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2006 Annual Report for the UK Black Smoke Network

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Approved on behalf of Managing Director, NPL
By S Windsor, Business Leader, Division of Quality of Life

Executive Summary

The National Physical Laboratory (NPL) was awarded the contract to set up and run the UK Black Smoke Network by the Department for Environment, Food and Rural Affairs (Defra) in September 2006 under contract "RMP 2951, The Provision of Consultancy Services for the Monitoring of Black Smoke in the UK".

The Network was required to meet the recommendations of the independent review of the UK Urban Network for measurement of Black Smoke, SO_2 and NO_2, which concluded that a network of around 20 sites would be required to measure Black Smoke concentrations.

This report covers the setting up of the UK Black Smoke Network, the operation of the Network and the data produced in 2006.

One significant change to the Network is that measurements of Black Smoke reflectance are made centrally at NPL rather than individually at sites.

New Quality Assurance and Quality Control (QA/QC) procedures are described that improve on those already in place when each local Council performed the measurements. A provisional measurement uncertainty for Black Smoke concentrations has been calculated.

The average data capture for the Network over the year for existing Black Smoke sites was 86%, with five of the fourteen sites then in place failing to reach a data capture rate of 90%.

Contents

1.0 Introduction

The National Physical Laboratory (NPL) was awarded the contract to set up and run the UK Black Smoke Network by the Department for Environment, Food and Rural Affairs (Defra) in September 2006 under contract "RMP 2951, The Provision of Consultancy Services for the Monitoring of Black Smoke in the UK".

This report discusses the rationale for the design of the Network along with its implementation. Details of the Quality Control and Quality Assurance procedures are given along with an explanation of the measurement uncertainty associated with Black Smoke measurements.

Results from site audits are presented along with the data recorded for 2006.

2.0 Background

In 2005, the Department for the Environment, Food and Rural Affairs (Defra) commissioned an independent review of the UK urban network for measurement of Black Smoke, SO_2 and NO_2[1]. The objectives of the review were:

1. To examine the value of the non-automatic networks of urban measurements of Black Smoke, SO_2 (by net acidity) and NO_2 (by diffusion tube).
2. To provide recommendations to Defra and the devolved administrations on ways of restructuring the networks to match current monitoring and research priorities.

Its recommendations for Black Smoke and SO_2 monitoring were:

<u>Black Smoke</u>

1. That up to 20 sites be retained using existing methods, as the method still has sufficient sensitivity for Black Smoke measurements. These sites should primarily be in the coal burning areas of the UK.
2. As many existing Black Smoke measurement sites are not ideally located for epidemiological studies, some of the sites should be relocated to AURN locations, which are located to represent general urban background exposure.
3. To equip some AURN sites with higher quality Black Smoke measurement systems (e.g. aethalometers) and as an option, to consider the use of two channel instruments to provide an indication of the contribution of local diesel contributions to the Black Smoke concentrations.

Sulphur dioxide

1. Stopping these measurements in almost all areas of the UK, as concentrations are very small and unsuitable for the method.
2. There are exceptions, notably in some parts of Northern Ireland and Northern England where some sites need to be maintained until ambient concentrations are no longer considered to be an issue. The monitoring at these sites is not considered to require central support from Defra and devolved administrations.

Using these recommendations, Defra competitively tendered a contract to run the UK Black Smoke Network in June 2006. In August 2006, NPL won the contract to run the UK Black Smoke Network and work started on 1st September 2006.

The design of the Network was planned to incorporate 11 existing Black Smoke sites and to install 10 Black Smoke samplers in Automatic Urban and Rural Network (AURN) stations. Figure 1 shows the locations of the Network sites.

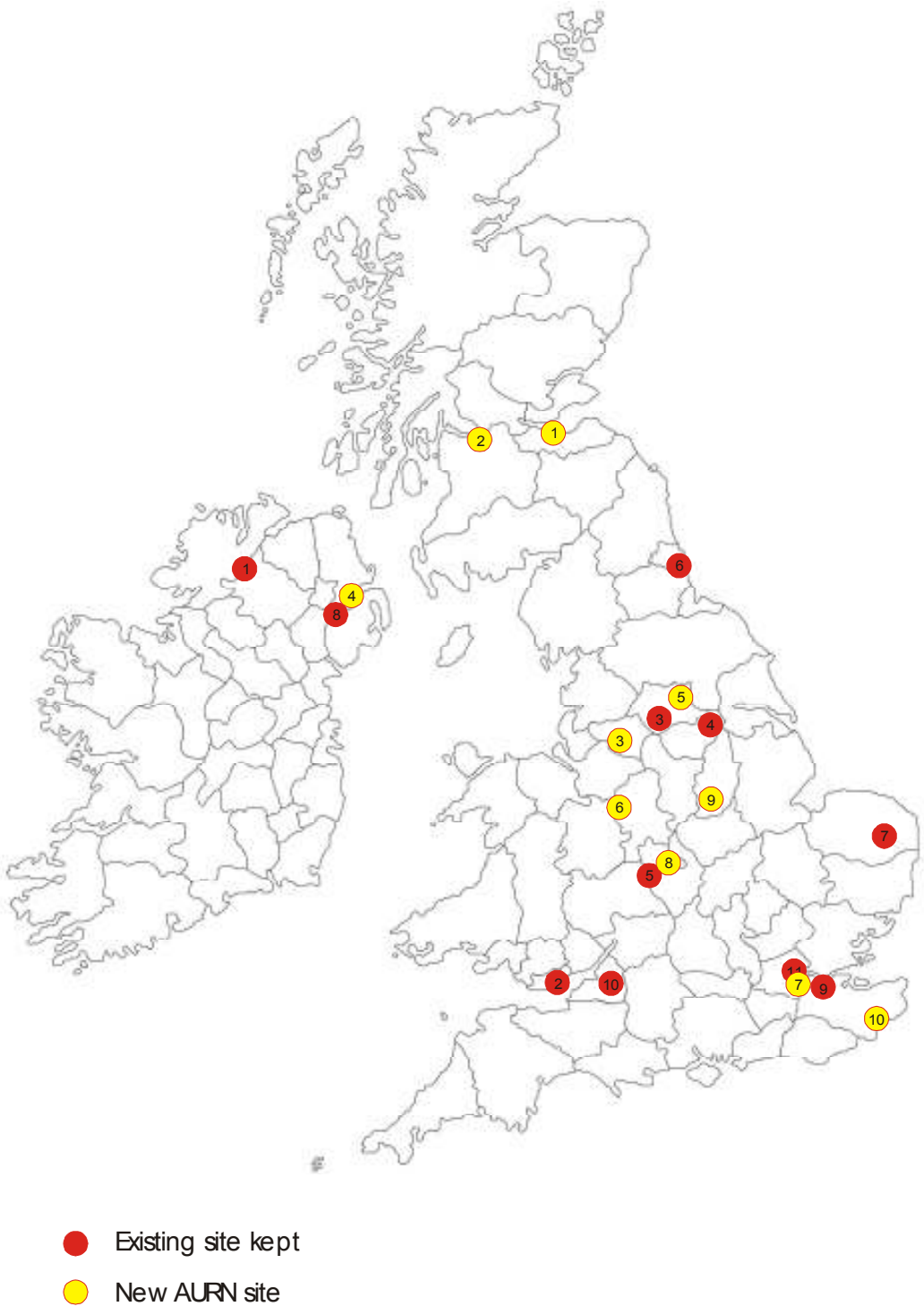


Figure 1 Location of UK Black Smoke Network Sites

Tables 1A and 1B below give the site names and classifications for the UK Black Smoke Network:

Key	Site Name	Site Type	Start year	Reason
1	Strabane 2	A3	1999	NI region, urban background, high Black Smoke
2	Cardiff 12	A1	1961	Wales region, urban background
3	Halifax 17	B3	2003	NW region, urban background
4	South Kirkby 1	B3	1970	NE region, urban background High Black Smoke
5	Halesowen 8	A2/E	2004	W Mid region, urban background
6	Sunderland 8	A2	1961	NE region, urban background
7	Norwich 7	A3	1961	SE region, urban background
8	Dunmurry 3	X	1993	NI region, urban background, high Black Smoke. Colocated with PAH Network
9	Woolwich 9	B3/E	1955	London region, urban background
10	Bath 6	B3	1981	SW region, urban background
11	Marylebone Road	D2	1997	London region, kerbside

Table 1A Existing Black Smoke sites

A1 Residential area with high-density housing (probably terraced), or with medium-density housing in multiple occupation, in either case surrounded by other built-up areas.

A2 Predominantly A1, but interspersed with some industrial undertakings.

A3 Residential area with high-density housing or medium-density housing in multiple occupation surrounded by, or interspersed with, other areas with low potential air pollution output (parks, fields, coast).

B3 Residential area with medium-density housing surrounded by or interspersed with areas with low potential air pollution output (parks, fields, coast), or any residential area with low-density housing.

D2 Town centre with limited commercial area, possibly mixed with old residential housing and/or minor industry.

E Smoke control area or smokeless zone (the letter to be added to the primary classification). X

X Unclassified or mixed area.

Key	Site Name	Site Type	Other Analysers
1	Edinburgh St Leonard's	Urban Background	TEOM PM_{10}
2	Glasgow Centre	Urban Centre	TEOM PM_{10} + CPC
3	Manchester Piccadilly	Urban Centre	TEOM PM_{10} + CPC
4	Belfast Centre	Urban Centre	TEOM PM_{10} + carbon + CPC + nitrate
5	Bradford	Urban Centre	TEOM PM_{10}
6	Stoke Centre	Urban Centre	TEOM PM_{10}
7	North Kensington	Urban Background	TEOM PM_{10} + carbon + manual $PM_{2.5}$
8	Birmingham Tyburn	Urban Background	TEOM PM_{10}
9	Nottingham Centre	Urban Centre	TEOM PM_{10}
10	Folkestone, Kent Network	Rural	TEOM PM_{10} + $PM_{2.5}$

Table 1B AURN sites to have Black Smoke samplers installed

Three other sites, described in Section 6.5, produce data on an affiliate basis.

3.0 Site Equipment and Installations

3.1 Site Equipment

An overview of the workings of a Black Smoke sampler is given here.

Black Smoke sampling uses the 8-port sampler that has historically been used in the UK network, based on the standard method BS 1747 Part 11, ISO 9835. The principle of the 8-port sampler method involves drawing air at a constant flow rate of around 1.4 l/min through a Whatman Number 1 cellulose filter, so that about 2 m^3 of air (at ambient conditions of temperature and pressure) is sampled for each daily sample. Suspended particulate matter is collected on the filter over an area determined by a choice of clamp – in this case with a one inch diameter - forming a dark stain. The inlet - an upturned funnel - is not designed to be size selective, and has been shown in one study[2] to collect the approximate size fraction $PM_{4.5}$.

The 8-port sampler is designed with eight pairs of filter clamps for weekly operation, providing daily sampling from a midnight-to-midnight basis. The timed eight-port valve was set to switch over at midnight to expose a fresh filter paper each day. Weekly visits were made to change filter papers and to record weekly sample volumes and flow rates.

Ambient air passes through approximately 4 metres of medical grade PVC tubing before it enters the sampler. The air then passes through a flow splitter to the active port, which is determined by the position of the 8-port valve. After passing through the filter, the air passes through a Drechsel bottle partially filled with distilled water. The Drechsel bottle is used as a flow indicator only as the Network no longer makes SO_2 measurements. After the Drechsel bottle, the air passes through the 8-port valve and on to the dry gas meter. The dry gas meter measures the volume of gas that passes through it and readings are taken by the LSO on a weekly basis and recorded on a proforma. After the dry gas meter the air passes through the rotameter, which reports the current flow rate. This value is also recorded by the LSO at the weekly visits. Lastly the air is drawn into the pump through a critical orifice that determines the sample flow throughout the whole system.

Figure 1 shows a schematic outline of a Black Smoke sampler as run on the Network.

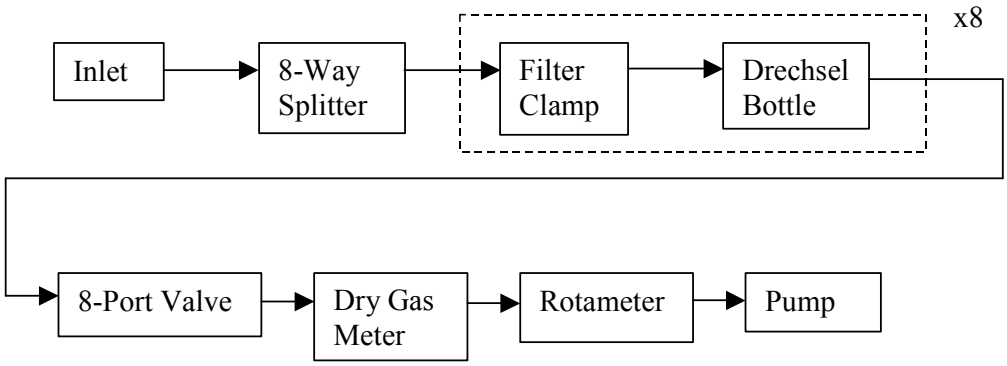


Figure 1 Schematic Outline of a Black Smoke Sampler

The rotameter is an addition to the standard Black Smoke sampler that NPL has instituted. It is discussed further in Section 4.1.3.

Black smoke concentrations are then estimated by means of a reflectance measurement. This is covered in detail later in the report.

3.2 Site Installations

At the start of the contract it was found that some of the existing Black Smoke samplers were no longer running due to instrument failure and site infrastructure problems. Table 2 below highlights the problem sites and the actions taken:

Site	Fault	Action	Date
Norwich 17	Sampler not run for a year and new pump required	New pump installed	02/10/06
Bath 6	No sampler or staff available	Council recruited new staff recruited due to income from network and new sampler installed.	01/02/07
Sunderland 8	New pump required and sample inlet needs replacing	New pump and sample inlet installed.	16/01/07

Table 2 Existing Black Smoke sites not running at the start of the contract

In parallel to getting the existing sites up and running, Black Smoke samplers were installed at the AURN sites on the dates shown in Table 3:

Site	Installation Date
Manchester Piccadilly	01/10/06
Belfast Centre	01/10/06
Glasgow Centre	05/10/06
Edinburgh St Leonard's	17/10/06
Stoke Centre	13/11/06
Folkestone	03/01/07
North Kensington	28/02/07
Birmingham Tyburn	07/03/07
Bradford	21/03/07
Nottingham Centre	22/03/07

Table 3 Installations of Black Smoke samplers into AURN sites

4.0 Quality Assurance and Quality Control (QA/QC)

Quality Assurance and Quality Control activities cover two main areas: site audits and reflectometer calibration. The first ensures that the quality of the sampling is maintained and the second ensures the consistency and accuracy of the reflectometry measurements.

4.1 Site Audits

The performances of the existing ex-council run Black Smoke samplers and the new AURN Black Smoke samplers were audited. The audit comprised:

- Measurement of sample flow
- Leak check of each sample port
- Installation of flow meter
- Intercomparison of Reflectometers
- Local Site Operator (LSO) training

Table 4 below shows when each site was audited:

Site	Audit Date	Start date for monitoring	Local Site Operator	LSO Institution
Edinburgh St Leonard's	17/10/2006	17/10/2006	Graham Davies	Edinburgh Council
Cardiff 12	23/10/2006	01/01/2006	Ian Leonard	Cardiff Scientific Services
Marylebone Road	25/10/2006	01/01/2006	Ana Rowan	King's College London
Woolwich 9	30/10/2006	01/01/2006	Ray Caswell	Greenwich Council
Norwich 7	06/11/2006	11/10/2006	Yvonne Burton	Norwich Council
Stoke Centre	13/11/2006	13/11/2006	Ann Beeston	Stoke Council
Belfast Centre	14/11/2006	01/10/2006	Graham Swindles	Belfast Council
Dunmurry 3	15/11/2006	01/01/2006	Cheryl Harkness	Lisburn Council
Strabane 2	16/11/2006	01/01/2006	Alan Haire	Strabane Council
Halesowen 8	30/11/2006	01/01/2006	Richard Gunning	Dudley Council
South Kirkby 1	04/12/2006	01/01/2006	Stephen Douglas	Wakefield Council
Halifax 17	05/12/2006	01/01/2006	Keith Crabtree	Calderdale Council
Glasgow Centre	11/12/2006	05/10/2006	Dominic Callahan	Glasgow Council
Folkestone	03/01/2007	03/01/2007	Wai Tse	Shepway Council
Sunderland 8	16/01/2007	16/01/2007	Jim Greaves	Sunderland Council
Bath 6	01/02/2007	01/02/2007	Andrew Jones	Bath Council
Manchester Piccadilly	12/02/2007	01/10/2006	Mike Concannon	Manchester Council
North Kensington	28/02/2007	28/02/2007	Jon Alexander	King's College London
Birmingham Tyburn	07/03/2007	07/03/2007	Peter Porter	Birmingham Council
Nottingham Centre	21/03/2007	22/03/2007	Chris Washington	Nottingham Council
Bradford Centre	22/03/2007	21/03/2007	Jim Coles	Bradford Council

Table 4 Audit dates for UK Black Smoke Network

4.1.1 Measurement of Sample Flow

The sample flow entering the dry gas meter was measured using a BIOS Dry-Cal2 flow meter, which was calibrated at NPL against National Standards. When taking into account the repeatability of the measurements in the field, the flow at the dry gas meter was measured with an uncertainty of ±2.5%, expressed with a level of confidence of 95%. Table 5 shows the results of the measurements of sample flow.

Site	Sample flow, litres per minute	Sample flow after repair, litres per minute	Remedial action
Bath 6	1.33		
Belfast Centre	1.19	1.50	1
Birmingham Tyburn	1.45		
Bradford Centre	1.38		
Cardiff 12	1.29	1.47	2
Dunmurry 3	1.35		
Edinburgh St Leonard's	1.43		
Folkestone	1.40		
Glasgow Centre	1.29		
Halesowen 8	1.43		
Halifax 17	1.29	1.41	3
Manchester Piccadilly	1.45		
Marylebone Road	1.45		
North Kensington	1.36		
Norwich 7	1.30		
Nottingham Centre	1.37		
South Kirkby 1	1.27	1.55	3
Stoke Centre	1.37		
Strabane 2	1.16	1.42	4
Sunderland 8	1.36		
Woolwich 9	1.39		

Remedial Action Key

1 Sampler pipe work had aged and become hard. All of the pipe work was replaced along with the critical orifice.
2 Sampler replaced due to faulty 8-port valve.
3 Critical orifice replaced.
4 Pump and critical orifice replaced.

Table 5 Sample flow at dry gas meter for each sampler

4.1.2 Leak Check Of Each Sample Port

The leak rate of each port on an 8-port sampler is calculated by comparing the flow at the dry gas meter to the inlet manifold flow while sampling through each port. Table 6 gives the percentage leak rate for each port of each sampler.

	Percentage Leak Rate, Port							
Site	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Bath 6	2.6	3.3	3.8	2.9	2.5	2.4	2.9	2.8
Belfast Centre	7.7	7.1	9.5	8.2	11.4	8.5	8.5	8.5
Birmingham Tyburn	4.4	3.7	3.3	4.2	5.9	5.6	3.8	4.1
Bradford Centre	4.1	4.3	4.1	7.3	4.3	4.5	4.5	4.4
Cardiff 12	2.7	2.7	2.9	2.9	2.9	3.2	F	F
Dunmurry 3	7.3	7.3	7.0	11.1	7.4	7.4	8.2	7.5
Dunmurry 3, replacement	5.9	5.4	5.0	6.8	5.6	6.1	6.4	4.9
Edinburgh St Leonard's	4.4	3.9	4.3	3.3	3.6	3.9	4.0	3.9
Folkestone	5.6	5.3	5.1	5.3	5.8	5.6	5.0	5.2
Glasgow Centre	9.3	10.1	10.1	10.1	10.1	10.1	9.3	10.1
Halesowen 8	11.2	12.5	11.8	10.9	11.5	13.9	13.0	12.1
Halifax 17	10.4	10.2	10.1	9.7	9.9	9.4	9.6	10.0
Manchester Piccadilly	5.5	9.0	8.7	6.0	6.6	5.4	5.5	5.4
Marylebone Road	2.9	2.6	3.5	3.4	2.8	2.6	3.6	3.4
North Kensington	5.0	4.2	4.9	5.1	5.1	4.9	4.6	4.6
Norwich 7	10.7	10.2	10.2	9.9	10.1	10.4	29.3	28.8
Norwich 7, repaired	7.7	7.4	7.4	7.5	7.5	8.2	8.1	7.7
Nottingham Centre	5.8	5.9	6.3	5.9	4.5	6.0	6.1	5.0
South Kirkby 1	6.8	6.3	6.7	6.2	7.6	15.0	6.6	6.5
Stoke Centre	4.9	5.4	4.0	6.0	5.9	5.8	5.6	5.0
Strabane 2	4.7	4.9	4.3	4.6	5.0	4.9	4.9	7.2
Sunderland 8	5.7	5.7	4.9	5.7	5.7	4.9	4.9	5.7
Woolwich 9	7.0	7.3	7.2	7.7	7.5	6.4	6.7	7.3

F Faulty 8-port valve. The sampler was replaced at the audit.

Table 6 Results of sampler leak tests

When the Belfast Centre sampler was re-plumbed to replace hardened tubing, the leak rate for each port dropped by around 2%.

The Dunmurry 3 sampler was swapped out with a hot spare sampler to upgrade to an inline flow meter and improved leak rates.

The inlet manifold to the Halesowen 8 sampler was found to be leaking due to an improper installation. When this was replaced the leak rate on all of the ports dropped to around 6% for each port.

The sampler at Norwich 7 was found to be severely leaking. This was traced to a split pipe between the filter and bubbler on port 1 of the sampler. When this was replaced and the glass joints greased the leak rates dropped to acceptable amounts. Other pipe work in the Norwich 7 sampler had become hard and these parts were replaced.

Port 6 of the South Kirkby 1 sampler gave a leak rate of 15% on arrival. The cause of this leak could not be traced to any component within the sampling system. The flow

just before the inlet splitter was similar to that at the dry gas meter, so the reduced flow before the flow splitter is thought to be due to flow impedance within the flow splitter itself.

4.1.3 Installation Of Inline Flow Meter

NPL has improved the design of the standard Black Smoke sampler by installing an inline flow meter in the flow path just downstream of the dry gas meter. The advantage of this is a direct reading of sample flow that will allow fault diagnostics of the dry gas meter and pump along with the ability to record the calibrated sample flow at each weekly visit by the LSO. This flow meter is calibrated at the audit using the same BIOS field calibrator that is used to measure the sample flow.

By recording the sample flow on a weekly basis a direct calibration of the dry gas meter can be obtained on a weekly basis.

Flow meters were installed into all of the ex-council samplers at the site audits and in the new Black Smoke samplers installed into the AURN sites.

4.1.4 Intercomparison Of Reflectometers

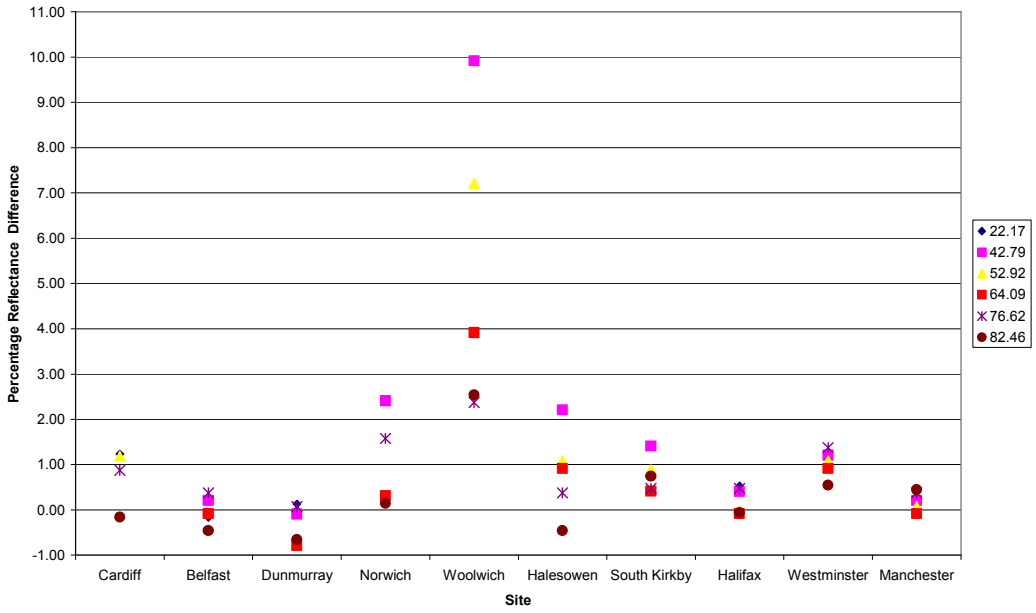
Local Authorities made reflectance measurements for samples taken before 18th September 2006, while those taken after were measured by NPL.

The reflectometers used by councils that were having their existing Black Smoke sites assimilated into the Network had their performance assessed against calibration tiles. The reflectance of these tiles has been UKAS calibrated by NPL to an uncertainty of ±0.71%, expressed with a level of confidence of 95%. Table 7 gives the results of these intercomparisons. All measurements were made relative to a common high reflectance (white) tile.

	Difference between Council and Certified Value, Percentage Reflectance					
Certified Value, Percentage Reflectance	**22.17**	**42.79**	**52.92**	**64.09**	**76.62**	**82.46**
Site						
Cardiff 12	1.23		1.18		0.88	-0.16
Belfast centre	-0.17	0.21		-0.09	0.38	-0.46
Dunmurry 3	0.13	-0.09		-0.79	0.08	-0.66
Norwich 7		2.41		0.31	1.58	0.14
Woolwich 9		9.92	7.21	3.91	2.38	2.54
Halesowen 8		2.21	1.08	0.91	0.38	-0.46
South Kirkby 1		1.41	0.88	0.41	0.48	0.74
Halifax 16	0.53	0.41	-0.02	-0.09	0.48	-0.06
Westminster		1.21	1.08	0.91	1.38	0.54
Manchester Piccadilly		0.21	0.08	-0.09	0.38	0.44

Table 7 **Difference between Council Reflectometer Reading and Certified Value**

This data is presented graphically in Chart 1 below:



Westminster Council used to perform the reflectance measurements for the Marylebone Road site.

Chart 1 **Difference between Council Reflectometer Reading and Certified Value**

The Woolwich reflectometer was found to be out of calibration by +3.5% when using the Council supplied calibration tile. The LSO reported that the last time the reflectometer was used that it was within calibration. Repeat measurements were made of filters with the out of calibration reflectometer and compared with previous measurements when the reflectometer was within calibration. These new results showed a consistent offset from the previous results. It was therefore concluded that the previous measurements were correct and no correction had to be made. This was supported by the apparent false offset seen in the data if the correction from the audit data was applied to the ambient air results.

The Sunderland and Strabane reflectometers had been returned to the manufacturers for repair and therefore were not audited.

The new procedure (Section 4.2), whereby all reflectometer measurements are made centrally by NPL, ensures that results from all sites are comparable and the reflectometer is fully checked and within calibration for every measurement.

4.1.5 Local Site Operator (LSO) Training

When the existing sites were audited and the new samplers installed at AURN sites, the Local Site Operators received full training in the operation of the samplers and the revised weekly check procedures implemented by NPL.

4.2 Reflectometer Calibration

Before NPL took over the running of the UK Black Smoke Network and implemented the central measurement of the reflectance of all of the filters sampled by the Network, all reflectometry measurements were performed by local Councils using their own reflectometers. These reflectometers were calibrated at a single reflectance point against a calibration tile provided by the manufacturer of the reflectometer. The calibration level was generally in the order of 33% reflectance, which is well below the reflectance of sampled filters. The minimum reflectance measured on a single filter across the Network for 2006 was 53%. A reflectometer was considered to be in calibration if the measurement was within ±1.5% of the certified value. Reflectometers were occasionally intercompared between local Councils on an irregular basis.

NPL has improved the calibration of the reflectometer by implementing a multi-point calibration using calibration tiles that have been calibrated under UKAS procedures at NPL. The uncertainty of each calibration tile value is ±0.71%, expressed with a level of confidence of 95%. By using a multi-point calibration curve, the calibration uncertainty is reduced. The uncertainty associated with the multi-point calibration is ±0.74%, expressed with a level of confidence of 95%. As well as performing regular multi-point calibrations, check tiles are also measured with every site pollution month. Chart 2 shows the calibration history of the NPL reflectometer when using these check tiles.

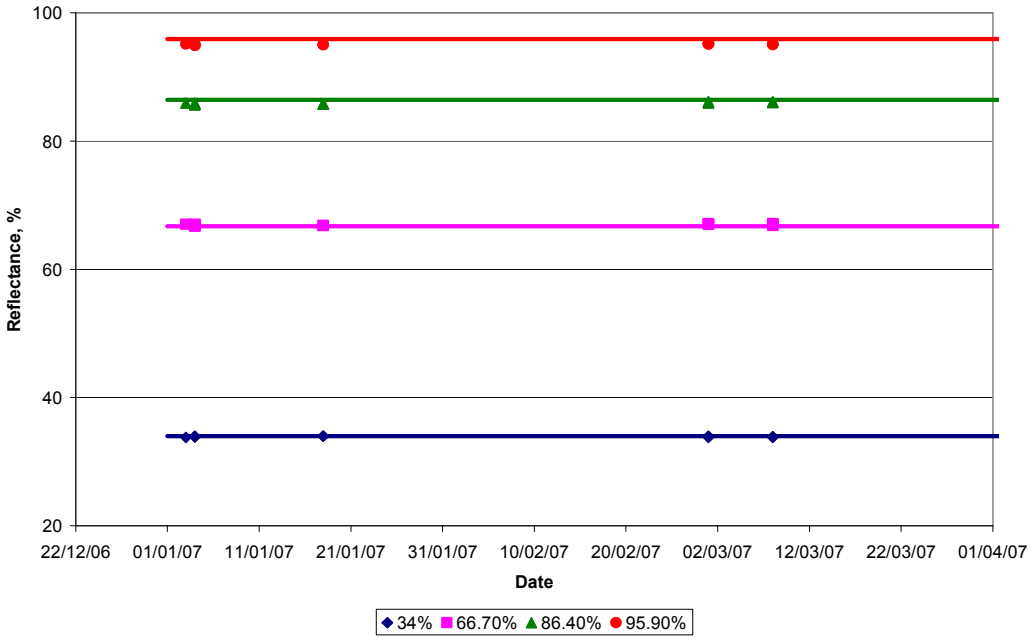


Chart 2 Calibration history of NPL Reflectometer

By centrally measuring all of the filters from the 21 sites on the Network on the same reflectometer, the intercomparability of each Black Smoke site has been improved.

5.0 Measurement Uncertainty

A breakdown of the uncertainty budget for the Black Smoke method is given below.

There are three main elements to this: sample volume, measurement of reflectance and conversion to Black Smoke concentration in µg.m^{-3}.

5.1 Sample Volume

With the installation of the inline flow meter the daily sample volume can be determined with an uncertainty of ±7.7%, expressed with a level of confidence of 95%. Included in this uncertainty are contributions from flow rate accuracy, repeatability, drift and sample port leaks. An action value of 6% has been decided on for sample port leak before any remedial action is taken. The leak rate is not used to correct the results, but is included as an extra uncertainty if the leak rate is above 6%. British Standard 1747 Part 11 states that the leak rate should be less than 2%, but in practice we find that this is impossible to achieve. New rotary 8-port valves are often supplied that only just meet this criterion. In addition to this, sample flow rates cannot be determined with an uncertainty less than ±2% in the field. Therefore a pragmatic value of 6% has been chosen. As leak rate is considered to be a rectangular distribution, its contribution to the standard uncertainty in sample volume is 3.5%.

5.2 Measurement of Reflectance

Those sample filters returned to NPL had the darkness of the stain measured with an EEL M43D reflectometer, the reflectance being determined relative to a blank filter of the same type. The instrument uses a light bulb to give a broad band source that is reflected back from the smoke stain to a photo-sensitive element and produces a reading between 0% and 100% reflectance.

We estimate that the percentage reflectance can be determined with an uncertainty of ±2%, expressed with a level of confidence of 95%. This uncertainty is made up of contributions from tile accuracy, reflectometer calibration, repeatability on filter samples and drift.

This is a cautious provisional estimate dominated by observations of the repeatability of measurements on sampled filters.

5.3 Conversion of Reflectance to Black Smoke Index

The measured reflectance is used to calculate the concentration of particulate matter in the sampled air, as Black Smoke Index, with units of μg/m^3, using the relationship given in BS 1747: Part 2:

$$C = \frac{1}{V}\left(91679.22 - 3332.046R + 49.618884R^2 - 0.35329778R^3 + 0.0009863435R^4\right)$$

where:

C = concentration in μg/m^3
V = volume of sampled air in ft^3
R = reflectometer reading (%)

The above relationship is only valid for a one inch diameter filter clamp. An additional factor is required for other clamp sizes. This relationship is only valid for values of R above 40%. This was true for all samples in the study.

Strictly speaking the formula used for converting the reflectance, sampled volume, (and filter clamp size) to a Black Smoke concentration is an approximation to the British Standard Black Smoke Curve. As the formula has been used consistently on the Network any errors arising from this approximation are not considered as part of the measurement uncertainty.

The uncertainty in Black Smoke Index (BSI) associated with the uncertainty in reflectance can be approximated in different reflectance zones as follows:

Reflectance %	50-60	60-70	70-80	80-90	90-100
BSI (μg/m^3)	157 - 97	97 - 58	58 - 31	31 - 12	12 – 0
Uncertainty (95%) in BSI (μg/m^3)	12.1	7.9	5.3	3.7	2.5
Uncertainty (95%) in BSI as % mid range	9.5	10.2	11.9	17.2	41

5.4 Overall Measurement Uncertainty in μg.m^{-3}

When the contributions from sample volume and measurement of reflectance are combined, the overall measurement uncertainty for Black Smoke concentrations in the range are as follows:

BSI (μg/m^3)	157 - 97	97 - 58	58 - 31	31 - 12	12 – 0
Uncertainty (95%) in BSI as % mid range	12.2	12.8	14.2	18.8	42

At the low average concentrations at the majority of sites the provisional uncertainty is around 30%, dominated by the repeatability of the reflectance measurement on real filter samples. It may be possible to address this in future. The provisional uncertainty at Marylebone Road is around 15%.

6.0 Results

Results for 2006 are a combination of measurements made by local councils up to 18th September and by NPL from 18th September. Data from the latter period have undergone quality control and quality assurance (QA/QC) procedures at NPL during ratification. 7 of the 21 sites were installed after the end of the year and therefore have no data presented.

6.1 Time Series

The following charts show the Black Smoke concentrations measured by the UK Black Smoke Network for 2006. Data has been split into regions of the UK for presentation purposes.

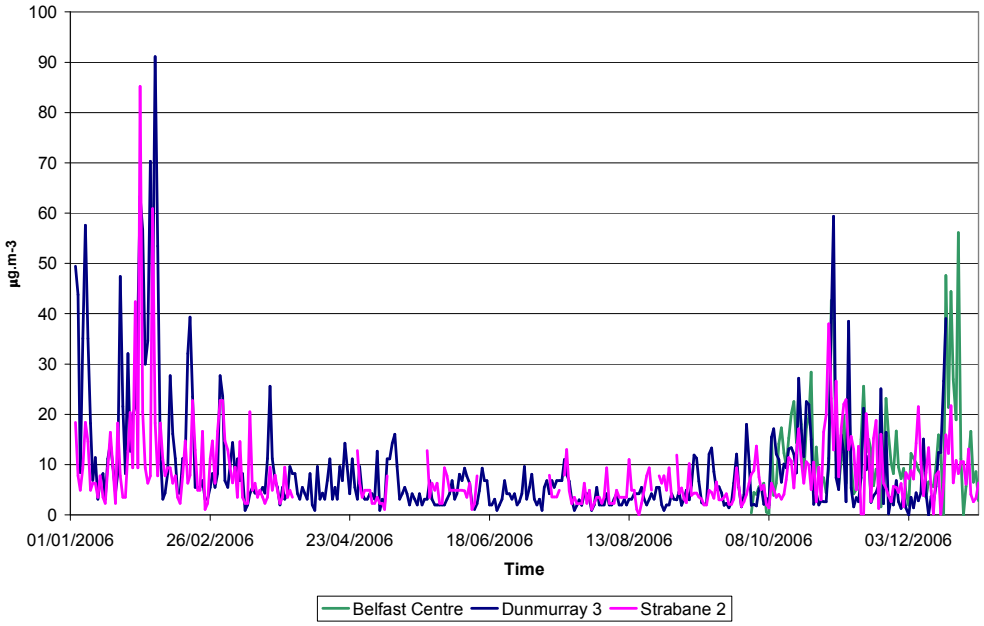


Chart 3 Black Smoke concentrations during 2006 in Northern Ireland

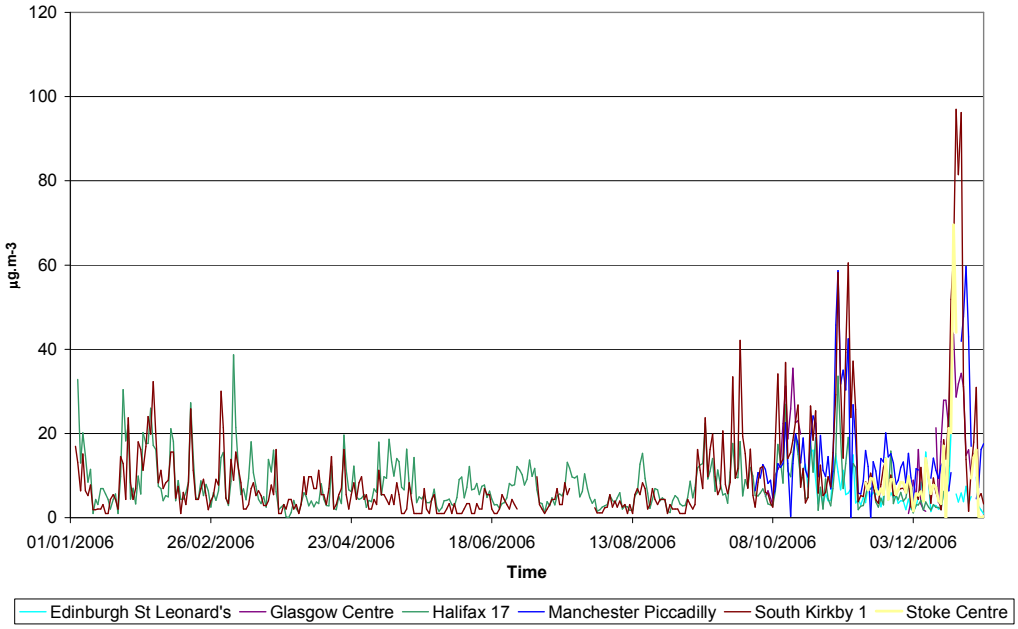


Chart 4 Black Smoke concentrations during 2006 in Scotland and Northern England

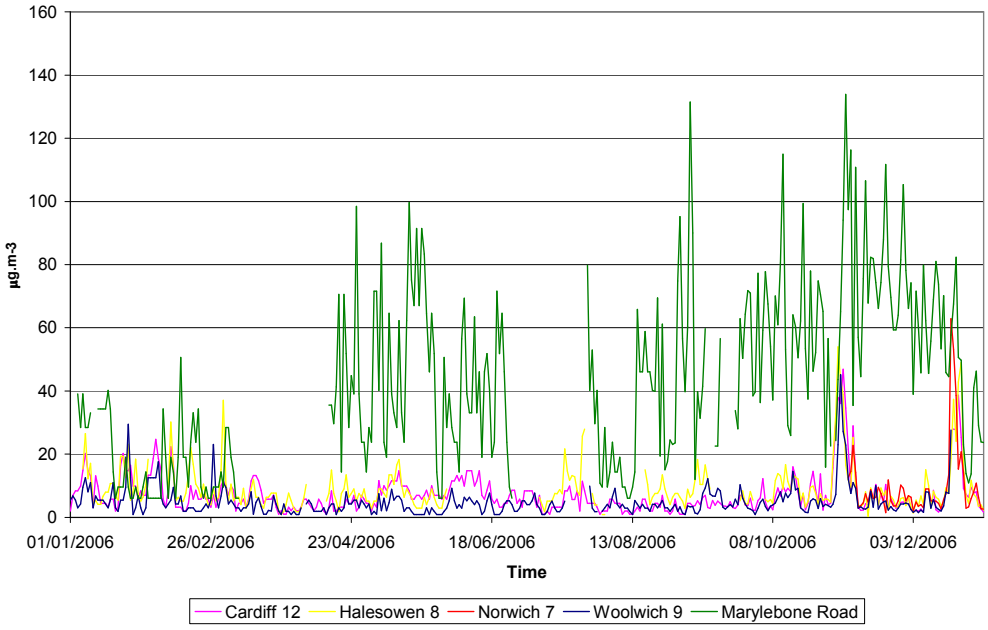


Chart 5 Black Smoke concentrations during 2006 in Southern England and Wales

It can be seen that the Marylebone Road concentrations are much higher than any other site on the Network. It can also be seen that there is a step change in the reported concentration at Marylebone Road between 09/03/06 and 14/04/06. There is no information to suggest a reason for this step change apart from the fact that the sampler was not run for this period. To put this change into perspective, Chart 6 shows the history of Black Smoke measurements at Marylebone Road and compares then to measurements made using a PM_{10} TEOM since June 1997. It can be clearly seen that there are many changes in the magnitude of Black Smoke concentrations, while the TEOM is relatively stable over the period. Some of these changes in Black Smoke concentration can be traced to the repositioning of the sampler in the cabin, while keeping the sample inlet position fixed. Different numbers of bends have been introduced to the sample pipe work and hence have changed the transfer efficiency of the inlet pipe work. This implies that the geometry of the sample inlet pipe work has a major bearing on the Black Smoke concentration measured. It can be clearly seen that the Black Smoke sampler significantly under reads the PM_{10} TEOM for periods in 1998, 2002 and 2004 – 2005. However, not all of these periods correspond to changes in sample line geometry, so there is no satisfactory explanation of these results.

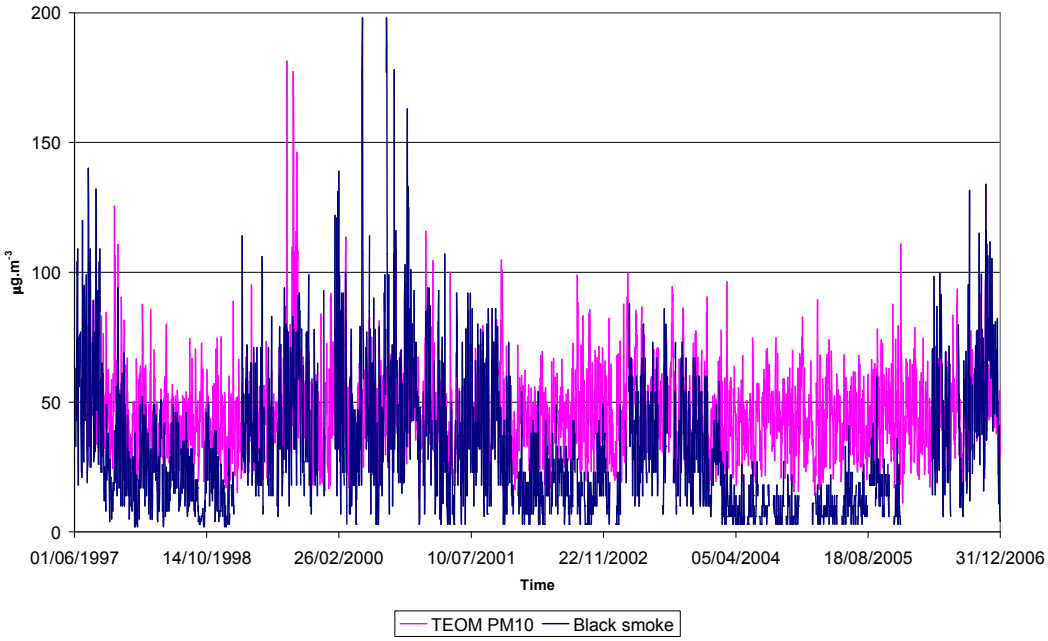


Chart 6 Black Smoke Concentrations Measured at Marylebone Road 1997 to 2006

6.2 Annual Averages and Data Capture

Table 8 gives the annual mean measurement for Black Smoke in 2006 for each site that was operating for at least part of the year.

Site	Black Smoke Concentration, $\mu g.m^{-3}$	Data Capture %
Belfast Centre	12.4*	100*
Cardiff 12	7.1	98
Dunmurry 3	8.9	96
Edinburgh St Leonard's	6.4*	97*
Glasgow Centre	17.5*	44*
Halesowen 8	9.1	76
Halifax 17	7.7	96
Manchester Piccadilly	15.6*	92*
Marylebone Road	42.5	79
Norwich 7	9.7*	67*
South Kirkby 1	9.2	95
Stoke Centre	10.1*	90*
Strabane 2	8.0	80
Woolwich 9	4.8	93

* Measurements for Belfast Centre, Edinburgh St Leonard's, Glasgow Centre, Manchester Piccadilly, Norwich 7 and Stoke Centre are not full calendar year averages.

Table 8 Annual Mean Black Smoke Concentration Measured by the UK Black Smoke Network for 2006

It was decided that the 5% leak found on the Halesowen sample inlet did not compromise the measurements made and that this data could be included in the Network dataset. Measurements made in 2006 were similar to those measured in 2005 and there was no step change in concentrations when the leak was fixed. However, the measurement uncertainty of the Halesowen data would have to be increased.

Data capture at Strabane 2 (80%) was low due to no reflectance measurements being performed by Strabane Council for samples between 01/04/06 and 25/04/06, between 09/05/06 and 23/05/06 and between 14/06/06 and 11/07/06.

Data capture is low at Marylebone Road (79%) due to no measurements being made from 10/03/06 to 10/04/06 due to staff shortages and from 27/06/06 to 25/07/06 due to 8-port valve failure.

Data capture at Halesowen (76%) is low due to no measurements being made from 01/06/06 to 06/07/06 due to staff shortages. Occasional weeks were also lost to 8-port valve failures.

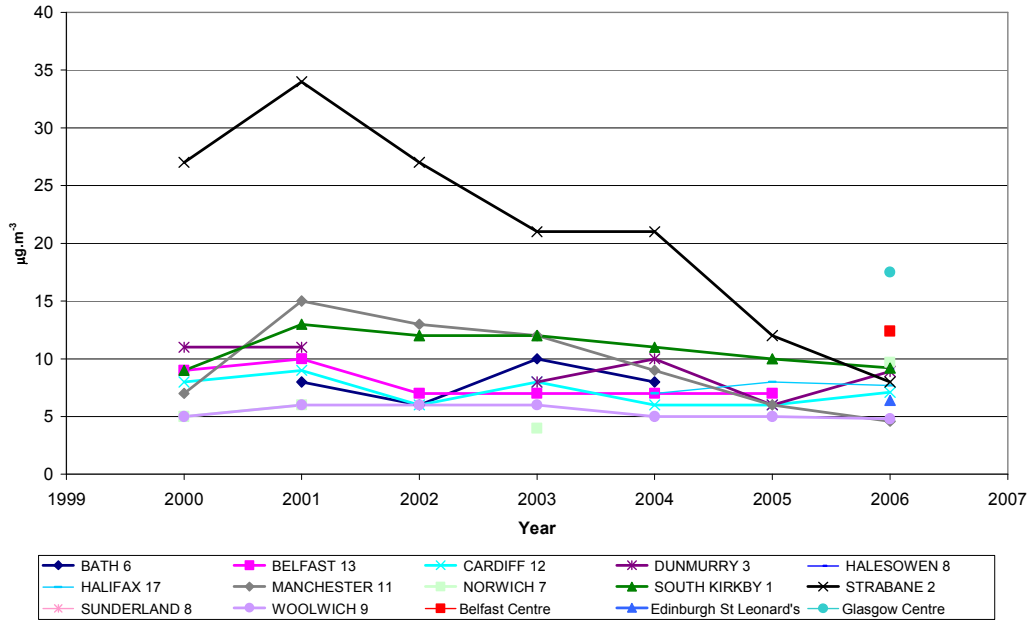
Data capture at Norwich (67%) was low due to split sample pipe work not being noticed by the Local Site Operator. The pipe work was replaced at the site audit by

NPL. The sampler had not been run by Norwich council for two years and had not been properly inspected before being put back into service. Data was lost from 11/10/06 to 07/11/06.

Data capture at Glasgow (44%) is very low because the filters for November were lost in the post and hence a month's data was lost. There were also sampling problems at the end of October that led to data being lost between 20/10/06 and 31/10/06.

6.3 Trends

Chart 7 shows the trend in Black Smoke concentration from 2000 to 2006.



Measurements for Belfast Centre, Edinburgh St Leonard's, Glasgow Centre, and Norwich 7 and are not full calendar year averages.

Chart 7 Trend in Black Smoke Concentration from 2000 to 2006

The drop in the Strabane 2 Black Smoke concentration between 2004 and 2006 is due to the installation of oil fired central heating (generally replacing coal burning) in the estate of houses that surround the monitoring site on three sides. Central heating replacement started in 2003. All of the other sites with the exception of Dunmurry 3 and Cardiff 12 have decreased in concentration year on year.

6.4 Comparisons with PM_{10} TEOM Data

To illustrate the relationship between Black Smoke measurements and colocated PM_{10} measurements, Black Smoke concentrations were compared with PM_{10} TEOM concentrations at sites where both were measured and a linear regression performed. The results of which can be seen in Table 11.

Black smoke concentration = m • TEOM concentration + c

Site	m	c	R^2
Dunmurry 3	0.97	-10.68	0.60
Belfast Centre	0.67	+0.51	0.42
Edinburgh St Leonard's	0.42	-0.68	0.33
Manchester Piccadilly	0.52	2.72	0.26
Marylebone Road	1.24	-4.89	0.55
Stoke	1.38	-20.31	0.68

Dunmurry 3 is a complete calendar year whereas the rest are for 1st October to 31st December.

Table 11 Relationship between Black smoke concentrations and TEOM PM_{10}

It can be seen that there is no simple correlation between Black Smoke concentrations and PM_{10} TEOM concentrations, although the shape of the time series plots for these sites are similar. The Dunmurry 3 full year time series can be seen in Chart 8.

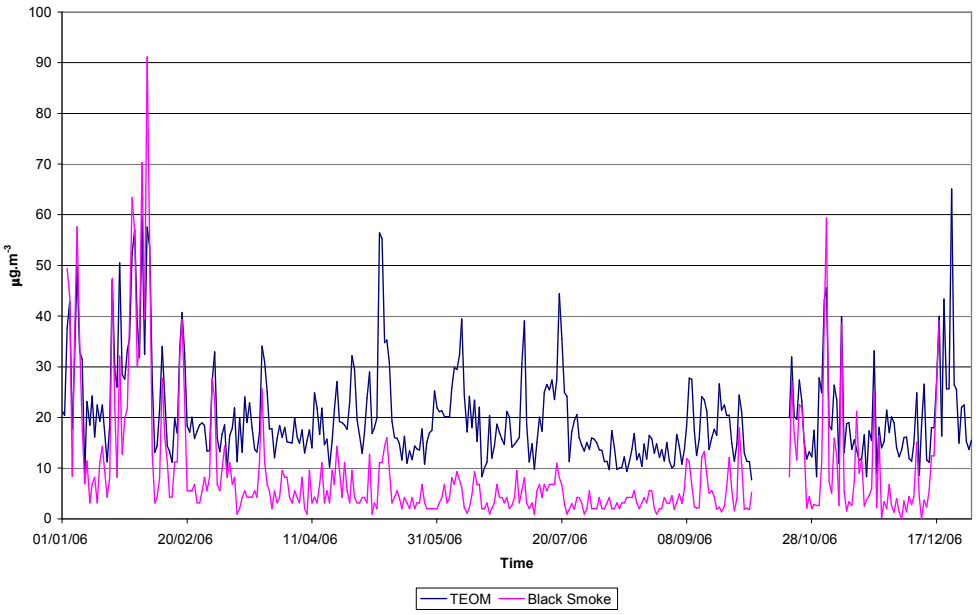


Chart 8 TEOM and Black Smoke concentrations measured at Dunmurry 3 for 2006

6.5 Affiliate Sites

Three further Councils have submitted their data for inclusion in this report, but this data has not undergone any QA/QC by NPL, with the exception of Manchester 11,

which has had its reflectometer intercompared with NPL. These sites have been listed as affiliate sites.

6.5.1 Time Series

Chart 9 shows the Black Smoke concentrations measured by the individual affiliate Councils for 2006.

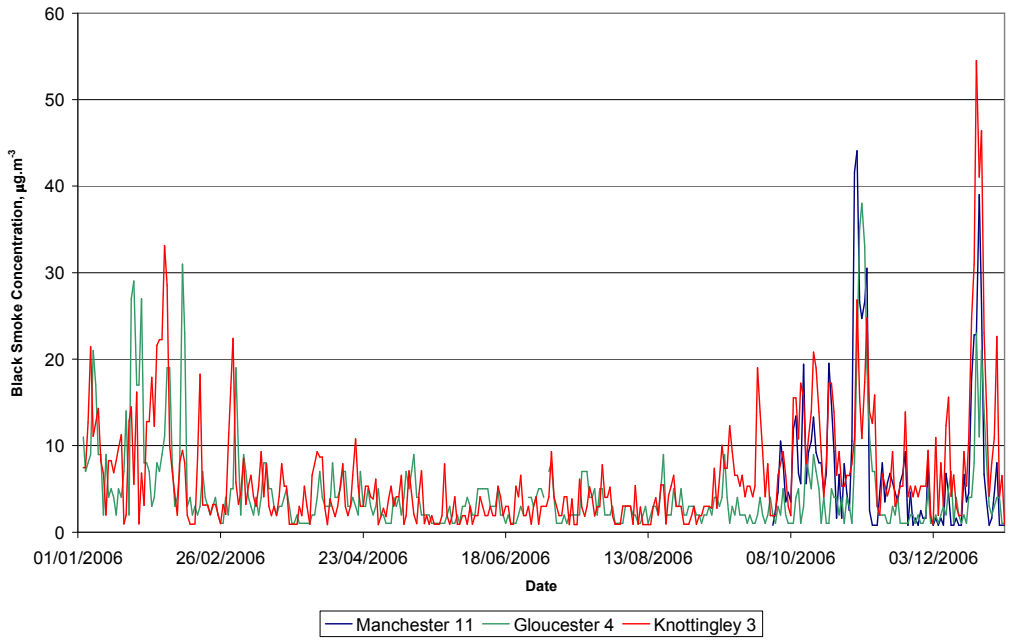


Chart 9 Black Smoke Concentrations Measured by Affiliate Councils for 2006

6.5.2 Annual Averages

Table 9 gives the annual mean measurement for Black Smoke in 2006 for each site.

Site	Black Smoke Concentration, $\mu g.m^{-3}$
Gloucester 4	7.9
Knottingley 3	6.4
Manchester 11	4.6*

* Measurements from 1st October 2006 to 31st December 2006.

Table 9 Annual Mean Black Smoke Concentration Measured by Individual Councils for 2006

References

1 D Fowler et al, A Review of the UK urban network for measurement of Black Smoke, SO_2 and NO_2: Summary report, Defra, April 2006.

2 McFarland AR, Ortiz CA, and Rodes CE, Wind tunnel evaluation of the British Smoke Shade sampler (Atmos Environ, 1982; 16: 325-328).