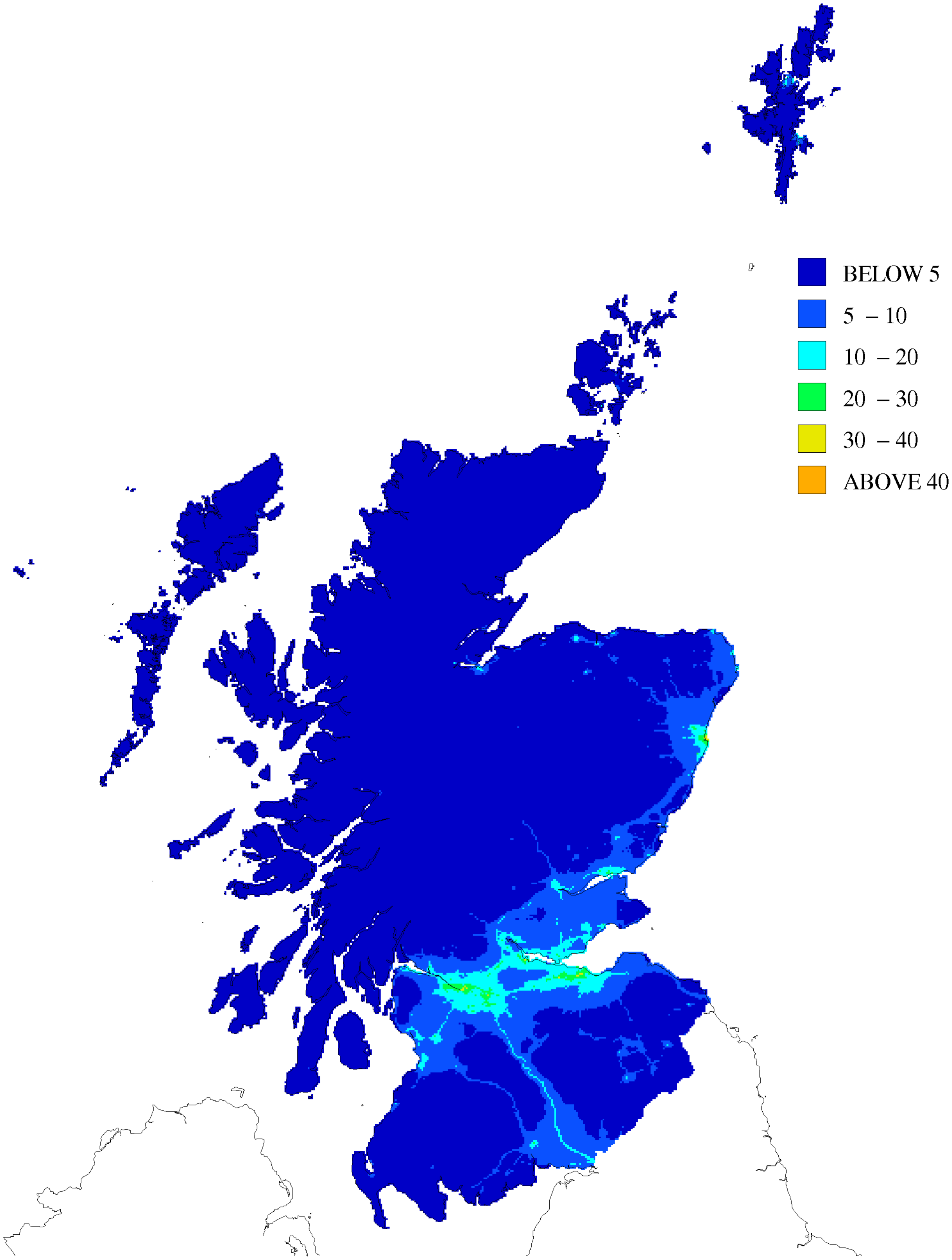


Figure 5.8 Roadside NO_2 map for 2008, $\mu g\ m^{-3}$ (Scotland-specific model).

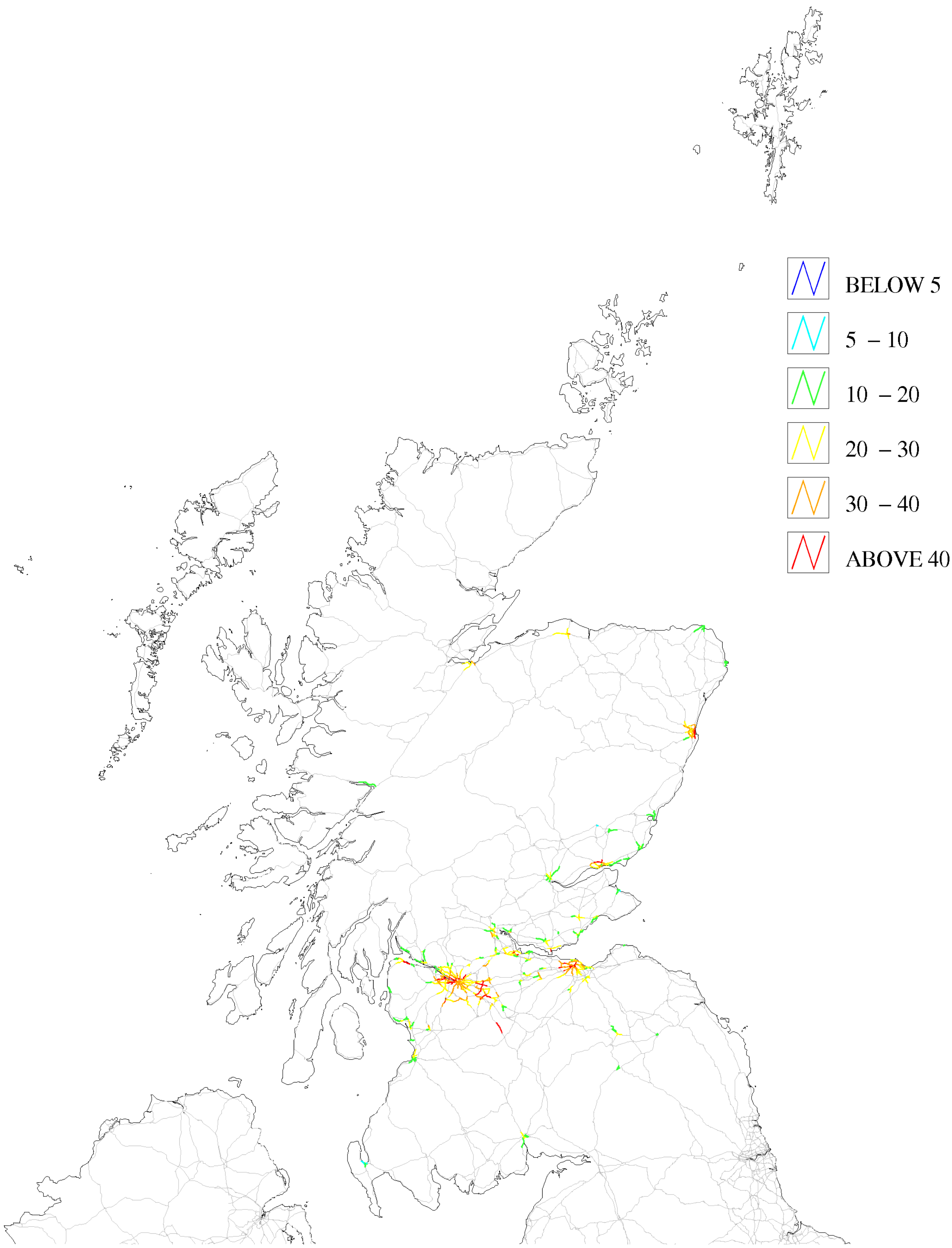


Figure 5.9 Detailed roadside NO_2 map for 2008, µg m^{-3} showing road-link emissions in North East Scotland (Scotland-specific model). Figure key as per Figure 5.8.

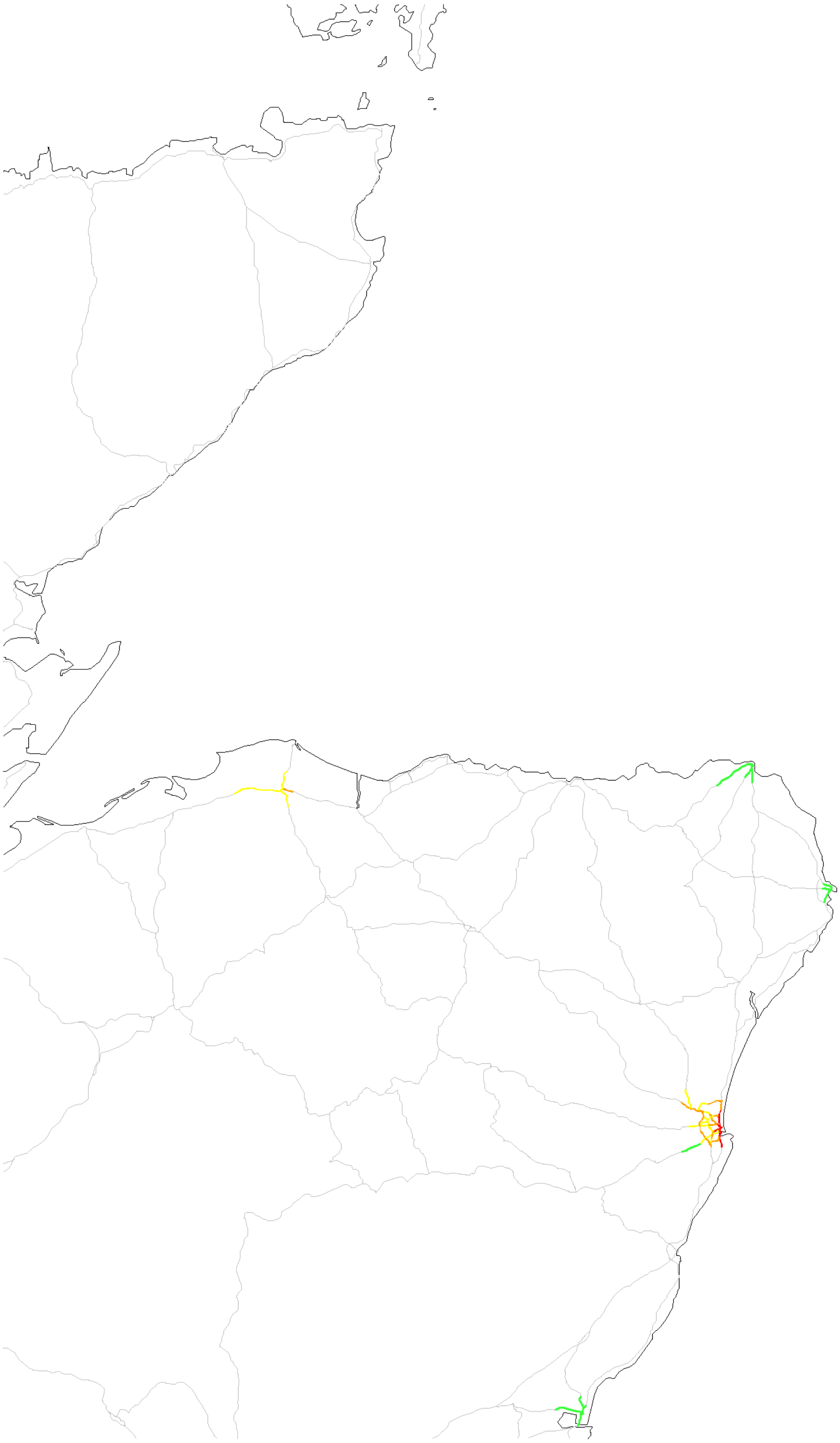


Figure 5.10 Detailed roadside NO_2 map for 2008, µg m^{-3} showing road-link emissions in South East Scotland (Scotland-specific model). Figure key as per Figure 5.8.

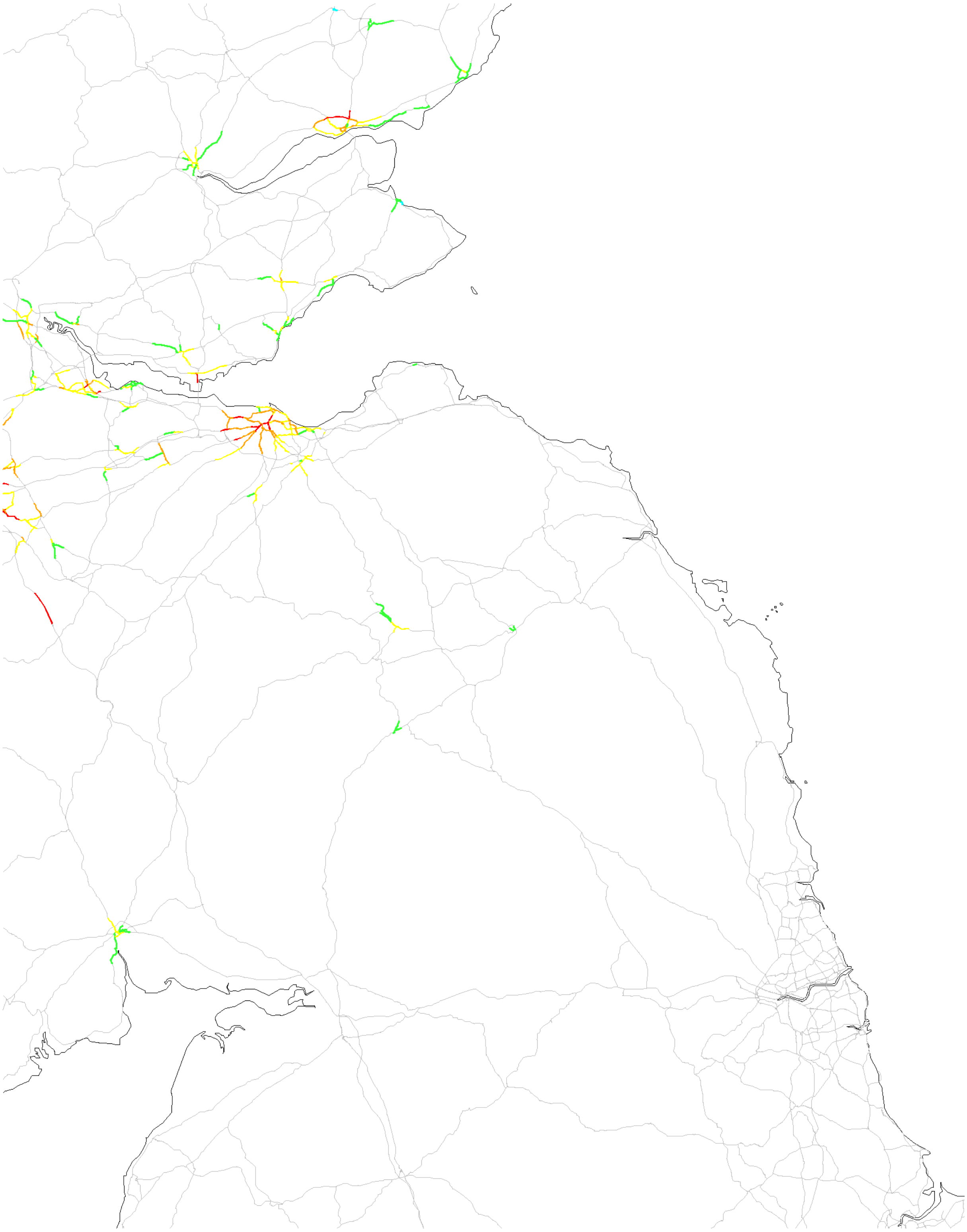


Figure 5.11 Detailed roadside NO_2 map for 2008, $\mu g\ m^{-3}$ showing road-link emissions in South West Scotland (Scotland-specific model). Figure key as per Figure 5.8.

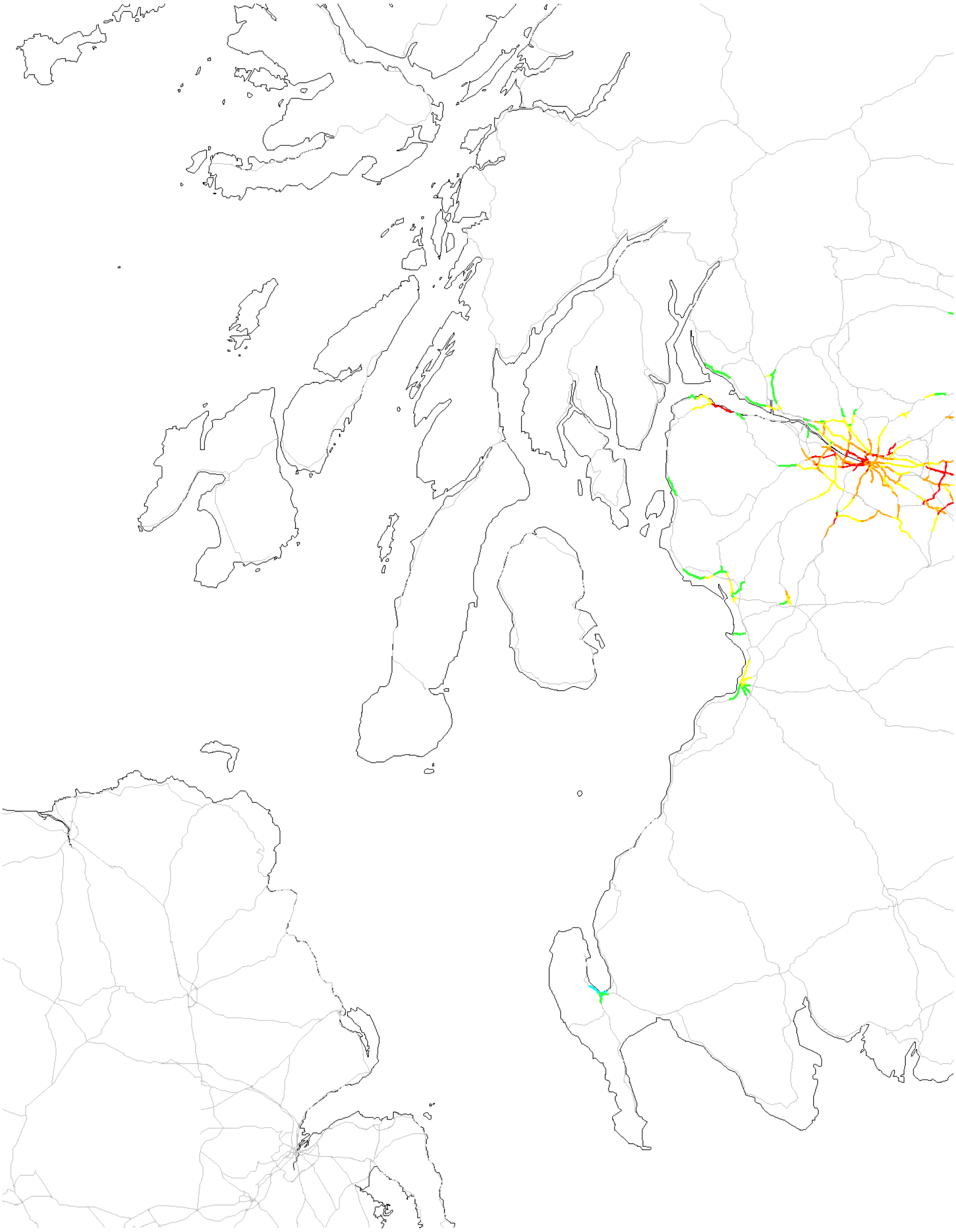
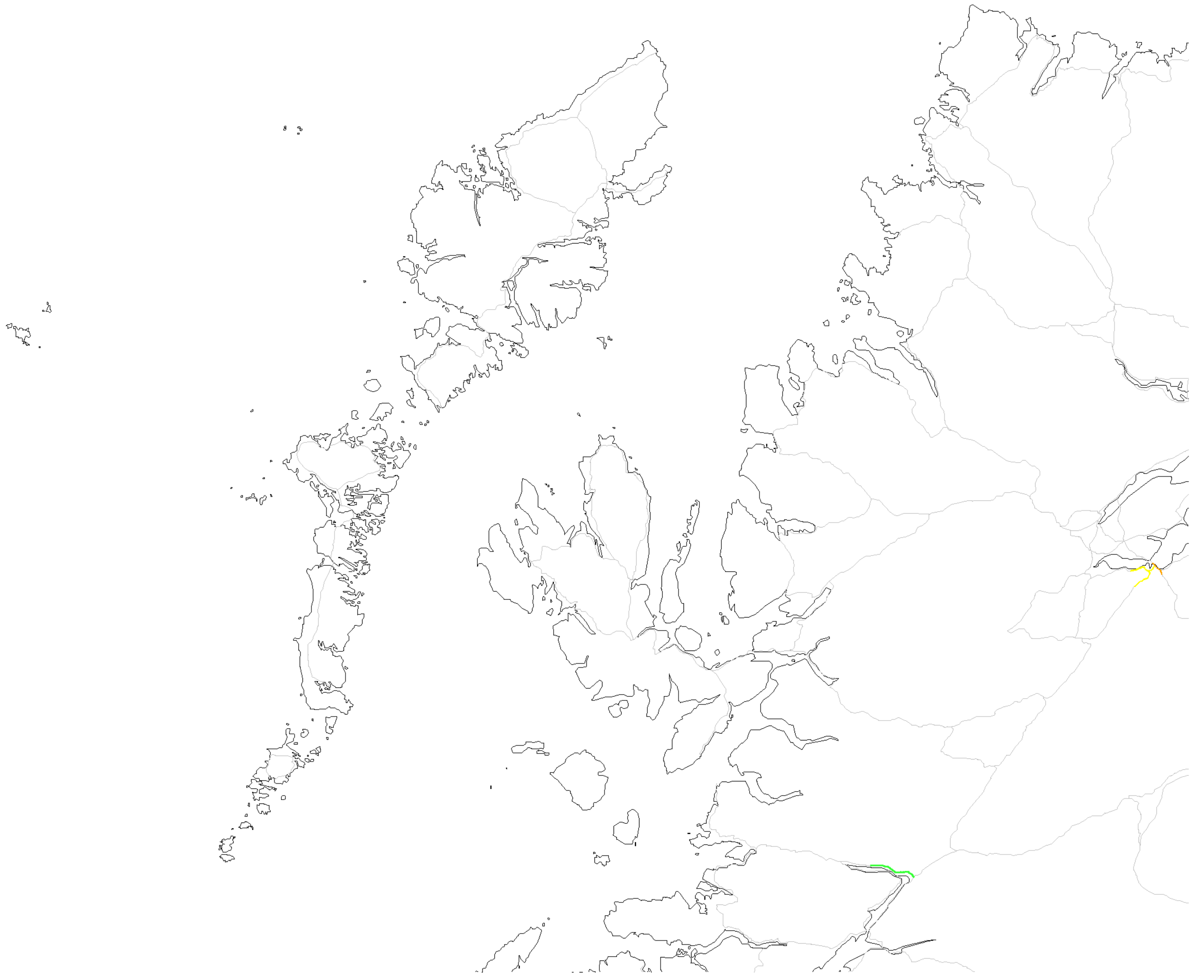


Figure 5.12 Detailed roadside NO_2 map for 2008, $\mu g\ m^{-3}$ showing road-link emissions in North West Scotland (Scotland-specific model). Figure key as per Figure 5.8.



5.4 Comparison of Scotland-specific maps with UK maps

In order to illustrate the differences between the Scotland-specific model output and the UK model output, maps showing the differences between the UK modelled and Scotland-specific modelled annual mean PM_{10} and NO_2 concentrations for 2008 were produced. These are presented in Figure 5.13 and Figure 5.14, respectively. These have been calculated by simply subtracting the Scotland-specific map from the UK map. Positive concentrations represent grid squares where the UK model concentration was higher than the Scotland-specific model concentration and whilst negative concentrations represent grid squares where the Scotland-specific model concentration was higher.

Figure 5.13 shows that there were small differences of the order of ±0.5 $\mu g\ m^{-3}$ between the mapped UK and Scotland-specific modelled PM_{10} concentrations. The limited degree of variance can be explained by the fact that the natural (sea salt) component and secondary particulate matter components (e.g., nitrate, sulphate, ammonium and secondary organic aerosol) were the same for both PM_{10} models. The greatest difference between the two modelling approaches tends to occur in urban areas, namely Glasgow, Edinburgh and Dundee, where differences of up to ±1.5 $\mu g\ m^{-3}$ exist.

These results should be interpreted cautiously as differences exist between the UK and Scotland-specific modelled PM_{10} concentrations throughout the whole mapping extent rather than just one or two specific locations. From an LAQM perspective, the maps presented in this report are intended as an indicative tool, showing pollutant concentrations throughout Scotland, not an absolute measure. In areas where modelled exceedences of the Scottish PM_{10} or NO_2 AQOs are indicated, confirmatory monitoring would need to be undertaken. If the monitoring programme demonstrated the existence of an exceedence of the Scottish PM_{10} or NO_2 AQO, then an AQMA would be declared. Under no circumstances should an AQMA be declared simply on the basis of the model results presented here.

Some thought should also be given to the spatial extent considered here. The modelled background air pollutant concentrations are presented on a 1 km^2 basis (1 x 1 km grid). From a national perspective this represents a detailed modelling domain. However, on a local scale, e.g., city or town, a finer grid would be required (of the order of hundreds of meters) – ideally one capable of identifying specific localised areas of high air pollutant concentrations or “hotspots”. Any such localised pockets of high air pollutant concentrations would not be represented in the modelled maps presented here.

Figure 5.14 shows that differences exist between the mapped UK and Scotland-specific modelled NO_2 concentrations. Throughout Scotland the differences tend to be of the order of ±2.0 $\mu g\ m^{-3}$, but the most noticeable differences occur around the urban areas, with the Scotland-specific model predicting NO_2 concentrations of between 1 and 6 $\mu g\ m^{-3}$ more than the UK model. This difference is believed to be due to the differences in the meteorology used in the two models, which affects the dispersion kernels used to calculate the annual mean NO_2 concentrations in each grid square. Generally speaking the Scottish dispersion kernels tend to be greater in value than those used in the UK model. In contrast the Scottish background NO_X calibration coefficient tends to be lower in value than that used in the UK model. When multiplied together to produce the modelled annual mean NO_X concentration in each grid square these small differences cancel one another out. However, for the 2008 Scotland-specific modelling the Scottish dispersion kernels were much greater in value than the UK dispersion kernels. Although the 2008 Scottish background NO_X calibration coefficient was lower than the equivalent UK calibration coefficient, it was not sufficiently small enough to ameliorate the effect of the higher 2008 Scottish dispersion kernels. Hence, this leads to the observed difference in the annual mean NO_2 concentration for each grid square for the 2008 Scotland-specific model when compared to the 2008 UK model.

5.5 Population-weighted mean calculations for 2008

Population-weighted mean calculations are performed on the modelled background maps. These provide a good measure of the health impact of modelled concentrations. Table 5.7 provides a summary of the calculated Scottish population-weighted mean concentration for 2008 for PM_{10} and NO_2 from the Scotland-specific model and the UK model. Whilst the Scotland-specific model provides a broadly similar concentration per person for PM_{10}, when compared to the output from the UK model, it results in a slight rise of just over 1 $\mu g\ m^{-3}$ for NO_2. The small increase in the value of the population weighted annual mean concentration of PM_{10} and NO_2 was due solely to the different calibration factors applied to the area source emissions component of the Scotland-specific model.

Table 5.7 Population weighted annual mean concentrations for background PM_{10} and NO_2, 2008.

2008 population weighted annual mean concentration for PM_{10} and NO_2		
Model	PM_{10} (µg m^{-3})	NO_2 (µg m^{-3})
Scotland-specific	10.53	13.2
UK PCM	10.48	11.9

Figure 5.13 Calculated difference between UK and Scotland-specific PM_{10} map for 2008, $\mu g\ m^{-3}$.

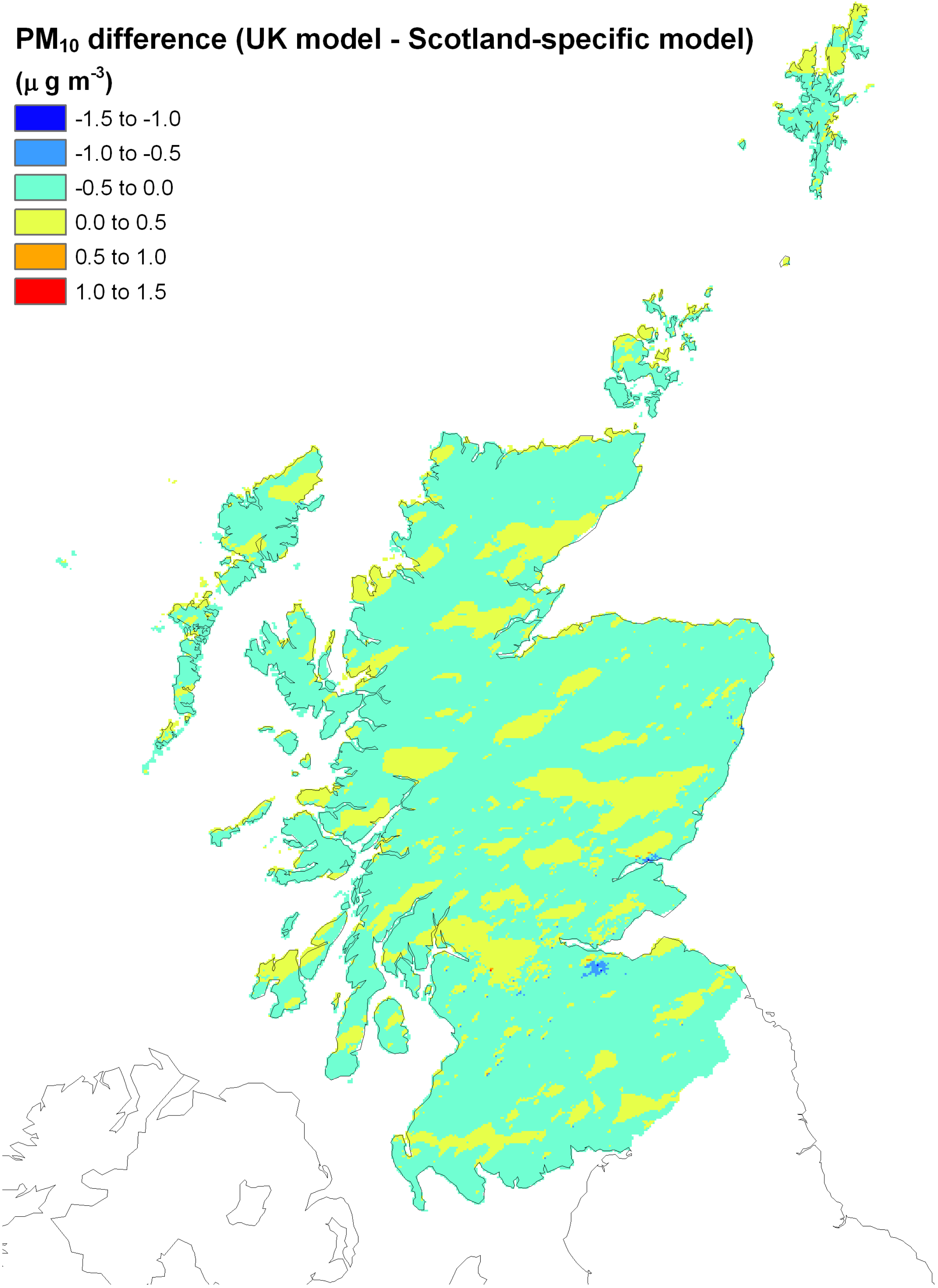
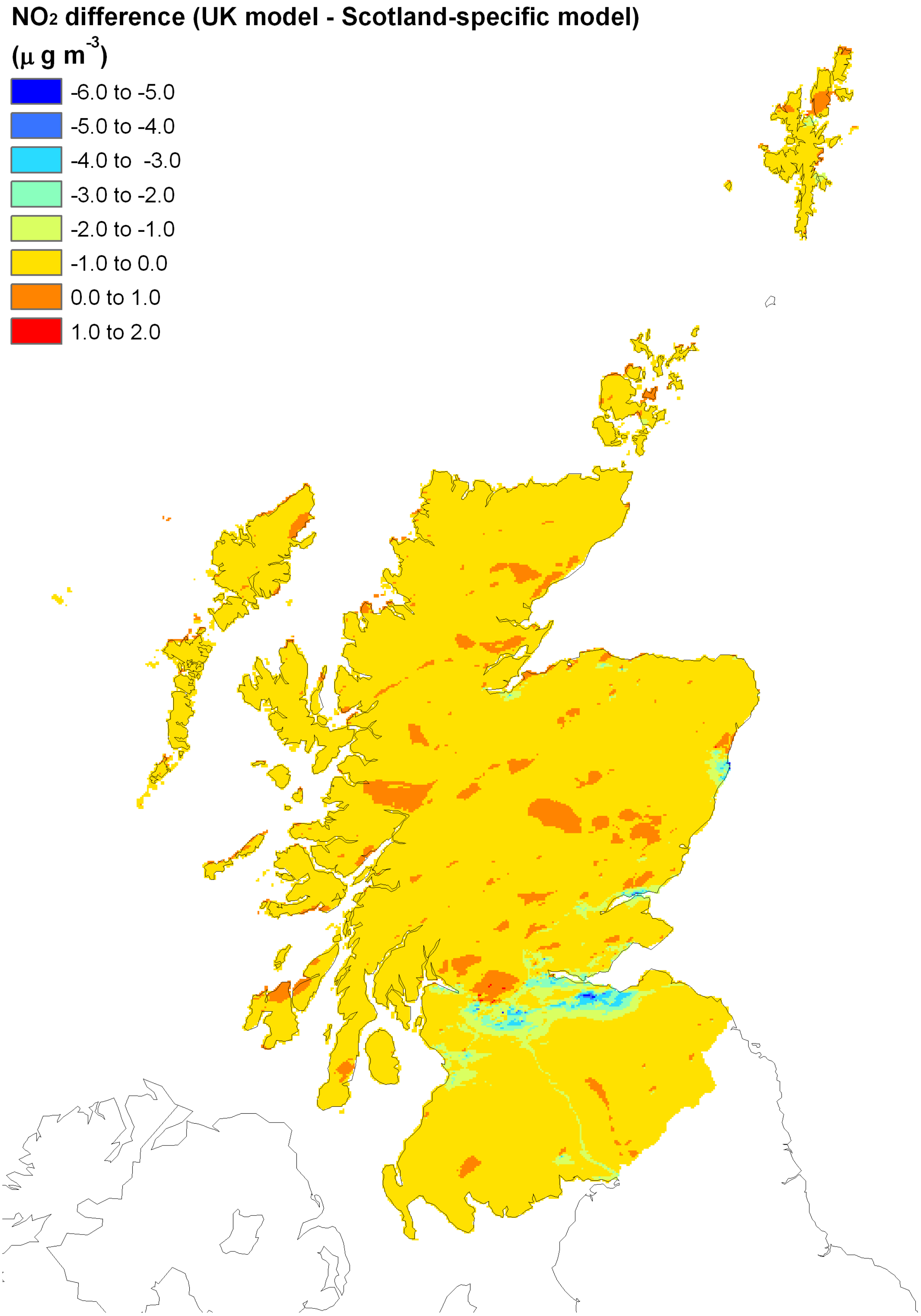


Figure 5.14 Calculated difference between UK and Scotland-specific NO_2 map for 2008, $\mu g\ m^{-3}$.



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

Projected annual mean concentrations of PM_{10}, NO_X and NO_2 for 2010, 2015 and 2020, from a base year of 2008, 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 2008, these were prepared using Scotland-specific data.

Recent analyses conducted for Defra and the DAs of historical air quality monitoring data from throughout the UK have identified a disparity between the measured concentrations of NO_X and/or NO_2 and the projected decline in concentrations associated with emissions forecasts. In many (but not all) areas, measured concentrations of NO_X and/or NO_2 have shown no significant decline over the past five or more years and in some locations may even have increased slightly. The precise reason for this disparity is not known, and is currently under investigation, but may be related to the actual on-road performance of diesel road vehicles (LDV and HDV) when compared with calculations based on the Euro standards.

The accuracy of the forward projection maps presented here is closely dependent on the future emission projections used to prepare the background pollutant maps. Future emissions projections were based on current, published “year-adjustment” factors for NO_X and NO_2 concentrations for all years up until 2020.

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

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

Figure 6.1, Figure 6.2 and Figure 6.3 provide background maps of projected annual mean PM_{10} concentrations for 2010, 2015 and 2020 based on the 2008 Scotland-specific model. The projected background maps show a progressive decrease in the background annual mean PM_{10} concentration to below 8 $\mu g\ m^{-3}$ between 2008 and 2020 for the majority of Scotland which is expected due to the predicted reduction in primary PM_{10} emissions, and associated pollutants, e.g., NO_X and SO_2, which contribute to secondary PM_{10} formation, in the form of nitrate and sulphate-based aerosol. High (10-14 $\mu g\ m^{-3}$) PM_{10} concentrations were projected to persist for the eastern coast of Scotland. The enhancement in the annual mean background PM_{10} concentration along the east coast is thought to be due to contributions to the overall PM_{10} concentration from wind-blown soil and dust.

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

Figure 6.4, Figure 6.5 and Figure 6.6 provide background maps of projected annual mean NO_2 concentrations for 2010, 2015 and 2020 based on the 2008 Scotland-specific model. As with PM_{10}, the projected background maps for NO_2 show a progressive decrease in the background annual mean concentration between 2008 and 2020 due to the predicted reduction in primary NO_X and oxidant emissions, which contribute to the formation of NO_2. However, as discussed above there is considerable on-going investigation of likely future emissions of NO_X and NO_2.

6.3 Annual CSV format Scottish Maps for LAQM Review and Assessment

Annual future projection data by source sector for each grid square in Scotland, based on the Scotland-specific mapping described in this report, have been prepared in CSV format files. These are analogous to the data already available to Local Authorities based on the UK PCM mapping for use in Review and Assessment reports for the purposes of LAQM (see http://laqm1.defra.gov.uk/review/tools/background-maps-info.php?year=2008). In future years, the data based on the Scottish mapping methodology could be made available to Scottish Local Authorities to use in the preparation of their annual Review and Assessment reports.

Figure 6.1 Background PM_{10} map for 2010, $\mu g\ m^{-3}$ (Scotland-specific model).

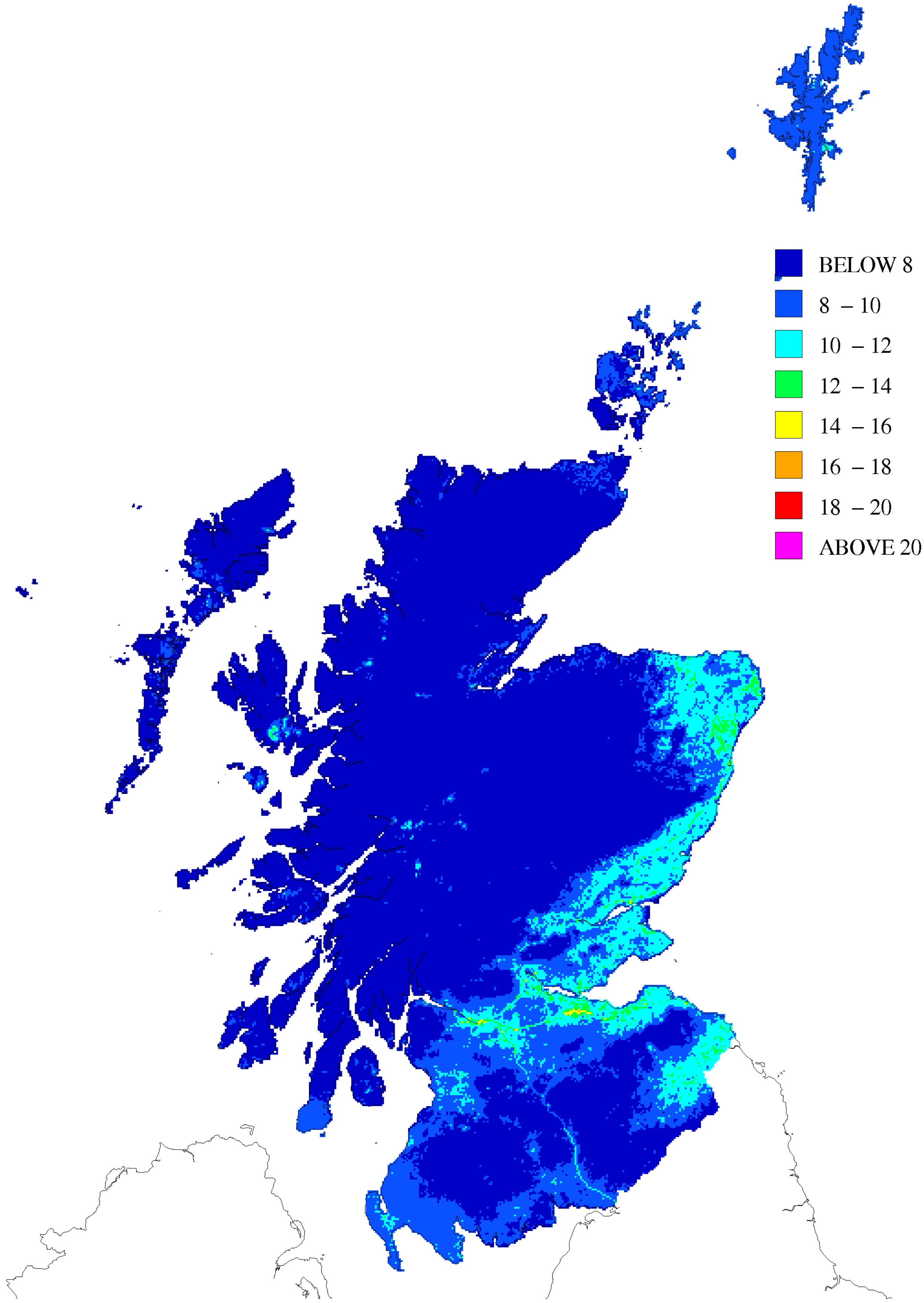


Figure 6.2 Background PM_{10} map for 2015, $\mu g\ m^{-3}$ (Scotland-specific model).

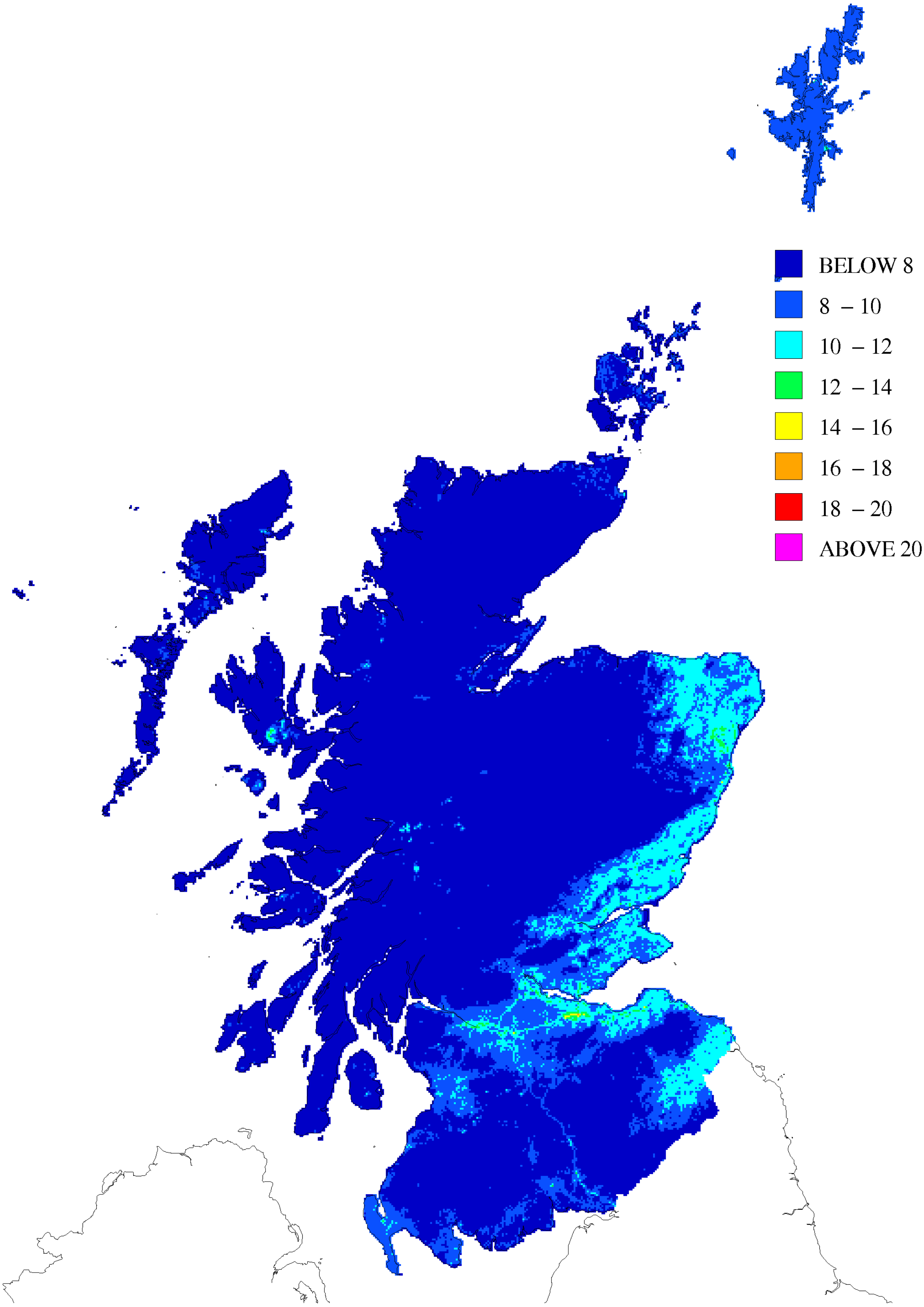


Figure 6.3 Background PM_{10} map for 2020, µg m^{-3} (Scotland-specific model).

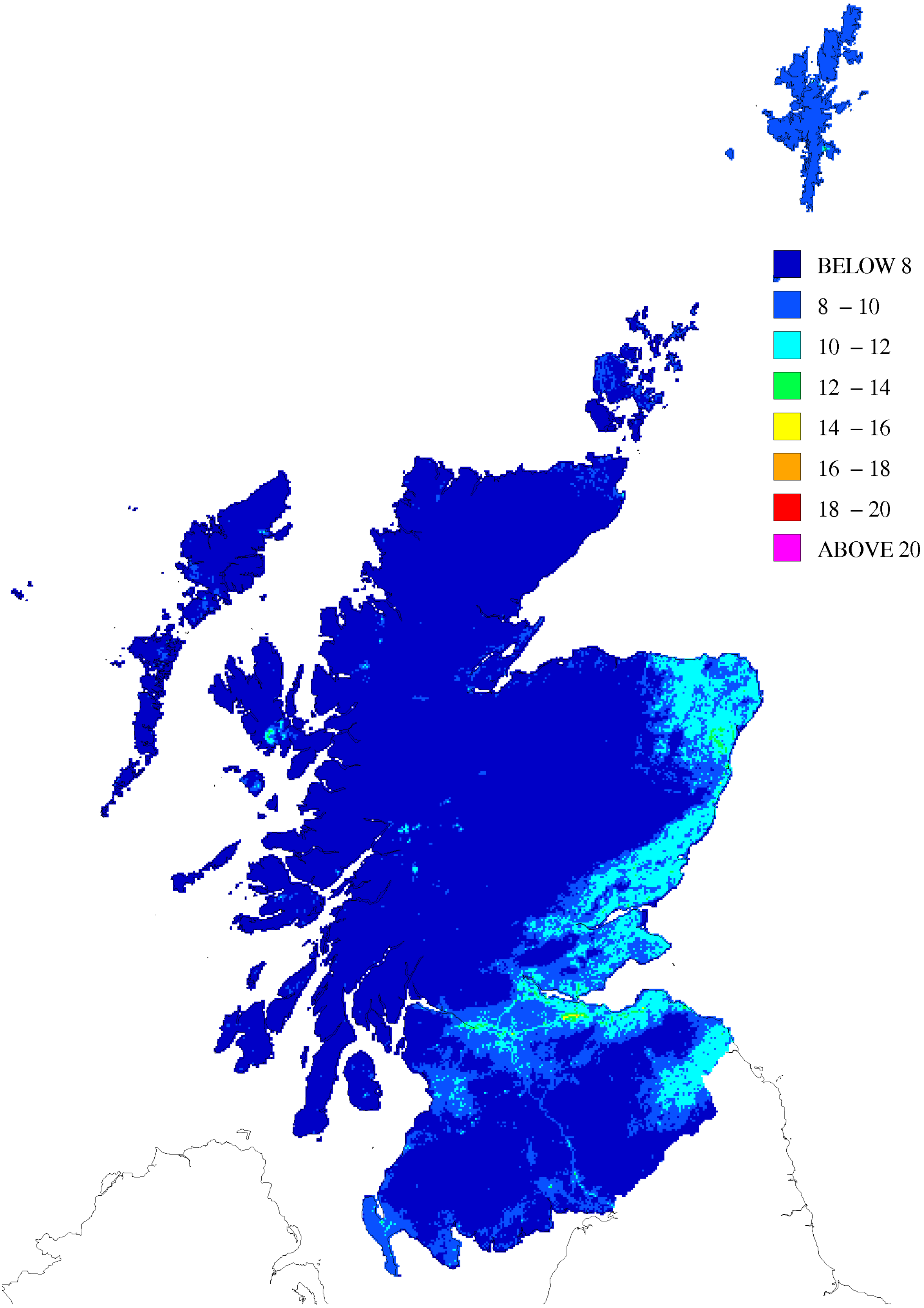


Figure 6.4 Background NO_2 map for 2010, µg m^{-3} (Scotland-specific model).

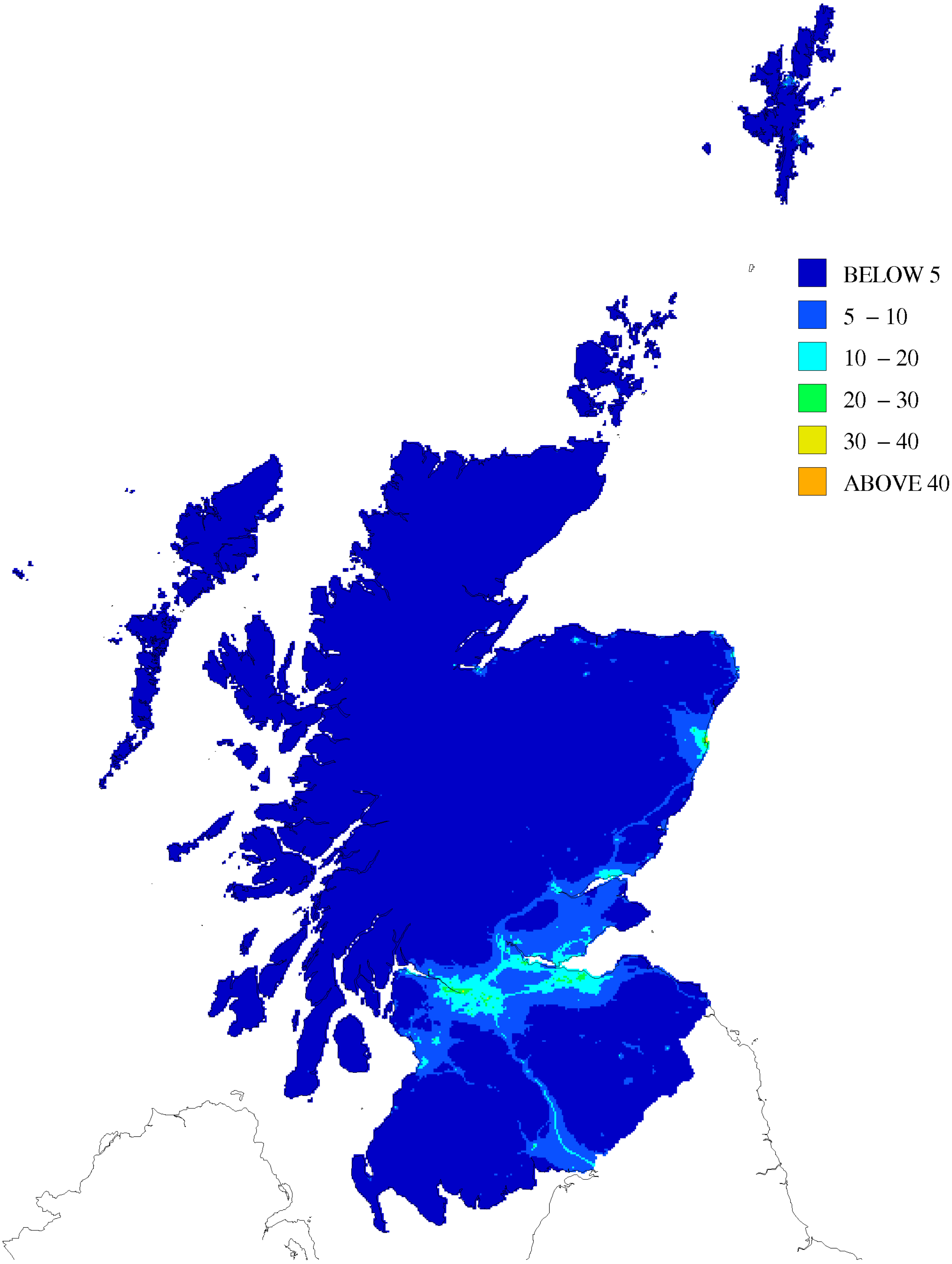


Figure 6.5 Background NO_2 map for 2015, µg m^{-3} (Scotland-specific model).

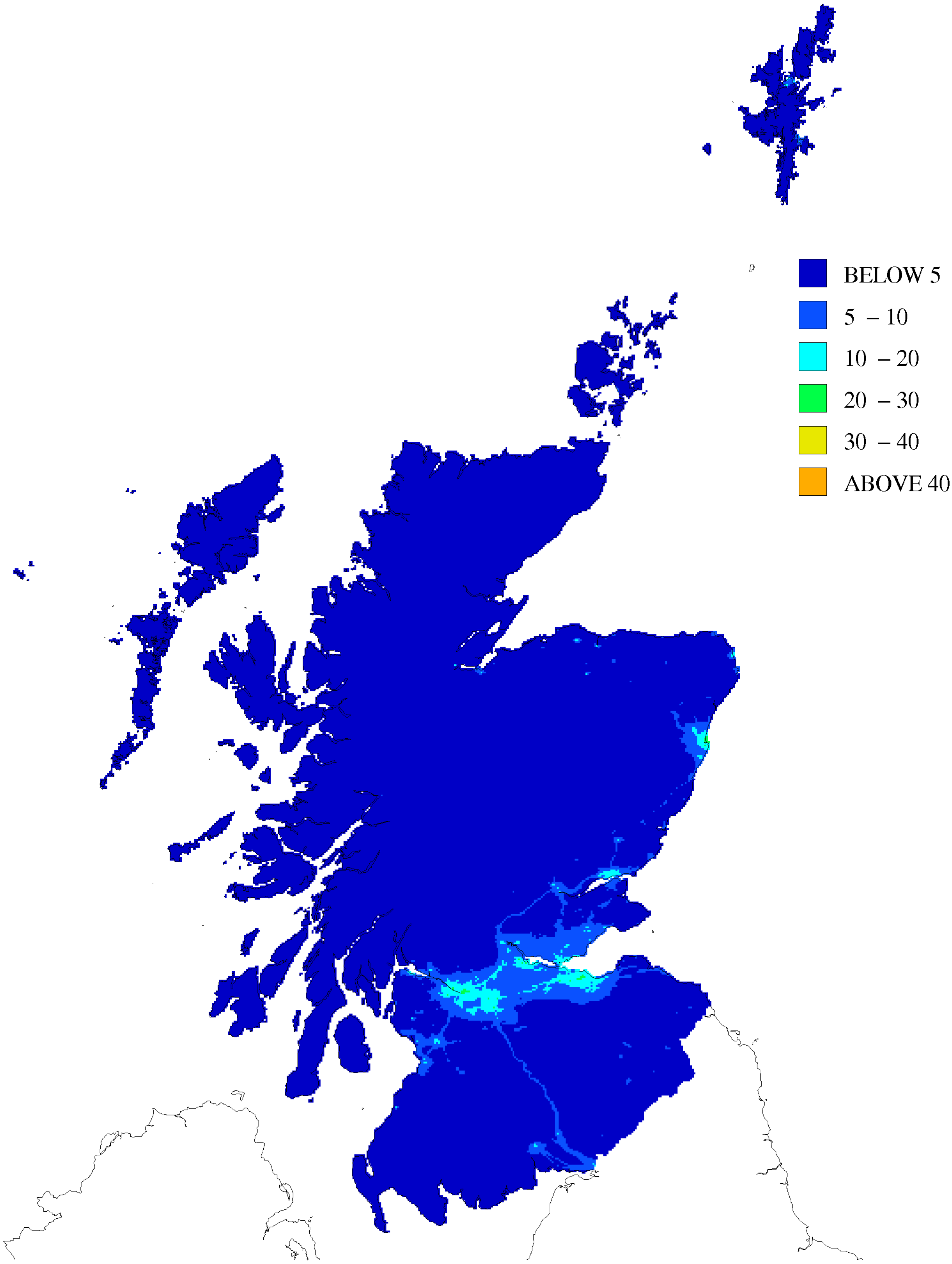
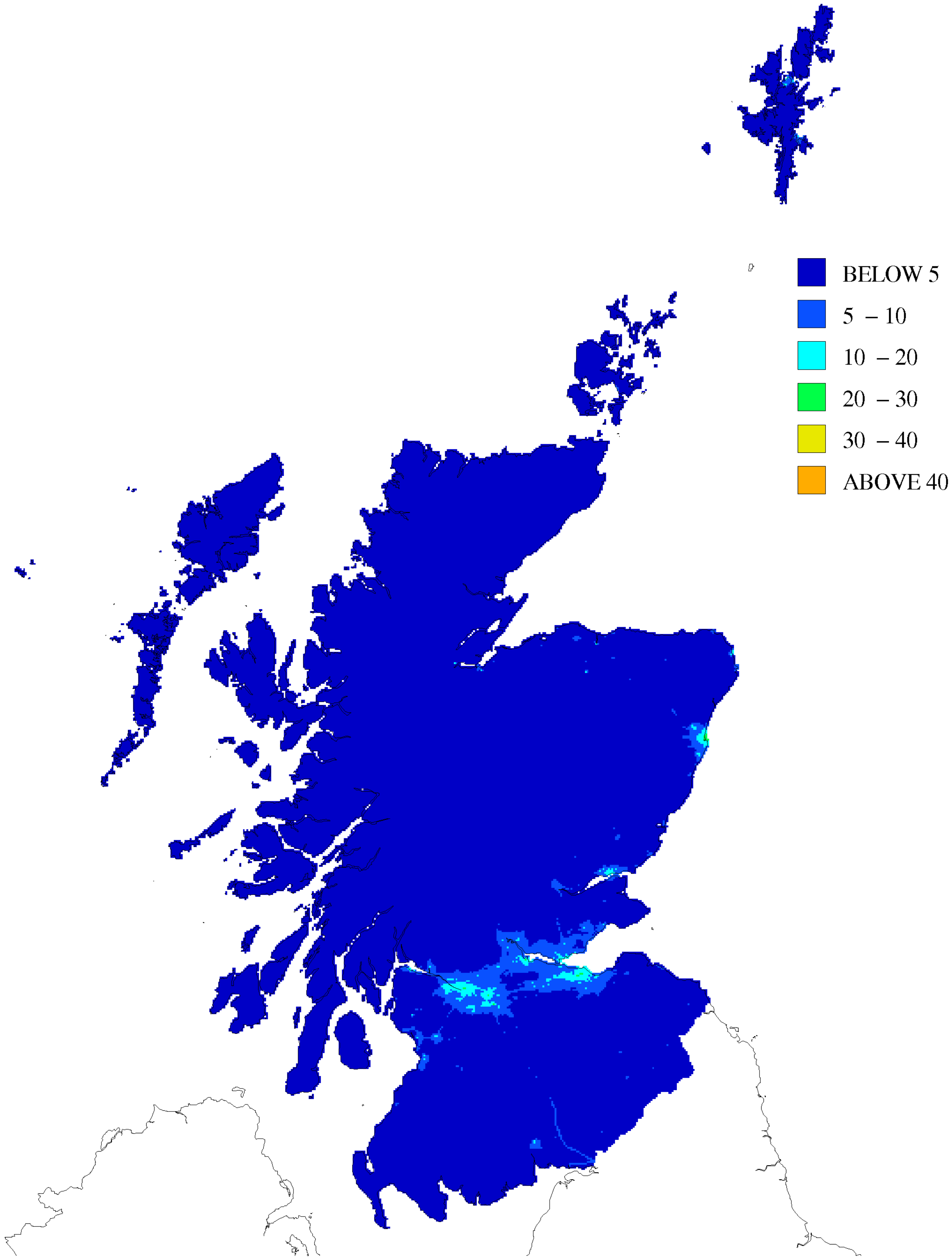


Figure 6.6 Background NO_2 map for 2020, µg m^{-3} (Scotland-specific model).



7 Conclusions and recommendations

There are now sufficient monitoring sites in the SAQD for mapping to be undertaken for PM_{10}, NO_X and NO_2 for Scotland. The UK PCM methodology has been applied to provide Scotland-specific pollutant maps for the Scottish Government for 2008 using measurements from Scottish air quality monitoring sites and Scottish meteorology. Future projection maps for 2010, 2015 and 2020 have also been prepared along with annual projections by source sector for each grid square, and are available in CSV format.

In summary, the results of the 2008 Scotland-specific modelling exercise show:

- The modelled annual mean background PM_{10} concentration from the Scotland-specific model provided good agreement with the annual mean measured background concentration. Similar agreement was seen with the modelled annual mean roadside PM_{10} concentration provided by the Scotland-specific model.
- The modelled annual mean background NO_2 concentration from the Scotland-specific model provided good agreement with the annual mean measured background NO_2 concentration. Less agreement was seen when the modelled annual mean roadside NO_2 concentration from the Scotland-specific model was compared to the annual mean measured roadside NO_2 concentration.
- At background locations, the Scottish maps indicate no exceedences of the Scottish air quality objectives for both PM_{10} and NO_2, except for a possible exceedence of the PM_{10} objective in one grid square in central Scotland.
- At roadside locations, exceedences of both the PM_{10} and NO_2 objectives are likely, with the majority of exceedences occurring in urban areas, particularly in Glasgow.
- Future projection maps show a steady decrease in concentrations of both PM_{10} and NO_2. However, as noted above, the accuracy of the forward projection maps is closely dependent on the future emission projections used to scale the NAEI emissions.

The Scotland-specific maps have been compared with the UK PCM maps for Scotland. Some differences between UK and Scottish pollutant maps are to be expected given the complexity of both measurement and modelling of pollutant concentrations over such a large spatial extent

The differences found can be summarised as follows:

- The Scotland-specific model predicted that annual mean AQO for PM_{10} (18 $\mu g\ m^{-3}$) was exceeded on 101 roads links. This was twice the number of roadside exceedences predicted by the UK model. This was due to the higher PM_{10} roadside calibration coefficient used in the Scottish-model. The PM_{10} roadside calibration coefficient used in the Scottish-model more sensitive to the traffic flow, and the associated PM_{10} roadside increment, on each Scottish road link used when compared to the PM_{10} roadside calibration coefficient used in the 2008 UK model.
- The modelled annual mean background NO_2 concentration from the Scotland-specific model exhibited some noticeable variations relative to the UK model in two urban areas, though throughout the full spatial extent the Scotland-specific model exhibited only small variations relative to the UK model. This variation was believed to be due to the Scotland-specific meteorology used in the Scotland-specific model. These results should be interpreted cautiously.
- A similar number of roadside exceedences of the Scottish annual mean AQO for NO_2 (40 $\mu g\ m^{-3}$) were predicted by the Scotland-specific model when compared to the number of roadside exceedences predicted by the UK model.

The UK model is verified annually against independent monitoring data available from sites throughout the UK, which have not been used in the model calibration. However, for 2008, all available Scottish air quality monitoring measurements were used for model calibration within the mapping process and therefore none were available for independent model verification.

In particular, the number of Scottish background PM_{10} and NO_X monitoring site monitoring sites is limited as Local Authority sites are concentrated at roadside or hot-spot areas to fulfil the requirements of LAQM.

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. Once partitioned, sites would remain in the same group year-on-year to maintain consistency. This can already be achieved for Scottish roadside NO_X model as there is a sufficient number of air quality monitoring sites in this category. For the 2009 mapping exercise independent verification of the roadside NO_X model will be undertaken. It is also anticipated that there will be sufficient sites to allow independent verification of the roadside PM_{10} model. Independent verification of the background NO_X/NO_2 model may be achievable, but with a much more limited number (approximately six) of verification sites, compared to the ten-twelve sites typically required for a robust, independent verification. Due to the limited number (ten) of background PM_{10} air quality monitoring sites, independent verification of the background PM_{10} will not be practicably achievable. In order to provide full independent verification of the model outputs a further ten to twelve background PM_{10} monitoring sites (ideally FDMS or Partisol-based). Likewise a further ten to twelve background NO_X/NO_2 monitoring sites would be required in addition to the number of monitoring sites which were available within the Scottish Air Quality monitoring network during 2008. However, it will be possible to undertake more limited verification with less additional sites.

The Scottish Government have put significant effort into increasing the number of sites in the SAQD in recent years. These efforts have contributed to the production of robust pollutant maps for PM_{10}, NO_X and NO_2 for Scotland for 2008 based on Scottish air quality measurements and Scottish meteorology. It is anticipated that additional sites available in 2009 or in future years will allow for independent verification of mapped concentrations produced.

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 PM_{10} and NO_2. The maps of modelled pollutant concentrations presented here are designed as an indicative, rather than absolute, measure of the annual mean PM_{10} and NO_2 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 monitoring data and scaled emissions projections. The scaling factors applied to the pollutant emissions are based on current understanding of the future variations in emissions and pollutant concentrations. As demonstrated in the case of roadside NO_2 there exists a considerable degree of uncertainty within the scaling factors, which may result in revisions in subsequent years. The mapping work, along with future projections by source sector will be updated next year and will be completed much earlier in the year so that they are available to Scottish Local Authorities in time for the next round of LAQM review and assessment reports.

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 a value for comparison with the *daily mean* objectives. This was calculated by examining the relationship between the measured annual mean concentration and the measured daily mean concentration over a 16 year period (1992-2007). The measured daily mean values were represented as the percentile concentrations that correspond to the appropriate number of permissible daily exceedences specified by each objective. These are summarised in Table A.1. In addition to the Scotland objective equivalent, the UK objective equivalent has also been presented here for comparison.

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

Daily mean air quality objective for PM_{10} and equivalent percentiles for the UK and Scotland				
Model area	Objective value (µg m^{-3})	Metric	Permissible exceedences	Percentile equivalent
Scotland	50	Daily mean	7	98^{th}
UK	50	Daily mean	35	90^{th}

The relationships are based on PM_{10} monitoring data from the whole of the UK as until recently there were insufficient Scottish monitoring sites to derive a robust relationship. The daily percentile concentrations are plotted against the annual mean concentration to determine the relationship and then the equation is used to calculate the annual mean equivalent value. Figure A.1 shows the plot for the Scottish objective and Figure A.2 shows the plot for the UK objective. The relationship on which the Scottish objective value is based on ($R^2 = 0.72$) was lower than that for the UK ($R^2 = 0.90$) but was still acceptable. The equation presented in Figure A.1 produced an annual mean equivalent value of the Scottish daily mean PM_{10} objective of 50 µg m^{-3}. The derived Scottish annual mean equivalent value was 22 µg m^{-3} and the corresponding value used for comparison against the UK daily mean objective was 31.5 µg m^{-3}.

Table A.2 summarises the equivalent daily mean air quality objective for PM_{10} for the UK and Scotland based on air quality monitoring data from 1992-2008 from the whole of the UK. Also included is the equivalent annual mean air quality objective for PM_{10} for Scotland based on Scottish air quality monitoring data exclusively. The relationship is shown in Figure A.3. This is the first year a Scotland-specific equivalence value has been derived based on Scottish air quality monitoring data alone. This has been made possible due to the increase in recent years in the number of Scottish air quality monitoring sites measuring ambient PM_{10} concentrations. Whilst comparison of the modelled Scottish annual mean PM_{10} concentration against these updated values would offer a more timely comparison, reflecting annual variations and progress made in reducing ambient PM_{10} concentrations, it is important to apply the same equivalence criteria consistently, rather than a dynamic criteria, thereby allowing fair comparisons to be made year-on-year. Table A.2 shows that the values are broadly consistent though there is a small degree of annual variation. The application of a Scottish annual mean PM_{10} equivalent value of 22 µg m^{-3} based on UK data measured from 1992-2007 is not unreasonable compared the Scottish annual mean PM_{10} equivalent value of 20 µg m^{-3} based on data measured from 1992-2008 from Scottish air quality monitoring sites exclusively.

Figure A.1 **Relationship between the UK annual mean PM_{10} concentration and the 98th percentile of the UK daily mean PM_{10} concentration.**

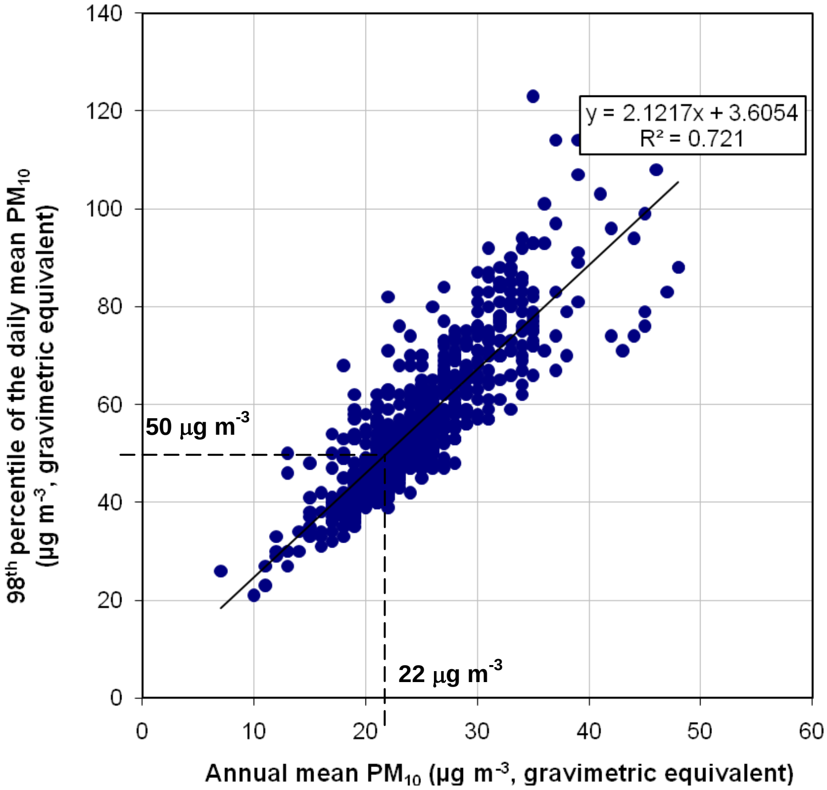


Figure A.2 **Relationship between the UK annual mean PM_{10} concentration and the 90th percentile of the UK daily mean PM_{10} concentration.**

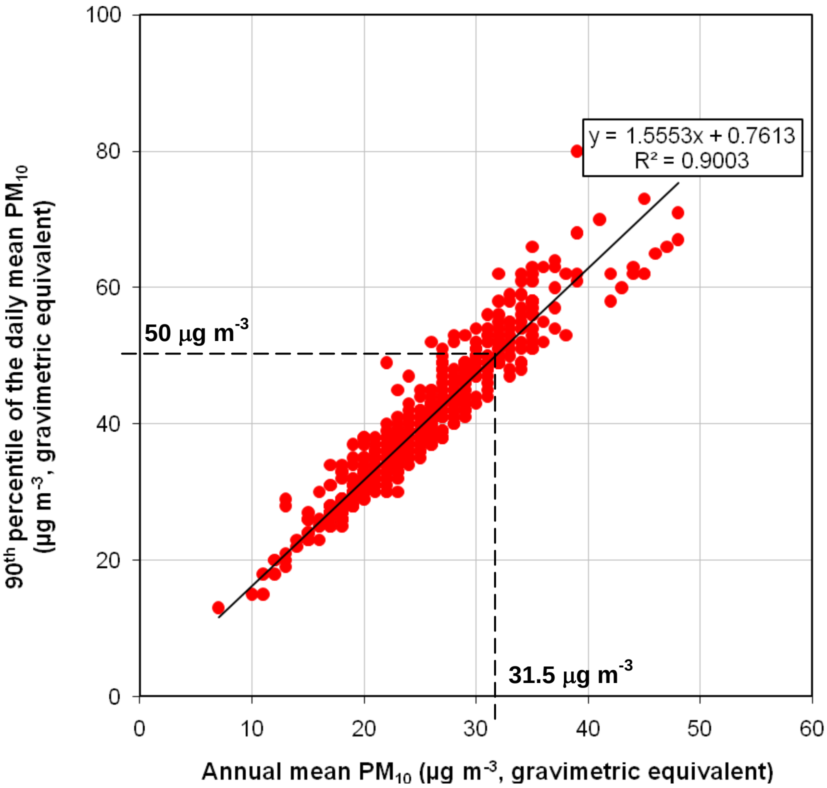
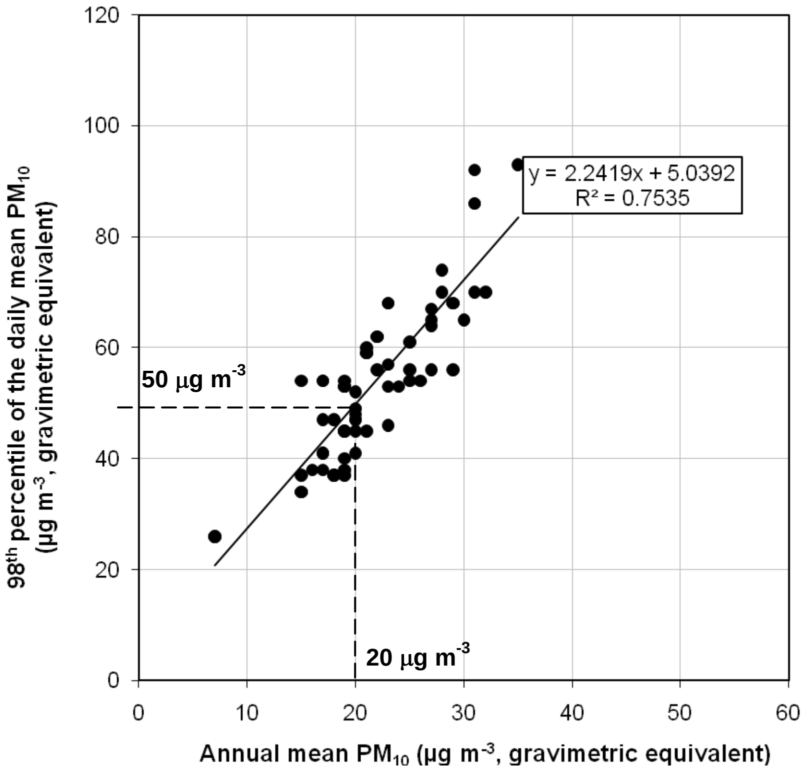


Table A.2 **Summary of the annual mean equivalent air quality objective for PM_{10} for the UK and Scotland based on air quality monitoring data 1992-2008.**

Annual mean equivalent air quality objective for PM_{10} for the UK and Scotland			
Model area	Scotland (Figure A.1)	UK (Figure A.2)	Scotland (Figure A.3)
Source of air quality monitoring	All UK AURN air quality monitoring sites	All UK AURN air quality monitoring sites	Scottish **only** air quality monitoring sites
Data range	1992-2008	1992-2008	1992-2008
Objective value (µg m^{-3})	50	50	50
Metric	Daily mean	Daily mean	Daily mean
Permissible exceedences	7	35	7
Percentile equivalent	98^{th}	90^{th}	98^{th}
2007 equivalent daily mean value (µg m^{-3})	22.0	31.5	N/A
Revised 2008 equivalent daily mean value (µg m^{-3})	21.0	31.9	20.0
R^2	0.72	0.90	0.75

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.**



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