Determining the impact of domestic solid fuel burning on concentrations of PAHs and sulphur dioxide in Northern Ireland

A report produced for the Department for Environment, Food and Rural Affairs; the Scottish Executive; the National Assembly for Wales and the Department of the Environment in Northern Ireland

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netcen (AEA Technology)
E1 Culham
Abingdon
Oxfordshire
OX14 3ED
Telephone 01235 463084
Facsimile 01235 463038

AEA Technology is the trading name of AEA Technology plc
AEA Technology is certificated to BS EN ISO9001:(1994)

	Name	Signature	Date
Author	Stephen Pye Keith Vincent		
Reviewed by	Peter Coleman		
Approved by	Garry Hayman		

Executive Summary

An air quality objective for PAH (polycyclic aromatic hydrocarbons) of 0.25 ng/m^3 benzo[*a*]pyrene as an annual average has been consulted upon for the United Kingdom. A modelling study undertaken by netcen (Coleman et al. 2001) assessed benzo[*a*]pyrene (BaP) concentrations for 1999, and for 2010, the proposed attainment date of the objective. It concluded that there would be exceedances of the proposed UK PAH objective during both years in Northern Ireland. Investigation of the likely main cause suggested that domestic solid fuel use was a significant local source in the absence of a widespread mains gas network.

This study was undertaken to re-examine the likely exceedances of BaP, and in doing so, help inform policy makers about setting a Northern Ireland specific air quality objective limit. A re-examination of likely exceedances was thought necessary in light of new data that could be used in the construction of a more robust spatial inventory. New data sources included recently commissioned fuel use surveys, smoke control order information, spatial information from the Northern Ireland Housing Executive and data from the sole licensed mains gas suppliers, Phoenix Gas.

Area source modelling was undertaken using a 2000 baseline year inventory and for four 2010 projected scenarios. Emission modelling from 500 m $\times$ 500 m squares predicts no exceedance in 2010 of the proposed EU directive limit value of 1 ng/m^3 BaP, very limited exceedance a 0.5 ng/m^3 BaP concentration threshold but a more widespread exceedance of the UK objective of 0.25 ng/m^3 BaP.

The impact of the various emissions scenarios explored on future exceedances is less than the difference between the modelled and measured values. However it is clear that the continuation of the NIHE's programme to replace solid fuel use with gas or oil burning heating appliances would significantly improve air quality. Further the licensing and development of the two gas interconnectors and the associated supply of natural gas to urban areas will also improve air quality though the full benefits of this may be felt further into the future than the 2010 Objective date. If neither of these presently proposed measures continue to be supported by Government then the emission scenarios will prove optimistic.

The use of Smoke Control Orders to reduce domestic PAH emissions in those areas thought likely to exceed 0.5 ng/m^3 BaP was predicted to reduce all the exceedances of that standard. Hence use of Smoke Control Orders has shown potential as a policy tool for controlling PAH concentrations in areas where domestic emissions are the dominant source sector.

However, modelling emissions within a 1 km $\times$ 1 km square which contains 2 housing estates (Seymour Hill and Conway) for which the main method of space heating is the combustion of solid fuel shows that there is a potential for BaP hotspots to exceed 1.0 ng/m^3 BaP. The potential of BaP concentrations to reach such high values over short spatial scales suggests that the spatial resolution of dispersion modelling is key in predicting the extent of exceedances. Further monitoring in areas where domestic space heating relies on solid fuel combustion such as Strabane and Newry work would assist in validating modelling approaches.

The improved spatial dissaggregation of the domestic emission inventory was used to improve the prediction of sulphur dioxide exceedances in 2001. There are three relevant short term air quality standards for sulphur dioxide concentrations for the Air Quality Strategy and First Air Quality Daughter Directive. The required

statistics are the 99.9 percentile of 15 minute means, the 99.73 percentile of hourly means and the 99.18 percentile of daily means. An analysis of sulphur dioxide concentrations measured at three monitoring sites in Northern Ireland shows that robust relationships link the annual mean with these three short term statistics. These relationships were used to prepare sulphur dioxide maps for each respective averaging period. This simpler method of preparing maps of short term averaging periods was compared to a more sophisticated modelling approach for which domestic emissions were modelled on an hour by hour basis.

A review of the short term average concentrations measured at the continuous monitoring sites in Northern Ireland showed, historically, that the 99.9 percentile of 15 minute concentrations occurred more frequently than either the 99.73 percentile of hourly concentrations or the 99.18 percentile of daily values. The 99.18 percentile of daily values occurred more frequently than the 99.73 percentile of hourly values. Based on these observations it is suggested that the 99.9 percentile of 15 minute concentrations would be the more stringent air quality standard to attain followed by the 99.18 percentile of daily values and the 99.73 percentile of hourly values.

Maps of sulphur dioxide concentration for each averaging period suggest that there will be exceedance of the concentration thresholds required as part of the Air Quality Strategy and First Air Quality Daughter Directive at a small number of locations in 2001. However, it maybe expected that sulphur dioxide concentrations may also vary significantly over short spatial scales and local fuel use surveys may improve the modelled predictions.

Contents

1 Introduction

An air quality objective for PAH (polycyclic aromatic hydrocarbons) of 0.25 ng/m^3 benzo[*a*]pyrene as an annual average has been consulted upon for the United Kingdom. A modelling study undertaken by netcen (Coleman et al. 2001) assessed benzo[*a*]pyrene (BaP) concentrations for 1999, and for 2010, the proposed attainment date of the objective. It concluded that there would be exceedances of the proposed UK PAH objective during both years in Northern Ireland. Investigation of the likely main cause suggested that domestic solid fuel use was a significant local source in the absence of a widespread mains gas network.

There was also evidence from the single measurement site then operating in the province that measured concentrations were not explicable by the modelled sources around the site.

Based on this study, further assessment of the Northern Ireland situation was concluded to be necessary. The spatial dissaggregation used within the study for solid fuel use was based on population. It is clear that in Northern Ireland where in some estates solid fuel is a major primary heating fuel that is not an appropriate distribution statistic.

Since the initial assessment, new information has been produced, primarily through fuel use surveys that have been undertaken by a number of District Councils. Other sources have also fed into the development of a spatial inventory, such as information from the NI gas supplier and from the Northern Ireland Housing Executive. These sources have been very important in being able to improve the Northern Ireland wide spatial domestic fuel use part of the emissions inventory. From this improved inventory new dispersion modelling has been carried out to assess compliance with the objective in 2010.

In February 2003 the Northern Ireland Department of Environment along with the other responsible administrations published an Addendum to the Air Quality Strategy for England, Scotland, Wales and Northern Ireland. In this it states that the UK Government and the devolved administrations in Scotland and Wales have adopted the objective of achieving the EPAQS recommended standard of 0.25 ng/m3 (BaP) as an annual average by the end of 2010.

This report outlines the work undertaken to improve the spatial emission inventory based on new available data. Section 2 describes the new sources of the data, the methodology used to construct a new high-resolution spatial inventory, and the development of 2010 scenarios. Section 3 of the report describes area source modelling work, using the new spatial inventory. Comparison is made with measured BaP emissions, and areas of predicted exceedances are identified in the baseline and projected years.

Section 4 outlines a local study undertaken focusing on the Seymour Hill monitoring site. It describes a methodology for producing a more localised inventory, and the modelling results based on this inventory. Section 5 describes how work to improve the BaP inventory has fed into the new SO_2 inventory for 2001, produced as part of the NAEI mapping work. Detailed modelling, based on empirical and dispersion techniques, has been undertaken on the new inventory, the result of which are described in this section. Section 6 draws out the main conclusions from this study.

2 Spatial Emissions Inventory

An improved spatial inventory at the Northern Ireland scale is essential in order to improve the understanding and quantification of BaP emissions from solid fuel burning. It is also important in order to be able to predict concentrations of BaP through modelling, based on the spatial emissions inventory.

Through the use of a greater range of data sources, and a revision of previous assumptions, a new spatial emissions inventory has been constructed, both for 2000 and 2010, where four scenarios have been constructed. Unlike previous spatial inventories, this inventory has been constructed using a bottom-up approach. In other words, the inventory has been compiled on the basis of household type and average fuel consumption rather than distribution of Northern Ireland total fuel consumption estimates.

Spatial distributions of household fuel use have been developed using the data outlined in section 2.1. These distributions have then been used to create BaP emission maps, as described in section 2.2. These emission maps have provided the baseline on which to produce four separate 2010 projected scenarios. Section 2.3 describes the methodology for constructing the scenarios, and the assumptions that have been used.

2.1 Data Sources

This section describes what base data has been used, and how it has been used in terms of inventory construction. There are six main sources of data on which this spatial inventory is based:

- NI Housing Executive (NIHE) household data (from NIHE property database)
- Gas household data (from Phoenix Gas)
- Belfast household data (from a fuel use survey undertaken by Belfast City Council)
- Other household data (including Housing Condition Survey (HCS) data)
- Fuel Use surveys (from 10 district councils)
- National Atmospheric Emissions Inventory (for emission factors)

The use of each of these data sources in the BaP emissions inventory is outlined below.

2.1.1 NIHE household data

The NIHE are responsible for the public housing stock in Northern Ireland. They provided an important dataset, based on information held in their property database. The property database is a current record of all houses currently owned by NIHE, with details of the main types of fuel / appliance used in each household. The data was supplied at the ward resolution and provided spatial coverage for the whole of Northern Ireland.

This data set provided a very good geographical coverage and data at a high resolution. This is important, given that NIHE properties account for approximately half of the households that presently use solid fuel (although such properties only represent 19% of the Northern Ireland households).

Using this ward level data, total numbers of households by fuel type were calculated for each ward. These ward household totals were then distributed within the ward boundaries on the basis of the population distribution. This methodology provided the basic household distribution for the NIHE tenure category.

Due to the size of wards, household grids were initially calculated on the basis of 125 x 125 m^2 so that the loss of accuracy was limited where ward boundaries intersect grid cells – these grids were eventually aggregated to a 500 x 500 m^2 resolution.

Some basic analysis was done to check the difference between the mapped totals by district council area, and those reported in the 2001 Northern Ireland Housing Condition Survey (HCS). This was necessary due to the difference between reporting years of the two datasets. Data was compiled in the HCS for 2001 while the property database reflected the current 2003 situation. A 7% scaling factor was applied to the NIHE property database data to compensate for the reduction in property numbers between the time the HCS was compiled and the output from the property database. This rescaling was considered important as all household numbers used were tied to the HCS numbers, to maintain consistency.

2.1.2 Gas household data

Gas data was provided by Phoenix Gas Ltd, in the format of numbers of household connections by postcode area. This data essentially only covers postcodes in or near the Greater Belfast area, the current geographical licensing area that Phoenix Gas supply to.

Based on these data, households supplied with gas were distributed within each postcode area using the relevant population distribution. Although not contributing to BaP emissions, gas households are important to map in order to remove them from the total household distributions, and in order to have a baseline case to look at future projections.

Other useful data provided by Phoenix included information on total households at a postcode resolution. These data were used in this analysis in order to improve the resolution at which general household fuel use distributions were constructed.

The gas household grid was compiled at a 500 x 500m resolution. An image of the area covered, and the density of houses connected to gas can be seen below in Figure 2.1.

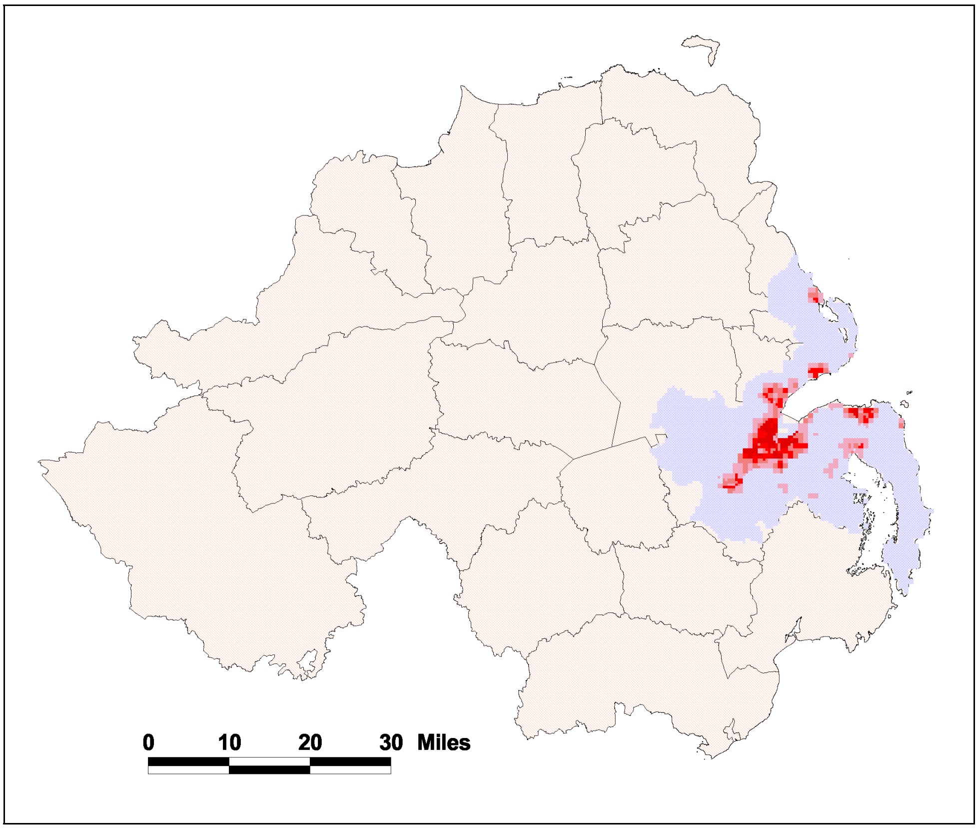


Figure 2.1: Area and density of households connected to gas in 2010 without taking into account the possible Pipelines

2.1.3 Belfast household data

Fuel use survey data, compiled by Belfast City Council, was incorporated into the Northern Ireland household grids where appropriate. From the fuel use survey data, it was possible to determine the proportion of households surveyed by ward who used different types of fuel and/or appliance. These proportions were again distributed across the ward areas on the basis of population. These Belfast distributions were added to the other household data grids to enhance distributions within the Belfast council area.

2.1.4 Other household data

The above three categories provide data to distribute households that are owned by the NIHE, that have gas supplied by Phoenix, and that are located in Belfast City. All other households are distributed using information supplied by the NIHE on the 2001 Housing Condition Survey (HCS). This data categorises household numbers at the district council level by tenure and by type of appliance / fuel. Within the district council, households are spatially distributed on the basis of population. The household distribution for the Greater Belfast area is also enhanced through the use of the postcode-based household data from Phoenix Gas.

Before this data is used, the NIHE tenure and gas categories are removed to prevent double counting.

2.1.5 Fuel Use Surveys

New information in the form of fuel use surveys originally provided the impetus for producing an improved spatial inventory and assessment of BaP concentrations. The strength of the fuel surveys has been to indicate where individual district councils understood the location of hotspots to be in terms of emissions from domestic solid fuel burning. Surveys (except for Belfast) have generally targeted a single 1x1 km square that has been identified as having a significant amount of households located within it that burn solid fuel. The total area covered by the Fuel Use Surveys other than Belfast is around $20km^2$ in the area of the province of 13630 km^2. In terms of producing a spatial inventory for the whole of Northern Ireland, the spatial representation of the surveyed area does not add a significant amount of value. The Belfast fuel survey is the notable exception.

In terms of assessing spatial emissions at a more localised level, this information could be very useful. A localised assessment of emissions around the Seymour Hill site has been performed in this study. However, it does not use fuel survey information, as a fuel use survey has not been conducted around this monitoring site.

The fuel surveys are considered important to this work in terms of building assumptions. Such assumptions include:

- Average annual household fuel consumption
- Compliance within Smoke Control Areas
- Projected changes in types of fuel based central heating systems being used

Assumptions have been developed by looking at all surveys and deriving typical trends. Specific information from individual fuel use surveys has not been used in the sense that the information it provides is representative of a specific area. Information from fuel use surveys on the type of appliance or fuel burnt in a 1 by 1 km area have not been used as they are thought to be representative of that specific geographical location and are not necessarily representative of the wider district council area or even ward area.

Assumptions were based on a review undertaken of the following fuel use surveys:

- Armagh
- Ballymena
- Belfast
- Carrickfergus
- Coleraine
- Cookstown
- Four Boroughs (North Down, Lisburn, Ards, Castlereagh)
- Larne
- Moyle
- Newtownabbey

2.1.6 Emission Factors

The emission factors used within the National Atmospheric Emissions Inventory (NAEI) for benzo[*a*]pyrene were reviewed. Experts within the UNECE Emission Inventory Task Force were asked for any recent data they might have which would improve the estimates used. Replies were received from Russia and Poland. Table 2.2 shows the data that was available when the NAEI emission factors were developed, the NAEI emission factors, the emission factors used in the Russian and Polish emissions inventories, and recent measurements carried out on behalf of DEFRA on an open fire using bituminous coal and wood.

The conclusion was that with the exception of that for oil the existing NAEI emission factors would be maintained. They fall within the range of data presently available. The Russian data were generally lower than the other data sources and as details were not provided the relevance to the Northern Ireland situation of the factors proposed could not be investigated. Hence the gas emission factor from Russia was not used. The oil combustion emission factor used by Poland, which derives from a TNO study was used and will be brought to the attention of the NAEI.

It will be noticed from looking at the data in Table 2.2 that the available emission factors for a particular fuel typically span almost an order of magnitude. This is an expression of the uncertainties in measurement of emission factors and in choosing appropriate fuels, and combustion conditions that are typical of domestic fuel use.

One issue, which the NAEI does not adequately address, is the strong dependence of PAH emissions not only on the fuel consumed but also on the appliance in which it is burnt and how that is operated and maintained. As a result the available five emission factors were used for a range of fuel–appliance combinations, as shown below in Table 2.1.

Table 2.1: Appliance-Fuel type emission factors (units are mg / tonne)

Appliance	Fuel type	Emission factor
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

The open fire and solid fuel non-glass fronted boiler categories use a range of different fuels and therefore, emission factors, as indicated in the above table. We have made assumptions about the split of fuel being used in the households that use these appliances – for example, it is assumed that in these two categories, 75% of households will use bituminous coal, which has an emission factor of 1550 mg (of BaP) / tonne fuel consumed. These assumptions are based on knowledge concerning the NI domestic fuel market, and have been validated to a limited extent by fuel use survey results.

Solid fuel single purpose boiler and solid fuel glass fronted boiler categories both have an emission factor of 30. They are thought to burn SSF as well as anthracite based fuels but because of the nature of the appliance, the emission factor of 30 is thought to be more appropriate than 330.

The dual household category describes houses that have two heating systems in a dwelling e.g. oil and solid fuel, or solid fuel and electricity. NIHE estimate that 60% of these dwellings have oil as their primary system. The rest are a mixture of oil as their secondary source or solid fuel / electricity as their primary source.

Table 2.2: Benzo[*a*]pyrene Emission Factors for Domestic Fuel Use (mg BaP /te fuel)

Fuel	Bituminous Coal	Anthracite	Wood	Coke	Solid Smokeless Fuel	Oil	Gas
NAEI value	1550	30	1300	30	330	-	-
Source	(500+2600) / 2	1550[1] x 1.3[2] / 63[3]	(600 x 2000) / 2	as anthracite	1550 x 13.4[4] / 63[3]	-	-
data used for NAEI value	2600 1850 1500 1150 500 449	2000 1300 600	27000 2500 730 700 500	as anthracite	-	-	-
Defra Emission Factor study	7970	-	557	-	-	-	-
Russian Emission Factor	100	-	2000	-	-	3.43	0.15
Polish Emission Factor	1500	-	2480	-	-	0.43	-

1 the emission factor for benzo[*a*]pyrene from domestic use of bituminous coal

2 the emission factor for the sum of 16 PAHs from domestic use of anthracite

3 the emission factor for the sum of 16 PAHs from domestic use of bituminous coal

4 the emission factor for the sum of 16 PAHs from domestic use of solid smokeless fuel

2.2 Baseline (2000) mapping methodology

From the above data sources, a range of household grids (500 x 500m^2 resolution) have been developed. Table 2.3 below lists the grids that were developed, and the number of houses in each grid category.

Table 2.3: Appliance-type household grids

All household data (excl. NIHE)		NIHE household data		Total household data	
Original Category Name	***Number***	***Original Category Name***	***Number***	***Inventory Category Name***	***Number***
Oil	352893	Oil	18489	Oil	371382
LPG	5445	LPG	137	LPG	5582
Solid fuel glass fronted boiler	14681	Glass fronted with back boiler	37925	Solid fuel glass fronted boiler	52606
Other open fire	16630	Open fire	1288	Open fire	17918
Solid fuel single purpose boiler	2495	Bulk Coal	30	Solid fuel single purpose boiler	2525
Solid fuel non-glass fronted boiler	20215	Open fire - back boiler	25552	Solid fuel non-glass fronted boiler	45767
		Range cooker and heater, burning coal	814	Range cooker and heater, burning coal	814
Other stove / space heater	7062			Other stove / space heater	7062
Other	7166			Other	7166
Dual	58846			Dual	58846
Electric – storage heater	28129	Electric	24682	Electric	54946
Electric – non storage heater	2135				
				Gas	20827
				Total households	**645441**

A household grid was created for each of these categories. As shown in Table 2.3, the NIHE houses were mapped separately to all other households. These were then added together to produce the inventory categories listed in the right hand column of the table.

Two examples of household grids are shown below, firstly illustrating the open fire household distribution (
Figure **2.2**), and secondly, the solid fuel glass fronted boiler distribution (Figure 2.3). These grids show household numbers at a 500 x 500m^2 resolution. The darker areas show the highest density of households, and in general, tend to be in the most populated / urban areas (as would be expected).

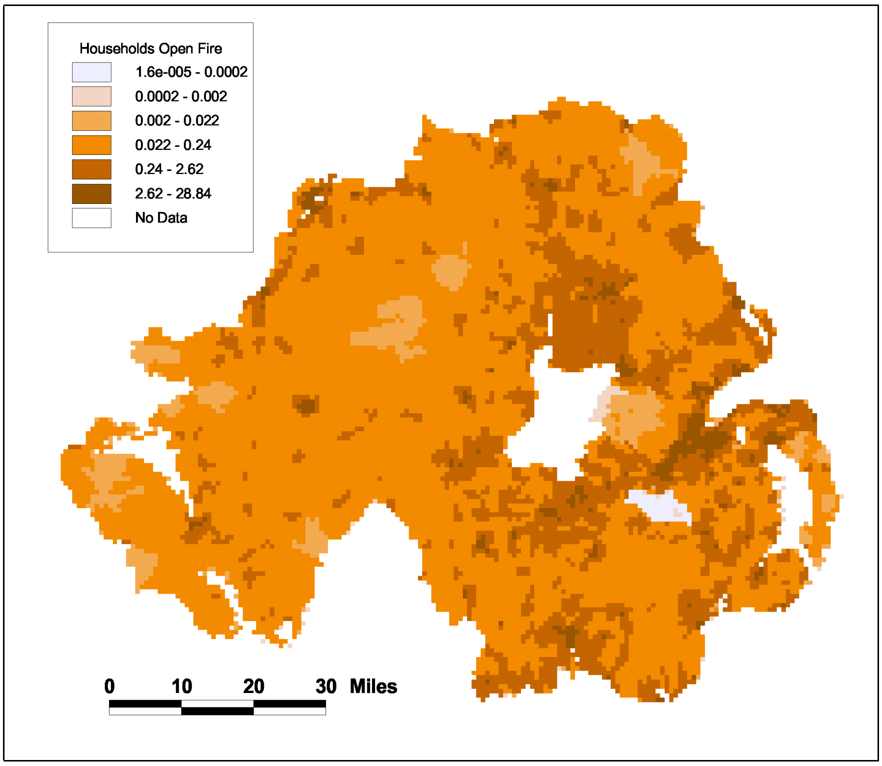


Figure 2.2: Open Fire Household Distribution

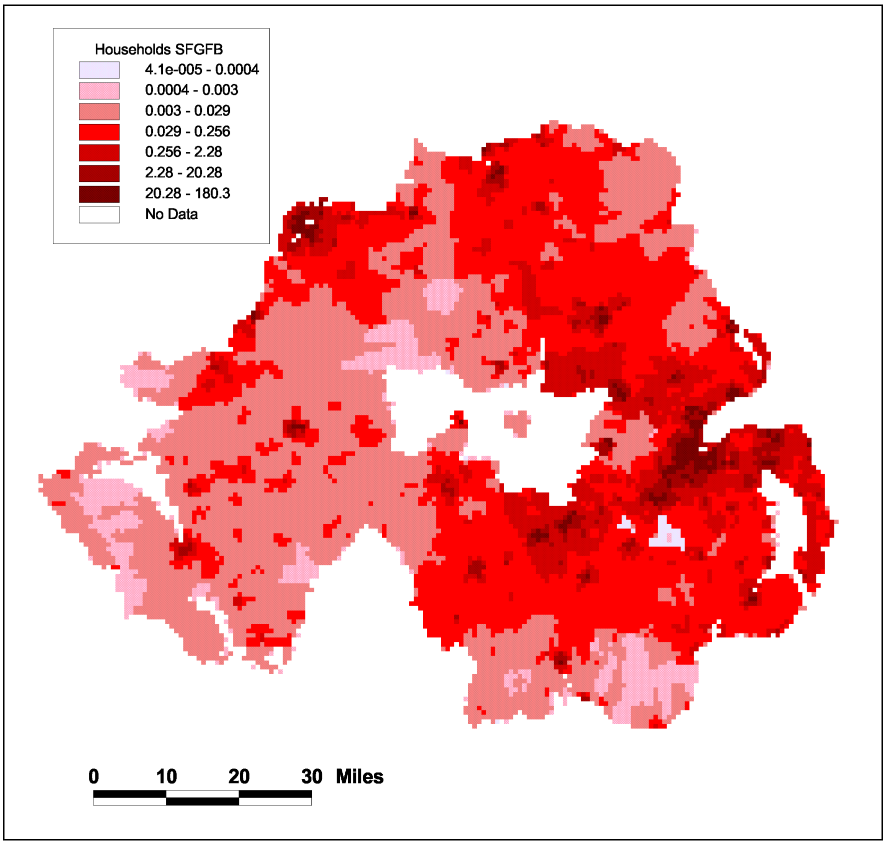


Figure 2.3: Solid Fuel Glass Fronted Boilers Household distribution

2.2.1 Mapping Approach

The mapping approach can be demonstrated by the following equation:

[No. of Households by type] x [Annual Average Fuel Consumption] x [Emission Factor]

As shown in Table 2.3 above, the household type, number and distribution were determined. Table 2.1 illustrates what emission factors were used. Annual average fuel consumptions were based on a two main data sources; NI Fuel Use Surveys and related literature.

From these sources the following annual average fuel totals per household were determined:

Table 2.4: Annual fuel consumption

Fuel type	Quantity
Solid fuels – main fuel	3.5 tonnes
Oil – main fuel	2194 litres
Solid fuel – backup fuel	0.9 tonnes

The following assumptions have been made for mapping emissions from *dual* categorised households. 60% are considered to use oil as the primary system with solid fuel backup (consuming 0.9 tonnes per year), based on the NIHE's estimate. 20% are assumed to use solid fuel as their primary fuel (consuming 3.5 tonnes per year) while 20% are assumed to use electricity as their primary fuel.

An exception to this mapping approach has been the mapping of wood fuel, where a top-down approach has been used. This approach has been based on using the *open fire* and *other stove / space heater* household distributions to distribute a total wood consumption figure. The total wood fuel consumption figure has been based on a report by Blackstock and Binggeli (2000) 'Development of a market strategy for domestic wood fuel in Ireland.' Based on their research sales of at least 22,000 m^3 per annum of wood fuel were identified. However they state. perhaps unhelpfully, that the actual size of the market is probably much bigger than this figure suggests.

A tonnage figure for wood was derived based on a wood density figure of 481 kg/m^3, for pine. To get a tonnage figure, we have used the following calculation:

22,000 x (481/1000) = 10,582 tonnes

This compares used in the earlier UK wide study for Northern Ireland of 25,550 tonnes of wood. This was based on the UK estimate of wood burnt in the home dissaggregated by the population distribution across the UK. A figure of 15,000 tonnes was estimated and used in this present inventory to reflect that Blackstock and Binggeli regarded the figure they provided as an underestimate.

30% of wood is distributed based on the *other stove / space heater* household grid. It is assumed that this appliance type will, in general, only use wood. The rest is distributed on the basis of being a backup fuel. All wood combustion was given an emission factor of 1300 mg/te except when burnt in a smoke control area when an emission factor of 330 mg/te was used.

2.2.2 Backup fuels

The incorporation of backup emissions is very important as these could account for a significant percentage of BaP emissions from the domestic sector. In this analysis, it has been established that 171,245 households use solid fuel (including the back up number that fell out of the Dual category). The General Consumer Council for NI suggest that approximately half of all households use solid fuel – 321,000 households. Based on this fact, it has been assumed that approximately 149,755 need to be mapped as households that use solid fuels as a back-up fuel.

The assumption is that 40,000 households that use electricity will use solid fuel as a backup. The other 109,755 households are assumed to use oil as their primary fuel. An assumption is made that 0.9 tonnes of solid fuel are consumed per annum by these users. This is based on information from the Belfast fuel use survey. The same split in the use of solid fuels is assumed as that applied to the open fire distributions.

The rest of the wood consumed in NI is distributed using the open fire distribution.

2.2.3 The use of Smoke Control Areas (SCAs)

Households that have open fire appliances or solid fuel non-glass fronted boilers and that are located within SCAs have different assumptions applied. The basic assumption applied to these types of households within an SCA is that they will not burn bituminous coal. 60% are thought to burn anthracite (included in a blended form) and 40% SSF. However, levels of non-compliance have been estimated. In Belfast, 10% non-compliance has been assumed, and therefore 10% of households are assumed to be burning bituminous coal. In Greater Belfast SCA areas (excluding Belfast), 20% non-compliance is assumed, while outside of Greater Belfast, 30% non-compliance has been assumed. In Derry complete non-compliance was assumed. This reflects the perceived lower knowledge of the requirements with regard to Smoke Control legislation away from the Belfast area. The above assumptions also apply to households burning wood.

Figure 2.4 below illustrates the area of NI that is covered by SCA. Much of Greater Belfast is covered by SCAs, as are a number of other urban areas.[1] The blue area represents Belfast SCA, green represents Greater Belfast SCA while red represents SCA areas outside of Greater Belfast in which some compliance with Smoke Control Orders was assumed.

[1] Note that the SCA coverage was supplied by DoENI.

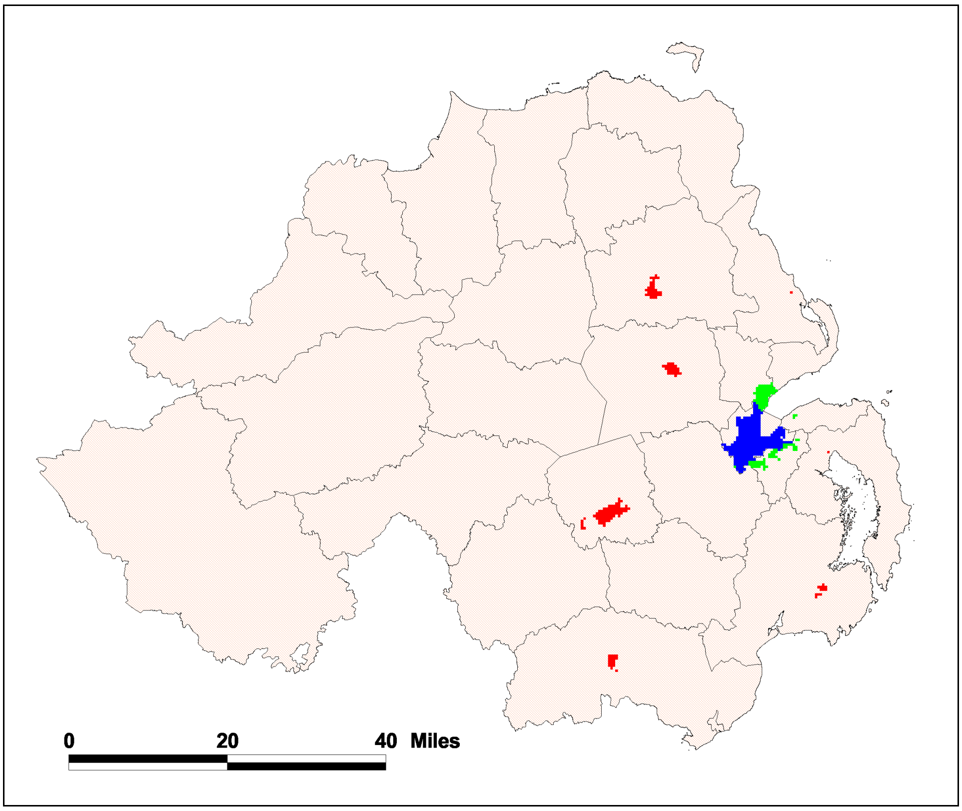


Figure 2.4: Northern Ireland Smoke Control Areas

2.2.4 2000 Benzo[*a*]Pyrene emission totals

Table 2.5 below outlines total Northern Ireland (NI) emission estimates by domestic source category. These estimates are based on the methodology outlined above. The importance of emissions from the use of back up fuel can be quantified – solid fuel consumed as a backup fuel equates to 36% of the total BaP emission total.

Table 2.5: BaP emission estimates by appliance-fuel type category

Inventory Category Name	***Household Number***	***BaP Emission totals (kg)***
Oil	371382	2.737
LPG	5582	0
Solid fuel glass fronted boiler	52606	5.524
Open fire	17918	68.331
Solid fuel single purpose boiler	2525	0.265
Solid fuel non-glass fronted boiler	45767	181.915
Range cooker and heater, burning coal	814	0.94
Other stove / space heater	7062	5.216
Other	7166	0
Dual (including backup solid fuel use)	58846	94.124
Electric	54946	0
Gas	20827	0
Open fire – wood fuel use		12.672
Solid fuel backup – oil households		99.736
Solid fuel backup – electricity households		33.477
Total households	**645,441**	**504.94**

The total amount of solid fuel that is being burnt based on these estimates is 626,455. The total amount of coal (including other solid fuels but not wood) used in the domestic sector as reported in the NI Annual Abstract of Statistics 2001 is 617,000 tonnes. This means that the calculated bottom-up numbers based on a number of different assumptions match quite closely to this NI total number reported in the official statistics.

The final BaP spatial inventory has an additional 157.6 kg contribution from non-domestic area sources.

2.3 Projections to 2010

Emission inventory projections to 2010 are key in understanding levels of emissions in the future, and in determining modelled concentrations. Due to the large uncertainties in spatial emissions in 2010, a number of different scenarios have been considered, each containing a set of different assumptions.

It has been difficult to establish projected fuel consumption patterns in the domestic sector given the lack of Northern Ireland specific projections. DETI, the Northern Ireland department that overseas energy issues, does not carry out projections of energy demand and supply, but uses the UK DTI projections.

The domestic projections have been essentially based on the bottom-up approach as described in the 2000 estimates, and have been driven by two key drivers; the NIHE heating appliance conversion programme and the increased penetration of natural gas pipelines. This approach is thought to be more robust than trying to work with centralised DTI projections that might not be entirely representative of future Northern Ireland domestic fuel demand.

2.3.1 Key Drivers

Emission reductions by 2010 will be based on two key issues, which include:

- The NIHE Fuel Appliance Conversion programme
- Increase take-up of mains gas

2.3.1.1 NIHE Conversion Programme

During the 1970s and 1980s solid fuel systems were put into public sector properties. Oil was not used due to the crisis in the world-wide market. The NIHE have been running a conversion programme since 1996, to replace central heating systems in properties with oil or gas. Since 2000, only oil (where gas is not available) and gas have been offered as the replacement fuel. Out of 110,000 properties, 40,000 use oil or gas. 50,000 properties use solid fuels, while 20,000 use electricity for heating.

The rate of conversion is 9000 properties a year (a third of which are gas) – and the solid fuel properties are being prioritised for conversion first. This could mean that all solid fuel has been phased out in the public sector housing stock by 2010. Where conversion is carried it has been assumed that there will be no burning of solid fuel as a backup fuel. This is because present NIHE policy is to remove other appliance types during conversion to reduce future maintenance costs.

2.3.1.2 Take-up of Natural Gas

Phoenix gas has provided estimates of gas use in 2010, in the current license area. For the rest of NI, estimates of gas take-up in the domestic market are difficult to predict, given that no licenses have been issued. However, with the building of two pipelines (to Londonderry, and between Greater Belfast and the Republic of Ireland), there is an understanding that other geographical locations outside of Greater Belfast could receive gas by 2010 depending on issue of licenses and the development of networks. Phoenix has provided us with what they perceive as possible availability of gas by population in the domestic market.

Based on what has happened in Greater Belfast, a take-up rate of gas can be assumed for population where gas could be available. Significant assumptions will needed to be made with regard to whether or not networks will be in place.

2.3.2 Development of Scenarios

A number of scenarios have been developed to look at what projected emissions in 2010 might be. These scenarios have been constructed on the basis of a number of assumptions:

1. The NIHE appliance conversion programme is completed. Most of the 2000 NIHE solid fuel (SF) housing stock will have been converted to gas or oil by 2010. Some of the current stock will have been bought by tenants, and a small minority of households may have refused / avoided conversion. This assumption assumes 90% SF conversion and 10% continuing to use solid fuel, primarily due to tenants buying properties prior to conversion. The 10% SF households will be randomly scattered.

2. An alternative assumption is that there will be a shortfall in funding of the NIHE conversion programme. On top of the 10% random SF households as mentioned in assumption 1, a further 15% of households will not have been converted from SF to oil or gas. This 15% of NIHE households will not be randomly scattered but clustered, based on the assumption that conversion will tend to happen for whole streets / estates rather than individual households.

3. Phoenix Gas has provided 2010 gas projections for the existing licensed area. This data will be built into the projections. The assumption will be that this gas data will account for conversions in both NIHE and private sector, with a maximum of 75% HE households converted in each postcode area. Priority will be given to conversion of SF households firstly, followed by households using electricity.

   1% per year new build will be assumed, meaning that such households will have to be removed from these 2010 households. Once they have been removed, it can be assumed that the rest of the household numbers are made up of the housing stock from 2000.

4. Phoenix gas has also provided some indication of the penetration of gas into the domestic market in the rest of NI. One assumption is that the North- West pipeline will be built, and that from the proposed date of availability to urban households, a 4% take-up rate per year will be assumed.

5. An alternative assumption is that both the North- West and North- South pipeline will be built, and a 4% take up rate will again be presumed.

6. Wood fuel use remains the same in 2010 as in 2000 – this fuel use is assumed to remain constant as a result of an increasing trend of burning wood for aesthetic / social reasons replacing wood burnt for primary heating.

7. The rest of households (not NIHE), and their conversion to other fuels, will be based on energy trends from EP68 (DTI 2001). As projections from EP68 are UK specific, it has been important to consider the fuel use surveys regarding what surveyed households state about their intentions to change to other fuels.

From these assumptions, the following four scenarios have been devised:

Table 2.6: 2010 Scenarios

Scenario	Assumption to include	Scenario name
1	3, 6, 7, 1, 4	Full NIHE conversion programme / North- West pipeline
2	3, 6, 7, 1, 5	Full NIHE conversion programme / Both pipelines
3	3, 6, 7, 2, 4	Reduced funding for conversion programme / North- West pipeline
4	3, 6, 7, 2, 5	Reduced funding for conversion programme / Both pipelines

2.3.3 Mapping 2010 projections

The two main influencing factors with regards to the 2010 spatial emissions inventory is gas penetration, and the NIHE conversion programme. As outlined in the table above, 4 scenarios have been developed and mapped. This section describes in more detail exactly how the maps have been put together.

2.3.3.1 Gas households in 2010

It is important to map projected gas households in 2010, in order to get an understanding of the domestic fuel types that they would have displaced. There are two components of mapping gas household numbers. Firstly, there are the projected numbers for the currently licensed Greater Belfast area, which Phoenix Gas has provided. This is included in all 4 scenarios, as it is considered a robust dataset, which has been put together by Phoenix Gas. Secondly, there is consideration of gas penetration in the rest of NI. Both are described below, in terms of how they were incorporated into the maps.

2.3.3.1.1 Current Licensed Area

2010 projected gas figures have been incorporated in all of the scenarios although will probably be driven to some extent by the NIHE conversion programme. However, it has been assumed that conversion in this area will be prioritised due to the availability of gas, so even if funding was removed, it is assumed that most of the conversions will have already have taken place.

In the licensed area, increases in the number of households using gas in 2010 will result in the removal of solid fuel households from other grids. Firstly, the NIHE solid fuel households are removed – due to conversion programme. This equates to 22,958 households through the conversion programme. Once NIHE households have been removed, the gas households are assumed to replace other solid fuel households (which are not NIHE households). It is also assumed that a small percentage of households that use oil as their primary fuel will convert to mains gas.

The increase in households using gas in 2010 in the current licensed area means that solid fuel in this area, used as a primary fuel, is virtually removed. Gas households have increased by over 5 times from the 2000 households figure.

2.3.3.1.2 Rest of NI

All four scenarios include the inclusion of further development of gas markets in other parts of NI, based on the route of the proposed north west and north-south pipelines. Phoenix Gas has provided some basic analysis as to where they perceive urban networks could be set up (based on the pipeline routes) and what the potential number of households might be to which gas would be available.

Based on this analysis, urban area wards have been selected as possibly having gas available by certain years. A take-up value has been attributed to these wards, and grids created that can be multiplied to household numbers to show the increase in gas, and subsequent displacement of other fuel types. NIHE households have been unaffected by this gas displacement as they are considered in the NIHE conversion programme part of the scenarios.

An example of the basic analysis done is as follows; Antrim could get gas provision by 2006 on current estimates. It has estimated that 5% of households could need new heating systems each year – therefore, we estimate that 4% will take up gas if available. Therefore, by 2010, an estimated 16% of households will have gas. It has been assumed that it will be primarily users of solid fuel and electricity who will switch, based on the fuel surveys. It has been assumed that the NIHE will have converted its properties that used solid fuel and therefore, these will not be affected – however, the dual and electricity categories have the potential to be affected.

The North West pipeline coverage has been included in all four scenarios, while the North- South pipeline coverage has only been included in two scenarios. Figure 2.5 below illustrates the areas where further gas penetration has been projected to occur.

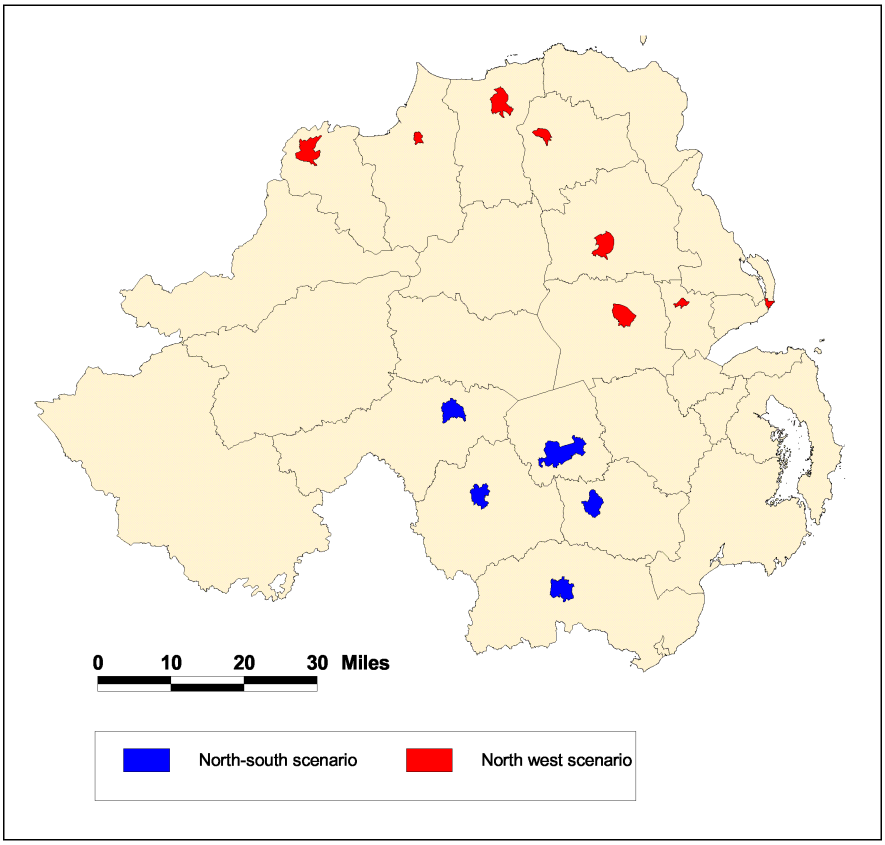


Figure 2.5: Northern Ireland Pipeline Scenarios outside of current licensed area

2.3.3.2 NIHE Conversion Programme

In terms of the NIHE conversion programme, two different scenarios – *full* and *part* completion of the conversion programme - feed into the overall four scenarios (as outlined in the previous section). For the full conversion scenarios, the five NIHE solid fuel household grids are considered as oil or gas. In Greater Belfast, all of the conversion will be to gas. Outside of Greater Belfast, they are considered to all convert to oil, except in those areas where gas penetration could take place.

Analysis has been undertaken to assess what the effect of only part conversion of NIHE properties may have on BaP levels. In an arbitrary way, certain areas have been selected, that will have no conversion of solid fuel appliances to oil or gas (see Figure 2.6 below). This methodology is trying to reflect a hypothetical situation if funding for the conversion programme does not continue for the proposed programme lifetime or the programme is subject to delay. Obviously it is not entirely realistic as the areas highlighted in the diagram below show. However, it may help indicate what levels of BaP emissions will be in areas where part conversion occurs.

The assumption was made that NIHE properties in Greater Belfast will already have been converted for reasons such as an established conversion programme and the availability of gas. In terms of determining which areas will be missed by the conversion programme, 6 squares have been created – 20 x 20km^2 in scale. These have been selected in a fairly arbitrary way, to cover both rural and urban areas. Squares have been positioned so as to represent different areas of NI (except Greater Belfast).

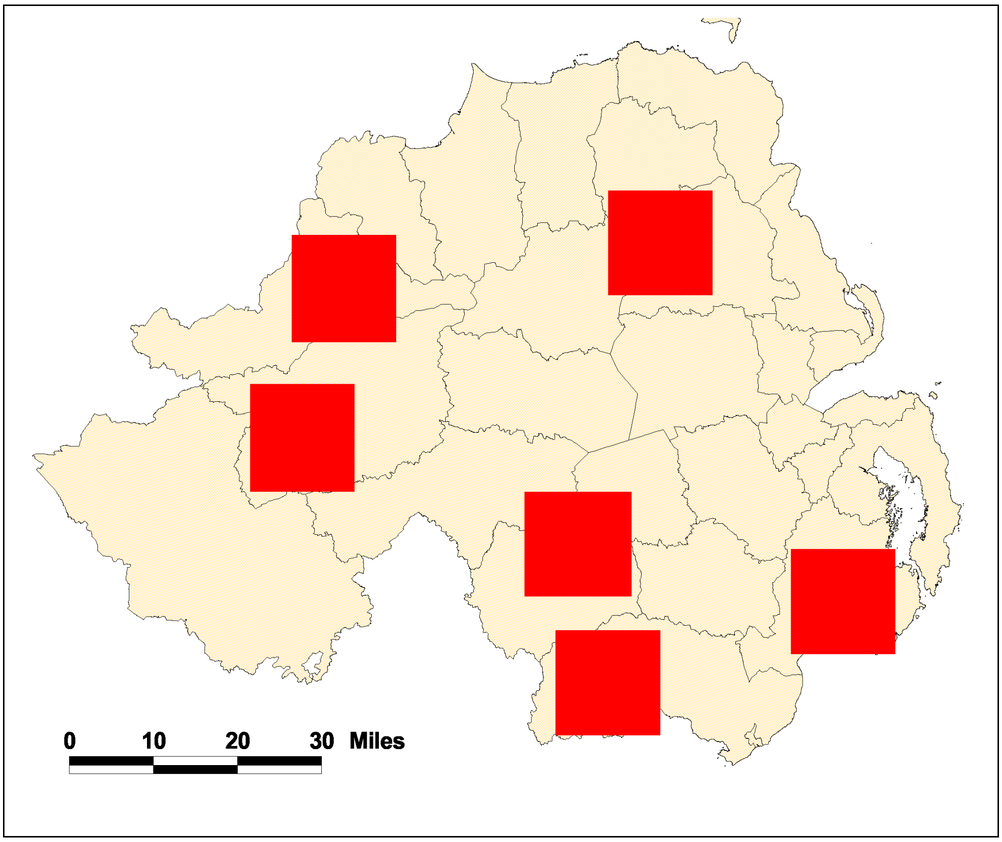


Figure 2.6: 20 x 20 km areas with no NIHE conversion

2.3.3.3 General household reduction

There is a need to apply some general reduction factors to other household grids – households that are not owned by the NIHE or displaced by the increase in gas connections. In terms of projections, we need to take into account general change based on the decisions of various households. These reduction factors are based to a large extent on fuel surveys undertaken by various district councils, and are included in all four 2010 scenarios.

A general discount factor of 12% for the solid fuel grids has been applied for the 10 years between 2000 and 2010. This takes into account the fact that some households are not owner occupied and therefore, decisions concerning switching to other fuel types may take longer. A discount factor of 6% for the dual grid has been applied - as most of these households use oil fuel and so will not change.

2.3.4 2010 Benzo[*a*]pyrene emission totals

The following emission totals were derived for the four 2010 scenarios:

Table 2.7: 2010 Emission totals for the Scenarios

Scenario No.	Scenario	Emissions of BaP (kg)
1	Full NIHE conversion programme / North West pipeline	289.478
2	Full NIHE conversion programme / Both pipelines	286.170
3	Reduced funding for conversion programme / North West pipeline	316.746
4	Reduced funding for conversion programme / Both pipelines	312.185

Other non-domestic area sources add an additional 46 kg of BaP to the total area source emissions map.

2.4 Development of additional scenario

An additional scenario has been developed to assess the effect of using smoke control orders to reduce exceedances of BaP. In section 3.2.4, the 2010 scenarios have been modelled. Table 3.3 shows the geographic area and number of people exposed where exceedances above certain limits are predicted.

Based on this data, the spatial inventory for scenario 3, the worst case, was selected for re-calculation, to illustrate reductions due to smoke control orders. The worst case scenario was chosen as this represents what hypothetically could happen. This scenario was based on two assumptions; firstly, reduced funding for conversion programme meant that NIHE properties in specific areas were not converted to gas or oil; and secondly, a North West pipeline was built which meant gas penetration in certain communities.

The approach taken for this analysis was to use smoke control restrictions in those areas where exceedances were predicted. The scenario was built on the assumption that any grid squares exceeding a 0.5 ng/m^3 (a potential NI-specific limit) would be located in a SCA.

Three 500x500m grid squares exceeded a limit of 0.5 ng/m^3. SCAs were developed that overlaid the exceeding grid squares only, and 30% non-compliance was assumed. The exceeding grids squares were in Strabane in the West and Newry in the South.

The reduction for those squares where a SCA is applied is significant, although the overall inventory total does not change considerably. The model was re-run for this additional scenario, and the results are presented in Section 3.3.

3 Area source modelling

3.1 Introduction

The approach to predict benzo[*a*]pyrene concentrations was based on that carried out previously for the UK scale assessment. A fuller description of the modelling method can be found in Coleman *et al.* (2002).

Emissions from area sources are considered to be the main sources of BaP in Northern Ireland as the previous study showed that point sources made an insignificant contribution to observed concentrations. Here emissions are modelled only from area sources. The concentration is then derived by the addition of a background concentration of 0.05 ng/m^3. This was applied to account for long range transport into the model domain.

The previous top down approach for deriving an emission inventory meant that concentration could only be predicted at the 1 km scale. With this new bottom up inventory the spatial resolution of the emission inventory is improved and concentrations are predicted at a 500 m resolution.

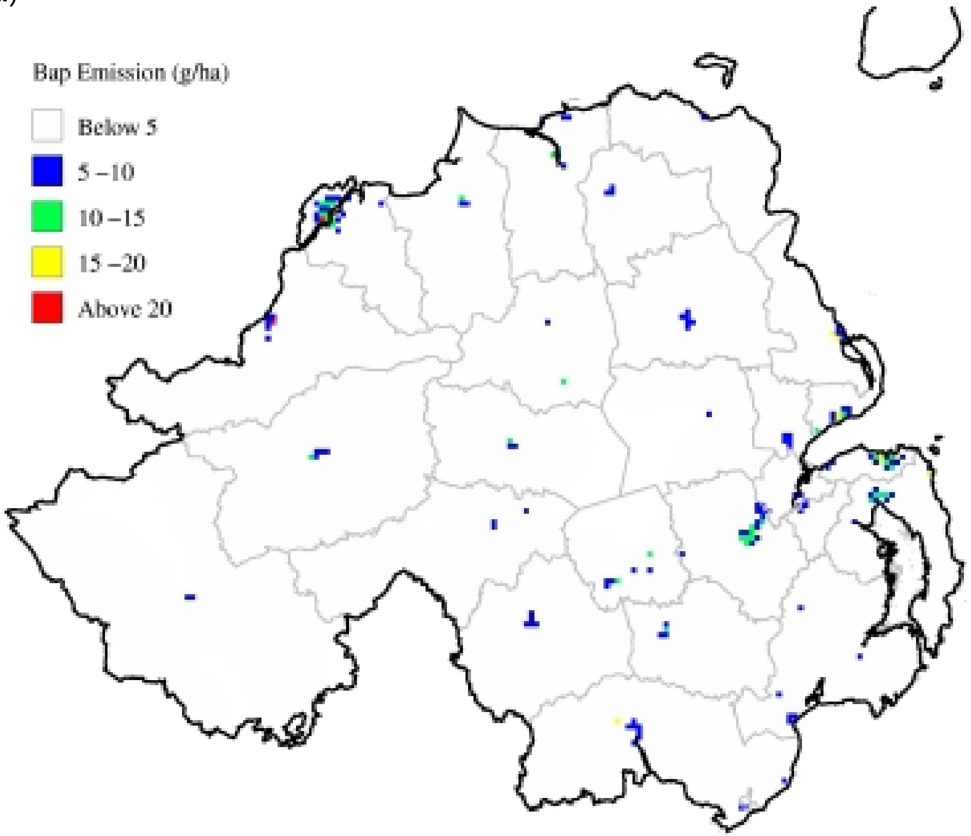
3.2 Modelling area sources

The emissions from each grid square were assumed to be distributed uniformly throughout with an initial height of 10 m. The estimate of 10 m is based on the height of a typical house and assumes that emissions will be entrained in the building wake.

Emissions have been calculated for the base emission year of 2000. However to assess the sensitivity of the predicted concentrations to meteorological variation, concentrations were predicted using 1999, 2000 and 2001 meteorological data from Aldegrove. In addition the emissions from the domestic sources were weighted using the degree day in which emissions are weighted towards the colder periods (the approach is described in Coleman *et al.,* 2002).

Figure 3.1 shows the BaP emissions predicted to occur from the 1km and 500 m squares.

a)



b)

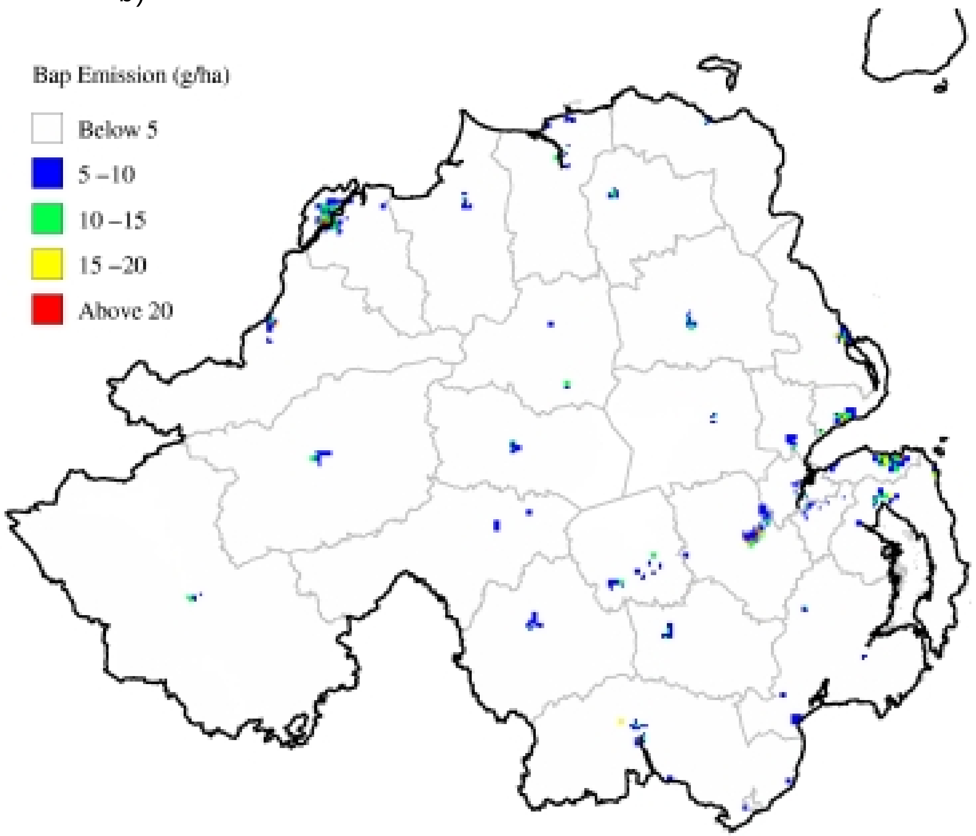


Figure 3.1: BaP emissions from 1 km squares (a) and 500 m squares (b). Emission units are in grams per hectare per year.

3.2.1 Model validation

There are only 2 sampling sites (Clara Street in East Belfast and Dunmurry High School in Dunmurry) against which the predicted concentrations can be compared.

Figure 3.2 shows that the predicted values for the 500m area model show a marginal improvement when compared to the 1 km area square prediction. The modelled concentration at Clara Street is predicted well for the 2001. The modelled concentrations at Dunmurry High School much less than the observed concentration - although the magnitude of the modelled concentrations reflects the observed concentration, for example the highest modelled concentration is for 2001.

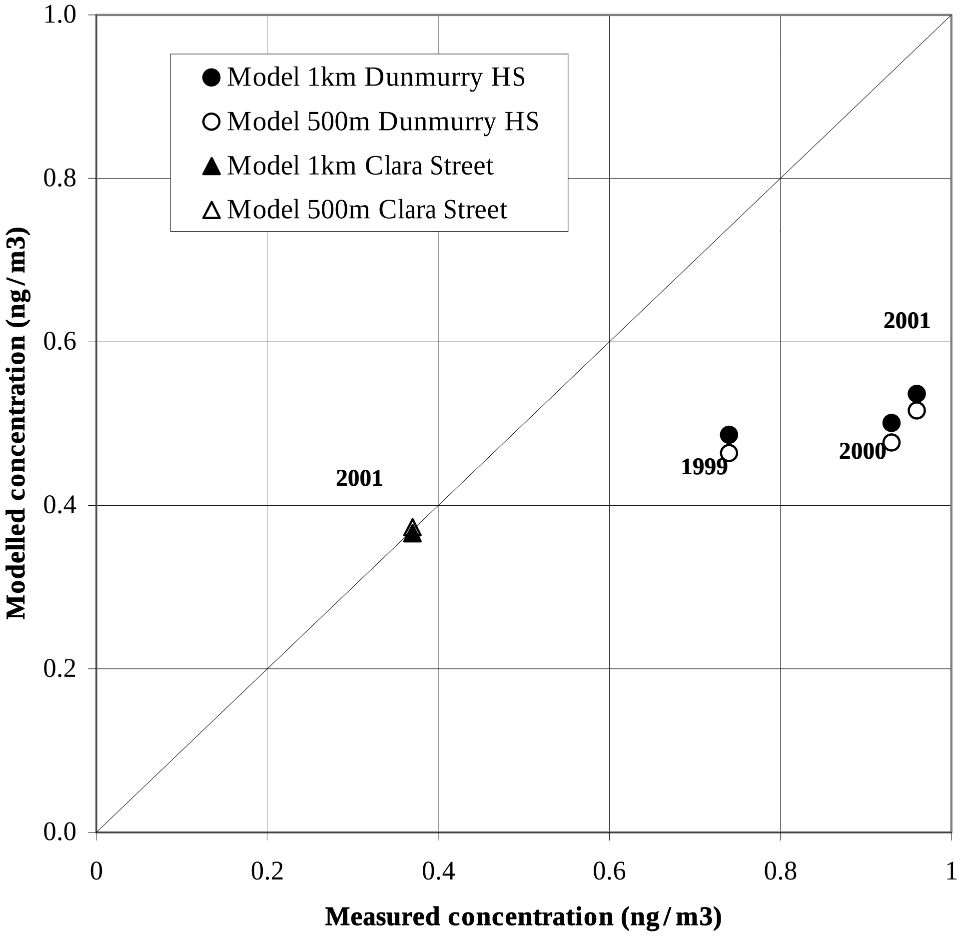


Figure 3.2: A comparison of measured and modelled benzo[*a*]pyrene concentrations based on both the 1 km and 500 m emission squares

3.2.2 Source apportionment

Area sources were modelled in two categories; domestic sources, which had an emission profile, and non domestic area emissions for which emissions were assumed to be emitted at a constant rate throughout the year. Figure 3.3 shows that the source apportionment of benzo[*a*]pyrene from the domestic, non domestic area and background sources. Emissions from the domestic source dominate the predicted concentrations. The emissions from the non domestic other source are seen to make a larger contribution in Clara Street than Lisburn.

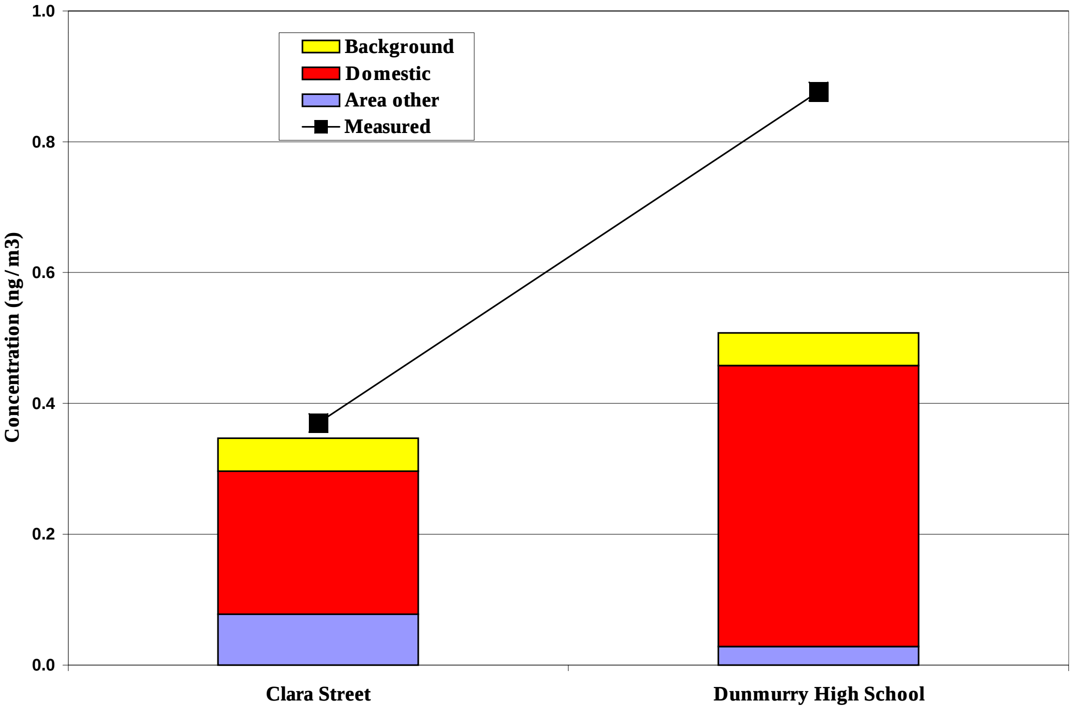


Figure 3.3: A source apportionment of the modelled benzo[*a*]pyrene concentration

3.2.3 Concentration Maps

Figure 3.4 to Figure 3.6 present 1 km concentration maps for each of the meteorological years modelled. In each case the highest concentrations are observed in the urban centres- notably the greater Belfast area, North Down, Newtownards and Derry.

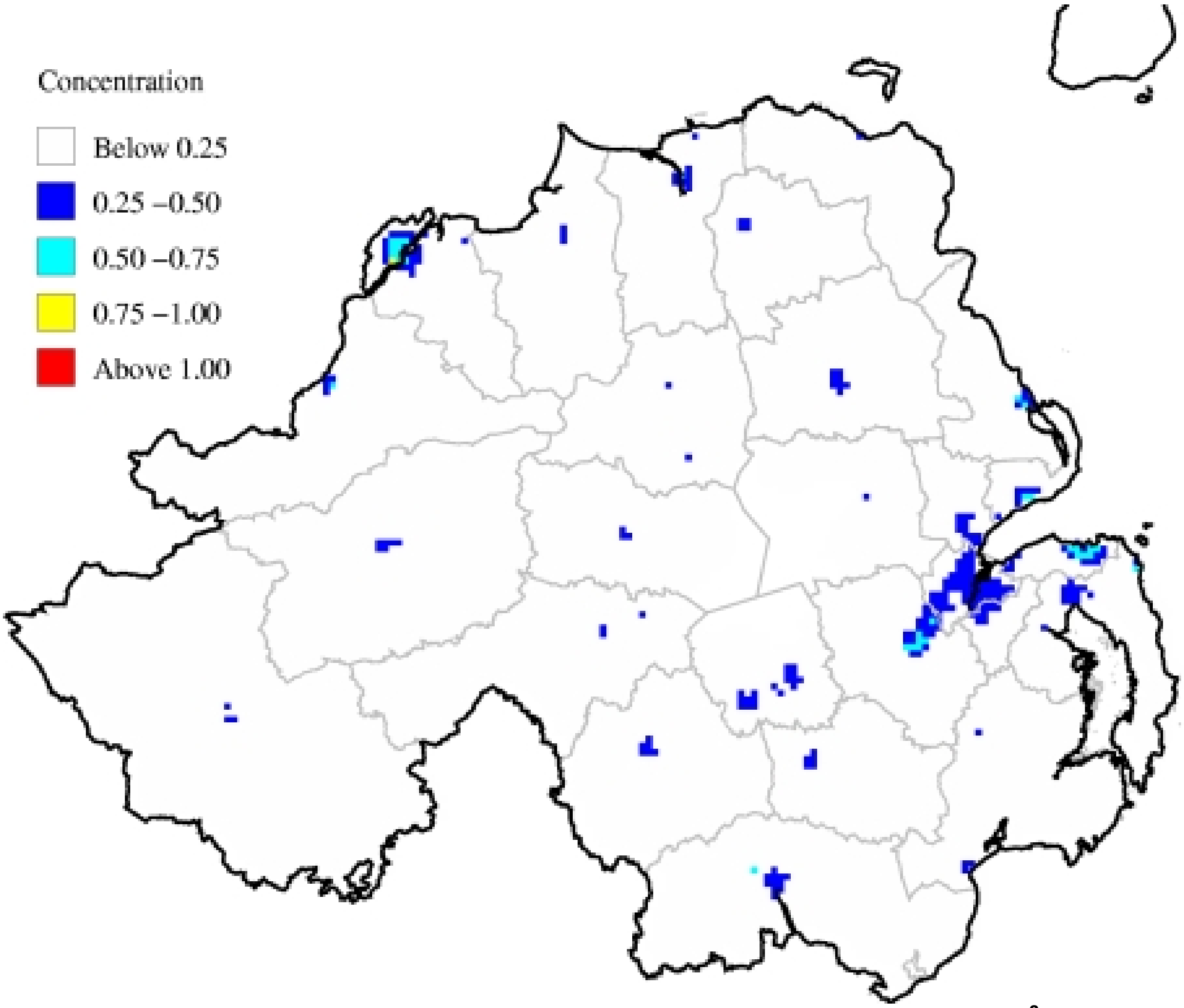


Figure 3.4: BaP Concentration predicted using 1999 Meteorology (ng/m^3)

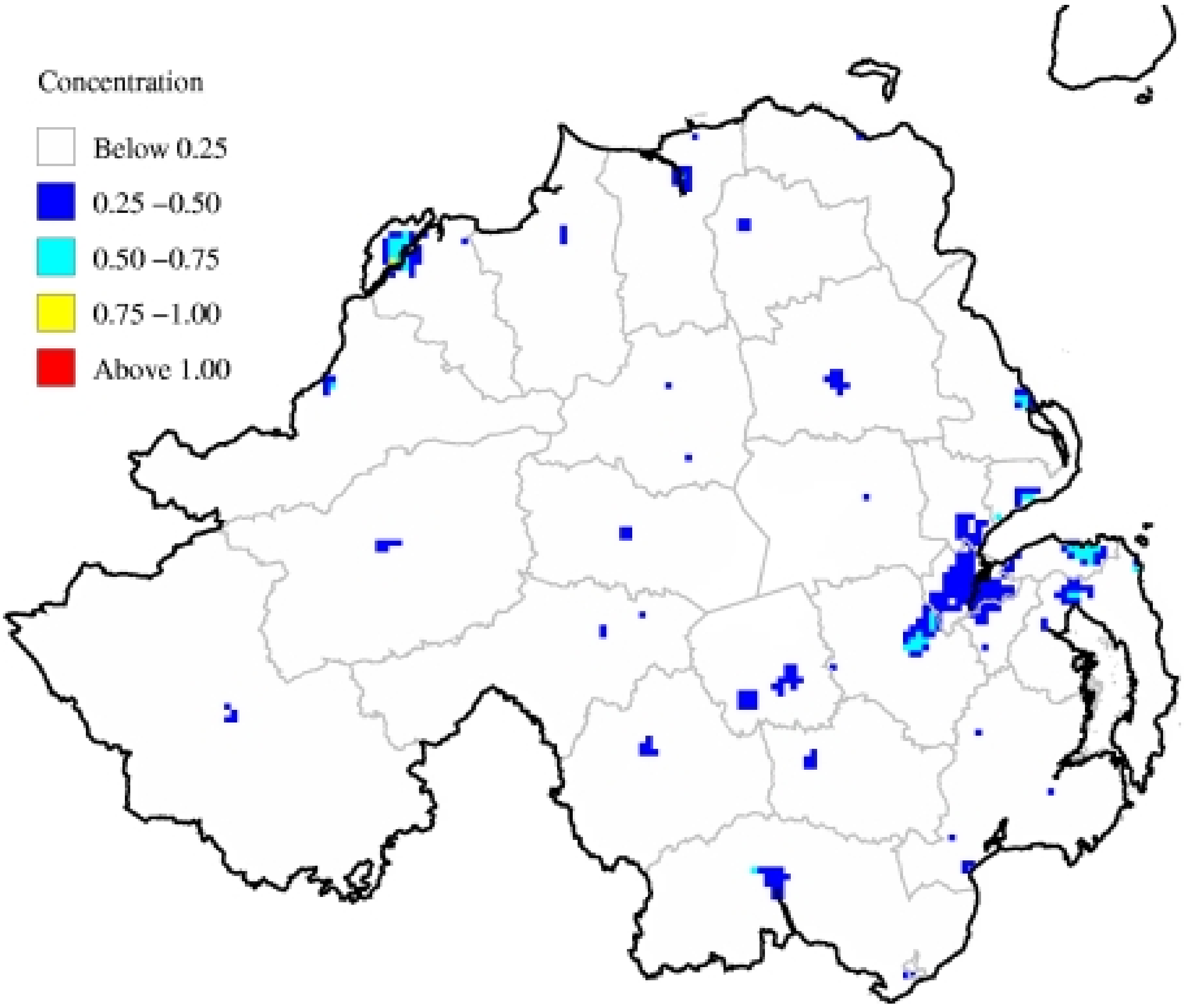


Figure 3.5: BaP Concentration predicted using 2000 Meteorology (ng/m^3)

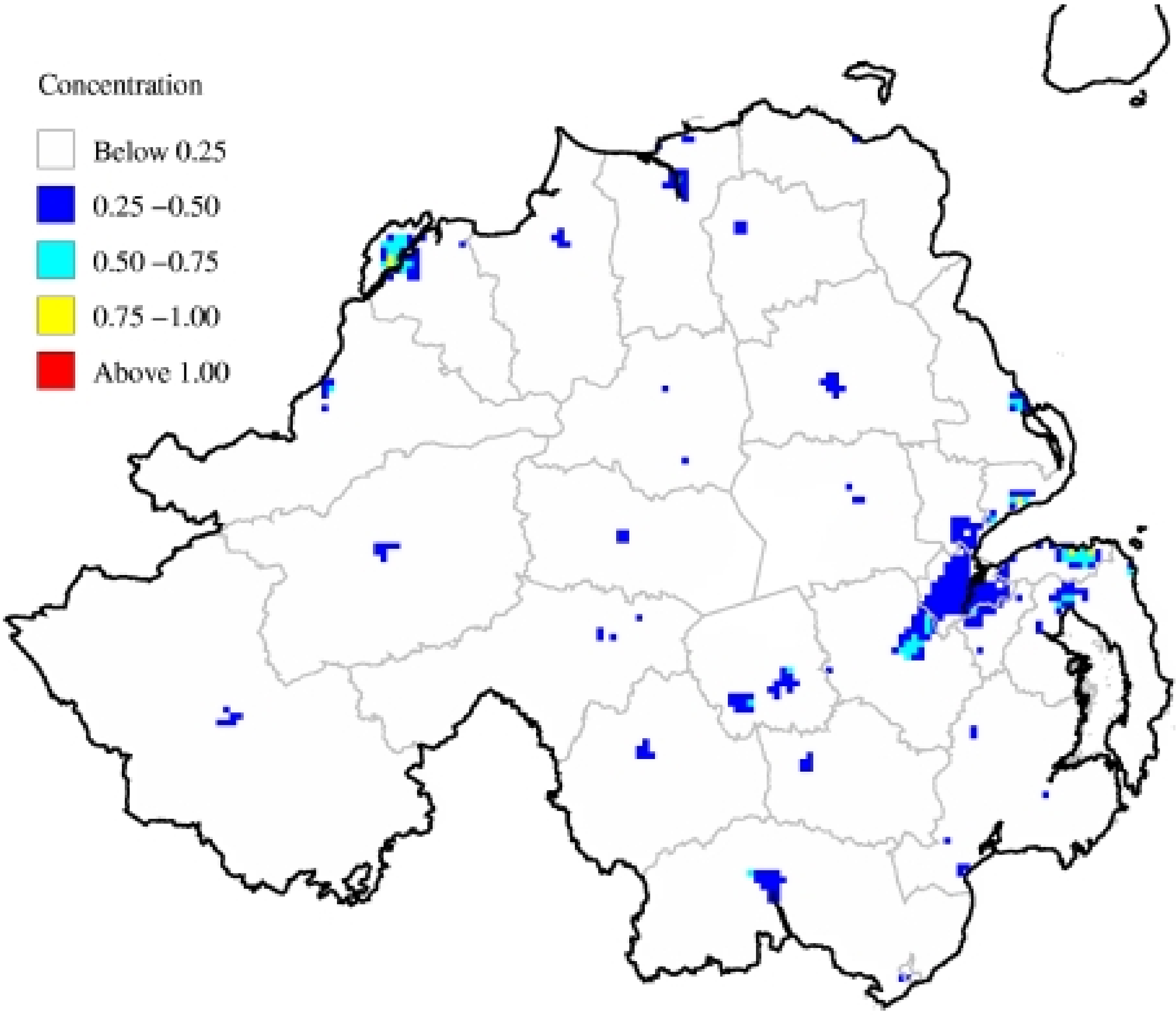


Figure 3.6: BaP Concentration predicted using 2001 Meteorology (ng/m^3)

3.2.4 Area of exceedance and numbers of people exposed to threshold concentrations

Table 3.1 and Table 3.2 present the area of Northern Ireland and number of people exposed to a range of benzo[*a*]pyrene concentrations calculated using the 2000 emission inventory and 1999, 2000 and 2001 meteorological data. Table 3.1 presents the area and number of people exposed based on the 1 km square modelling approach. Table 3.2 presents the same information based on the 500 m square modelling approach. The largest exposures are observed for the 2001 meteorological data- it is this meteorological year that was used to calculate exposures for 2010. Table 3.3 shows area exceeded for scenarios 1 to 4 based on the 500 m square modelling approach.

Table 3.1: Area of exceedance and number of people exposed to benzo[*a*]pyrene concentrations above a range of concentration thresholds using the 2000 emission inventory on 1000 m squares with a range of meteorology

Meteorological year	Threshold concentration (ng/m^3)	Area exposed to threshold concentration (km^2)	Number of people exposed to the threshold concentration
1999	>0.25	280	653925
	>0.50	32	97955
	>0.75	1	4038
	>1.0	0	0
2000	>0.25	320	720770
	>0.50	43	128428
	>0.75	1	4038
	>1.0	0	0
2001	>0.25	362	779591
	>0.50	55	163923
	>0.75	5	17720
	>1.0	0	0

Table 3.2: Area of exceedance and number of people exposed to benzo[*a*]pyrene concentrations above a range of concentration thresholds using the 2000 emission inventory on 500 m squares with a range of meteorology

Meteorological year	Threshold concentration (ng/m^3)	Area exposed to threshold concentration (km^2)	Number of people exposed to the threshold concentration
1999	>0.25	278.25	649068
	>0.50	31	93327
	>0.75	2	7356
	>1.0	0	0
2000	>0.25	309.75	695936
	>0.50	41.5	122591
	>0.75	4	13912
	>1.0	0	0
2001	>0.25	358	763504
	>0.50	56	161923
	>0.75	7.5	23770
	>1.0	0	0

Table 3.3: Area of exceedance and number of people exposed to benzo[*a*]pyrene concentrations above a range of concentration thresholds for 2010. Using 2001 meteorological data and the 500 m square modelling approach

Scenario	Concentration threshold (ng/m^3)	Area exposed to threshold concentration (km^2)	Number of people exposed to the threshold concentration
1	>0.25	26.75	81727
	>0.50	0	0
	>0.75	0	0
	>1.0	0	0
2	>0.25	24	76263
	>0.50	0	0
	>0.75	0	0
	>1.0	0	0
3	>0.25	44.25	111451
	>0.50	0.75	2177
	>0.75	0.25	613
	>1.0	0	0
4	>0.25	38.25	102075
	>0.50	0.75	2177
	>0.75	0.25	613
	>1.0	0	0

3.3 Modelling the additional scenario

As described in Section 2.4, an additional scenario was developed which meant that grid cell exceeding a specified limit of 0.5 ng/m^3 were covered by smoke control orders (a total of 3 500m $\times$ 500m squares. The area source model was run and the following results were observed.

Limit	Area of exposure (km^2)	Population exposed
>0.25	43.75	110389
>0.50	0	0
>0.75	0	0
>1.0	0	0

As expected the introduction of smoke control orders reduced to zero the number of squares with a predicted concentration greater than 0.5 ng/m^3.

4 Local Scale Benzo[*a*]pyrene modelling at the Lisburn Site

The Lisburn sampling site is located with the grounds of Dunmurry High School within the Conway housing estate and adjacent to the Seymour Hill housing estate. Below is a description of the methodology used to calculate benzo[*a*]pyrene concentrations within the Seymour Hill and Conway Estates. The area of interest is a 1 km square centred on an area that comprises both estates. The sampling site at Dunmurry High School is located to the south west of the square.

The description is set out into a number of stages. These are:

- Details of how BaP emissions were assigned to each house
- How the concentrations predicted from the estate scale study were incorporated into the province scale study

4.1 Modelling concentrations at the Dunmurry High School sampling site

The area source modelling predicted that the contribution from all sources at the Dunmurry High School site was 0.47 ng/m^3 in 1999 (for the case of the 500 m $\times$ 500 m area source). This comprised of 0.39 ng/m^3 from the domestic sector, 0.03 ng/m^3 from the non-domestic sector and 0.05 ng/m^3 from background sources. The measured concentration was 0.74 ng/m^3.

However the area source modelling using emissions from either 500 m $\times$ 500 m or 1000 m $\times$ 1000 m squares is a relatively coarse modelling resolution and it might be expected that concentrations will vary significantly within a grid square. Hence, a more detailed study was conducted in which emissions from individual houses are modelled individually.

4.2 Assignment of Benzo[*a*]pyrene emissions to each house

To identify those houses which burn solid fuel or oil for space heating would require a detailed fuel survey. The fuel use survey would also need to determine the pattern of use within the day and throughout the year.

In the absence of such a fuel use survey emission amounts have been estimated based on information contained within the NIHE database. This database provides the number and type of appliances that belong to the NIHE within each enumeration ward. The Seymour Hill and Conway estates fall within three ward areas. These are; Seymour Hill, Lambeg and Derriaghy. Based on local knowledge and use of a geographical information system houses that would potentially use solid fuel or oil were identified.

The houses belonging to each ward are identified in Figure 4.1. The number of houses belonging to each ward is shown in Table 4.1.

Table 4.1: Number of houses within the Seymour Hill and Conway Estates belonging to each ward

Ward	No of houses
Derriaghy	46
Seymour Hill	432
Lambeg	580
Total	1058

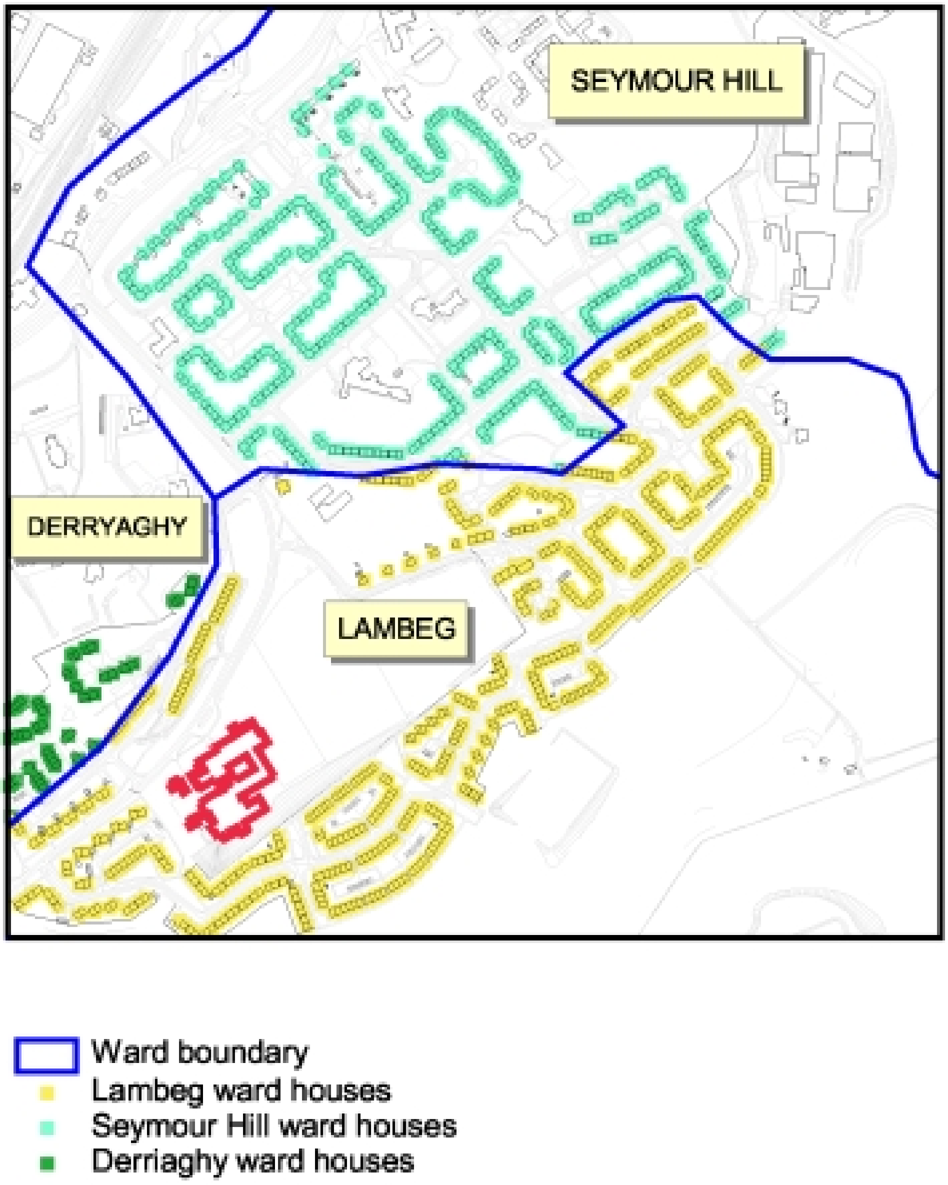


Figure 4.1: Houses within the Seymour Hill and Conway estates that potentially may burn solid fuel or oil. (Also presented are the boundaries for the Derriaghy, Seymour Hill and Lambeg wards that intersect within the estates. The sampling site is on the western side of the school (shown by red in the figure)).

It has been assumed that the profile of heating appliances for privately owned houses within the estates are the same as those contained within the NIHE housing stock.
shows the number of appliances burning solid fuel or oil within each ward. A weighted average of appliance type was then calculated based on the number of houses from each ward in the estates. For example, the relatively large number of open fire back boilers identified within the Derriaghy ward was given a relatively low weighting since there are only 41 houses out of a total of 1058 houses identified from the GIS information as being in the Conway Estate.
also shows presents an appliance profile- which shows that the predominate appliance type is the glass fronted fire type (61 %).

Table 4.2: Appliance profile estimated for the Seymour Hill and Conway Estates

	Number of NIHE houses in each ward for each appliance type			
Ward	***Open fire***	***Open fire back boiler***	***Glass fronted smokeless***	***Oil***
Derriaghy	1	122	73	26
Seymour Hill	13	74	182	18
Lambeg	11	61	121	9
Weighted average*	11	69	144	13
Appliance profile	**5%**	**29%**	**61%**	**6%**
Number of houses within estate for each appliance type (total 1058 houses)	51	307	640	60

*See Table 4.1 for number of houses used to weight appliance type

Table 4.3 shows the total BaP emission calculated for each appliance type within the estates. The same emission factors, consumption and fraction of each fuel consumed each year applied to the larger scale modelling were applied here.

The predominate sources are open fires with backboilers and open fires only. However, because there is no information available as regards how the appliances may be distributed within the estates it was assumed that the total emission is allocated equally to each house. This results in a BaP emission of 1.49 g $house^{-1}$ $year^{-1}$ (1578 g/1058 houses).

Table 4.3: Benzo[*a*]pyrene emissions from each appliance type in the Seymour Hill and Conway Estates

	Number of houses having each appliance type	Emission factor for each appliance type (mg tonnes^{-1})	Amount of fuel consumed each year (tonnes)	Type of fuel consumed	Fraction of each fuel consumed each year	Total amount of BaP released (g year^{-1})
Open fire	51	1550	3.5	Coal	0.75	206
		330		SSF	0.1	6
		30		Anthracite	0.15	1
Open fire with back boiler	307	1550	3.5	Coal	0.75	1250
		330		SSF	0.1	35
		30		Anthracite	0.15	5
Glass fronted smokeless	640	30	3.5	-	1	67
Oil	60	3.43	2.149	-	1	8
Total emission based on appliance type						1578

4.3 Incorporating predicted concentrations into the wider scale study

The concentrations predicted from the detailed modelling need to be incorporated into the wider scale modelling. To do this the emission amount modelled in the detailed study needs to be subtracted from larger scale area modelling work. Figure 4.2 shows the BaP emissions from the 9 500 m × 500 m squares which encompass the Seymour Hill and Conway Estates. The emissions amounts are in g of BaP released from each 500 m × 500 m square per year. The total BaP emission from the nine squares is 1881 g. When the emission amount from the individual houses (see Table 4.3; 1578 g) is subtracted from the 1881 g this leaves 303 g to be allocated amongst the nine squares- this is done on a pro rata basis with each emission being multiplied by 0.16. The area source domestic model is rerun with the corrected emission.

The emission amounts shown in Figure 2 are presented on the Great Britain Ordnance Survey projection - this is the default setting for the National Atmospheric Emission Inventory.

The resultant area source concentration are also on the Great Britain Ordnance Survey projection and these are required to be reprojected in order that they can be added correctly to the concentrations derived from the detailed modelling- which are predicted using co-ordinates from the Northern Ireland Ordnance Survey projection.

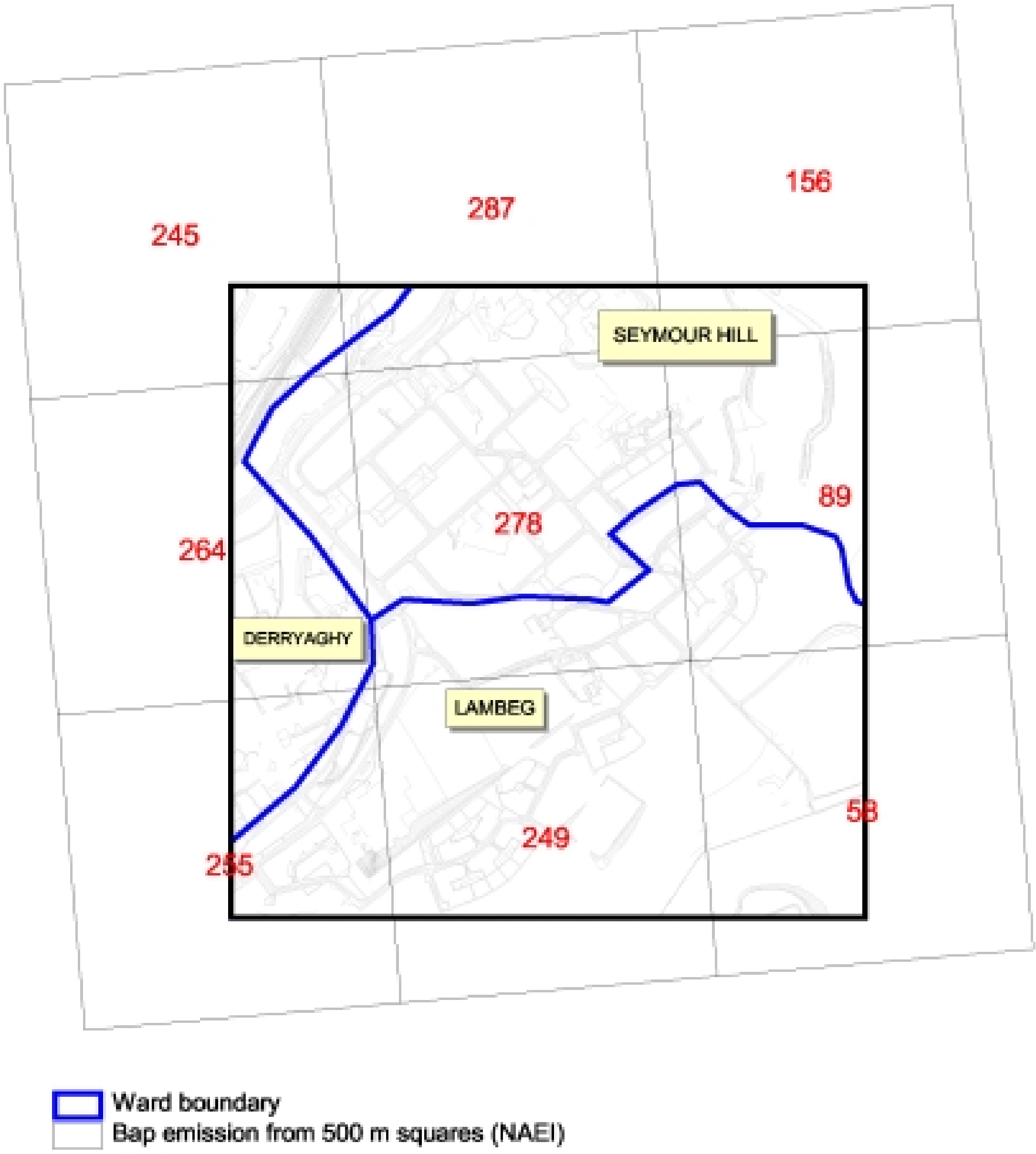


Figure 4.2: BaP emission from domestic source category (The 500 × 500 m squares are presented on the Great Britain Ordnance Survey projection. The detailed map of Seymour Hill and Conway estates is presented on the Irish Ordnance Survey projection).

Table 4.4 shows the concentrations predicted from each of the component source sectors (detailed modelling study; corrected domestic emission; non domestic area sources and background). The detailed modelling has shown only a relatively small improvement (increase by 0.12 ng/m^3) in predicted concentration compared to modelling emissions using the area source approach alone.

Figure 4.3 shows the concentration predicted through the Seymour Hill and Conway estates. The highest concentrations (greater than 1 ng/m^3) are predicted to occur for the areas of densest housing.

Table 4.4: A comparison of modelled concentrations at the Dunmurry High School sampling site

Source category	Concentration all area source modelling (ng/m^3)	Concentration area source and detailed modelling (ng/m^3)
Detailed modelling	-	0.35
Domestic non corrected	0.39	-
Domestic corrected	-	0.16
Non domestic area	0.03	0.03
Background	0.05	0.05
Total	**0.47**	**0.59**

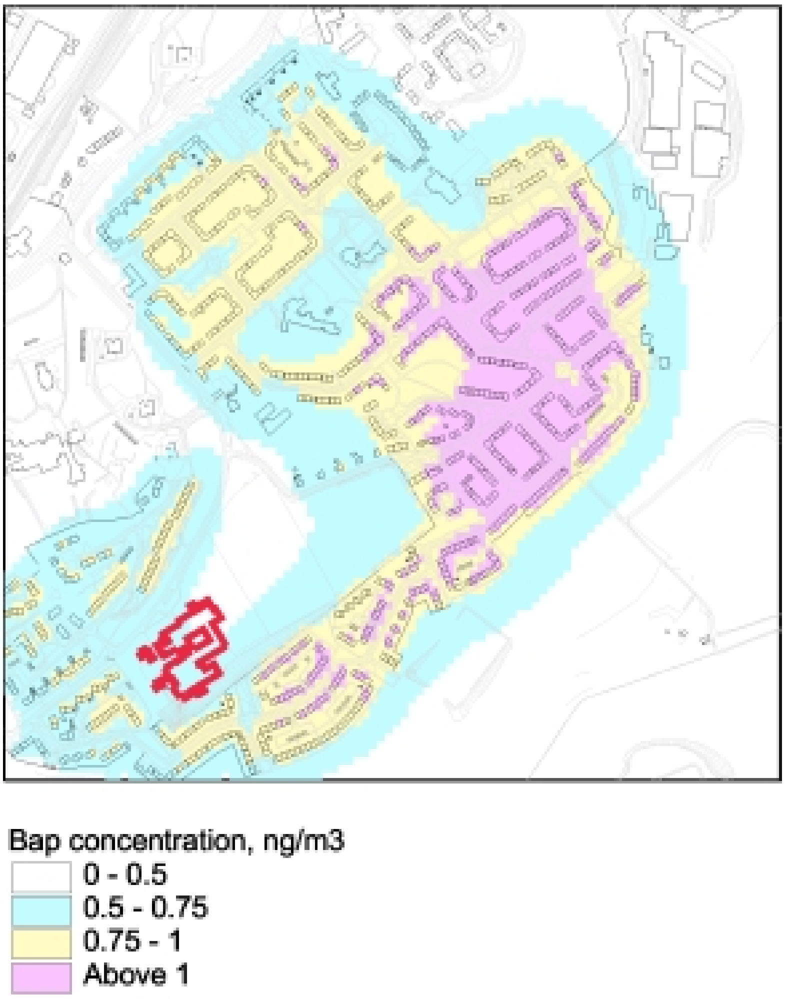


Figure 4.3: BaP concentrations predicted to occur with the Seymour Hill and Conway Estates in 1999

5 Sulphur Dioxide inventory improvement and area source modelling

5.1 2001 Sulphur Dioxide emission inventory for Northern Ireland

The household-appliance data that has been used to construct the BaP spatial inventory has also been fed in the National Atmospheric Emissions Inventory (NAEI) mapping for 2001. This has led to a significant improvement in the spatial distribution of household fuel consumption for Northern Ireland. The data that have been used include fuel use surveys, housing condition survey data, and Housing Executive data

From the appliance-fuel based grids constructed for the BaP spatial inventory, a number of household distributions that are used in the NAEI have been reconstructed based on this new information. These include coal, SSF, coke, wood, anthracite and oil. Some manipulation has been needed as the grids developed for the BaP spatial inventory are appliance-fuel based, while the grids used in the NAEI mapping are primarily fuel-based.

Another important new development has been the use of a reliable smoke control coverage. In previous inventories, the SCA coverage has been based on assumptions about where SCAs may be located. However, this new SCA coverage has been built by DoENI using SCA order documents, which provide accurate spatial information.

Significant areas of uncertainty, however, include the emission factors used, and types of solid fuel burnt. Emission factors vary not only according to the type of solid fuel that is being burnt but also the specific source of the fuel. The emission factors used in the NAEI for the domestic sector in 2001 are shown below in Table 5.1.

Table 5.1: NAEI SO_2 emission factors for the domestic sector (2001)

Fuel	Emission Factor (kt/mtonne)
WOOD	0.04
SSF	16.00
GAS_OIL	2.40
FUEL_OIL	25.57
COKE	13.26
COAL	17.06
BURNING_OIL_(P)	0.02
BURNING_OIL	0.42
ANTHRACITE	13.26

Using data on household appliance provides an indication of the type of fuel that is being burnt. However, it does not provide enough detail to get an understanding, for example, of the distribution of fuel used that contains differing amounts of pet coke. These are limitations within the inventory that would only be overcome by much more detailed data at a local level. As a result of these issues, significant variation might be seen at a localised level.

For this regionally based inventory, based on the available data, changes to the SO_2 spatial inventory do mark a significant improvement on preceding years. However, limitations as described above do need to be taken into consideration.

5.2 Sulphur Dioxide area source modelling

5.2.1 Introduction

In this section sulphur dioxide concentrations are estimated for Northern Ireland using the 2001 emission inventory. Concentrations are predicted for short term averaging periods- that is, the 15 minute, hourly and daily averaging periods and are compared with the concentration thresholds required as part of the Air Quality Strategy and the First Air Quality Daughter Directive. The concentration thresholds, together with the date by which the concentration must be achieved, are presented in Table 5.2.

Table 5.2: Air quality standards which will be estimated for Northern Ireland using the 2001 sulphur dioxide emission inventory

Concentration limit (µg/m^3)	**Averaging period**	**Air Quality Standard** Date for objective	**Air Quality Daughter Directive** Date by which limit value is to be met
266	**15 minute** mean [maximum of 35 exceedances a year. Equivalent to the 99.9th percentile]	By 31.12.2005	Not required
350	**1 hour** mean [maximum of 24 exceedances a year. Equivalent to the 99.73th percentile]	By 31.12.2004	By 01.01.05
125	**24 hour** mean [maximum of 3 exceedances a year. Equivalent to the 99.18th percentile]	By 31.12.2004	By 01.01.05

To calculate the short term average concentrations two approaches were considered:

- The first examined the relationship between the annual mean and short term mean concentration measured at those sites in Northern Ireland where sulphur dioxide is monitored continuously. These relationships were then applied to the annual mean concentration map derived by modelling area sources. The annual mean sulphur dioxide concentration was calculated in a similar way to that used for BaP (Section 3.1)

- that is the emissions from domestic and non-domestic area sources were modelled separately and a background component added. The derivation of maps of sulphur dioxide concentrations over short term averaging periods based on the modelling of annual means is subsequently referred to as the empirical model.

- The second attempted to explicitly predict the short term concentrations using a dispersion model. This is subsequently referred to as the explicit modelling approach.

5.2.2 Relationship between annual mean and short term sulphur dioxide concentrations

From 1990 and 1992 sulphur dioxide concentrations have been measured over short term averaging periods at the Belfast East and Belfast Centre sites, respectively. Short term mean concentrations have been available at a third site in Derry since 2000.

When the annual mean concentrations for all years and for each site are plotted against each of the short term average concentrations, strong associations can be observed. A steady decline in concentrations can be observed. Figure 5.1 to Figure 5.3 show how the annual mean concentration is associated with the 99.9 percentile of 15 minute means, 99.73 percentile of hourly means and 99.18 percentile of daily values, respectively. The regression equations are presented in Table 5.3. These empirical relationships will be applied to a map of annual mean concentrations to produce the respective map of short term mean sulphur dioxide concentrations.

Table 5.3: Regression equations used to predict sulphur dioxide concentrations over short term averaging times

Short term mean (Y) Averaging period	Regression equation	R^2
15 minute (99.9 %ile)	Y = 15.6 × Annual mean concentration – 23.6	0.91
Hourly (99.73 %ile)	Y = 11.9 × Annual mean concentration – 18.7	0.87
Daily (99.18 %ile)	Y = 5.87 × Annual mean concentration – 17.8	0.95

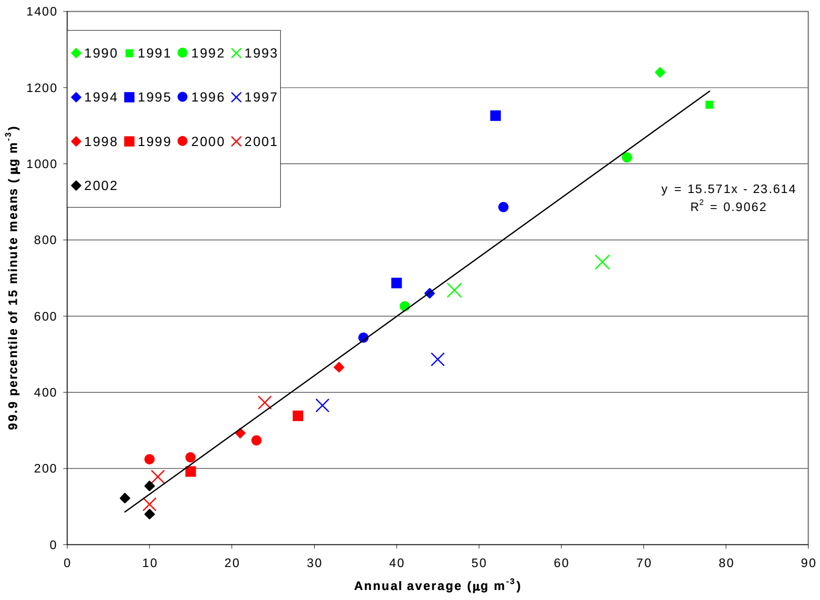


Figure 5.1: Relationship between the annual average and 99.9 percentile of 15 minute sulphur dioxide concentrations for the automatic monitoring stations in Northern Ireland (1990 to 2002).

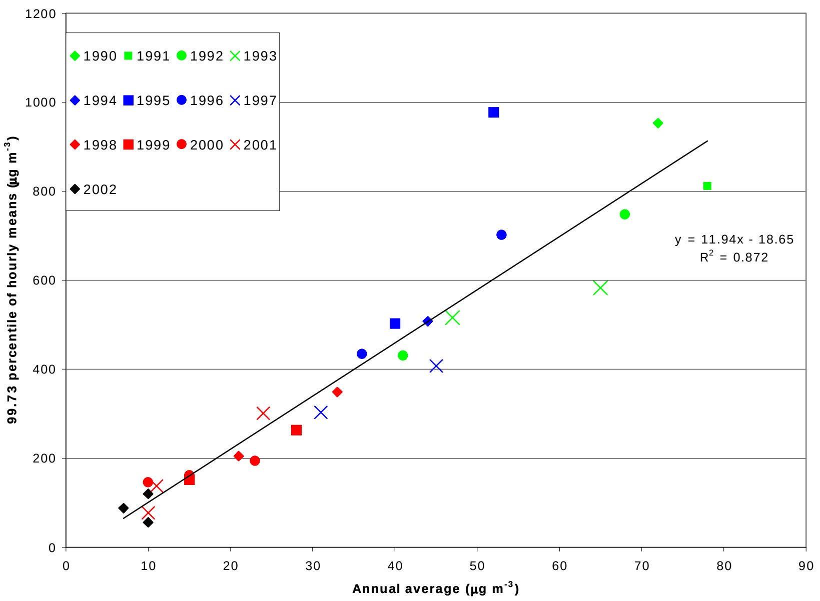


Figure 5.2: Relationship between the annual average and 99.73 percentile of hourly sulphur dioxide concentrations for the automatic monitoring stations in Northern Ireland (1990 to 2002)

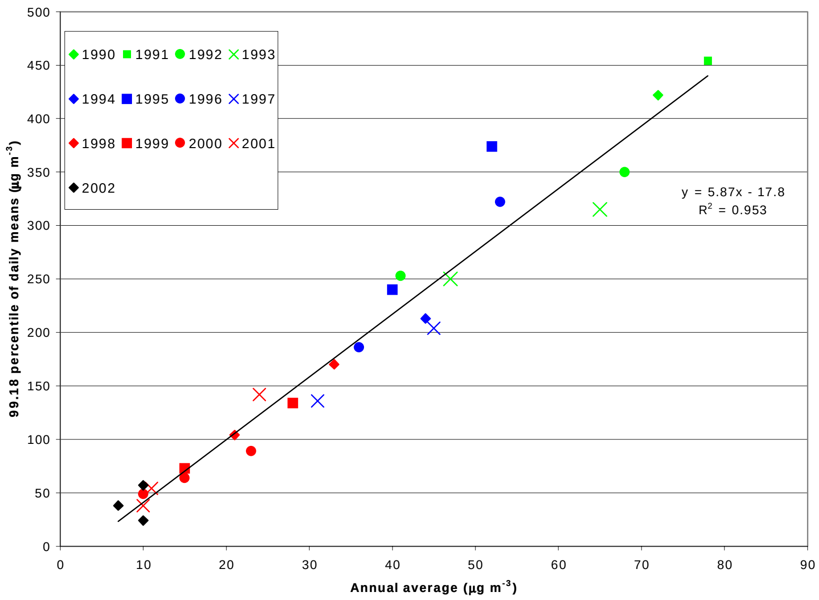


Figure 5.3: Relationship between the annual average and 99.18 percentile of daily sulphur dioxide concentrations for the automatic monitoring stations in Northern Ireland (1990 to 2002)

5.2.3 Dispersion modelling of the short term concentrations

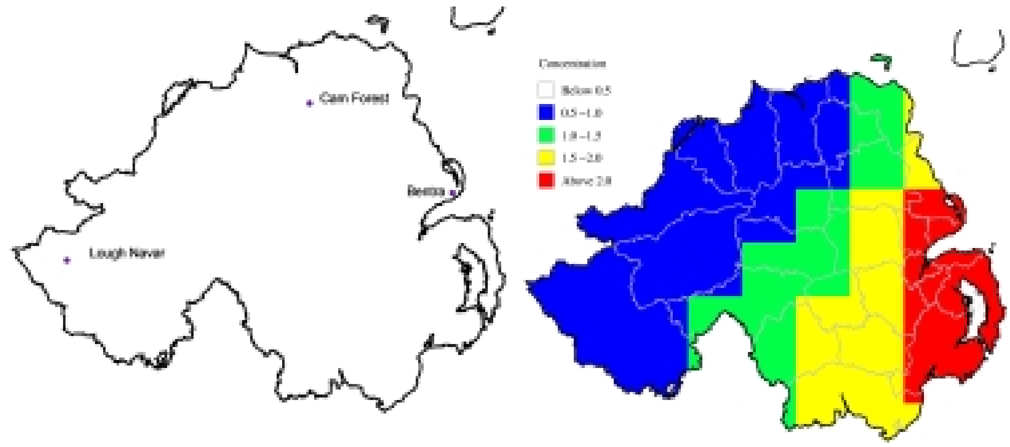
Estimating sulphur dioxide concentrations from area sources over short term averaging periods using a dispersion model is not a trivial task. This is because area sources will influence neighbouring squares and in turn will receive a contribution from their neighbouring squares. The relative contribution to and from adjacent squares will vary for each hour of the year and it is hence necessary to predict concentrations for each grid square in Northern Ireland for every hour of the year. The required percentiles for each grid square can then derived by sorting and selecting the relevant percentile. It is also necessary to take account of the different emission rates throughout the year. These emission rates were derived by calculating the degree day for Northern Ireland (based on the Aldegrove meteorological data for 2001) and imposing a diurnal profile for each day. The emission profiles are described in more detail by Coleman *et al.* (2001). Only emissions from the domestic source sector were modelled.

The short term average concentrations were modelled by adapting the NETCEN area source model so that for every grid square in Northern Ireland 8760 concentrations were predicted and the emission profile based on the degree day approach applied. The required short term average concentrations were calculated from the relevant percentile. The 99.9 percentile of 15 minute concentrations was derived by multiplying the concentration corresponding to 99.9 percentile of hourly values by 1.34 (Turner, 1984)

5.2.4 Annual mean concentration map for 2001

The annual mean map is derived by modelling emissions from the domestic and non domestic area sources separately using the area source model (see Section 3.1) and adding a background component.

A background concentration map was derived from the national rural sulphur dioxide monitoring network (Hasler *et al*., 2001). This network consists of approximately 50 sites located in rural locations throughout the UK with the concentration field being derived by interpolation. There are three sites from this network in Northern Ireland (Figure 5.4). The concentrations measured are small (Lough Navar 0.5 $\mu g/m^3$; Cam Forest 0.5 $\mu g/m^3$ and Bentra 2.9 $\mu g/m^3$). The background concentration map will represent non-area sources, for example, emissions from point sources in Northern Ireland and Great Britain, which are not modelled explicitly in this work.



a) b)

Figure 5.4: a) Sampling sites in the rural sulphur dioxide monitoring network. b) Background sulphur dioxide concentrations, 2001 ($\mu g/m^3$).

Figure 5.5 presents the annual mean concentration map for 2001 derived using the area source model. Concentrations are predicted to be highest in urban areas. Highest concentrations are observed in the greater Belfast conurbation, Derry City, North Down, Craigavon and where Carrickfergus borders onto Belfast Lough.

This map will form the basis used to predict, using the empirical model, the short term mean concentrations.

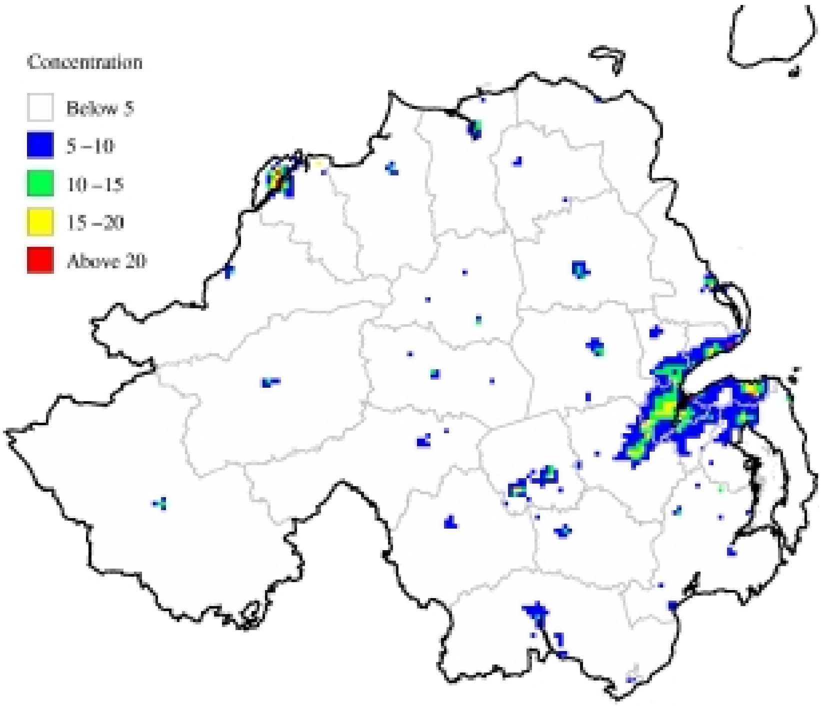


Figure 5.5: Annual concentrations (µg/m^3) for 2001

Figure 5.6 compares the annual mean concentration measured at the sites equpped with a continuous sulphur dioxide monitor with the modelled concentration. In each case emissions from the domestic sector is the dominant contributing source. The annual mean concentration modelled at the Belfast Centre and Derry sampling sites show excellent agreement with the measured concentration. There is an underprediction at the Belfast East sampling site- this may be attributed to the NAEI not adequately representing the actual amount of sulphur released from solid fuel in the area surrounding the sampling site. Further work to characterise emissions in this area maybe required.

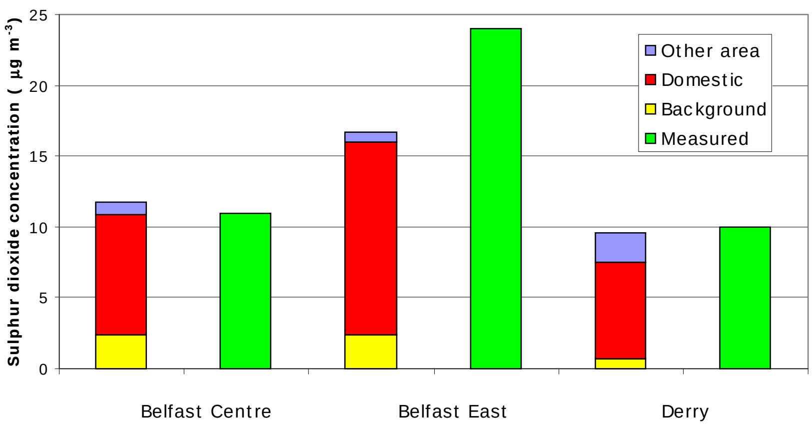


Figure 5.6: A comparison of measured annual mean sulphur dioxide with modelled annual mean concentration of each the source sectors modelled.

5.2.5 Comparison of the short term measured concentration with the empirical and explicit modelling approaches

Figure 5.7 and Figure 5.8 shows how the measured 99.9 percentile of 15 minute concentrations and the 99.73 percentile of hourly values for 2001 compares to the concentrations predicted using the empirical model and modelling each hour explicitly using the dispersion model. In general the empirical model appears to predict concentrations which are much closer to the measured values. This may be in part due to the fact that the dispersion model only considered emissions from the domestic source sector, that is, a background component was not added and the non-domestic area source was not modelled. Further work is required to do this.

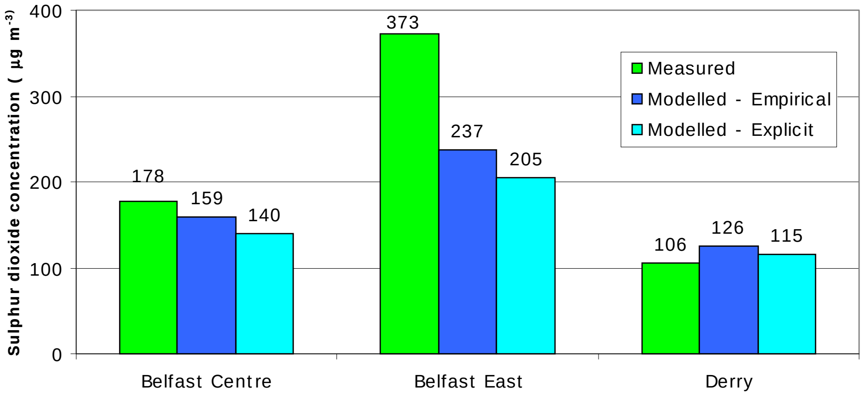


Figure 5.7: A comparison of measured (2001) and modelled 99.9 percentile of 15 minute sulphur dioxide concentrations at the three continuous monitoring sites in Northern Ireland.

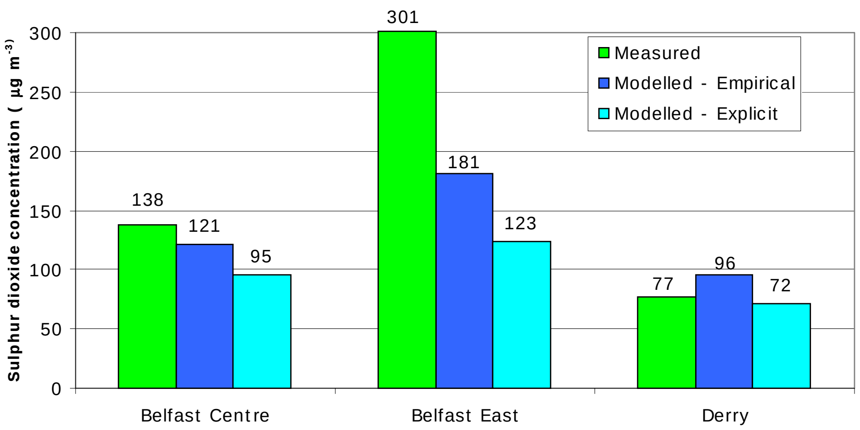


Figure 5.8: A comparison of measured (2001) and modelled 99.73 percentile of hourly sulphur dioxide concentrations at the three continuous monitoring sites in Northern Ireland.

Figure 5.9 compares the measured 99.18 percentile of daily mean concentrations with the predicted concentration based on the empirical approach. Excellent agreement at the Belfast East and Derry sampling sites. Further work is required to derive the 99.18 percentile based on modelling concentrations on an hour by hour basis.

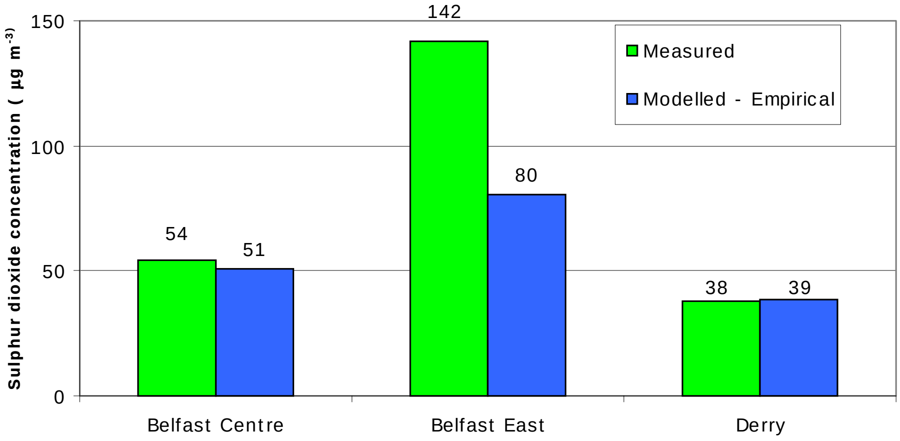


Figure 5.9: A comparison of measured (2001) and modelled 99.18 percentile of daily sulphur dioxide concentrations at three continuous monitoring sites in Northern Ireland.

5.2.6 Maps of short term average concentration

Figure 5.10 to Figure 5.12: 99.18 percentile of daily mean sulphur dioxide concentration in 2001

show the maps of sulphur dioxide concentrations predicted for 2001 for each of the short term concentrations derived by fitting the regression equations shown in Table 5.3 to the annual mean concentration map (Figure 5.5). In each case exceedances of the short term average standard concentration are observed. Table 5.4 presents the number of squares which show an exceedance of each concentration threshold.

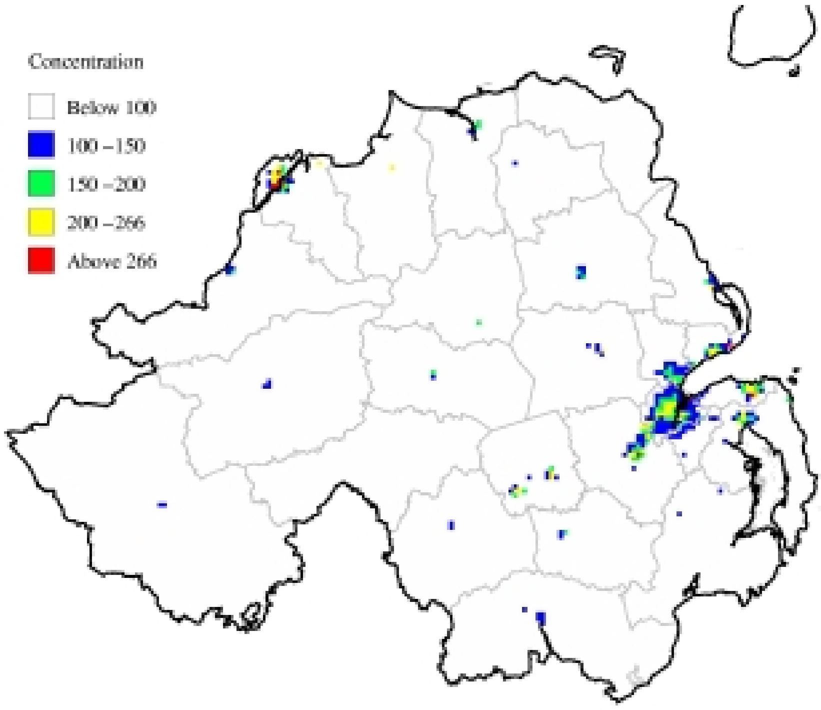


Figure 5.10: 99.9 percentile of 15 minute mean sulphur dioxide concentration in 2001

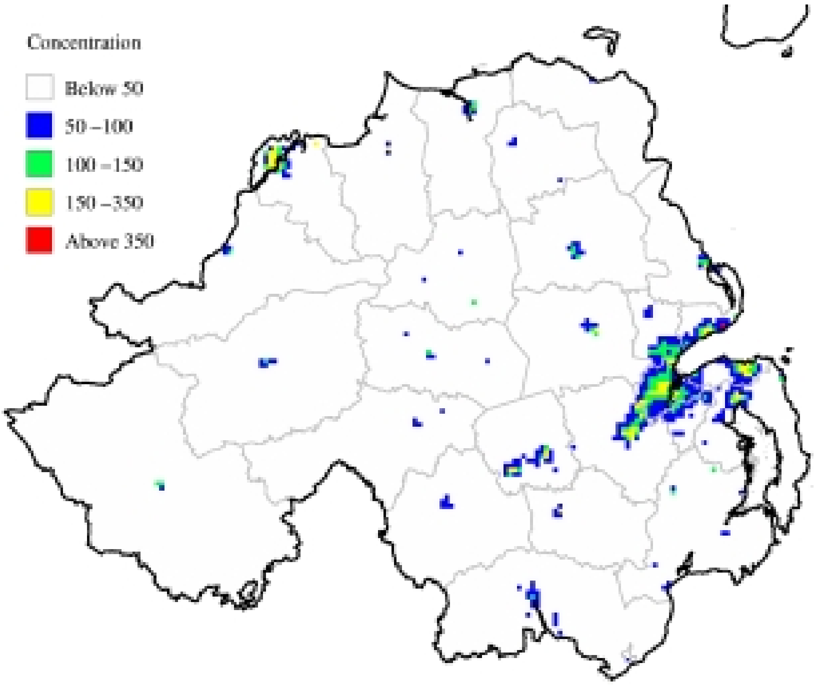


Figure 5.11: 99.73 percentile of hourly mean sulphur dioxide concentration in 2001

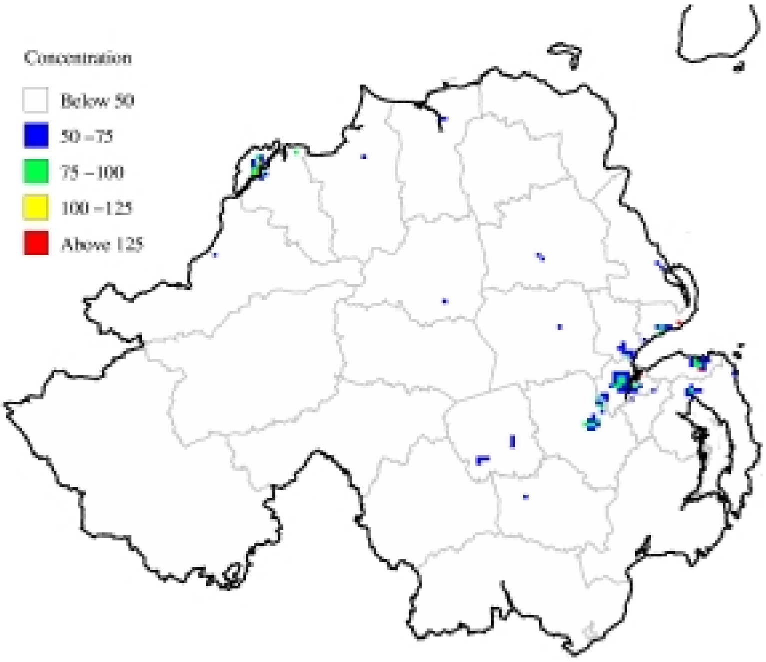


Figure 5.12: 99.18 percentile of daily mean sulphur dioxide concentration in 2001

Table 5.4: Number of squares showing exceedance of each of the short term average concentrations in 2001

Short term average	Concentration threshold (µg/m³)	Number of squares showing an exceedance
99.9 percentile of 15 minute average	266	9
99.73 percentile of hourly average	350	1
99.18 percentile of daily average	125	4

5.2.7 Relationships between short term average concentrations for sulphur dioxide

Figure 5.13 to Figure 5.15 and the summary information provided in Table 5.5 show the number of times each of the short term mean concentrations have been exceeded since continuous monitoring began in 1990. The data presented in this way shows that the 99.9 percentile of 15 minute concentrations was historically the most frequently occurring short term mean concentration. The 24 hour limit value of 125 µg/m^3 is more stringent than the 1 hour limit value of 350 µg/m^3

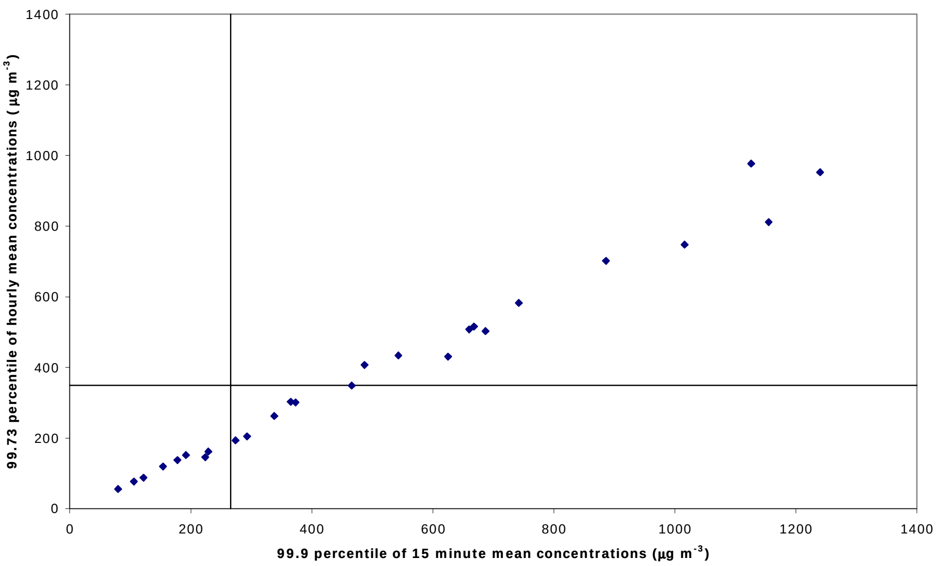


Figure 5.13: **Relationship between 99.9 percentile of 15 minute mean sulphur dioxide concentration and the 99.73 percentile of hourly mean concentrations (1990-2002)**

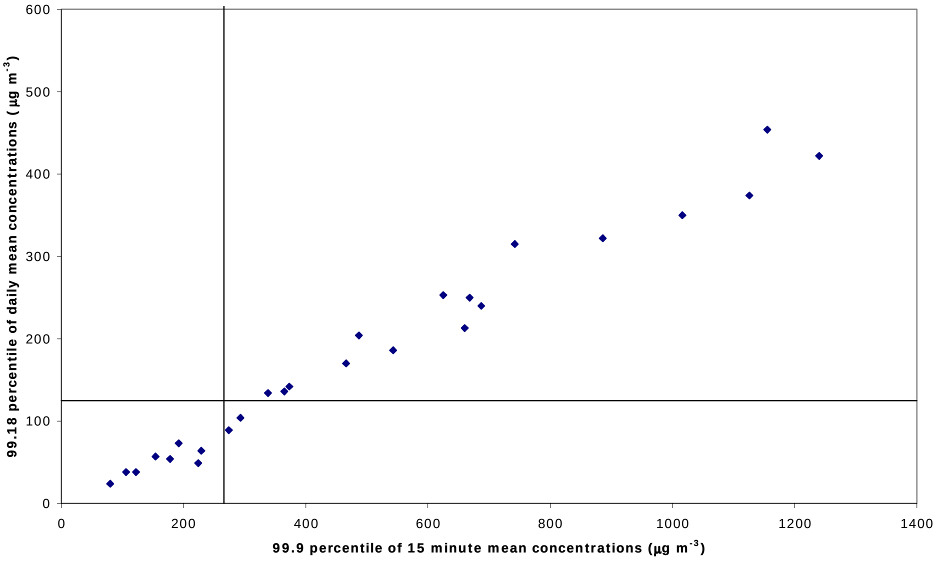


Figure 5.14: **Relationship between 99.9 percentile of 15 minute mean sulphur dioxide concentration and the 99.18 percentile of daily mean concentrations (1990-2002)**

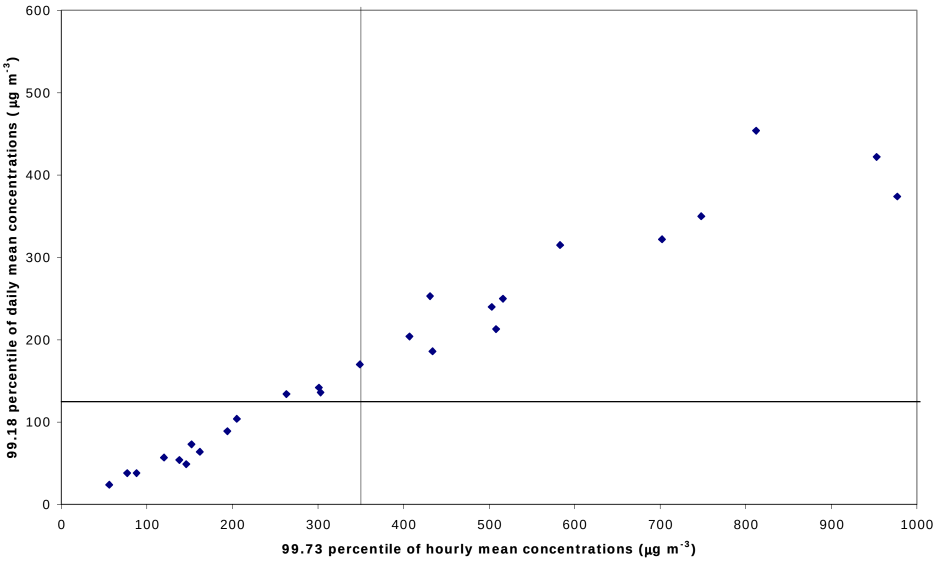


Figure 5.15: **Relationship between 99.73 percentile of hourly mean sulphur dioxide concentration and the 99.18 percentile of daily mean concentrations (1990-2002)**

Table 5.5: The number of exceedances of the short term mean concentrations in Northern Ireland since 1990

Short term average	Concentration threshold ($\mu g/m^3$)	Number of exceedances since 1990
99.9 percentile of 15 minute average	266	18
99.73 percentile of hourly average	350	12
99.18 percentile of daily average	125	16

6 Conclusions

Due to the number of data sources that have been used, and careful consideration of assumptions, the spatial emission inventory for domestic fuel use in Northern Ireland has been significantly improved. The most significant improvements have been due to the information supplied by the NIHE and Phoenix Gas. This highly spatially resolved data has enabled a better understanding of household fuel use distribution. NIHE housing represents a significant proportion of households that burn solid fuels – approximately half of all households. Therefore, use of this data (supplied at a ward resolution) meant that an accurate spatial distribution of a large proportion of the houses that burn solid fuel could be constructed.

Although this spatial inventory is more robust than previous ones, a variety of assumptions have had to be made. As far as possible, these have been made on the basis of literature, consultation and expert judgement. However, there is still a need for further work to ensure such assumptions are correct. For example, assumptions have been made regarding the type of solid fuel used in certain appliances.

It has been important to consider the impact of burning solid fuels as a backup or for social / aesthetic reasons. This is an important development – it means that houses that burn oil or have an electricity-based central heating system may still be burning solid fuel. More work needs to be undertaken on the assumptions regarding the spatial distribution of solid fuel use as a secondary heating source.

Significant areas of uncertainty remain in terms of the range of solid fuels in use, especially those for which a significant fraction is not traded commercially. Peat has not been considered in emission inventories in the UK or in this bottom-up inventory. In terms of total contribution to BaP emissions it is not considered as a significant source. However, it may have significant impacts on a local scale. The total quantity of wood estimated to be used as a fuel is also uncertain.

Another significant source of uncertainty in the emission inventory is the lack of BaP emission factors for a wide range of the fuel – appliance combinations encountered in a domestic setting. The variability between different fuel – appliance combinations is large for BaP and the range of fuel sulphur contents is also large.

A detailed study of a particular housing estate established that there is significant spatial variability in BaP concentrations as a result of domestic solid fuel use. Although this spatial inventory is considered to be more robust than previous ones, a caveat must be understood, that at this scale and based on a significant assumptions, the inventory may not entirely reflect more localised conditions that give rise to specific concentrations of BaP. The present study uses average emission factors and predicts considerable spatial variability in concentration. The actual variability may be considerably higher if individual consumer behaviour was better understood however this is probably an unattainable data collection objective.

The improvements to the spatial dissaggregation of domestic solid fuel use in Northern Ireland have also resulted in an improved spatial dissaggregation of the emission inventory for sulphur dioxide. However, a recent analysis of the sulphur content of solid fuel sulphur content suggests that the emission factors used in the NAEI might be too low. A detailed fuel use survey identifying the brand and amount of coal consumed may provide a more accurate estimate of sulphur released and hence improve the prediction of sulphur dioxide concentrations.

Two modelling approaches to predict sulphur dioxide concentration over short term averaging periods were used. The empirical method, based on monitoring data, provided as good or better representation of the short term sulphur dioxide concentrations in Northern Ireland, at the locations for which it was calibrated as the explicit method, which modelled emissions on an hour by hour basis. The empirical method required considerably less computing resources than the more sophisticated explicit modelling approach.

It is clear that the limited monitoring of PAHs in areas of domestic solid fuel use coupled with the highly spatially variable nature of the modelled concentrations makes predictions of concentrations subject to considerable uncertainty. The installation of further monitoring sites in areas of high predicted concentrations e.g. Strabane, Derry or Newry would help towards validating the modelling approaches.

The continuation of the NIHE's programme to replace solid fuel use with gas or oil burning heating appliances would significantly improve air quality with respect to BaP and SO_2. Delays or reductions in the effectiveness of this programme may jeopardise the attainment of the possible EU standard for BaP.

Further the licensing and development of the two gas interconnectors and the associated supply of natural gas to urban areas will also improve air quality though the full benefits of this may be felt further into the future than the 2010 Objective date. If licensing of these pipelines is significantly delayed the assumptions about attainment of the 2010 Objectives will become over optimistic.

It is clear that benzo[*a*]pyrene concentrations in urban areas of Northern Ireland, and possibly other parts of the UK without access to mains natural gas, may result in concentrations in 2010 in excess of the EPAQS standard of 0.25 ng/m^3 of benzo[*a*]pyrene. Exceedances of the possible EU daughter directive limit of 1 ng/m^3 appear likely to be limited. As these exceedances result from domestic solid fuel use and other local activities, the impact of the industrial air pollution control regime will be limited. Hence measures to attain the likely EU concentration standard and more particularly the EPAQS standard will need to be based on Local Air Quality Management such as extension of smoke control orders to affected areas.

Maps of sulphur dioxide concentration for 2001 for each of the three concentration thresholds required as part of the Air Quality Strategy and First Air Quality Daughter Directive suggest that there will have been exceedances of at a small number of locations in 2001. However, it maybe expected that sulphur dioxide concentrations may also vary significantly over short spatial scales and local fuel use surveys enquiring as the brand of solid fuel used and hence its sulphur content may improve the modelled predictions.

A review of the short term average concentrations measured at the continuous monitoring sites in Northern Ireland showed, historically, that the 99.9 percentile of 15 minute concentrations occurred more frequently than either the 99.73 percentile of hourly concentrations or the 99.18 percentile of daily values. The 99.18 percentile of daily values occurred more frequently than the 99.73 percentile of hourly values. Based on these observations it is suggested that the 99.9 percentile of 15 minute concentrations would be the more stringent air quality standard to attain followed by the 99.18 percentile of daily values and the 99.73 percentile of hourly values.

7 References

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NB. Fuel Use surveys have not been individually referenced. The 10 councils that undertook fuel use surveys are listed in Appendix 1.

Appendices

Appendix 1: Organisations consulted

A number of organisations were consulted as part of this study. They include:

Department of Environment for Northern Ireland (DoENI)
Phoenix Gas Limited
Northern Ireland Housing Executive
Belfast City Council
Lisburn District Council
Department of Enterprise, Trade and Investment (DETI (NI))

Councils contacted in relation to fuel use surveys include:

Armagh
Ballymena
Carrickfergus
Coleraine
Cookstown
Ards (representing four boroughs of North Down, Lisburn, Ards, and Castlereagh)
Moyle
Newtownabbey
Larne