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Assesment of Benzo[a]Pyrene Concentrations in the UK in 2005, 2010, 2015 and 2020

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Executive summary

This is the third national scale assessment of benzo[a]pyrene (BaP) concentrations in the United Kingdom. The first assessment aimed to inform the development of a possible National Air Quality Strategy objective for benzo[a]pyrene (Coleman *et al.*¸ 2001). The United Kingdom Government and the Devolved Administrations have adopted an annual average concentration value of 0.25 ng m^{-3} to be achieved by 2010 as a provisional objective. Revised national scale concentration maps and population exposure statistics were determined in a second assessment (Vincent, 2006) as part of a review of the Air Quality Strategy (Defra, 2006).

The purpose of this third review is to further inform the Air Quality Strategy with regard to the extent of exceedence of the 0.25 ng m^{-3} concentration threshold for BaP. A major revision to the spatial distribution of the emissions from domestic solid fuel combustion resulted in a significant reduction in the number of people estimated to be exposed to the 0.25 ng m^{-3} concentration threshold (from 2.4 million in the 2006 study to 1.0 million in this current work). Projected estimates of BaP emissions based on energy demand forecasts, shows that there will be only a slight decrease in the number of people exposed to BaP concentrations of 0.25 ng m^{-3} to 0.88 million by 2010.

This report is also intended to provide a summary of the modelling method used to assist in the preliminary assessment of BaP as required by Article 5 of the Framework Directive (Council Directive 96/62/EC). The objective of the preliminary assessment for the 4th Daughter Directive (Council Directive 2004/107/EC) is to establish the overall distribution and levels of pollutants, and to identify monitoring necessary to fulfil obligations under the Framework and 4th Daughter Directive. National scale modelling of BaP concentrations forms an important supplementary source of information for the preliminary assessment since there are relatively few sampling sites compared to other pollutants such nitrogen dioxide.

The 4th Daughter Directive provides a target value of 1.0 ng m^{-3} and lower (0.4 ng m^{-3}) and upper assessment (0.6 ng m^{-3}) thresholds that are used to determine the extent of monitoring required in the agglomerations and regional zones. The number of people exposed to these thresholds is presented in this report. The number of people exposed to the target value of 1.0 ng m^{-3} is estimated to remain constant from 2005 to 2020 at about two thousand.

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1 Introduction

This is the third national scale assessment of benzo[a]pyrene (BaP) concentrations in the United Kingdom. The first assessment aimed to inform the development of a possible National Air Quality Strategy objective for benzo[a]pyrene (Coleman *et al.*¸ 2001). At that time the Expert Panel on Air Quality Standards had already recommended 0.25 ng m^{-3} (as an annual average) for BaP as a marker for the health effects of polyaromatic hydrocarbons. Revised national scale concentration maps and population exposure statistics were determined for a second assessment (Vincent, 2006) as part of a review of the Air Quality Strategy (Defra, 2006).

The purpose of this third review is to further inform the Air Quality Strategy with regard to the extent of exceedence of the 0.25 ng m^{-3} concentration threshold for BaP. The report is also intended to provide supporting information to the Preliminary Assessment for BaP (Bush, 2007) required as part of the 4^{th} Daughter Directive.

The United Kingdom Government and the Devolved Administrations have adopted an annual average concentration value of 0.25 ng m^{-3} to be achieved by 2010 as a provisional objective within the Air Quality Strategy.

This report is also intended to provide a summary of the modelling method used to assist in the preliminary assessment of BaP as required by Article 5 of the Framework Directive (Council Directive 96/62/EC). The objective of the preliminary assessment for the 4th Daughter Directive (Council Directive 2004/107/EC) is to establish the overall distribution and levels of pollutants, and to identify monitoring necessary to fulfil obligations under the Framework Directive and 4th Daughter Directive. National scale modelling of BaP concentrations forms an important supplementary source of information for the preliminary assessment since there is relatively few sampling sites compared to other pollutants such nitrogen dioxide.

The 4^{th} Daughter Directive provides a target value of 1.0 ng m^{-3} and lower (0.4 ng m^{-3}) and upper assessment (0.6 ng m^{-3}) thresholds that are used to determine the extent of monitoring required in the agglomerations and regional zones.

The number of monitoring stations measuring BaP concentrations has increased since the last report (Vincent, 2006). There are now twenty-four. This increase is required to support the assessment of BaP concentrations required as part of the Fourth Daughter Directive. Further increases are planned to fulfil requirements of the 4^{th} Daughter Directive as indicated in the Article 5 Assessment.

This report will describe the modelling work undertaken to produce concentration maps in the United Kingdom for 2005, 2010, 2015 and 2020. It is comprised of the following sections:

- Description of BaP emission sources (Section 2)
- Summary of measured BaP concentrations (Section 3)
- Concentration modelling (Section 4)
- Population exposures (Section 5).

2 Emissions

Emissions are modelled using emissions for 2004. These were obtained from the National Atmospheric Emission Inventory (Dore *et al.*, 2006).

2.1 Improvements to BaP inventory

Since the previous report (Vincent, 2006) there has been a major revision to BaP emissions arising from domestic combustion of coal and wood. This involved improving the geographical distribution of where solid fuel was consumed throughout the United Kingdom. The methodology was developed as part of improvements to local and regional estimates of carbon dioxide emissions for the United Kingdom (King *et al.,* 2006a). Information regarding total energy consumption and domestic gas consumption for all major dwelling types allowed the non-gas domestic energy consumptions to be determined much more accurately than before. Figure 2-1 and Figure 2-2 show the areas of the United Kingdom where coal is consumed for domestic space and water heating. The maps are presented as the 'distribution' grid that will sum to unity. Areas within Great Britain that are coloured white indicate smoke control areas.

The major differences between the maps are:

- Smoke control is now much accurately represented – it is assumed that there is no consumption of solid fuel (coal and wood) in large urban areas in Great Britain;
- An increase in solid fuel consumption in north eastern England, north Wales and south Wales;
- A reduction in solid fuel consumption in Northern Ireland. This will result in a decrease in BAP emissions in Northern Ireland. Using the same regional driver for Northern Ireland as used in the 2002 inventory would increase the proportion of BaP emission in Northern Ireland to previous levels.

In addition, a change of the emission factors used for coal and treated wood in the "combustion in manufacturing" sector (SNAP code 3) resulted in the emissions from this source sector being significantly higher (2226 kg) than for previous years (69 kg in the 2002 inventory). Emissions for this sector are disaggregated based on information within the Inter-Departmental Business Register (King *et al.*, 2006b). Emissions are allocated proportionally to the number of employees and type of fuel consumed within each business. However in reality, larger centres of employment may not correlate with fuel use, for example, it may not be possible to distinguish between administration and production.

Uncertainty in the emissions inventory is probably the most uncertain component of the modelling process. Emissions from point sources are better characterised than emissions from area sources. Latest estimates of uncertainty for BaP emissions are estimated in the range –70 % to 200 % (Dore *et al.*, 2006).

Figure 2-1: Previous domestic coal distribution (domcoaluse02)

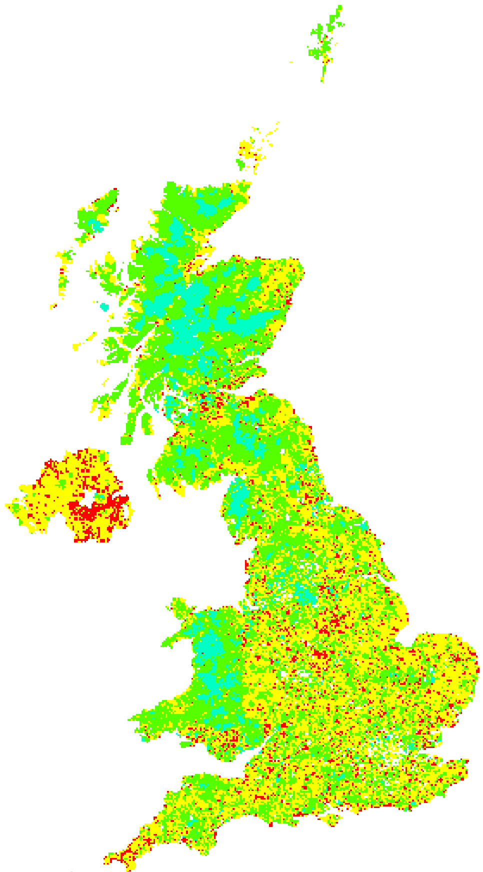
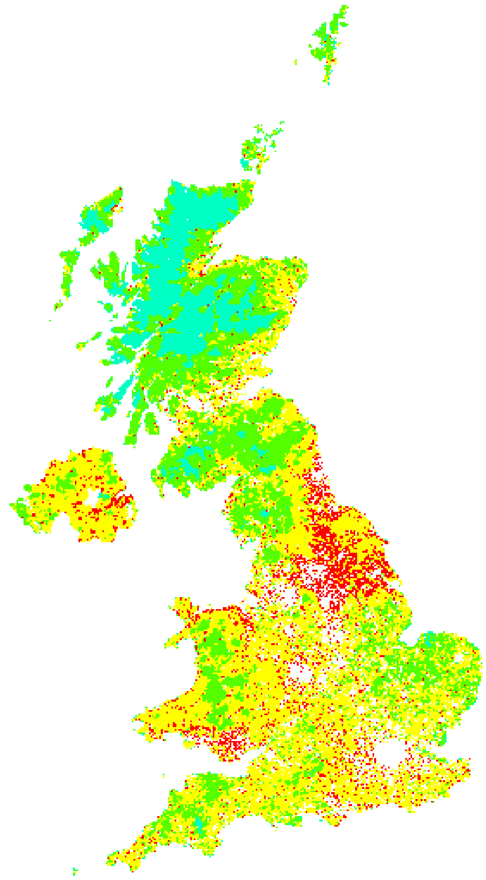
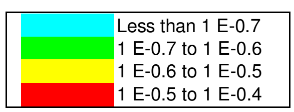


Figure 2-2: Revised domestic coal distribution (domcoaluse04)



Domestic coal distribution (fraction of UK total)



2.2 Emission Projections

Trends in activity within industrial sectors are derived from Department of Trade and Industry energy demand forecasts based on the projections provided by UEP26 (DTI, 2006). Emissions are predicted for 2005, 2010, 2015 and 2020.

The emissions projections for BaP are consistent with the economic assumptions that were used in deriving emission projections for other pollutants such as sulphur dioxide and oxides of nitrogen.

Emissions are available at the highest tier within the Standard Nomenclature for Air Pollutants (SNAP) classification. Table 2.1 presents the estimated BaP emission in 2004 and the projected emission for 2005, 2010, 2015 and 2020 as a function of SNAP sectors.

Table 2.1: Estimated BaP emissions for 2004 and projected emissions from 2005 to 2020.

SNAP Code	Source description	BAP emissions (kg)				
		2004	2005	2010	2015	2020
01	Combustion in energy production	57	67	67	66	64
02	Non-industrial combustion plants	3790[1]	3526[1]	2953[1]	3010[1]	3203[1]
03	Combustion in industry	2266	2266	2601	2532	2566
04	Production processes	1027	1294	1342	1342	1342
06	Solvent and other product use	25	44	51	51	51
07	Road transport	442	341	245	204	196
08	Other mobile sources	59	59	58	57	57
09	Waste treatment and disposal	681	681	681	681	681
11	Other sources and sinks	3185	3185	3185	3185	3185
	Emission total	11533	11463	11182	11128	11346

Notes:

[1]For the purposes of modelling BAP emissions the domestic area emissions were increased by 50 % to improve the model prediction at the urban locations. The BAP emission presented in the tables reflects this increase.

In 2004 emission from the non-industrial combustion plants (domestic space, water heating and in other non-residential buildings) was the largest emission sector contributing to about 25 % of the national total. This consists principally of the estimates of emissions from domestic wood and coal combustion. The next largest emission sector was from SNAP sector 11, Other Sources and Sinks- the predominant component was the emission resulting from natural fires (2880 kg), other components include emissions from accidental fires and bonfires.

2.3 Comparison of National Atmospheric Emission Inventory and Pollution Inventory

Estimates of BaP emission from the National Atmospheric Emission Inventory and the Pollution Inventory vary for some sources. This may be attributed to differences in assumptions used by those who compile the respective inventories. In the main the NAEI point source inventory is probably the more comprehensive representation of the national point source since it has more sources and a wider geographical coverage. Perhaps the most significant variation between estimates, and important for ground level concentration, occurs for emissions from the coking plant. Table 2.2 presents the NAEI and PI emission estimates. The modelled BaP emission from the coking plant was hence taken as the twice the PI estimate. This produced a BaP emission estimate that was approximately intermediate between the NAEI and PI estimates at Port Talbot, Scunthorpe and Teeside. It is recommended that the emissions from the coking plant be investigated further. The total emission from point emission sources used in modelling was 761 kg.

Table 2.2: A comparison of the BaP emissions from the NAEI and Pollution Inventory

Authorisation code	Location	Operator	NAEI (kg)	PI (kg)
BL7108IM[1]	Port Talbot	Corus UK Ltd	279.8	17
BL3838IW[2]	Scunthorpe	Corus UK Ltd	167.4	60.6
BK3441IA	Barnsley	Monckton Coke and Chemical Co Ltd	32.6	32
BK0493IP[3]	Teesside	Corus UK Ltd	214.0	62

Notes:

[1]The coking plant is at Morfa.

[2]The emission estimate for Corus at Scunthorpe is assigned equally to the Dawes Lane and Appleby plants.

[3]Emissions are assumed to arise equally from the coking plant at Redcar and Southbank

3 Measured BaP concentrations

Monitoring of BaP concentrations has taken place at Hazelrigg, London, Middlesbrough and Manchester since the early 1990's. Since then there has been a significant reduction in concentrations at all sites. Figure 3-1 shows that concentrations trends at Hazelrigg and London have generally decreased in line with the total national BaP emissions.

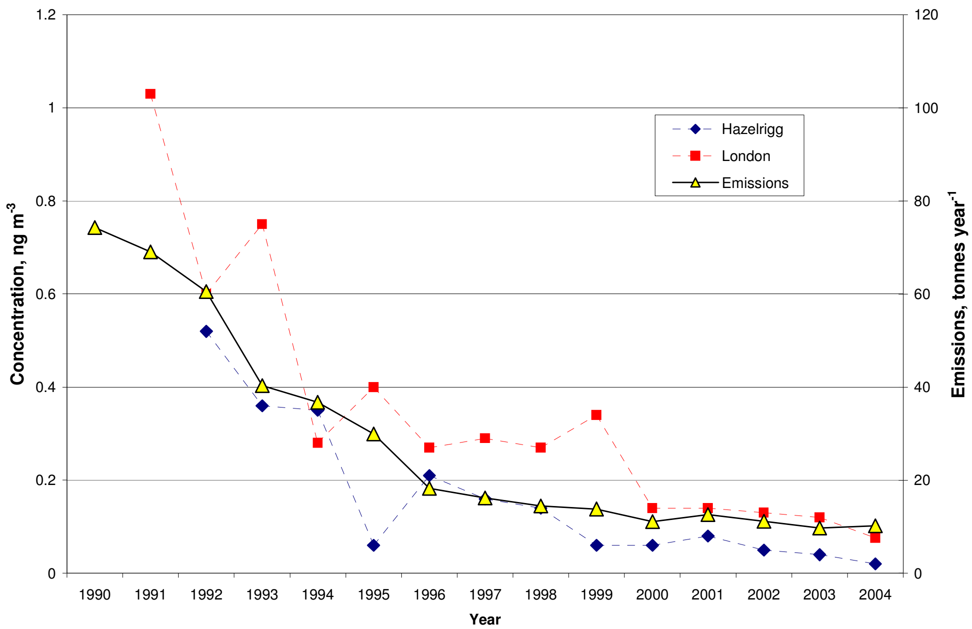


Figure 3-1: BaP concentration measured at the Hazelrigg and London sampling sites compared with the national BaP emission total.

A detailed review of the pollutants measured in the polycyclic aromatic hydrocarbon network from 2000 to 2004 is provided by Conolly (2005). To aid the discussion in this work, current and historic mean concentrations are presented in Table 3.1. The table shows that concentrations tend to be highest closest to integrated steel works and at the Lisburn site where very local domestic emissions contribute to the high concentrations measured.

Table 3.1 Annual mean benzo[a]pyrene concentrations (ng m^{-3}) measured at all sites (former and current) within the UK polycyclic aromatic hydrocarbon monitoring network.

	Site	Site Type	Year														
			1991	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
1	Ashington	Urb-Industrial									0.20	0.17	0.20	0.15†[3]	0.19	0.15	0.16
2	Belfast	Urban											0.37	0.13	<0.08	0.15	0.27
3	Birmingham 1	Urban											0.16	0.13	0.16	-	0.12
4	Birmingham 2	Urban														0.14†[5]	-
5	Bolsover	Ex-Industrial									0.24	0.25	0.28	0.24	0.46	0.22	0.23
6	Brent	Urban												0.18†[2]	0.14	0.095	0.11
7	Bromley	Urban-Traffic											0.21†[3]	0.25	0.21	0.19	0.17
8	Cardiff 1	Urban	2.23†[3]	1.23†[3]	0.35†[2]											-	-
9	Cardiff 2	Urban													0.12†[3]	0.069	0.09
10	Edinburgh	Urban													0.05[2]	0.035	0.046
11	Glasgow	Urban									0.20†[3]	0.12	0.12	0.12	0.06	0.071	0.1
12	Hazelrigg	Rural		0.52†[1]	0.36	0.35	<0.06	0.21	0.16	0.14	0.06	0.06	0.08	0.05	0.04	<0.02	<0.021
13	High Muffles	Rural							0.14	0.09	0.06	0.04	0.05	0.04	0.05	<0.026	<0.025
14	Holyhead	Urb-Industrial									0.11	0.11	0.15	0.18†[3]	0.14	-	-
15	Hove	Urban												0.18†[1]	0.10	0.094	0.099
16	Kinlochleven	Ex-Industrial									6.78	2.28	0.34	0.38	0.21	0.32	0.31
17	Leeds 1	Urban											0.16	0.18	0.21	-	-
18	Leeds 2	Urban														0.13†[5]	0.17
19	Lisburn	Urban									0.74†[3]	0.93	0.96	0.66	0.95	0.62	0.61
20	London 1	Urban	1.03†[3]	0.60	0.75†[3]	0.28	0.40	0.27	0.29	0.19†[1]						-	-
21	London 2a	Urban								0.27†[2]	0.34	<0.14	0.14	0.13	0.12	<0.076	<0.081
22	Manchester	Urban	1.63†[3]	1.53	0.78	0.78	0.40	0.47	0.81	0.47	0.15	0.24	0.34	0.17	0.24	0.11	<0.097
23	Middlesbrough	Urban		0.67†[3]	0.55	0.40	0.53	0.73	0.60	0.30	0.24	0.28	0.37	0.21	0.24	0.14	0.18
24	Newcastle	Urban											0.11	0.12	0.16	0.064	0.1
25	Newport	Ex-Industrial									0.23	0.35	0.36	0.19	0.11	0.10	0.084
26	Port Talbot	Industrial									0.24	0.59	0.40	0.34	0.47	0.29	0.41
27	Scunthorpe	Industrial									0.37	1.18	0.34	1.35	1.26	-	-
28	Scunthorpe 2	Industrial														0.69†[4]	0.95
29	Speke	Urban											0.08†[3]	0.14	0.14	0.10	0.1
30	Stevenage	Urban	0.60†[3]	0.70†[1]												-	0
31	Stoke Ferry	Rural							0.14	0.18	0.11	<0.09	0.09	0.08	0.08	<0.043	<0.06

Notes: The result rounded to two significant figures
†[1] based on one quarter. †[2] based on two quarters. †[3] based on three quarters , †[4] based on Q1 Scunthorpe 1 and Q2, Q3 and Q4 for Scunthorpe 2 due to limited data capture at Scunthorpe 2 due to timing of site move, †[5] based on Q1 and Q2 from site 1 and Q3 and Q4 from Site 2 based on Q1 and Q2
< indicates that at least one of the quarter year samples were below the detection limit.

2005 concentrations obtained from the Air Quality Archive on 16/10/2006
http://www.airquality.co.uk/archive/data/pah/Annual_data_to_end_2005V2.xls

4 Concentration modelling

4.1 Modelling method

Emissions from area and point sources are modelled separately. On a national basis approximately 93% of the emission is allocated to the area source type. Emissions from area sources were modelled using dispersion kernels[1] within the GIS ArcInfo program.

4.1.1 Area source modelling

The NETCEN area source model has been used previously to predict annual sulphur dioxide and BaP concentrations (Abbott and Vincent, 1999 and Coleman *et al.,* 2001). The current NETCEN area source model incorporates results from the dispersion model, ADMS-3 and calculates the annual average contribution from area sources on a 1 km receptor grid covering the country. To take account of contributions at each receptor from sources at distances greater than 15 km in the north-south or east-west directions a rural background concentration of 0.05 ng m^{-3} was added (see Section 4.1.4). Wet and dry deposition were ignored on the basis of that they were shown to be insignificant in sensitivity studies (Abbott and Vincent, 2001). The emissions from each square for both industrial and domestic were assumed to be uniformly distributed throughout the square at an initial height of 10 m: i.e., each 1 km square was represented by an emitting volume 1 km × 1 km × 10 m high. The estimate of 10 m is based on the height of a typical house and assumes that emissions will be entrained in the building wake.

4.1.2 Point source modelling

BaP emissions from “point” sources are either fugitive, in the case of coking plants, or from clearly defined stacks for the other sources. The emission amount is derived from either a direct measurement or by emission factors. For this current BaP modelling assessment, emissions and their characteristics were obtained directly from the 2004 NAEI and/or Pollution Inventory (see Section 2.3). The receptor area for the point sources was 50 km x 50 km at a resolution of 1 km x 1 km.

The release parameters required for the dispersion modelling of metal processing and coking plant are shown in Appendix 1. Dispersion characteristics for all other point sources were obtained from the NAEI points source database. BaP emission was modelled using the dispersion model ADMS 3.3.

4.1.3 Meteorological data

Dispersion from all point sources was modelled using 1 hour sequential meteorological data collected at Waddington in 2005. Area emissions in Great Britain were modelled using the same meteorological data as used for the point source modelling. Area emissions in Northern Ireland were modelled using the ten-year statistical mean data collected at Aldegrove from 1987 to 1996.

4.1.4 Background concentrations

Concentrations from the area and point source were combined within a geographical information system and a background concentration value added. The background component (0.05 ng m^{-3}) should take account of sources outside the modelled receptor area. This concentration was the same as that used in previous assessments (Coleman *et al.* 2001; Vincent, 2006) but seems high when compared to current concentrations measured at the two most rural sites (Hazelrigg and High Muffles; see Table 3.1). This high value was required to account for the deficiency in the modelling method to predict the observed concentration at most locations (see Section 4.3).

[1] The dispersion kernels are derived from the dispersion model ADMS 3.3.

4.2 BaP concentration model validation

Figure 4-1 shows how the measured and modelled annual mean concentrations for BaP compare. Also presented on Figure 4-1, as dashed lines, are the data quality objectives of ± 60 % from the 4th Daughter Directive (Council Directive 2004/107/EC). For most sites the modelled concentration is acceptably predicted when compared with the data quality objectives. However there are two sites for which the modelled concentration falls above the DQO line and two that fall below it. For those sites where the predictions that fall above the line (Hazelrigg and High Muffles) the over prediction is attributed to the relatively large background concentration that was applied. For the sites that fall below the line (Port Talbot and Kinlochleven), the modelling method has missed an important component of the collected concentration.

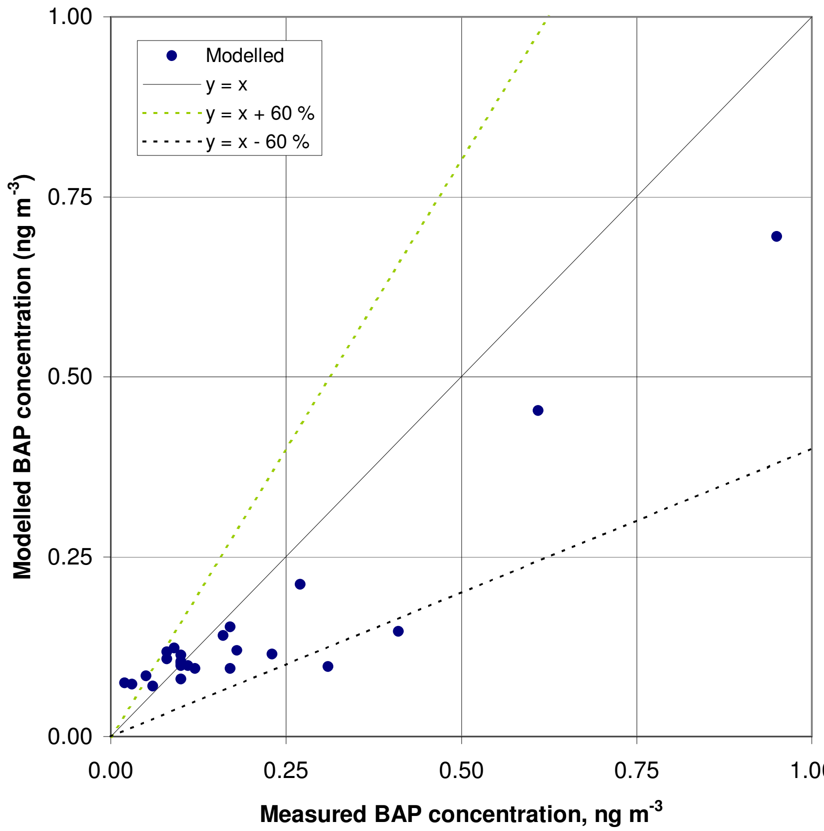


Figure 4-1 Scatter plot showing predicted and modelled BaP concentrations

4.3 Source apportionment

Figure 4-2 shows the same data but with the modelled concentrations split by source sector. The source sectors are combined as follows- domestic emission (SNAP code 2), transport (SNAP code 7) and Other Area (SNAP codes 1, 3, 4, 6, 9 and 11).

The plot shows that at the Lisburn sampling site the domestic emission was the dominant emission source. At Scunthorpe, emissions from the coking plants dominate. At the majority of the other sites the emissions from the Other Area source was the dominant source. This source is dominated by the contribution from the combustion in manufacturing sector. As was discussed above in Section 2.1 this emission is disaggregated based on employment statistics that may result in the emission being concentrated into too small an area. The resulting hot spots occur at the centres of employment. A ceiling of 0.28 ng m^{-3} was applied at these locations due to emissions from this Other Area source sector. The number of squares that had this ceiling set was relatively small (35 squares).

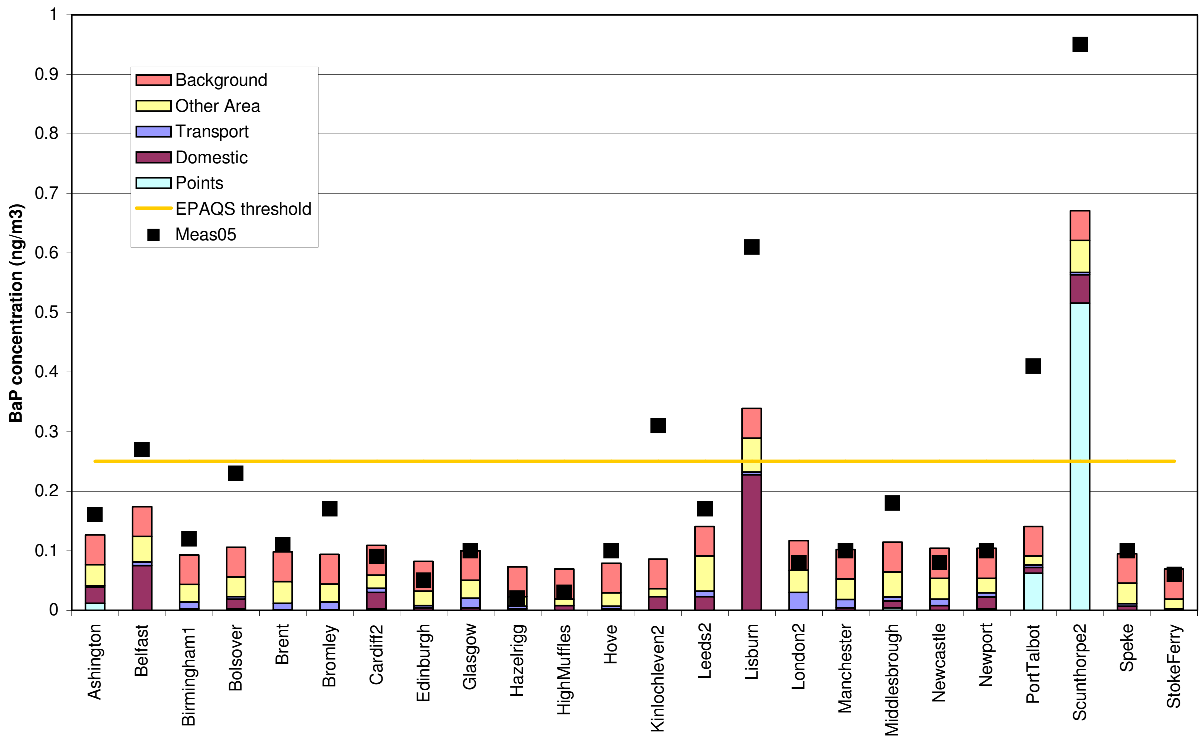


Figure 4-2 BaP source apportionment at monitoring site locations.

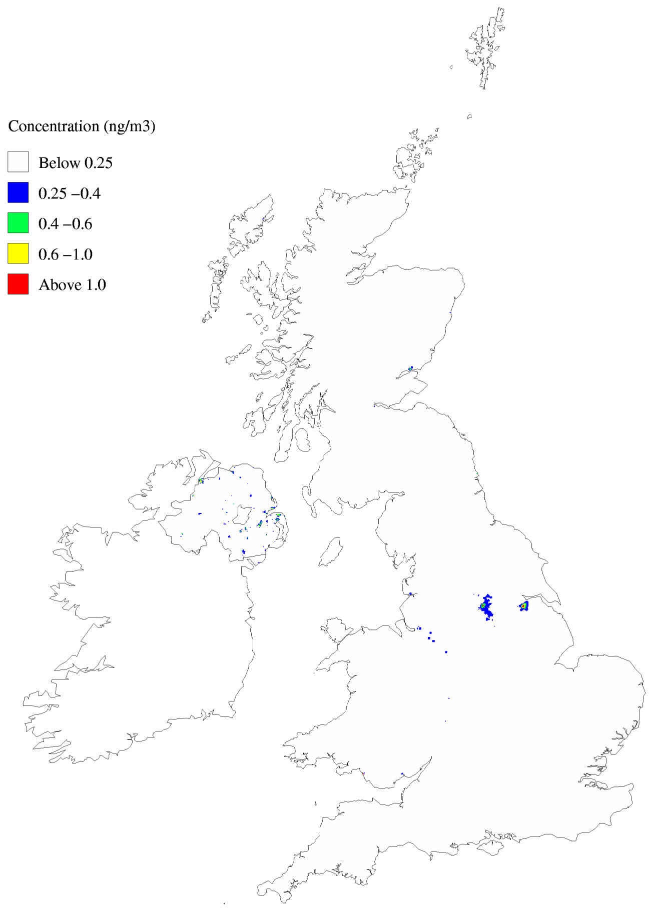
4.4 Concentration maps

The emissions modelled from the area, point and background sources were combined to produce BaP concentration maps for 2005, 2010, 2015 and 2020. The legends for each map provide colours showing the extent of exceedence for the EPAQS standard (blue), lower assessment threshold (green), upper assessment threshold (yellow) and target value (red). Tables 5.1 to 5.4 in the next section tabulate the area of exceedence for each threshold category.

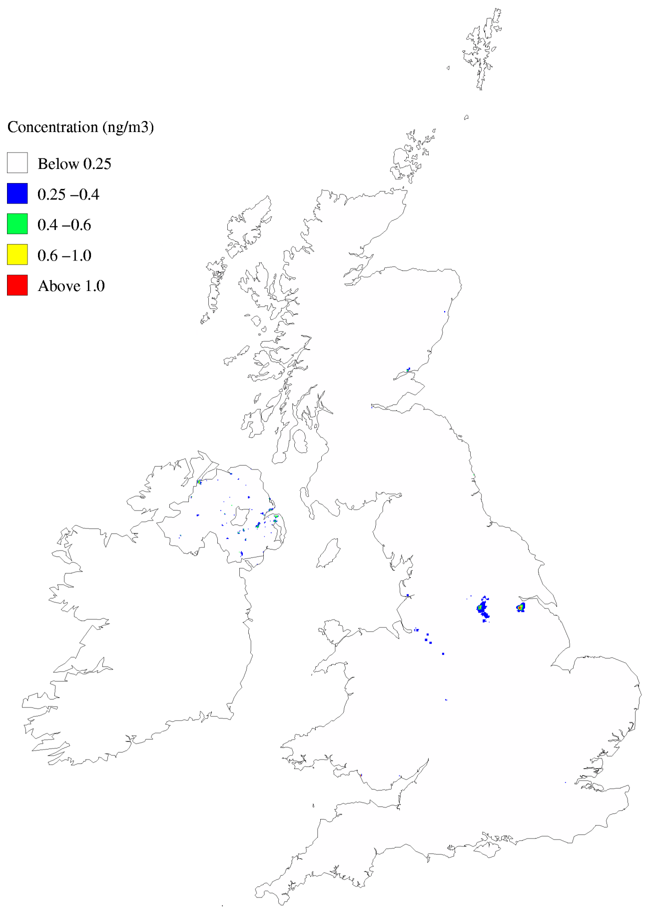
Figure 4-3 show areas of the UK, in 2005 and 2010 estimated to exceed a BaP concentration of 0.25 ng m^{-3}. Figure 4-4 shows maps for 2015 and 2020. Where the 0.25 ng m^{-3} concentration is exceeded, the overwhelming majority of 1 km squares do not exceed the lower assessment threshold of 0.4 ng m^{-3}.

A comparison of measured and modelled BaP concentration at the sampling site locations showed that the measured concentrations at most sites were predicted according to the data quality objectives (see validation plot; Figure 4-1). The modelled concentration will reflect the inherent uncertainty in emission estimates or assumptions used in modelling emissions from both the point and area sources and the assumed background concentration. For the BaP point sources, few emission measurements have been made both nationally and internationally and the relevant activity statistics in some cases are not collected regularly. Further work is required to understand better the magnitude and spatial pattern of emissions from accidental, malicious, demolition and natural fires, waste fires, industrial combustion of coal and wood and domestic solid fuel use particularly in urban and rural communities without access to natural gas.

Figure 4-3 BaP concentrations in 2005 and 2010.

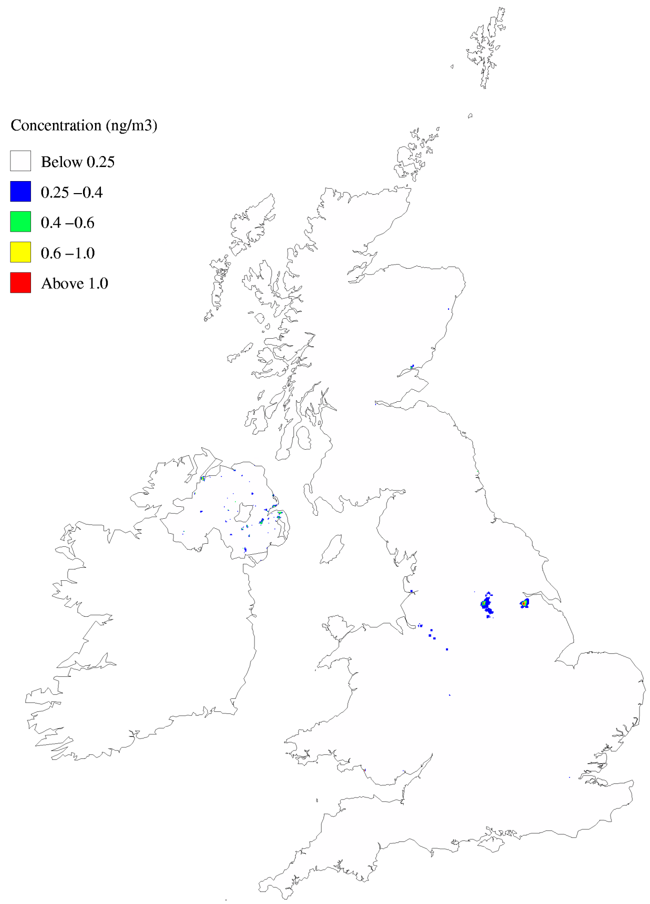


BAP concentrations, 2005.

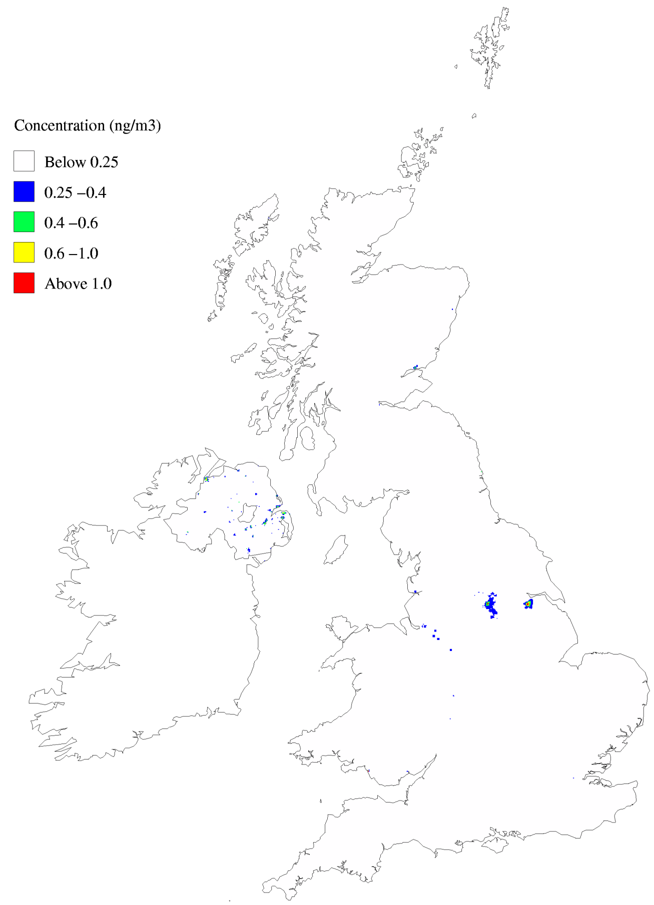


BAP concentrations, 2010.

Figure 4-4: BaP concentrations in 2015 and 2020.



BAP concentrations, 2015.



BAP concentrations, 2020.

5 Population exposures

A summary of the number of people exposed to BaP concentrations at national and regional levels together with exposures within a number of urban areas (agglomerations) is presented in this section. The urban and regional zones were defined previously for the preliminary Article 5 Assessment carried out in 2000 (Bush, 2000).

The agglomerations were defined as contiguous urban areas for which the population exceeded 250,000. The boundaries of the twenty eight agglomeration zones are presented in Figure 5-1. Figure 5-2 presents the boundaries for the 15 regional zones. For England these are based on official Government Office boundaries. For Scotland, Wales or Northern Ireland the boundaries were provided or authorised by the respective devolved administrations. For the purposes of the population exposure calculations the agglomerations zones are excluded from the larger regional zones.

The number of people within the urban agglomerations and regional zones exposed to the of BaP concentration thresholds for 2005, 2010, 2015 and 2020 are provided in Tables 5.1 to 5.4. The thresholds chosen were the air quality objective value, 0.25 ng m^{-3}, the upper and lower assessment thresholds 0.6 ng m^{-3} and 0.4 ng m^{-3} and the target value of 1.0 ng m^{-3}.

The number of people exposed to the 0.25 ng m^{-3} concentration is significantly less than in the previous assessment for which the 2.4 million people were exposed to concentrations above 0.25 ng m^{-3} (Vincent, 2006). This decrease is attributed to the revised domestic distribution, which incorporated additional information on domestic fuel use.

Nationally the number of people exposed to the air quality objective concentration of 0.25 ng m^{-3} is expected to decrease from 1.0 million in 2005 to 0.88 million by 2010 and 2015. There is a slight increase in number of people exposed to concentrations above this threshold by 2020 (0.94 million). This is attributed to the predicted increase in emission from the combustion in manufacturing and production processes by 2020 due to projected increases in economic activity (see Table 2.1).

For the urban agglomeration zones, the air quality objective concentration of 0.25 ng m^{-3} showed significant exposures within the Belfast, The Potteries and Sheffield agglomeration zones in 2005. The exposures in these zones are not predicted to change significantly by 2020.

For the regional zones, in 2005, there were significant numbers of people exposed to 0.25 ng m^{-3} in Yorkshire and Humberside, Northern Ireland, and the North West and Merseyside. By 2010, there were slight decreases in Yorkshire and Humberside and Northern Ireland but with a rise in exposures in the North West and Merseyside. Increases in exposures in the North West and Merseyside are attributed to projected increases in emissions from manufacturing and production processes.

The number of people exposed above the target value of 1 ng m^{-3} was predicted to remain approximately the same in Yorkshire and Humberside (Scunthorpe) and Northern Ireland for all years from 2005 to 2020.

Code	Area
1	Greater London Urban Area
2	West Midlands Urban Area
3	Greater Manchester Urban Area
4	West Yorkshire Urban Area
5	Tyneside
6	Liverpool Urban Area
7	Sheffield Urban Area
8	Nottingham Urban Area
9	Bristol Urban Area
10	Brighton/Worthing/Littlehampton
11	Leicester Urban Area
12	Portsmouth Urban Area
13	Teesside Urban Area
14	The Potteries
15	Bournemouth Urban Area
16	Reading/Wokingham Urban Area
17	Coventry/Bedworth
18	Kingston upon Hull
19	Southampton Urban Area
20	Birkenhead Urban Area
21	Southend Urban Area
22	Blackpool Urban Area
23	Preston Urban Area
24	Glasgow Urban Area
25	Edinburgh Urban Area
26	Cardiff Urban Area
27	Swansea Urban Area
28	Belfast Urban Area

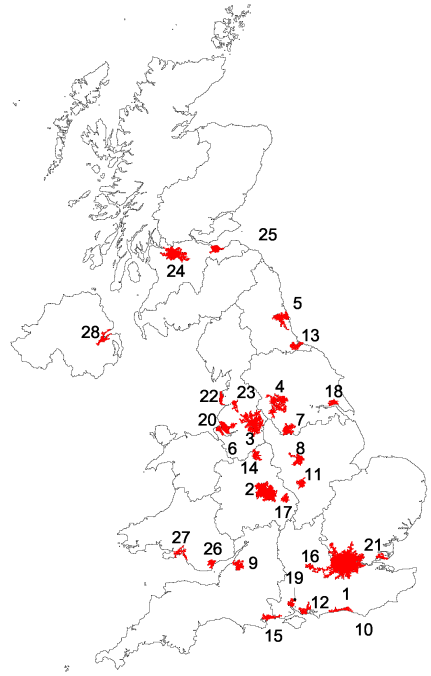
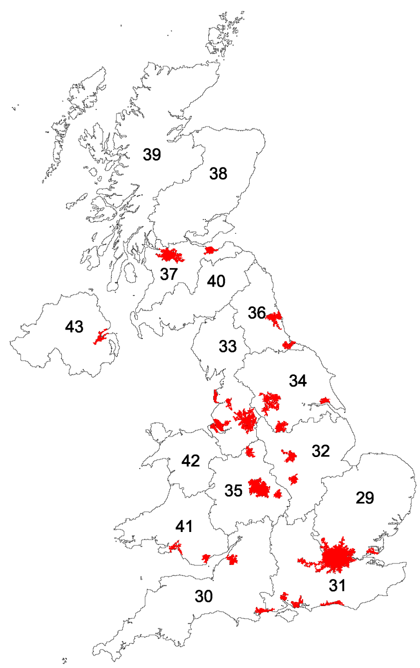


Figure 5-1 Location of agglomeration zones used to predict number of people exposed to various concentration thresholds.



Code	Area
29	Eastern
30	South West
31	South East
32	East Midlands
33	North West & Merseyside
34	Yorkshire & Humberside
35	West Midlands
36	North East
37	Central Scotland
38	North East Scotland
39	Highland
40	Scottish Borders
41	South Wales
42	North Wales
43	Northern Ireland

Figure 5-2 Regional zones used to predict number of people exposed to various concentration thresholds.

Table 5.1 BaP exposures in 2005

Agglomeration/Regional Zones	Code	Concentration threshold								
			0.25 ng m^{-3}		0.40 ng m^{-3}		0.60 ng m^{-3}		1.00 ng m^{-3}	
		Area (km^2)	Area above threshold (km^2)	Population exposed	Area above threshold (km^2)	Population exposed	Area above threshold (km^2)	Population exposed	Area above threshold (km^2)	Population exposed
Greater London Urban Area	1	1628	0	0	0	0	0	0	0	0
West Midlands Urban Area	2	594	2	4662	0	0	0	0	0	0
Greater Manchester Urban Area	3	557	0	0	0	0	0	0	0	0
West Yorkshire Urban Area	4	363	1	2265	0	0	0	0	0	0
Tyneside	5	217	0	0	0	0	0	0	0	0
Liverpool Urban Area	6	184	0	0	0	0	0	0	0	0
Sheffield Urban Area	7	165	11	24337	0	0	0	0	0	0
Nottingham Urban Area	8	169	0	0	0	0	0	0	0	0
Bristol Urban Area	9	142	0	0	0	0	0	0	0	0
Brighton/Worthing/Littlehampton	10	97	0	0	0	0	0	0	0	0
Leicester Urban Area	11	102	0	0	0	0	0	0	0	0
Portsmouth Urban Area	12	91	0	0	0	0	0	0	0	0
Teesside Urban Area	13	111	0	0	0	0	0	0	0	0
The Potteries	14	91	9	32203	0	0	0	0	0	0
Bournemouth Urban Area	15	113	0	0	0	0	0	0	0	0
Reading/Wokingham Urban Area	16	97	0	0	0	0	0	0	0	0
Coventry/Bedworth	17	76	0	0	0	0	0	0	0	0
Kingston upon Hull	18	80	0	0	0	0	0	0	0	0
Southampton Urban Area	19	77	0	0	0	0	0	0	0	0
Birkenhead Urban Area	20	88	0	0	0	0	0	0	0	0
Southend Urban Area	21	64	0	0	0	0	0	0	0	0
Blackpool Urban Area	22	63	0	0	0	0	0	0	0	0
Preston Urban Area	23	58	0	0	0	0	0	0	0	0
Glasgow Urban Area	24	366	0	0	0	0	0	0	0	0
Edinburgh Urban Area	25	117	0	0	0	0	0	0	0	0
Cardiff Urban Area	26	72	0	0	0	0	0	0	0	0
Swansea Urban Area	27	84	2	1833	1	24	1	24	0	0
Belfast Urban Area	28	193	72	198525	31	90910	8	23684	0	0
Eastern	29	19113	0	0	0	0	0	0	0	0
South West	30	23506	0	0	0	0	0	0	0	0
South East	31	18645	0	0	0	0	0	0	0	0
East Midlands	32	15491	0	0	0	0	0	0	0	0
North West & Merseyside	33	13722	50	55711	0	0	0	0	0	0
Yorkshire & Humberside	34	14787	405	354761	67	35216	25	8809	10	2210
West Midlands	35	12192	1	5693	0	0	0	0	0	0
North East	36	8282	1	522	1	522	0	0	0	0
Central Scotland	37	9314	2	7955	0	0	0	0	0	0
North East Scotland	38	18595								
Highland	39	38404	2	3110	0	0	0	0	0	0
Scottish Borders	40	11145	0	0	0	0	0	0	0	0
South Wales	41	12221	7	7107	1	19	1	19	1	19
North Wales	42	8368	0	0	0	0	0	0	0	0
Northern Ireland	43	13941	186	309965	46	117020	9	30289	0	0
Total		243785	751	1008647	147	243711	44	62825	11	2229

Table 5.2 BaP exposures in 2010

Agglomeration/Regional Zones	Code	Area (km^2)	0.25 ng m^{-3} Area above threshold (km^2)	0.25 ng m^{-3} Population exposed	0.40 ng m^{-3} Area above threshold (km^2)	0.40 ng m^{-3} Population exposed	0.60 ng m^{-3} Area above threshold (km^2)	0.60 ng m^{-3} Population exposed	1.00 ng m^{-3} Area above threshold (km^2)	1.00 ng m^{-3} Population exposed
Greater London Urban Area	1	1628	0	0	0	0	0	0	0	0
West Midlands Urban Area	2	594	4	8829	0	0	0	0	0	0
Greater Manchester Urban Area	3	557	0	0	0	0	0	0	0	0
West Yorkshire Urban Area	4	363	3	9904	0	0	0	0	0	0
Tyneside	5	217	0	0	0	0	0	0	0	0
Liverpool Urban Area	6	184	0	0	0	0	0	0	0	0
Sheffield Urban Area	7	165	11	24337	0	0	0	0	0	0
Nottingham Urban Area	8	169	0	0	0	0	0	0	0	0
Bristol Urban Area	9	142	0	0	0	0	0	0	0	0
Brighton/Worthing/Littlehampton	10	97	0	0	0	0	0	0	0	0
Leicester Urban Area	11	102	0	0	0	0	0	0	0	0
Portsmouth Urban Area	12	91	0	0	0	0	0	0	0	0
Teesside Urban Area	13	111	0	0	0	0	0	0	0	0
The Potteries	14	91	9	32203	0	0	0	0	0	0
Bournemouth Urban Area	15	113	0	0	0	0	0	0	0	0
Reading/Wokingham Urban Area	16	97	0	0	0	0	0	0	0	0
Coventry/Bedworth	17	76	0	0	0	0	0	0	0	0
Kingston upon Hull	18	80	0	0	0	0	0	0	0	0
Southampton Urban Area	19	77	0	0	0	0	0	0	0	0
Birkenhead Urban Area	20	88	0	0	0	0	0	0	0	0
Southend Urban Area	21	64	0	0	0	0	0	0	0	0
Blackpool Urban Area	22	63	0	0	0	0	0	0	0	0
Preston Urban Area	23	58	0	0	0	0	0	0	0	0
Glasgow Urban Area	24	366	0	0	0	0	0	0	0	0
Edinburgh Urban Area	25	117	0	0	0	0	0	0	0	0
Cardiff Urban Area	26	72	0	0	0	0	0	0	0	0
Swansea Urban Area	27	84	2	1833	1	24	1	24	0	0
Belfast Urban Area	28	193	64	180089	26	74255	1	4719	0	0
Eastern	29	19113	0	0	0	0	0	0	0	0
South West	30	23506	0	0	0	0	0	0	0	0
South East	31	18645	1	356	0	0	0	0	0	0
East Midlands	32	15491	0	0	0	0	0	0	0	0
North West & Merseyside	33	13722	51	58193	0	0	0	0	0	0
Yorkshire & Humberside	34	14787	329	284451	63	34029	24	8793	9	2060
West Midlands	35	12192	0	0	0	0	0	0	0	0
North East	36	8282	1	522	1	522	0	0	0	0
Central Scotland	37	9314	2	7955	0	0	0	0	0	0
North East Scotland	38	18595								
Highland	39	38404	0	0	0	0	0	0	0	0
Scottish Borders	40	11145	0	0	0	0	0	0	0	0
South Wales	41	12221	4	2899	1	19	1	19	1	19
North Wales	42	8368	0	0	0	0	0	0	0	0
Northern Ireland	43	13941	152	270956	34	93337	6	20763	0	0
Total		243785	633	882527	126	202186	33	34319	10	2079

Table 5.3 BaP exposures in 2015

Agglomeration/Regional Zones	Code	Area (km^2)	Concentration threshold 0.25 ng m^{-3} Area above threshold (km^2)	0.25 ng m^{-3} Population exposed	0.40 ng m^{-3} Area above threshold (km^2)	0.40 ng m^{-3} Population exposed	0.60 ng m^{-3} Area above threshold (km^2)	0.60 ng m^{-3} Population exposed	1.00 ng m^{-3} Area above threshold (km^2)	1.00 ng m^{-3} Population exposed
Greater London Urban Area	1	1628	0	0	0	0	0	0	0	0
West Midlands Urban Area	2	594	3	7634	0	0	0	0	0	0
Greater Manchester Urban Area	3	557	0	0	0	0	0	0	0	0
West Yorkshire Urban Area	4	363	1	2265	0	0	0	0	0	0
Tyneside	5	217	0	0	0	0	0	0	0	0
Liverpool Urban Area	6	184	0	0	0	0	0	0	0	0
Sheffield Urban Area	7	165	11	24337	0	0	0	0	0	0
Nottingham Urban Area	8	169	0	0	0	0	0	0	0	0
Bristol Urban Area	9	142	0	0	0	0	0	0	0	0
Brighton/Worthing/Littlehampton	10	97	0	0	0	0	0	0	0	0
Leicester Urban Area	11	102	0	0	0	0	0	0	0	0
Portsmouth Urban Area	12	91	0	0	0	0	0	0	0	0
Teesside Urban Area	13	111	0	0	0	0	0	0	0	0
The Potteries	14	91	9	32203	0	0	0	0	0	0
Bournemouth Urban Area	15	113	0	0	0	0	0	0	0	0
Reading/Wokingham Urban Area	16	97	0	0	0	0	0	0	0	0
Coventry/Bedworth	17	76	0	0	0	0	0	0	0	0
Kingston upon Hull	18	80	0	0	0	0	0	0	0	0
Southampton Urban Area	19	77	0	0	0	0	0	0	0	0
Birkenhead Urban Area	20	88	0	0	0	0	0	0	0	0
Southend Urban Area	21	64	0	0	0	0	0	0	0	0
Blackpool Urban Area	22	63	0	0	0	0	0	0	0	0
Preston Urban Area	23	58	0	0	0	0	0	0	0	0
Glasgow Urban Area	24	366	0	0	0	0	0	0	0	0
Edinburgh Urban Area	25	117	0	0	0	0	0	0	0	0
Cardiff Urban Area	26	72	0	0	0	0	0	0	0	0
Swansea Urban Area	27	84	2	1833	1	24	1	24	0	0
Belfast Urban Area	28	193	65	181487	27	78315	1	4719	0	0
Eastern	29	19113	0	0	0	0	0	0	0	0
South West	30	23506	0	0	0	0	0	0	0	0
South East	31	18645	1	356	0	0	0	0	0	0
East Midlands	32	15491	0	0	0	0	0	0	0	0
North West & Merseyside	33	13722	51	58193	0	0	0	0	0	0
Yorkshire & Humberside	34	14787	335	288250	63	34029	25	8809	9	2060
West Midlands	35	12192	0	0	0	0	0	0	0	0
North East	36	8282	1	522	1	522	0	0	0	0
Central Scotland	37	9314	2	7955	0	0	0	0	0	0
North East Scotland	38	18595								
Highland	39	38404	0	0	0	0	0	0	0	0
Scottish Borders	40	11145	0	0	0	0	0	0	0	0
South Wales	41	12221	4	2899	1	19	1	19	1	19
North Wales	42	8368	0	0	0	0	0	0	0	0
Northern Ireland	43	13941	152	271766	35	97518	6	20763	0	0
Total		243785	637	879701	128	210426	34	34334	10	2079

Table 5.4 BaP exposures in 2020

Agglomeration/Regional Zones	Code	Area (km^2)	Concentration threshold 0.25 ng m^{-3} Area above threshold (km^2)	0.25 ng m^{-3} Population exposed	0.40 ng m^{-3} Area above threshold (km^2)	0.40 ng m^{-3} Population exposed	0.60 ng m^{-3} Area above threshold (km^2)	0.60 ng m^{-3} Population exposed	1.00 ng m^{-3} Area above threshold (km^2)	1.00 ng m^{-3} Population exposed
Greater London Urban Area	1	1628	0	0	0	0	0	0	0	0
West Midlands Urban Area	2	594	3	7634	0	0	0	0	0	0
Greater Manchester Urban Area	3	557	0	0	0	0	0	0	0	0
West Yorkshire Urban Area	4	363	3	9904	0	0	0	0	0	0
Tyneside	5	217	0	0	0	0	0	0	0	0
Liverpool Urban Area	6	184	0	0	0	0	0	0	0	0
Sheffield Urban Area	7	165	11	24337	0	0	0	0	0	0
Nottingham Urban Area	8	169	0	0	0	0	0	0	0	0
Bristol Urban Area	9	142	0	0	0	0	0	0	0	0
Brighton/Worthing/Littlehampton	10	97	0	0	0	0	0	0	0	0
Leicester Urban Area	11	102	0	0	0	0	0	0	0	0
Portsmouth Urban Area	12	91	0	0	0	0	0	0	0	0
Teesside Urban Area	13	111	0	0	0	0	0	0	0	0
The Potteries	14	91	9	32203	0	0	0	0	0	0
Bournemouth Urban Area	15	113	0	0	0	0	0	0	0	0
Reading/Wokingham Urban Area	16	97	0	0	0	0	0	0	0	0
Coventry/Bedworth	17	76	0	0	0	0	0	0	0	0
Kingston upon Hull	18	80	0	0	0	0	0	0	0	0
Southampton Urban Area	19	77	0	0	0	0	0	0	0	0
Birkenhead Urban Area	20	88	0	0	0	0	0	0	0	0
Southend Urban Area	21	64	0	0	0	0	0	0	0	0
Blackpool Urban Area	22	63	0	0	0	0	0	0	0	0
Preston Urban Area	23	58	0	0	0	0	0	0	0	0
Glasgow Urban Area	24	366	0	0	0	0	0	0	0	0
Edinburgh Urban Area	25	117	0	0	0	0	0	0	0	0
Cardiff Urban Area	26	72	0	0	0	0	0	0	0	0
Swansea Urban Area	27	84	2	1833	1	24	1	24	0	0
Belfast Urban Area	28	193	67	187485	30	88380	4	12261	0	0
Eastern	29	19113	0	0	0	0	0	0	0	0
South West	30	23506	0	0	0	0	0	0	0	0
South East	31	18645	1	356	0	0	0	0	0	0
East Midlands	32	15491	0	0	0	0	0	0	0	0
North West & Merseyside	33	13722	51	58193	0	0	0	0	0	0
Yorkshire & Humberside	34	14787	368	321280	64	34045	25	8809	10	2210
West Midlands	35	12192	1	5693	0	0	0	0	0	0
North East	36	8282	1	522	1	522	0	0	0	0
Central Scotland	37	9314	2	7955	0	0	0	0	0	0
North East Scotland	38	18595								
Highland	39	38404	1	1307	0	0	0	0	0	0
Scottish Borders	40	11145	0	0	0	0	0	0	0	0
South Wales	41	12221	5	3768	1	19	1	19	1	19
North Wales	42	8368	0	0	0	0	0	0	0	0
Northern Ireland	43	13941	166	284637	39	102476	8	27524	0	0
Total		243785	691	947106	136	225466	39	48637	11	2229

6 Conclusions

BaP concentrations were measured at twenty four locations in 2005. Of these, only five- Port Talbot, Scunthorpe, Kinlochleven, Belfast and Lisburn measured an annual mean concentration greater than 0.25 ng m^{-3}. The first two sites are in industrial areas with emissions from industrial processes making significant contributions to the collected concentrations. The later two sites are in urban areas where localised solid fuel combustion is the likely source of the elevated concentrations. At Kinlochleven, which historically had the highest measured concentration, exceedence of the 0.25 ng m^{-3} concentration threshold stills occurs despite the aluminium smelter being closed for several years. Possible reasons for the relatively high concentration could be resuspension of previously deposited material or burning of solid fuel for space heating within the local population settlement.

A revision to the spatial distribution of domestic solid fuel combustion, since the last BaP modelling study, has resulted in a reduction in the amount of BaP emission estimated to arise in urban areas. This, in turn, resulted in a significant reduction in the number of people estimated to be exposed to the 0.25 ng m^{-3} concentration threshold (from 2.4 million in the previous study to 1.0 million in this current work).

Using projected estimates of BaP emissions, the number of people exposed to the BaP concentrations of 0.25 ng m^{-3} is estimated to decrease from 1.0 million in 2005 to 0.88 million by 2010. However, for the 4th Daughter Directive, the number of people exposed to the target value of 1.0 ng m^{-3} is estimated to remain relatively constant from 2005 to 2020 at about two thousand within an area of about 10 square kilometres.

7 Acknowledgements

This work was funded by the UK Department for Environment, Food and Rural Affairs, Welsh Assembly Government, the Scottish Executive and the Department of the Environment for Northern Ireland.

8 References

Abbott J A and Vincent K J (1999). Annual Average Sulphur Dioxide Concentration Maps Derived by Dispersion Modelling. A report produced for DETR. AEA Technology. Report Number AEAT-4629. http://www.aeat.co.uk/netcen/airqual/reports/kvann1/so2ann.html

Abbott J A and Vincent K J (2001). Further dispersion modelling studies of benzo[a]pyrene. AEA Technology Report Number AEAT/ENV/R/2206.

Bush, T. (2000) Article 5 Assessment of nitrogen dioxide, PM_{10}, sulphur dioxide and lead in the UK. A report produced for DETR, the Scottish Executive, the National Assembly for Wales and the DoE in Northern Ireland. AEAT/R/ENV/0165

Bush, T (2007). Preliminary Assessment of PAH and heavy metal levels in the UK, A report produced for Department for Environment, Food and Rural Affairs, the Scottish Executive, Welsh Assembly Government and the Department of the Environment in Northern Ireland. AEA/ENV/R/2243

Coleman, P., Bush, T., Conolly C., Irons, S., Murrells, T., Vincent, K.J., Watterson, J. (2001). Assessment of benzo[*a*]pyrene atmospheric concentrations in the UK to support the establishment of a national PAH objective. AEAT/ENV/R/0620 http://www.aeat.co.uk/netcen/airqual/reports/naqs2001/aeat-env-r-0620.pdf

Conolly, C., (2005). Polycyclic Aromatic Hydrocarbon Monitoring and Analysis Network; 2004 Annual Report. A report produced for Department for Environment, Food and Rural Affairs, The Scottish Executive, The National Assembly for Wales and the Northern Ireland Department of the Environment, Report Number AEAT/ENV/R/1894 Issue 1.

Council Directive 96/62 EC, of 27 September 1996 on ambient air quality assessment and management, (The Framework Directive). From the Official Journal of the European Communities, 21.11.1996, En Series, L296/55.

Council Directive 2004/107/EC, of 15 December 2004. Relating to arsenic, cadmium, mercury, nickel and polycyclic aromatic hydrocarbons in ambient air, (The 4th Daughter Directive). From the Official Journal of the European Communities, 26.1.2005, En Series, L23/3.

Defra (2006) The Air Quality Strategy for England, Scotland, Wales and Northern Ireland. A consultation document on options for further improvements in air quality. A report produced by Department for Environment, Food and Rural Affairs, The Scottish Executive, The National Assembly for Wales and the Northern Ireland Department of the Environment. Report available from http://www.defra.gov.uk/corporate/consult/airqualstrat-review/consultation-vol1.pdf

Dore, C. J., Watterson, J. D., Goodwin, J. W. L. *et al.,* (2006). UK Emissions of Air Pollutants 1970 to 2004. National Atmospheric Emissions Inventory, AEA Technology, National Environmental Technology Centre. Report Number AEAT/ENV/R/2359

DTI (2006). UK Energy and CO_2 Emissions Projections, July 2006. Part 1. Updated Projections to 2020. http://www.dti.gov.uk/files/file31861.pdf

King, K., Passant, N., Li, Y., Goodwin, J. and Jackson, J. (2006a). Local and Regional CO_2 emission estimates for 2004 for the UK. Report to Defra, Report Number ED48209015/AEA/ENV/R/2297.

King, K., Sturman, J., and Passant, N. (2006b) NAEI UK Mapping methodology. A report of the National Atmospheric Emission Inventory. Report available from http://www.airquality.co.uk/archive/reports/cat07/0606231101_NAEIMappingMethodReport2003Final.pdf

Vincent, K. Assessment of benzo[a]pyrene concentrations in the United Kingdom in the period 2003-2020. A 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 Number AEAT/ENV/R/1861

Appendix 1
Plant Emission Characteristics

Table A.1 Emission characteristics for each of the individual industrial plant

Point source	Authorisation Number	Line or point source	Emission Height (m)	Stack diameter (m)	Velocity ($m\ s^{-1}$)	Volume ($m^3\ s^{-1}$)	Temperature
Appleby coke works	AF7193	Line+	5	-	-	149	115
Dawes Lane coke works	AF7193	Line+	5	-	-	149	115
Monckton coke works	BK3441	Line+	5	-	-	49	115
Morfa coke works	AF8645	Line+	5	-	-	101	115
Redcar coke plant	AF8548	Line+	5	-	-	156	115
South Bank coke plant	AF8530	Line+	5	-	-	78	115
Anglesey	BL1100	Point[1]	121	9.807	-	594.4	82
Ashington (1)	BL6861	Point[2]	32	1.96	16.1	-	109
Ashington (2)	BL6861	Point	46	2.125	13	-	131
Ashington (3)	BL6861	Point	36	2.15	5.9	-	32
Koppers, Scunthorpe	AU8296	Point	10.05	0.0508	0.05	-	150
Port Talbot sinter plant	AR0357	Point[3]	133	6.5	-	450	120
Scunthorpe sinter plant	AR0080	Point[4]	107	6.4	-	388	168
Teeside sinter plant	AR0241	Point[5]	105	6.2	-	257	134

Notes
+ Each of the steel plant at Middlesbrough and Scunthorpe have two sets of coking ovens with the emission split as follows: 50:50 between Southbank and Redcar works; 50:50 between Dawes Lane and Appleby works. As the coking plant at Grange has been closed since the last modelling exercise 100 % of the emission is attributed to Morfa. Each of the coke works was treated as a line source with dimensions taken from the relevant Ordnance Survey 1:25000 map (typically 80-225 m long and 15 m wide). Coke ovens require gas heating in order to overcome heat losses and maintain the pyrolysis reaction. The heat loss and volume flow rates were estimated by scaling the estimates for obtained previously for the Cwm coke works in South Wales. At this plant the total fuel consumption was estimated to be approximately 10500 m3 h-1. Assuming a heating value of the gas used of 4.7 MJ m-3 (Perry,1973), it is estimated that 13.6 MW is required to maintain the reaction. For this assessment, it has been assumed that all this heat is lost through the walls and roof of the coke ovens. This assumption ignores the heat lost through battery stacks and heat lost or gained from endothermic or exothermic reactions: however, it is considered that the assumption is sufficient to provide order of magnitude estimates of the heat loss. The heat loss from the ovens is then assumed to be contained within the discharging plume from the ovens, providing buoyancy so that there is some limited plume rise. A nominal initial plume temperature of 115°C, specific heat 1012 J K^-1 kg^-1 and density 1.25 kg m^{-3} was used to estimate the initial volume flow rate of the plume.

1. Information provided by Colin Hardman (EA), personal communication to Keith Vincent, 6 th July 1999. The stack at Holyhead exhausts gases from two separate processes; the carbon bake and the pot rooms. The stack consists of two concentric stacks, one inside the other with the exhaust from the pot room being the outer stack and carbon bake the inner one. BaP emissions are only expected to occur from the inner stack. As both processes are running at the same time it is necessary to take account of the influence of the buoyancy of the larger stack will have on the buoyancy of the emission from the inner stack. To do this the buoyancy and momentum of the both plumes were combined and an effective stack diameter and combined stack temperature was determined.
2. Dispersion characteristics for Ashington were provided by Alcan Smelting and Power UK. Personal Communication from John Clarkson to Peter Coleman, 9th May and 15th May 1999.
3. The emission characteristic from the Port Talbot works was supplied by Mark Broom of the Environment Agency (21/10/04). All the BaP emission from the steel manufacture is assumed to come from the sinter plant.
4 The emission characteristics for the sinter plant were provided by Rob McClellen of the Environment Agency (20/10/04).
5. The emission characteristics for the sinter plant were provided by Paul Siddle of the Environment Agency (27/10/04).

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