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Polycyclic Aromatic Hydrocarbons in Northern Ireland

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Executive Summary

The aim of this report was to review PAH emissions and measured concentrations in Northern Ireland, and then to model concentrations under different emissions scenarios. A cost benefit analysis was then performed for reducing Commercial, Institutional and Residential (CIR) emissions to a level where ambient benzo[a]pyrene (BaP) concentrations across Northern Ireland would be below the EU Target Value. It should be noted that the model and the assumptions set out for this research project are not the same as those adopted for the UK's national compliance assessment and there may be discrepancies in the results due to the different approaches used.

European Union (EU) legislation and the UK Air Quality Strategy require the measurement of Polycyclic Aromatic Hydrocarbons (PAHs) (organic compounds containing only carbon and hydrogen which are composed of two or more fused benzene rings) in ambient air. This is performed by the UK PAH Air Quality Network, currently operated by the National Physical Laboratory on behalf of Defra and the Devolved Administrations at 31 monitoring sites across the country. Whilst many PAHs are measured, benzo[a]pyrene (BaP) is the compound targeted by legislation because of its very high contribution to the overall toxicity load of PAHs in ambient air (a combination of its toxicity – as defined by the International Agency for Research in Cancer as a human carcinogen – and its concentration in ambient air). The EU target value for BaP in the PM_{10} fraction (particles with an aerodynamic diameter of 10 μm or less) of ambient air is 1 $ng.m^{-3}$ (with upper and lower assessment thresholds of 0.6 and 0.4 $ng.m^{-3}$, respectively) and the UK air quality objective for BaP is 0.25 $ng.m^{-3}$.

The current levels and trends of PAH emissions and concentrations in the UK and in Northern Ireland have been assessed and compared. In general, both emissions and measured concentrations of PAHs in ambient air have fallen over the last 20 years, most dramatically between 1990 and 1995 and then steadily thereafter. The BaP monitoring sites in Northern Ireland have regularly recorded concentrations in excess of the EU target value. A comparison of UK concentrations showed that the values measured at urban sites in Northern Ireland are comparable with industrial locations in Great Britain (steel, coke and aluminium extraction plants), and substantially in excess of levels recorded at much larger urban centres in Great Britain (London, Birmingham, Cardiff and Middlesbrough).

Whilst the use of natural gas has increased across Northern Ireland in recent years, there is still substantial solid fuel burning, mostly for domestic heating purposes and this is thought to be the origin of the elevated BaP levels. This has been confirmed by several pieces of additional data such as black carbon aethalometry, and principal component analysis of PAH concentrations in the UK. Emissions of PAHs from residential and commercial combustion per head of population are currently about four times higher in Northern Ireland than in Great Britain, whilst those from traffic are similar to those in Great Britain, and emissions from industry in Northern Ireland are substantially less.

Trends in ambient BaP concentrations in Northern Ireland in recent years have been difficult to discern, in part because of the lack of long term data series from monitoring. The data set from the Lisburn Dunmurry site dates back to 1999 and shows a steady decrease from this time until 2006, followed by a slight increase in concentrations between 2006 and 2009. This

increase may correlate with the slight increase in residential emissions observed across the UK during this period, possibly as a result of colder than average winters.

Dispersion modelling carried out for 2008 scenarios based on inputs of 2008 BaP emissions from the National Atmospheric Emissions Inventory (NAEI) and meteorological data from Met Office stations across Northern Ireland predicted BAP concentrations exceeding the EU Target Value in 47 1km x 1km squares. Sensitivity analysis of scaling factors shows that NAEI data for Northern Ireland may underestimate PAH emissions when compared to emission values for the rest of the UK. One possible reason for inaccuracy in NAEI data in Northern Ireland may be the burning of non-smokeless fuel in smoke control areas.

Analysis of BaP emissions shows that the dominant source is from Commercial, Institutional and Residential (CIR) emissions. For grid squares in exceedance of the EU Target Value, on average 93% of BaP emissions came from CIR emissions. Modelling the effect of reducing the CIR emissions in the exceedance squares showed that CIR emissions had to be reduced to 50% of their 2008 levels to ensure no exceedances of the EU Target Value.

The amount of BaP emitted varies dramatically dependent on the fuel burnt and how it is burnt. Increased use of smokeless fuel including gas and oil in both Northern Ireland Housing Executive (NIHE) and private homes could drastically reduce the BaP concentrations across Northern Ireland. Conversion schemes for privately owned/let homes ought to be encouraged, perhaps through the provision of financial support to aid the rate of conversion across Northern Ireland. Further conversions from solid fuel will help to reduce BaP emissions and concentrations as well as PM_{10} concentrations. Addressing fuel poverty may also help to reduce PAH emissions.

Increasing the availability of natural gas through extending current pipelines and encouraging uptake in areas already served should also be considered as a means to increase conversions from solid fuel.

Increased energy efficiency will also help to reduce PAH emissions and therefore the continuation, promotion and improvement of current schemes should be encouraged.

The predominant health effect linked to PAH exposure is lung cancer. A cost benefit analysis performed based on the method used by the EU CAFE Programme showed that the number of people liable to contract lung cancer due to being exposed to BaP concentrations above the EU target value of $1ng.m^{-3}$ in the 47 1km x 1km exceedance squares was 3 per lifetime. Turning these 3 lung cancers into economic damage equates to an annual cost of £55,617.

The annualised cost of reducing all CIR emissions by the Northern Ireland -wide replacement of solid fuel central heating systems and the enforcement of smokeless zones comes to a value of £3,184,383 per annum, thus, far outweighing the economic damage due to the BaP exposure, and suggesting that such an expensive retrofitting programme would not be justified.

However, effective enforcement of existing smoke control areas may deliver reduced BaP concentrations in these areas and deliver some improved health outcomes more quickly and cheaply than implementing nationwide smoke control. The costs for this could involve the employment of one to two full time enforcement officers to cover the whole of Northern Ireland (not at an individual council level) at an annual cost of around £40,000 to 80,000. This is in line with the annualised cost of the economic damage caused by the BaP exposure (£56,000).

If the modelled concentration hotspots for BaP are to be confirmed and subsequently monitored over time to determine the effect of emission reduction measures, then measurements of ambient concentrations will need to be made at more locations than are currently monitored by the UK PAH Network. To reduce the cost of existing manual filter based methods, screening of areas of likely high concentration could be performed by using the upcoming spare Magee Aethalometers from the UK Black Carbon Network reorganisation.

Contents

1.0 Introduction

European Union (EU) legislation[1,2] and the UK Air Quality Strategy[3] require the measurement of a number of harmful pollutants in UK ambient air to determine population exposure, assess compliance with limit and target values, and evaluate the effectiveness of abatement strategies. In this context the measurement of Polycyclic Aromatic Hydrocarbons (PAHs) (organic compounds containing only carbon and hydrogen which are composed of two or more fused benzene rings) in ambient air is performed by the UK PAH Air Quality Monitoring Network[4]. The Network is currently operated by the National Physical Laboratory on behalf of Defra and the Devolved Administrations at 31 monitoring sites across the country. Whilst many PAHs are measured, benzo[a]pyrene (BaP) is the compound targeted by legislation because of its very high contribution to the overall toxicity load of PAHs in ambient air (a combination of its toxicity – as defined by the International Agency for Research in Cancer as a human carcinogen – and its concentration in ambient air[5]). The EU target value for BaP in the PM_{10} fraction (particles with an aerodynamic diameter of 10 μm or less) of ambient air is 1 $ng.m^{-3}$ with upper and lower assessment thresholds of 0.6 and 0.4 $ng.m^{-3}$ respectively, and the UK air quality objective for BaP is 0.25 $ng.m^{-3}$. The 4th Daughter Directive gives requirements for mandatory measurements, indicative measurements and modelling depending on the level of the BaP concentrations.

Since 2008 the EU Reference Method for measuring PAHs has been used and has measured BaP concentrations in Northern Ireland in excess of the EU Target Value of 1 $ng.m^{-3}$ and the upper assessment threshold of 0.6 $ng.m^{-3}$. Table 1-1 shows the annual average BaP concentrations measured from 2008 onwards. The sampling method used by the UK PAH Network is described in Section 1.1.

Site	**2008, $ng.m^{-3}$**	**2009, $ng.m^{-3}$**	**2010, $ng.m^{-3}$**
Ballymena	2.46	1.55	2.01
Derry	1.34	1.05	1.94
Lisburn Dunmurry	0.75	0.91	1.44

Table 1-1 2008 – 2010 BaP concentrations in Northern Ireland

The current levels and trends of PAH emissions and concentrations in the UK and in Northern Ireland were assessed and compared. In general, both emissions and measured concentrations of PAHs in ambient air have fallen over the last 20 years, most dramatically between 1990 and 1995 and then steadily thereafter. A comparison of UK concentrations showed that the values measured at urban sites in Northern Ireland are comparable with industrial locations in Great Britain (Scunthorpe steel works 2.4 $ng.m^{-3}$, Royston coke works 1.0 $ng.m^{-3}$), and substantially in excess of levels recorded at much larger urban centres in Great Britain (Birmingham 0.26 $ng.m^{-3}$).

Modelling was undertaken to assess the spatial distribution of BaP concentrations across Northern Ireland in 2008 and to also assess the impact of different emission reduction scenarios.

The results from the modelling were then used to assess the possible health impacts of BaP concentrations above the EU Target Value and a cost benefit analysis performed comparing these health effects with the cost of reducing concentrations across Northern Ireland to below the EU Target Value.

Since the modelling work was performed the emission levels of PAHs in the UK have been published for 2009 by the National Atmospheric Emission Inventory (NAEI). Comparing the 2008 and 2009 emissions shows that there has been a small decrease in the predicted BaP emissions in 2009 compared to 2008. This decrease is not significant and therefore would not have a significant effect on the modelled concentrations, especially as the report highlights additional uncertainties associated with the Commercial, Institutional and Residential emissions in the NAEI for Northern Ireland.

1.1 PAH Network Sampling Method

Until 2007, Andersen GPS-1 samplers were used at all sites in the PAHs Network. However, concerns over the ability of these instruments to representatively sample the PM_{10} fraction of ambient air resulted in them being replaced by Digitel DHA-80 samplers. Degradation of PAHs through exposure to ambient levels of ozone or other species in ambient air once sampled onto the filter is also thought to be a larger issue with the Andersen sampler than the Digitel sampler, as samples are typically taken for longer periods of time.

Andersen GPS-1 samples are, however, still used in the Toxic Organic Micro-Pollutants (TOMPs) Network and were also utilised for a comparison of the BaP concentrations obtained from Andersen and Digitel samplers which concluded at the end of 2010. Parallel running tests of the Digitel and Andersen samplers[4] have shown that measurements made with the previously used Andersen sampler under-reported the BaP concentration by a factor of between 1.5 and 2.

1.2 Status of Modelling Results

It should be noted that the model and the assumptions set out for this research project are not the same as those adopted for the UK’s national compliance assessment and therefore there may be discrepancies in the results due to the different approaches used.

2.0 Trends in Emissions and Measured Concentration of Polycyclic Aromatic Hydrocarbons in Northern Ireland

Solid fuel use in Northern Ireland is a major source of Polycyclic Aromatic Hydrocarbons (PAH) emissions and therefore of ambient concentrations locally. Concentrations in excess of the EU target value for BaP have been regularly measured in Northern Ireland[6]. Domestic solid fuel is widespread as a result of many households not being connected to a natural gas supply. This problem is exacerbated by predictions that the Northern Irish population will grow more rapidly in areas where solid fuel use is prevalent than in areas with access to natural gas. The Northern Ireland Statistics and Research Agency (NISRA) projects that overall population growth between 2008 and 2023, by region, will be[7]:

- Greater Belfast: 4.9 %
- East of Northern Ireland: 13 %
- North of Northern Ireland: 5.2 %
- West and South of Northern Ireland: 17 %

Generally the use of natural gas is most widespread in the Greater Belfast area. However, as Figure 2-1 shows, whilst the gas pipeline now extends to most of the major settlements within Northern Ireland, the take up of natural gas is currently much lower outside Greater Belfast.

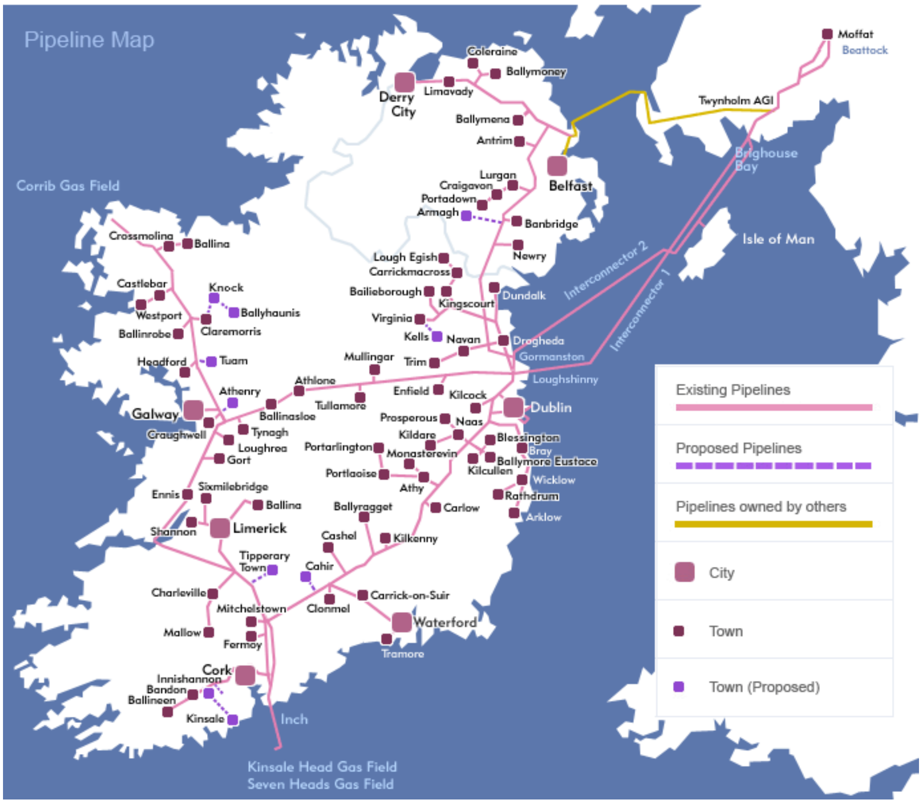


Figure 2-1 **Gas pipeline map in the island of Ireland courtesy of the Bord Gais website[8]. Armagh is due for connection in 2010.**

Whilst the natural gas supply in Northern Ireland [9] is reaching an increasing number of dwellings (for example between 1997 and 2001 the number of natural gas consumers increased ten-fold to 35,000 and has continued to increase since), and some solid fuel use has been replaced by oil burning appliances, emissions of PAHs from domestic appliances remains a significant issue. Indeed, imports of solid fuel into Northern Ireland (according to data from NISRA[10]), whilst decreasing steadily since 1992 to about 2002, have remained fairly stable in recent years (see Table 2-1).

Year	1992	1993	1994	1995	1996	1997	1998	1999	2000
Solid fuel imports / kTonnes	1,154	1,082	1,211	932	919	997	732	795	617

Year	2001	2002	2003	2004	2005	2006	2007	2008	2009
Solid fuel imports / kTonnes	589	442	360	480	421	468	483	462	358

Table 2-1 **Solid fuel imports into Northern Ireland from 1992 to 2009**

There is also substantial and widespread oil burning in Northern Ireland for domestic heating and this has been used in the past as an alternative to solid fuels. Whilst producing substantially less BaP per mass of fuel consumed than solid fuels, it is not as clean as natural gas – which produces almost no BaP. The relative emissions factors of a variety of BaP producing fuels are shown in Table 2-2. Actual emissions depend strongly on the type of appliance used, as discussed in Section 5.2.

Fuel	BaP production / kg per Mt of fuel consumed
Coal	**1550**
Wood	**1300**
Solid smokeless fuel	**330**
Coke	**30**
Anthracite	**30**
Fuel Oil	**4.7**
Gas Oil	**4.7**
Natural Gas	**~0**

Table 2-2 2008 UK Emissions factors for benzo[a]pyrene production per mass of fuel consumed (taken from the National Atmospheric Emissions Inventory)

In addition to solid fuel use, Northern Ireland experiences similar additional PAH emissions from point sources (such as industrial facilities) and diffuse sources (such as road transport) as the rest of the UK. Northern Ireland is also subject to high levels of PAH emissions in residential areas during bonfire night like the rest of the UK and, uniquely to Northern Ireland, emissions associated with bonfires associated with 12th July celebrations.

Domestic solid fuel burning is a particular problem as it releases PAHs close to ground level in areas of high population density where their impact on the maximum recorded ground level concentration, as compared to the same mass of PAH emitted by an industrial process from a tall chimney stack, can be up to 100 times greater. Road transport would have an intermediate effect, releasing BaP at ground level but along major roads, and generally not impacting greatly on areas of high population density. It has been assumed that trans-boundary contributions of PAHs from the Irish Republic will be very small. Therefore, it is thought that by far the most cost effective and successful strategy in terms of reduced ambient PAH concentrations is the targeting of emissions from domestic solid fuel use.

2.1 UK Emissions

Emissions of most pollutants in the UK have shown dramatic decreases over the last couple of decades as tighter and tighter emissions regulations and the decline of heavy industry have both had their effect. PAHs are no exception. The National Atmospheric Emissions Inventory[11] (NAEI) has contained estimates of PAH emissions since 1990. The ratios of emission estimates of BaP to other PAHs are very strongly correlated, although BaP only accounts for 0.3 % of the total emissions of the 16 PAHs considered by the NAEI. BaP emissions, the marker compound for PAHs in the atmosphere, have shown a 95 % decrease in the last 20 years: from 66 tonnes in 1990 to only 3 tonnes in 2008. The BaP emissions profile from various sectors is shown in Figure 2-2.

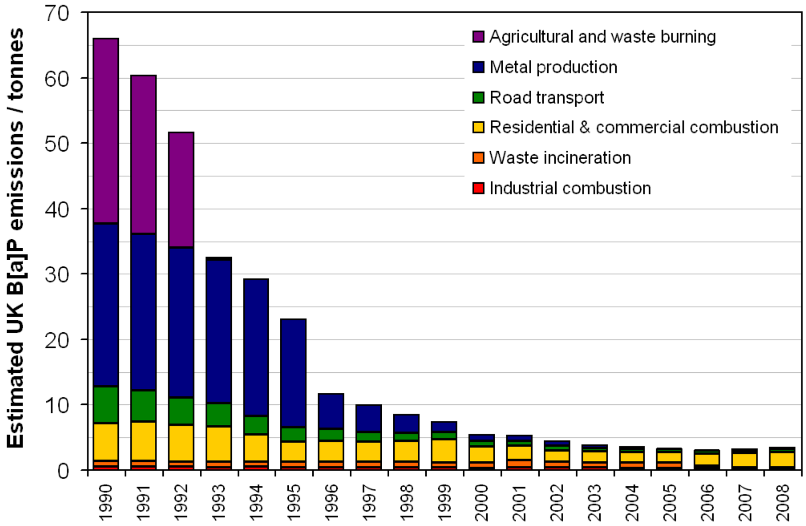


Figure 2-2 Estimated UK emissions of BaP per sector from 1990 to 2008

The greatest reductions over the period displayed in Figure 2-2, in absolute terms, have been from:

Field burning of agricultural wastes:	28 tonnes
Aluminium production:	25 tonnes
Road vehicles:	5 tonnes
Residential emissions:	3 tonnes

It is noted that UK residential emissions of BaP dropped monotonically from 1990 onwards to a level of only 1.6 tonnes in 2003, but have since risen again to 2.3 tonnes in 2008, and are currently responsible for 65 % of the total UK output, far in excess of the next highest contributing sector (excluding natural emissions such as from forest fires, long range transport from volcanoes, and other natural combustion events).

According to the NAEI, in 2008, of the UK's 3.56 tonnes of anthropogenic emitted BaP, 0.25 tonnes originated from Northern Ireland. Assuming Northern Ireland represents 2.9 % of the UK's population, based on 2008 estimates from the Office of National Statistics, this represents a Northern Irish emissions rate per head 2.6 times greater than that of Great Britain. Table 2-3 gives the relative emissions rates per head of population for the main sources of BaP in Northern Ireland and in Great Britain.

Emissions class	Northern Irish BaP emissions / kg per 1M inhabitants	Great British BaP emissions / kg per 1M inhabitants	Ratio NI/GB
Residential & commercial combustion	**128**	**35**	**3.7**
Road Transport	**8.3**	**6.8**	**1.2**
Waste treatment and disposal	**1.0**	**2.9**	**0.35**
Industrial processes	**0.9**	**4.0**	**0.23**
Industrial combustion	**0.4**	**4.0**	**0.09**

Table 2-3 BaP emissions per sector in 2008 expressed per head of population in Northern Ireland and in Great Britain, and the ratio of the rate in Northern Ireland to that in Great Britain (Ratio NI/GB)

Table 2-3 clearly shows that emissions from residential and commercial combustion are much higher per head of population in Northern Ireland than the rest of Great Britain, whereas per head emissions from other sectors are comparable (road transport) or significantly less (waste treatment and industrial processes – including point source industrial emissions). This emphasises the importance of solid fuel use in Northern Ireland to PAH emissions profiles.

2.2 UK Concentrations

Concentrations of PAHs in the PM_{10} fraction of air are measured in the UK by the PAH Air Quality Monitoring Network. The Network currently consists of 31 monitoring sites at background, rural, urban and industrial locations providing monthly PAH concentrations of over 20 different compounds, including BaP. This provides the public and Government with air quality information to assist in complying with the UK's obligations under the EU's Fourth Air Quality Daughter Directive and other PAH-related legislation and in assessing population exposure and the effectiveness of abatement strategies. The target value for BaP in the PM_{10} fraction of ambient air, set by the Fourth Daughter Directive (published in 2004) is 1 $ng.m^{-3}$ and the UK objective (suggested by EPAQS in 1999) is 0.25 $ng.m^{-3}$.

Data from the UK PAH Network is publicly available on the UK-AIR web pages[6]. This shows that UK PAH concentrations have fallen steadily since 1990. This is consistent with the decrease in emissions of PAHs and is similar to the trends that have been observed for other pollutants, such as metals in PM_{10}. It is difficult to produce a representative average UK value for PAH concentrations because of the changes of monitoring site location and number that have occurred in the PAH Network over the last 20 years. However, a reasonable representation of an average UK PAH concentration can be provided by the median yearly value across all sites on the PAH Network. The evolution of this parameter over time has been plotted together with the changing emissions profile of BaP in the UK in Figure 2-3.

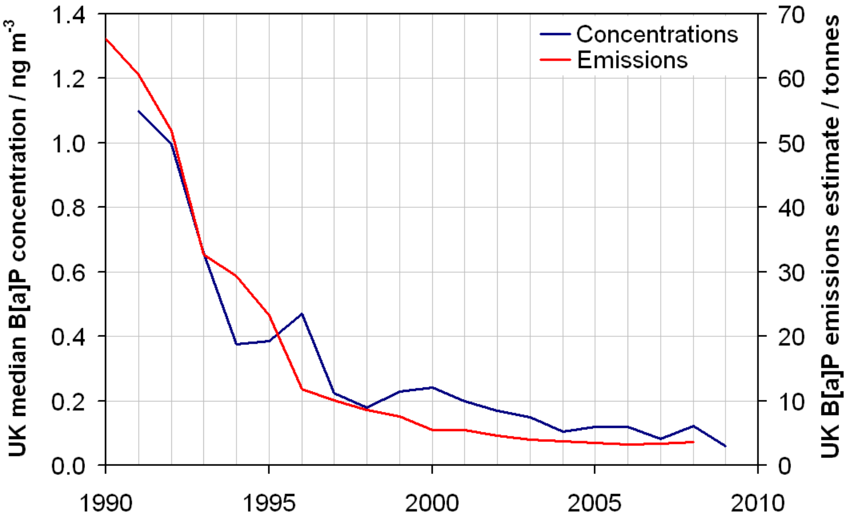


Figure 2-3 Comparison of UK BaP estimated emissions and UK median BaP measured concentrations from 1990 to 2009

It is clear from Figure 2-3 that both emissions and measured concentrations of BaP have fallen dramatically over the last 20 years. It is also clear that these decreases are highly correlated. If we directly compare emissions against concentrations, and assign uncertainties to each value (for BaP concentrations this is the Fourth Daughter Directive data quality objective for expanded uncertainty of 50 %, and for BaP emissions this is the lower end of the NAEI estimated uncertainty of 60 %) we may extrapolate this relationship to its intercept with the y-axis when emissions are zero. This has been done in Figure 2-4, using a generalised least squares approach (taking into account the uncertainties on both axes).

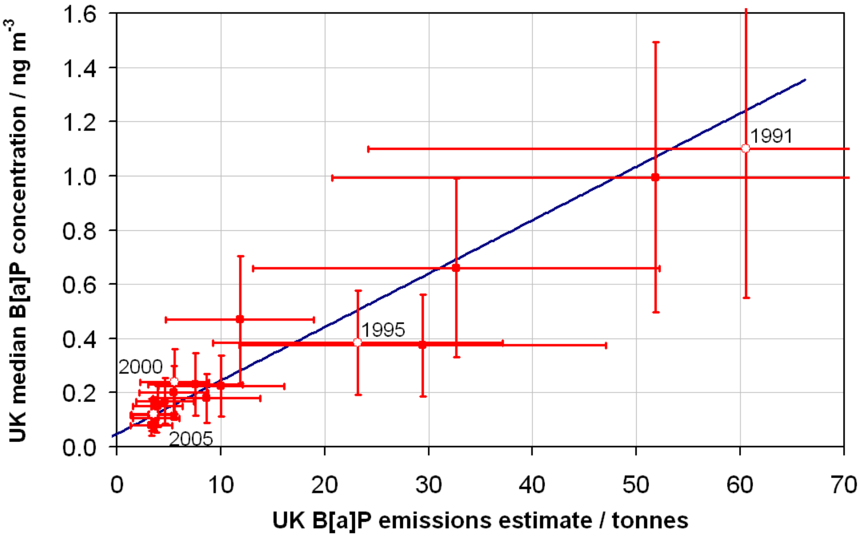


Figure 2-4 **Generalised least squares extrapolation of UK median BaP concentration against UK BaP emissions estimates from 1991 to 2008. The years 1991, 1995, 2000 and 2005 are indicated by the empty circles. The expanded uncertainties in each data point at the 95 % confidence interval are represented by the error bars**

Figure 2-4 confirms that the fall in emissions is mirrored by a fall in measured ambient concentrations. The extrapolation displayed produces a gradient of 0.02 ng.m^{-3} tonnes^{-1} which is very similar to analogous figures recently produced for other UK pollutant data (for instance this figure is the same as that calculated for Ni in UK air[12]). This implies that every tonne of BaP emitted into UK air contributes 0.02 ng.m^{-3} to concentrations measured in ambient air. The intercept of Figure 2-5 with the y-axis represents the predicted concentration of BaP in ambient air in the absence of any anthropogenic emissions. This is an indication of the lower limit of ambient BaP which could ever be expected when no anthropogenic emissions are present. The extrapolation predicts this to be 0.05 ng.m^{-3}. This figure agrees extremely well with the BaP emissions from natural sources, which have been consistently estimated by the NAEI as 2.88 tonnes per year. At a sensitivity of 0.02 ng.m^{-3} t^{-1} this would represent a contribution to UK ambient air by natural sources of 0.06 ng.m^{-3} – very close to the level predicted by this extrapolation.

2.3 Comparison of UK monitoring site concentrations

The 2009 annual average BaP concentrations measured at each monitoring site on the PAH Network are shown in descending order in Figure 2-5 below.

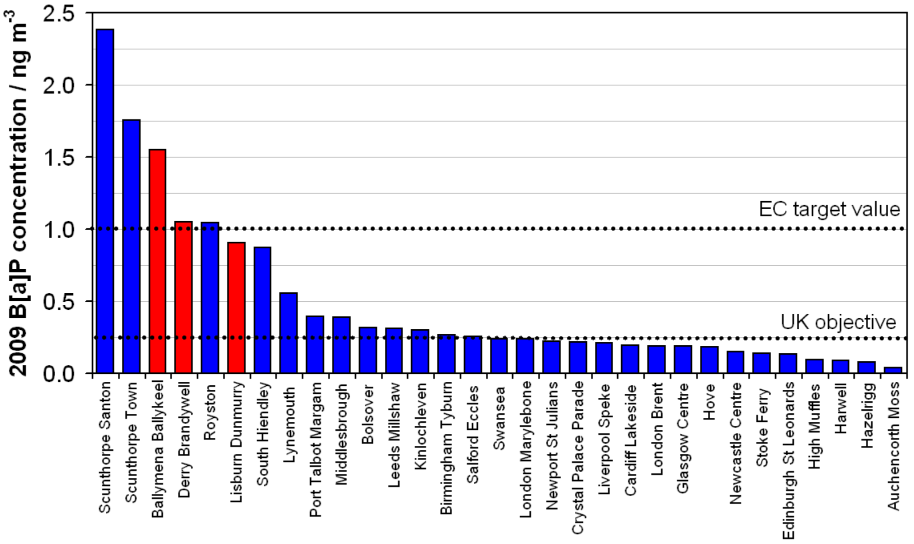


Figure 2-5 2009 annual BaP concentrations measured at each monitoring site on the PAH Network shown in descending order. The Northern Irish sites are coloured in red

As can be seen there were 5 sites which exceeded the EC target value in 2009 (including two of the Northern Irish sites) and 15 sites which exceeded the UK objective in 2009 (including all of the Northern Irish sites). The sites exceeding the UK objective are listed in Table 2-4 below with the concentration measured, and the most likely source of the BaP measured at that site.

It can be seen from Table 2-4 that with the exception of the Northern Irish sites (where the main BaP source is domestic solid fuel use) the highest concentrations are measured at sites located near to industrial point sources such as steel, coke or aluminium works. At Middlesbrough and Lynemouth there may be small contributions from domestic solid fuel use but the measured concentrations are still dominated by industrial contributions. At Bolsover and Kinlochlevan there are contributions from historical industrial processes. In addition, concentrations resulting from domestic solid fuel use in Kinlochlevan are exacerbated by the surrounding steep valley hindering dispersion of ambient pollutants.

Site	BaP concentration / ng m^{-3}	Significant source of BaP
Scunthorpe Santon	**2.4**	**Steel works (downwind)**
Scunthorpe Town	**1.8**	**Steel works (upwind)**
Ballymena Ballykeel	**1.6**	**Domestic solid fuel use**
Derry Brandywell	**1.0**	**Domestic solid fuel use**
Royston	**1.0**	**Coke works (upwind)**
Lisburn Dunmurry	**0.90**	**Domestic solid fuel use**
South Hiendley	**0.87**	**Coke works (downwind)**
Lynemouth	**0.55**	**Aluminium works and possible domestic solid fuel use**
Port Talbot Margam	**0.39**	**Steel works**
Middlesbrough	**0.39**	**Steel works and possible domestic solid fuel use**
Bolsover	**0.32**	**Ex-industrial coke works**
Leeds Millshaw	**0.31**	**Urban**
Kinlochlevan	**0.30**	**Domestic solid fuel use and ex-industrial aluminium works**
Birmingham Tyburn	**0.26**	**Urban**
Salford Eccles	**0.26**	**Urban**

Note: all three NI sites also exceeded the EU TV in 2010, see Table 1.1

Table 2-4 Sites on the UK PAH monitoring Network exceeding the UK objective in 2009, the concentration measured at the site, and most likely source of the BaP measured at that site

Towards the bottom of Table 2-4 are sites measuring concentrations in urban environments where the concentrations are thought to be primarily a result of traffic and commercial contributions. Of the sites measuring less than the UK objective, 11 are urban in nature, with background rural sites occupying five of the six lowest 2009 annual concentrations – averaging 0.09 ng m^{-3} between them. In Figure 2-6 the measured BaP concentration in 2009 at monitoring stations in urban locations has been compared against the estimated core urban size of the city or town in which each of the monitoring sites is located.

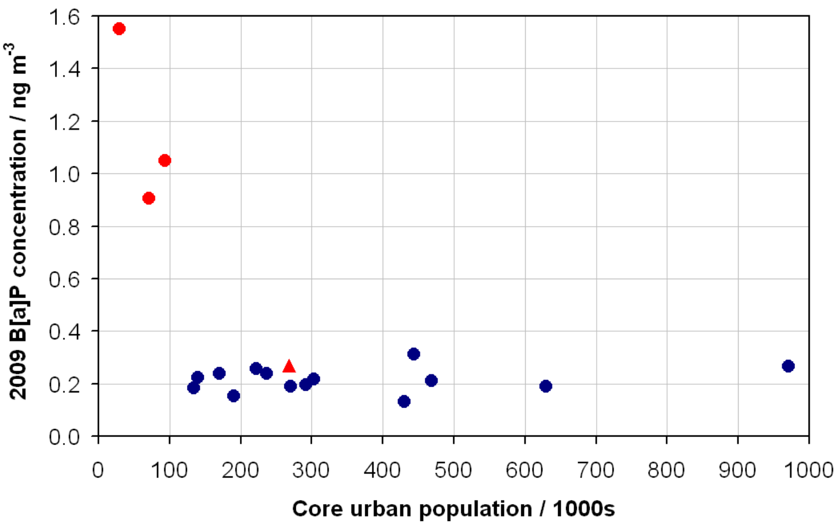


Figure 2-6 **The 2009 BaP concentrations measured at urban monitoring sites on the UK PAH network against the estimated core urban size of the city or town in which the monitoring station is located. For London, the size of the relevant borough has been used. The red markers indicate Northern Irish sites. (The red triangle is the 2005 BaP concentration measured at Belfast Clara Street, for comparison)**

It is quite clear from this Figure that in urban locations where BaP emissions are from traffic and commercial sources there is very little correlation between the measured BaP concentrations and the core urban size – concentrations of between 0.13 and 0.31 ng m^{-3} are observed for core urban sizes of between 100,000 and 1,000,000 inhabitants. This observation includes the 2005 annual average in Belfast of 0.27 ng m^{-3} at a time prior to the closure of the site, when there was very little domestic solid fuel use in Belfast and the monitoring site at Clara Street was situated within a smoke control zone. However, for the current monitoring sites in Northern Ireland, all with core urban populations of under 100,000, the measured concentrations range from 0.9 to 1.6 ng m^{-3}. The elevated BaP levels at these Northern Irish locations clearly indicate the effect of the presence of a substantial proportion of local emissions from domestic solid fuel combustion.

2.4 Northern Irish Concentrations

A summary of the annual average BaP concentrations measured by the PAH Network in Northern Ireland are shown in Figure 2-7.

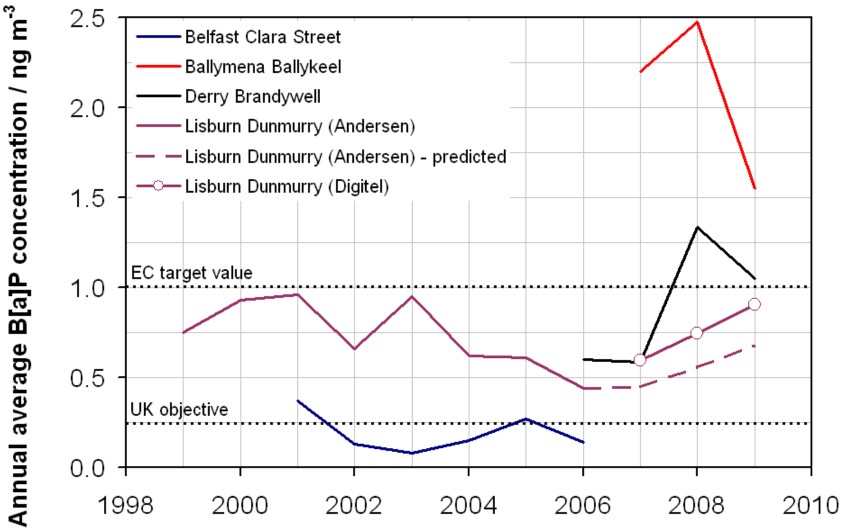


Figure 2-7 The annual average BaP concentrations measured by the PAH Network in Northern Ireland. Predicted data for the Andersen sampler at Lisburn is based on the Digitel sampler concentrations reduced by a correction factor of 0.67

Given the relatively limited and fractured nature of sampling in Northern Ireland it is relatively difficult to draw any firm conclusions about long-term trends in concentration. A Network reorganisation occurred at the end of 2006, resulting in a change in the location of many monitoring locations in the UK, and additionally a change in the sampler type employed (from ‘Andersen’ to ‘Digitel’). Both measures were to ensure that the UK Network complied with the requirements of the Fourth Air Quality Daughter Directive for site location, and the sampling requirements of the European reference method for PM_{10} – EN 12341. As a result, the Belfast Clara Street site, which used an Andersen sampler, closed, whilst two new sites were commissioned in Londonderry and Ballymena, both using Digitel samplers. The monitoring site at Lisburn Dunmurry has sampled from 1999 to the present day, although the sampler type changed in 2007 from Andersen to Digitel, making time series comparisons difficult. However, predicted concentrations based on the continued use of the Andersen sampler at Lisburn have been projected, using the concentrations measured with the Digitel sampler multiplied by a correction factor associated with the likely under-reading of the Andersen sampler (because of increased ozone degradation of BaP collected on the filter owing to longer sampling times). This correction factor of 0.67 has been estimated based on a comparison of co-located Andersen and Digitel samplers performed by the PAH Network during 2009 and 2010[4].

Whilst the Belfast site was generally below the UK objective concentration, the concentrations recorded at Lisburn have consistently been above the UK objective, but below the EU target value. The trends at both of these sites have generally been downwards, despite the increases observed at Lisburn in 2008 and 2009 – which seems contrary to the expected effect of the introduction of natural gas into the housing estate within which the monitoring station is located at the end of 2007. This increase may be as a result of the last two winters being significantly colder than average, requiring high fuel usage for heating purposes, and therefore higher than expected PAH emissions. The sites at Ballymena and Derry are too new for a reliable trend to be discerned. However it is clear that concentrations at Londonderry are around the EU target value, whilst those at Ballymena are well in excess of the EU target value.

As shown in Section 4.2, 93% of BAP emissions come from Commercial, Institutional and Residential (CIR) emissions. If we make the assumption that measured BaP concentrations in Northern Ireland are driven mainly by residential emissions, and that changes in Northern Ireland residential emissions have a larger impact than those in the rest of the UK, we can compare the long term BaP measurements at Lisburn with the UK emissions of BaP from residential sources to look for any correlation. This is shown in Figure 2-8.

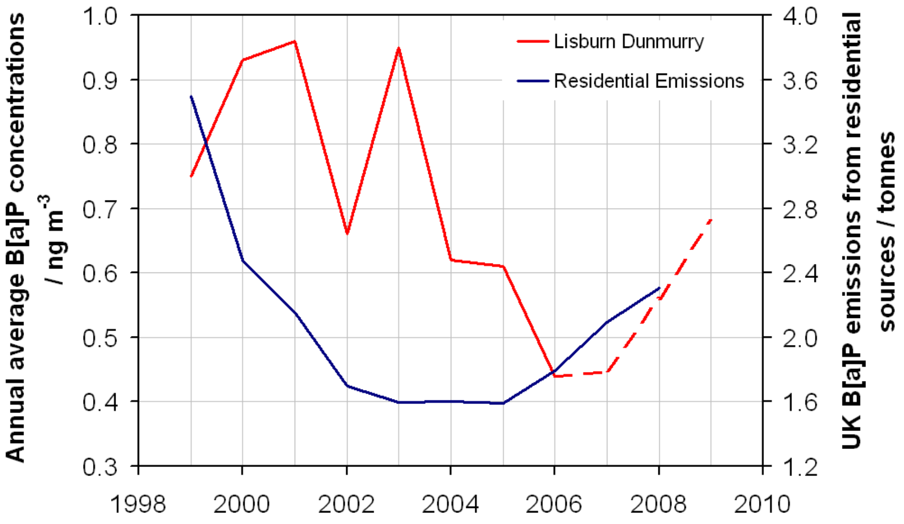


Figure 2-8 The annual average BaP concentrations measured by the PAH Network at Lisburn Dunmurry and the UK BaP emissions from residential sources from 1999 to 2009. (Predicted data for the Andersen sampler at Lisburn is based on the Digitel concentrations reduced by a correction factor, and is shown as the dashed orange line)

The two plots in Figure 2-8 show some broad agreement, with both decreasing from 1999 to 2005/2006 followed by a small increase in both parameters towards the end of the decade. As mentioned above, the installation of natural gas supply to the housing area immediately around the Lisburn Dunmurry sampler at the end of 2007 does not seem to have resulted in a decrease of measured BaP concentrations.

Similar measured concentrations to estimated emissions sensitivity analysis as to that which was performed in Figure 2-4 has been performed for the data in Figure 2-8. This is shown in Figure 2-9.

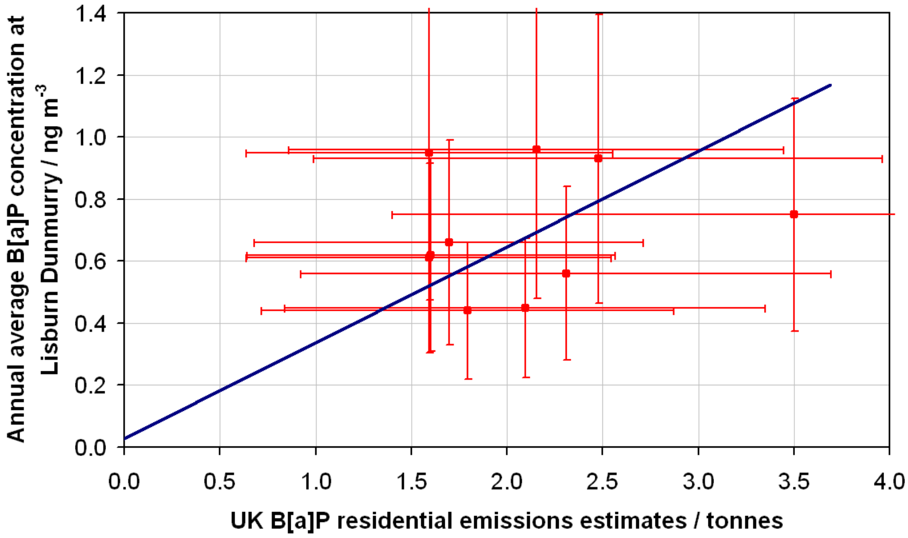


Figure 2-9 **Generalised least squares extrapolation of Lisburn Dunmurry BaP concentration against UK BaP residential emissions estimates from 1999 to 2008. The expanded uncertainties at the 95 % confidence interval in each data point are represented by the error bars**

Whilst a lot more uncertain than the extrapolation shown in Figure 2-5, the data in Figure 2-9 predicts a gradient of 0.3 ng m^{-3} tonnes^{-1} with an intercept with the y-axis of 0.03 ng m^{-3}. Because of the large uncertainty in the extrapolation, conclusions have to be drawn with caution. However, the data shows much higher sensitivities to ground level concentrations from residential emissions, than from the whole UK emissions profile, even when the uncertainty in the extrapolation is taken into account. This is significant, because monitoring sites dominated by residential emissions are expected to show a higher sensitivity of ground concentrations to emissions, since PAHs from these sources are generally released at ground level, unlike point source emissions that are generally released from a high chimney stack and usually dissipate substantially before they ground. This gradient is similar to that observed for metals occurring from diffuse ground level emissions such as Cu (and historically Pb) from transport sources. Moreover the predicted intercept with the y-axis – the ambient concentration in the absence of residential emissions – is comparable with that predicted for the UK wide analogue. This yields further evidence that BaP concentrations in Northern Ireland have a substantial contribution from domestic combustion, as per the conclusions from Table 3, and provides a measure of confidence that reducing residential emissions will have a large impact on measured ambient concentrations.

A further indication of the prevalence of PAHs in PM in Northern Ireland comes from the measurements of ‘Black Carbon’ made by NPL using Aethalometers which are able to measure the transmittance of light through the collected particulate matter and convert this into a mass concentration of black carbon using a standard formula[13]. Using the more common visible wavelength Aethalometer, the responses at Birmingham and Lisburn in 2009 can be seen to be relatively similar – see Figure 2-10.

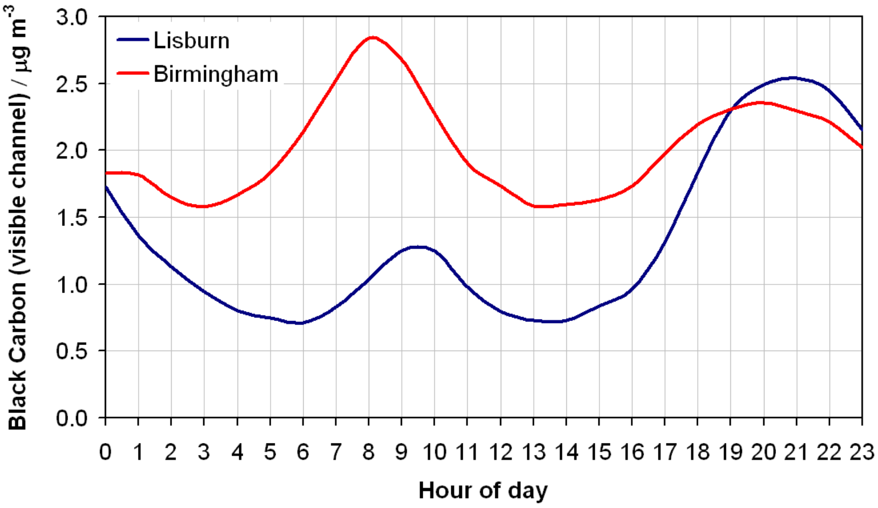


Figure 2-10 **Average daily variations in the black carbon concentration during 2009 at Birmingham Tyburn and Lisburn Dunmurry using a visible wavelength Aethalometer**

A clear diurnal pattern is observed at both sites. At Birmingham both peaks are ascribed to the increase in traffic during the morning and evening rush hours. At Lisburn the morning peak is much smaller than is seen at Birmingham – as expected given that the Lisburn Dunmurry site is exposed to considerably less traffic than at Birmingham Tyburn. However, the evening peak at Lisburn Dunmurry is larger than expected. This indicates the presence of sources other than traffic, and this is shown clearly when examining the data from the ultra-violet channel of the same Aethalometer which is much more sensitive to aromatic compounds such as PAHs. This is shown in Figure 2-11.

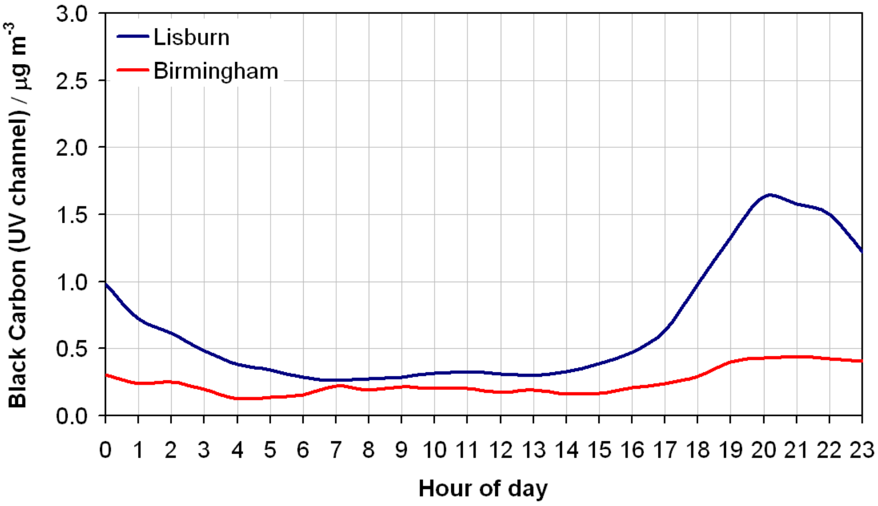


Figure 2-11 **Average daily variations in the black carbon concentration during 2009 at Birmingham Tyburn and Lisburn Dunmurry using an ultra-violet wavelength Aethalometer**

It is clear from Figure 2-11 that the black carbon collected at Birmingham was related almost entirely to traffic related emissions, which have a relatively low PAH content per mass of particulate, and hence very little is measured when using the ultra-violet channel on the

Aethalometer. Whereas, the plot from Lisburn shows that whilst the morning peak was most probably traffic related, the large peak in the evening is due to increased solid fuel burning, producing much more PAH per mass of particulate and showing up very clearly on the ultra-violet channel of the Aethalometer.

For comparison with the Northern Irish data presented above it is instructive to examine BaP concentrations measured in the Irish Republic. Following an initial study for the Irish Environmental Protection Agency[14,15] a monitoring network of five sites was established in 2009 to meet the requirements of the Fourth Air Quality Daughter Directive. The concentrations measured at these sites in 2009 are shown in the table below.

Site	**BaP concentration / ng m^{-3}**	**Site classification**
Cork Heatherton Park	**0.52**	**Suburban background**
Galway Bodkin	**0.48**	**Urban traffic**
Dublin Rathmines	**0.37**	**Suburban background**
Dublin Winetavern	**0.30**	**Urban background**
Monaghan Kilkitt	**0.08**	**Rural background**

Table 2-5 Annual average BaP concentration measured in 2009 at the five monitoring sites in the Republic of Ireland, with their relevant site classifications

The concentrations shown in Table 2-5 are similar, if perhaps a little higher, than analogous sites in Great Britain, but significantly lower than concentrations measured in urban locations on the UK PAH Network in Northern Ireland. This again highlights the contribution to BaP concentrations of extensive solid fuel use in Northern Ireland. The rural background concentration measured at Monaghan Kilkitt is very similar to concentrations measured at rural locations in Great Britain, and as Monaghan is a county bordering Northern Ireland, this provides a useful background concentration against which to benchmark measurements in Northern Ireland.

2.5 Seasonality of PAH concentrations

The majority of UK PAH Network sites show some degree of seasonality, with higher concentrations in the winter months. This is particularly prevalent at urban locations, not affected by more constant sources of BaP emissions as might be found at industrial sites. The most pronounced seasonality is seen at locations where the major source of BaP emissions is owing to domestic combustion. This is very clear in Northern Ireland where significant seasonal variation is observed as a result of the much higher use of solid fuel for heating in the colder winter months. The monthly concentration measured at each of the Northern Irish monitoring sites in 2009 is shown in Figure 2-12, which clearly shows the seasonality of BaP concentrations in Northern Ireland, and shows the very clear correlation of these emissions with the monthly average temperature in Northern Ireland during 2009.

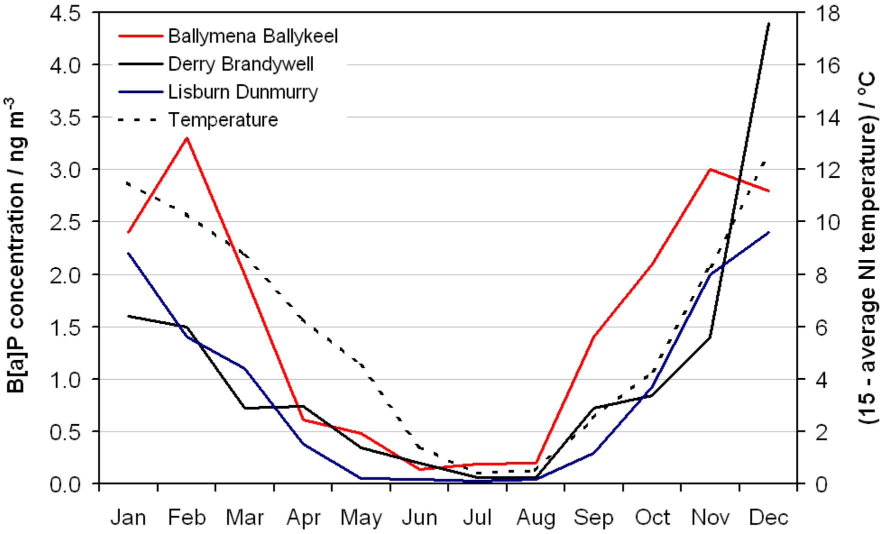


Figure 2-12 The monthly concentration measured at each of the Northern Irish monitoring sites in 2009, plotted together with the monthly average temperature (T) in Northern Ireland during 2009, as (15-T)

Figure 2-12 also highlights the dependence of the annual average on the concentrations measured in the winter months – especially so in areas where solid fuel use is prevalent. Moreover, where solid fuel is used for heating, as in Northern Ireland, the concentrations of BaP during the winter months are in turn dependent on the average ambient temperature, and other less predictable meteorological parameters which may act to alter the pollution dispersion conditions, e.g. boundary layer inversions, variable wind speed and direction. Assessment of any trends in concentrations as a result of abatements strategies or changing fuel usage would therefore need to take into account the variability imposed by meteorological parameters.

2.6 Correlation of PAH concentrations

There is a very strong correlation between the concentrations of the various PAHs measured by the Network. This is because all PAHs are compounds related to combustion processes, and thus emissions from a given source would be expected to show similar PAHs ratios – for instance where measured concentrations are dominated by domestic solid fuel use. In locations where monitoring stations are impacted on by two sources (for instance solid fuel use and industrial processes) a slightly lower correlation would be expected which recognised the superposition of two processes each producing slightly different PAH ratios. This correlation is still substantially stronger than on similar multi-species air quality Networks such as the UK Metals Network where metals are produced from a number of different processes and many monitoring sites are impacted upon by several processes at once[16]. A demonstration of the correlation between measured PAH concentrations is shown in Figure 2-13. In this case the correlation between BaP and benzo[ghi]perylene has been displayed purely as an exemplar case – almost any pair of PAH compounds could have been chosen.

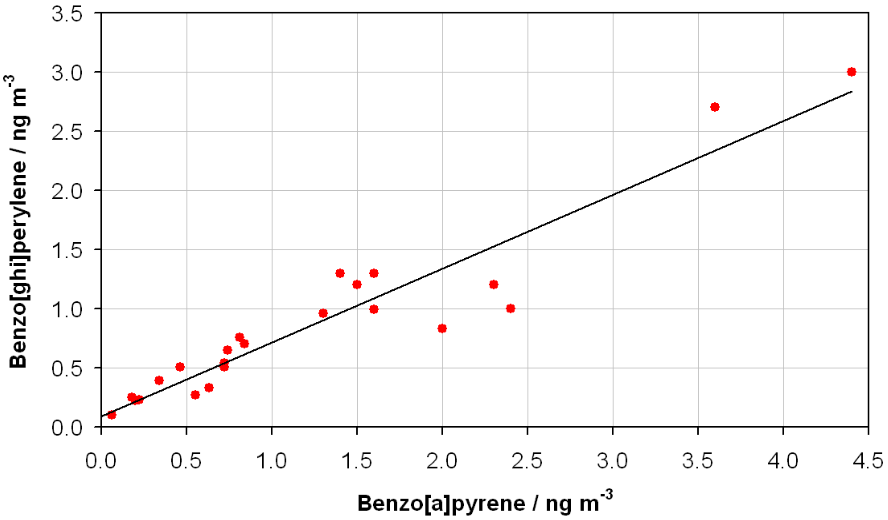


Figure 2-13 The monthly concentrations of Benzo[a]pyrene and Benzo[ghi]perylene at Londonderry from January 2008 to December 2009 inclusive. A line of least squares best fit is shown

The strong correlation between the measured PAH concentrations is additional evidence that BaP is a suitable marker compound to use to represent the concentrations of all PAHs.

The high correlation of PAHs as compared to metals in ambient air is highlighted by a principal component analysis (PCA). PCA allows us to consider a multivariate data set (more than just two variables, as in Figure 12) and re-plot that data in two dimensions with respect to the axes which best describe the variability of the data set. In the resulting ‘loadings plot’, analytes appearing close together in the plot show correlation, and the nearer to the edge of the plot they are, then the stronger the correlation. This analysis has been performed for monthly UK PAH Network results in Londonderry and monthly UK Metals Network results in Belfast[17] during 2008 and 2009. Analytes that are routinely below the detection limit have been excluded as they simply add noise to the system. The results of this analysis are shown in Figure 2-14.

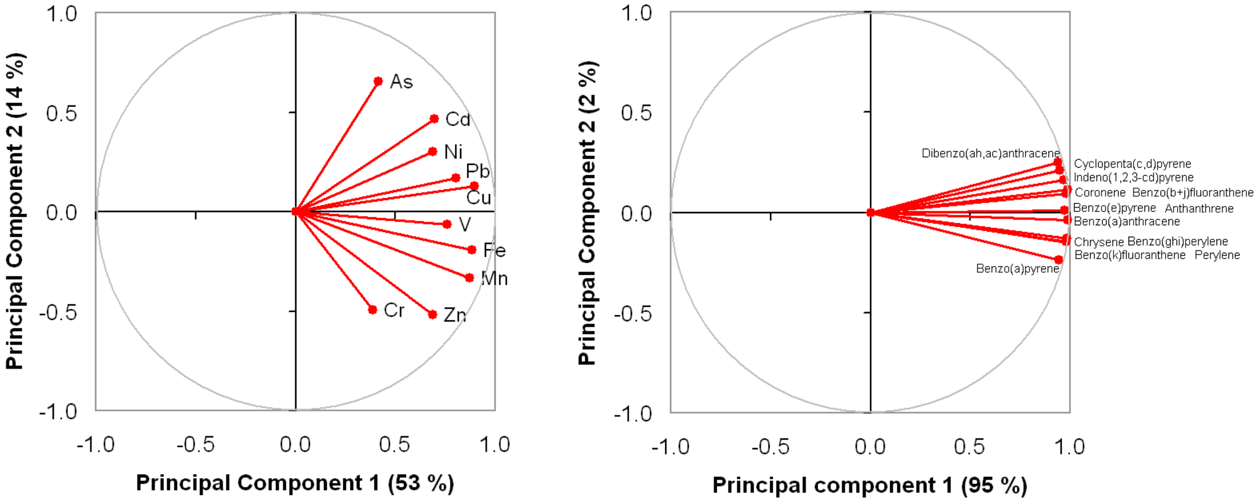


Figure 2-14 Principal component analysis 'loadings plot' for monthly Metals Network results in Belfast (left) and monthly PAH Network results in Londonderry (right) during 2008 and 2009

Figure 2-14 clearly shows the very strong correlation between concentrations of measured PAHs in Northern Ireland – notice how all the analytes are tightly grouped and at the edge of the circle. In this case the first two principal components account for 97 % of the total variability of the system. Conversely the metallic analytes are widely spread and not close to the edge of the circle, indicating a much lower correlation between their values. In this case the first two principal components account for only 67 % of the total variability of the system.

The correlations observed between PAHs in the rest of the UK are also strong, but not as strong as those seen in Northern Ireland. As an example of this the loadings plot for the Marylebone Road PAH site in London is shown in Figure 2-15. Note that the analytes are more widely spread than in the Londonderry plot in Figure 2-14 and that the first two principal components at Marylebone Road account for only 89 % of the variability of the data set, compared to 97 % at Londonderry. This is a further indication of the dominance of one emission source – domestic solid fuel burning – around the monitoring sites in Northern Ireland as compared to other sites around the UK.

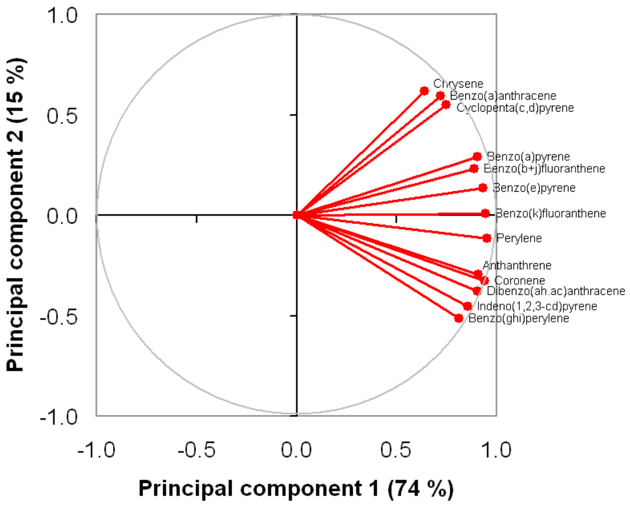


Figure 2-15 Principal component analysis 'loadings plot' for monthly PAH Network results at London Marylebone Road during 2008 and 2009

This analysis can be taken a step further, similarly to previous studies of UK PAH concentrations[18], to compare the average profile of the different PAH concentrations at each of the sites on the UK PAH Network. This has been done for the annual average concentrations measured around the UK in 2009. The resulting 'scores plot' is displayed in Figure 2-16.

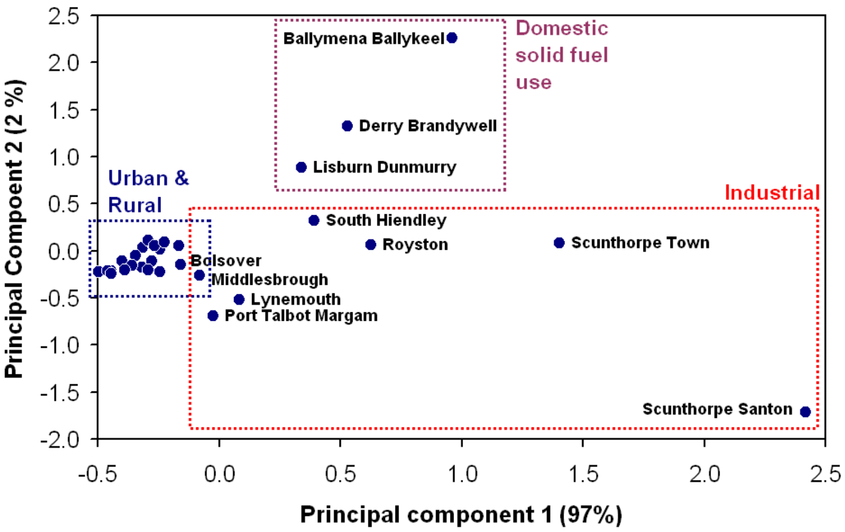


Figure 2-16 Principal component analysis 'scores plot' using data for the 2009 annual average PAH concentrations at each of the 31 UK PAH Network monitoring sites. The broken squares represent the grouping of sites according to site classification

As expected the PAH concentrations observed across different sites are very highly correlated, such that the first two principal components account for 99 % of the total variability of the system. Despite this very high general correlation, Figure 2-16 is still able to clearly display the different source types impacting on the various UK sites. The profile of urban and rural sites shows a very tight clustering, showing that there is very little variation in the type of emissions impacting on these locations. The cluster of monitoring location impacted by industry is more diffuse, presumably as a result of the different industrial processes being considered (steel works, coke works, ex-industrial etc). Interestingly, the Northern Irish sites also appear as a definable cluster, yielding further evidence that domestic solid fuel use is the characteristic emission type impacting on these sites. The spread of this cluster is most probably due to the differing percentage of additional urban background type emissions at these sites (i.e. a greater influence of traffic at Lisburn than at Londonderry).

2.7 Conclusions

The current levels and trends of PAH emissions and concentrations in the UK and in Northern Ireland have been assessed and compared. In general, both emissions and measured concentrations of PAHs in ambient air have fallen over the last 20 years, most dramatically between 1990 and 1995 and then steadily thereafter.

The BaP monitoring sites in Northern Ireland have regularly recorded high concentrations, often in excess of the EU target value. A comparison of UK concentrations showed that the values measured at urban sites in Northern Ireland are comparable with industrial locations in Great Britain, and substantially in excess of levels recorded at much larger urban centres in Great Britain. It has been noted that whilst the use of natural gas has increased across Northern Ireland in recent years, there is still substantial solid fuel burning, mostly for domestic heating purposes and this is thought to be the origin of the elevated BaP levels in Northern Ireland. This has been confirmed by several pieces of additional data such as black carbon aethalometry, and principal component analysis of PAH concentrations in the UK.

Emissions of PAHs from residential and commercial combustion per head of population are currently about four times higher in Northern Ireland than in Great Britain, whilst those from traffic are similar to those in Great Britain, and emissions from industry in Northern Ireland are substantially less. It has been observed additionally that emissions released at ground level, such as from residential combustion, have a much greater effect on measured concentrations in ambient air than releases from chimney stacks; hence abatement strategies which reduce residential emissions are likely to significantly reduce measured concentrations of ambient BaP.

Trends in ambient BaP concentrations in Northern Ireland in recent years have been difficult to discern, in part because of the lack of long term data series from monitoring sites in Northern Ireland. The data set from the Lisburn Dunmurry site dates back to 1999 and shows a steady decrease from this time until 2006, followed by a slight increase in concentrations between 2006 and 2009. This increase may correlate with the slight increase in residential emissions observed across the UK during this period, possibly as a result of colder than average winters over the last few years.

3.0 Model Description

The ADMS-Urban dispersion model uses parameterisation of the boundary layer structure based on the Monin-Obukhov length and the boundary layer height, along with metrological data to calculate the dispersion of pollutants from various emission sources. 1km x 1km grid source data on BaP emissions was taken from the National Atmospheric Emission Inventory, with the assumption that the emissions were evenly distributed within each grid square. BaP emissions were assumed to be all in the Particulate PM_{10} phase and dispersion modelling performed with dry and wet deposition. Atmospheric chemistry was not taken into account.

Model Platform: ADMS-URBAN 3.0.0 Release Date: 23rd November 2010

Input Data

Emission data: National Atmospheric Emission Inventory, 1km x 1km grid sources
Meteorological data: Four Met Office Weather Stations
Lisburn Council Weather Station

Output Data

1km x 1km grid plus specific points

3.1 Input Data

The following sections describe the input data required for the model.

3.1.1 Emissions Data

The National Atmospheric Emission Inventory (NAEI) provided Benzo[a]pyrene (BaP) emission data for 2008 on a 1km x 1km grid square basis. The emissions for each of the 14836 squares covering Northern Ireland are broken down into 12 categories: Energy Production and Transformation; Commercial; Institutional and Residential Combustion; Industrial Combustion; Industrial Process; Production and Distribution of Fossil Fuels; Solvent Use; Road Transport; Other Transport; Waste Treatment and Disposal; Agriculture; Natural and Point Sources.

Figure 3-1 shows the spatial distribution of the BaP emissions across Northern Ireland. It can be clearly seen that most of the emissions come from built up areas.

Since the modelling work was performed the emission levels of PAHs in the UK have been published for 2009 by the National Atmospheric Emission Inventory (NAEI). Comparing the 2008 and 2009 emissions show that there has been a small decrease in the predicted BaP emissions in 2009 compared to 2008. This decrease is not significant and therefore would not have a significant effect on the modelled concentrations, especially as additional uncertainties associated with the Commercial, Institutional and Residential emissions in the NAEI for Northern Ireland are discussed, see Section 4.1.1.

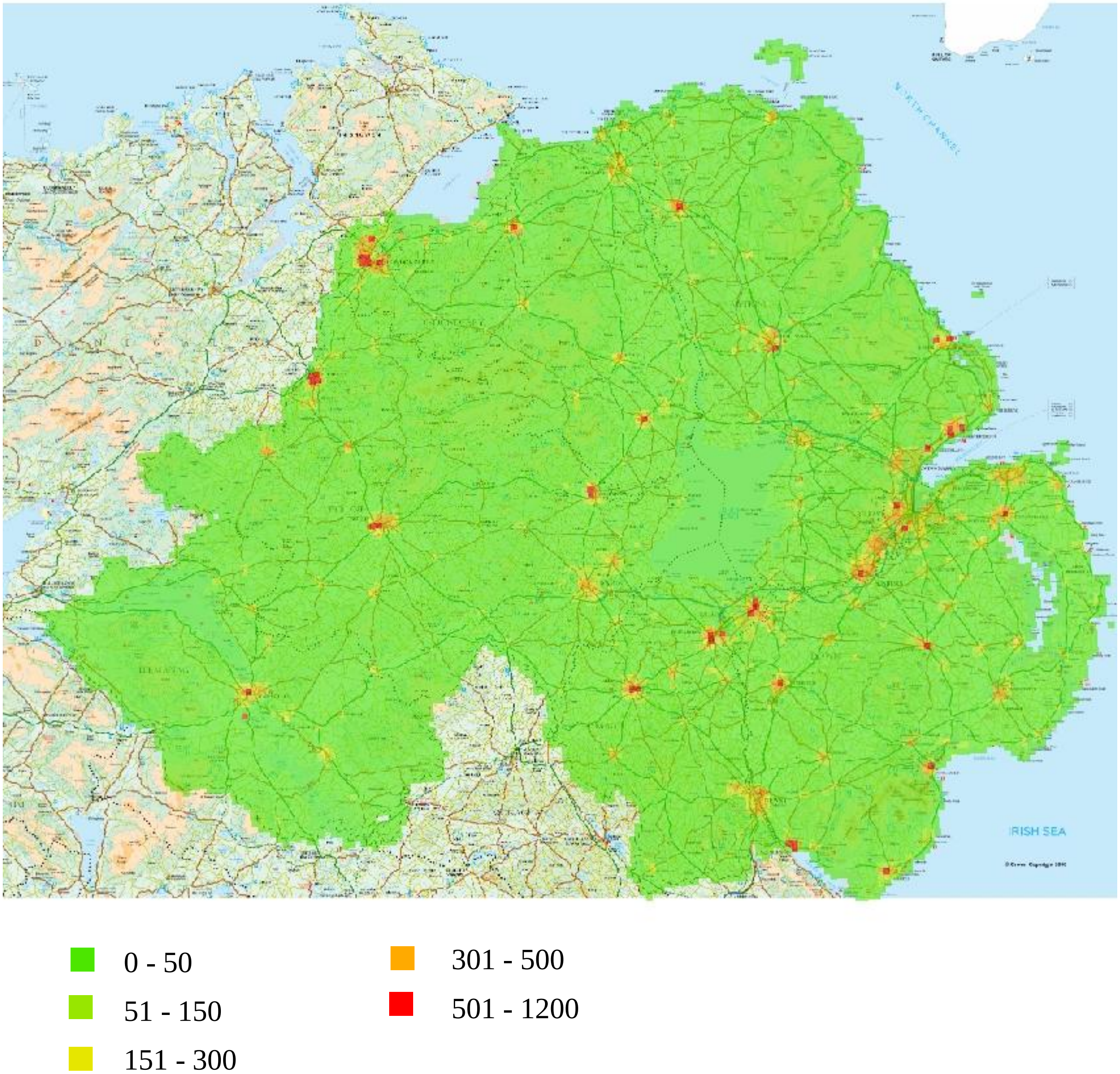


Figure 3-1 2008 NI BaP emissions in grams per year

Note: All Ordnance Survey Northern Ireland maps reproduced in this report are covered by Land and Property Services Digital Data Sub-licence.

3.1.2 Meteorological Data

2008 Meteorological data were used from four stations run by the UK Met Office at the following locations:

Belfast International Airport (Aldergrove)	Latitude: 54.65; Longitude: -6.22
Londonderry Airport	Latitude: 55.04; Longitude: -7.16
Enniskillen Airport (St Angelo)	Latitude: 54.40; Longitude: -7.65
Glenanne	Latitude: 54.23; Longitude: -6.50

Some of the parameters for these data sets were not complete. The Londonderry data was supplemented with missing data from Ballykelly (another Met Office site near Londonderry) and then Malin Head. The Glenanne data was supplemented with cloud cover data from Aldergrove. The Enniskillen data was supplemented with missing cloud cover from Ballykelly and then Malin Head.

Additional meteorological data for 2008 was used from the Lisburn Council Dunmurry monitoring site. This was used for model testing and examining the effect of urban wind speeds and open field wind speeds on the model.

3.1.3 Background Concentration

To account for long-range transport, the background level of BaP was taken as the annual mean from the Southern Irish rural background site at Kilkitt, Co. Monaghan. The site was not monitoring in 2008 so the 2010 annual mean concentration of 0.18 ng.m^{-3} was used.

The Kilkitt monitoring station is run by the Eire Environmental Protection Agency to the requirements of the European Directive 2004/107/EC relating to arsenic, cadmium, mercury, nickel and polycyclic aromatic hydrocarbons in ambient air. This background level is comparable with other remote monitoring stations in the UK, i.e. Kinlochlevan 0.27 ng.m^{-3} (some local solid fuel use), Stoke Ferry 0.13 ng.m^{-3} and Harwell 0.11 ng.m^{-3}. This is higher than remote locations in the UK where there is no solid fuel use (Auchencorth Moss 0.03 ng.m^{-3}), however there is solid fuel usage in Eire, which will contribute to the concentrations in Northern Ireland.

4.0 Model Results

The model can give different outputs, such as:

- BaP concentration at the centre of each 1km x 1km grid square
- BaP concentration at specific points (PAH Network Monitoring sites)
- BaP interpolated concentration contour maps for specific areas

depending on the application required.

4.1 Comparison of Model Results and Measured Results

The model was run using the total emissions of BaP for 2008 and the modelled concentrations for the monitoring locations on the UK PAH Network were then compared to the actual annual mean measurements for 2008 as shown below in Table 4-1:

	Monitoring results	Modelled	Ratio
Dunmurry	0.745	0.273	2.729
Ballymena	2.460	0.296	8.311
Derry	1.338	0.376	3.559

Table 4-1 Modelled and measured BaP concentrations for 2008

The modelled results contained a regional background contribution taken as the 2010 annual mean measured BaP concentration from the rural monitoring site at Kilkitt in Co. Monaghan in Eire. Monitoring only started at this location in 2009, so no 2008 regional background data is available.

If the background level of 0.18 ng.m^{-3} is subtracted from the monitoring and modelled data the results in Table 4-2 are obtained:

	Monitoring results	Modelled	Ratio
Dunmurry	0.565	0.093	6.075
Ballymena	2.28	0.116	19.655
Derry	1.158	0.196	5.908

Table 4-2 Background corrected modelled and measured BaP concentrations for 2008

There is an obvious inconsistency with the results from the Ballymena site compared to the other two monitoring sites. It was therefore decided to base the scaling factor for the model on the ratios from the Dunmurry and Londonderry sites.

The use of a scaling factor in modelling is an acceptable practice due to known problems in trying to match the theoretical and real world. The use of a scaling factor points to either inaccuracies in the input data to the model or the underlying workings of the model. Errors in the input data are covered below. Investigations into the underlying working of ADMS-Urban have not been performed in this project, but this is widely used and well validated modelling package. In addition, the model has been validated using monitored data at a site not in Northern Ireland, as described below.

4.1.1 Uncertainties associated with NAEI Data

The quoted uncertainty in the emissions of BaP in the NAEI is +60% to –200% of value. This uncertainty does not cover the difference between the model and measured results. It is suspected that the NAEI is artificially low as it does not include the estimates of unregulated burning of non-smokeless fuel in smoke control zones. Evidence for the use of unregulated non-smokeless fuel for heating (primary) and recreation (secondary) is discussed later on in this report.

Modelling of an area on the UK mainland was performed as a validation of the NAEI emissions data. Emissions from the Swansea and Port Talbot area of Wales were modelled and the concentration calculated for the Swansea Cwm Level Park PAH Network site. The model was run with the same parameters as for Northern Ireland, except that local meteorology measured at Mumbles Head was used instead of the Northern Ireland data. The Mumbles Head wind data is collected in the same way as the Northern Ireland wind data, in an open field site and may overestimate the wind speed in urban locations, as described in Section 4.1.2. The same regional background concentration of 0.18 ng.m^{-3} was included in the modelled results. Table 4-3 shows the 2008 modelled concentration along with the 2008, 2009 and 2010 measured concentrations.

2008 Modelled ng.m^{-3}	2008 Measured ng.m^{-3}	2009 Measured ng.m^{-3}	2010 Measured ng.m^{-3}
0.22	0.32	0.24	0.26
Measured / Modelled	**1.45**	**1.09**	**1.18**

Table 4-3 Modelled concentrations at the Swansea Cwm Level Park PAH Network site

This successful model validation shows that the underlying modelling principle is sound and that the NAEI data is probably correct for the Swansea and Port Talbot area. As this area is on the Natural Gas Grid, it is likely that there is little burning of smokeless fuel. Therefore, the NAEI has correctly accounted for all emission sources in this area.

4.1.2 Effect of Wind Speed

The wind speed and direction data used for the model was collected from UK Met Office stations designed to give accurate measurements of prevailing wind. Wind data is collected on tall masts to remove surface effects and on open field sites to remove local effects due to buildings and trees. However, the wind speeds measured in urban environments are generally much lower than those measured at open field sites. For example, if the daily averaged wind speed measured at Heathrow airport is compared to the daily averaged wind speeds measured at sites in central London, then the urban wind speed is a factor of 2 to 3 lower.

Wind speed directly affects the rate of dispersion of a pollutant from a site, so any inaccuracy in this will have a direct result in the modelled concentration. The effect of wind speed on modelled concentration was investigated by running the model with the wind speed set to half the measured value for every wind speed used. The resulting modelled concentration was a factor of 1.39 higher than for the concentration obtained using measured wind speed, which is close to a factor of √2 (1.414).

The model was also run using the meteorological data collected from the Dunmurry PAH Network station instead of the four Met Office stations. This data is collected in an urban area with a lower mast than at Office stations. The background corrected concentrations are given in Table 4-4

	Monitoring results, ng.m^{-3}	Modelled, ng.m^{-3}	Ratio
Dunmurry	0.565	0.29	1.95
Ballymena	2.28	0.34	6.71
Derry	1.158	0.63	1.84

Table 4-4 Modelled concentrations using Dunmurry wind data

The modelled results show the same inconsistency in the Ballymena results, but show the effect of reduced wind speed on measured concentrations. The wind roses for the four Met Office Stations and Dunmurry are shown in Figure 4-1.

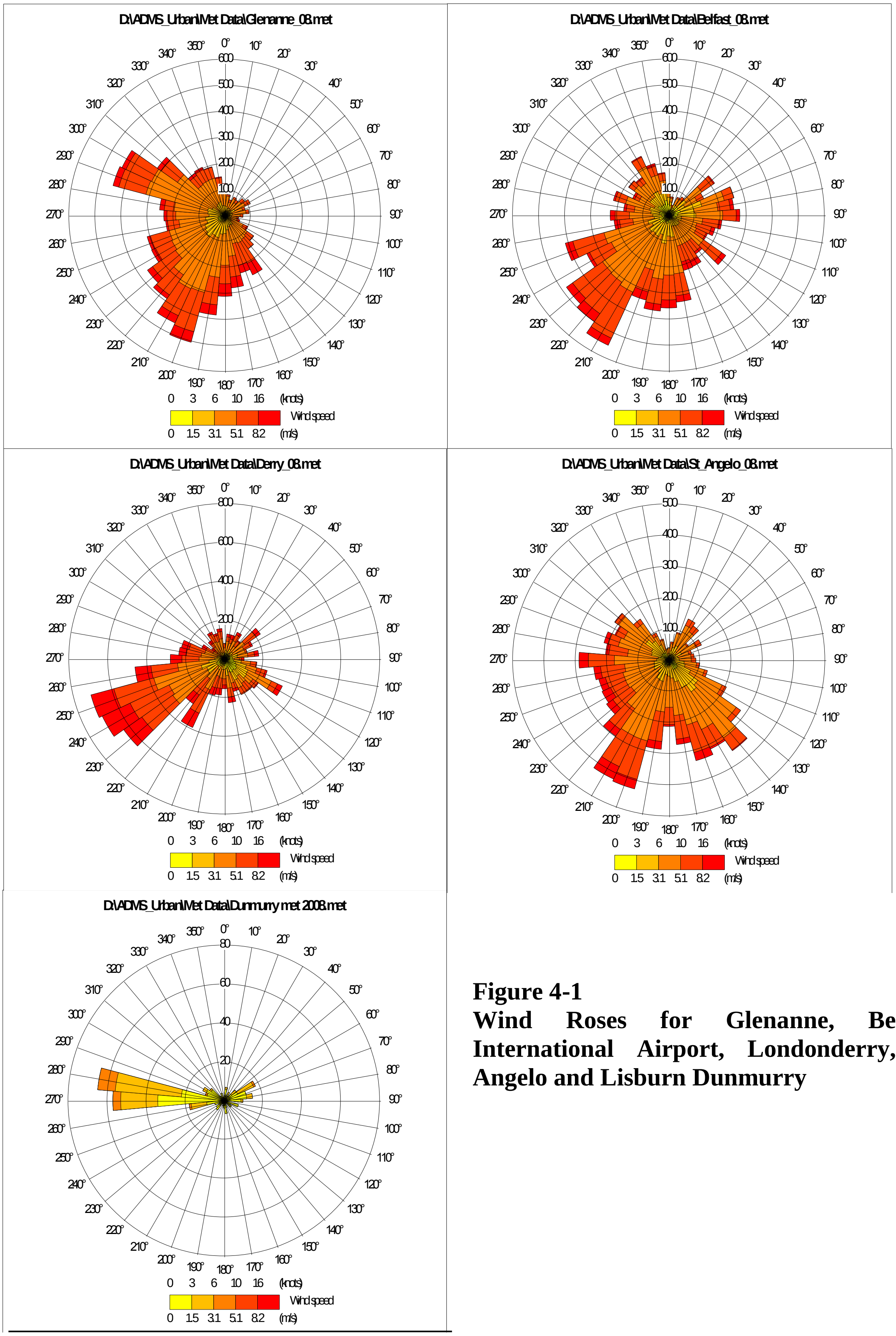


Figure 4-1
Wind Roses for Glenanne, Belfast International Airport, Londonderry, St Angelo and Lisburn Dunmurry

4.1.3 Effect of Scaling Factor on Modelled Results

A scaling factor for the model was determined by the ratio of the background subtracted modelled and measured results from the Londonderry and Lisburn Dunmurry sites (Section 4.1).

The model was then rerun with different scaling factors and the results are shown in Table 4-5. The results have been summarised to show the number of 1km x 1km squares below the lower assessment threshold, the number of squares between the upper and lower assessment thresholds, the number of squares between the upper assessment threshold and the target value and the number of cells above the target value:

	Scaling Factor							
Modelled concentration	**1**	**2**	**3**	**4**	**5**	**5.5**	**6**	**6.5**
Below LAT <0.4 $ng.m^{-3}$	39993	39890	39730	39558	39349	39218	**39072**	38858
Between LAT and UAT 0.4 $ng.m^{-3}$ to <0.6 $ng.m^{-3}$	8	102	229	316	442	535	**641**	812
Between UAT and TV 0.6 $ng.m^{-3}$ to <1 $ng.m^{-3}$	0	9	40	116	186	212	**241**	266
>TV 1 $ng.m^{-3}$ and above	0	0	2	11	24	36	**47**	65

Table 4-5 Effect of Scaling Factor on Modelled Concentrations

A scaling factor of 6.0 was decided upon for all future calculations, taken from the values in Table 4-2 in Section 4.1 (mean of the Dunmurry and Derry ratios = 5.99). The background concentration is added in after the scaling factor is applied to the modelled concentrations.

Due to the large magnitude of the scaling factor, concentrations where there is little modelled contribution have been amplified. Therefore, modelled concentrations in low concentration areas (< 0.30 $ng.m^3$) may be over estimated by the model. However the modelled concentrations at the high concentration values are likely to be more accurate.

The use of a high scaling factor shows that there is likely to be a significant underestimate in the NAEI emission inventory as discussed in the previous section.

The scaled modelled concentrations for the forty seven 1 km x 1km squares exceeding the target value are given in Table 4-6. The table is ordered by location and then by concentration.

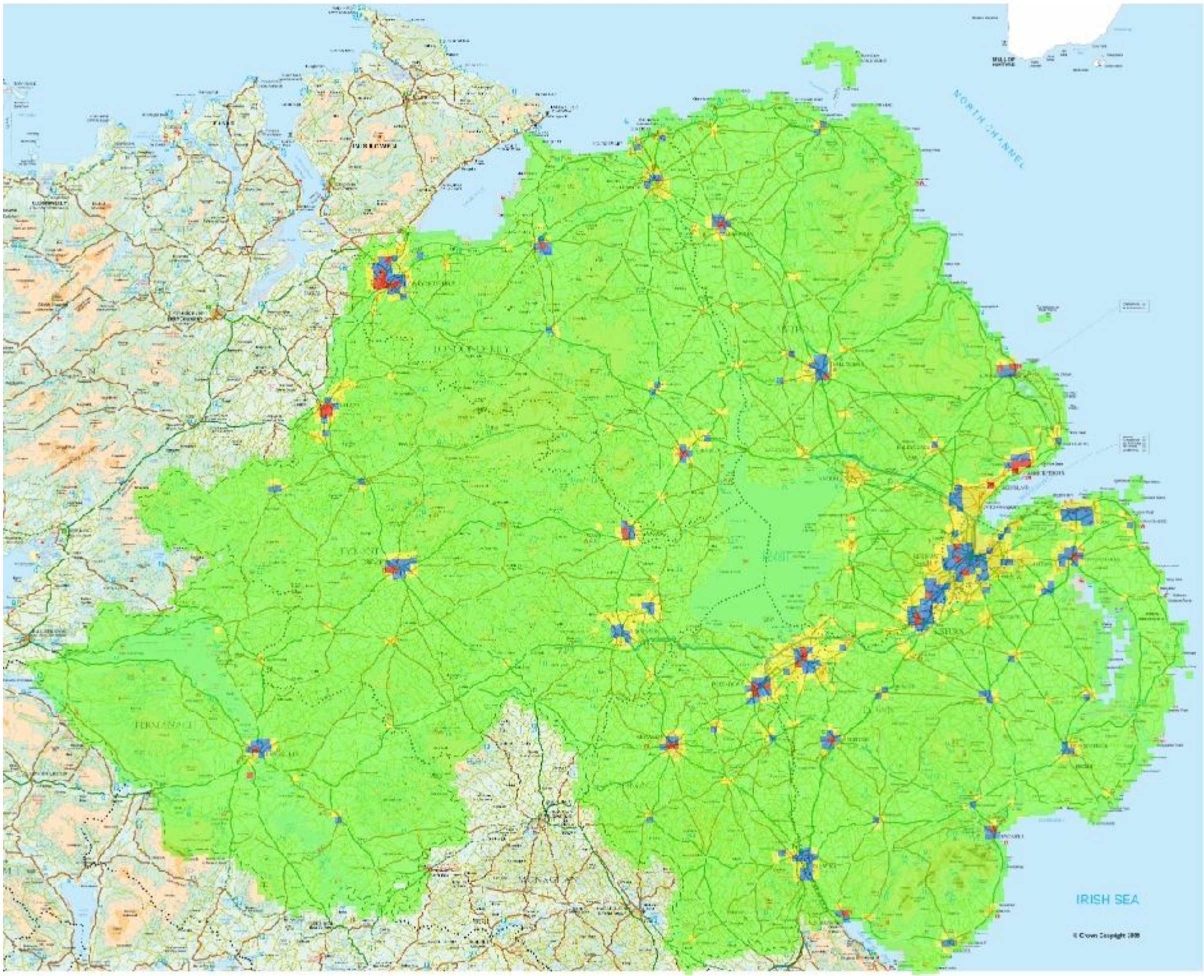
UK grid		**NI Grid**			
X	**Y**	**X**	**Y**	**ng.m^{-3}**	**Location**
98500	504500	288412	345064	1.18	Armagh East
97500	504500	287417	344979	1.04	Armagh East
126500	559500	311607	402224	1.17	Ballymena Ballykeel
112500	584500	295523	425922	1.73	Ballymoney
122500	503500	312398	346108	1.05	Banbridge
144500	529500	332098	373879	1.07	Belfast South West, Falls Road
145500	527500	333265	371972	1.12	Belfast, South, Lisburn Rd
144500	531500	331928	375872	1.22	Belfast, West, Crumlin Rd
154500	542500	340951	387683	1.32	Carrickfergus
154500	543500	340866	388680	1.32	Carrickfergus
155500	543500	341862	388765	1.04	Carrickfergus
156500	543500	342858	388850	1.02	Carrickfergus
150500	540500	337137	385349	1.01	Carrickfergus South
93500	538500	280538	378493	1.36	Cookstown
93500	537500	280624	377497	1.20	Cookstown
59500	579500	243186	416402	1.45	Derry Centre
61500	579500	245177	416573	1.29	Derry East
60500	583500	243839	420469	1.07	Derry North
59500	581500	243015	418392	1.01	Derry North
58500	579500	242191	416316	1.37	Derry West
58500	580500	242105	417311	1.08	Derry West
60500	579500	244181	416487	1.06	Derry, just east of river
59500	580500	243100	417397	1.62	Derry, just west of river
139500	524500	327544	368472	1.05	Dunmurry
33500	509500	223283	344517	1.11	Enniskillen A4 bridge
32500	505500	222628	340451	1.08	Enniskillen South West - Derrylin Rd
153500	558500	338587	403538	1.24	Larne
155500	558500	340580	403709	1.01	Larne
84500	583500	267729	422526	1.43	Limavady
137500	520500	325893	364317	1.32	Lisburn West
137500	521500	325807	365313	1.08	Lisburn West
119500	517500	308219	359796	1.91	Lurgan
119500	516500	308305	358800	1.14	Lurgan
118500	515500	307394	357719	1.08	Lurgan
103500	549500	289557	390299	1.53	Magherafelt
146500	487500	337664	332209	1.13	Newcastle
162500	528500	350116	374418	1.10	Newtownards
57500	535500	244956	372436	1.18	Omagh Centre
56500	535500	243960	372351	1.16	Omagh Centre
113500	512500	302669	354306	1.41	Portadown
111500	511500	300763	353140	1.40	Portadown
111500	512500	300678	354136	1.08	Portadown
49500	561500	234774	397631	1.56	Strabane Centre
49500	560500	234859	396635	1.86	Strabane South East

UK grid		**NI Grid**			
X	**Y**	**X**	**Y**	**ng.m^{-3}**	**Location**
48500	560500	233864	396550	1.65	Strabane South West
48500	561500	233778	397545	1.55	Strabane West
122500	476500	314690	319216	1.00	Warrenpoint, South of Newry

Grid coordinates denote centre of 1km x 1km square

Table 4-6 Modelled BaP concentrations based on 2008 total emissions

Figure 4-2 below shows the modelled concentration for all the 1km x 1km squares covering Northern Ireland:



Key:

🟩 < 0.4 ng.m^{-3} (<LAT)

🟨 0.40 to < 0.6 ng.m^{-3} (LAT to <UAT)

🟦 0.6 to 1.0 ng.m^{-3} (UAT to <TV)

🟥 >1.0 ng.m^{-3} (>TV)

Figure 4-2 Modelled BaP concentrations with emissions at 2008 levels

Some of the hot spot areas with modelled concentrations above the target value of 1 ng.m^{-3} were remodelled only using sources within 15 km of the hot spots areas and the results are shown in Figures 4-3 to 4-6. These reduced model runs slightly underestimate the concentrations when compared to the full model run, but the full model run cannot output contoured data, only average 1km x 1km data. These figures show the interpolated concentrations from the 1km x 1km modelled values and not the absolute exceedance areas. The colour key is the same as Figure 4-2.

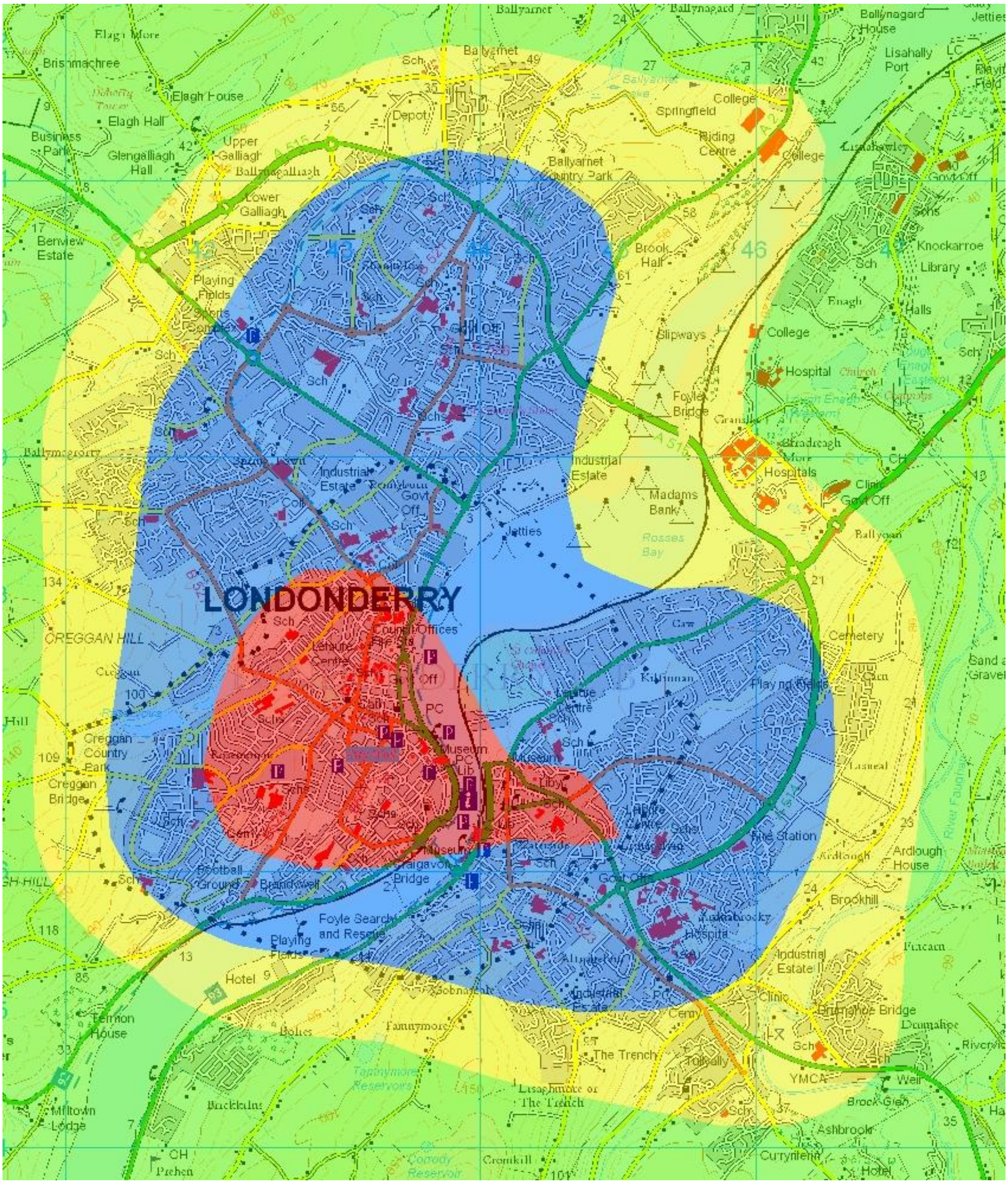


Figure 4-3 Derry - Modelled BaP concentrations with emissions at 2008 levels

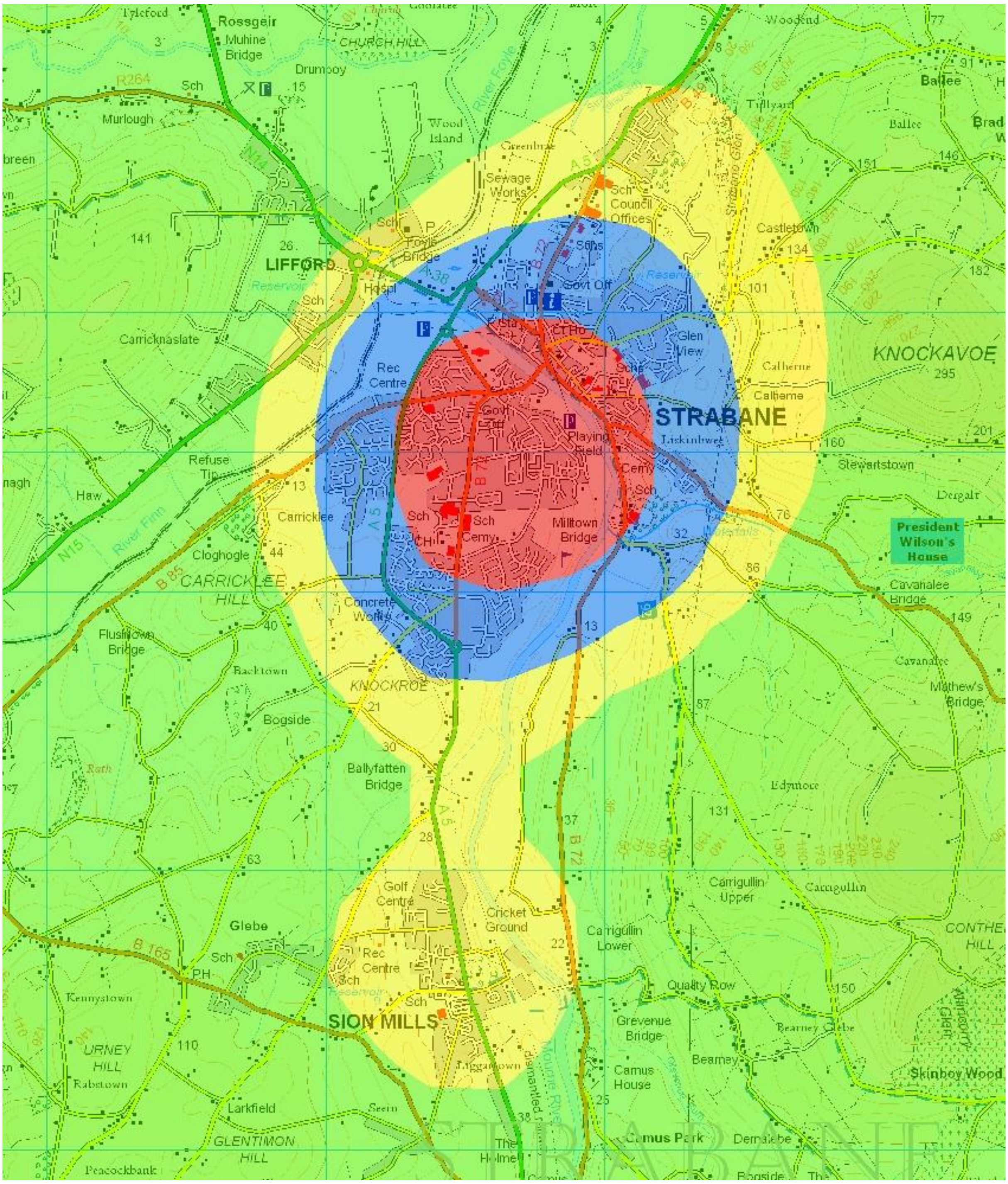


Figure 4-4 Strabane - Modelled BaP concentrations with emissions at 2008 levels

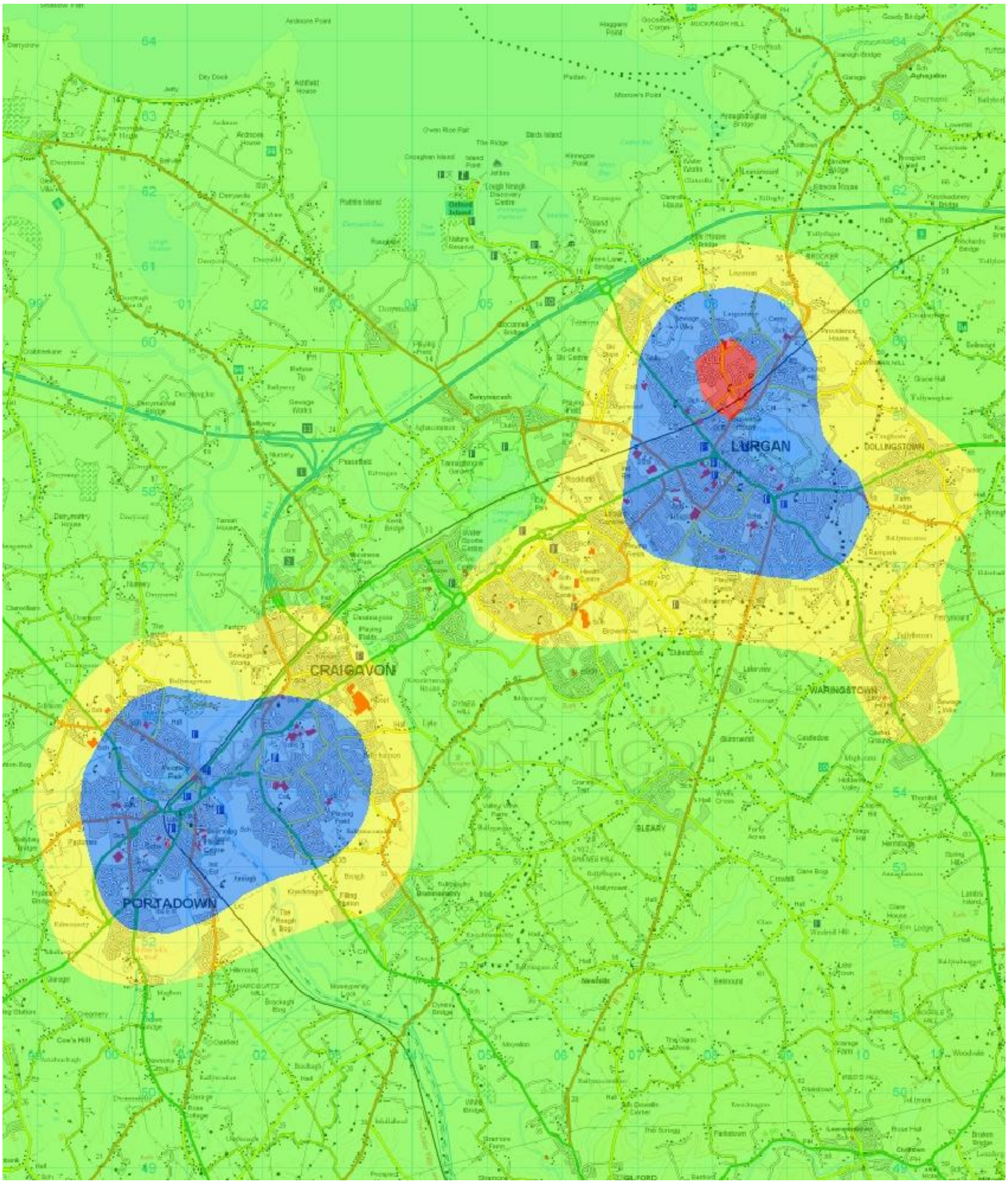
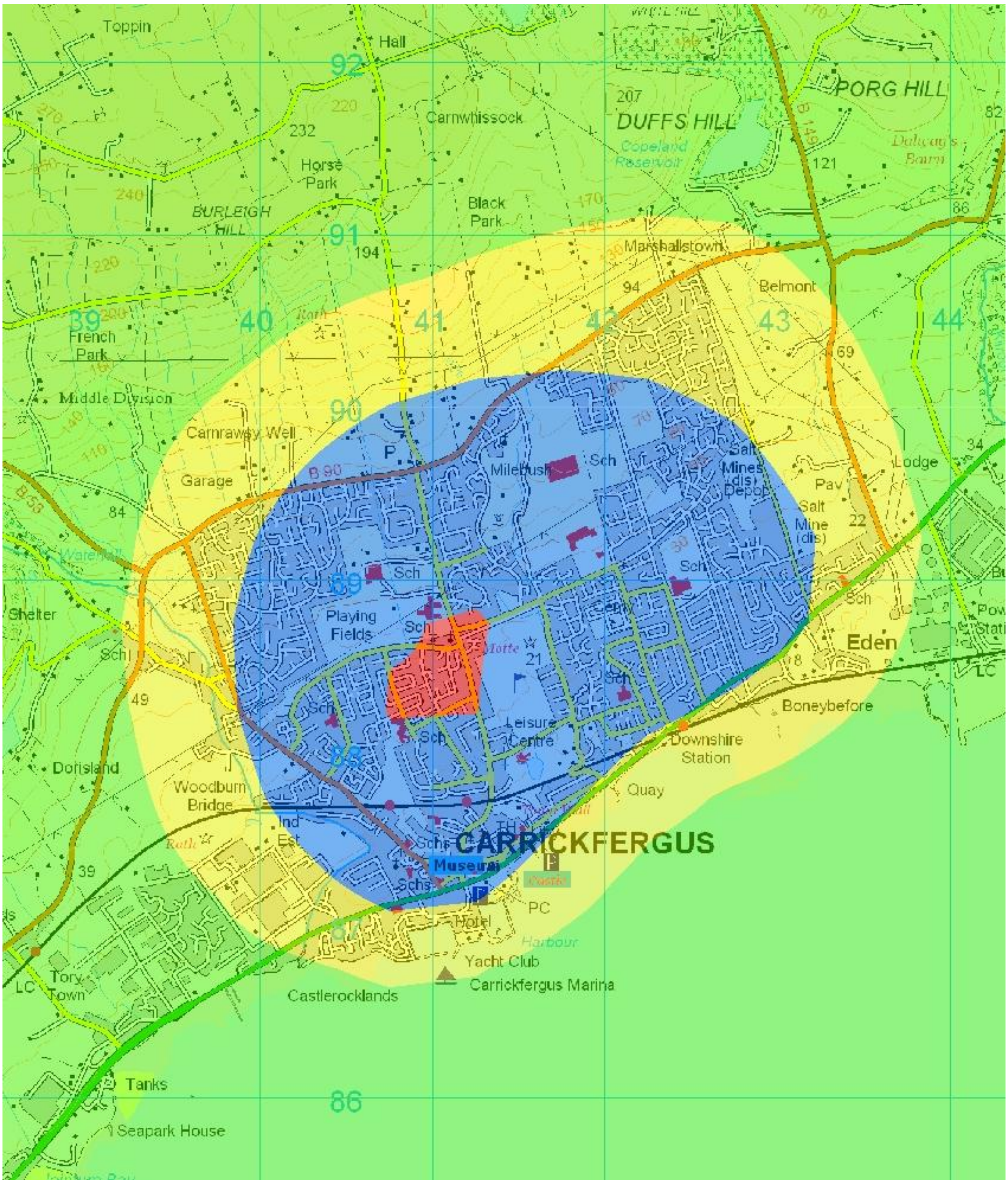


Figure 4-5 Lurgan and Portadown - Modelled BaP concentrations with emissions at 2008 levels



Note: The yellow lines in the blue highlighted area are ‘B’ roads and not modelled concentrations

Figure 4-6 Carrickfergus - modelled BaP concentrations with emissions at 2008 levels

4.2 Commercial, Institutional and Residential Emissions

From looking at the breakdown of the emissions from each square where the European Union target value of $1ng.m^{-3}$ is exceeded it can be seen that the predominant source of BaP is from Commercial, Institutional and Residential (CIR) combustion. Table 4-7 shows the breakdown of emission sources for the 47 1km squares above the target value. The exceedance of the target value in the Enniskillen South West - Derrylin Rd square is driven by an industrial solvent use process and not CIR emissions.

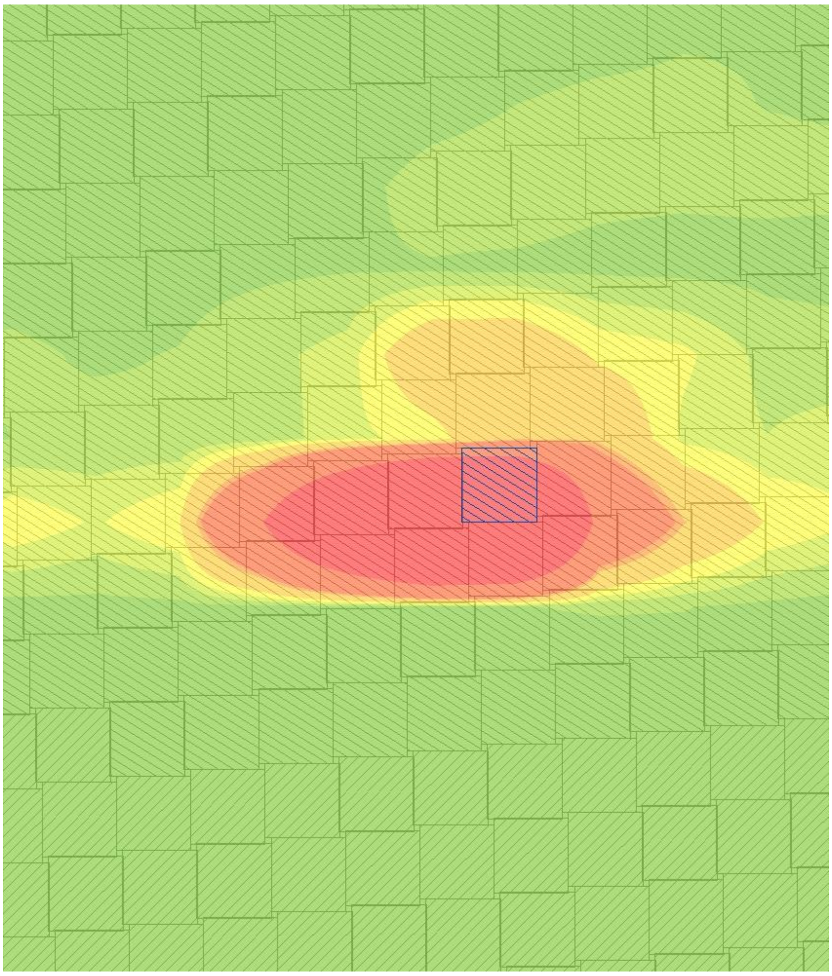
Location	**CIR Kg / year**	**Total Kg/year**	**CIR / Total**	**Location**	**CIR Kg / year**	**Total Kg/year**	**CIR / Total**
Armagh East	0.672	0.698	0.963	Enniskillen A4 bridge	0.548	0.570	0.961
Armagh East	0.558	0.592	0.943	Enniskillen South West - Derrylin Rd	0.004	0.630	0.006
Ballymena Ballykeel	0.619	0.655	0.945	Larne	0.689	0.716	0.962
Ballymoney	1.080	1.104	0.978	Larne	0.481	0.514	0.936
Banbridge	0.547	0.572	0.956	Limavady	0.846	0.871	0.971
Belfast South West, Falls Road	0.419	0.472	0.888	Lisburn West	0.650	0.686	0.948
Belfast, South, Lisburn Rd	0.512	0.548	0.934	Lisburn West	0.428	0.461	0.928
Belfast, West, Crumlin Rd	0.536	0.590	0.908	Lurgan	1.130	1.161	0.973
Carrickfergus	0.734	0.762	0.963	Lurgan	0.508	0.535	0.950
Carrickfergus	0.659	0.686	0.961	Lurgan	0.510	0.542	0.941
Carrickfergus	0.438	0.460	0.952	Magherafelt	0.901	0.931	0.968
Carrickfergus	0.477	0.508	0.939	Newcastle	0.670	0.692	0.968
Carrickfergus South	0.493	0.516	0.955	Newtownards	0.531	0.561	0.947
Cookstown	0.739	0.761	0.971	Omagh Centre	0.531	0.570	0.932
Cookstown	0.647	0.667	0.970	Omagh Centre	0.571	0.593	0.963
Derry Centre	0.752	0.800	0.940	Portadown	0.836	0.858	0.974
Derry East	0.648	0.681	0.952	Portadown	0.841	0.875	0.961
Derry North	0.484	0.523	0.925	Portadown	0.508	0.543	0.936
Derry North	0.380	0.428	0.888	Strabane Centre	0.745	0.765	0.974
Derry West	0.773	0.803	0.963	Strabane South East	1.060	1.085	0.977
Derry West	0.483	0.510	0.947	Strabane South West	0.891	0.925	0.963
Derry, just east of river	0.410	0.455	0.901	Strabane West	0.786	0.813	0.967
Derry, just west of river	0.850	0.906	0.938	Warrenpoint, south east of Newry	0.571	0.590	0.968
Dunmurry	0.442	0.472	0.936				

Table 4-7 BaP emissions in the 1km squares exceeding the EU target value

The mean CIR / Total ratio is 0.929, excluding the solvent driven emissions in the Enniskillen South West - Derrylin Rd square.

Results from daily monitoring performed in the Lisburn area[19] over the period December 2007 to March 2008 reinforce the conclusion that the main source of BaP in Northern Ireland is from commercial, institutional and residential combustion. The measurements showed a marked increase in daily BaP concentrations on public and school holidays. The report concluded, “While it is possible that this was caused by operation of domestic central heating systems for longer periods of time as home occupancy is higher it is likely that secondary open fires or room heaters were used to a greater extent on these days.”

If the concentrations from the emissions from a single square are modelled (with no background added) to show their dispersion, it can be seen that concentrations are highest within 2.5 km from the source and drop to a tenth of the highest concentration within 5 to 6 km. This dispersion can be seen in Figure 4-7. It should be noted that the high concentrations close to the source are driven by low wind speeds when dispersion is reduced, and the two areas to the N and NW of the source are driven by the higher wind speeds from the prevailing wind direction.



Key, $\mu g.m^{-3}$

🟩 0
🟩 0 - 0.00014531
🟩 0.00014531 - 0.000363275
🟨 0.000363275 - 0.000581239
🟨 0.000581239 - 0.000871859
🟧 0.000871859 - 0.001598408
🟧 0.001598408 - 0.001816373
🟥 0.001816373 - 0.004649915
🟥 0.004649915 - 0.018527005

Blue square:
Source of BaP

Grey squares
1km x 1km grid

Figure 4-7
Modelled concentrations from a single square

The above shows that the concentrations of BaP depend on the local dispersion of CIR emissions. The effect of reduced CIR emissions on BaP concentrations is discussed in the following section.

4.3 Reduced Commercial, Institutional and Residential Emissions

The model was re-run with the CIR emissions reduced to 90%, 80%, 70%, 60% and 0% of their 2008 levels. The modelled concentrations include the use of a scaling factor of 6 and a background concentration of 0.18 ng.m^{-3} as measured at Kilkitt. Table 4-8 shows the effect of the reductions on all of the squares in Northern Ireland.

	2008 total	**90% CIR**	**80% CIR**	**70% CIR**	**60% CIR**	**NO CIR**
Below LAT <0.4 ng.m^{-3}	39072	39195	39304	39402	39509	39997
Between LAT and UAT 0.4 ng.m^{-3} to <0.6 ng.m^{-3}	641	556	488	429	371	2
Between UAT and LV 0.6 ng.m^{-3} to <1.0 ng.m^{-3}	241	214	186	152	112	1
>LV 1.0 ng.m^{-3} and above	47	36	23	18	9	1

Table 4-8 Effect of reduced CIR emissions on modelled concentrations

It should be noted that the 1 exceedance shown for no CIR emissions is due to industrial solvent use in the Enniskillen South West, Derrylin Rd square and not CIR emissions.

If the exceedance due to industrial solvent use is deleted from the data in Table 4-8 and a regression line calculated, then the reduction required in CIR levels to bring the modelled 1 x 1 km results below 1 ng.m^{-3} is 50% of the 2008 emissions levels. It should be noted that monitoring stations close to sources may still record exceedances of the target value despite this reduction.

To examine the effect of CIR reduction in more detail, the concentrations for the 47 squares exceeding the target value was modelled for the above reduction scenarios. The results can be seen in Tables 4-9a and 4-9b. Table 4-9a is sorted by location and then concentration and table 4-9b is sorted by concentration only.

	2008 total	90% CIR	80% CIR	70% CIR	60% CIR	NO CIR
Location	**Modelled Concentration, ng.m^{-3}**					
Armagh East	1.18	1.08	0.99	0.90	0.81	0.25
Armagh East	1.04	0.96	0.88	0.81	0.73	0.26
Ballymena Ballykeel	1.17	1.08	0.99	0.91	0.82	0.29
Ballymoney	1.73	1.59	1.44	1.30	1.15	0.27
Banbridge	1.05	0.97	0.89	0.81	0.73	0.26
Belfast South West, Falls Road	1.07	1.00	0.93	0.85	0.78	0.33
Belfast, South, Lisburn Rd	1.12	1.04	0.96	0.87	0.79	0.30
Belfast, West, Crumlin Rd	1.22	1.13	1.04	0.95	0.86	0.33
Carrickfergus	1.32	1.22	1.11	1.01	0.90	0.27
Carrickfergus	1.32	1.22	1.11	1.01	0.90	0.27
Carrickfergus	1.04	0.96	0.88	0.81	0.73	0.26
Carrickfergus	1.02	0.94	0.87	0.79	0.72	0.27
Carrickfergus South	1.01	0.93	0.86	0.79	0.71	0.27
Cookstown	1.36	1.25	1.14	1.03	0.92	0.27
Cookstown	1.20	1.11	1.01	0.92	0.83	0.27
Derry Centre	1.45	1.33	1.22	1.10	0.99	0.30
Derry East	1.29	1.19	1.09	0.99	0.89	0.28
Derry North	1.07	0.99	0.91	0.84	0.76	0.29
Derry North	1.01	0.94	0.87	0.80	0.73	0.30
Derry West	1.37	1.26	1.15	1.04	0.93	0.27
Derry West	1.08	1.00	0.92	0.84	0.76	0.27
Derry, just east of river	1.06	0.98	0.90	0.83	0.75	0.30
Derry, just west of river	1.62	1.49	1.36	1.23	1.10	0.31
Dunmurry	1.05	0.97	0.89	0.82	0.74	0.29
Enniskillen A4 bridge	1.11	1.02	0.94	0.85	0.77	0.26
Enniskillen South West, Derrylin Rd	1.08	1.07	1.07	1.07	1.06	1.05
Larne	1.24	1.14	1.05	0.95	0.85	0.27
Larne	1.01	0.94	0.87	0.79	0.72	0.27
Limavady	1.43	1.32	1.20	1.09	0.97	0.27
Lisburn West	1.32	1.21	1.11	1.01	0.91	0.29
Lisburn West	1.08	1.00	0.92	0.84	0.77	0.29
Lurgan	1.91	1.74	1.58	1.42	1.25	0.28
Lurgan	1.14	1.05	0.97	0.88	0.79	0.27
Lurgan	1.08	1.00	0.92	0.84	0.76	0.28
Magherafelt	1.53	1.41	1.28	1.16	1.03	0.28
Newcastle	1.13	1.04	0.95	0.86	0.77	0.24
Newtownards	1.10	1.02	0.94	0.85	0.77	0.27
Omagh Centre	1.18	1.09	1.00	0.91	0.83	0.30
Omagh Centre	1.16	1.07	0.99	0.90	0.81	0.28
Portadown	1.41	1.30	1.18	1.07	0.95	0.26
Portadown	1.40	1.29	1.17	1.06	0.95	0.27
Portadown	1.08	1.00	0.92	0.84	0.76	0.28

	2008 total	90% CIR	80% CIR	70% CIR	60% CIR	NO CIR
Location	**Modelled Concentration, ng.m^{-3}**					
Strabane Centre	1.56	1.43	1.30	1.17	1.04	0.27
Strabane South East	1.86	1.70	1.54	1.38	1.22	0.27
Strabane South West	1.65	1.52	1.38	1.24	1.11	0.28
Strabane West	1.55	1.43	1.30	1.17	1.04	0.27
Warrenpoint, south of Newry	1.00	0.92	0.85	0.77	0.69	0.22

Table 4-9a Effect of reduced CIR Emissions on modelled concentrations, sorted by location and then concentration

It should be noted that the exceedance shown for the Enniskillen South West, Derrylin Rd square is due to BaP emissions from industrial solvent use in and not CIR emissions.

	2008 total	90% CIR	80% CIR	70% CIR	60% CIR	NO CIR
Location	**Modelled Concentration, ng.m^{-3}**					
Lurgan	1.91	1.74	1.58	1.42	1.25	0.28
Strabane South East	1.86	1.70	1.54	1.38	1.22	0.27
Ballymoney	1.73	1.59	1.44	1.30	1.15	0.27
Strabane South West	1.65	1.52	1.38	1.24	1.11	0.28
Derry, just west of river	1.62	1.49	1.36	1.23	1.10	0.31
Strabane Centre	1.56	1.43	1.30	1.17	1.04	0.27
Strabane West	1.55	1.43	1.30	1.17	1.04	0.27
Magherafelt	1.53	1.41	1.28	1.16	1.03	0.28
Derry Centre	1.45	1.33	1.22	1.10	0.99	0.30
Limavady	1.43	1.32	1.20	1.09	0.97	0.27
Portadown	1.41	1.30	1.18	1.07	0.95	0.26
Portadown	1.40	1.29	1.17	1.06	0.95	0.27
Derry West	1.37	1.26	1.15	1.04	0.93	0.27
Cookstown	1.36	1.25	1.14	1.03	0.92	0.27
Carrickfergus	1.32	1.22	1.11	1.01	0.90	0.27
Carrickfergus	1.32	1.22	1.11	1.01	0.90	0.27
Lisburn West	1.32	1.21	1.11	1.01	0.91	0.29
Derry East	1.29	1.19	1.09	0.99	0.89	0.28
Larne	1.24	1.14	1.05	0.95	0.85	0.27
Belfast, West, Crumlin Rd	1.22	1.13	1.04	0.95	0.86	0.33
Cookstown	1.20	1.11	1.01	0.92	0.83	0.27
Omagh Centre	1.18	1.09	1.00	0.91	0.83	0.30
Armagh East	1.18	1.08	0.99	0.90	0.81	0.25
Ballymena Ballykeel	1.17	1.08	0.99	0.91	0.82	0.29
Omagh Centre	1.16	1.07	0.99	0.90	0.81	0.28
Lurgan	1.14	1.05	0.97	0.88	0.79	0.27
Newcastle	1.13	1.04	0.95	0.86	0.77	0.24
Belfast, South, Lisburn Rd	1.12	1.04	0.96	0.87	0.79	0.30
Enniskillen A4 bridge	1.11	1.02	0.94	0.85	0.77	0.26

	2008 total	90% CIR	80% CIR	70% CIR	60% CIR	NO CIR
Location	**Modelled Concentration, ng.m^{-3}**					
Newtownards	1.10	1.02	0.94	0.85	0.77	0.27
Derry West	1.08	1.00	0.92	0.84	0.76	0.27
Lisburn West	1.08	1.00	0.92	0.84	0.77	0.29
Portadown	1.08	1.00	0.92	0.84	0.76	0.28
Lurgan	1.08	1.00	0.92	0.84	0.76	0.28
Enniskillen South West, Derrylin Rd	1.08	1.07	1.07	1.07	1.06	1.05
Belfast South West, Falls Road	1.07	1.00	0.93	0.85	0.78	0.33
Derry North	1.07	0.99	0.91	0.84	0.76	0.29
Derry, just east of river	1.06	0.98	0.90	0.83	0.75	0.30
Banbridge	1.05	0.97	0.89	0.81	0.73	0.26
Dunmurry	1.05	0.97	0.89	0.82	0.74	0.29
Armagh East	1.04	0.96	0.88	0.81	0.73	0.26
Carrickfergus	1.04	0.96	0.88	0.81	0.73	0.26
Carrickfergus	1.02	0.94	0.87	0.79	0.72	0.27
Derry North	1.01	0.94	0.87	0.80	0.73	0.30
Larne	1.01	0.94	0.87	0.79	0.72	0.27
Carrickfergus South	1.01	0.93	0.86	0.79	0.71	0.27
Warrenpoint, south of Newry	1.00	0.92	0.85	0.77	0.69	0.22

Table 4-9b Effect of reduced CIR Emissions on modelled concentrations, sorted by concentration

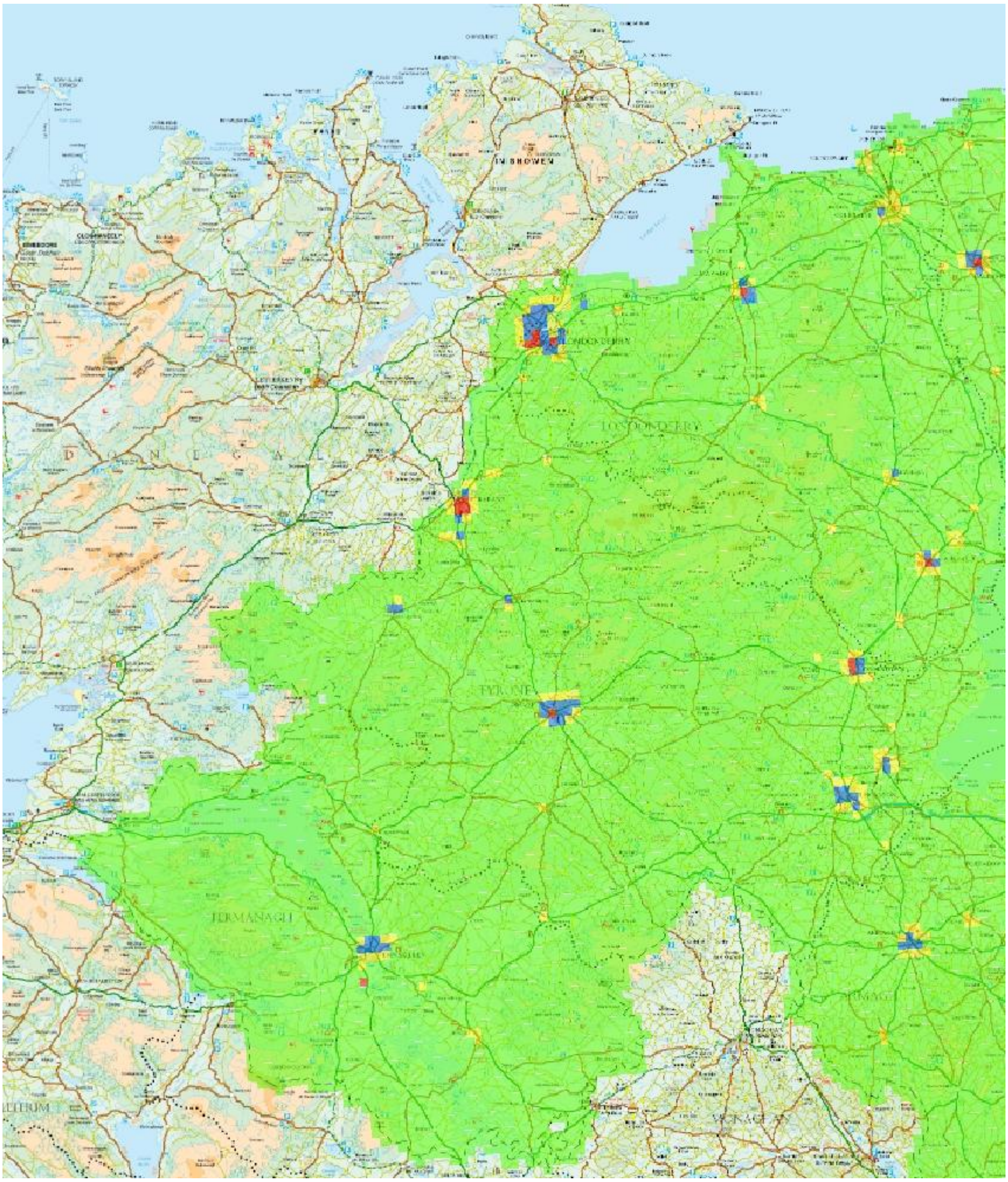
It should be noted that the exceedance shown for the Enniskillen South West, Derrylin Rd square is due to BaP emissions from industrial solvent use and not CIR emissions.

The effect of the reduction in CIR Emissions on the modelled concentrations can also be seen in Figures 4-8a and 4-8b below:

Key:

- 🟩 < 0.4 ng.m^{-3} (<LAT)
- 🟨 0.40 to < 0.6 ng.m^{-3} (LAT to <UAT)
- 🟦 0.6 to 1.0 ng.m^{-3} (UAT to <TV)
- 🟥 >1.0 ng.m^{-3} (>TV)

Figure 4-8a Modelled BaP concentrations with CIR emissions at 80% of 2008 levels



Key:

- 🟩 < 0.4 ng.m^{-3} (<LAT)
- 🟨 0.40 to < 0.6 ng.m^{-3} (LAT to <UAT)
- 🟦 0.6 to 1.0 ng.m^{-3} (UAT to <TV)
- 🟥 >1.0 ng.m^{-3} (>TV)

Figure 4-8b Modelled BaP concentrations with CIR emissions at 80% of 2008 levels

The same hot spot areas, shown in Figures 4 to 7, where the BaP concentration exceeded the target value, were remodelled with the CIR emissions set at 80% of their 2008 values. The resulting interpolated modelled concentrations are shown in Figures 4-9 to 4-12. The colour key is the same as Figure 4-8.

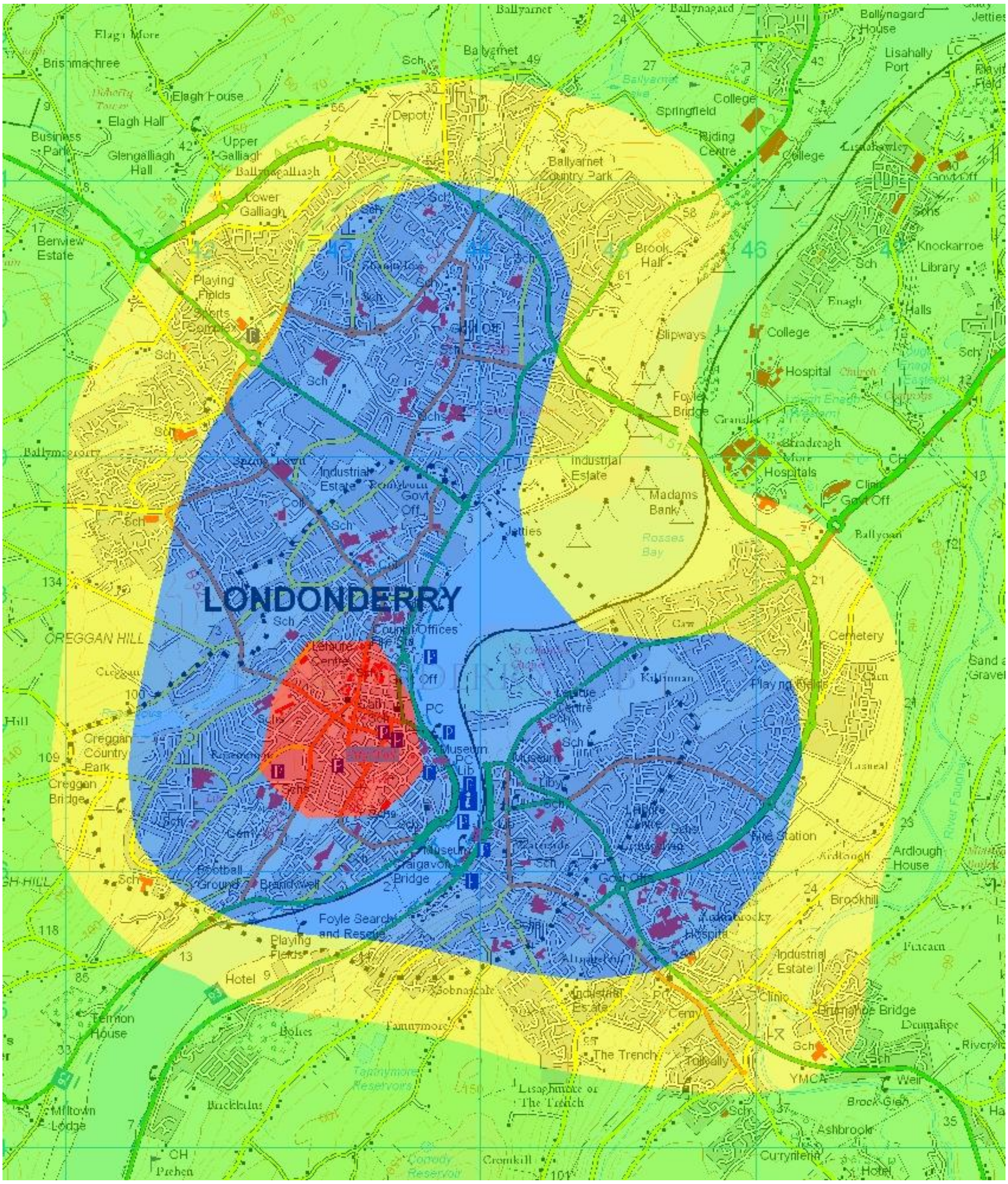


Figure 4-9 Derry - Modelled BaP concentrations with CIR Emissions at 80% of 2008 levels

Compared to Figure 4-3, exceedance areas have reduced to the east and north of the city, with the number of exceedance squares dropping from 8 to 4 due to a modelled reduction in CIR emissions of 80% of 2008 values.

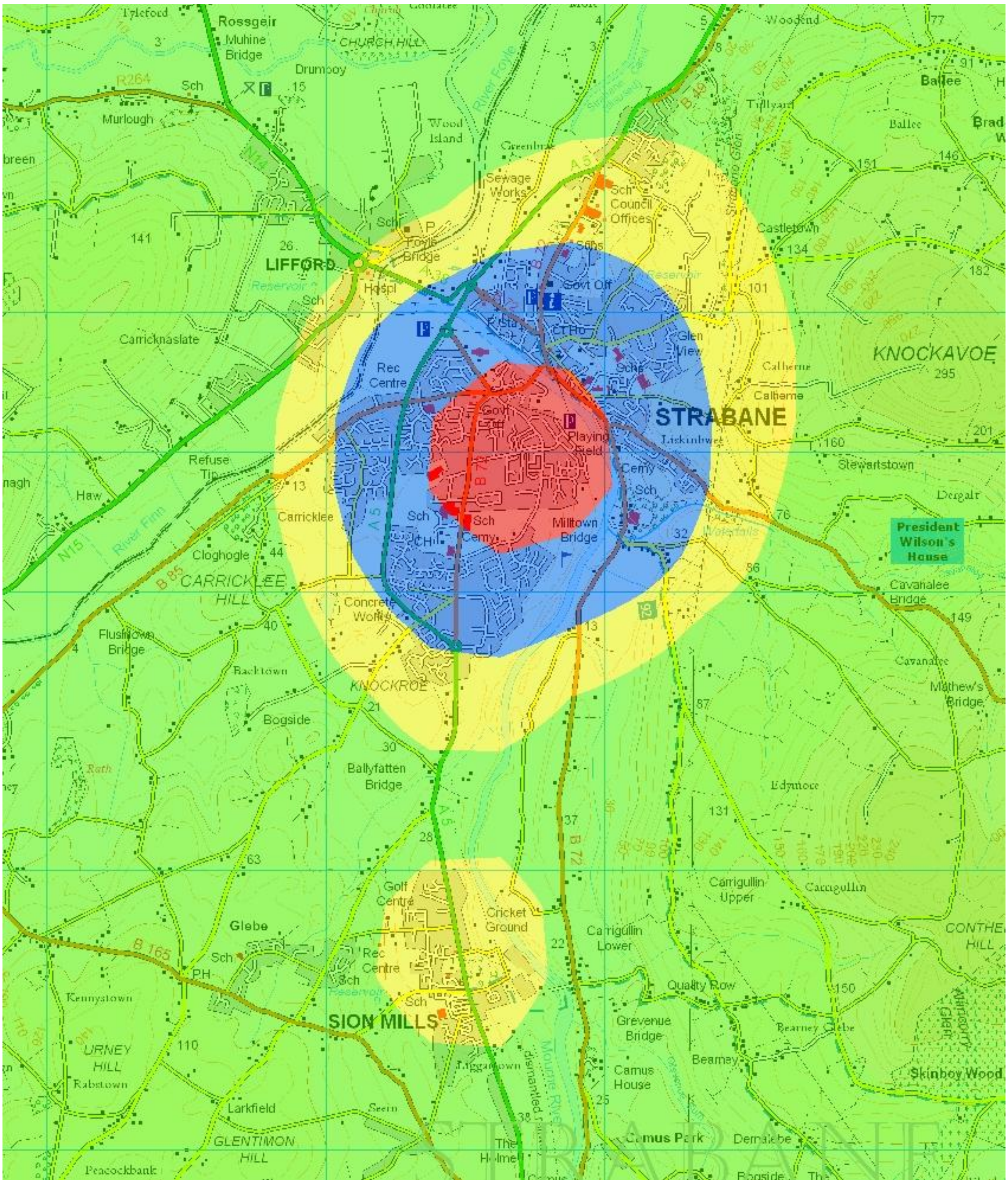


Figure 4-10 Strabane - Modelled BaP concentrations with CIR emissions at 80% of 2008 levels

Compared to Figure 4-4, the exceedance area has reduced in the town centre, but with the same number of exceedance squares as for the 2008 CIR emissions.

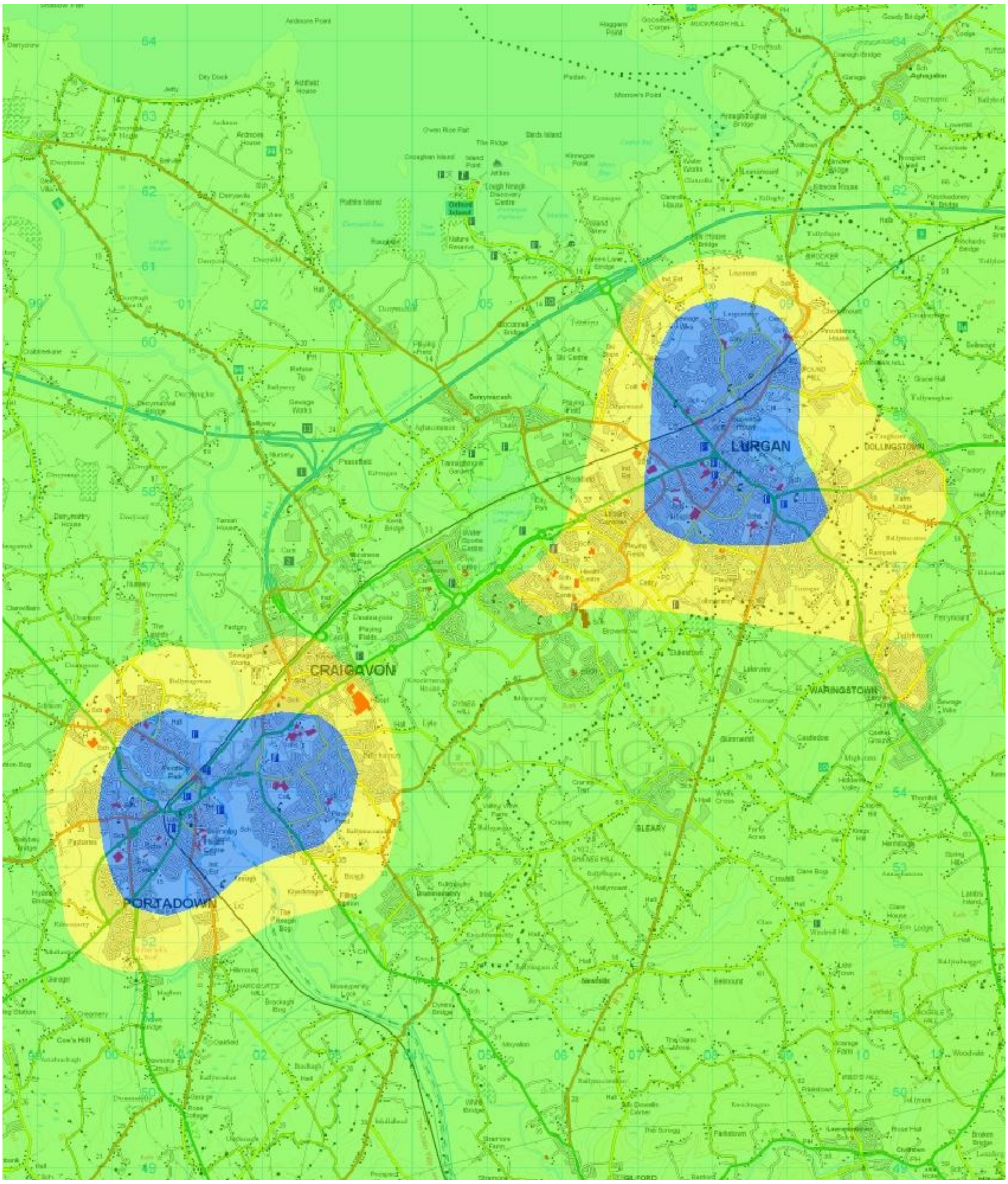
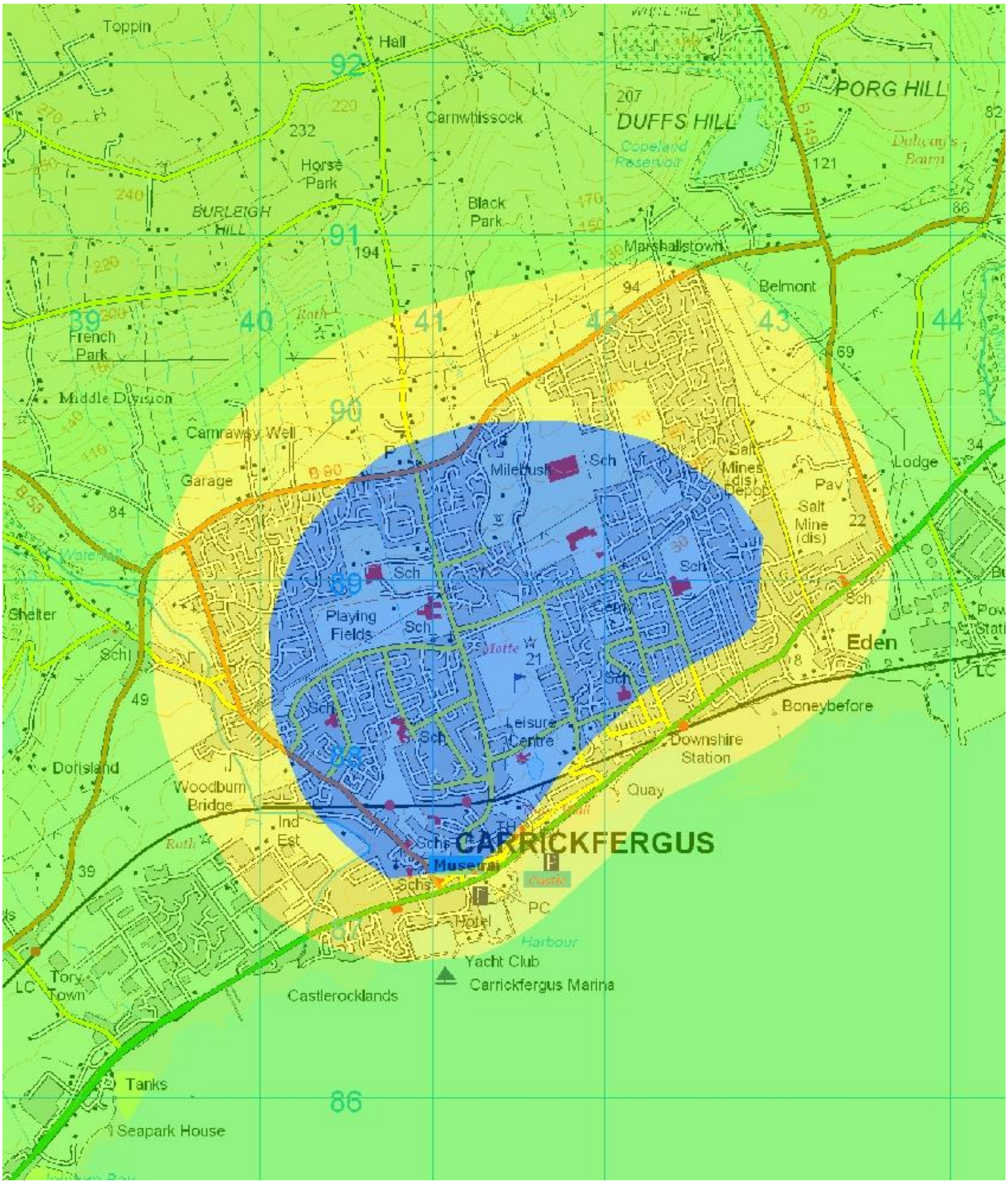


Figure 4-11 Lurgan and Portadown - Modelled BaP concentrations with CIR emissions at 80% of 2008 levels

Compared to Figure 4-5, the exceedance in the centre of Lurgan has not been plotted as it is a single square and therefore can not be extrapolated. Lurgan has 1 exceedance square with CIR emissions of 80% of 2008 values compared with 3 squares at 2008 levels.



Note: The yellow lines in the blue highlighted area are 'B' roads and not modelled concentrations

Figure 4-12 Carrickfergus - Modelled BaP concentrations with CIR emissions at 80% of 2008 levels

Compared to Figure 4-6, the above figure shows no exceedance areas, even though the full model shows 2 exceedance squares for Carrickfergus. This is due to sources only within 15km being included in this model run. The modelled exceedance squares are only 0.1ng.m^{-3} above the EU target value in the full model run. Figures 4-9 to 4-12 show the interpolated concentrations from the 1km x 1km modelled values and not the absolute exceedance areas.

4.4 Other sources

According to the National Atmospheric Emissions Inventory (NAEI) there are 14836 1km x 1km squares covering Northern Ireland. For each square the BaP emissions are broken down into 11 UNECE Sectors plus point sources. Emissions from each of these Sectors were included in the model and are discussed below. The heading number specifies the UNECE Sector number.

4.4.1 01 Energy Production and Transformation

The NAEI lists no emissions squares as having BaP emissions from energy production and transformation.

44.2 02 Commercial, Institutional and Residential Combustion

The NAEI lists 14319 emission squares as having BaP emissions from commercial, institutional and residential combustion. The maximum emission for 2008 is 1.13kg, with 454 squares having emissions greater than 100g and 13865 squares with less than 100g. When modelled these emissions have significant impact on ambient concentrations, which are discussed in the sections above. Commercial, institutional and residential combustion emissions make up 91% of anthropogenic BaP emissions in 2008.

4.4.3 03 Industrial Combustion

The NAEI lists 2146 emission squares as having BaP emissions from industrial combustion. The maximum emission for 2008 is 0.313kg, with only one additional square having emissions greater than 30g and the rest of the squares with emissions less than 30g. When modelled these emissions do not have a significant impact on ambient concentrations.

4.4.4 04 Industrial Processes

The NAEI lists 14371 emission squares as having BaP emissions from industrial processes. The maximum for 2008 is 11g, with only 12 squares having emissions greater than 1g and the rest of the squares with emissions less than 1g. When modelled these emissions do not have a significant impact on ambient concentrations.

4.4.5 05 Production and Distribution of Fossil Fuels

The NAEI lists no emissions squares as having BaP emissions from production and distribution of fossil fuels.

4.4.6 06 Solvent Use

The NAEI has 30 1km x 1km squares showing BaP emissions from solvent use. When modelled these emissions have significant impact on ambient concentrations. These emissions squares are shown in Table 4-10:

UK Grid		**Irish Grid**		**BaP from Solvent Use, g**	**Location**
X	**Y**	**X**	**Y**		
32500	505500	222628	340451	608	Culky, 2.5 SW of Enniskillen
39500	504500	229679	340051	143	Farnamullan, 1M south of Lisbellaw
104500	591500	286956	432207	143	SE Coleraine, A29 ring road
117500	483500	309117	325764	112	Newry, Centre / South
84500	586500	267472	425513	98	North of Limavady
128500	534500	315734	377495	33	N of Crumlin
54500	511500	244013	348292	29	Fivemiletown
131500	484500	322976	327947	24	SW of Hilltown
143500	527500	331273	371802	22	Kennedy Way Industrial Estate Belfast / Water treatment plant
48500	512500	237956	348778	19	Stragole, 4m W of Fivemiletown
160500	506500	349998	352328	19	South of B7, 1.5 miles West of Killyleagh
44500	519500	233380	355404	17	South of Trillick
134500	519500	322989	363066	17	Lissue Industrial Estate West, Lisburn
143500	491500	334336	335939	17	Castlewellan
105500	507500	295128	348646	14	East of Richhill
113500	549500	299515	391154	14	North of Toomebridge
147500	532500	334831	377124	14	North docks area, Belfast, SW of Jn1 M2
64500	514500	253712	352129	7	W of Clogher
104500	548500	290638	389389	7	7miles SE of Cookstown
27500	501500	217992	336046	5	Croaghrim Two, 6 miles SW of Enniskillen
121500	563500	306285	405780	5	East Cullybackey
143500	488500	334591	332950	5	Bryansford
154500	499500	344615	344844	5	Woodgrange, 2.8 miles WNW Downpatrick
76500	536500	263784	375051	2	Sultan, 11 miles East of Omagh
96500	520500	285060	360826	2	SE of Laghey Corner
100500	480500	292441	321335	2	Cullyhanna
105500	497500	295978	338688	2	SW of Markethill
122500	507500	312058	350092	2	South of Ballykelly, 2.4 miles N of Banbridge
139500	536500	326521	380426	2	Killcross, 3.5miles SW of Mallusk
146500	519500	334943	364088	2	1.4 miles SW of Mealough

Table 4-10 BaP emissions from solvent use

The concentrations from these emissions were modelled and the results are summarised in Table 4-11. These emissions were treated the same way as other sources emitted at close to ground level and not through an elevated stack. Modelled concentrations include the use of a scaling factor of 6 and a background concentration of 0.18 ng.m^{-3}. This is to aid comparison with the modelled concentrations presented in the rest of the report.

UK Grid		Irish Grid		Solvent only	2008 Total emissions	
X	Y	X	Y	Modelled BaP concentration, ng.m^{-3}	Modelled BaP concentration, ng.m^{-3}	Urban area affected
32500	505500	222628	340451	0.88	1.08	Enniskillen
39500	504500	229679	340051	0.35	0.48	Enniskillen
104500	591500	286956	432207	0.35	0.53	Coleraine
117500	483500	309117	325764	0.31	0.70	Newry
84500	586500	267472	425513	0.29	0.48	Limavady
32500	506500	222543	341446	0.23	0.35	Enniskillen
33500	505500	223623	340536	0.23	0.31	Enniskillen
128500	534500	315734	377495	0.22	0.41	Crumlin
33500	506500	223538	341531	0.22	0.32	Enniskillen
54500	511500	244013	348292	0.21	0.49	Fivemiletown

Table 4-11 Modelled BaP concentrations from solvent sources only

It can be seen that solvent sources emitting close to ground level can significantly contribute towards raised ambient concentrations.

The emissions of BaP from solvent sources in the NAEI are calculated from the employment distribution from the wood treatment sector, as this derived from data from the Office for National Statistics and are therefore an approximation of the BaP emissions from this source.

4.4.7 07 Road Transport

The NAEI lists 12788 emission squares as having BaP emissions from road transport. The maximum for 2008 is 62g, with 430 squares having emissions greater than 6g and 12358 squares having less than 6g. When modelled these emissions do not have a significant impact on ambient concentrations.

4.4.8 08 Other Transport

The NAEI lists 14451 emission squares as having BaP emissions from other transport. The maximum for 2008 is 48g, with 43 squares having emissions greater than 5g and 14408 squares having less than 5g. When modelled these emissions do not have a significant impact on ambient concentrations.

4.4.9 09 Waste Treatment and Disposal

The NAEI lists 11111 emission squares as having BaP emissions from waste treatment and disposal. The maximum for 2008 is 3g. When modelled these emissions do not have a significant impact on ambient concentrations.

4.4.10 10 Agriculture

The NAEI lists no emissions squares as having BaP emissions from agriculture.

4.4.11 11 Nature

The NAEI lists 14456 emission squares as having BaP emissions from natural sources. The maximum for 2008 is 42g, with 14177 squares having emissions greater than 4g and 279 squares having less than 4g. When modelled these emissions do not have a significant impact on ambient concentrations.

4.4.12 Point sources

The NAEI lists 2 emission squares as having BaP emissions from point sources. The emissions levels for 2008 are 101g and 82g. When modelled these emissions do not have a significant impact on ambient concentrations.

5.0 Reducing Commercial, Institutional and Residential BaP Emissions

The model results show that the main contributor to BaP concentrations across Northern Ireland is emissions from Commercial, Institutional and Residential (CIR) emissions along with a small contribution of emissions from solvent use in the wood treatment industry.

Mechanisms for reducing CIR emissions are discussed below:

5.1 Current Hot Spots

The model predicts 47 1km x 1km squares that exceed the BaP EU Target Value (TV) of 1 ng.m^{-3}. All but one of these squares is in an urban area where the CIR emissions are the driving factor behind the exceedance of the LV. These 46 squares cover residential areas in 21 urban areas. Table 5-1 shows the current pollution prevention measures being implemented in these areas to control and reduce particulate emissions. BaP emissions are mainly dependent on the burning of non-smokeless fuels from CIR properties.

Urban Area	**Smoke Control Areas**	**Comments**	**PM$_{10}$ Air Quality Management Areas**	**Comments**
Lurgan	Yes	All except central commercial district, stretches SW to Craigavon	None	
Newtownards	Yes	West Winds Estate	None	Instituted in 2004, revoked 2007 due to lower concentrations than expected.
Portadown	Yes	West, NE and Craigavon to Lurgan	None	
Strabane	Yes	Whole of Strabane town centre, effective June 2004	Strabane	Whole of Strabane town centre.
Ballymena	Yes	Galgorm, not enforced, with no complaints regarding non-compliance	Ballykeel Dunclug	Ballykeel AQMA will be reviewed in 2012 regarding 2011/2012 winter data and completion of on-going fuel-switching. Exceedances predicted to drop with natural gas conversions. To be revoked.
Belfast	Yes	Entire city, docks excluded	M1/Westlink corridor	Dominated by traffic emissions.
Derry City	Yes	Derry East and West	None	PM$_{10}$ monitoring in Brandywell ceased 2010 but continuing at background site in Brooke Park.
Armagh	None		None	
Ballymoney	None		Eastern Ballymoney	Revoked in 2010. Exceedances predicted to drop with NG conversions.
Banbridge	None		None	

Urban Area	Smoke Control Areas	Comments	PM_{10} Air Quality Management Areas	Comments
Carrickfergus	None		Carrickfergus Greenisland	Revoked Feb 2007. Revoked Feb 2007.
Cookstown	None		None	
Dunmurry		In part	None	Part of Lisburn City Council.
Enniskillen	None		None	
Larne		In part	None	
Limavady	None		None	
Lisburn		In part	None	
Magherafelt	None		None	
Newcastle	None	From Down Council Web site: “Further reviews may indicate a need to expand the domestic smoke control programme”	None	
Omagh	None		None	
Warrenpoint	None	Newry covered by smoke control, 6 miles to NW	None	

Table 5-1 Smoke control areas and air quality management areas where BaP target value is exceeded

Table 5-1 shows that only 7 of the towns where the BaP target value is exceeded have smoke control instituted and that 3 have currently declared Air Quality Management Areas (AQMA) for PM_{10}. PM_{10} concentrations in the Belfast AQMA are dominated by traffic emissions and are therefore not relevant to BaP emissions and resultant concentrations. AQMAs in Strabane, Ballymena and Ballymoney are all due to domestic fuel use dominating particulate emissions. Local Authority action plans for Strabane are discussed below.

The implementation and enforcement of smoke control legislation in the hot spots listed above could have a significant impact in reducing CIR emissions and therefore BaP concentrations. If CIR emissions are reduced by 50%, the modelling undertaken as part of this study suggests that at a 1 x 1 km grid level, no grid squares are likely to have average concentrations in excess of 1 $ng.m^{-3}$, the BaP target value. It should be noted that monitoring stations close to sources may still record exceedances of the target value despite this reduction.

5.1.1 Strabane

The whole town of Strabane has been declared as an AQMA for PM_{10} particulates from domestic sources. Below is a summary of Strabane District Council’s action plans to reduce PM_{10} concentrations. Any reductions in PM_{10} will also have a beneficial effect on the BaP concentrations.

Two schemes have been implemented in conjunction with Northern Ireland Electricity, which have replaced approximately 170 solid fuel appliances in owner-occupied and privately rented properties. A significant number of properties were also referred to the Warm Homes Scheme funded by the Department for Social Development. The Northern Ireland Housing Executive (NIHE) heating conversion scheme is also substantially complete and it is estimated that there are approximately 80 further conversions required across the district, which were completed during 2010.

Funding has been secured to implement the Western Homes Environmental Assessment Project (WHEAP) for a period of 5 years from November 2009. This project is targeted at vulnerable homes with persons aged 65 years and over and those with children less than 5 years of age. The project includes assessment of a range of matters including fuel poverty and energy efficiency. The project is also a referral agency for the DSD Warm Homes Scheme and thereby provides continuity in improving the energy efficiency of such homes and reducing emissions of PM_{10}.

The following table is a summary of Strabane District Council's Action Plan as laid out in their 2010 Air Quality Progress Report.

Measure	Focus	Lead authority	Planning phase	Implementation phase	Indicator	Progress to date	Estimated completion date	Comments relating to emission reductions
Smoke control Zone	Domestic emissions	Strabane District Council	Complete	Complete	Reduced coal burning	PM_{10} and SO_2 Objectives met	Complete and on-going monitoring	Substantial emission reductions achieved
NIHE Conversions	Domestic emissions	NIHE	Complete	On-going	Reduced coal burning	Substantial majority of homes with OFCH	2010	Substantial emission reductions achieved
Warm Home Scheme promotion	Domestic emissions	Strabane District Council	Complete	On-going	Reduced coal burning	Referrals made to warm homes	On-going referrals WHEAP funded for 5 years	Complementary Emissions reductions achieved
Energy Efficiency Promotion	Domestic emissions	Strabane District Council	Complete	On-going	Reduced emissions	NIE Energy Efficiency Schemes complete, routine referrals to EST Advice Line. WHEAP project initiated	On-going	
Planning Controls	Domestic & commercial/ Industrial emissions	Planning Service	Complete	On-going	Informatives placed on planning approvals	On-going	On-going	Some developments constructed without solid fuel burning appliances installed
Bonfire Guidance and Controls	Commercial emissions	Strabane District Council	Complete	On-going	Reduced detections of illegal burning	On-going	On-going	

5.2 Fuel Use

The amount of BaP emitted varies dramatically dependent on the fuel burnt. Table 5-2 shows the emission factors for BaP from the combustion of different fuels in different types of appliance.

Appliance Fuel type	**Appliance Fuel type**	**Emission factor, mg.tonne^{-1}**
Solid fuel glass fronted boiler	Anthracite / SSF	30
Solid fuel single purpose boiler	Anthracite / SSF	30
Solid fuel non-glass fronted boiler	Coal (75%) / SSF (10%) / Anthracite (15%)	1550 / 330 / 30
Open fire	Coal (75%) / SSF (10%) / Anthracite (15%)	1550 / 330 / 30
Oil	Oil	3.43
Range cooker and heater burning coal	SSF	330
Other stove / space heater	Wood	1300

Anthracite	Classed as smokeless fuel
SSF	Smokeless Solid Fuel
Coal	Bituminous coal

Table 5-2 BaP emission factors from different fuels and appliances

These emission factor figures are derived from tests on appliances running at ideal conditions. In real-life this is not often the case. Damping down a fire at night with slack (very small pieces of coal and coal dust) lowers the combustion temperature and therefore increases the emission rate of PAHs. This increased emission is not taken account of in the above table or the NAEI. Damping down a fire at night is a common practice and should be discouraged to reduce the emission of PAHs.

There is also anecdotal evidence that slack is burnt for a quick small fire for decorative effect / secondary heating. This type of fire burns at a lower temperature than large lumps of coal and hence emits higher levels of PAHs. The same is true of wood and peat burnt in hand fed open fires, which have low thermal efficiency and potentially high PAH emissions.

As discussed above BaP emissions can be reduced by the use of smokeless fuel (anthracite), operating appliances at their designed combustion temperatures, reduce ‘slacking’ and by reducing the amount of solid use fuel burnt across Northern Ireland.

5.2.1 Solid Fuel

Solid fuel is widely available across Northern Ireland, sold directly from providers and from other outlets such as petrol stations. Table 5-3 gives two sets of prices collected in 2011. The first was obtained from a fuel survey by Strabane District Council (smoke control area) and the second from a petrol station in a non-smoke controlled area in County Antrim.

Grade	**Strabane survey**	**Antrim survey, cost per 25kg bag**
Premium coal – anthracite	£7.68	£7.80
Household coal – bituminous coal	£7.49	£5.99
Doubles – large lumps	-	£7.70
Slack	-	£6.90
Burnglow – smokeless fuel	-	£7.50

Note: Strabane survey was for the average price of 50kg bags; the price has been halved for comparison.

Table 5-3 Indicative solid fuel prices

If it is assumed that the average household burns around 3 - 4 tonnes of coal a year[33] then the difference in fuel cost between anthracite and bituminous coal, assuming a £1 per 25kg bag difference, would be £120 - £160 in a total fuel bill of ~£1160.

During the 1970s and 1980s solid fuel systems were installed in public sector properties. Oil was not used due to the crisis in the worldwide market. The Northern Ireland Housing Executive (NIHE) has been implementing a conversion programme since 1996 to replace existing solid fuel central heating systems in their housing stock with oil or gas systems. Since 2000, only oil (where gas is not available) and gas have been offered as the replacement fuel. Out of 110,000 NIHE properties, 40,000 currently use oil or gas, 50,000 properties use solid fuels, while 20,000 use electricity for heating[20].

NIHE was performing conversions at a rate of 9,000 properties a year (a third of which are conversions to gas) with a priority on solid fuel properties being converted first. Table 5-4 shows data supplied by NIHE on the number of NIHE controlled properties still using solid fuel as their primary fuel. These figures are per District Office Area and therefore will also include rural villages with lower CIR emission (population) densities.

District Office Area	Number of Properties using Solid Fuel for Primary Heating
Derry	752
Armagh	488
Newtownards	452
Ballymena	436
Downpatrick	398
Limavady	349
Omagh	339
Fermanagh	291
Banbridge	273
Magherafelt	248
Portadown	219
Cookstown	203
Strabane	197
Larne	164
Ballymoney	140
Belfast West	101
Belfast South & Belfast South West	91
Carrickfergus	88
Lurgan	69
Lisburn	58
Total	5356

Table 5-4 Number of NIHE properties still using solid fuel as a primary fuel

The 5356 NIHE owned homes correspond to ~10% of the number of homes in NI using solid fuel for primary heating. This may explain some of the lack of correlation between the modelling results in Tables 4-9a / 4-9b and the values in Table 5-4.

In some housing estates that are traditionally considered to be NIHE controlled estates this is no longer the case due to the “Right to Buy” scheme, which has enabled tenants to purchase their properties from the NIHE.

Policy Recommendation 1: Conversion schemes for privately owned/let homes ought to be encouraged, perhaps through the provision of financial support to aid the rate of conversion across Northern Ireland. Further conversions will help to reduce BaP emissions and concentrations as well as PM_{10} concentrations.

As well as reducing the use of solid fuel, the areas where solid fuel is still burnt need to be controlled and monitored by effective use of smoke control legislation. Figure 5-1 shows the smoke control areas in Northern Ireland as listed on the DOE – Northern Ireland Air Website, http://www.airqualityni.co.uk/laqm_sca.php?n_action=sca. However, this is out of date, as it does not include the smoke control areas of Strabane, Derry City and Coleraine and may well not include any recently declared smoke control areas.

Figure 5-1 Smoke control areas in Northern Ireland

It can be seen that smoke control areas have only been implemented in a small number of the urban areas across Northern Ireland. From discussions with local Environmental Health Officers there is still a considerable amount of non-regulated burning of solid fuel in smokeless zones. This backs up the evidence from Section 4.1.1 that the estimated emissions of BaP in the NAEI are considerably less than in real-life.

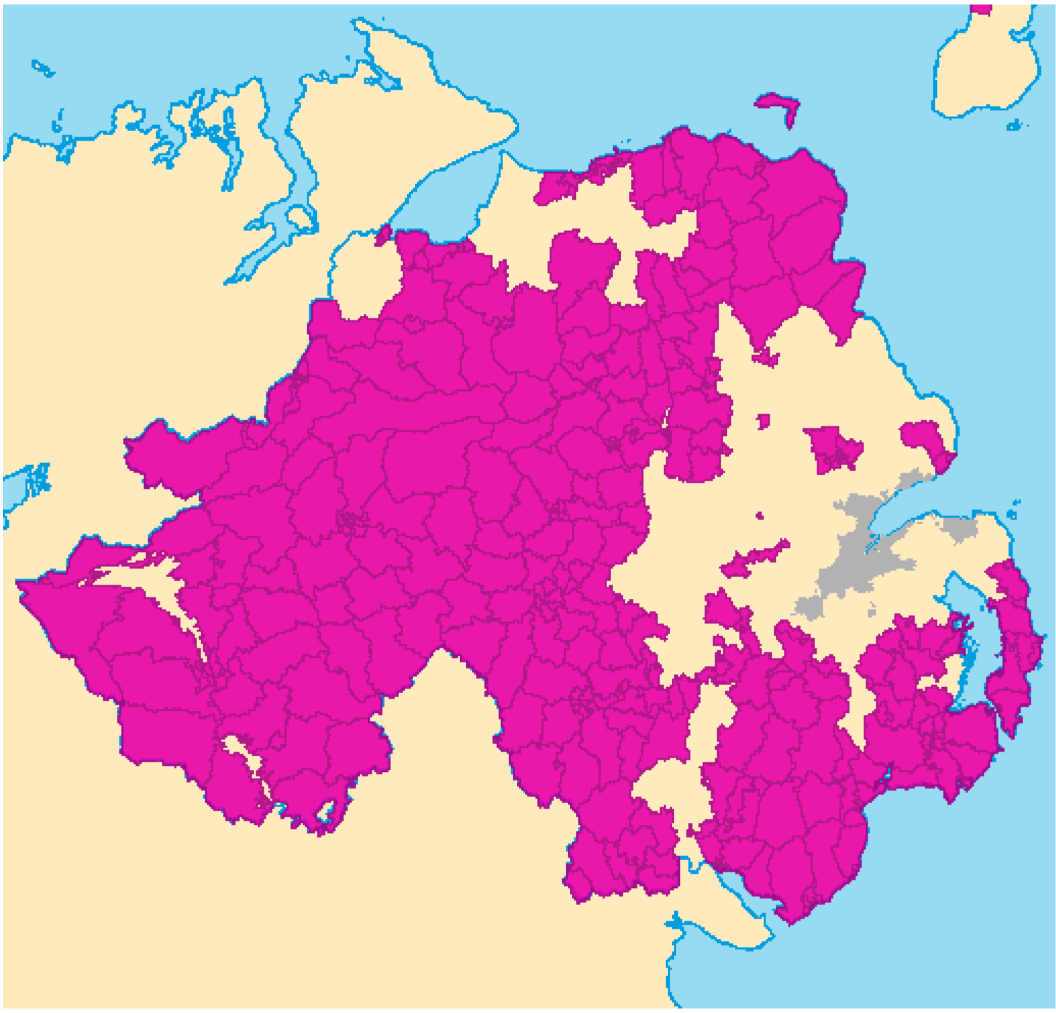
In addition, a survey of councils performed by NPL in 2011 has re-affirmed findings of a previous report[21] which summarised the predicted level of non-compliance with smoke control legislation as 10% in the Belfast city area, 20% in the Belfast surrounding area, 30%

in other urban areas and complete non-compliance in the Derry area. These predictions also apply to those households burning wood.

5.2.2 Gas

In 2001 the Northern Ireland Executive announced its support for the development of a multi million pound natural gas project. The project involves the construction of a gas pipeline from Greater Belfast to Dublin (known as the South North pipeline), which will link with a pipeline from near Carrickfergus to Londonderry (the North West pipeline). The 112km gas pipeline, which connects the Scottish Northern Ireland Pipeline (SNIP), at Carrickfergus, outside Belfast, to the newly built Coolkeeragh power station in Londonderry was commissioned in October 2004. The pipeline has facilitated the development of gas networks in five towns adjacent to the route; Ballymena, Ballymoney, Coleraine, Limavady and Derry.

Figure 2-1 shows the locations of the two gas pipelines supplying Northern Ireland along with those supplying the rest of Ireland. Figure 5-2 shows the areas of Northern Ireland where gas is unavailable, with these areas highlighted in magenta. Urban areas are highlighted in grey.



Areas without gas highlighted in magenta

Figure 5-2 Areas where gas is unavailable

Using 2008 population data from the National Office for Statistics and the list of major towns supplied by gas above, the percentage of the population able to access natural gas is 64%.

Phoenix gas supply ~300,000 homes and businesses in the Greater Belfast Area. After 10 years of supply they have achieved an average of 50% market penetration. If this is split into sectors then the market penetration is:

• Industrial	99%
• Commercial	65%
• Social housing	75%
• Private housing	35%

Affordability remains the main hurdle to conversion to natural gas from solid fuel with conversions costing in the region of £2500 - £5000.

Table 5-5 shows meter point data from Firmus Energy, who supply gas to the rest of Northern Ireland.

	No of Meter points		
Area	**Domestic**	**SME's**	**Contract**
Antrim	1687	103	124
Armagh	100	19	22
Ballymena	1113	184	32
Ballymoney	411	29	12
Banbridge	421	42	10
Coleraine	902	77	28
Craigavon	1316	189	46
Derry	3181	295	54
Limavady	302	54	6
Lisburn	15	12	17
Newry & Mourne	558	98	23
Newtownabbey	1	0	0

Table 5-5 Firmus Energy meter points

It can be seen that the uptake of natural gas in the rest of Northern Ireland is varied and needs to be increased in certain areas.

Greater uptake of natural gas over solid fuel will reduce the emissions of PAHs. However this will require major investment in the conversion of homes in supplied areas and the extension of the current gas pipelines to new areas.

Policy Recommendation 2: Increase the availability of natural gas through extending current pipelines and encouraging uptake in areas already served.

5.2.3 Energy Efficiency Schemes

Increasing energy efficiency and therefore reducing fuel consumption will have a positive effect on the air quality in Northern Ireland due to the reduced emissions of pollutants. This measure will have other benefits on top of the reduction in PAH emissions. The scheme in NI to promote energy efficiency and provide help to disadvantaged homeowners to increase their energy efficiency is the “Warm Homes Scheme”.

The Warm Homes Scheme is funded by the Department for Social Development to make homes warmer, healthier and more energy efficient. The scheme is for people who receive certain qualifying benefits and own or rent their home from a private landlord in Northern Ireland. Housing Executive and Housing Association tenants do not qualify. Under the scheme recipients may be eligible for help with the following:

- Cavity wall insulation
- Loft insulation
- Hot water tank jacket
- Benefit Entitlement Check
- Energy advice

As well as the improvements available under ‘Warm Homes', householders who are in receipt of one of the qualifying benefits may also be eligible for:

- Installation of a energy-efficient oil or gas central heating system where no system currently exists
- Conversion of an existing bottled gas (LPG), solid fuel or Economy 7 heating system to oil or natural gas

If natural gas is available in the applicant’s area then this fuel will be the fuel of choice.

In addition to the above scheme, the Energy Savings Trust run an Insulation Cash-Back Scheme available to all owner-occupiers and private landlords, regardless of income levels or whether or not the householder is in receipt of benefits. The scheme offers £150 cash back for cavity wall insulation and £75 cash back for loft insulation.

Promotion of energy efficiency and the Warm Homes Scheme contributes towards providing improved air quality and increased energy efficiency in homes through heating system conversions and improvements to home insulation. The schemes are of particular benefit to those householders who would otherwise lack the financial means to undertake the conversion or insulation measures.

Policy Recommendation 3: Continue / improve promotion of current energy efficiency schemes to increase the uptake rate and hence reduce emissions and improve quality of life.

5.3 Fuel Poverty

Fuel poverty is defined[22] as the inability to adequately heat your home or use appliances due to a number of factors including:

- the cost of fuel
- greater heating needs due to long periods at home through illness or caring responsibilities
- energy inefficiency, including poor insulation and no or inefficient heating system
- low income, reliance on benefit or reluctance to claim benefit

The Government’s definition of fuel poverty is if a householder needs to spend more than 10% of income to maintain required levels of energy use.

Information from the Northern Ireland House Condition Survey 2001 indicates that there are 203,000 households suffering from fuel poverty in Northern Ireland, which represents 33% of NI households.

The reasons for the high incidence of fuel poverty are attributed to the following:

- There is a lower than average presence of central heating and a more marked reliance on non-traditional dual fuel systems.
- Many Councils have higher proportions of fuel poverty in rural areas (e.g. Magherafelt).
- Levels of insulation in homes are low in places, for example in Newtownabbey it is estimated that 51% of homes have no wall insulation.
- Whilst levels of employment are generally high, household incomes are below the UK average

To address fuel poverty the Government set the target of eliminating fuel poverty in vulnerable households by 2010 and in non-vulnerable households by 2016.

Information from the NI Assembly[23] shows considerable progress had been made in reducing fuel poverty in Northern Ireland between 2001 and 2004 (from 27% to 23%). However, by 2006 the rate of fuel poverty had increased to 34% (a rise of 11%). Much of the increase in fuel poverty rates has been attributed to rising fuel prices between 2004 and 2006. The Northern Ireland Housing Executive's Housing Market Review and Perspectives 2009-2012 Report[24] maintains that it is likely (given increases in fuel prices between 2006 and 2008) that the current level of fuel poverty is at least 40%.

In March 2011 the Minister for Social Development promised £63 million of capital funding over the next 4 years to fund the Warm Homes Scheme for private sector housing[25]. In addition the Housing Executive is planning to spend £16 million in 2011/12 improving its own properties.

From estimates of fuel use[33] and the cost of solid fuels listed in section 5.2.1, the estimated annual heating cost for a house using anthracite is approximately ~£1240, compared to ~£1080 for bituminous coal compared to ~£1500 for oil. Fuel poverty is undoubtedly a driver behind the use of non-smokeless fuel over oil, due to the reduced cost. This may lead to higher than predicted and variable levels of PAHs. In addition to the social and economic benefit of cutting fuel poverty there will also be a benefit to air quality.

6.0 Health Standards and Health Effects

The International Agency for Research on Cancer (IARC) has classified a number of PAHs as possible or probable human carcinogens. Epidemiological studies have established a significant link between lung cancer and occupational exposure to PAHs in both the aluminium smelting industry and at coke works. Probable links to skin and bladder cancer have also been found. The quantitative risk estimates arising from these studies suggest that PAH exposure at concentrations found in ambient air may be a significant public health issue.

It is accepted that the increased risk of cancer observed in occupational studies is likely to be a result of the carcinogenic activity of the whole PAH mixture present, however for practical purposes a marker compound for this carcinogenetic activity is used for legislation purposes. The chosen marker is Benzo[a]pyrene (BaP).

6.1 National Air Quality Objectives

The UK Government and the devolved administrations published the most recent Air Quality Strategy for England, Scotland, Wales and Northern Ireland in July 2007. The strategy contains policies for the assessment and management of UK air quality and implementation of European Union (EU) and International agreements. The strategy sets out air quality standards and objectives to be achieved in subsequent years.

This strategy sets the National Air Quality Objective for an annual mean BaP concentration of 0.25 ng.m^{-3} to be met by 2010. The level is based on the 1999 recommendations from the UK Expert Panel on Air Quality Standards[5]. This recommendation was intended to reduce any risk to the population from exposure to PAHs to one that the panel believed would be so small as to be undetectable. The panel also commented that it does not necessarily follow that all exposure above this standard carries a significant risk, in view of the effective application of an additional tenfold safety factor in deriving the standard.

The National Air Quality Objective came into force on 31st December 2010.

6.2 European Union 4th Air Quality Directive

In December 2004 the Fourth Air Quality Daughter Directive (2004/107/EC) relating to five pollutants including PAHs was published. The Directive set a target value of 1 ng.m^{-3} for PAHs in terms of BaP collected in the PM_{10} fraction. It also set out lower and upper assessment thresholds for BaP. These thresholds are 0.4 ng.m^{-3} and 0.6 ng.m^{-3} respectively. The Directive states that measurement is mandatory in the following areas:

- Zones and agglomerations where levels exceed the upper assessment threshold (0.6 ng.m^{-3}) in at least three of the preceding five years
- Zones and agglomerations in which levels are found to be between the upper and lower assessment threshold (0.4 ng.m^{-3} to 0.6 ng.m^{-3}) in at least three of the preceding five years. In this case measurements can be a combination of measurement, indicative methods and modeling.

In zones and agglomerations where the levels are below the lower assessment threshold (0.4 ng.m^{-3}) modeling or objective estimation techniques can be used to assess concentration levels.

The 4th Daughter Directive states that Member States shall take all necessary measures not entailing disproportionate costs to ensure that, as from 31st December 2012 the target value for BaP is not exceeded.

The modelling undertaken for the purposes of this research project using the input data defined in this report has indicated that forty seven squares of 1 x 1 km were in excess of 1 ng.m^{-3} in 2008. It should be noted that the model used for this assessment and the assumptions set out for this research project are not the same as those adopted for the UK's national compliance assessment and there may be discrepancies in the results due to the different approaches used.

These exceedances of the target value by the modelled concentrations are backed up by measurements in 2008 at Ballymena (2.46 ng.m^{-3}) and Derry (1.39 ng.m^{-3}) being above the target value and measurements at Dunmurry (0.75 ng.m^{-3}) being above the upper assessment threshold. Measurements in 2009 are also above the target value in Ballymena and Derry and above the upper assessment threshold in Dunmurry. Measurements in 2010 are above the target value for all three sites.

6.3 Health Effects

Health effect studies[26] have shown a clear link between exposure to high levels of PAHs and an increased level of lung cancer. Secondary links to bladder cancer have been found, but the direct link to PAHs is hard to prove due to other contributing factors. When setting the National Air Quality Objective for BaP in 1999, EPAQS based their determination of a safe air quality objective on lung cancer as the most relevant outcome of PAH exposure.

The EPAQS method was based on a health study on aluminium smelters[27] showing that a cumulative exposure to 10-99 μg.m^{-3}.year^{-1} of a mixture of PAH compounds represented by BaP was associated with approximately 50% increase in the risk of lung cancer. This exposure is the lowest level where significant effects have been observed. If the amount of exposure to BaP over a year, to increase the lung cancer risk by 50%, is spread over a working life (40 years) then this is equivalent to a continuous working exposure of 0.25 – 2.5 μg.m^{-3}. As no safe level of PAH exposure was found in the literature a safety factor of 10 was applied to the lower end of the range of concentrations at which effects were observed. This working life concentration (40 years, 5 days per week, 8 hours per day) was then extrapolated to an entire life by using an additional factor of 10. A third safety factor of 10 was then applied to take into account the range of sensitivity to carcinogens likely to exist in the general population.

In summary a safety factor of 1000 was used to obtain the air quality standard (0.25 ng.m^{-3}) from the lower range of working life exposure to BaP that would increase the risk of lung cancer by 50%. It does not necessarily follow that all exposure above this standard carries a significant risk, in view of the effective application of an additional tenfold safety factor in EPAQS derivation of the standard.

When the European Union set their Target Value in the EU 4th Air Quality Directive (2004/107/EC) they used a Quantitative Risk Assessment (QRA) method based on two different epidemiology studies[27,28] and one best estimate study[29]. These studies concentrate on the increased risk of lung cancer due to industrial exposure to PAHs. Other studies on the increased risk of lung cancer due to exposure to diesel exhaust were not taken into account, as their results, although showing a positive effect due to diesel exposure, did not have a strong enough statistical significance for inclusion. This QRA method is laid out in the European Union's "Ambient air pollution by Polycyclic Aromatic Hydrocarbons (PAH)" Position Paper[26]. Using this method and the World Health Organisation (WHO) unit risk of lung cancer (87 x 10^{-6} BaP.m^{-3} for lifetime exposure) estimate for PAH compounds, the European Union calculated the increased risk for three possible Target Values as shown in Table 6-1.

Possible Target Value, ng.m^{-3} BAP	**Increased Risk, Life-time exposure to target value**
0.01	1 x 10^{-6}
0.1	1 x 10^{-5}
1.0	1 x 10^{-4}

Table 6-1 QRA calculated increased risk for possible BaP Target Values

Based on the health evidence and acceptance that the upper limit of the additional lifetime risk should be less than 1 x 10^{-4}, the European Union decided on a Target Value for the annual mean concentration of BaP to be 1 ng.m^{-3}. Upper assessment and lower assessment BaP concentration thresholds where also recommended in the position paper.

The European Union also concluded PM_{10} is the most appropriate measurement fraction, because lung cancer associated with inhaled PAH compounds occurs both in the large airways and in the deep lung. Provisions for 'alert thresholds' to protect against short term exposures are inappropriate since there is no evidence for acute effects at likely ambient concentrations.

Detailed descriptions of the toxicology and health effects of PAHs are given in the World Health Organisation's Air Quality Guidelines[30]. The WHO concludes that no specific guideline value can be recommended for PAHs in air, as these compounds are typically constituents of complex mixtures. They also conclude that BaP alone will probably underestimate the carcinogenic potential of airborne PAH mixtures, since co-occurring substances are also carcinogenic. Nevertheless, the well-studied common constituent of PAH mixtures, BaP, was chosen as an indicator, although the limitations and uncertainties in such an approach were recognized.

Based upon epidemiological data from studies in coke-oven workers, a unit risk for BaP as an indicator in air constituent is estimated to be 87 × 10^{-6} ng.m^{-3}, which is the same as that established by WHO in 1987. The corresponding concentrations of BaP producing excess lifetime cancer risks of 1 in 10,000, 1 in 100,000 and 1 in 1,000,000 are 1.2, 0.12 and 0.012 ng.m^{-3} respectively.

7.0 Cost Benefits of Meeting the EU Target Value

As discussed in Section 5 the predominant health effect due to the exposure to BaP is lung cancer. A Cost Benefit Analysis (CBA) was performed on reducing the concentration of BaP in the modelled 47 1km x 1km squares exceeding the EU target value of 1 ng.m^{-3}.

7.1 Benefits

The model for quantifying the benefits of reduced exposure to PAH concentrations is based on the CBA model developed for the European Union's Clean Air for Europe (CAFE) Programme[31]. The design of the model for calculating the impact and economic damage is laid out below:

$$impact = \sum pollution \times stock\ at\ risk \times response\ \ function$$

where:

impact = total number of people liable to contract lung cancer
pollution = modelled concentration of BaP in each square (ng.m^{-3})
stock at risk = population in each exceedance square
response function = risk factor for lung cancer derived by the European Union, 1 x 10^{-4} (ng^{-1}.m^{3})

The European Union risk factor of 1 x 10^{-4} is discussed in Section 6.3 and is derived from extrapolating work place 1 year BaP exposure levels to lifetime exposure levels. A lifetime exposure to a concentration of 1.0 ng.m^{-3} BaP corresponds to an excess lifetime cancer risk of 1 in 10,000.

And:

$$economic\ damage = impact \times unit\ value\ of\ \ impact$$

where:

economic damage = damage to the economy caused by raised BaP concentrations
impact = number of people liable to contract lung cancer
unit value of impact = value of a statistical life

Population data for the Council Ward represented by each of the squares exceeding the EU target value was obtained from the Northern Ireland Neighbourhood Information Service and the Northern Ireland Statistics and Research Agency. The total population exposed to BaP concentrations above the target value in 2008 is 93,785. This is equivalent to a population density of 1995 per km^2, which corresponds well with other urban areas across the UK. This population density is high for the whole of Northern Ireland, but as all bar one of the exceedance squares are in residential urban areas it is considered to be representative of the areas exposed to concentrations above the Target Value.

Using the population figures for each of the 47 1 km x 1km squares exceeding the target value, the modelled concentration for that square and the risk factor for lung cancer derived by the European Union, the total number of additional cancers (impact) that can be attributed to exposure to BaP is 12, over a lifetime exposure.

If BaP concentrations in these squares were reduced to the target value then the total number of cancers (impact) that can be attributed to exposure to BaP would be 9, over a lifetime exposure. Therefore the number of extra cancers attributed to breaching the BaP target value is 3 per lifetime exposure, across the whole NI population.

To put this number of cancers attributable to exceeding or meeting the target value into context: in Northern Ireland 4898 people contracted lung cancer over the period 2004 to 2008 (Northern Ireland Cancer Registry), mainly due to tobacco smoking. Lung cancers make up 19% of all cancers diagnosed in Northern Ireland. 90% of people die within 5 years of being diagnosed with lung cancer, which equates annually to 882 deaths, this contributes to 6% of all deaths across Northern Ireland in 2008.

The Value of a Statistical Life (VOSL) has been taken from the CAFE Programme[32] cost benefit analysis mean value of €2 million, without any adjustment for inflation as CAFE use this figure for their estimations between 2003 and 2010. Using an exchange rate of £0.86 : €1 gives a VOSL of £1,720,000. This is similar to the Department of Transport's (DfT) figure for VOSL[33]. In 2003 DfT set VOSL at £1,250,000; adjusting this at a 3% rate of inflation gives a 2010 value of £1,540,000. The CAFE figure of £1,720,000 has been used for all further calculations.

This VOSL needs to be adjusted for various factors and this adjustment is based on a previous report to Defra on the costs and benefits of reducing PAH concentrations in Northern Ireland[33]. The first factor is the perspective of the public's "willingness to pay" (WTP) for cancer prevention. The second factor is based on cigarette smoking studies showing that there is a 20 year lag between exposure and incidence of lung cancer. Using these two factors the VOSL is adjusted by the following:

$$Adjusted\ VOSL = VOSL * \left[(1 + WTP) \times lag\ \ factor\right]$$

where:

WTP	= 0.5	
Lag factor	= 0.503	including recommended HM Treasury discount rate of 3.5%

The adjusted VOSL calculated from above is £1,297,740. Calculating the economic damage from the 3 additional deaths due to lung cancer from exposure to BaP concentrations above the EU target value is £3,893,220 over a 70 year life time. This represents an annual economic damage of £55,617.

7.2 Costs

It is proposed that the most effective way to reduce BaP concentrations in urban areas in Northern Ireland is to reduce the emissions from Commercial, Institutional and Residential (CIR) sources. Extrapolation of the sensitivity analysis performed in Section 4.3 shows that

CIR emissions need to be reduced by 50% compared to the 2008 levels. Due to the emission factors for BaP from solid smokeless fuels being in the range 5 to 50 times lower than for bituminous coal (and wood) and for oil being 450 times lower than bituminous coal then it is recommended that smokeless fuel should be mandated through the use of smoke control legislation. Where natural gas is available then the emission factors are so low that the emissions are considered negligible when compared to bituminous coal.

It would not be feasible to apply smoke control legislation to just the 1km squares exceeding the BaP target value, so it is recommended that smoke control legislation be applied to the whole of Northern Ireland. Cutting the emissions in just the 47 exceeding squares will not have the desired effect as the hot spot concentrations are a function of local emissions and medium range transport. Also the exceedance squares are spread over the whole of Northern Ireland, making local smoke control implementation and enforcement confusing and unenforceable.

The costs in applying the smoke control legislation are two fold. First the cost of replacing existing appliances with compliant heating systems and secondly the on-going enforcement of the smoke control legislation.

7.2.1 Domestic Heating Replacement

The capital costs of installing a replacement central heating system are composed of the purchase of the boiler or gas fire and its installation into the property. There is a wide range of appliances available on the market and the cost of these varies dramatically depending on the type of property they are installed into. A guide price for the calculations of £4000 per property has been used, based on the levels of Government grant available for central heating installation for the capital purchase and installation of a new central heating system.

The Northern Ireland Executive estimates that there are 692,000 households in 2008 in Northern Ireland, 64% of these having access to natural gas. Assuming that there has been a 35% market penetration of natural gas into the market place (Section 5.2.2) then 155,000 properties are already using natural gas. A further 70% of properties use oil for central heating (Department for Social Development), accounting for 484,400 properties. This leaves 52,600 properties relying on solid fuel burning to provide heating to their homes. In a worse case scenario it can be assumed that the 52,600 properties need replacement central heating systems resulting in a total capital outlay in the region of £210 million.

Under the current replacement scheme the householder meets 30% of the cost and the State 70% of the outlay. For the purposes of future calculations the total cost has been used, so that the monetary costs are taken as a whole and considered irrespective of who pays.

7.2.2 Smoke Control Enforcement

Once smoke control has been established across the whole of Northern Ireland it will have to be enforced. It is assumed that each county (6) will have to have a minimum of one full time enforcement officer each. Assuming that the cost of employing an enforcement officer is £40,000 per annum including overheads, then the cost of enforcement per annum would be £240,000.

7.3 Cost Benefit Comparison

Table 7-1 below summarises the estimates of the costs and benefits, in financial terms, in reducing the BaP concentrations below the EU Target value in the 47 exceedance squares and for implementing and enforcing smoke control legislation across the whole of Northern Ireland.

	Annualised benefits £ per year	Annualised Costs £ per year
Reduced deaths from lung cancer (not including healthcare costs during treatment)	55,617	
Replacement of solid fuel heating (over 70 year lifetime)		3,000,000
Enforcement of smoke control legislation		240,000
Total	55,617	3,240,000
Net cost		**3,184,383**

Table 7-1 Cost benefit comparison for reducing BaP concentrations across Northern Ireland

There is a considerable disparity (factor ~60) between the cost of implementing Northern Ireland -wide smoke control legislation and the benefits calculated from the reduction in lung cancers.

While there is significant uncertainty in both the benefits and costs calculated it is difficult to justify the implementation of smoke control legislation across the whole of Northern Ireland purely on economic grounds. This is in line with the 4th European Daughter Directive[2] (2004/107/EC) on PAHs, which states in Article 3 on Target Values, "Member States shall take all necessary measures not entailing disproportionate costs to ensure that, as from 31st December 2012, concentrations of arsenic, cadmium, nickel and benzo(a)pyrene, used as a marker for the carcinogenic risk of polycyclic aromatic hydrocarbons, in ambient air, as assessed in accordance with Article 4, do not exceed the target values laid down in Annex I." The calculated benefits do not include any fines from the EU for breaching target values for BaP concentrations.

However, it is likely that more effective enforcement of existing smoke control areas will deliver reduced BaP concentrations in these areas and deliver some improved health outcomes more quickly than implementing nationwide smoke control. The costs for this could involve the employment of one to two full time enforcement officers to cover the whole of Northern Ireland (not at an individual council level) at an annual cost of around £40,000 to 80,000, which is more in line with the economic impact costs of the BaP exposure (£56,000).

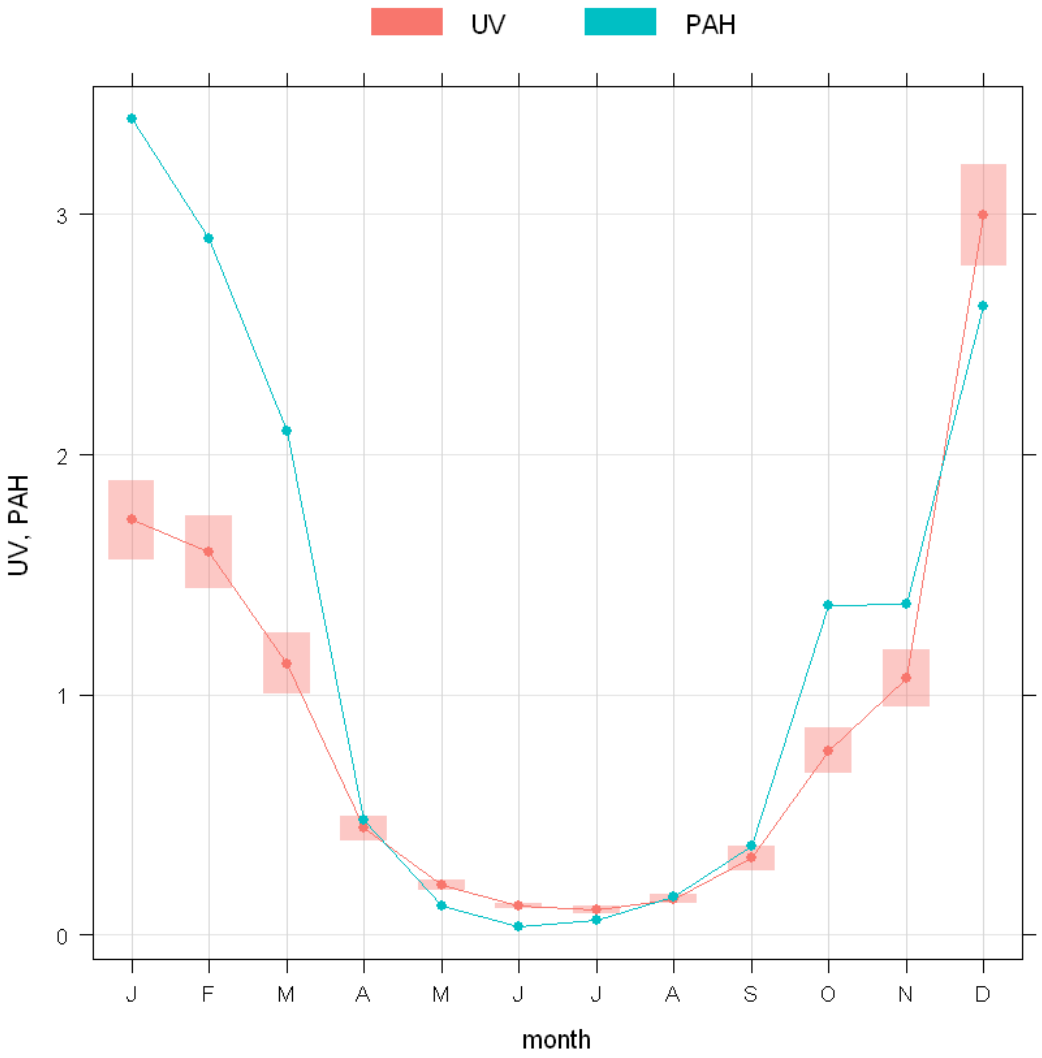
Policy Recommendation 4: Smoke control areas ought to be effectively enforced. The areas covered by smoke control legislation should be examined.

8.0 Additional Monitoring

Currently PAHs are only measured on a routine basis at 3 locations in Northern Ireland on the UK PAH Network at Dunmurry, Ballymena and Londonderry. Daily samples are collected onto filters followed by chemical analysis to provide monthly concentrations for more than 20 individual PAHs. This is an expensive measurement method with a 3 month delay between sampling and the publication of data. If the modelled concentration hotspots for BaP are to be confirmed and monitored over time to determine the effect of emission reduction measures then measurements of ambient concentrations will need to be made.

It would be useful to screen an area for high PAH concentrations before committing to expensive filter based methods. Currently Defra run the UK Black Carbon Network that uses real-time Magee Aethalometers to measure Black Carbon and UV Component concentrations. The Aethalometer takes continuous measurements and reports them as hourly averages. The UV Component concentration is made up of a response to PAHs and other strongly UV absorbent components in the ambient air. Currently there are 3 monitoring stations in Northern Ireland on the Black Carbon Network at Strabane, Belfast and Dunmurry (collocated with the PAH filter sampler). Figure 8-1 shows the BaP and UV Component concentrations measured at Dunmurry during 2010[34].

While confirming the predictions of the model is a major part of the additional monitoring, there is no legal requirement for more measurement points according to EU directive 2004/107/EC. The Directive specifies minimum monitoring requirements passed on zones, agglomerations and population. Northern Ireland has been declared as a single zone with one agglomeration (Belfast). Taking the population into account, three monitoring sites are required for NI and these are delivered through the UK PAH Network.



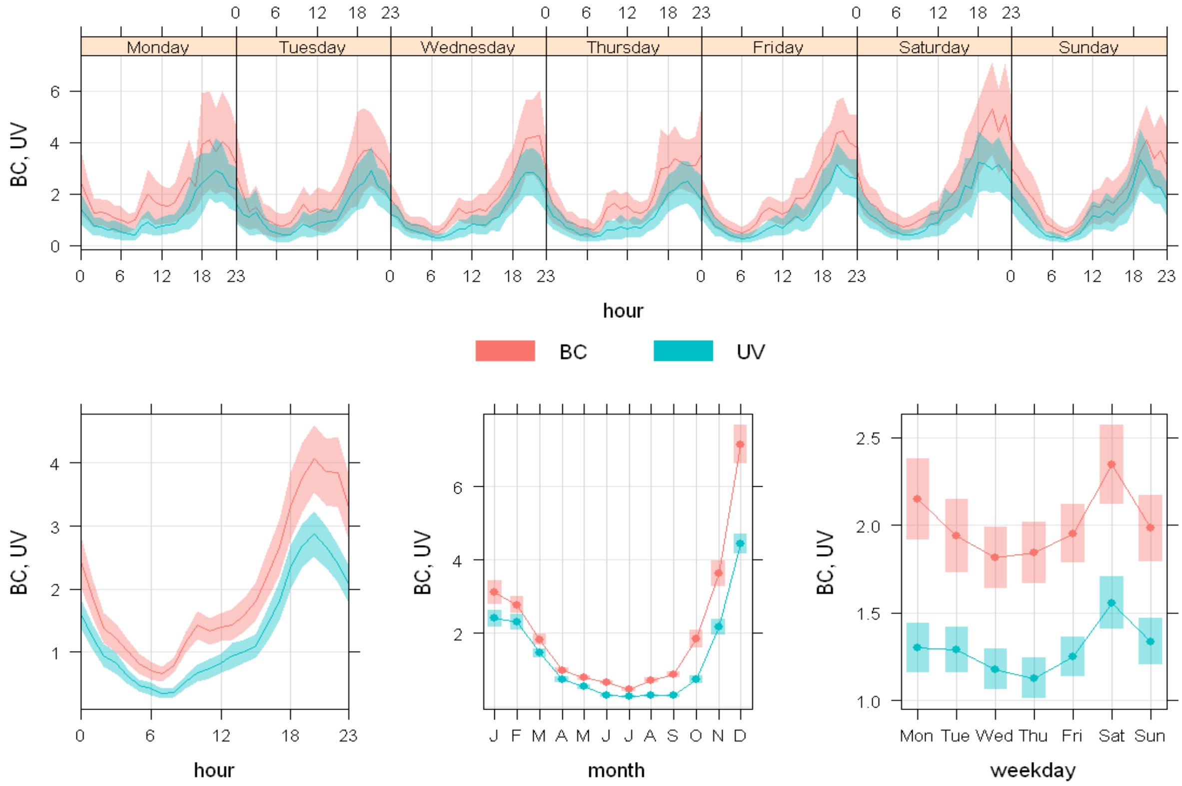
Note: Figure generated using the Open-Air Tools run on the R software platform[35, 36]

Figure 8-1 **BaP and UV Component concentrations measured at Dunmurry during 2010**

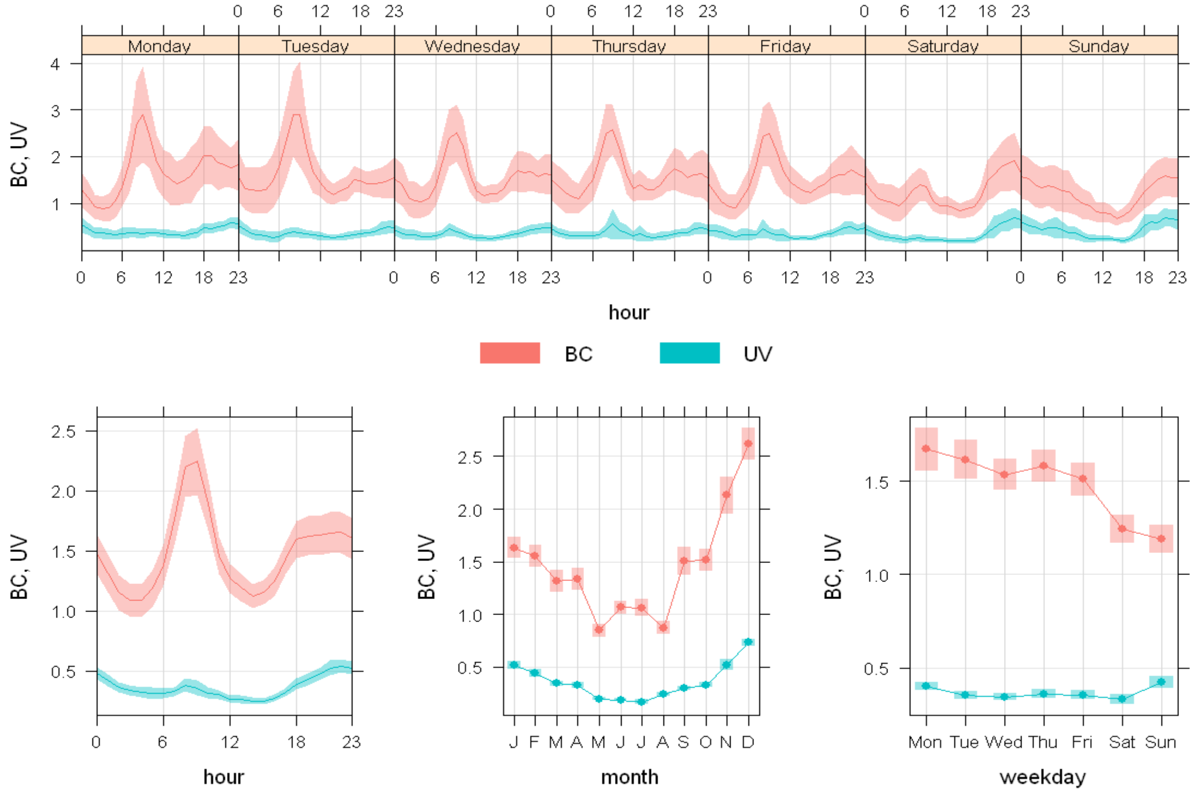
The shaded area on the y-axis represents the uncertainty in the mean y-value due to the spread of the results over that averaging period, expressed with a level of confidence of 95%. It is not the overall measurement uncertainty. As the PAH measurements are a monthly average there is no spread in the result over the month and therefore no uncertainty displayed in the y-value. The shaded area on the x-axis is for display purposes only, to allow the uncertainty in the mean value to be seen more clearly.

The units are different for the two quantities, the PAH measurements are represented in ng.m^{-3} while the UV Component is represented as µg.m^{-3}. However it can be seen that there is good temporal agreement between the two species due to similar emission sources such as solid fuel burning.

Figure 8-2 shows a comparison between Black Carbon and UV component concentrations measured at the Strabane and Birmingham Tyburn sites.



Strabane



Birmingham Tyburn

Figure 8-2 **Black Carbon and UV Component measurements at Strabane and Birmingham Tyburn during 2010**

It can be seen that at Strabane the Black Carbon and UV component concentrations map each other over the day, week and month suggesting that a similar source is producing both pollutants. This is likely to be the domestic heating from the housing estate surrounding the site; note the high concentrations in the evening and over the weekend. There is a small contribution to the Black Carbon concentration in the morning rush hour, but the evening peak is masked by the central heating contribution. Strabane is in a smoke control zone and the houses in this estate have oil central heating as their primary heating fuel, however there is still a large UV component corresponding to pollutants like or similar to PAHs. This is likely to be due to non-smokeless fuels being burnt either as secondary heating or as primary heating due to the expensive cost of oil, as discussed in Section 5.

The Birmingham site is situated in an urban area comprising a mixture of residential homes and small industrial units. It can be seen that the Black Carbon concentrations have a peak in the morning rush hour and then another peak in the evening period, so the predominant source of Black Carbon is assumed to be road traffic. There is a small UV component concentration present that shows little variation across the day or week, but is slightly raised during the colder periods of the year, indicating a small contribution from heating. The main source of heating in Birmingham is from natural gas.

In early 2012 Defra is reorganising the Black Carbon Network. Under this reorganisation the number of monitoring sites is being rationalised leading to the closure of some sites. Once these sites have been closed there will be spare Aethalometers available that could be used to quickly and cheaply screen areas for elevated PAH concentration prior to making measurements using the filter based method.

Policy recommendation 5: Use spare Aethalometers to quickly and cheaply screen projected hotspot areas for elevated PAH concentration prior to making measurements using the filter based method.

9.0 Conclusions

An ADMS-Urban dispersion model based on inputs of 2008 BaP emissions from the National Atmospheric Emissions Inventory (NAEI) and meteorological data from Met Office stations across Northern Ireland predict BAP concentrations exceeding the EU Target Value of 1 ng.m^{-3} in 47 1km x 1km squares. The scaling factor used for the model to align modelled concentrations with measured concentrations in Londonderry and Dunmurry was 6.0.

The NAEI data for Northern Ireland may underestimate PAH emissions. When the same model was run for Swansea / Port Talbot area (where little solid fuel is used), a scaling factor of 1.45 was required to match modelled and measured concentrations. One possible reason for inaccuracy in NAEI data in Northern Ireland may be the burning of non-smokeless fuel in smoke control areas.

Analysis of BaP emissions shows that the dominant source is from Commercial, Institutional and Residential (CIR) emissions. Therefore controlling and reducing these emissions is the best way to reduce BaP concentrations in the 47 exceedance squares and across Northern Ireland. It was found that on average 93% of BaP emissions came from CIR emissions in the 47 exceedance squares. One of the exceedance squares was dominated by emissions from industrial solvent use. Modelling the effect of reducing the CIR emissions in the 46 exceedance squares showed that CIR emissions had to be reduced to 50% of their 2008 levels to ensure no exceedances on the EU Target Value.

Information from local councils shows that only 7 towns where the BaP target value is exceeded have smoke control instituted and that 3 have currently declared Air Quality Management Areas (AQMA) for PM_{10}. AQMAs declared for PM_{10} in Strabane and Ballymena are due to domestic fuel use dominating particulate emissions (AQMA declared for PM_{10} in Belfast is due to transport emissions). Strabane have implemented a detailed action plan to address the problem and this is discussed in detail. One of the leading measures is to enforce smoke control legislation for the whole of the town.

The amount of BaP emitted varies dramatically dependent on the fuel burnt, with bituminous coal emitting 5 to 50 times the amount of BaP than solid smokeless fuels and 450 times the amount of BaP than oil. Therefore the type of fuel used and how it is burnt has a dramatic effect on the ambient BaP concentrations. Increased use of smokeless fuel including gas would drastically reduce the BaP concentrations across Northern Ireland. Conversion schemes for privately owned/let homes ought to be encouraged, perhaps through the provision of financial support to aid the rate of conversion. Increased energy efficiency will also help to reduce PAH emissions and therefore the continuation, promotion and improvement of current schemes should be encouraged.

Natural gas is now available to 64% of Northern Ireland’s population, with data from the two companies supplying natural gas (Firmus Energy and Phoenix NG) showing 35% penetration into the domestic market. Increasing the availability of natural gas through extending current pipelines and encouraging uptake in areas already served should also be considered as a means to increase conversions from solid fuel.

The Northern Ireland Housing Executive (NIHE) and the Department for Social Development have implemented different programmes to reduce the reliance on solid fuel, to improve fuel efficiency and address fuel poverty, with £63 million of capital funding being promised over the next 4 years to fund the Warm Homes Scheme for private sector housing. In addition the Housing Executive is planning to spend £16million in 2011/12 improving its own properties. Price is undoubtedly a driver behind the use of non-smokeless fuel over oil. This leads to higher than predicted levels of PAHs, especially in smokeless zones due to inaccurate emission inventories.

The predominant health effect linked to PAH exposure is lung cancer. The European Target Value for BaP exposure is calculated from health studies on coke oven workers exposed to BaP in the work place. This exposure is then extrapolated to cover a lifetime background exposure with an additional safety factor. Based on the health evidence and acceptance that the upper limit of the additional lifetime risk should be less than 1×10^{-4}, the European Union decided on a Target Value for the annual mean concentration of BaP to be 1 $ng.m^{-3}$. This level agrees well with calculations performed by the World Health Organisation.

A cost benefit analysis performed based on the method used by the EU CAFE Programme showed that the number of people liable to contract lung cancer due to being exposed to BaP concentrations above the EU target value of $1ng.m^{-3}$ in the 47 1km x 1km exceedance squares was 3 per lifetime. Turning these 3 lung cancers into economic damage equates to an annual cost of £55,617.

When the costs for reducing the CIR emissions by the use of smoke control legislation across the whole of Northern Ireland were examined it was determined that the capital replacement cost for converting the heating systems of houses that rely on solid fuel was £210,000,000. In addition to the capital cost is the cost of enforcement of the smoke control legislation. If Northern Ireland -wide smoke control is implemented, it is estimated that each county (6) would have to employ a full time enforcement officer at a total annual cost of £240,000.

When comparing the economic damage due to exposure to BaP concentrations above the EU target value with the economic cost of reducing emissions by implementation of smoke control legislation, it was assumed that the capital cost of heating replacement was spread over the same lifetime length (70 years) as the BaP exposure. When this assumption is made the net annualised cost would be £3,184,383, thus far outweighing the economic damage due to the BaP exposure.

However, effective enforcement of existing smoke control areas may deliver reduced BaP concentrations in these areas and deliver some improved health outcomes more quickly than implementing nationwide smoke control. The costs for this could involve the employment of one to two full time enforcement officers to cover the whole of Northern Ireland (not at an individual council level) at an annual cost of around £40,000 to 80,000. This expenditure is in line with the annualised cost of the economic damage caused by the BaP exposure (£56,000). In addition, reducing BaP and PM_{10} / $PM_{2.5}$ concentrations through the implementation of smoke control would have other health benefits outside the scope of this assessment.

If the modelled concentration hotspots for BaP are to be confirmed and or monitored over time to determine the effect of emission reduction measures, then measurements of ambient concentrations may need to be made at more locations than are currently monitored by the UK PAH Network. To reduce the cost of filter based methods, screening of areas could be performed by using the upcoming spare Magee Aethalometers from the UK Black Carbon Network reorganisation.

10 Policy Recommendations

Policy Recommendation 1: Conversion schemes for privately owned/let homes ought to be encouraged, perhaps through the provision of financial support to aid the rate of conversion across Northern Ireland. Further conversions will help to reduce BaP emissions and concentrations as well as PM_{10} concentrations.

Policy Recommendation 2: Increase the availability of natural gas through extending current pipelines and encouraging uptake in areas already served.

Policy Recommendation 3: Continue / improve promotion of current energy efficiency schemes to increase the uptake rate and hence reduce emissions and improve quality of life.

Policy Recommendation 4: Smoke control areas ought to be effectively enforced and the areas covered by smoke control legislation should be examined.

Policy recommendation 5: Use spare Aethalometers to quickly and cheaply screen projected hotspot areas for elevated PAH concentration prior to making measurements using the filter based method.

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Figures and Tables

Figures

Tables