Ricardo Energy & Environment

PM2.5 and PM10 in Scotland

PM2.5 and PM10 in Scotland

$PM_{2.5}$ and PM_{10} in Scotland

Investigation of concentrations and ratios of $PM_{2.5}$ and PM_{10} across Scotland to help inform potential changes to Air Quality Strategy Objectives and Local Air Quality Management

Report for the Scottish Government
ED57729

The Scottish Government

Customer:

Scottish Government

Customer reference:

ED57729

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30 March 2016

Ricardo Energy & Environment reference:

Ref: ED57729(ratio)DRAFT1

Executive Summary

The Scottish Government has committed to aligning the Scottish Air Quality Objectives for ambient particulate pollution (currently 18 and 12 µg m^{-3} for PM_{10} and $PM_{2.5}$ respectively as annual means) with the annual mean WHO guidelines for PM_{10} and $PM_{2.5}$ which are 20 and 10 µg m^{-3} respectively. These values are considerably more stringent than the equivalent EU and UK targets, but similar to the Scottish objectives of 18 and 12 µg m^{-3}.

This report looked at particle concentration using current and historical data from Scottish Air Quality Database (SAQD) network, Pollution Concentration Mapping (PCM) and mobile monitoring, to establish how these proposed changes would affect the current Air Quality Management Areas (AQMAs) and Air Quality Action Plans (AQAPs).

The report also investigated the relationship between $PM_{2.5}$ to PM_{10}, to understand whether measured PM_{10} concentration could be used to estimate $PM_{2.5}$ concentration. If so, this could help our understanding of the impact of the proposed changes, and in the development of AQMAs and AQAPs.

In general, particle concentration has decreased over the long term from 2009 to 2015, and in the short-term from 2014 to 2015 for SAQD monitoring sites. The modelled data from Pollution Concentration Mapping also show a decline in particle concentration for both $PM_{2.5}$ and PM_{10}.

Exceedances of the current annual objectives (of 18 and 12 µg m^{-3} for PM_{10} and $PM_{2.5}$ respectively) have also reduced from 2014 to 2015 at SAQD sites, from 19 to 11 exceedances for PM_{10} and from three to zero for $PM_{2.5}$. Increasing the PM_{10} objective from 18 to 20 µg m^{-3} would result in fewer exceedances: six in 2014 and three exceedances in 2015. By lowering the $PM_{2.5}$ objective from 12 µg m^{-3} to 10 µg m^{-3} the number of exceedances in 2015 would increase very slightly.

PCM data indicated that the number of exceedances would increase from zero to 22 as a result of the proposed decrease in the $PM_{2.5}$ objective of 12 to 10 µg m^{-3}. Mobile monitoring results were also compared with the objectives but since the mobile monitoring was only carried out on a short-term basis the results were not comparable with the annual mean objective. The mobile monitoring data could only provide a “snap shot” representative of local conditions and weather at a specific location and time.

It was concluded that changing the PM_{10} objective to 20 µg m^{-3} would impact on the Air Quality Management Areas across Scotland, with many current PM_{10} AQMAs becoming unnecessary. This would have effects on the Air Quality Action Plans that have been developed by local authorities to improve local concentrations of PM_{10}, perhaps leading the abandoning of such plans. This could be counter-productive to efforts to reduce PM_{10} and $PM_{2.5}$: by tackling PM_{10} (or more specifically primary PM), $PM_{2.5}$ is also targeted indirectly. Thus by maintaining the PM_{10} objective at 18 µg m^{-3} the AQMAs and Action Plans will stay as they are and $PM_{2.5}$ may reduce proportionally (albeit to a limited extent, because reduction of primary PM does not address the problem of transboundary particulate pollution which is believed to make a large contribution to $PM_{2.5}$.). This proportional reduction for annual mean $PM_{2.5}$ is estimated to be in the order of 0.8 µg m^{-3} for a 30% reduction in primary PM, thus there is limit to what can be achieved. The modelled background concentration of $PM_{2.5}$ for Scotland is 6.6 µg m^{-3}, whereas within the Scotland’s cities this is around 8 µg m^{-3}, thus an annual mean objective of less than 10 µg m^{-3} might be difficult to achieve in some areas.

Changes in the $PM_{2.5}$ objectives may also require further planning to develop AQMAs specifically for $PM_{2.5}$, and thus need to increase the current $PM_{2.5}$ network. The study investigated the feasibility of using data from the PM_{10} network to estimate $PM_{2.5}$ concentrations. The SAQD network operates over 70 PM_{10} monitors measuring particulates, and although the number of $PM_{2.5}$ monitors is rising (from nine to fourteen between 2014 and 2015), there are still many more monitoring sites for PM_{10} than for $PM_{2.5}$. If it is possible to estimate $PM_{2.5}$ from PM_{10} data on the basis of typical relationships between the two metrics – specifically, the ratio of annual mean $PM_{2.5}$ to annual mean PM_{10} - this could increase the number of $PM_{2.5}$ data points by fivefold throughout Scotland.

The data from the SAQD from recent years suggest that the ratio of annual mean $PM_{2.5}$ / annual mean PM_{10} are changeable, but largely similar to those seen across the continent of Europe, especially Northern Europe. Four methods were examined to develop a ratio of $PM_{2.5}/PM_{10}$, these where:

i. Linear regression of paired hourly mean $PM_{2.5}$ and PM_{10} concentrations from eight SAQD sites over the period 2009 – 2015 indicated that there was an approximately linear relationship between the two metrics, with **$[PM_{2.5}] \approx 0.66 \times [PM_{10}]$.** The slope ranged from 0.56 to 0.80 and the intercept was less than the limit of detection of the PM monitoring method for all sites included in the investigation.

ii. The annual average ratio of daily mean $PM_{2.5}$ concentration to daily mean PM_{10} concentration typically varied from 0.51 to 0.69 with a mean of **0.63**.

iii. This was supported by the PCM modelled data, which indicated that the ratio of *annual* mean $PM_{2.5}/PM_{10}$ ranged from 0.63 to 0.69.

iv. For the mobile monitoring data the average of hourly mean $PM_{2.5}/PM_{10}$ was 0.52, with a larger range of 0.21 to 0.69. (However, this was short-term).

As an approximate indication, based on the sites and years included in this study, this study concluded that **annual mean $[PM_{2.5}] \approx 0.63 \times$ annual mean $[PM_{10}]$** would provide the best estimate of this ratio.

The ratio may be used to provide an *indicative estimate* of annual $PM_{2.5}$ concentration at locations where only PM_{10} is measured. However, it should be noted that:

- The ratio varies from site to site,
- The ratio varies from year to year, so it is recommended that the ratio should be calculated annually if this method is to be used for estimating annual mean $PM_{2.5}$,
- The ratio of the two metrics varies from hour to hour and day to day, so this ratio is only intended to apply to the annual mean, not shorter periods.

Thus this method is only intended to provide an indicative estimate of annual mean $PM_{2.5}$ concentration. It is not recommended to rely on this method without having a $PM_{2.5}$ measurement network as a backup.

The best estimate of the ratio of $PM_{2.5}/PM_{10}$ from this study (**0.63**) was applied to 2015 annual mean PM_{10} data from SAQD sites. Based on this approach, it was estimated that five SAQD PM_{10} sites would have exceeded the current AQS Objective for $PM_{2.5}$ (12 µg m^{-3}). Twenty-seven SAQD PM_{10} sites are likely to have exceeded the proposed new AQS Objective for (10 µg m^{-3}). This number of exceedances for $PM_{2.5}$ was significant higher compared with using currently measured $PM_{2.5}$ data from the limited number of $PM_{2.5}$ sites, and similar to those seen with PCM data.

The increased number of exceedances of the $PM_{2.5}$ objectives (proposed or current) using this method suggests that $PM_{2.5}$ could be a greater problem than previously thought. This adds weight to the argument for tightening the objective. Thus the determination of the ratio and the subsequent calculated concentration for $PM_{2.5}$ might have numerous potential implications for air quality management in Scotland, including:

- The need to further develop of the $PM_{2.5}$ monitoring network, especially considering that $PM_{2.5}$ is thought to have a greater impact on health than PM_{10}.
- The development of AQMAs for $PM_{2.5}$
- The subsequent AQAPs

Aligning Scotland's PM_{10} objective with the more lenient WHO guideline would lead to fewer exceedances and possible questioning of the need for the AQMAs / AQAPs; and thus it may be prudent in the short term to leave the current PM_{10} objective in place. By contrast the alignment of the $PM_{2.5}$ objective with the more stringent WHO guideline would lead to more exceedances, more AQMAs and AQAPs, probably prompting more monitoring and hopefully a better understanding of $PM_{2.5}$. Thus this alignment could be considered prudent.

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1 Introduction

1.1 Background

The recent Scottish Government document[1] 'Cleaner Air for Scotland' reviews Scotland's Air Quality Objectives for particulate pollution. It states: "*The WHO has set guideline PM_{10} and $PM_{2.5}$ values of 20 and 10 µg m^{-3} respectively as annual means. These values are considerably more stringent than the equivalent EU and UK targets, but similar to the Scottish objectives of 18 and 12 µg m^{-3} (see below) The Scottish Government considers that there may be value in aligning the Scottish objectives with the WHO guidelines, both for consistency and because an increasing body of evidence suggests that $PM_{2.5}$ is the more significant particulate fraction in terms of health impacts*".

Scotland's current Air Quality Objectives for particulates (which are already lower than those used elsewhere in the UK[2]) are:

- For PM_{10} a 24 hour mean of 50 µg m^{-3}, not to be exceeded more than 7 times a year
- For PM_{10} an annual mean of 18 µg m^{-3}
- For $PM_{2.5}$ an annual mean of 12 µg m^{-3} (Although this is an objective it has not been incorporated into LAQM Regulations and authorities have no statutory obligation to review or assess air quality against this objective).

The Scottish Government has committed to the following changes to Scotland's Air Quality Objectives:

1. the inclusion of $PM_{2.5}$ particulate matter within the Local Air Quality Management (LAQM) regime and
2. to change the annual mean PM_{10} objective from 18 µg m^{-3} to 20 µg m^{-3}, and annual mean $PM_{2.5}$ objective in Scotland from 12 µg m^{-3} to 10 µg m^{-3}, in line with WHO guidelines[1]

However, these changes would have numerous potential implications for air quality management in Scotland. These include the need to develop a $PM_{2.5}$ monitoring network (see separate report[3]), the impact on Air Quality Management Areas (AQMAs) across Scotland and also on Air Quality Action Plans (AQAPs) that have been developed by local authorities to improve local concentrations of PM_{10}.

In 2014 there were only nine $PM_{2.5}$ monitoring sites located across Scotland, a relatively small number compared with the number of PM_{10} monitoring sites. Therefore it is difficult to envisage the potential impacts that the proposed changes to the Scottish Air Quality Objectives for PM_{10} and $PM_{2.5}$ would have in term of existing AQMAs for PM_{10} and new AQMAs for $PM_{2.5}$.

One possible approach to assessing the possible impacts of the proposed changes would be to use PM_{10} data (which are plentiful) as a surrogate for $PM_{2.5}$ data (which are less so). To do this, it would be necessary to understand the ratios and relationships between PM_{10} and the smaller $PM_{2.5}$ size fraction. This report describes a study carried out by Ricardo Energy & Environment to investigate the relationship between PM_{10} and $PM_{2.5}$ in Scotland, and to use the findings to investigate the impacts of changing the Air Quality Objectives on Scotland's Air Quality Management Areas.

1.2 Scope of the Study

The scope of the study was as follows:

1. Firstly, to use existing measured data from Scotland's network of fixed air quality monitoring sites, and modelled Pollution Climate Mapping data to assess:
    a. Current PM concentrations and compliance with the existing Objectives for PM on a site-specific and Local Authority-specific basis.

[1] Scottish Government (2015b) *Cleaner Air for Scotland: The Road to a Healthier Future*, The Scottish Government, St Andrew's House, Edinburgh, EH1 3DG, UK. Available at: http://www.gov.scot/Resource/0048/00488493.pdf.

[2] Air Quality in Scotland (2015b) *Standards - Air Quality in Scotland*. Available at: http://www.scottishairquality.co.uk/air-quality/standards (Accessed: 08/10/15.

[3] Sykes, D. (2016) *$PM_{2.5}$ network in Scotland: Investigation of $PM_{2.5}$ network within Scotland to help inform the expansion of the network*.

   b. How PM concentrations are changing over time, and forecast concentrations for future years.
   c. The impact of changing the PM Objectives, in terms of how many additional AQMAs may be needed.
2. Secondly, to carry out measurements of ambient PM_{10} and $PM_{2.5}$ concentrations at locations in a selection of PM_{10} Air Quality Management Areas in in Aberdeen, West Lothian, South Lanarkshire, North Lanarkshire, East Dunbartonshire and Renfrewshire, using Ricardo Energy & Environment's mobile monitoring platform.
3. Using the above measurements, together with data from an earlier mobile monitoring study, data from Scotland's network of fixed air quality monitoring sites, and modelled PM_{10} and $PM_{2.5}$ concentrations, to investigate the relationship between PM_{10} and $PM_{2.5}$.

Some of the data used in this study were obtained using the **mobile monitoring platform**. The development of the mobile monitoring platform as part of the Scottish Government's PM with height[4] study has demonstrated that with appropriate quality assurance/quality control (QA/QC) the platform can provide valuable information regarding the spatial distribution of air quality pollutants within an AQMA. Furthermore, the platform's ability to monitor $PM_{2.5}$ and PM_{10} concurrently provides an almost unique opportunity to monitor concentrations of both pollutants at a large number of locations within an AQMA and calculate relevant $PM_{2.5}/PM_{10}$ ratios and inform the likely outcome of the proposed Scottish objectives on AQMAs across Scotland.

During 2014, mobile monitoring studies were undertaken in Glasgow, Fife and Perth and Kinross. Data from these studies were supplemented with:

- $PM_{2.5}$ and PM_{10} measurements from throughout 2014 and 2015 from SAQD monitoring sites where both $PM_{2.5}$ and PM_{10} concentrations are measured providing input to the study and to cross reference the mobile monitoring measurements.
- $PM_{2.5}$ and PM_{10} measurements by the mobile monitoring at a selection of AQMAs (declared for PM_{10}) across Scotland.

Thus this study used data from these various sources to investigate the ratio of $PM_{2.5}/PM_{10}$. This information was used to in combination with measured and mapped PM_{10} concentrations to predict likely concentrations of $PM_{2.5}$ in local authorities across Scotland and thus a picture of likely future $PM_{2.5}$ AQMAs in Scotland. The study also provided valuable information for the $PM_{2.5}$ network evaluation option (reported separately).

[4] Scottish Government (2015a) *Air Quality Study - Scotland - Assessing variations in roadside air quality with sampling height*: Scottish Government, St. Andrew's House, Regent Road, Edinburgh EH1 3DG Tel:0131 556 8400 ceu@scotland.gsi.gov.uk [Report]. Available at: http://www.gov.scot/Publications/2015/08/4504 (Accessed: 28/01/16.

2 Technical Background

This technical section introduces PM definitions, health aspects, sources etc. It also looks at data from previous reports and studies that relate directly to, or introduce the scope of this work.

2.1 PM_{10} and $PM_{2.5}$

2.1.1 Definition

PM_{10} is correctly defined as particles which pass through a size-selective inlet with a 50 % efficiency cut-off at 10 µm mean aerodynamic diameter. $PM_{2.5}$ is defined similarly, for an inlet with 50 % efficiency cut-off at 2.5 µm mean aerodynamic diameter[5]. (The two size fractions are however often quoted as being of a diameter of less than 10 and 2.5 µm respectively). PM_{10} particles are also defined as both respirable and coarse particles, $PM_{2.5}$ particles are also defined as fine particulates. Particles smaller than $PM_{1.0}$ are referred to as ultrafines. As a particle reduces in size it penetrates more easily into the lungs, with ultrafines being able to cross the membrane of the lungs into the blood.

2.1.2 PM and Health

It was estimated that in 2012 nearly 7 million people worldwide died prematurely due to air pollution[6]. The WHO stated that "*high concentrations of small and fine particulate pollution is particularly associated with high numbers of deaths from heart disease and stroke, as well as respiratory illnesses and cancers. Measurement of fine particulate matter of 2.5 micrometres or less in diameter ($PM_{2.5}$) is considered to be the best indicator of the level of health risks from air pollution*"[7]. "Diseases caused by $PM_{2.5}$ exposure include stroke, ischaemic heart disease, acute lower respiratory disease, chronic obstructive pulmonary disease, and lung cancer"[8]. The WHO suggest to reduce health burdens of PM the air quality guidelines for particulate matter should be set at 20 and 10 µg m^{-3} for annual mean PM_{10} and $PM_{2.5}$ respectively (see Table 2-1 for guidelines).

Table 2-1: World Health Organization guidelines for particulate matter (PM)[9]

	Guideline (µg m^{-3})
$PM_{2.5}$ annual mean	10
$PM_{2.5}$ 24h mean	25
PM_{10} annual mean	20
PM_{10} 24h mean	50

[5] Okuda, T., Isobe, R., Nagai, Y., Okahisa, S., Funato, K. and Inoue, K. (2015) 'Development of a High-Volume PM2. 5 Particle Sampler Using Impactor and Cyclone Techniques', *Aerosol Air Qual. Res,* 15, pp. 759-767.
[6] WHO (2014a) *7 million premature deaths annually linked to air pollution*. WHO: World Health Organization. Available at: http://www.who.int/mediacentre/news/releases/2014/air-pollution/en/.
[7] WHO (2014b) *WHO | Air quality deteriorating in many of the world's cities*. WHO: World Health Organization. Available at: http://www.who.int/mediacentre/news/releases/2014/air-quality/en/ (Accessed: 09/11/15.
[8] Scovronick, N. (2015) *Reducing Global Health Risks: Through mitigation of short-lived climate pollutants - Scoping report for policymakers*, World Health Organization. Available at: http://apps.who.int/iris/bitstream/10665/189524/1/9789241565080_eng.pdf?ua=1.
[9] WHO (2014c) *WHO | Ambient (outdoor) air quality and health. Fact sheet No 313*. WHO: World Health Organization. Available at: http://www.who.int/mediacentre/factsheets/fs313/en/ (Accessed: 13/11/15.

The Sniffer project[10] noted the following about $PM_{2.5}$:

- Both short and long-term exposure to $PM_{2.5}$ causes a range of detrimental health effects.
- Exposure to $PM_{2.5}$ reduces life expectancy by around six months averaged over the whole of the UK.
- In terms of the overall impact on human health, the detrimental effects of long-term exposure are more significant than for short-term exposure.
- There is no clear evidence as to which $PM_{2.5}$ component(s) produce these harmful effects. Therefore, all components must be treated as potentially harmful.
- Additionally there are no currently recognised threshold below which negative health effects are absent.

2.1.3 PM Components & Sources

PM is made of both solid and liquid material of various sizes[11], and consists of primary and secondary components. The primary components are released from the sources into the air. These sources are often the combustion of fuels, from mobiles sources such as transport or stationary sources, such as domestic or commercial / industrial uses. Natural sources (sea salt and dust) and other anthropogenic sources (quarrying and construction) can also contribute.

Secondary components are formed within the atmosphere by chemical reaction from smaller precursors (see Table A1 in the appendices), many of which are released from farming practices.

Primary components include: sodium chloride, elemental carbon, trace metals, mineral components and organic carbon. Secondary components include: sulphate, nitrate, water and organic carbon (for more details see **Table** A2 in the appendices).

The Sniffer project[10] stated that sources included:

- *"Industrial sources and power stations contribute most to national, primary, man-made emissions (35%), followed by road transport (24%), residential (13%), and shipping (10%)"*
- *"Natural sources of PM include sea salt, which accounts for ~5-15% of urban background $PM_{2.5}$, with greater contributions found towards the coastal areas of the UK"*
- Primary man-made particles (from all sources) make a small contribution to urban background $PM_{2.5}$.
- *"Secondary particles dominate urban background $PM_{2.5}$ in the UK, with ammonium sulphate, ammonium nitrate, and organic particles accounting for some 30-50% of the $PM_{2.5}$ in urban areas*." Many of these secondary particles migrate into Scotland from the rest of the UK, whilst analysis shows UK emissions contribute around 50-55% of total annual average $PM_{2.5}$ (see Table A3 in the appendix) [12]

2.1.4 Mitigation of $PM_{2.5}$

As stated above, UK emissions contribute around only 50-55% of total annual average $PM_{2.5}$ in the UK. This means that any emission reduction measures that only involve the UK will have limited effectiveness, because such a large proportion of $PM_{2.5}$ comes from elsewhere. However, a report[12] by AQEG for Defra highlights that of five alternatives to reduce $PM_{2.5}$ (reduction of primary particulate matter (PM), sulphur dioxide (SO_2), nitrogen oxides (NOx), volatile organic compounds (VOCs) and ammonia emissions), the reduction of primary PM and ammonia represent the most effective options.

Reduction of primary $PM_{2.5}$ emissions in the UK delivers reductions in $PM_{2.5}$ mass predominantly in areas of higher population density, while ammonia reductions lead to decreases mainly in non-urban areas[10] It is estimated that a 30% reduction in primary PM could lead to 0.8 µg m^{-3} reduction in $PM_{2.5}$ (see Table A4 in the appendix), which suggests that the most effective method of mitigation is for Local Authorities to tackle PM within urban areas.[12]

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[10] Laxen, D., Moorcroft, S., Marner, B., Laxen, K., Boulter, P., Barlow, T., Harrison, R. and Heal, M. (2010) *PM2.5 in the UK*: Sniffer - www.sniffer.org.uk. Available at: http://www.sniffer.org.uk/files/2413/4183/8000/ER12_Project_Summary_electronic.pdf.
[11] AQEG (2005) *Particulate Matter in the United Kingdom*, Air Quality Expert Group, UK Department for Environment, Food and Rural Affairs. Available at: http://uk-air.defra.gov.uk/assets/documents/reports/aqeg/pm-summary.pdf.
[12] Monks, P., Carruthers, D., Carslaw, D., Dore, C., Harrison, R., Heal, M., Jenkin, M., Lewis, A., Stedman, J. and Tomlin, A. (2015) 'Mitigation of United Kingdom PM2. 5 Concentrations'.

2.2 Particulate Measurement & Mapping in Scotland

2.2.1 Particulate Matter Measurement

PM_{10} and $PM_{2.5}$ are measured throughout the country using a network of Roadside, Kerbside, Urban Background, Urban Industrial and Rural fixed monitoring stations, all of which form part of the Scottish Air Quality Database (SAQD).

As of January 2016, 75 stations were actively measuring PM_{10}. Fifteen also included hourly $PM_{2.5}$ measurement, whilst two further sites monitored daily $PM_{2.5}$. A number of stations have ceased operation since the beginning of the study (five and one respectively); however this is outweighed by the number that have since become operational, six PM_{10} and a further eight $PM_{2.5}$ measuring particulate matter since March 2014 (see Appendix 5).

The majority of the monitoring sites are situated near centres of urban population, as such they are concentrated in and around Scotland's cities and towns, which are predominantly in the central belt of the country, see Figure 2-1.

The 2014 annual mean PM concentrations for 77 SAQD monitoring sites of different types are shown in Table 2-2. It can be seen that the annual average PM_{10} is greater than $PM_{2.5}$. Also Roadside PM concentrations are greater than Urban Background, which are in turn greater than Rural Background.

Table 2-2: Average annual PM concentrations (µg m^{-3}) from 2014 from different types of SAQD monitoring sites in Scotland[13]

	Roadside / Kerbside		Urban Background		Urban Industrial		Rural	
	(µg m^{-3})	n =	(µg m^{-3})	n =	(µg m^{-3})	n =	(µg m^{-3})	n =
Annual Mean PM_{10} for 2014	17	62	14	11	12	1	9	3
Annual Mean $PM_{2.5}$ for 2014	12	3	9	3	8	1	5.5	2

The SAQD 2014 annual report[13] discusses these result in full: However, in summary 19 sites equalled or exceeded the Scottish annual average PM_{10} objective of 18 µg m^{-3}, with the maximum annual average 26 µg m^{-3} and some sites also exceeded the 24 hour mean of 50 µg m^{-3}, on more than 7 times in 2014. For $PM_{2.5}$ three sites exceeded the Scottish AQS objective of 12 µg m^{-3} in 2014, however, like some sites measuring PM_{10}, the data capture was less than 75% for these sites.

The average annual mean concentrations for both $PM_{2.5}$ & PM_{10} can be seen to generally decline across a selected number of sites in Scotland from 2009-2014 (see Table 2-3).

[13] David Hector, S. S., Rebeca Rose, Alison Loader, Alistair Dorman Smith (2015) *Scottish Air Quality Database: Annual Report 2014*.

Figure 2-1: $PM_{2.5}$ and PM_{10} sites (in highlighted in orange) and PM_{10} only (red) in Scotland since March 2014.

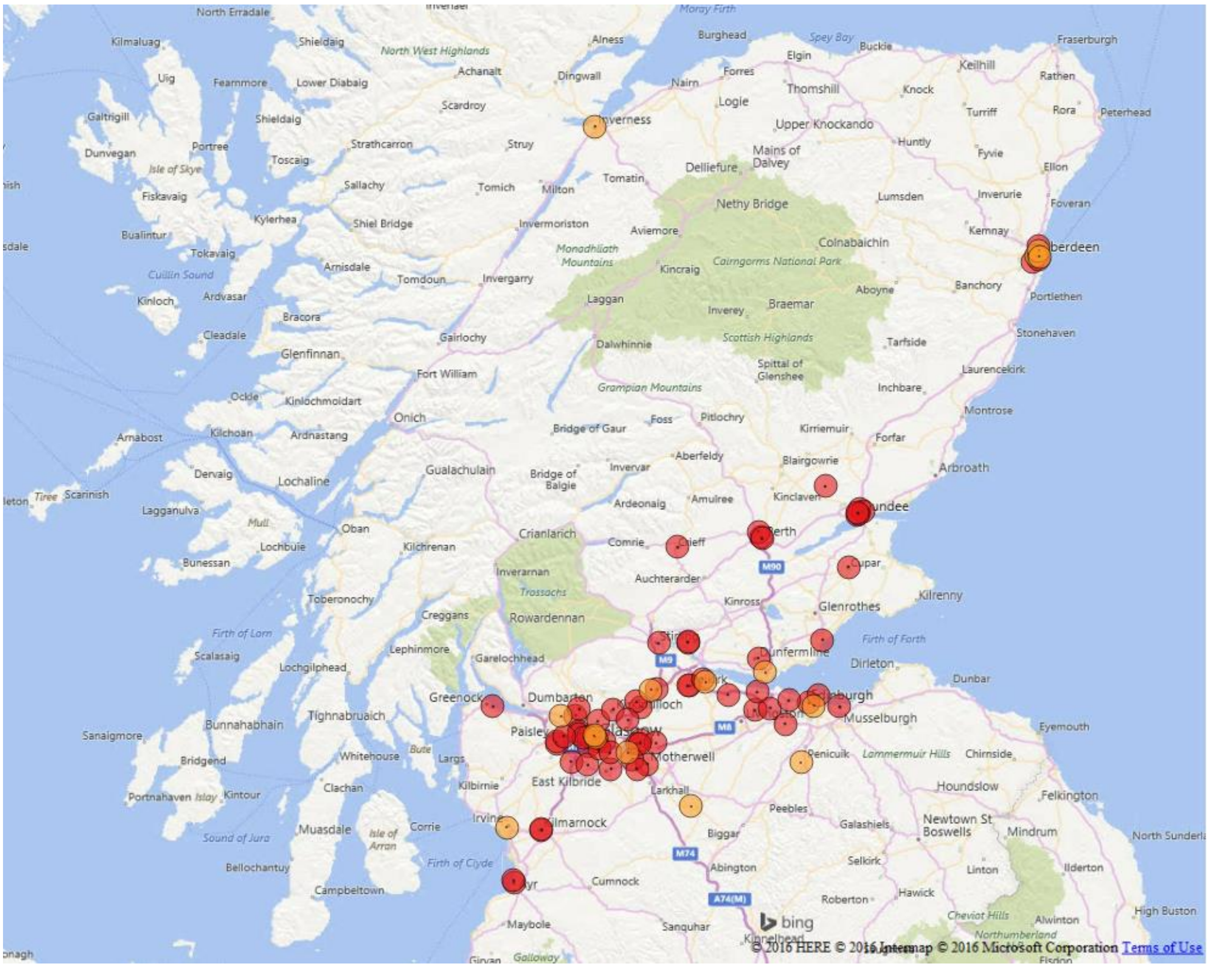


Table 2-3: Average annual $PM_{2.5}$ & PM_{10} concentrations ($\mu g\ m^{-3}$) from SAQD monitoring sites in Scotland

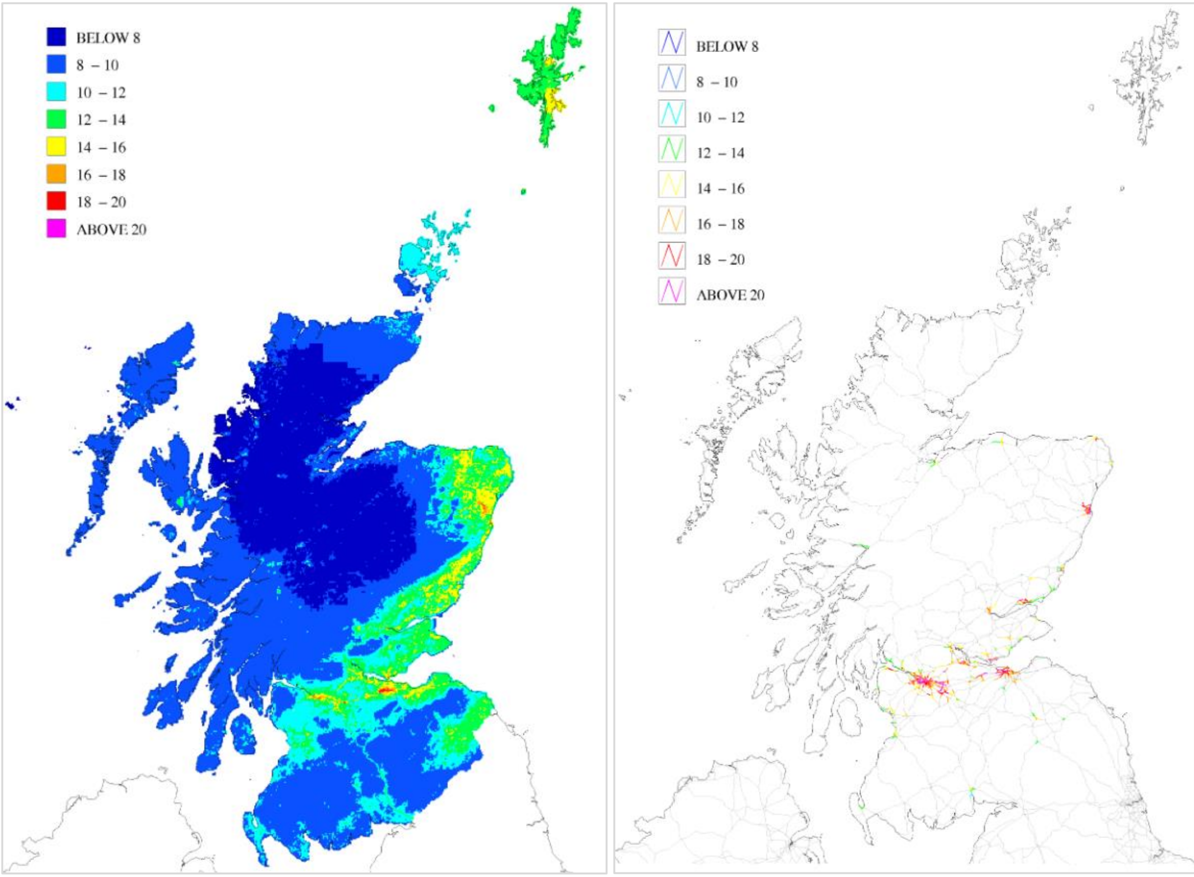
		2008	2009	2010	2011	2012	2013	2014	Mean
Aberdeen Errol Place	$PM_{2.5}$	3	7	7	8	9	9	10	**8**
	PM_{10}	16	15	13	14	12	13	15	**14**
Auchencorth Moss	$PM_{2.5}$	10	3	4	4	4	4	7	**5**
	PM_{10}	7	7	7	7	7	8	8	**7**
Edinburgh St Leonards	$PM_{2.5}$	14	8	9	12	11	8	9	**10**
	PM_{10}	15	18	14	15	16	14	13	**15**
Glasgow Kerbside	$PM_{2.5}$	11	20	23	22	20	5	7	**16**
	PM_{10}	27	26	29	13	24	23	22	**23**
Glasgow Centre / Townhead	$PM_{2.5}$	18	12	12	10	10	16	7	**12**
	PM_{10}	27	26	29			23	13	**24**
Average annual mean concentration	**$PM_{2.5}$**	**11**	**10**	**11**	**11**	**11**	**8**	**8**	**10**
	PM_{10}	**18**	**18**	**18**	**12**	**15**	**16**	**14**	**16**

2.2.2 Particulate Mapping

PM_{10} is also modelled and mapped throughout Scotland[14] using a Scotland-specific pollution climate mapping, enabling the mapping of exceedances where fixed monitoring is not possible. The modelling is carried out for both background and roadside PM_{10} (see Figure 2-2). Only nineteen exceedances of 18 µg m^{-3} for 1 km squares were noted (from a total of 83956 km^2), though some of these were thought to be anomalies. Roadside exceedances numbered 262 road links of 193km of roads, more than half were in the Glasgow Urban Area.

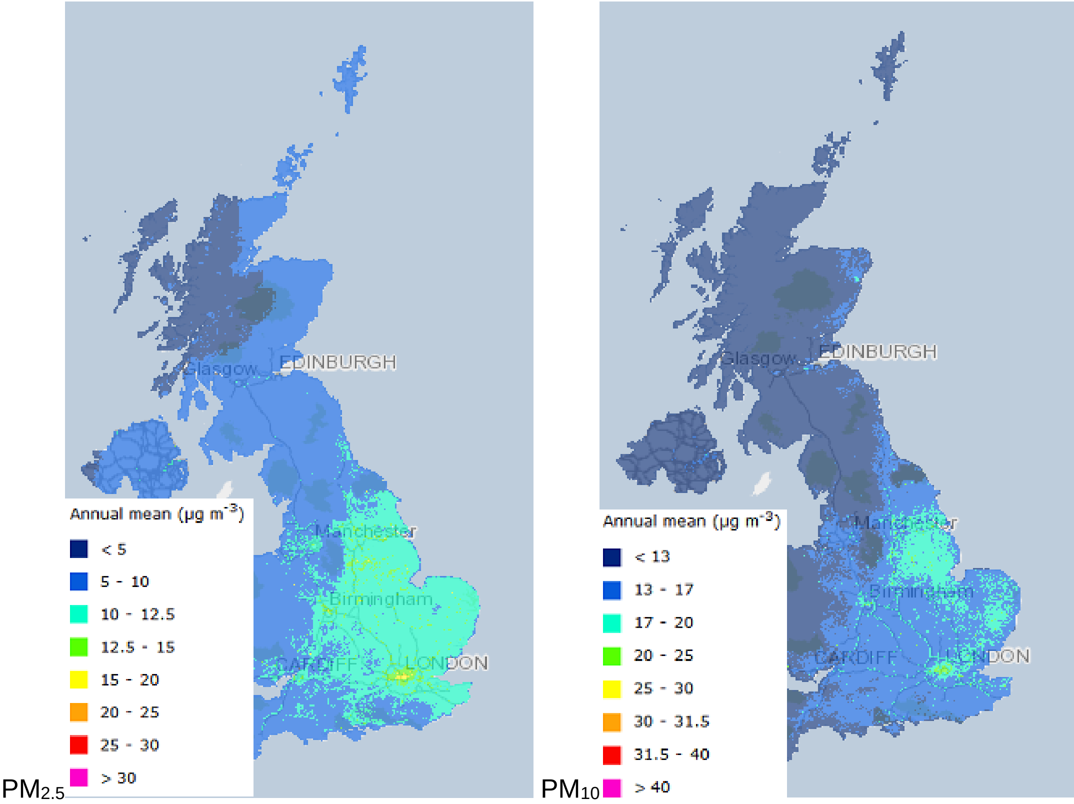
PM_{10} and $PM_{2.5}$ pollution climate mapping model data from 2014 are also available[15], this uses the UK model, see Figure 2-3.

Figure 2-2: Background and roadside PM_{10} modelled and mapped using a Scotland specific model



[14] Lingard, J. and Morris, R. (2013) *Scottish Air Quality Maps - Pollutant modelling for 2011 and projected concentrations for 2015, 2020, 2025 and 2030: annual mean NOx, NO2 and PM10*, Scottish Government. Available at: http://www.scottishairquality.co.uk/assets/documents/reports2/ScottishAQmapping2012_final.pdf.
[15] Defra (2015) *UK Ambient Air Quality Interactive Map - Defra, UK*: Department for Environment, Food and Rural Affairs (Defra), Nobel House, 17 Smith Square, London SW1P 3JR helpline@defra.gsi.gov.uk. Available at: http://uk-air.defra.gov.uk/data/gis-mapping (Accessed: 09/11/15.

Figure 2-3: Background $PM_{2.5}$ and PM_{10} annual mean modelled maps for the UK



2.3 The Ratio of $PM_{2.5}$ to PM_{10}

One of the aims of this study is to investigate whether the ratio of these two particulate metrics can be used to determine $PM_{2.5}$ from PM_{10} SAQD data thus providing significantly more data for assessment of compliance with the $PM_{2.5}$ Objective. Thus to understand the likely implication of changes in the objectives, the measurement of ratio of $PM_{2.5}/PM_{10}$ from this study, as well as current and previous concentration measurements were assessed.

The annual mean $PM_{2.5}/PM_{10}$ ratios calculated for nine sites across Scotland for the years 2009 to 2014 are shown in Table 2-4. (*These data have been previously published in the Scottish Air Quality Database Annual Report for 2014*[13]*.*) The highest $PM_{2.5}/PM_{10}$ ratios during 2014 for sites with greater than 75% data capture was calculated at Auchencorth Moss with a calculated ratio of 0.88. The average in 2014 for all sites was 0.67, whilst for 6 years shown was 0.64[13]. A study from 2007[16] showed similar results, though the equipment used daily gravimetric collection at five sites, the ratio was 0.65 during the collection period (see Table 2-5).

[16] Stevenson, K., Kent, A., Maggs, R. and Harrison, D. (2009) *Measurement of PM10 and PM2. 5 in Scotland with gravimetric samplers*. Available at: http://www.scottishairquality.co.uk/assets/documents/reports2/242090615_Scottish_Partisol_Report_Issue_1_12-06-09.pdf.

Table 2-4: Results from SAQD monitoring sites for annual average $PM_{2.5}$ and PM_{10} means, data capture and respective annual average mean $PM_{2.5}/PM_{10}$ ratios, and $PM_{2.5}/PM_{10}$ ratios and data capture for proceeding years.[13]

Site Name	Annual Mean PM_{10} 2014 (mg m^{-3})	Annual mean $PM_{2.5}$ 2014 (mg m^{-3})	Ratios 2009	2010	2011	2012	2013	2014	Mean
Aberdeen Errol Place	15	10	0.47	0.54	0.57	0.75	0.69	0.67	**0.62**
Aberdeen Union Street	18	13	-	-	-	-	-	0.72	**0.72**
Auchencorth Moss (Partisol - Measured Daily)	7	4	0.64	0.50	0.71	0.57	0.57	0.57	**0.59**
Auchencorth Moss	8	7	0.51	0.57	0.50	0.57	0.50	0.88	**0.59**
Edinburgh St Leonards	13	9	0.50	0.64	0.80	0.69	0.57	0.69	**0.65**
Glasgow Kerbside	22	16	0.46	0.52	0.59	0.63	0.70	0.73	**0.61**
Glasgow Centre	13	7	0.81	0.79	1.22	0.83			**0.91**
Glasgow Townhead	13	7					0.50	0.54	**0.52**
Grangemouth	12	8	0.68	0.79	0.79	0.79	0.64	0.67	**0.73**
Inverness (Partisol - Measured Daily)	11	6	0.55	0.50	0.50	0.55	0.50	0.55	**0.53**
Averages	**13**	**9**	**0.58**	**0.61**	**0.71**	**0.67**	**0.58**	**0.67**	**0.64**

Shaded sites indicate data only available for part year and/or <75% data capture

Table 2-5: Annual average mean $PM_{2.5}/PM_{10}$ ratios for 2007 using a gravimetric method

Site Name	Ratio: Annual Period	Ratio: Calendar Year 2007
Inverness	0.69	0.64
Fort William	0.64	0.71
Bush Estate	0.67	0.62
Eskdalemuir	0.67	0.67
Dumfries	0.6	0.67
Averages	0.65	0.66

Ratios within Europe have been typically reported as between 0.6 and 0.7[17]. Ratios across the world vary and may depend in part upon how developed a country is, the transportation within the country, and the climate/location[18] (see Table 2-6). Hence it can be seen that typically ratios within Scotland are within the typical range for Europe.

[17] Querol, X., Alastuey, A., Rosa, J. d. l., Sánchez-de-la-Campa, A., Plana, F. and Ruiz, C. R. (2002) 'Source apportionment analysis of atmospheric particulates in an industrialised urban site in southwestern Spain', *Atmospheric Environment,* 36(19), pp. 3113-3125.
[18] Khodeir, M., Shamy, M., Alghamdi, M., Zhong, M., Sun, H., Costa, M., Chen, L.-C. and Maciejczyk, P. (2012) 'Source Apportionment and Elemental Composition of PM2.5 and PM10 in Jeddah City, Saudi Arabia', *Atmospheric pollution research,* 3(3), pp. 331-340.

Table 2-6: Comparative concentrations of PM (μg m^{-3}), and $PM_{2.5}/PM_{10}$ ratio[18]

Country	Site	PM2.5	PM10	PM2.5/PM10
Saudia Arabia	Jeddah	28.4	87.3	0.33
	Central EU	22–39	30–53	
European Union	Northern EU	13–19	26–51	0.6–0.7
	Southern EU	28–35	45–55	
Spain	Barcelona	25, 27	39, 43	0.64, 0.62
	Tarragona	22.2	37.4	0.59
	Eastern Spain	33.9	50	0.69
	Navarra	17.4	28	0.63
Greece	Athens	40.2	76	0.53
	Finokalia	18.2	31	0.63
Italy	Milan	45	63	0.71
Turkey	Izmir (urban)	64	80	0.80
Egypt	Cairo	86	184	0.47
Lebanon	Beirut	28, 39	87, 104	0.32, 0.37
China	Hong Kong	42	80	0.53
Korea	Seoul	49	51	0.98
India	Hyderabad City	50	135	0.37

2.3.1 Variation in $PM_{2.5}/PM_{10}$ Ratio

Ratios decline with increasing distance from the south-east of England, which is primarily with secondary PM being more significant in the $PM_{2.5}$ fraction, attributed both to sources from the SE of the UK (England) and Europe (see Figure 2-4). With ratios in the south-east being approximately 0.8 within 100 km of Dover, whereas being less than 0.6 more than 600 km from Dover (data from 2009 and 2010)[19].

The ratio has also been seen to be overall lower at the roadside sites, the prominence of particulate matter between $PM_{2.5}$ to PM_{10} is thought to be contributory[19]. This isn't necessarily evident for sites within Scotland during the 2007 survey using Partisol instruments (a type of gravimetric sampler), where ratios at one suburban site and two rural sites were 0.71, 0.62 and 0.67 respectively, while those for two roadside sites were 0.64 and 0.67[16]. Similarly this isn't evident the annual means (Table 2-4) for suburban/rural sites from 2009-2014 which have ratios of 0.62, 0.59, 0.59, 0.65, 0.78 compared to roadside/kerbside site ratios of 0.72 and 0.61.

The average monthly ratio has been shown to vary throughout the year, this is primarily due to increased $PM_{2.5}$ concentrations in the winter months[20]: "*patterns seen relate to greater emissions of both primary PM and secondary PM precursors during the winter, due to the higher heating load, as well as to the reduced dispersion of local sources during the winter period. It will also relate, in part, to the loss of semi-volatile PM during summer months, which will be less prevalent during winter months"*. Such an increase in $PM_{2.5}$ tends to be proportionally greater than the corresponding PM_{10} concentrations and result in an elevation of the $PM_{2.5}/PM_{10}$ ratio.

Fluctuations of ratios throughout the day, or day on day basis can range from 0.1 to 2.0 or more. This has been seen across a number of sites both rural and urban, see Figure 2-5 for hourly ratios over a 6 day period in 2015 at an urban site.

[19] AQEG (2012) *Fine Particulate Matter ($PM_{2.5}$) in the United Kingdom*: Air Quality Expert Group, for Defra.
[20] Monks, P., Carruthers, D., Carslaw, D., Dore, C., Harrison, R., Heal, M., Jenkin, M., Lewis, A., Stedman, J. and Tomlin, A. (2015) 'Mitigation of United Kingdom PM2. 5 Concentrations'. Page 50

Figure 2-4: Decline in $PM_{2.5}/PM_{10}$ ratio from SE of England

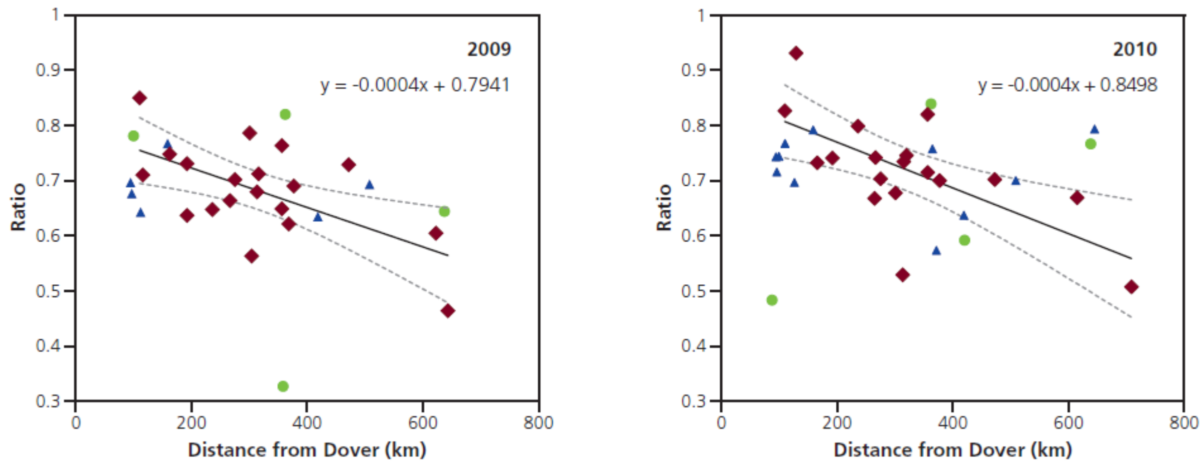
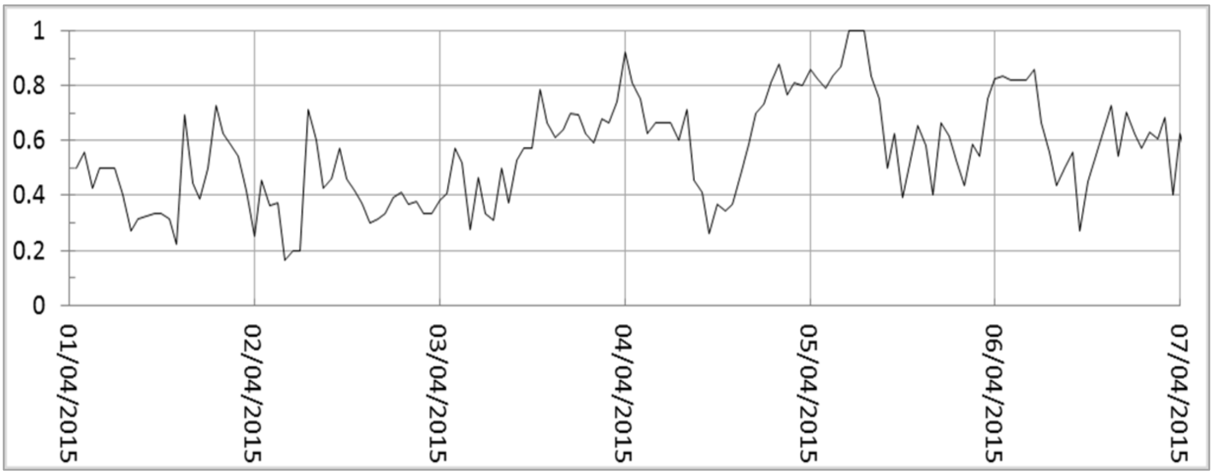


Figure 2-5: Hourly $PM_{2.5}/PM_{10}$ ratios from Aberdeen Union St



3 Methodology

3.1 Approach

This study used data from three sources:

1. Fixed SAQD monitoring sites throughout Scotland that measure both $PM_{2.5}$ and PM_{10}, were used to study both concentrations and ratios.
2. Studies using a mobile monitoring platform. Mobile monitoring was undertaken in representative of PM_{10} AQMAs from across Scotland, including selected areas of AQMAs in Aberdeen, West Lothian, South Lanarkshire, North Lanarkshire, East Dunbartonshire and Renfrewshire. The study also included sampling from 2014 as part of the air monitoring at height study. Where the AQMA is focused on a limited area(s) of exceedance, the study maps much of this area. However, for larger AQMAs it was necessary to limit the study to smaller selected areas of each AQMA.
3. Modelled concentrations using a Scotland-specific model.

3.2 Equipment and its use

3.2.1 Fixed (SAQD Network)

Data were gathered from fixed monitoring sites within the SAQD. Fifteen SADQ sites monitor both $PM_{2.5}$ and PM_{10} and were therefore included in this study. Data from these sites are publicly available online, via the Scottish Air Quality Website at http://www.scottishairquality.co.uk/ .

At one SAQD site, Glasgow Kerbside, the mobile monitoring platform was co-located in order to compare its performance with that of the fixed instrumentation. (See Table 3-1, Table 3-2 and Table 3-3 for instrument locations, types and dates data used).

The instrument (analyser) types used across the SAQD to measure $PM_{2.5}$ and PM_{10} are as follows:

- Thermo Scientific TEOM FDMS (various models), measures either $PM_{2.5}$ or PM_{10} as a single channel instrument, or both $PM_{2.5}$ and PM_{10} as a dual channel instrument. The instrument utilizes a tapered element oscillating microbalance (TEOM) and Filter Dynamics Measurement System (FDMS) to provide measurements with of short-term precision and account for volatile and non-volatile PM[21].
- Thermo Scientific Partisol, measures either $PM_{2.5}$ or PM_{10} as a single channel instrument. The instrument utilizes a filters to gravimetrically collect PM, and has 16 filter cassettes, allowing for two weeks of unattended daily-sampling of particulate matter[22].
- Palas FIDAS, measures $PM_{2.5}$ and PM_{10} continuously as well as other PM fractions and particulates. The instrument utilizes a white light LED source to measure optical light scattering of single particles to measure both size and number of particles[23].

3.2.2 Mobile

PM_{10} and $PM_{2.5}$ were measured using a Lighthouse IAQ 3016[24] PM analyser, a light based (optical) particulate sampler. This was either conveyed (as part of a separate experiment)[25] on a purpose-built trolley (see Figure 3-1a), or (for the 2015 experiments) carried in a backpack with an external battery and air sampling tube. (See Figure 3-1b, which shows the purpose-built backpack with other instruments included.) GPS measurements and the respective time stamp were taken using a Garmin Etrex, Garmin 110 watch or using an iPhone GPS and Strava (see Table 3-4 for study areas and dates),

[21] Thermo Scientific (2016a) *1405-F TEOM™ Continuous Ambient Air Monitor*. Available at: http://www.thermoscientific.com/content/tfs/en/product/1405-f-teom-continuous-ambient-air-monitor.html (Accessed: 3/3/16.
[22] Thermo Scientific (2016b) *Partisol™ 2025i Sequential Air Sampler*. Available at: http://www.thermoscientific.com/en/product/partisol-2025i-sequential-air-sampler.html.
[23] Palas GmbH (2016) *Fidas ® 200 - Product Lines - Palas*. Available at: http://www.palas.de/en/product/fidas200 (Accessed: 22/1/16.
[24] Lighthouse (2015) *Handheld Particle Counters*. Available at: http://www.golighthouse.com/particle-counting-type/handheld-airborne-particle-counters/ (Accessed: 17/11/15.
[25] Stratton, S., Hector, D., Sykes, D., Stacey, B. and Sneddon, S. (2015) *Air Quality Study - Scotland: Assessing variations in roadside air quality with sampling height (CR/2013/10)*, Scottish Government: Ricardo-AEA Ltd.

also see Figure A4-1 to Figure A4-16 in the appendix for mobile route details. This allowed each PM measurement to be linked to a specific time and place.

Table 3-1: SAQD monitoring sites in 2014 for $PM_{2.5}$ and PM_{10} (further details about site location and type is in appendices, Table A5)

Monitoring Site	Instrument Type(s)	Dates in Service*	
Aberdeen Errol Place	FDMS	01/01/2014	31/12/2014
Aberdeen Union St	FIDAS	24/12/2014	31/12/2014
Auchencorth Moss	FDMS / Partisol	01/01/2014	31/12/2014
Edinburgh St Leonards	FDMS	01/01/2014	31/12/2014
Glasgow Kerbside	FDMS	01/01/2014	31/12/2014
Glasgow Townhead	FDMS	01/01/2014	31/12/2014
Grangemouth	FDMS	01/01/2014	31/12/2014
Inverness	Partisol	01/01/2014	31/12/2014

* Indicates instrument in place though not necessarily operational throughout

Table 3-2: SAQD monitoring sites in 2015 for $PM_{2.5}$ and PM_{10} (further details about site location and type is in appendices, Table A5)

Monitoring Site	Instrument Type(s)	Dates in Service*	
Aberdeen Errol Place	FDMS	01/01/2015	31/12/2015
Aberdeen Market St 2	FIDAS	30/09/2015	31/12/2015
Aberdeen Union St	FIDAS	01/01/2015	31/12/2015
Auchencorth Moss	FDMS / Partisol	01/01/2015	31/12/2015
Edinburgh St Leonards	FDMS	01/01/2015	31/12/2015
Glasgow High St	FDMS	27/01/2015	31/12/2015
Glasgow Townhead	FDMS	01/01/2015	31/12/2015
Grangemouth	FDMS	01/01/2015	31/12/2015
Falkirk Banknock	FIDAS	28/01/2015	31/12/2015
Fife Rosyth	FIDAS	21/07/2015	31/12/2015
Inverness	Partisol	01/01/2015	31/12/2015
North Ayrshire Irvine High St	FIDAS	16/04/2015	31/12/2015
South Lanarkshire Lanark	FIDAS	10/04/2015	31/12/2015
South Lanarkshire Uddingston	FIDAS	01/03/2015	31/12/2015
West Dunbartonshire Clydebank	FIDAS	13/03/2015	31/12/2015

* Indicates instrument in place though not necessarily operational throughout

Table 3-3: Co-location sites & dates in 2014

Co-location Site	When
Glasgow Kerbside	15/04/2014
Glasgow Kerbside	25/04/2014
Glasgow Kerbside	19/06/2014
Glasgow Kerbside	17/07/2014
Glasgow Kerbside	13/08/2014
Glasgow Kerbside	27/08/2014

Figure 3-1 a&b: a) Trolley containing air sampling instruments, including Lighthouse IAQ 3016 b) Purpose-built backpack , including Lighthouse IAQ 3016

Table 3-4: Mobile monitoring areas & dates for studies in 2014 & 2015 (see Figure A4-1 to Figure A4-16 in the appendix for mobile route details)

Mobile Sample Area	When
Glasgow City Centre	8 days in 2014
Rosyth	21/03/2014
Dunfermline	24/03/2014
Cupar	25/03/2014
Kirkcaldy	27/03/2014
Perth Central	23/05/2014
Perth Central	24/05/2014
Crieff	27/05/2014
Perth Glasgow Rd	29/05/2014
Perth Blackford	30/05/2014
Perth Crieff Rd	03/06/2014
Paisley	18/09/2015
Bearsden	25/09/2015
Edinburgh	02/10/2015
Aberdeen	14/10/2015
Broxburn	27/10/2015
East Kilbride	26/11/2015

3.3 Data Gathering

3.3.1 SAQD Fixed Monitor Data

Where possible, ratified* data were either taken directly from the Air Quality in Scotland website[26], or from proprietary data processing systems Ricardo Energy & Environment has access to in-house.

** Data from the SAQD are ratified in quarterly batches in arrears. Because of the timing of the study, some of the data uses had not undergone the full ratification process. Ratified data were available for at least the first 6 months of the 2015. Some data from the latter part of the year were still provisional at the time of writing but this is not expected to substantially affect the outcome or results from the study.*

3.3.2 Pollution Climate Mapping Data

Two sets of data were downloaded:

i. $PM_{2.5}$ and PM_{10} concentration for each 1 km^2 for the entire country for 2011 through to 2030[27].
ii. Mean $PM_{2.5}$ and PM_{10} concentration for each local authority area for 2014[28].

[26] Air Quality in Scotland (2015a) *Data Selector - Air Quality in Scotland*. Available at: http://www.scottishairquality.co.uk/data/data-selector (Accessed: 17/11/15.
[27] Defra (2014) *Background Mapping data for local authorities - 2011 - Defra, UK*: Department for Environment, Food and Rural Affairs (Defra), Nobel House, 17 Smith Square, London SW1P 3JR helpline@defra.gsi.gov.uk. Available at: http://uk-air.defra.gov.uk/data/laqm-background-maps.
[28] Defra (2015) *UK Ambient Air Quality Interactive Map - Defra, UK*: Department for Environment, Food and Rural Affairs (Defra), Nobel House, 17 Smith Square, London SW1P 3JR helpline@defra.gsi.gov.uk. Available at: http://uk-air.defra.gov.uk/data/gis-mapping (Accessed: 09/11/15.

3.3.3 Mobile Monitoring Data

3.3.3.1 Study Data

Data were gathered during day-long studies (normally 6 hours or longer) using the Lighthouse instrument on set-routes (see above for details of routes and dates of study).

3.3.3.2 Co-location or Local SAQD Site Data

i. Ratified co-location data were gathered during day-long studies (normally 6 hours or longer) using the Lighthouse instrument placed on top of an SAQD fixed monitoring site next to the instrument inlets. Data for the SAQD instrument were taken directly from the Air Quality in Scotland website[26], or from Ricardo Energy & Environment's proprietary data handling systems.

ii. For mobile monitoring studies where there was no local SAQD fixed monitoring site or where the Lighthouse measurements gathered were affected by the weather or some other factor, then data from one or more of the closest SAQD instrument(s), for the day and time of the study was used. The data were either taken directly from the Air Quality in Scotland website[26], or from Ricardo Energy & Environment's proprietary data handling systems.

3.3.4 AQMAs and AQAPs

Information and data were taken from the Air Quality for Scotland website[29] about Air Quality Management Areas and Action Plans. This information and data were assessed to determine the effect of the proposed changes on these plans.

3.4 Data Analysis

3.4.1 Concentrations from SAQD Fixed Monitoring, PCM or Mobile Monitoring data

Simple statistics (mean, median, min, max or SD) were calculated using Microsoft Excel.

3.4.2 Ratios from SAQD fixed monitor data

The PM for different sites across Scotland for both $PM_{2.5}$ and PM_{10} was calculated. The PM ratio taken from the date on the SAQD sites was developed using three different methods.

3.4.2.1 Linear regression to fit a linear relationship of the form y = mx + c

The approach used here was to use linear regression to fit a linear relationship of the form ***y = mx + c*** (where ***m*** is the slope and ***c*** the y intercept) to the full hourly or daily dataset from relevant each site, for years 2009-2015.

The following SAQD sites were included. Most have measured both PM_{10} and $PM_{2.5}$ using the FDMS since this instrument first came into use in 2008 or 2009:

- Aberdeen Errol Place (urban background), 2009 - 2015
- Auchencorth Moss (rural), 2009 – 2015. This site measured both $PM_{2.5}$ and PM_{10} using co-located pairs of FDMS and gravimetric Partisol instruments. In this part of the study the hourly datasets from the FDMS instruments were used. (The Partisols produce only daily means).
- Edinburgh St Leonards (urban background), 2009 - 2015
- Glasgow Centre, (urban background) 2009 – 2012, December data removed (see below).
- Glasgow Kerbside (urban traffic) 2009 - 2014
- Glasgow Townhead (urban traffic) 2013 – 2015
- Grangemouth (urban industrial), 2009 – 2015.
- Inverness (urban traffic) 2009 – 2015, daily data only using Partisol gravimetric instrument.

[29] Air Quality in Scotland (2016) *Air Quality Management Areas - Air Quality in Scotland*. Available at: http://www.scottishairquality.co.uk/laqm/aqma (Accessed: 10/8/16.

The scatter plots were prepared using Openair: a free, open-source software package of tools for analysis of air pollution data. Openair was developed by King's College London with the University of Leeds. A range of Openair tools are available on the "Air Quality in Scotland" website: for more information on the tools and how to use them, please see:

http://www.scottishairquality.co.uk/openair/openair.php

3.4.2.2 Calculation of point ratio (daily or hourly) & annual mean ratio from this data

The daily or hourly data points for both $PM_{2.5}$ and PM_{10} for each SAQD monitoring site were taken from Air Quality in Scotland website[26] or from Ricardo Energy & Environment's proprietary data processing system. The ratio for each pair of data points was calculated by dividing the data point for $PM_{2.5}$ by PM_{10}, however if no data for either point was available or problems with the data was notice, this pair of points was excluded from the calculations.

The annual mean ratio was calculated from the average of the ratios calculated in the above manner. The number of data points and the possible percentage of total data capture was shown for each year and site using this methodology.

3.4.2.3 Calculation of monthly mean ratio & annual mean ratio from this data

The monthly mean for both $PM_{2.5}$ and PM_{10} for each SAQD monitoring site was taken from Air Quality in Scotland website[26], as well as the data capture rates. The monthly mean ratio was calculated by dividing the monthly mean for $PM_{2.5}$ by PM_{10}.

The annual mean ratio was calculated from the average of the monthly ratios. If the data capture rate was below 75% this was removed from calculations, as this was seen to affect the overall result.

3.4.3 PCM Data

3.4.3.1 Annual mean from modelled PCM 1 km squares

The annual mean concentration for both $PM_{2.5}$ and PM_{10} from modelled PCM 1 km squares was taken from the background maps and the annual mean ratio calculated by dividing annual mean $PM_{2.5}$ by PM_{10}.

3.4.3.2 Annual mean from each local authority

The annual mean concentration for both $PM_{2.5}$ and PM_{10} from modelled PCM for each of Scotland's Local Authorities was taken from the background maps and the annual mean ratio calculated by dividing annual mean for $PM_{2.5}$ by PM_{10}.

3.4.4 Mobile Monitoring Data

Data were downloaded from the Lighthouse instrument using the proprietary software (LMS Xchange V1.6).[24] A Grubbs' test for outliers was performed on each dataset to remove any extraneous data points. GPX files were downloaded from the GPS device.

It was necessary to ensure the data downloaded from the instrument (raw data) was adjusted, as it was noted during experiments that the Lighthouse instrument despite being calibrated, was sensitive to a number of sources of interference, especially relative humidity. Thus raw data was treated with a bias adjustment, much like NO_2 diffusion tubes. There were two methods of adjustment used.

3.4.4.1 Co-location/local data

i. Co-location plots: Hourly mean $PM_{2.5}$ & PM_{10} concentrations measured at the fixed monitoring site (detailed in Section 3.2) were plotted against the mean of data points taken from the Lighthouse instrument. Residual plots were performed; any points with a residual greater than two-standard deviations or out with of 95% of a normal distribution was removed. Orthogonal regression plots were then performed, and any further data points that were deemed to be erroneous were also removed. The slope, intercept & regression was then calculated. This method was used only for Glasgow based data from the 2014 study, not enough data were gathered during collocation studies conducted from other locations, thus the local adjustment factors were used for all other datasets.

ii. Local data adjustment factors: An average of the hourly mean $PM_{2.5}$ & PM_{10} concentrations measured at the fixed monitoring sites (detailed in Section 3.2) for the day and time period of the study, were compared against the mean $PM_{2.5}$ & PM_{10} concentrations taken from the Lighthouse instrument. The adjustment factors for both $PM_{2.5}$ & PM_{10} were then calculated.

3.4.4.2 Adjustment of raw study data

i. Using the slope & intercept from the orthogonal regression plots for the co-location, the study data were adjusted to give a corrected $PM_{2.5}$ & PM_{10} concentrations.

ii. Or using the calculated factor, the study data were adjusted to give a corrected $PM_{2.5}$ & PM_{10} concentrations.

3.4.4.3 Data point mean

The ratio for each pair of data points was calculated by dividing the data point for $PM_{2.5}$ by PM_{10}, however if no data for either point was available or problems with the data was notice, this pair of points was excluded from the calculations.

The day mean ratio was calculated from the average of the ratios calculated in the above manner. The number of data points and the possible percentage of total data capture was shown for each study.

3.4.4.4 Number of data points used

The number of data point pairs used was calculated using count() function in Excel.

4 Results and Discussion Part 1: Impact of Changing PM Objectives

4.1 SAQD Particulate Matter Concentration

4.1.1 Long-term PM Concentration for Selected SAQD Sites

The average annual mean concentrations for both $PM_{2.5}$ & PM_{10} can be seen to decline across a selected number of sites in Scotland (see Table 4-1). The 2015 $PM_{2.5}$ & PM_{10} concentrations exhibit the lowest annual mean for a number of years.

However, the trends individual sites vary (see Figure 4-1 & Figure 4-2): Glasgow Kerbside has a highly significant decline for both $PM_{2.5}$ and PM_{10}, whereas Edinburgh shows a less significant decline. (See note under graph relating to statistical significance.) Auchencorth Moss shows a small but significant increase in $PM_{2.5}$ and PM_{10}, whereas the other sites show no significant trend.

Table 4-1: Average annual mean $PM_{2.5}$ & PM_{10} concentrations (µg m^{-3}) from selected SAQD monitoring sites in Scotland

		2008	2009	2010	2011	2012	2013	2014	2015	Mean
Aberdeen Errol Place	$PM_{2.5}$	3	7	7	8	9	9	10	8	**8**
	PM_{10}	16	15	13	14	12	13	15	12	**14**
Auchencorth Moss	$PM_{2.5}$	10	3	4	4	4	4	7	3	**5**
	PM_{10}	7	7	7	7	7	8	8	8	**7**
Edinburgh St Leonards	$PM_{2.5}$	14	8	9	12	11	8	9	6	**10**
	PM_{10}	15	18	14	15	16	14	13	14	**15**
Glasgow Kerbside	$PM_{2.5}$		20	23	22	20	16			**20**
	PM_{10}	27	26	29		24	23	22		**25**
Glasgow High St	$PM_{2.5}$								9	**9**
	PM_{10}								16	**16**
Glasgow Centre	$PM_{2.5}$	18	12	12	10	10	16			**13**
	PM_{10}	27	26	29			23			**26**
Glasgow Townhead	$PM_{2.5}$							7	7	**7**
	PM_{10}							13	12	**13**
Grangemouth	$PM_{2.5}$	15	9	11	11	11	9	8	9	**10**
	PM_{10}	15	13	14	14	14	14			**14**
Average annual mean concentration	**$PM_{2.5}$**	**12**	**10**	**11**	**11**	**11**	**10**	**8**	**7**	**10**
	PM_{10}	**18**	**17**	**18**	**13**	**15**	**16**	**14**	**12**	**15**

Shaded sites indicate data available for part year or <75% data capture. Dataset provisional for 2015 as not fully ratified

Figure 4-1: Trend plots showing mean $PM_{2.5}$ concentrations (μg m^{-3}) from selected SAQD monitoring sites.

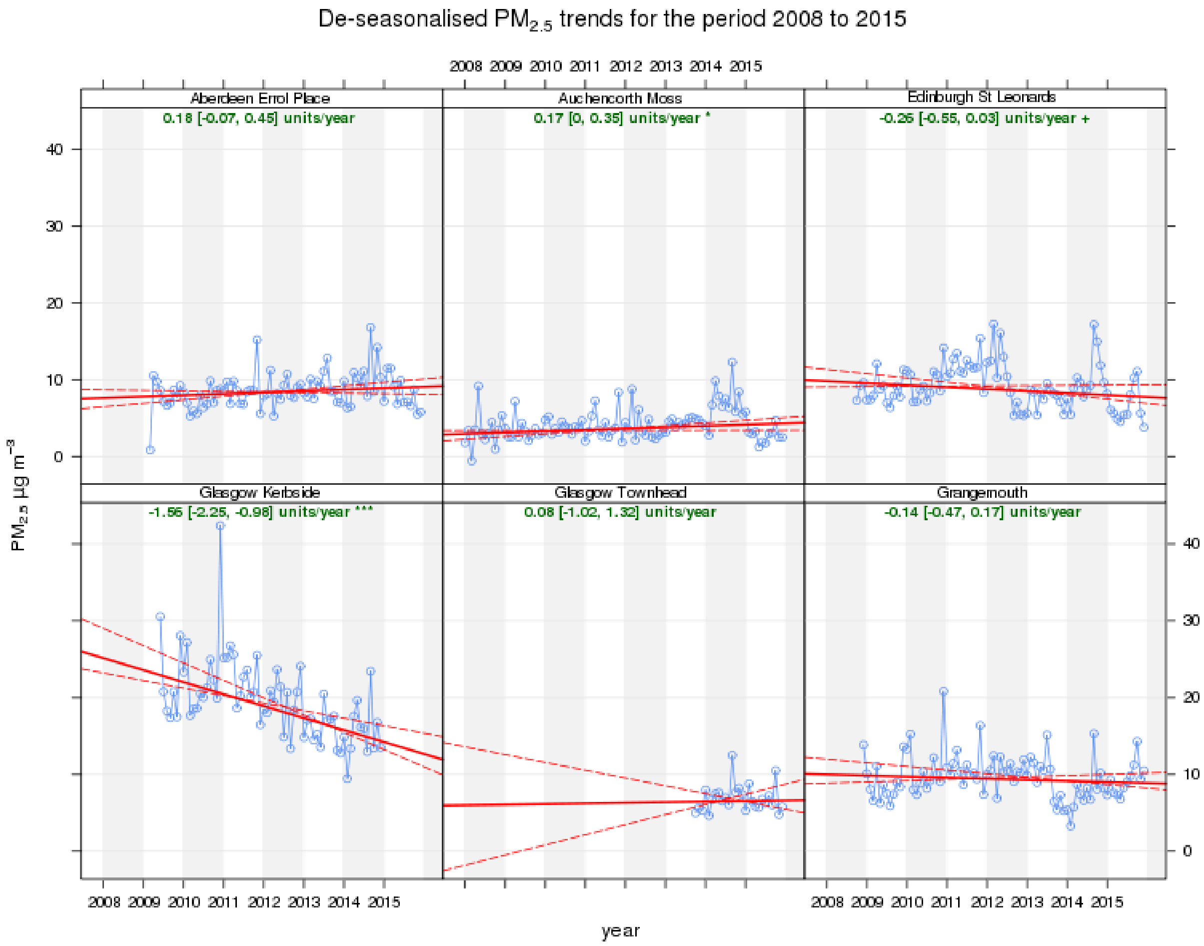
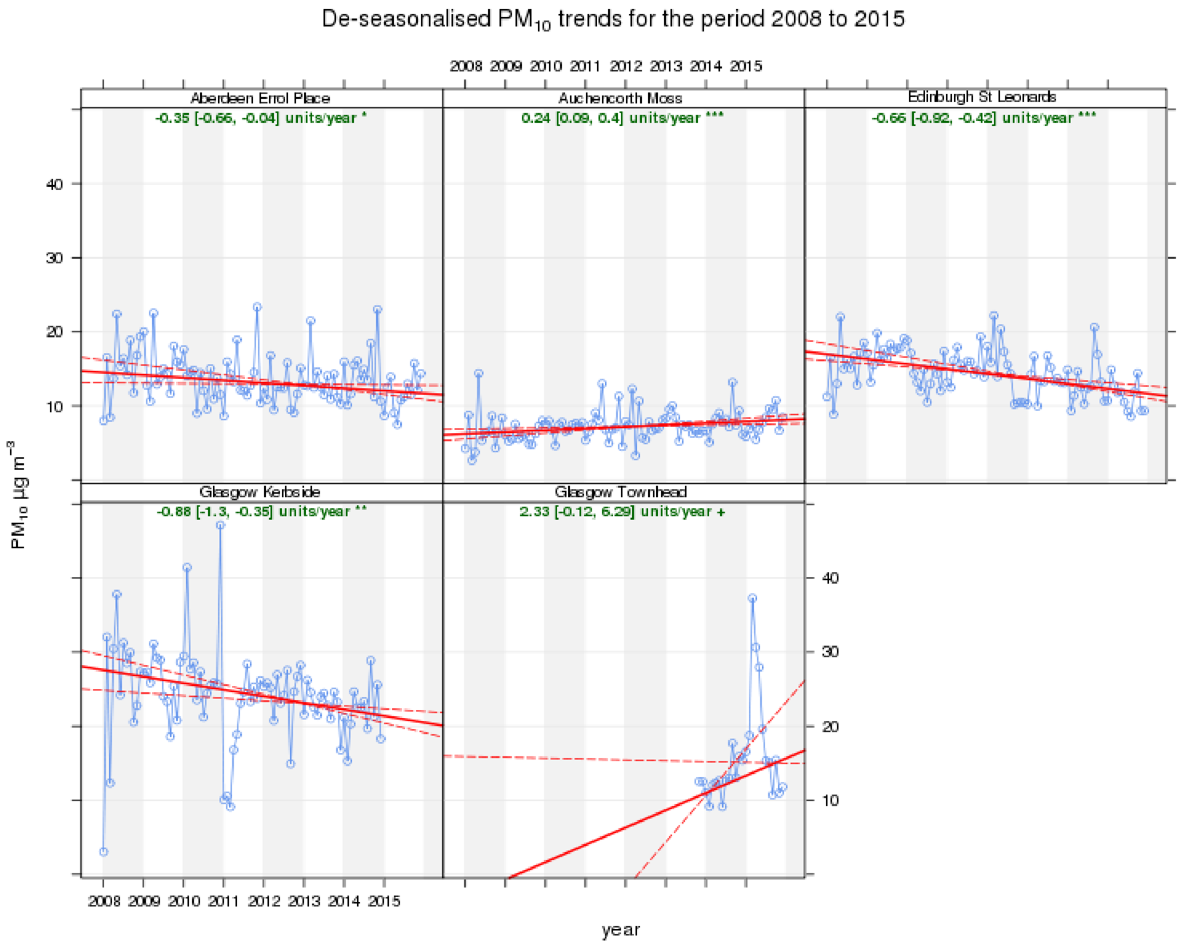


Figure 4-2: Trend plots showing mean PM_{10} concentrations (µg m^{-3}) from selected SAQD monitoring sites.



<u>Notes relating to Openair trend plots:</u> The solid red line shows the trend estimate and the dashed red lines show the 95 % confidence intervals. The figures at the top of each graph represent the overall trend (µg m^{-3}/year), and the [95 % confidence intervals] in the slope (µg/year). The symbols shown next to each trend estimate relate to how statistically significant the trend estimate is: $p < 0.001 = ***$, $p < 0.01 = **$, $p < 0.05 = *$ and $p < 0.1 = +$.

4.1.2 Overall Annual PM Concentration for SAQD Sites in 2014 & 2015

The average annual mean PM_{10} concentration for 77 SAQD monitoring sites in 2014 was 15.1 µg m^{-3}, whereas for 2015 for 75 sites this was slightly lower at 14.8. For $PM_{2.5}$ the concentrations were 9.1 and 7.3, for nine and fourteen sites for 2014 and 2015 respectively (see Table 4-2, also see Table A5 in Appendix for information about sites).

Table 4-2: Average annual mean PM concentrations (µg m^{-3}) and site number from both 2014 & 2015 from different types of SAQD monitoring sites

	Roadside / Kerbside		Urban Background		Urban Industrial		Rural		Overall Mean	
	(µg m^{-3})	n =	(µg m^{-3})	n =	(µg m^{-3})	n =	(µg m^{-3})	n =	(µg m^{-3})	n =
Annual Mean $PM_{2.5}$ for 2014	12.0	3	9.0	3	8.0	1	5.5	2	**9.1**	**9**
Annual Mean $PM_{2.5}$ for 2015	7.3	9	7.5	3	9.3	1	4.9	1	**7.3**	**14**
Annual Mean PM_{10} for 2014	15.7	62	14.0	11	12.0	1	9.0	3	**15.1**	**77**
Annual Mean PM_{10} for 2015	15.3	63	12.4	9	12.5	1	10.3	2	**14.8**	**75**

Dataset provisional for 2015 due to it not being fully ratified

4.1.3 Exceedances Using SAQD Data

At the time of reporting (with non-ratified data) 11 sites would have exceeded the annual average PM_{10} objective of 18 µg m^{-3}, with the maximum concentration of 22.7 µg m^{-3}. No sites exceeded the Scottish AQS $PM_{2.5}$ objective of 12 µg m^{-3} in 2015, this is an improvement over the previous year.

As discussed previously, the WHO guideline[9] for PM_{10} and $PM_{2.5}$ concentrations of 20 µg m^{-3} and 10 µg m^{-3} respectively as annual means are similar to the Scottish objectives of 18 & 12 µg m^{-3}.

Data gathered for this and other reports for PM_{10} concentrations indicates that a number of SAQD monitoring sites and associated AQMAs would exceed the 18 µg m^{-3} objective (nineteen for 2014 and eleven for 2015). This number would be reduce to just six and three exceedances if the objective was raised to 20 µg m^{-3}, in 2014 & 2015 respectively (see Table 4-3). This would be reversed for $PM_{2.5}$ with the number of exceedances increasing slightly if the AQ objective was lowered.

Table 4-3: Exceedances for 2014 & 2015 of AQ objectives and with changes to proposed changes to objectives

	2014	2015
Exceedances $PM_{2.5}$ @ 12 µg m^{-3}	3	0
Exceedances $PM_{2.5}$ @ 10 µg m^{-3}	3	1
Exceedances PM_{10} @ 18 µg m^{-3}	19	11
Exceedances PM_{10} @ 20 µg m^{-3}	6	3

Dataset provisional for 2015 due to it not being fully ratified

4.2 Pollution Concentration Mapping (PCM) for Particulate Matter

4.2.1 PCM Annual $PM_{2.5}$ & PM_{10} Concentrations

The PCM mean for each individual mapped km square of PM_{10} concentrations in Scotland for 2014 was 9.3 µg m^{-3}, whereas the mean for $PM_{2.5}$ was 5.9 µg m^{-3}, with the maxima and minima also described in Table 4-4. PM over the next 25 years is predicted to decrease by ~5% (see Table 4-5). The local authority annual mean concentrations were also largely dependent upon population density (see Table 4-6).

Table 4-4: PCM annual $PM_{2.5}$ & PM_{10} concentrations (µg m^{-3}) from 2014 PCM data[27]

	$PM_{2.5}$	PM_{10}
PCM annual max	11.8	20.5
PCM annual min	4.6	6.6
PCM annual mean	5.9	9.3

Table 4-5: PCM annual $PM_{2.5}$ & PM_{10} concentrations (µg m^{-3}) from 2011-2030 PCM data[27]

	2011	2012	2013	2014	2015	2020	2025	2030
$PM_{2.5}$	6.14	6.08	6.03	5.97	5.92	5.73	5.61	5.62
PM_{10}	9.48	9.41	9.35	9.29	9.23	9.00	8.87	8.89

Table 4-6: PCM annual mean $PM_{2.5}$ & PM_{10} concentrations (µg m^{-3}) from 2014 PCM data for local authority areas[28]

Local Authority	Population	LA size (Km^2)	Pop. Density (People Km^{-2})	$PM_{2.5}$	PM_{10}
City of Glasgow	599650	175	3427	8.25	11.53
City of Dundee	148260	60	2471	7.86	11.38
City of Edinburgh	492680	264	1866	8.45	12.35
City of Aberdeen	228990	186	1231	8.20	12.52
North Lanarkshire	337950	470	719	7.44	10.54
Renfrewshire	174230	261	668	6.43	9.03
East Dunbartonshire	106730	175	610	6.79	9.40
West Dunbartonshire	89730	159	564	6.13	8.46
East Renfrewshire	92380	174	531	6.44	9.01
Falkirk	157640	297	531	7.76	11.07
Inverclyde	79860	160	499	5.66	7.79
West Lothian	177150	427	415	7.64	11.48
Clackmannanshire	51190	159	322	6.89	9.81
Fife	367260	1325	277	7.70	11.40
Midlothian	86210	354	244	7.47	10.61
South Lanarkshire	315360	1772	178	6.61	9.07
North Ayrshire	136450	885	154	5.61	7.82
East Lothian	102050	679	150	7.68	11.19
East Ayrshire	122150	1262	97	6.21	8.56
South Ayrshire	112510	1222	92	6.02	8.33
Angus	116660	2182	53	7.03	10.40
Moray	94750	2238	42	5.72	8.11
Stirling	91580	2187	42	5.42	7.44
Aberdeenshire	260500	6313	41	6.94	10.56
Perth and Kinross	148880	5286	28	5.65	8.00
Scottish Borders	114030	4732	24	6.88	9.64
Dumfries and Galloway	149940	6426	23	6.15	8.45
Orkney Islands	21590	990	22	5.62	9.39
Shetland Islands	23230	1466	16	6.23	11.46
Argyll and Bute	87660	6909	13	4.98	6.87
Highland	233100	25659	9	4.67	6.87
Na h-Eileanan Siar (Western Isles)	27250	3071	9	4.39	6.72
			Mean	6.59	9.54
			SD	1.07	1.67
			Min	4.39	6.72
			Max	8.45	12.52

4.2.2 Exceedances Using PCM Data

No local authority's PM annual mean data exceeded either the objectives as they stand or the potential modified objectives. Individual 1 km squares within some LA areas did exceed these PM objectives (see Table 4-7), and with the objectives brought in line with WHO guidelines the $PM_{2.5}$ exceedances increase significantly from zero to 22 in 2015, however, the number of exceedances is expected to drop six by 2030.

Table 4-7: Exceedances for 2011 – 2030 from 1 km^2 PCM data of AQ objectives with changes to concentrations

	2011	2012	2013	2014	2015	2020	2025	2030
Exceedances $PM_{2.5}$ @ 12µg m^{-3}	3	2	0	0	0	0	0	0
Exceedances $PM_{2.5}$ @ 10µg m^{-3}	79	56	45	34	22	6	6	6
Exceedances PM_{10} @ 18µg m^{-3}	13	8	7	6	2	2	2	2
Exceedances PM_{10} @ 20µg m^{-3}	1	1	1	1	1	0	0	1

4.3 Mobile Monitoring Particulate Matter Concentrations

The average mean concentrations for the mobile monitoring (see Table 4-8) were 10.2 and 21.1 µg m^{-3} for $PM_{2.5}$ & PM_{10} respectively. The data ranged were from 1.7 to 22.4 µg m^{-3} and from 8.4 to 47.2 µg m^{-3} for $PM_{2.5}$ & PM_{10}. These figures are elevated compared to daily means from sites in the SAQD (see Table 4-1); this is probably because the mobile measurements were taken during the daytime, when concentrations are usually higher, while daily means include the night, when concentrations are usually lower.

There would be no exceedances of objectives as these concentrations are below 24 hour WHO guidelines[9] for both $PM_{2.5}$ & PM_{10} (see Table 2-1 above)

Table 4-8: Mean concentration for mobile monitoring period for different local authority areas/cities in Scotland during 2014 and 2015

Mobile Sample Area	When	$PM_{2.5}$ conc	PM_{10} conc
Glasgow City Centre	8 days in 2014	17.3	26.5
Rosyth	21/03/2014	5.7	13.8
Dunfermline	24/03/2014	8.0	19.7
Cupar	25/03/2014	15.7	47.2
Kirkcaldy	27/03/2014	15.2	22.6
Perth Central	23/05/2014	4.1	12.2
Perth Central	24/05/2014	5.1	10.4
Crieff	27/05/2014	13.6	21.4
Perth Glasgow Rd	29/05/2014	10.5	22.7
Perth Blackford	30/05/2014	11.8	21.3
Perth Crieff Rd	03/06/2014	5.8	19.6
Paisley	18/09/2015	4.6	10.8
Bearsden	25/09/2015	6.4	19.5
Edinburgh	02/10/2015	16.8	24.5
Aberdeen	14/10/2015	9.3	21.2
Broxburn	27/10/2015	22.4	37.4
East Kilbride	26/11/2015	1.7	8.4
	Averages	**10.2**	**21.1**

4.4 AQMAs and AQAPs

There are 11 Local Authorities in Scotland with AQMAs[29] (see Figure 4-3) and a total of 21 AQMAs for PM_{10} (see Table 4-9). Of these only four AQMAs have $PM_{2.5}$ monitors. Many are also AQMAs for nitrogen dioxide.

Within these AQMAs there were 9 monitoring sites which reported annual mean PM_{10} concentrations greater than 16 µg m^{-3} in 2014, and six in 2015. If the proposed objective was raised to 20 µg m^{-3}, then the number above 18 µg m^{-3} would be 3 and 1 for 2014 and 2015 respectively.

Figure 4-3: Local Authorities with PM_{10} AQMAs in Scotland[29]

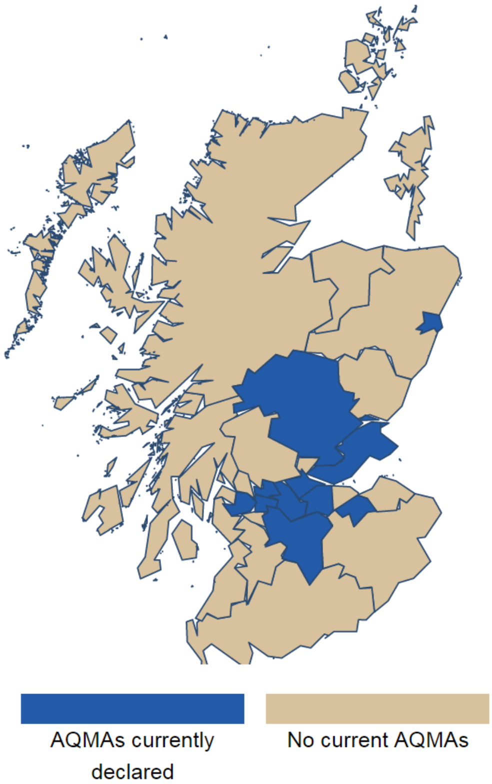


Table 4-9: AQMAs within Scotland for PM_{10}[29]

Local Authority	Area (AQMA)	Other pollutants within AQMA	$PM_{2.5}$ measured?
Aberdeen City Council	City Centre	NO_2	YES x2
Aberdeen City Council	Anderson Drive	NO_2	NO *
Aberdeen City Council	Wellington Road	NO_2	NO *
Dundee City Council	Dundee	NO_2	NO
East Dunbartonshire Council	Kirkintilloch Road	NO_2	NO
East Dunbartonshire Council	A809	NO_2	NO
Falkirk Council	Falkirk Centre	NO_2	NO *
Falkirk Council	Banknock	None	YES
Fife Council	Bonnygate	NO_2	NO *
Glasgow City Council	Glasgow City Centre	NO_2	YES
North Lanarkshire Council	Coatbridge	None	NO
North Lanarkshire Council	Chapelhall	None	NO
North Lanarkshire Council	Motherwell	None	NO
North Lanarkshire Council	Moodiesburn	None	NO
North Lanarkshire Council	Croy	None	NO
Perth & Kinross Council	Perth	NO_2	NO
Perth & Kinross Council	Perth No 2	NO_2	NO
Renfrewshire Council	Paisley Town Centre	NO_2	NO
South Lanarkshire Council	Whirlies Roundabout	None	NO
South Lanarkshire Council	Rutherglen	None	YES
West Lothian Council	West Lothian	NO_2	NO

* PM2.5 within LA but not at this AQMA

Table 4-10: PM_{10} concentrations (those in RED highlighting exceedances of current objective) for 2014 & 2015 within at SAQD PM_{10} sites within Scotland's AQMAs

AQMA	Measured Annual PM_{10} in 2015	Measured Annual PM_{10} in 2014
Aberdeen City City	n/a	**18**
Aberdeen City Anderson Dr	14	15
Aberdeen City Wellington Rd	**22**	**21**
Dundee City	16	**18**
East Dunbart. Kirkintilloch Rd	17	17
East Dunbart. A809	14	14
Falkirk Centre	**18**	16
Falkirk Banknock	11	15
Fife Bonnygate	17	17
Glasgow City Centre	16	n/a
North Lanark. Coatbridge	14	13
North Lanark. Chapelhall	n/a	**19**
North Lanark. Motherwell	n/a	15
North Lanark. Moodiesburn	10	n/a
North Lanark. Croy	14	15
Perth	17	**20**
Perth No 2	14	**14**
Renfrew. Paisley Town	13	15
South Lanark. Whirlies	16	**18**
South Lanark. Rutherglen	**18**	n/a
West Lothian	15	17

Dataset provisional for 2015 due to it not being fully ratified

5 Results and Discussion Part 2: Relationship between $PM_{2.5}$ and PM_{10}

One of the objectives of this study was to investigate the feasibility of using a simple relationship or factor, to allow annual mean $PM_{2.5}$ concentrations to be estimated from annual mean PM_{10}, at sites where only the latter metric is monitored.

In order to be able to do this, we need to establish that:

1. There is a simple linear (or approximately linear) relationship between $PM_{2.5}$ and PM_{10}, and that
2. The relationship is reasonably consistent from site to site.

Sections 5.1 and 5.2 attempt to answer the above questions using data from several SAQD sites at which $PM_{2.5}$ and PM_{10} have been monitored simultaneously, both using the same type of instrument, since 2009.

Section 5.3 and Section 5.4 further explore the relationship between $PM_{2.5}$ and PM_{10} using modelled data from the PCM project, and measurements from the short-term mobile monitoring study. Section 5.5 then applies the findings to PM_{10} data from other SAQD sites and finally Section 5.6 estimates the number of additional exceedances of the current and proposed $PM_{2.5}$ objective that might result from applying this approach.

5.1 Comparison of Hourly PM_{10} and $PM_{2.5}$ Data from SAQD sites

The approach used here was to use linear regression to fit a linear relationship of the form $y = mx + c$ (where m is the slope and c the y intercept) to the full hourly or daily dataset from relevant each site, details are above in Methodology. Since $PM_{2.5}$ is a subset of PM_{10} it must therefore be zero if PM_{10} is zero; hence, we would expect the y intercept ('c' above) to be close to zero. The slope (m) of the regression line (if it is linear) is the ratio $PM_{2.5}/PM_{10}$.

Glasgow Kerbside ceased monitoring PM at the end of 2014; Glasgow Townhead started operation in October 2013. **The former Glasgow Centre site, which closed in 2012, also measured both $PM_{2.5}$ and PM_{10} as of 2009: however, it is believed that the December data from the site were affected by diesel emissions associated with the city's annual Christmas Market (generators for street-food vendors etc.). Therefore, the December data from Glasgow Centre have been removed from the dataset before using the data here.**

It was not assumed that the relationship between $PM_{2.5}$ and PM_{10} would be linear or indeed straightforward. It is known that the composition of PM varies throughout the year, depending on meteorological and other factors. For example, during spring and summer particulate episodes there is likely to be a higher proportion of fine secondary particulate (much of which will be $PM_{2.5}$), while during winter particulate episodes there may be more locally-emitted, possibly coarser, material.

Figure 5-1 to Figure 5-7 below show scatter plots, with $PM_{2.5}$ as y and PM_{10} as x, for Aberdeen Errol Place, Auchencorth Moss (hourly FDMS data), Edinburgh St Leonards, Glasgow Kerbside, Glasgow Townhead and Grangemouth.

Figure 5-1 Scatter plot for Aberdeen Errol Place with $PM_{2.5}$ as y and PM_{10} as x.

Scatter plot of PM_{10} vs. $PM_{2.5}$ at Aberdeen Errol Place
for the period 2009 to 2015

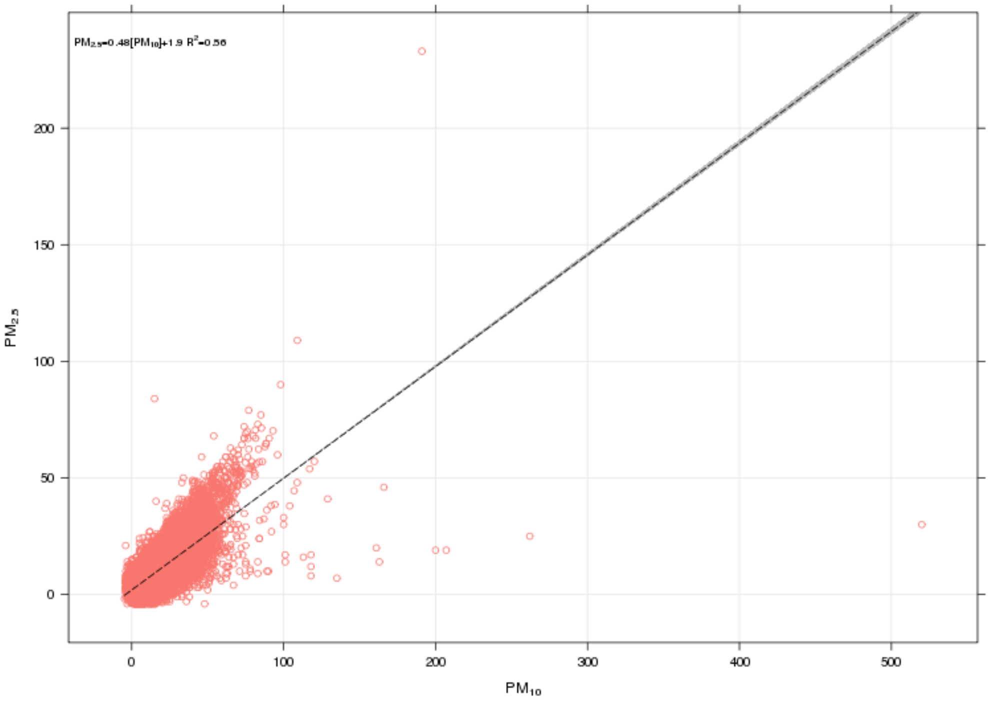


Figure 5-2 Scatter plot for Auchencorth Moss with $PM_{2.5}$ as y and PM_{10} as x.

Scatter plot of PM_{10} vs. $PM_{2.5}$ at Auchencorth Moss
for the period 2009 to 2015

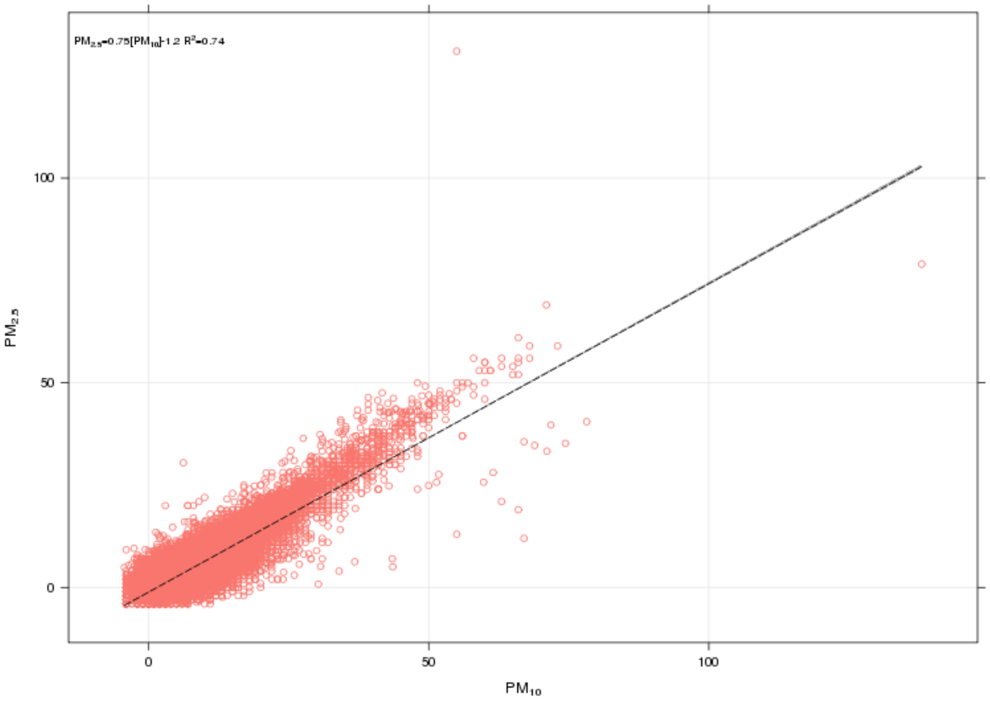


Figure 5-3 Scatter plot for Edinburgh St Leonards with $PM_{2.5}$ as y and PM_{10} as x.

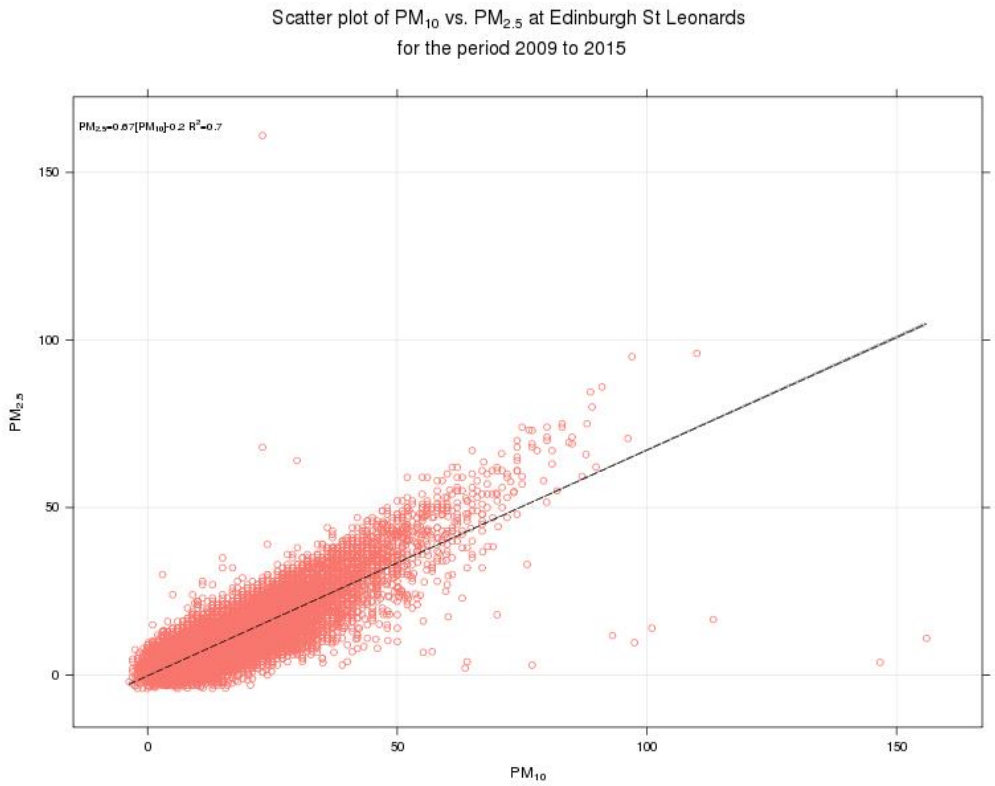


Figure 5-4 Scatter plot for Glasgow Centre (every December excluded) with $PM_{2.5}$ as y and PM_{10} as x.

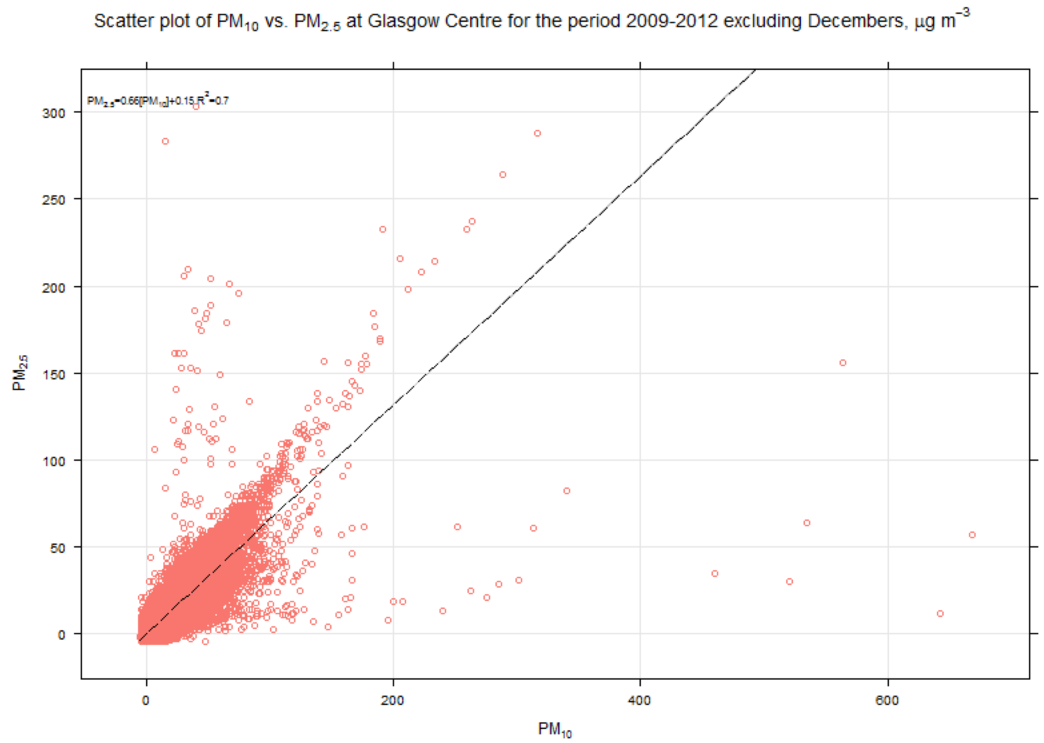


Figure 5-5 Scatter plot for Glasgow Kerbside with $PM_{2.5}$ as y and PM_{10} as x.

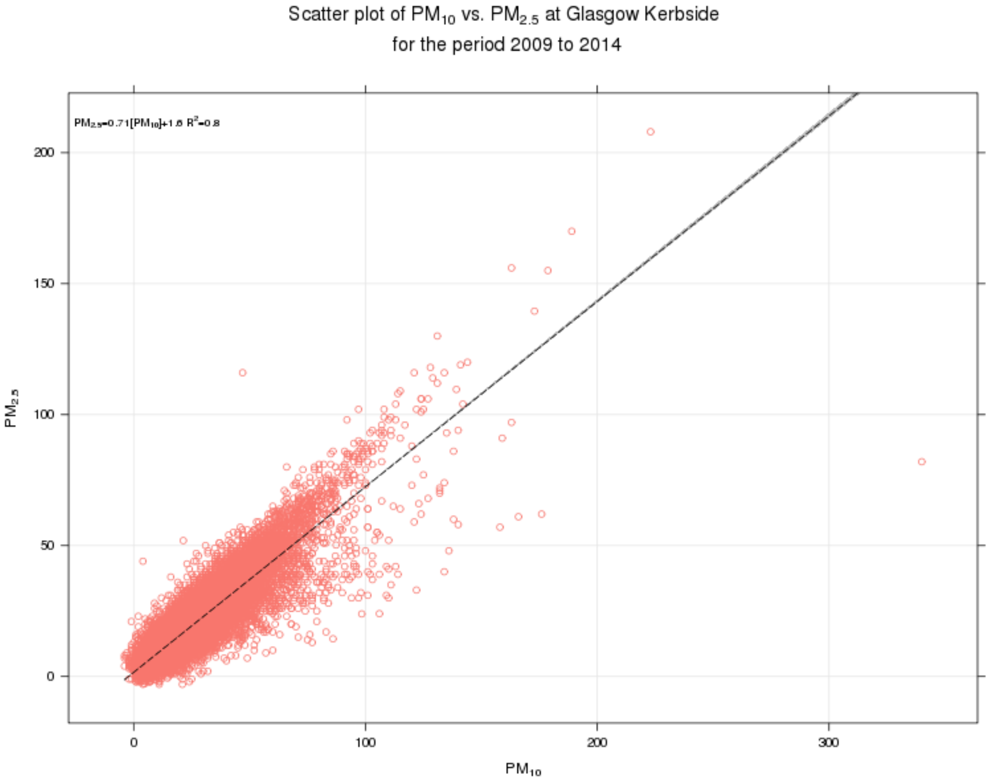


Figure 5-6 Scatter plot for Glasgow Townhead with $PM_{2.5}$ as y and PM_{10} as x.

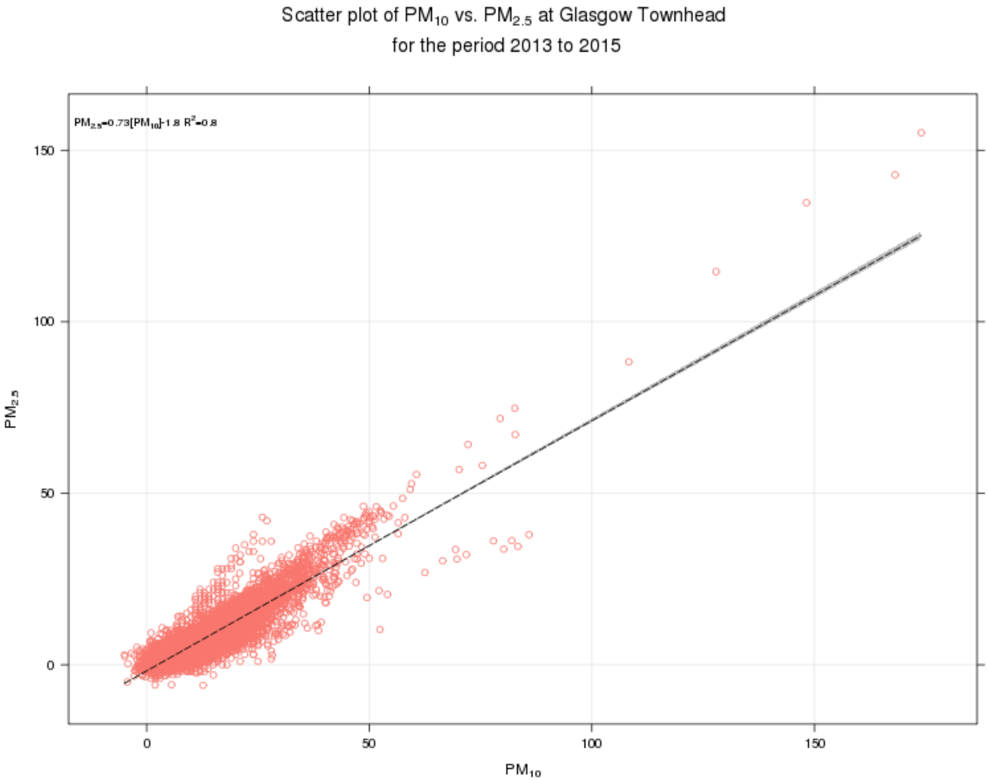


Figure 5-7 Scatter plot for Grangemouth with $PM_{2.5}$ as y and PM_{10} as x.

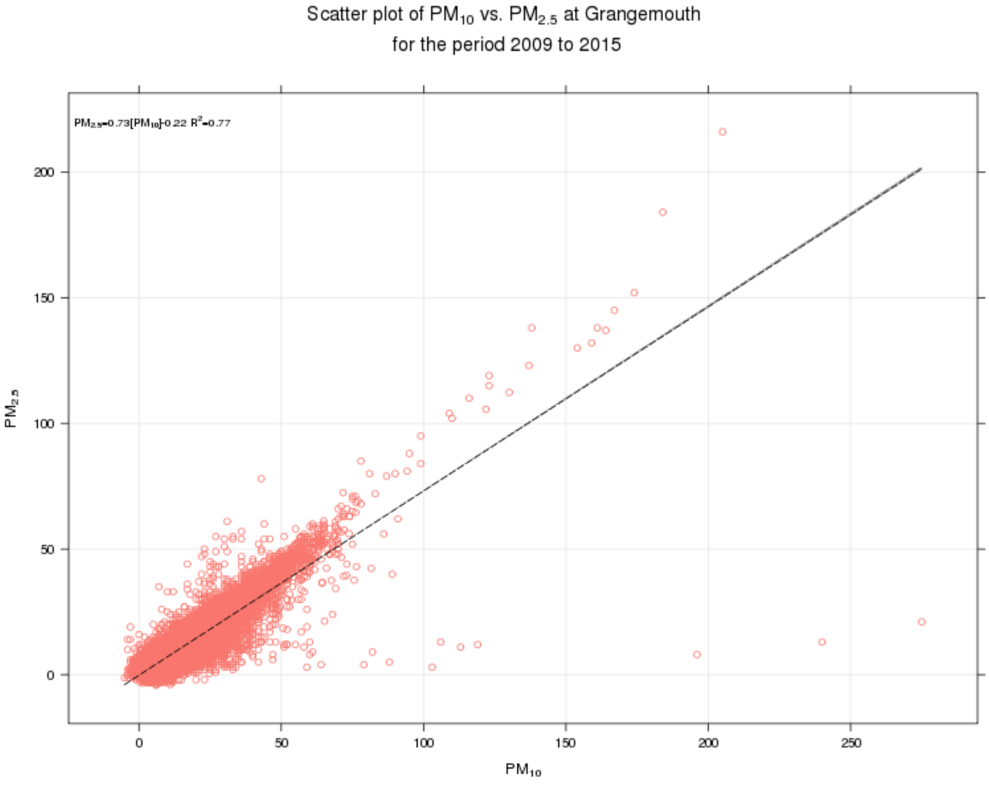
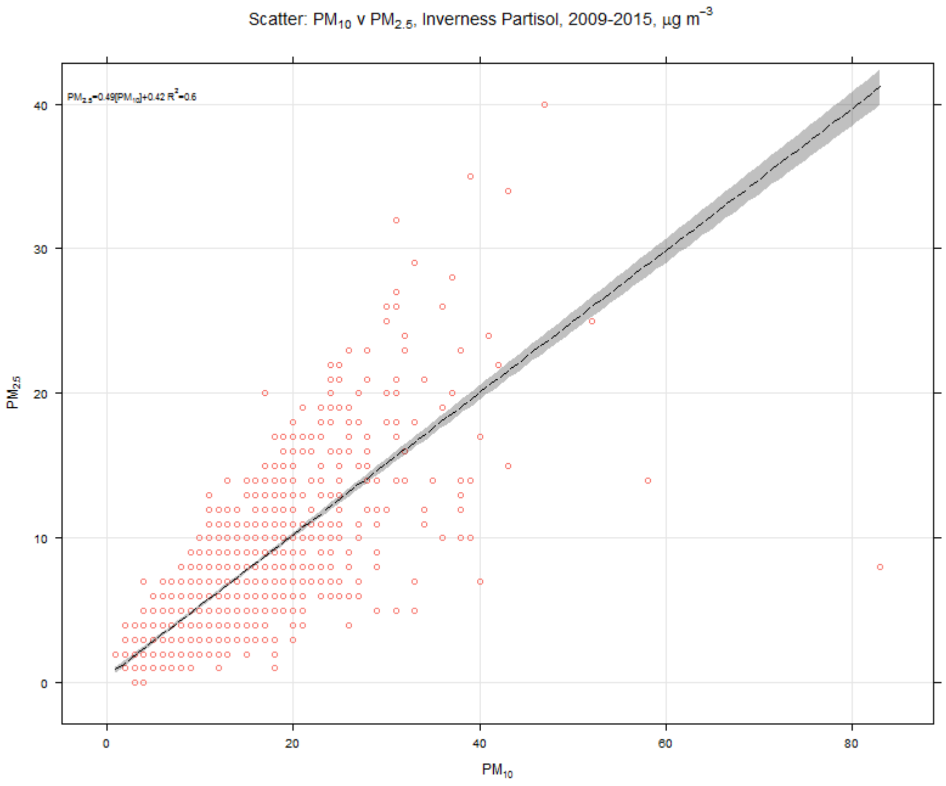


Figure 5-8 Scatter plot for Inverness (daily) with $PM_{2.5}$ as y and PM_{10} as x.



The scatter plots indicate that:

- The relationship between $PM_{2.5}$ and PM_{10} was approximately linear for most of the sites.
- However, in many cases there were clearly two or more separate ‘lines’ or ‘groups’ of points for each site, possibly reflecting different seasons, weather conditions or times when different types or sources of PM predominated.
- The correlation coefficient R^2 was > 0.7 in all cases except Aberdeen Errol Place.

The equations of the regression lines are shown in Table 5-1.

Table 5-1 Regression Line Equations for $PM_{2.5}$ and PM_{10}

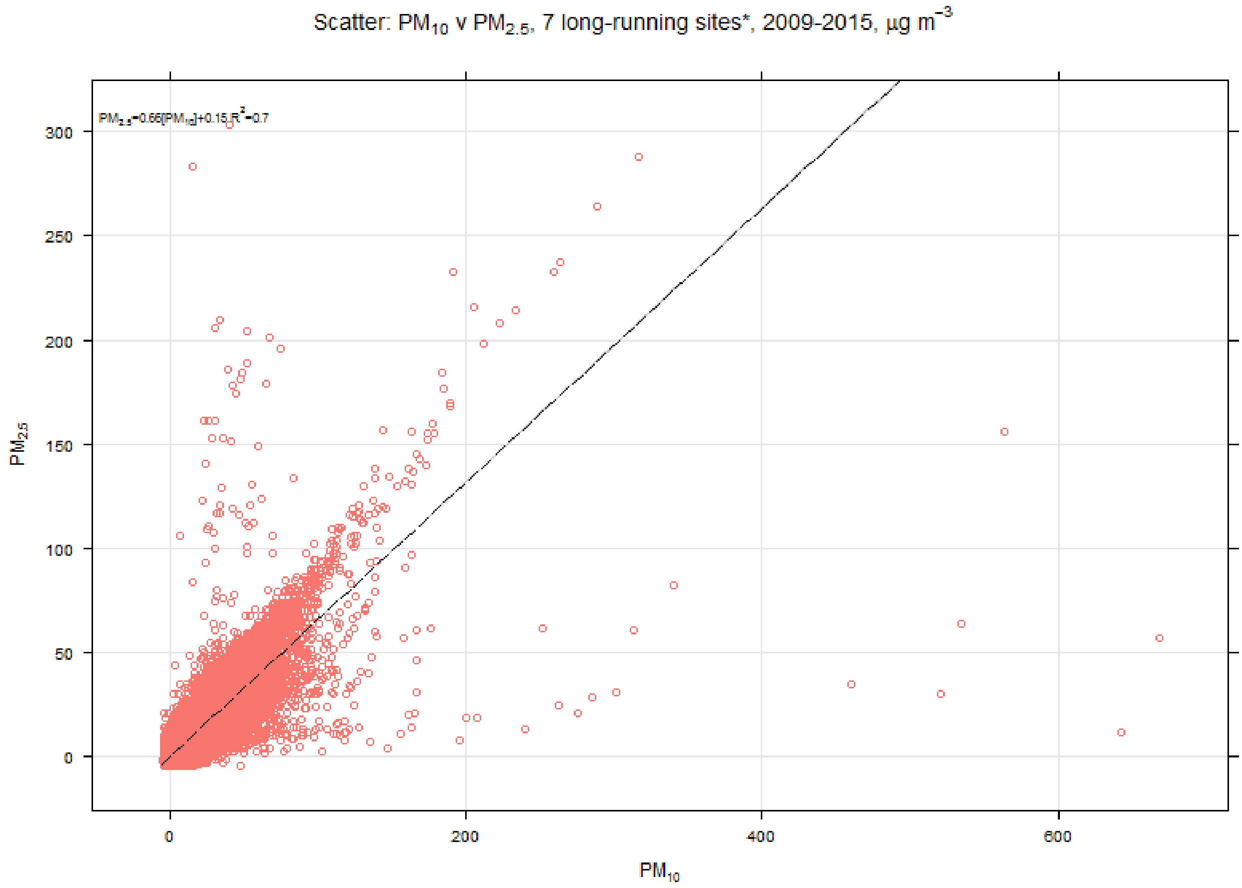
Site	Equation of regression line (µg m^{-3})	Correlation coefficient (R^2)
Aberdeen Errol Place	$[PM_{2.5}] = 0.48\ [PM_{10}] + 1.9$	0.56
Auchencorth Moss	$[PM_{2.5}] = 0.75\ [PM_{10}] - 1.2$	0.74
Edinburgh St Leonards	$[PM_{2.5}] = 0.67\ [PM_{10}] - 0.2$	0.70
Glasgow Centre (2009-12 only, no December data)	$[PM_{2.5}] = 0.66\ [PM_{10}] + 0.15$	0.70
Glasgow Kerbside (to end 2014)	$[PM_{2.5}] = 0.71\ [PM_{10}] + 1.6$	0.80
Glasgow Townhead (2013-15 only)	$[PM_{2.5}] = 0.73\ [PM_{10}] - 1.8$	0.80
Grangemouth	$[PM_{2.5}] = 0.73\ [PM_{10}] - 0.22$	0.77
Inverness (Partisol, daily)	$[PM_{2.5}] = 0.49\ [PM_{10}] + 0.42$	0.60
All hourly sites’ data	**$[PM_{2.5}] = 0.66\ [PM_{10}] + 0.15$**	**0.70**
Average slope and intercept	***Slope = 0.66, intercept = 0.08***	***n/a***

Since $PM_{2.5}$ is a subset of PM_{10} and therefore must be zero if PM_{10} is zero, the regression line should theoretically go through the origin. In the above examples, there is a small non-zero y-intercept in each case: however, the intercept is consistently within ± 2 µg m^{-3}. The limit of detection of the FDMS method is usually quoted as 3 µg m^{-3}, therefore the y-intercept in each case is less than the limit of detection.

The table shows the mean slope and intercept for the regression lines, which are 0.66 and 0.08 respectively. Therefore as a rough approximation based on the above, $[PM_{2.5}] \approx 0.66\ [PM_{10}]$. However, this is arguably not a valid approach, since not all the regressions are based on exactly the same period of data. Instead, a regression analysis has been carried out for all available pairs of hourly data points from the sites above (it was not possible to include Inverness as this only has daily data). This gives the same slope, 0.66, and intercept of 0.15 (which is well within the limit of detection). On this basis, **$[PM_{2.5}] \approx 0.66\ [PM_{10}]$.**

However, referring back to the scatter plots it is clear that the relationship between the two metrics varies considerably. Therefore it is only recommended to use a $PM_{2.5}/PM_{10}$ ratio to estimate annual mean $PM_{2.5}$ concentrations, not short-term concentrations such as daily or hourly means.

Figure 5-9 Scatter plot for Seven Scottish Sites, 2009 – 2015, with PM2.5 as y and PM10 as x.



**The sites are: Aberdeen Errol Place, Auchencorth Moss (FDMS), Edinburgh St Leonards, Glasgow Centre (2009 – 2012, December data removed), Glasgow Kerbside (2009 – 2014), Glasgow Townhead (2011 – 2015) and Grangemouth.*

5.1.1 Testing $PM_{2.5}/PM_{10}$ ratio derived from scatter plots

The above relationship has been tested below using 2015 annual mean PM_{10} and $PM_{2.5}$ data from sites which only began monitoring both metrics in recent years, most using the FIDAS analyser. As these sites are not long-running, their data were not used in developing the ratio. They therefore can be used to independently test the predictions of the two above approaches.

Table 5-2 shows the actual 2015 annual mean PM_{10} concentration as measured at the site, the estimated $PM_{2.5}$ concentration based the various approaches where possible, and the actual 2015 $PM_{2.5}$ concentration as measured at the site.

Table 5-2 Testing the derived ratio using 2015 annual means (DC = % data capture)

Site	Actual mean measured PM_{10} µg m^{-3}	Estimated $PM_{2.5}$ µg m^{-3} i.e. PM_{10} x 0.66	Actual mean measured $PM_{2.5}$ µg m^{-3}
Falkirk Banknock	11.0 (95% DC)	7.3 (+1.5)	5.8 (87% DC: FIDAS started 28/01/2015)
Glasgow High St	15.9 (91% DC)	10.6 (+2.0)	8.6 (91% DC)
North Ayrshire Irvine High St	14 (97% DC)	9.2	None - (monitoring began 16/04/2015)

South Lanarkshire Uddingston	11 (80% DC)	7.3 (+1.3)	6.0 (80% DC)
West Dunbartonshire Clydebank	10 (78% DC)	6.6 (0.0)	6.6 (78% DC)
Auchencorth Moss Partisol	6.1 (97% DC)	4.0 (+0.6)	3.4 (96% DC)
Inverness Partisol	9.3 (96% DC)	6.1 (+1.3)	4.8 (94% DC)

Based on the FIDAS and Partisol sites, using the approximate relationship **$[PM_{2.5}] \approx 0.66\ [PM_{10}]$**, tended to slightly over-estimate the 2015 $PM_{2.5}$ concentration but gave results typically within 2.0 µg m^{-3} of the measured annual mean. It is concluded that a $PM_{2.5}/PM_{10}$ ratio based approach can be used to provide an estimate of annual mean $PM_{2.5}$ concentration where only PM_{10} is measured, though this should only be regarded as indicative.

5.2 Comparison of Annual Mean PM_{10} and $PM_{2.5}$ Data from SAQD sites

The estimated ratio of $PM_{2.5}/PM_{10}$ was calculated as follows:

- Daily mean PM_{10} and $PM_{2.5}$ datasets were extracted from the SAQD database for the nine sites that measured both metrics during part or all of the period 2009-2013.
- Some sites had small amounts of TEOM x 1.3 data or VCM-corrected TEOM data for PM_{10} at the start of 2009. These data were removed from the 2009 PM_{10} datasets.
- For Glasgow Centre, all December data were removed due to concerns that the site was directly affected by diesel emissions during Christmas Markets. This only affects 2009, 2010 and 2011.
- For each day with a valid daily mean for *both* PM_{10} *and* $PM_{2.5}$, the ratio of $PM_{2.5}/PM_{10}$ was calculated.
- These daily mean ratios ($PM_{2.5}/PM_{10}$) were then averaged over each year for each site.
- The annual data capture for the ratio was also calculated, i.e. the number of days with a valid daily mean for both metrics, as a percentage of the full year.

Table 5-3 shows the annual mean $PM_{2.5}$ and PM_{10} concentrations for years 2009 to 2015, as measured at the nine sites. It also shows the ratio of annual mean $PM_{2.5}$/ annual mean PM_{10}, for each site, together with a combined mean for all sites and all years for which there were data. (Auchencorth Moss measures both metrics with two different techniques: the hourly monitoring FDMS and the daily monitoring gravimetric Partisol: both sets of statistics are shown, but only those based on the hourly FDMS dataset, which had the better data capture, are included in the overall mean, to avoid double-counting this site.)

Table 5-3 Ratio of Annual Mean $PM_{2.5}/PM_{10}$ concentrations, 2009 – 2015, for SAQD monitoring sites. Data Capture (%) in brackets. Means with 50%-75% data capture shaded amber, means with < 50% data capture shaded red.

Site	Ratio 2009	Ratio 2010	Ratio 2011	Ratio 2012	Ratio 2013	Ratio 2014	Ratio 2015*
Aberdeen Errol Place	0.47 *(59%)*	0.55 *(72%)*	0.62 *(88%)*	0.73 *(95%)*	0.68 *(82%)*	0.78 *(73%)*	0.76 (90%)
Aberdeen Union Street	-	-	-	-	-	0.68 *(32%)*	0.58 (61%)
Auchencorth Moss FDMS	0.50 *(52%)*	0.45 *(48%)*	0.44 *(80%)*	0.42 *(90%)*	0.58 *(51%)*	0.90 *(84%)*	0.33 (70%)
Auchencorth Moss Partisol	*0.71 (85%)*	*0.57 (82%)*	*0.60 (90%)*	*0.61 (20%)*	*0.55 (64%)*	*0.57 (98%)*	*0.52 (71%)*
Edinburgh St Leonards	0.52 *(52%)*	0.66 *(89%)*	0.76 *(98%)*	0.69 *(68%)*	0.54 *(93%)*	0.73 *(64%)*	0.64 (37%)
Glasgow Centre	0.43 *(66%)*	0.71 *(18%)*	0.57 *(81%)*	0.56 *(60%)*	-	-	-
Glasgow Kerbside	0.83 *(46%)*	0.81 *(94%)*	-	0.83 *(54%)*	0.70 *(81%)*	0.67 *(60%)*	- *(1%)*
Glasgow Townhead	-	-	-	-	0.50 *(15%)*	0.56 *(75%)*	0.58 (42%)
Grangemouth	0.61 *(89%)*	0.77 *(93%)*	0.75 *(93%)*	0.74 *(92%)*	0.62 *(71%)*	0.61 *(91%)*	0.88 (66%)
Inverness Partisol	0.55 *(91%)*	0.53 *(78%)*	0.53 *(80%)*	0.57 *(87%)*	0.54 *(91%)*	0.55 *(93%)*	0.50 (90%)
Mean All Sites (except Auchencorth Moss Partisol to avoid double-counting)	**0.63**						
Annual Mean All Sites except Auchencorth Moss Partisol, minimum data capture 75%	0.51	0.66	0.61	0.65	0.61	0.69	0.61
Mean All Sites except Auchencorth Moss Partisol, minimum data capture 75%	**0.63**						
Mean All Sites except Auchencorth Moss Partisol, minimum data capture 50%	**0.62**						

** Dataset for Oct –Dec 2015 remains provisional at the time of writing, pending full ratification at the end of March 2016.*

The annual mean ratio of daily $PM_{2.5}/PM_{10}$ varied from 0.33 to 0.90 for the above SAQD sites over the period 2009-2015, though typically in the range 0.5 to 0.8 and with a mean of **0.63**. If cases with valid daily ratios on <75% of days in the year were excluded, the annual mean was within the range of 0.51 and 0.69 and the overall mean was still **0.63**. Excluding cases with valid daily ratios on < 50% of days in the year, the overall mean changed slightly to 0.62. The above analysis indicates that **$[PM_{2.5}] \approx 0.63\ [PM_{10}]$** – a similar value to that obtained using regression. The ratios of 0.63 and 0.69 from the SAQD and regression respectively broadly agree with ratios previously seen in other studies: For example the data from 2007 Partisol study in Scotland of 0.67[16]; and the ratios within Europe typically reported as between 0.6 and 0.7[18].

For the long-running sites, there was no clear increase or decrease in the ratio over the period 2009 to 2015. There was however some year-to-year variation in the annual mean $PM_{2.5}/PM_{10}$ ratio: this may reflect changes in the composition and sources of particulate matter, depending on weather or other external conditions.

Table 5-4 shows the annual mean PM_{10} and $PM_{2.5}$ concentrations for all 15 sites that monitored both in 2015. This includes the long-running sites shown in Table 5-3 (with the exception of those that closed before the start of 2015), together with a number of additional sites which began monitoring $PM_{2.5}$ in 2015. The annual mean daily ratio of $PM_{2.5}/PM_{10}$ at the eight newer sites which have only monitored $PM_{2.5}$ from 2015 was typically lower, ranging from 0.42 to 0.62 (though the value of 0.42 came from a site with very low data capture and may not be representative of the year). The generally lower ratios at the newer sites might be due to the new sites being mainly roadside sites, which tend to give lower ratios[15]. A number of sites data capture less than 75%: the ratios for these are shaded amber. Red shading denotes sites with less than 50% data capture. The ratio of $PM_{2.5}/PM_{10}$ averaged over all sites in 2015 was 0.59 (0.58 if only sites with at least 75% data capture are included).

Table 5-4 Annual Mean PM Concentrations and Ratio of $PM_{2.5}$ and PM_{10} Annual Means for 2015, all sites

Site	Site Type	2015 Annual Mean $PM_{2.5}$ ($\mu g\ m^{-3}$)	2015 Annual Mean PM_{10} ($\mu g\ m^{-3}$)	$PM_{2.5}/PM_{10}$ ratio
Aberdeen Errol Place	UB	8.1 (93%)	12 (96%)	0.76 (90%)
Aberdeen Union Street	Traffic	10.6 (83%)	17.2 (62%)	0.58 (61%)
Auchencorth Moss Partisol	Rural	3.4 (96%)	6.1 (97%)	0.56 (96%)
Auchencorth Moss FDMS	*Rural*	*3.0 (95%)*	*7.5 (72%)*	*0.38 (70%)*
Edinburgh St Leonards	UB	6.4 (85%)	11.0 (45%)	0.64 (37%)
Glasgow Townhead	UB	6.5 (92%)	12.0 (44%)	0.58 (42%)
Grangemouth	Industrial	9.2 (94%)	12.3 (66%)	0.88 (66%)
Inverness Partisol	Traffic	4.8 (94%)	9.3 (96%)	0.52 (94%)
Aberdeen Market Street 2	Traffic	8.0 (24%)	19.5 (89%)	0.42 (17%)
Falkirk Banknock	Traffic	5.8 (87%)	11.0 (95%)	0.55 (87%)

Site	Site Type	2015 Annual Mean $PM_{2.5}$ ($\mu g\ m^{-3}$)	2015 Annual Mean PM_{10} ($\mu g\ m^{-3}$)	$PM_{2.5}/PM_{10}$ ratio
Fife Rosyth	Traffic	6.3 (45%)	13.8 (90%)	0.60 (45%)
Glasgow High Street	Traffic	8.6 (91%)	15.9 (90%)	0.50 (90%)
North Ayrshire Irvine High St	Traffic	6.8 (68%)	13.6 (97%)	0.53 (68%)
South Lanarkshire Lanark	Traffic	6.2 (72%)	10.4 (72%)	0.59 (72%)
South Lanarkshire Uddingston	Traffic	6.3 (80%)	10.9 (81%)	0.56 (80%)
West Dunbartonshire Clydebank	Traffic	6.6 (77%)	9.8 (78%)	0.62 (77%)
Mean all*				**0.59**
Mean sites with > 75% DC only (for daily ratio)				**0.58**

**except Auchencorth Moss FDMS, to avoid double-counting this site. In 2015 the Partisol had the better data capture so this is used here rather than the FDMS. The FDMS data are included in the table for information only.*

5.2.1 Testing $PM_{2.5}/PM_{10}$ ratio derived from annual mean concentrations

The above relationship has been tested below using 2015 annual mean PM_{10} and $PM_{2.5}$ data from sites which only began monitoring both metrics in recent years, most using the FIDAS analyser. As these sites are not long-running, their data were not used in developing the ratio. They therefore can be used to independently test the predictions of the two above approaches.

Table 5-5 shows the actual 2015 annual mean PM_{10} concentration as measured at the site, the estimated $PM_{2.5}$ concentration based the various approaches where possible, and the actual 2015 $PM_{2.5}$ concentration as measured at the site.

Table 5-5 Testing the derived ratio on 2015 annual means (DC = % data capture)

Site	Actual mean measured PM_{10} $\mu g\ m^{-3}$	Estimated $PM_{2.5}$ $\mu g\ m^{-3}$ i.e. PM_{10} x 0.63 (difference to actual in brackets)	Actual mean measured $PM_{2.5}$ $\mu g\ m^{-3}$
Falkirk Banknock	11.0 (95% DC)	6.9 (+1.1)	5.8 (87% DC: FIDAS started 28/01/2015)
Glasgow High St	15.9 (91% DC)	10.0 (+1.4)	8.6 (91% DC)
North Ayrshire Irvine High St	13.6 (97% DC)	8.6	None - (monitoring began 16/04/2015)
South Lanarkshire Uddingston	10.9 (80% DC)	6.9 (+0.6)	6.3 (80% DC)
West Dunbartonshire Clydebank	9.8 (78% DC)	6.1 (-0.5)	6.6 (78% DC)

Site	Actual mean measured PM_{10} µg m^{-3}	Estimated $PM_{2.5}$ µg m^{-3} i.e. PM_{10} x 0.63 (difference to actual in brackets)	Actual mean measured $PM_{2.5}$ µg m^{-3}
Inverness Partisol	9.3 (96% DC)	5.9 (+1.1)	4.8 (94% DC)

Based on the FIDAS and Partisol sites, using the approximate relationship **[$PM_{2.5}$] ≈ 0.63 [PM_{10}]**, mostly tended to over-estimate the 2015 $PM_{2.5}$ concentration but gave results typically within 1.5 µg m^{-3} of the measured annual mean. It can be seen if the ratio for 2015 (see Table 5-4) was used of **[$PM_{2.5}$] ≈ 0.58 [PM_{10}]**, then the estimated $PM_{2.5}$ might be closer to the actual mean measure concentration for $PM_{2.5}$, as can be seen in Table 5-6, with estimate the 2015 $PM_{2.5}$ concentrations within 0.9 µg m^{-3} of the measured annual mean

Table 5-6 Testing the 2015 annually derived ratio on 2015 annual means (DC = % data capture)

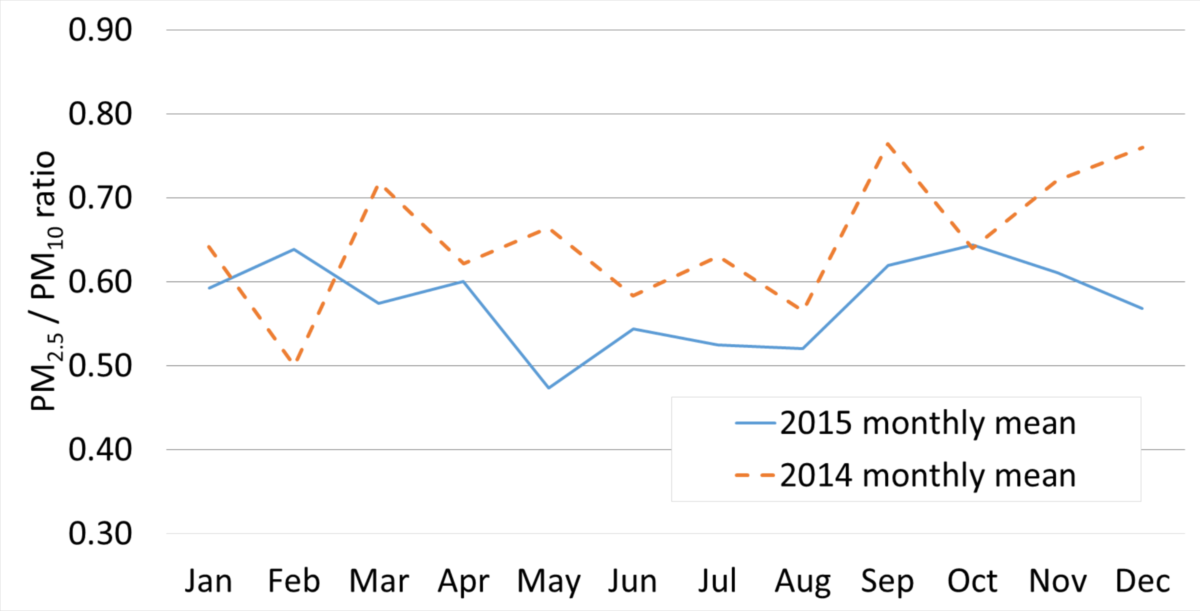
Site	Actual mean measured PM_{10} µg m^{-3}	Estimated $PM_{2.5}$ µg m^{-3} i.e. PM_{10} x 0.58 (difference to actual in brackets)	Actual mean measured $PM_{2.5}$ µg m^{-3}
Falkirk Banknock	11.0 (95% DC)	6.4 (+0.8)	5.8 (87% DC: FIDAS started 28/01/2015)
Glasgow High St	15.9 (91% DC)	9.2 (+0.6)	8.6 (91% DC)
North Ayrshire Irvine High St	13.6 (97% DC)	7.9	None - (monitoring began 16/04/2015)
South Lanarkshire Uddingston	10.9 (80% DC)	6.3 (0.0)	6.3 (80% DC)
West Dunbartonshire Clydebank	9.8 (78% DC)	5.7 (-0.9)	6.6 (78% DC)
Inverness Partisol	9.3 (96% DC)	5.4 (+0.8)	4.8 (94% DC)

Thus, it is concluded that a $PM_{2.5}/PM_{10}$ ratio based approach can be used to provide an estimate of annual mean $PM_{2.5}$ concentration where only PM_{10} is measured, though this should only be regarded as indicative.

5.2.2 Seasonal Variation in Monthly $PM_{2.5}/PM_{10}$ Ratio

Figure 5-10 shows the monthly mean $PM_{2.5}/PM_{10}$ ratio, averaged over all sites, in 2014 and 2015. There is no obvious pattern for 2014, but for 2015 the ratio appeared lower in the non-winter months[20] (Figure 5-10, also see Table A9 to Table A10 in the Appendix).

Figure 5-10: Average monthly mean $PM_{2.5}/PM_{10}$ ratios from all SAQD monitoring sites



The average annual mean ratio calculated from the monthly mean ratios were 0.67 and 0.58 for 2014 and 2015 respectively, which is similar to the average of the annual means for the SAQD monitoring sites.

Calculating the average annual mean ratio from data points (hourly or daily) gave a value of 0.65 for 2014 and 0.61 for 2015.

5.3 PCM Ratios

The modelled average annual mean $PM_{2.5}/PM_{10}$ ratio from PCM data decreases slightly over the modelled years from 2011 to 2030 (see Table 5-7), however they are largely the same as the ratios seen with the average annual mean ratios seen in Table 5-3 above. Individual local authority regions gave a slightly elevated overall average annual ratio for 2014 of 0.69 (see Table 5-8).

Table 5-7: Results from averaged modelled $PM_{2.5}$ and PM_{10} concentration and averaged calculated $PM_{2.5}/PM_{10}$ ratios from PCM from 2011 to 2030

	2011	2012	2013	2014	2015	2020	2025	2030
$PM_{2.5}$	6.14	6.08	6.03	5.97	5.92	5.73	5.61	5.62
PM_{10}	9.48	9.41	9.35	9.29	9.23	9.00	8.87	8.89
$PM_{2.5}$ / PM_{10} ratio	0.65	0.65	0.64	0.64	0.64	0.64	0.63	0.63

Table 5-8: Results from modelled $PM_{2.5}$ and PM_{10} concentration from PCM in 2014 and calculated $PM_{2.5}/PM_{10}$ ratios for each local authority region

Local Authority	$PM_{2.5}$	PM_{10}	$PM_{2.5}$ / PM_{10} Ratio
City of Glasgow	8.25	11.53	0.72
City of Edinburgh	8.45	12.35	0.68
Fife	7.70	11.40	0.68
North Lanarkshire	7.44	10.54	0.71
South Lanarkshire	6.61	9.07	0.73
Aberdeenshire	6.94	10.56	0.66
Highland	4.67	6.87	0.68
City of Aberdeen	8.20	12.52	0.65
West Lothian	7.64	11.48	0.67
Renfrewshire	6.43	9.03	0.71
Falkirk	7.76	11.07	0.70
Dumfries and Galloway	6.15	8.45	0.73
City of Dundee	7.86	11.38	0.69
Perth and Kinross	5.65	8.00	0.71
North Ayrshire	5.61	7.82	0.72
East Ayrshire	6.21	8.56	0.73
Angus	7.03	10.40	0.68
South Ayrshire	6.02	8.33	0.72
Scottish Borders	6.88	9.64	0.71
East Dunbartonshire	6.79	9.40	0.72
East Lothian	7.68	11.19	0.69
Moray	5.72	8.11	0.71
Argyll and Bute	4.98	6.87	0.72
East Renfrewshire	6.44	9.01	0.71
West Dunbartonshire	6.13	8.46	0.72
Midlothian	7.47	10.61	0.70
Stirling	5.42	7.44	0.73
Inverclyde	5.66	7.79	0.73
Clackmannanshire	6.89	9.81	0.70
Na h-Eileanan Siar (Western Isles)	4.39	6.72	0.65
Shetland Islands	6.23	11.46	0.54
Orkney Islands	5.62	9.39	0.60
Mean	6.59	9.54	0.69
SD	1.07	1.67	0.04
Min	4.39	6.72	0.54
Max	8.45	12.52	0.73

5.4 Mobile Monitoring Ratios

The average $PM_{2.5}/PM_{10}$ ratio for the mobile monitoring (see Table 5-9) over all the routes and dates was 0.52 with a range of 0.21 – 0.74. This is lower than the annual mean ratio of 0.63 found for the fixed SAQD sites (see Table 5-3). However, the mobile monitoring was short-term, mostly during spring, summer and autumn, rather than for a full year as in the case of the SAQD. The range was also likely to be a function of weather, the sample area, and other unknown external conditions. It was considered that the lower overall mean for the mobile monitoring was consistent with lower monthly SAQD means during spring/summer months.

Table 5-9: Mean ratio for mobile monitoring period for different areas/cities in Scotland during 2014 and 2015

Mobile Sample Area	When	Mobile Ratio	Sample Size
Glasgow City Centre	14/03/2014	0.47	530
Glasgow City Centre	10/04/2014	0.49	617
Glasgow City Centre	21/05/2014	0.68	106
Glasgow City Centre	23/06/2014	0.68	169
Glasgow City Centre	08/07/2014	0.56	450
Glasgow City Centre	13/07/2014	0.67	50
Glasgow City Centre	09/08/2014	0.74	97
Glasgow City Centre	15/08/2014	0.72	309
Rosyth	21/03/2014	0.63	448
Dunfermline	24/03/2014	0.45	310
Cupar	25/03/2014	0.43	587
Kirkcaldy	27/03/2014	0.33	628
Perth Central	23/05/2014	0.33	608
Perth Central	24/05/2014	0.53	419
Crieff	27/05/2014	0.54	302
Perth Glasgow Rd	29/05/2014	0.42	618
Perth Blackford	30/05/2014	0.69	304
Perth Crieff Rd	03/06/2014	0.31	514
Paisley	18/09/2015	0.43	430
Bearsden	25/09/2015	0.34	444
Edinburgh	02/10/2015	0.69	403
Aberdeen	14/10/2015	0.49	410
Broxburn	27/10/2015	0.72	352
East Kilbride	26/11/2015	0.21	374
	Average	0.52	

5.5 Using $PM_{2.5}$ / PM_{10} Ratios to Estimate $PM_{2.5}$ Concentrations from PM_{10}

It can be seen above that the $PM_{2.5}/PM_{10}$ ratio may provide an *indicative estimate* of annual mean $PM_{2.5}$ concentration for sites where only PM_{10} data are available. Reviewing the different methods (see Table 5-10) the mean ratios varied from 0.52 to 0.69. However, the best estimate of the $PM_{2.5}/PM_{10}$ ratio was thought to be based upon the SAQD data from sites where both are measured, over 2009 to 2015. This ratio was **0.63**, with a typical range from 0.51 to 0.69 (see Section 5.2 above).

Table 5-11 shows the actual 2015 annual mean PM_{10} concentration as measured at the site, the estimated $PM_{2.5}$ concentration based on using the mean ratio of 0.63 and the range, and the actual 2015 $PM_{2.5}$ concentration as measured at the site. Thus it can be seen that the 0.63 ratio overestimates, whereas the minimum of the range (0.51) underestimates $PM_{2.5}$ concentration and the maximum ratio of 0.69 overestimates still further. Thus the 2015 data sits between 0.51 and 0.63 ratio, thus using a ratio derived from the same year, i.e. the ratio 0.58 derived in Table 5-4 might be prudent.

Table 5-10: Mean, minimum and maximum ratios for different methods to calculated $PM_{2.5}/PM_{10}$ ratio

Method used to calculate ratio	Mean ratio	Minimum ratio from dataset	Maximum ratio from dataset
Scatterplot mean 2009-2015	0.66	0.56	0.80
Annual mean SAQD 2009-2015 (excluding <75%)	0.63	0.51	0.69
Mean SAQD 2015 (all sites)	0.58	0.50	0.76
PCM 2014 (LAs)	0.69	0.54	0.73
Mobile monitoring data 2014-2015	0.52	0.21	0.74

Table 5-11 Testing the maximum, minimum and mean ratio with 2015 annual means

Site	Actual mean measured PM_{10} ($\mu g\ m^{-3}$)	Estimated $PM_{2.5}$ i.e. PM_{10} x 0.63 (difference to actual in brackets) ($\mu g\ m^{-3}$)	Estimated $PM_{2.5}$ i.e. PM_{10} x 0.51 ($\mu g\ m^{-3}$)	Estimated $PM_{2.5}$ i.e. PM_{10} x 0.69 ($\mu g\ m^{-3}$)	Actual mean measured $PM_{2.5}$ ($\mu g\ m^{-3}$)
Falkirk Banknock	11.0	6.9 (+1.1)	5.6 (-0.2)	7.6 (+1.8)	5.8
Glasgow High St	15.9	10.0 (+1.4)	8.1 (-0.5)	11.0 (+2.4)	8.6
South Lanarkshire Uddingston	10.9	6.9 (+0.6)	5.6 (-0.7)	7.5 (+1.2)	6.3
West Dunbartonshire Clydebank	9.8	6.2 (-0.4)	5.0 (-1.6)	6.8 (+0.2)	6.6
Inverness Partisol	9.3	5.9 (+1.1)	4.7 (-0.1)	6.4 (+1.6)	4.8

Hence, the use of the $PM_{2.5}/PM_{10}$ ratio from the SAQD data is thought to give the best estimate for $PM_{2.5}$ from PM_{10} concentrations, whilst accepting the possible range of this estimate. When reviewing data historically, the use of an annual ratio to estimate $PM_{2.5}$ might give better data.

5.6 Estimated Exceedances Using $PM_{2.5}/PM_{10}$ Ratios

It was shown earlier (Table 4-3) that the number of sites exceeding the PM_{10} objective in 2015 reduces from 11 to 6 if the annual objective is changed from 18 to 20 $\mu g\ m^{-3}$. For $PM_{2.5}$ the number of sites exceeding the objective would increase from zero to 1 if the objective changed from 12 to 10 $\mu g\ m^{-3}$.

Utilising the 2015 SAQD data from all 75 PM_{10} monitoring sites it is possible to estimate $PM_{2.5}$ exceedances. Table 5-12 clearly shows that by using the $PM_{2.5}/PM_{10}$ ratio of 0.63 the number exceedances would be 5 for an annual objective of 12 $\mu g\ m^{-3}$, and that by decreasing the objective the number would be 27. Utilising a minimum and maximum ratio of 0.51 and 0.69 respectively, would result in a different number of exceedances, unsurprisingly with less exceedances if the ratio was lower and more if the ratio was higher (see Table 5-13 & Table 5-14), thus again emphasising that understanding the limitations due to the range of these ratios and possibly suggesting the use of an annual ratio for historical data would be prudent.

Table 5-12: Calculated exceedances of $PM_{2.5}$ annual objective using average annual mean $PM_{2.5}/PM_{10}$ ratio of 0.63

	Roadside / Kerbside		Urban Background		Urban industrial		Rural	
	n =	Exceedances	n =	Exceedances	n =	Exceedances	n =	Exceedances
Exceedances $PM_{2.5}$ @ 12µg m^{-3}	63	5	9	0	1	0	2	0
Exceedances $PM_{2.5}$ @ 10µg m^{-3}		27		0		0		0
Dataset provisional for 2015 due to it not being fully ratified								

Table 5-13: Calculated exceedances of $PM_{2.5}$ annual objective using average annual mean $PM_{2.5}/PM_{10}$ ratio of 0.51

	Roadside / Kerbside		Urban Background		Urban industrial		Rural	
	n =	Exceedances	n =	Exceedances	n =	Exceedances	n =	Exceedances
Exceedances $PM_{2.5}$ @ 12µg m^{-3}	63	0	9	0	1	0	2	0
Exceedances $PM_{2.5}$ @ 10µg m^{-3}		3		0		0		0
Dataset provisional for 2015 due to it not being fully ratified								

Table 5-14: Calculated exceedances of $PM_{2.5}$ annual objective using average annual mean $PM_{2.5}/PM_{10}$ ratio of 0.70

	Roadside / Kerbside		Urban Background		Urban industrial		Rural	
	n =	Exceedances	n =	Exceedances	n =	Exceedances	n =	Exceedances
Exceedances $PM_{2.5}$ @ 12µg m^{-3}	63	11	9	0	1	0	2	0
Exceedances $PM_{2.5}$ @ 10µg m^{-3}		37		0		0		0
Dataset provisional for 2015 due to it not being fully ratified								

6 Conclusions and Recommendations

6.1 Impact of Changing Particulate Matter Objectives

Changing the PM_{10} objective from 18 µg m^{-3} to 20 µg m^{-3} would clearly result in fewer exceedances of this objective. Based on the dataset from SAQD monitoring sites, the number of sites exceeding the current PM_{10} objective in 2015 was 11: the number exceeding the proposed new PM_{10} objective was just three.

By contrast, lowering the $PM_{2.5}$ objective from 12 µg m^{-3} to 10 µg m^{-3} would clearly increase the number of exceedances for this metric. Based on dataset from SAQD monitoring sites, the number of sites exceeding the current $PM_{2.5}$ objective in 2015 was zero: one site exceeded the proposed $PM_{2.5}$ objective of 10 µg m^{-3}.

Based on modelling carried out by the PCM project, no Scottish Local Authority's *average* annual mean PM_{10} or $PM_{2.5}$ concentration for 2015 data exceeded either the objectives as they stand or the proposed modified objectives. However, individual 1 km squares within some Local Authority areas did exceed these PM objectives. As a result of the proposed changes, the number of 1 km squares with modelled 2015 annual mean $PM_{2.5}$ concentrations above the objective would increase substantially from zero to 22.

There are 11 Local Authorities in Scotland with AQMAs, and a total of 21 AQMAs for PM_{10} (alone or together with nitrogen dioxide) throughout Scotland. Within these AQMAs there were six PM_{10} monitoring sites which reported annual mean PM_{10} concentrations greater than the current objective of 18 µg m^{-3} in 2015. If the PM_{10} objective was raised to 20 µg m^{-3}, then the number above the objective would fall to just one.

The above research and analysis of data indicates that alignment of Scotland's annual mean PM_{10} objective with the WHO PM_{10} objective of 20 µg m^{-3}, would impact on the Air Quality Management Areas across Scotland, with many current PM_{10} AQMAs becoming unnecessary. This would have effects on the Air Quality Action Plans that have been developed by local authorities to improve local concentrations of PM_{10} perhaps leading the abandoning of such plans. This could be counter-productive to efforts to improve air quality.

Also it should be remembered that by tackling PM_{10} (or more specifically primary PM), $PM_{2.5}$ is also targeted indirectly to some extent (though it is known that tackling primary PM has a limited effect on $PM_{2.5}$ because a large proportion of the latter is secondary material[12]). Thus by maintaining the PM_{10} objective at 18 µg m^{-3} the existing AQMAs and Action Plans stay in place, PM_{10} is reduced and with it, $PM_{2.5}$ may reduce proportionally.

It is therefore concluded that relaxing the PM_{10} objective in the short term may be counter-productive to efforts to reduce both PM_{10} and $PM_{2.5}$.

The proposed reduction in the $PM_{2.5}$ objective would probably require the development of AQMAs specifically for $PM_{2.5}$, with new Action Plans. The likely scenario is that the LAs with current PM_{10} AQMAs would also require new $PM_{2.5}$ AQMAs (this is discussed at greater length in the sister document: $PM_{2.5}$ network in Scotland[3]).

If the $PM_{2.5}$ objective is reduced as proposed, additional monitoring of this metric will be necessary, i.e. an expansion of the $PM_{2.5}$ measurement network will be required if the new objective is adopted.

This is potentially expensive and will take time to implement. One short-term option which could be used prior to the enhancement of the $PM_{2.5}$ network would be to supplement data from existing sites by estimating annual mean $PM_{2.5}$ concentrations, based upon the relationship between $PM_{2.5}$ and PM_{10}.

6.2 Relationship between Annual Mean PM_{10} and $PM_{2.5}$

The SAQD network operates over 70 PM_{10} monitors. However, the number of $PM_{2.5}$ monitoring sites, although rising (from nine to fourteen between 2014 and 2015), is still much smaller.

This study has investigated the feasibility of using ratio of $PM_{2.5}/PM_{10}$ concentration (based upon data from sites at which both are measured) to estimate annual mean $PM_{2.5}$ concentrations at sites where only PM_{10} is measured.

The data from SAQD sites at which both PM metrics are measured (using three different monitoring methods) suggest that the ratio of $PM_{2.5}/PM_{10}$ at sites in Scotland are comparable with those seen across the continent of Europe, especially Northern Europe[17]. The ratio of $PM_{2.5}/PM_{10}$ (based on annual means of paired daily means) ranged between 0.33 and 0.9 (though typically in the range 0.5 to 0.8). The mean was 0.63. Excluding instances with paired daily means for less than 75% of the relevant year also gave a mean of 0.63

Modelled data from the PCM project gave average $PM_{2.5}/PM_{10}$ ratios in a similar range of 0.63 to 0.69. Data from short-term mobile monitoring data gave typically lower $PM_{2.5}/PM_{10}$ ratios, with a mean of 0.52, and a large range of 0.21 to 0.69. However, these data were based on much shorter period, typically less than one day per location, and therefore were not representative of the full calendar year on which the objective is based.

The study concluded that it would be feasible to use the $PM_{2.5}/PM_{10}$ ratio to provide an *indicative estimate* of annual mean $PM_{2.5}$ concentration for sites where only PM_{10} data are available. The best estimate of the $PM_{2.5}/PM_{10}$ ratio (based upon the SAQD data from sites where both are measured, over 2009 to 2015) was **0.63**, with a typical range from 0.51 to 0.69.

However, the composition and sources of PM varies from site to site, from hour to hour, day to day and from year to year. Therefore it is not recommended to rely on this ratio as a method for calculating $PM_{2.5}$ concentrations: it is intended only to provide an indicative estimate. It should also only be used for estimating annual mean $PM_{2.5}$ concentrations, not for shorter periods.

Applying the average $PM_{2.5}/PM_{10}$ ratio of 0.63 to 2015 annual mean PM_{10} concentrations from SAQD sites monitoring only PM_{10} not $PM_{2.5}$ identified a total of five sites at which the annual mean $PM_{2.5}$ concentration was predicted to exceed the current objective of 12 µg m^{-3}, and 22 which were predicted to exceed the proposed new objective of 10 µg m^{-3}. This is a substantial increase compared with the exceedances identified on the basis of current measured $PM_{2.5}$ data.

The increased number of predicted exceedances of the $PM_{2.5}$ objectives (proposed or current) using this method suggests that $PM_{2.5}$ could be a greater problem than previously thought. Using a ratio such as that above might have numerous potential implications for air quality management in Scotland, including the need to further develop of the $PM_{2.5}$ monitoring network, especially considering that $PM_{2.5}$ is thought to have a greater impact on health than PM_{10}.

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Appendices

Appendix 1: Contract for the Support and Maintenance of the Scottish Air Quality Database and Website - Option E

Appendix 2: Components of Particulate Matter

Appendix 3: Source Attribution for Annual Average $PM_{2.5}$

Appendix 4: Routes for mobile study

Appendix 5: Tables & Results of $PM_{2.5}$ and PM_{10} Monitoring Sites in Scotland

Appendix 1: Contract for the Support and Maintenance of the Scottish Air Quality Database and Website - Option E

e. Investigation of ratios of $PM_{2.5}/PM_{10}$ at representative AQMAs across Scotland to help inform potential changes to LAQM and AQMAs in Scotland

The Scottish Government's intentions to include $PM_{2.5}$ within the Local Air Quality Management regime and to change the Annual Mean PM_{10} objective from 18 µg m^{-3} to 20 µg m^{-3} in Scotland have numerous potential implications for air quality management in Scotland. These include the need to develop a $PM_{2.5}$ monitoring network, the impact on Air Quality Management Areas across Scotland and also on Air Quality Action Plans that have been developed by local authorities to improve local concentrations of PM_{10}.

Currently there are few $PM_{2.5}$ monitoring sites located across Scotland, and as such it is difficult to envisage the potential impacts that the proposed changes to the Scottish Air Quality Objectives for PM_{10} and $PM_{2.5}$ would have in term of existing AQMAs for PM_{10} and new AQMAs for $PM_{2.5}$. The development of the mobile monitoring platform as part of the Scottish Government's PM with height study has demonstrated that with appropriate QA/QC the platform can provide valuable information regarding the spatial distribution of air quality pollutants within an AQMA. Furthermore, the platform's ability to monitor $PM_{2.5}$ and PM_{10} concurrently provides an almost unique opportunity to monitor concentrations of both pollutants at a large number of locations within an AQMA and calculate relevant $PM_{2.5}/PM_{10}$ ratios and inform the likely outcome of the proposed Scottish Objectives on AQMAs across Scotland. During 2014 and 2015, such studies have already been undertaken in Glasgow, Fife and Perth and Kinross and it is therefore proposed that data from these studies are supplemented with:

- $PM_{2.5}$ and PM_{10} measurements by the mobile monitoring platform at a selection of AQMAs (declared for PM_{10}) across Scotland. It is recommended that the mobile monitoring is undertaken in representative PM_{10} AQMAs from across Scotland, including selected areas of AQMAs in Aberdeen, West Lothian, South Lanarkshire, North Lanarkshire, East Dunbartonshire and Renfrewshire. Where the AQMA is focused on a limited area(s) of exceedance, the study will look to map much of this area. However, for larger AQMAs it will be necessary to limit the study to selected areas of each AQMA.
- $PM_{2.5}$ and PM_{10} measurements by the mobile monitoring platform at several urban background, and background locations.
- $PM_{2.5}$ and PM_{10} measurements at SAQD monitoring sites where both $PM_{2.5}$ and PM_{10} concentrations are measured to provide input to the study and to cross reference the mobile monitoring measurements.

The study will use the new measurement data and other information available from the SAQD monitoring network to calculate the $PM_{2.5}/PM_{10}$ ratio at a range of different monitoring types and locations. This information can then be used to in combination with measured and mapped PM_{10} concentrations to predict likely concentrations of $PM_{2.5}$ in local authorities across Scotland and thus a picture of likely future $PM_{2.5}$ AQMAs in Scotland. The study will also provide valuable information for the earlier network evaluation option.

Appendix 2: Components of Particulate Matter

Table A1: Precursors of secondary particulate matter.

Primary components	Sources
SO_2	SO_2 is formed by the combustion of sulphur-containing fuels such as coal. Ship fuels such as heavy fuel oil are also a source. However, SO_2 emissions from coal-burning power stations have been much reduced by the use of a technology called flue gas desulphurisation and automotive fuels are now low in sulphur.
NO_x	NO_x is formed by the combustion of fuels used in power generation, domestic heating and traffic. See the AQEG report *Nitrogen Dioxide in the United Kingdom* for more details.
NH_3	Ammonia (NH_3) is emitted mainly from agricultural sources, particularly livestock waste.
VOCs	Aromatic compounds such as benzene and toluene are generated by traffic and solvents. Monoterpenes come from vegetation, especially conifers and heathers.

Table A2: Components of particulate matter

Primary components	Sources
Sodium chloride	Sea salt.
Elemental carbon	Black carbon (soot) is formed during high temperature combustion of fossil fuels such as coal, natural gas and oil (diesel and petrol) and biomass fuels such as wood chips.
Trace metals	These metals are present at very low concentrationsand include lead, cadmium, nickel, chromium, zinc and manganese. They are generated by metallurgical processes, such as steel making, or by impurities found in or additives mixed into fuels used by industry. Metals in particles are also derived from mechanical abrasion processes, e.g. during vehicle motion and break and tyre wear.
Mineral components	These minerals are found in coarse dusts from quarrying, construction and demolition work and from wind-driven dusts. They include aluminium, silicon, iron and calcium.
Secondary components	**Sources**
Sulphate	Formed by the oxidation of sulphur dioxide (SO_2) in the atmosphere to form sulphuric acid, which can react with ammonia (NH_3) to give ammonium sulphate.
Nitrate	Formed by the oxidation of nitrogen oxides (NO_x – which consists of nitric oxide (nitrogen monoxide, NO) and nitrogen dioxide (NO_2) in the atmosphere to form nitric acid, which can react with NH_3 to give ammonium nitrate. Also present as sodium nitrate.
Water	Some components of the aerosol form of particulate matter, such as ammonium sulphates and ammonium nitrates, take up water from the atmosphere.
Primary and secondary components	**Sources**
Organic carbon	Primary organic carbon comes rom traffic or industrial combustion sources. Secondary organic carbon comes from the oxidation of volatile organic compounds (VOCs). There may be several hundred individual components. Some of these trace organic compounds, such as certain polycyclic aromatic hydrocarbons, are highly toxic.

Appendix 3: Source Attribution for Annual Average $PM_{2.5}$

TableA3: Source attribution for annual average $PM_{2.5}$[12]

Component	Contribution to total $PM_{2.5}$	Estimated % contribution to total $PM_{2.5}$				
		UK	Non-UK	Shipping	Natural	Other
Primary PM	23%[3]-25%[2*]	19%[3]	4%[3]			
Secondary inorganic aerosol	32%[3]-44%[2]	13%[3] 20%[1,2]	14%[3] 24%[1,2]	6%[3]		
– sulphate	8%[3]	2%[3]	5%[3]	2%[3]		
– nitrate	16%[3]	8%[3]	6%[3]	3%[3]		
– chloride						
– ammonium	7%[3]	3%[3]	3%[3]	1%[3]		
Secondary Organic Aerosol	14%[2]-17%[3]	14%[4,3] 12%[4,2]	3%[4,3] 2%[4,2]			
Mineral dust/soil	7%[2]-10%[3]				7%-10%	
Traffic non-exhaust	4%[3] (<13%[2])	4%				
Sea salt	5%[3]-7%[2]				5%-7%	
Other	3%[2]-9%[3]					
Total (PCM)[†]		50%	21%	6%	15%	9%
Total (Yin *et al.* (2010); Nemitz *et al.* (2014))		55%	30%	–	14%	3%

* Incorporates "Industry/commercial/domestic", "Off-road/smoking engines" and "Traffic" in Yin *et al.* (2010), and so includes non-exhaust traffic emissions;

(1) Nemitz *et al.* (2013) for 2007, gives a contribution of non-UK sources to UK SIA of about 55% of the spatial average UK value from EMEP4UK;

(2) Yin *et al.* (2010), Birmingham estimates for 2007-08 from CMB model and measurements, annual mean $PM_{2.5}$ = 11.63 $\mu g\ m^{-3}$;

(3) PCM model, Ricardo-AEA, population-weighted UK mean (see Figure 4.12 in AQEG, 2012);

(4) Redington and Derwent (2013) NAME model, average over Harwell, Auchencorth, Birmingham and London Bloomsbury used in conjunction with PCM, result for Birmingham used in conjunction with Yin *et al.* (2010), with NAME UK/non-UK split used to scale PCM and Yin *et al.* (2010) contribution to total $PM_{2.5}$; authors calculate on average 83% of UK and 71% of non-UK SOA is biogenic. This does not necessarily mean that the biogenic SOA is uncontrollable as it will include some contribution from cooking;

† Based on PCM figures, 9% of total $PM_{2.5}$ is unaccounted for, 'Other' in the table.

Table A4: Effect of reductions in primary PM and SIA precursors on $PM_{2.5}$ mass (AEI) concentrations[12]

Reduction of 30% in:	Resulting $PM_{2.5}$ mass (AEI) in 2020 ($\mu g\ m^{-3}$) from baseline of 10.64 $\mu g\ m^{-3}$	Reduction in $\mu g\ m^{-3}$
UK primary PM	9.84	0.80
European primary[a] PM	10.50	0.14
UK NH_3	10.48	0.16
European NH_3	10.47	0.17
UK SO_2	10.58	0.06
European SO_2	10.58	0.06
UK NO_x	10.55	0.09
European NO_x	10.52	0.12

a 'European' means non-UK, i.e. rest of Europe.

Appendix 4: Routes for mobile study

Using mostly the AQMA maps available from Air Quality in Scotland website or the local authority's (LAs) websites, routes for the mobile study where overlayed and included the SAQD sites. As each LA uses a different map (or system of maps) then the mobile study route colouring isn't one standard colour.

Figure A4-1: City of Glasgow AQMA, mobile study route and SAQD monitoring sites

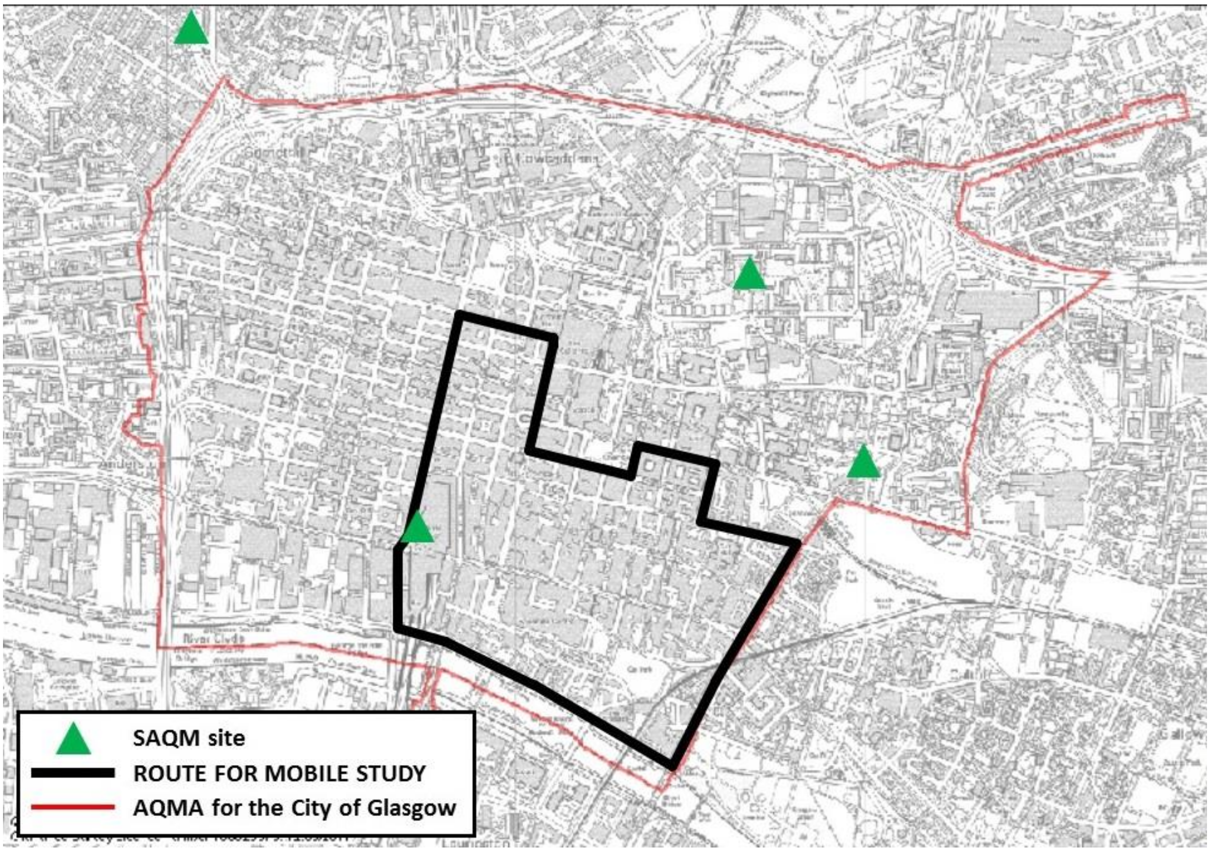


Figure A4-2: Admiralty Road, Rosyth, Fife mobile study route and SAQD monitoring site

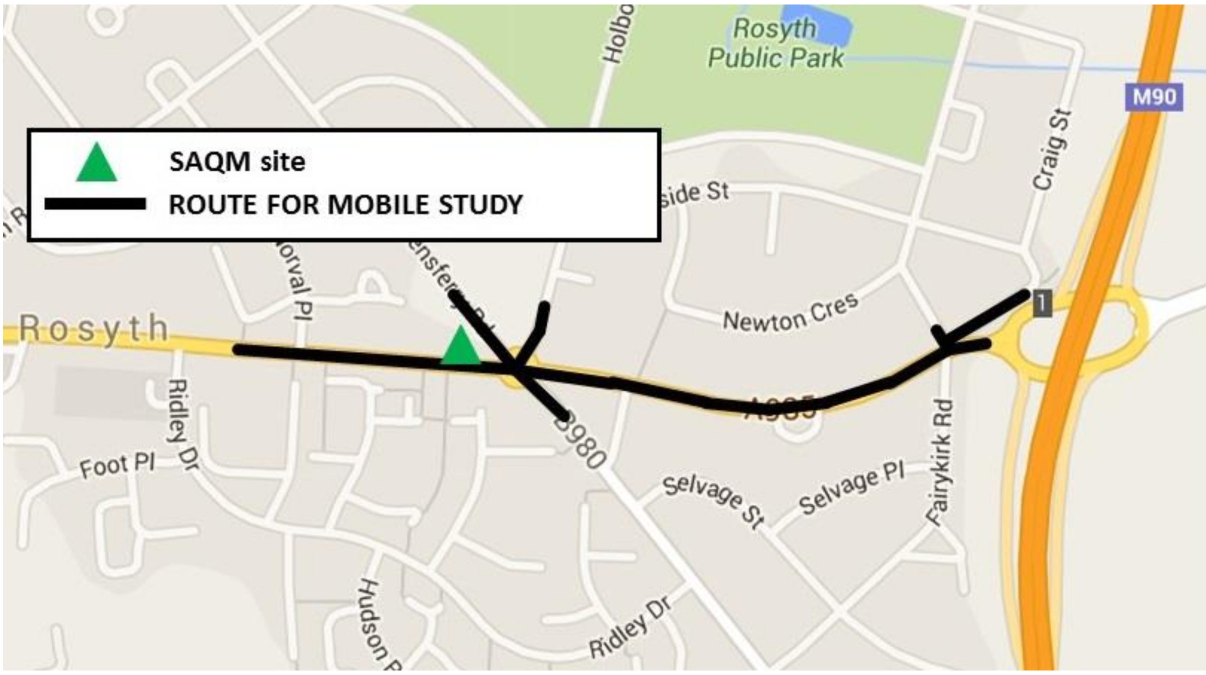


Figure A4-3: Appin Crescent, Dunfermline, Fife AQMA, mobile study route and SAQD monitoring site

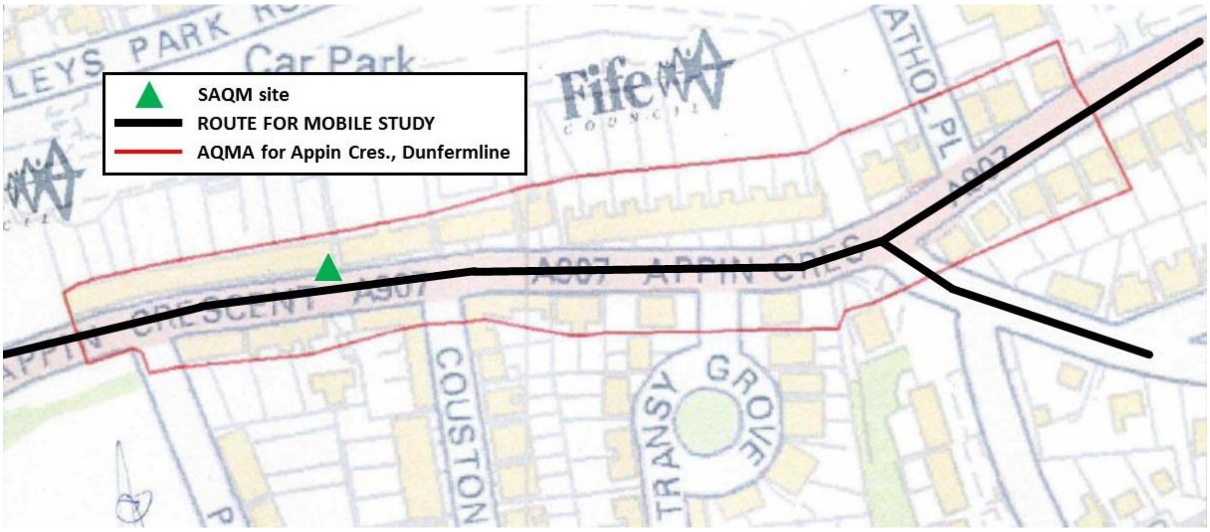


Figure A4-4: Bonnygate, Cupar, Fife AQMA, mobile study route and SAQD monitoring site

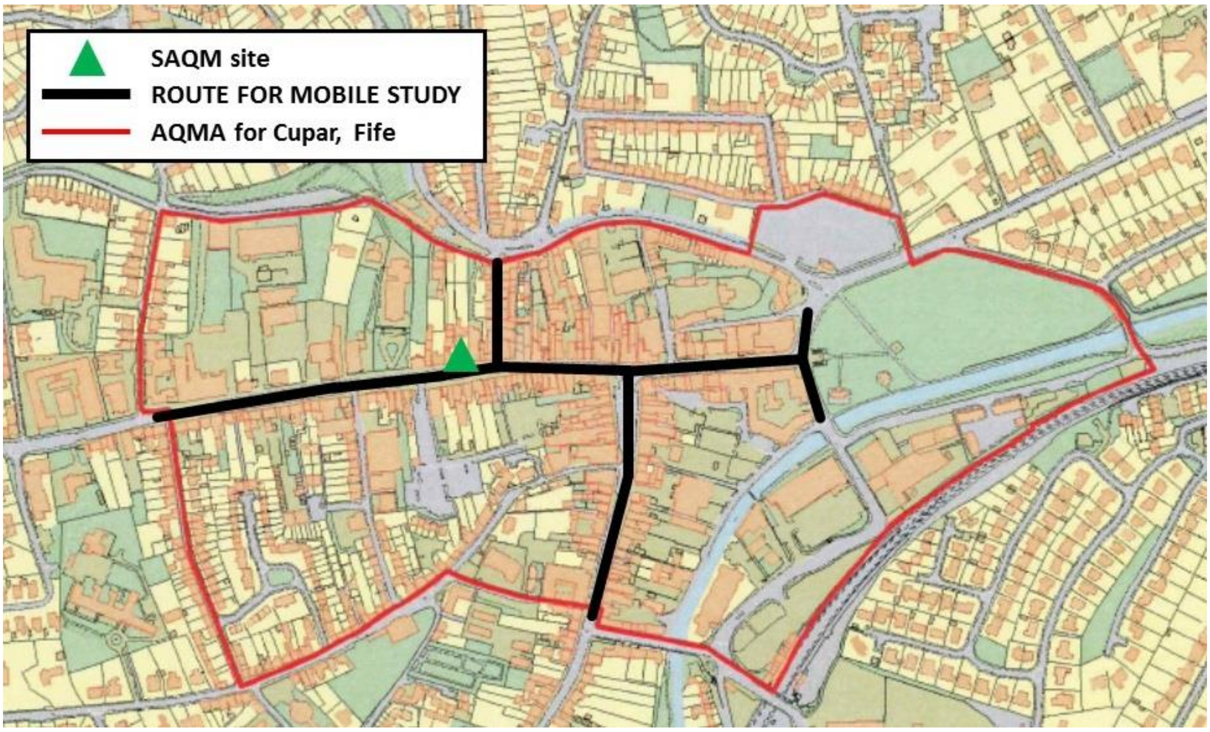


Figure A4-5: St Clair, Kirkcaldy, Fife mobile study route and SAQD monitoring site

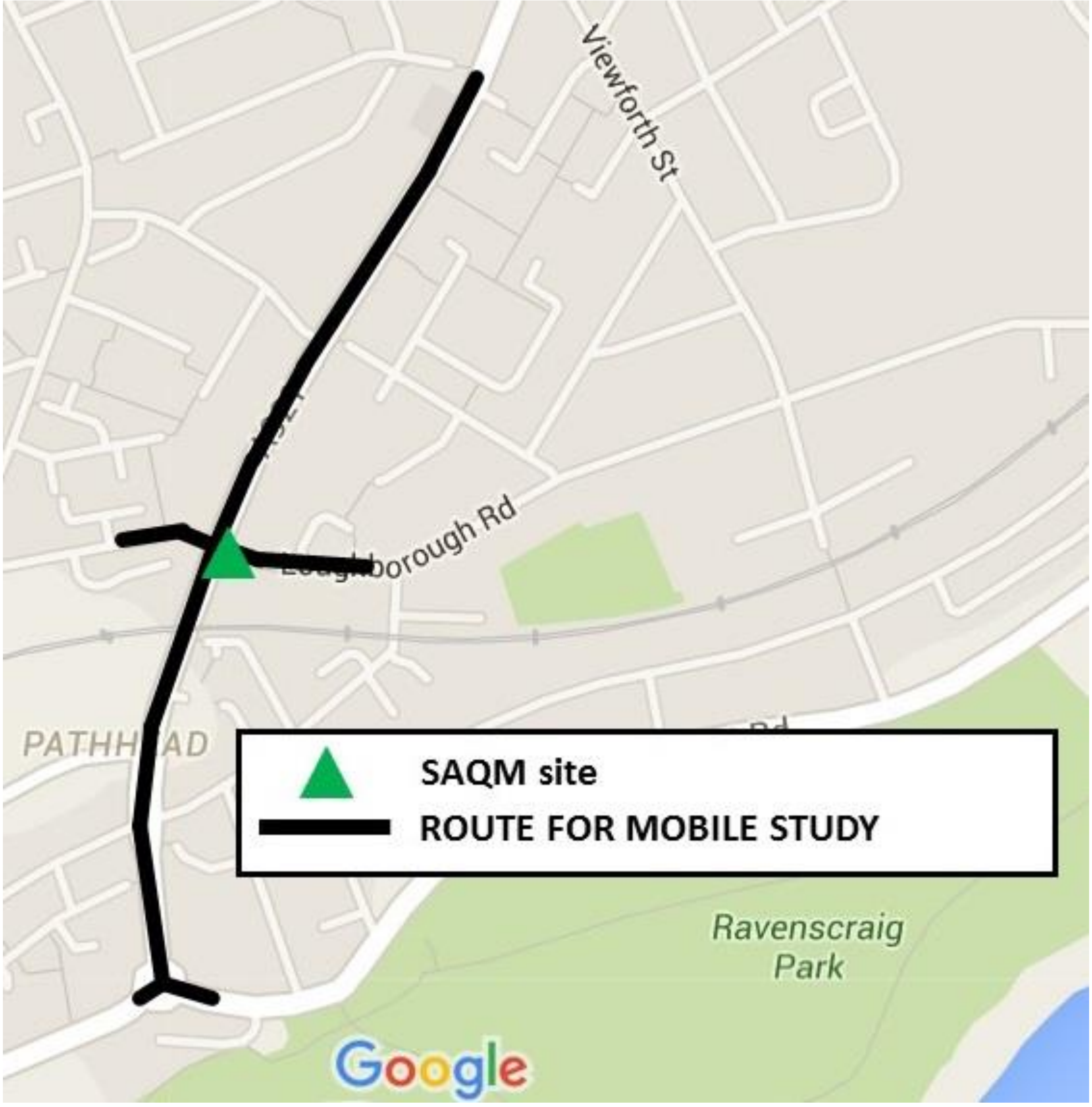


Figure A4-6: Perth city centre AQMA, mobile study route and SAQD monitoring sites

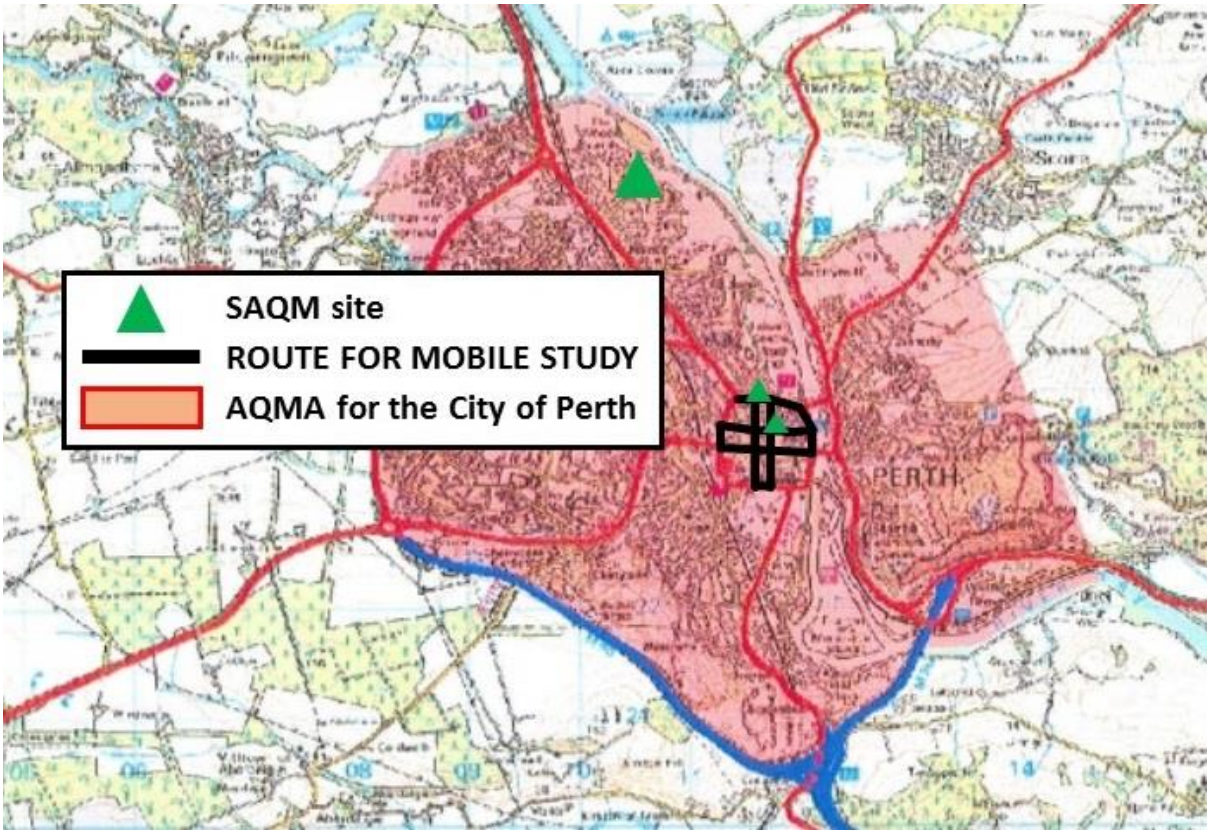


Figure A4-7: Perth city centre AQMA, Crieff Road mobile study route and SAQD monitoring sites

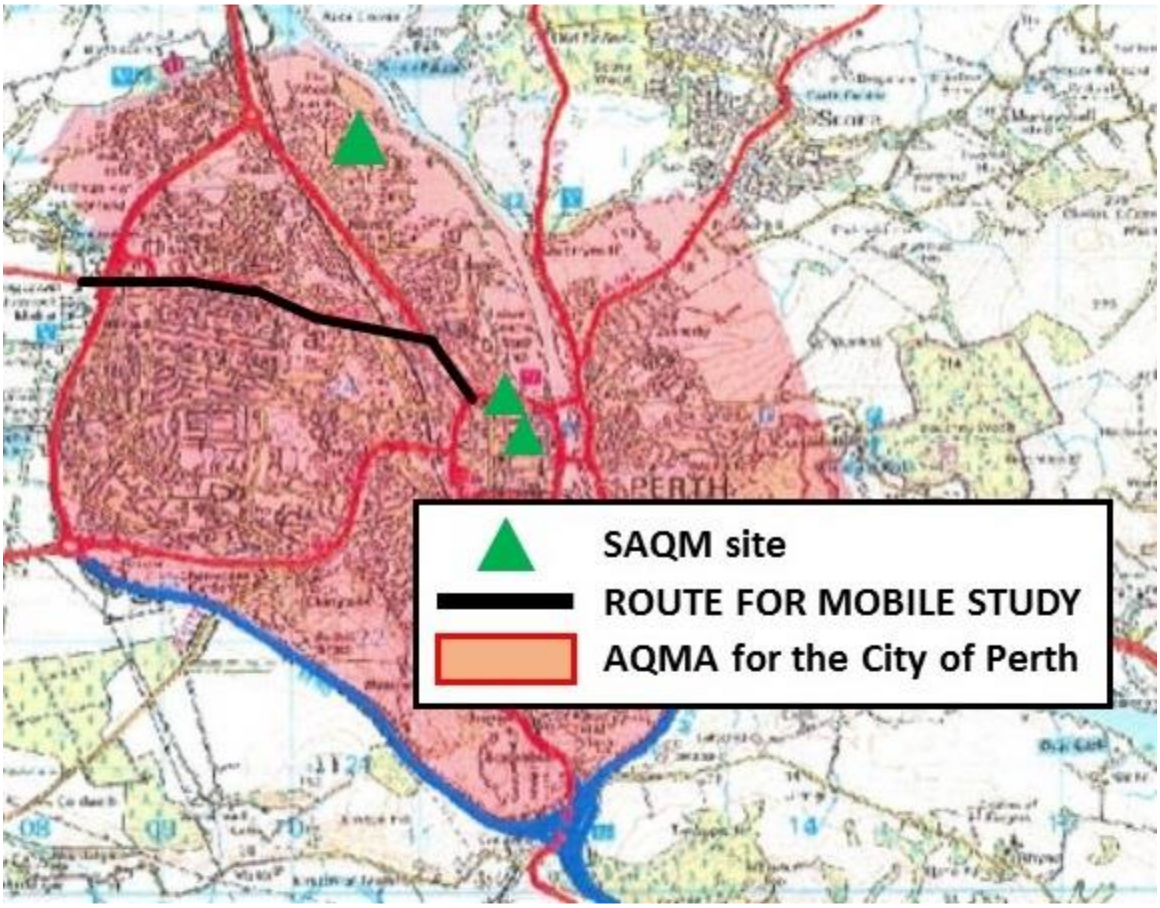


Figure A4-8: Perth city centre AQMA, Glasgow Road mobile study route and SAQD monitoring sites

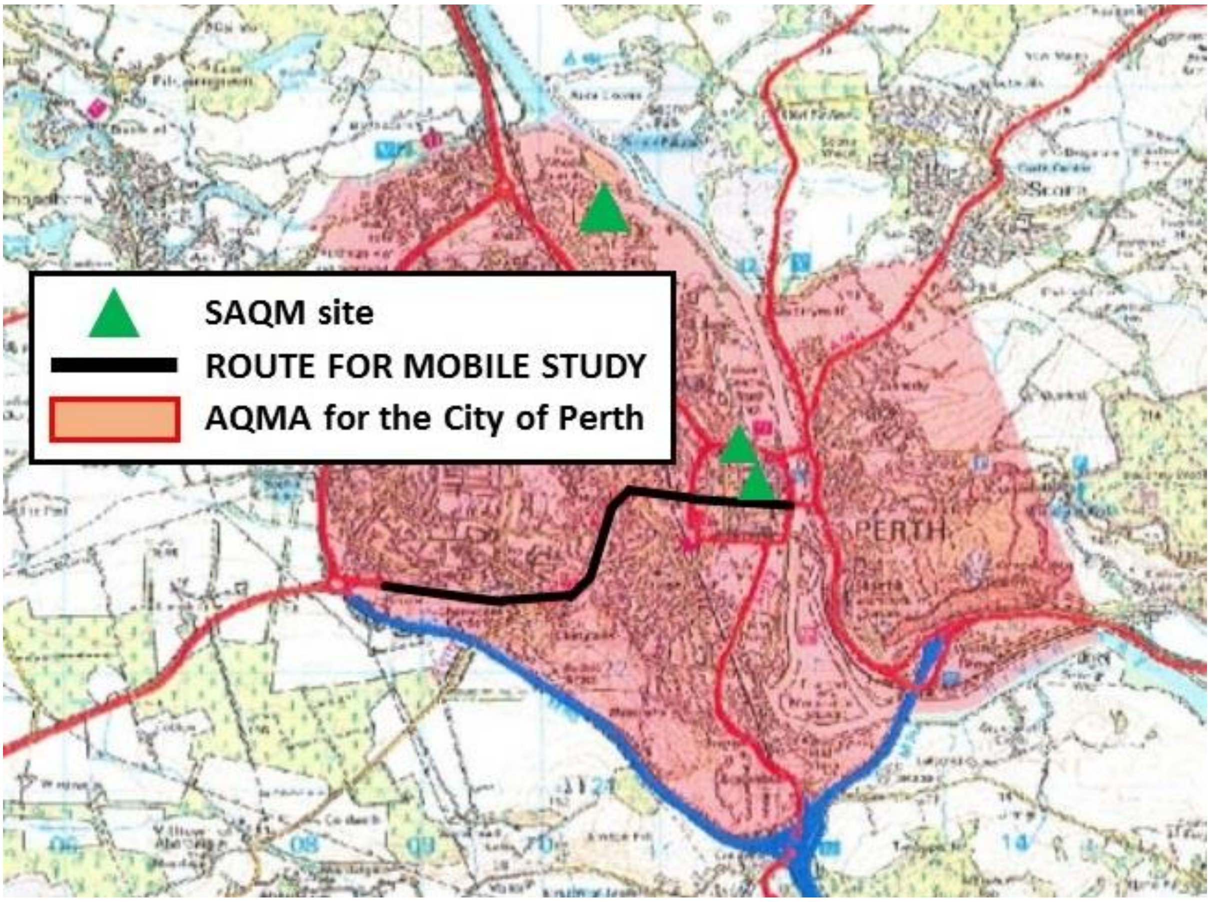


Figure A4-9: Blackford, Perthshire mobile study route

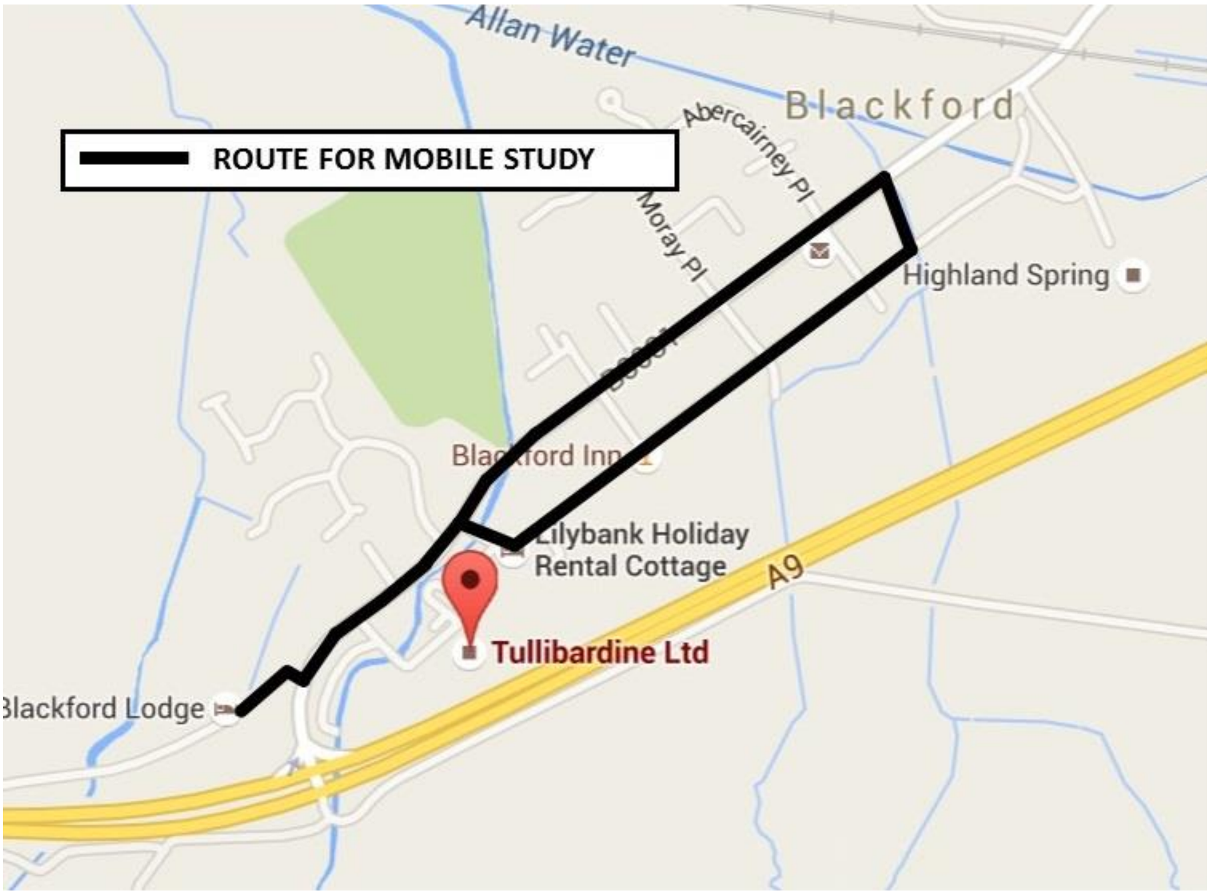


Figure A4-10: Crieff, Perth & Kinross AQMA, mobile study route and SAQD monitoring site

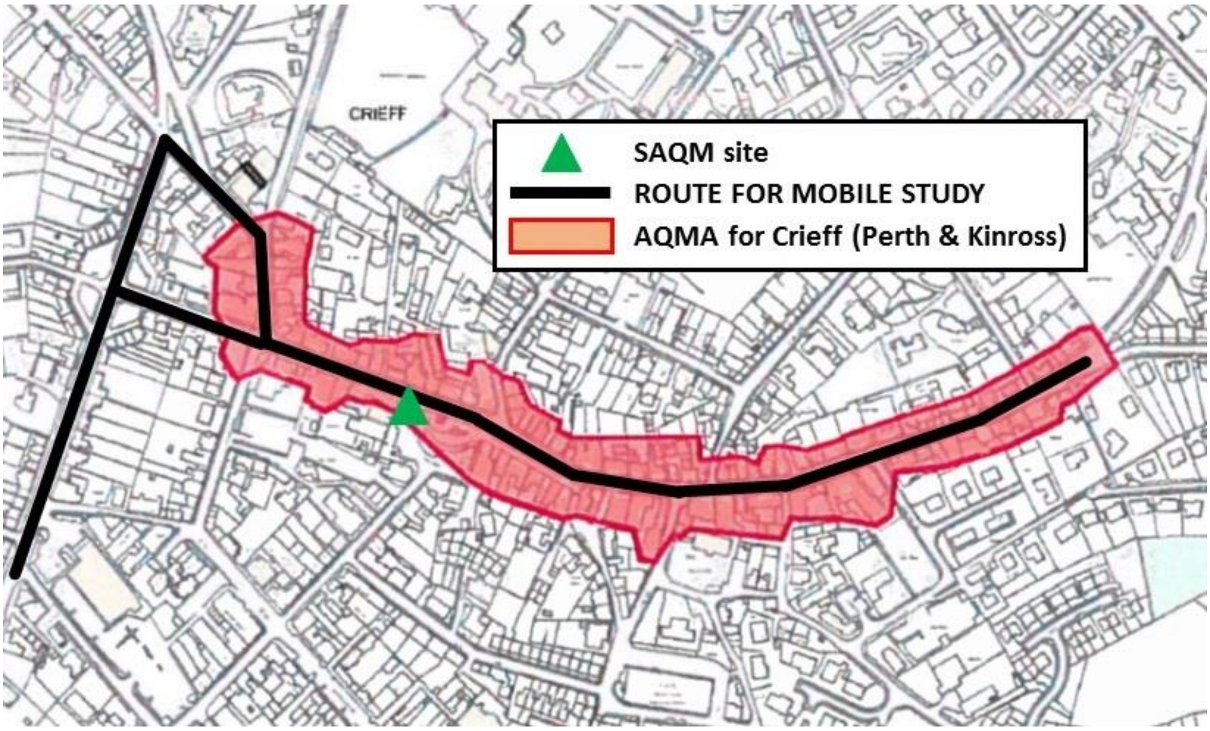


Figure A4-11: Paisley, Renfrewshire AQMA, mobile study route and SAQD monitoring site

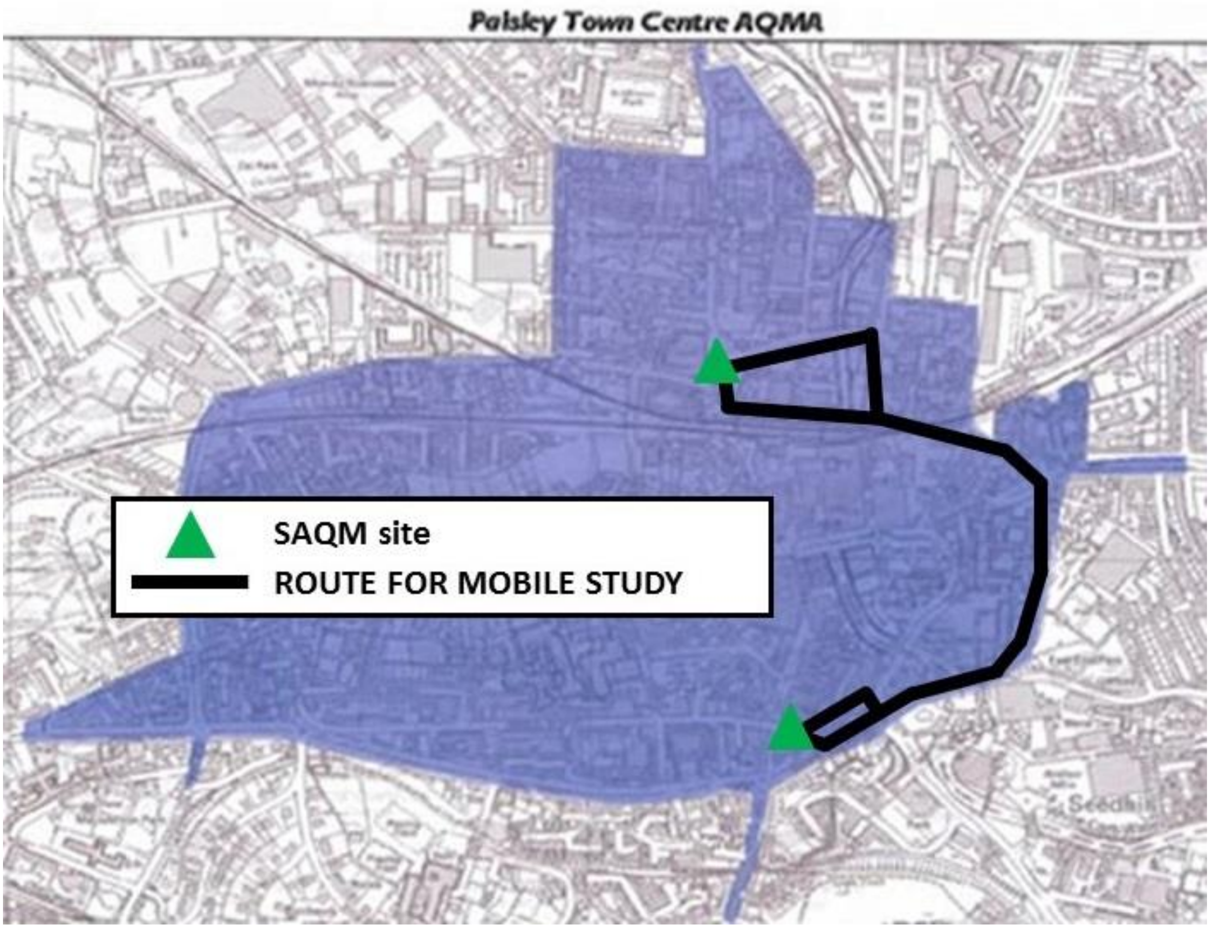


Figure A4-12: Bearsden, East Dunbartonshire AQMA, mobile study route and SAQD monitoring site

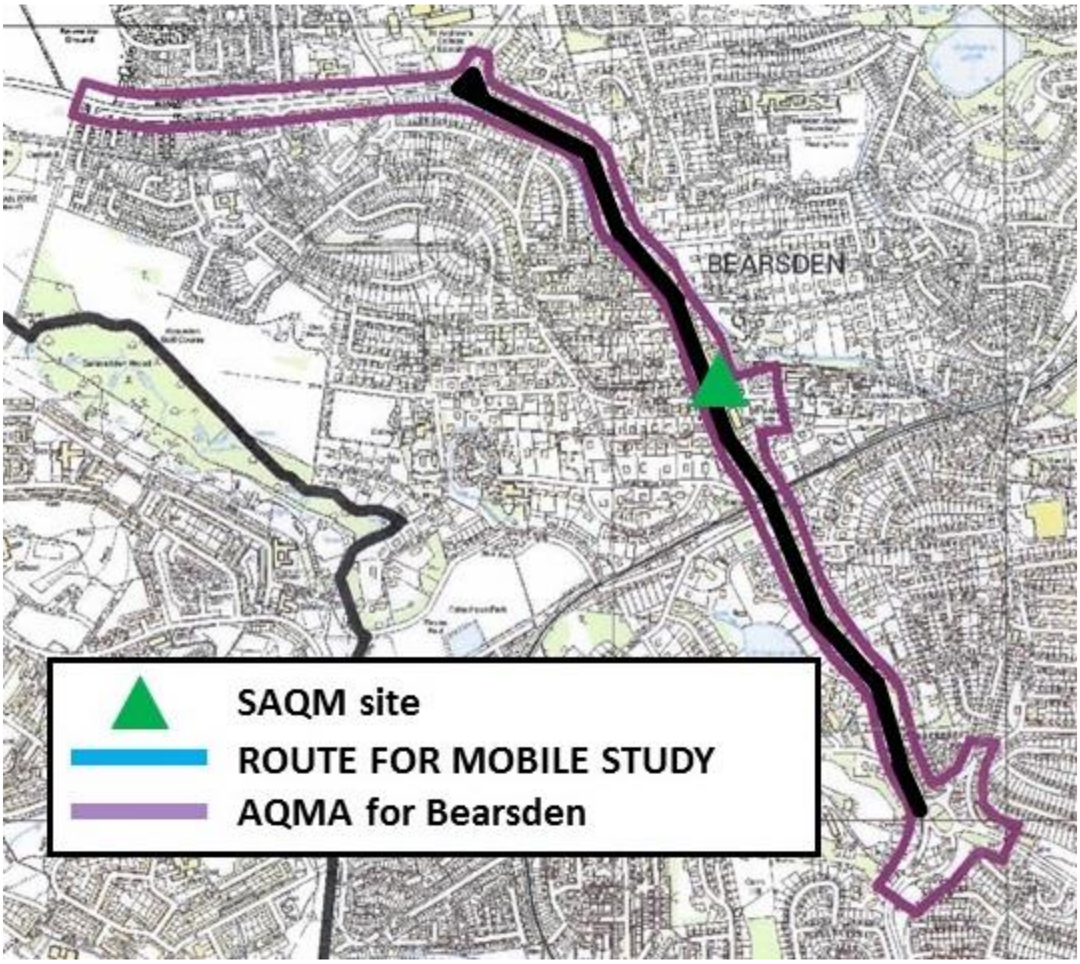


Figure A4-13: Edinburgh AQMA No.1 (since 2015 this AQMA has been expanded, but is not shown), mobile study route and SAQD monitoring sites

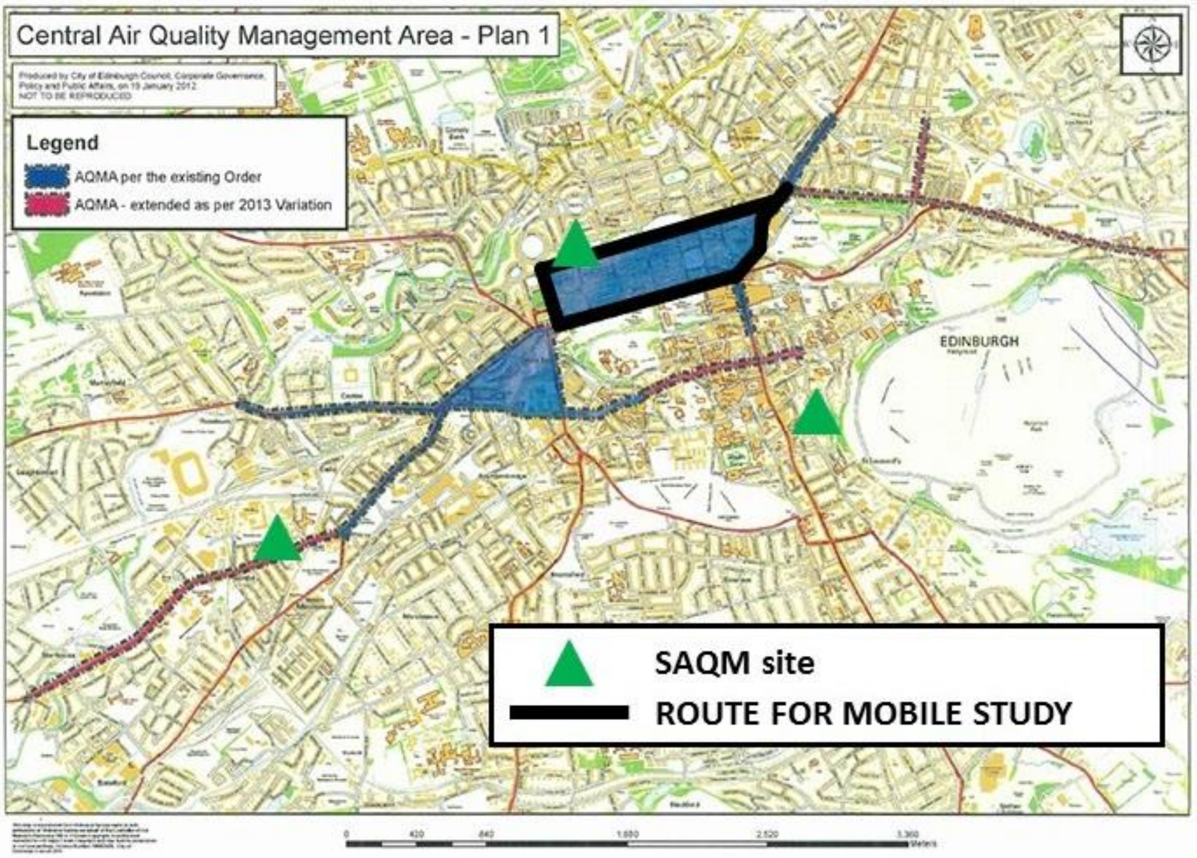


Figure A4-14: Aberdeen City Centre AQMA, mobile study route and SAQD monitoring sites

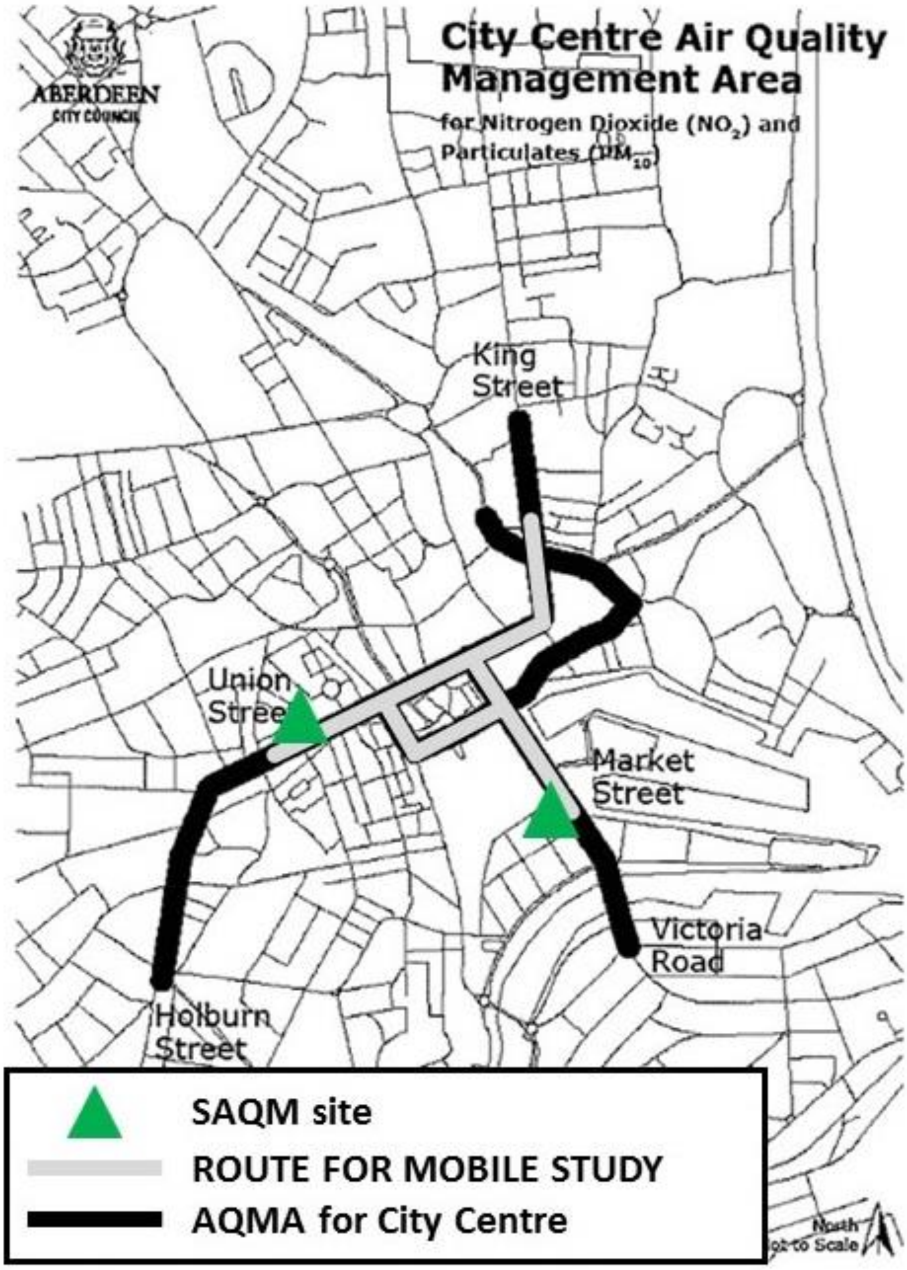


Figure A4-15: Broxburn, West Lothian AQMA, mobile study route and SAQD sites

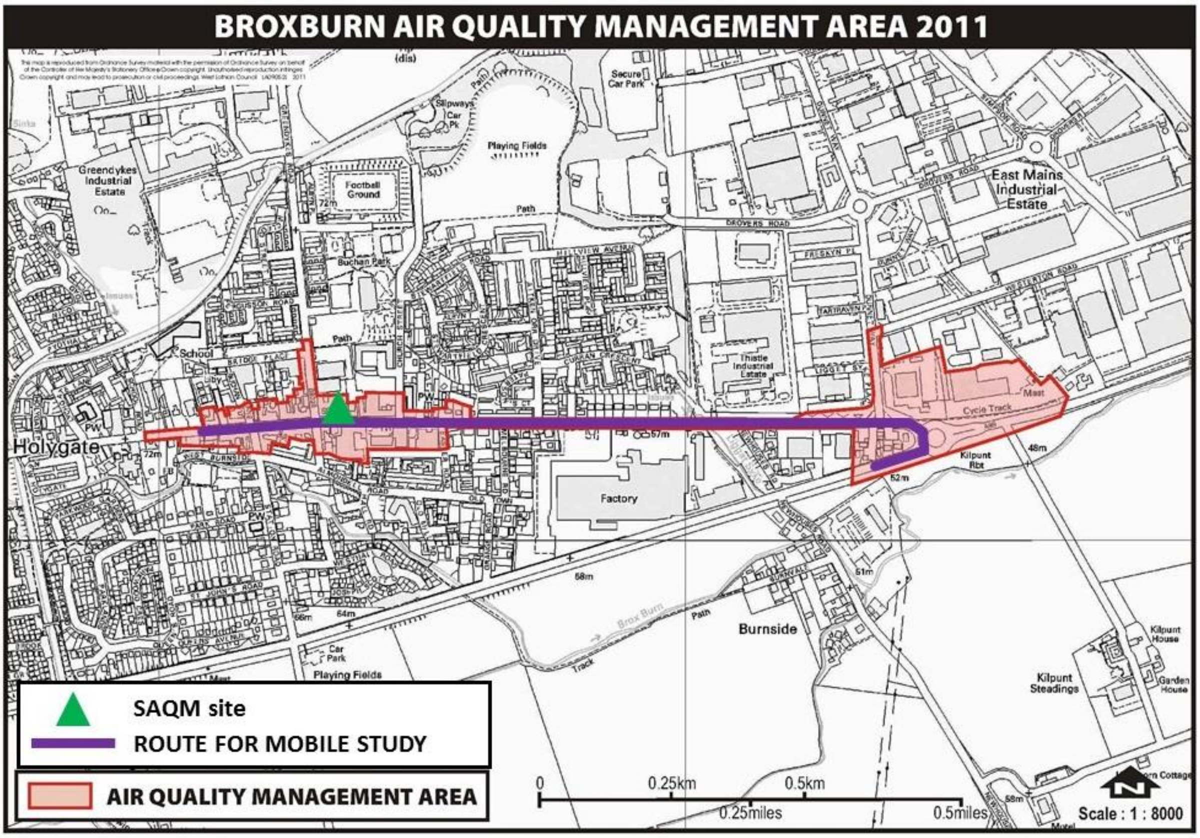
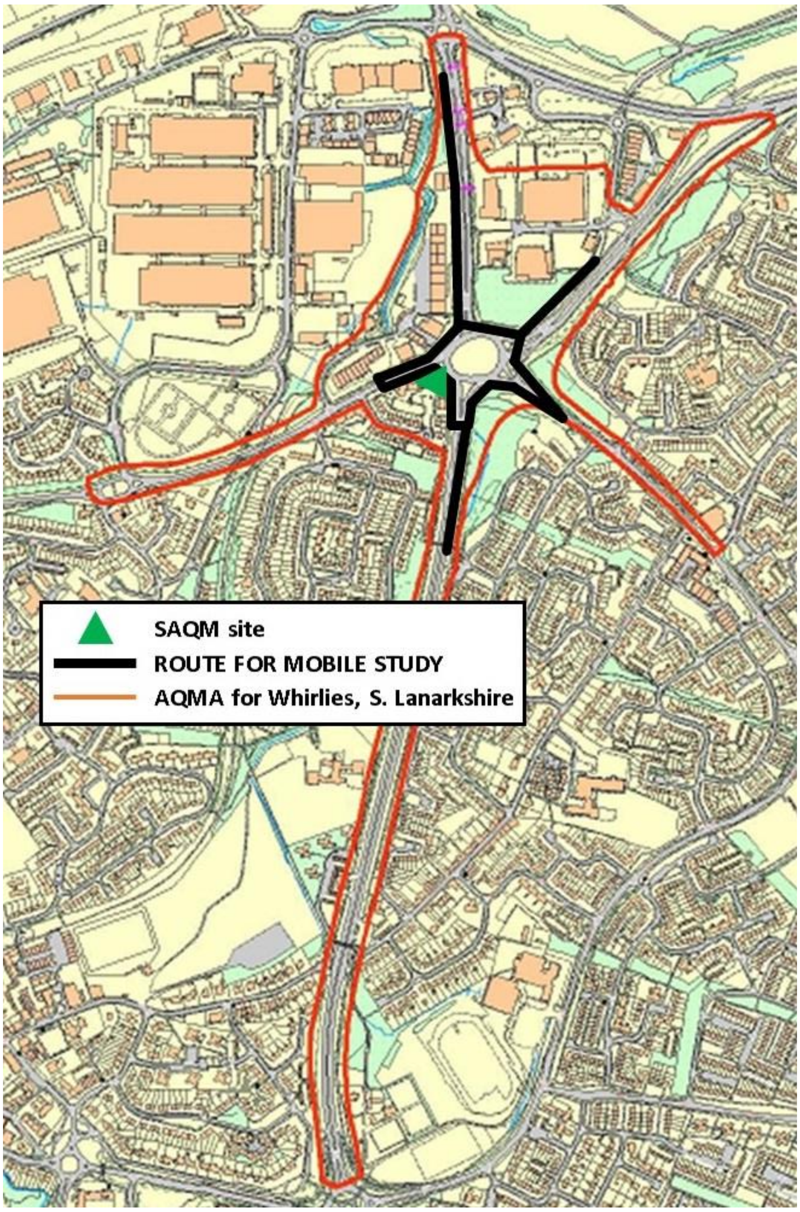


Figure A4-16: Whirlies, South Lanarkshire AQMA, mobile study route and SAQD monitoring site



Appendix 5: Tables & Results of $PM_{2.5}$ and PM_{10} Monitoring Sites in Scotland

Table A5: $PM_{2.5}$ and PM_{10} monitoring stations in Scotland operating from (during part of the period) January 2014 to January 2016

Site Code	Site Name	Pollutants Measured	Latitude	Longitude	Type	Currently Operational	Start of $PM_{2.5}$ measure	End of $PM_{2.5}$ measure	Start of PM_{10} measure	End of PM_{10} measure
ABD	Aberdeen	$PM_{2.5}$ PM_{10}	57.157504	-2.0939445	URBAN BACKGROUND	Yes	20/02/09		18/09/99	
ABD3	Aberdeen Union St	$PM_{2.5}$ PM_{10}	57.144702	-2.1064877	ROADSIDE	Yes	11/04/14		01/01/05	
ACTH	Auchencorth Moss*	$PM_{2.5}$ PM_{10}	55.793236	-3.2447825	RURAL	Yes	01/01/06		14/08/07	
AD2	Aberdeen Market St 2	$PM_{2.5}$ PM_{10}	57.141922	-2.091664	ROADSIDE	Yes	29/09/15		27/11/12	
ED3	Edinburgh St Leonards	$PM_{2.5}$ PM_{10}	55.945546	-3.1824137	URBAN BACKGROUND	Yes	01/10/08		24/11/03	
FAL7	Falkirk Banknock	$PM_{2.5}$ PM_{10}	55.988456	-3.9692891	ROADSIDE	Yes	28/01/15		01/01/13	
	Glasgow High St	$PM_{2.5}$ PM_{10}	55.860936	-4.238214	ROADSIDE	Yes	27/01/15		27/01/15	
GLA4	Glasgow Kerbside	$PM_{2.5}$ PM_{10}	55.859218	-4.2589863	KERBSIDE	No	28/05/09	31/12/14	10/03/97	31/12/14
	Glasgow Townhead	$PM_{2.5}$ PM_{10}	55.865782	-4.243631	URBAN BACKGROUND	Yes	07/10/13		07/10/13	
GLO1	Glasgow Airport Osiris	$PM_{2.5}$ PM_{10}	55.868025	-4.425942	AIRPORT	No	05/02/14	31/03/14	05/02/14	31/03/14
GRAN	Grangemouth	$PM_{2.5}$ PM_{10}	56.010449	-3.7042905	URBAN INDUSTRIAL	Yes	03/12/08		01/01/01	
INV2	Inverness[#]	$PM_{2.5}$ PM_{10}	57.481411	-4.2412714	ROADSIDE	Yes	01/06/08		11/07/01	
IRV	North Ayrshire Irvine High St	$PM_{2.5}$ PM_{10}	55.614578	-4.6667898	KERBSIDE	Yes	16/04/15		12/02/09	
ROSY	Fife Rosyth	$PM_{2.5}$ PM_{10}	56.03636	-3.4178835	ROADSIDE	Yes	20/07/15		13/03/08	
SL03	South Lanarkshire Lanark	$PM_{2.5}$ PM_{10}	55.673931	-3.7756585	ROADSIDE	Yes	10/04/14		10/04/15	
SL06	South Lanarkshire Uddingston	$PM_{2.5}$ PM_{10}	55.818357	-4.081839	ROADSIDE	Yes	04/03/15		04/03/15	
WDB3	W. Dunbartonshire Clydebank	$PM_{2.5}$ PM_{10}	55.917921	-4.4061851	ROADSIDE	Yes	13/03/15		01/02/07	

* Two different instruments are used at Auchencorth Moss, a Partisol recording daily measurements and FDMS recording hourly $PM_{2.5}$ and PM_{10} measurements

[#] Inverness operates a Partisol instrument recording daily measurements for $PM_{2.5}$ and PM_{10}

TableA6: PM_{10} monitoring stations in Scotland operating from (during part of the period) January 2014 to January 2016

Site Code	Site Name	Pollutants Measured	Latitude	Longitude	Type	Currently Operational	Start of PM_{10} measure	End of PM_{10} measure
ABD1	Aberdeen Anderson Dr	PM_{10}	57.128533	-2.1254203	ROADSIDE	Yes	01/01/05	
ABD8	Aberdeen Wellington Road	PM_{10}	57.133888	-2.0942315	ROADSIDE	Yes	01/01/08	
AD1	Aberdeen King Street	PM_{10}	57.169738	-2.0953482	ROADSIDE	Yes	25/11/08	
	Angus Forfar Glamis Road	PM_{10}	56.642076	-2.894328	ROADSIDE	Yes	23/10/15	
ALO2	Alloa A907	PM_{10}	56.117343	-3.791818	ROADSIDE	Yes	14/01/15	
ALOA	Alloa	PM_{10}	56.11809	-3.7908739	ROADSIDE	No	20/09/06	13/01/15
AYR	South Ayrshire Ayr High St	PM_{10}	55.464579	-4.6316039	ROADSIDE	Yes	11/09/07	
BRX	West Lothian Broxburn	PM_{10}	55.934526	-3.4683967	ROADSIDE	Yes	01/01/08	
CUPA	Fife Cupar	PM_{10}	56.31939	-3.0136538	KERBSIDE	Yes	19/12/05	
DUN1	Dundee Mains Loan	PM_{10}	56.47544	-2.9598377	URBAN BACKGROUND	Yes	28/03/06	
DUN3	Dundee Union Street	PM_{10}	56.459152	-2.97137	KERBSIDE	Yes	01/01/06	
DUN4	Dundee Broughty Ferry Road	PM_{10}	56.467516	-2.9434394	ROADSIDE	Yes	01/01/06	
DUN5	Dundee Seagate	PM_{10}	56.462381	-2.967379	KERBSIDE	Yes	09/05/11	

Site Code	Site Name	Pollutants Measured	Latitude	Longitude	Type	Currently Operational	Start of PM_{10} measure	End of PM_{10} measure
DUN6	Dundee Lochee Road	PM_{10}	56.536638	-3.1272266	KERBSIDE	Yes	08/04/11	
DUNF	Fife Dunfermline	PM_{10}	56.073947	-3.4488252	ROADSIDE	Yes	01/04/11	
DUNM	Dundee Meadowside	PM_{10}	56.464258	-2.971386	ROADSIDE	Yes	22/06/11	
EASM	East Ayrshire St Marnock St FDMS	PM_{10}	55.607465	-4.4979918	ROADSIDE	Yes	17/02/12	
ED10	Edinburgh Glasgow Road	PM_{10}	55.939026	-3.3927272	ROADSIDE	Yes	04/09/12	
ED11	Edinburgh Currie	PM_{10}	55.897224	-3.3193576	SUBURBAN	Yes	01/01/13	
ED7	Edinburgh Queen Street	PM_{10}	55.954031	-3.2044538	ROADSIDE	Yes	01/01/07	
ED8	Edinburgh Salamander St	PM_{10}	55.97459	-3.1613306	ROADSIDE	Yes	17/09/09	
ED9	Edinburgh Queensferry Road	PM_{10}	55.960492	-3.3033126	ROADSIDE	Yes	01/01/11	
EDB1	East Dunbartonshire Bishopbriggs	PM_{10}	55.904145	-4.22501	ROADSIDE	Yes	04/12/03	
EDB2	East Dunbartonshire Bearsden	PM_{10}	55.919544	-4.3335416	ROADSIDE	Yes	01/11/05	
EDB3	East Dunbartonshire Kirkintilloch	PM_{10}	55.935738	-4.1514887	ROADSIDE	Yes	03/08/07	

Site Code	Site Name	Pollutants Measured	Latitude	Longitude	Type	Currently Operational	Start of PM_{10} measure	End of PM_{10} measure
EDB4	East Dunbartonshire Milngavie	PM_{10}	55.938248	-4.3177571	ROADSIDE	Yes	01/08/11	
EK0	South Lanarkshire East Kilbride	PM_{10}	55.775177	-4.1635185	ROADSIDE	Yes	13/03/08	
FAL2	Falkirk Park St	PM_{10}	56.000662	-3.78316	ROADSIDE	Yes	01/01/07	28/04/14
FAL5	Falkirk Haggs	PM_{10}	55.991087	-3.9416854	ROADSIDE	Yes	01/01/13	
FAL6	Falkirk West Bridge Street	PM_{10}	56.000507	-3.7901288	ROADSIDE	Yes	16/09/09	
FALK	Falkirk Grangemouth MC	PM_{10}	56.018969	-3.7210468	URBAN BACKGROUND	Yes	01/01/03	
FINI*	East Ayrshire Kilmarnock John Finnie St	PM_{10}	55.61095	-4.4990233	ROADSIDE	Yes	01/02/10	
GL1	Glasgow Abercromby Street	PM_{10}	55.850514	-4.2311296	ROADSIDE	Yes	16/03/07	
GL2	Glasgow Nithsdale Road	PM_{10}	55.836288	-4.2708318	ROADSIDE	Yes	23/03/07	
GL3	Glasgow Broomhill	PM_{10}	55.876036	-4.3187636	ROADSIDE	Yes	23/10/07	
GL6	Glasgow Burgher St	PM_{10}	55.851062	-4.1971631	ROADSIDE	Yes	28/07/11	
GL9	Glasgow Dumbarton Road	PM_{10}	55.870766	-4.3184494	ROADSIDE	Yes	21/11/12	
GLA5	Glasgow Anderston	PM_{10}	55.861564	-4.2716357	URBAN BACKGROUND	Yes	01/01/05	03/11/14

Site Code	Site Name	Pollutants Measured	Latitude	Longitude	Type	Currently Operational	Start of PM_{10} measure	End of PM_{10} measure
GLA6	Glasgow Byres Road	PM_{10}	55.861158	-4.2935378	ROADSIDE	Yes	01/01/05	
GLA7	Glasgow Waulkmillglen Reservoir	PM_{10}	55.79358	-4.3539024	RURAL	Yes	01/01/05	
HARB	South Ayrshire Ayr Harbour	PM_{10}	55.470162	-4.633681	ROADSIDE	Yes	05/05/12	
INC2	Inverclyde Greenock A8	PM_{10}	55.943936	-4.7349155	ROADSIDE	Yes	18/03/14	
KIR	Fife Kirkcaldy	PM_{10}	56.124319	-3.1413398	ROADSIDE	Yes	08/02/11	
MUS1	East Lothian Muss N High St PM10	PM_{10}	55.944008	-3.0592228	ROADSIDE	Yes	01/05/11	
NL1	N Lanarkshire Coatbridge Whifflet	PM_{10}	55.85204	-4.01956	URBAN BACKGROUND	Yes	01/01/07	
NL10*	N Lanarkshire Cumbernauld	PM_{10}	55.943115	-4.0161322	URBAN BACKGROUND	No	01/01/11	01/05/14
NL11	N Lanarkshire Kirkshaws	PM_{10}	55.843583	-4.037413	URBAN BACKGROUND	Yes	28/06/14	
NL3	N Lanarkshire Chapelhall	PM_{10}	55.84589	-3.9472645	ROADSIDE	Yes	01/01/05	
NL4	N Lanarkshire Croy	PM_{10}	55.957759	-4.0393693	ROADSIDE	Yes	01/01/06	
NL6	N Lanarkshire Motherwell	PM_{10}	55.788275	-3.9876759	ROADSIDE	Yes	30/10/07	

Site Code	Site Name	Pollutants Measured	Latitude	Longitude	Type	Currently Operational	Start of PM_{10} measure	End of PM_{10} measure
NL7	N Lanarkshire Shawhead Coatbridge	PM_{10}	55.843523	-4.0232232	ROADSIDE	Yes	16/06/09	
NL9	N Lanarkshire Moodiesburn	PM_{10}	55.908941	-4.0823404	ROADSIDE	Yes	08/10/08	
PAI3	Paisley Gordon Street	PM_{10}	55.841795	-4.4239688	ROADSIDE	Yes	01/01/06	
PAI4	Paisley St James St	PM_{10}	55.848115	-4.426619	ROADSIDE	Yes	19/08/10	
PET1	Perth Crieff	PM_{10}	56.373126	-3.8414753	ROADSIDE	Yes	01/04/10	
PET2	Perth Atholl Street	PM_{10}	56.399328	-3.4341056	ROADSIDE	Yes	28/07/04	
PET3	Perth Muirton	PM_{10}	56.41467	-3.44964	URBAN BACKGROUND	Yes	05/07/12	
PETH	Perth High Street	PM_{10}	56.396599	-3.4322856	ROADSIDE	Yes	11/06/03	
REN1	Renfrew Cockels Loan	PM_{10}	55.863313	-4.390978	ROADSIDE	Yes	26/09/13	
SHED *	East Renfrewshire Sheddens	PM_{10}	55.786255	-4.2746818	ROADSIDE	No	01/05/08	03/09/14
SL01*	South Lanarkshire Raith Interchange	PM_{10}	55.8001578	-4.057717	ROADSIDE	No	08/04/10	23/04/14
SL04	South Lanarkshire Rutherglen	PM_{10}	55.828403	-4.2187978	ROADSIDE	Yes	01/01/11	
SL05	South Lanarkshire Hamilton	PM_{10}	55.774018	-4.03736	ROADSIDE	Yes	16/10/13	
SL07	South Lanarkshire Cambuslang	PM_{10}	55.818802	-4.167073	ROADSIDE	Yes	18/02/15	

Site Code	Site Name	Pollutants Measured	Latitude	Longitude	Type	Currently Operational	Start of PM_{10} measure	End of PM_{10} measure
STRL	Stirling Craig's Roundabout	PM_{10}	56.11472	-3.9321788	ROADSIDE	Yes	01/01/09	
WLC1	West Lothian Linlithgow High St 2	PM_{10}	55.976518	-3.5976177	ROADSIDE	Yes	25/10/13	
WLN4	West Lothian Newton	PM_{10}	55.983654	-3.4568585	URBAN BACKGROUND	Yes	23/05/12	

Table A7: Results from SAQD monitoring sites in 2014 for PM$_{2.5}$ & PM$_{10}$ means & % data capture, and monthly & annual calculated PM$_{2.5}$ / PM$_{10}$ ratios

Monitoring Site	Value	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Means
Auchencorth Moss (Partisol - Measured Daily)	PM$_{2.5}$	4	2	6	6	4	3	3	2	8	2	5	2	4
	% data capture	100	96	100	100	100	97	100	90	100	100	100	100	99
	PM$_{10}$	6	4	9	11	7	7	6	4	11	5	6	4	7
	% data capture	100	96	100	100	100	97	100	97	100	100	100	100	99
	PM$_{2.5}$ / PM$_{10}$ ratio	0.67	0.50	0.67	0.55	0.57	0.43	0.50	0.50	0.73	0.40	0.83	0.50	0.57
Inverness (Partisol - Measured Daily)	PM$_{2.5}$	8	5	8	8	5	3	4	4	8	5	9	5	6
	% data capture	97	96	48	100	100	100	100	97	100	100	100	100	95
	PM$_{10}$	11	10	15	16	11	9	8	8	13	8	13	8	11
	% data capture	97	96	100	100	100	97	100	84	97	100	100	100	98
	PM$_{2.5}$ / PM$_{10}$ ratio	0.73	0.50		0.50	0.45	0.33	0.50	0.50	0.62	0.63	0.69	0.63	0.55
Aberdeen Errol Place	PM$_{2.5}$	11	8	8	12	10	9	10	7	15	8	13	10	10
	% data capture	99	78	49	99	97	93	83	82	81	99	88	91	87
	PM$_{10}$	17	13	14	18	16	13	14	13	17	11	20	9	15
	% data capture	72	58	86	99	99	100	84	40	71	85	76	91	80
	PM$_{2.5}$ / PM$_{10}$ ratio				0.67	0.63	0.69	0.71			0.73	0.65	1.11	0.74
Aberdeen Union Street Roadside	PM$_{2.5}$				17	12					9	11	12	12
	% data capture				56	26					37	20	25	33
	PM$_{10}$	20	16	23	26	22	14	15	12	23	16	18	15	18
	% data capture	97	99	100	88	35	100	99	99	92	89	21	25	79
	PM$_{2.5}$ / PM$_{10}$ ratio													
Auchencorth Moss	PM$_{2.5}$	4	3	9	10	8	7	7	6	12	6	7	5	7

Monitoring Site	Value	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Means
	% data capture	79	57	95	74	91	89	78	71	100	100	100	100	86
	PM_{10}	6	5	9	11	8	8	8	6	13	7	8	5	8
	% data capture	99	72	99	100	99	99	95	89	99	100	100	99	96
	$PM_{2.5}$ / PM_{10} ratio	0.67		1.00		1.00	0.88	0.88		0.92	0.86	0.88	1.00	0.90
Edinburgh St Leonards	$PM_{2.5}$	9	7	11	12	9	7	8	7	15			10	10
	% data capture	98	66	84	100	100	100	100	80	38			19	79
	PM_{10}	15	12	15	17	12	10	11	10	19			10	13
	% data capture	99	63	99	100	100	100	100	80	38			61	84
	$PM_{2.5}$ / PM_{10} ratio	0.60		0.73	0.71	0.75	0.70	0.73	0.70					0.70
Glasgow Kerbside	$PM_{2.5}$	18	14	18	18	19	15		8	21	13	20	13	16
	% data capture	72	74	78	74	6	50		66	71	77	82	83	67
	PM_{10}	24	19	27	25		19	19	13	29	20	28	19	22
	% data capture	82	86	90	57		29	86	83	78	89	88	89	78
	$PM_{2.5}$ / PM_{10} ratio			0.67							0.65	0.71	0.68	0.68
Glasgow Townhead	$PM_{2.5}$	7	5	9	10	7	5	6	4	14	7	9	7	8
	% data capture	72	95	99	100	100	100	89	84	83	95	100	55	89
	PM_{10}	11	10	15	15	12	11	13	7	18	12	16	14	13
	% data capture	66	8	98	100	86	100	88	90	99	100	100	19	80
	$PM_{2.5}$ / PM_{10} ratio			0.60	0.67	0.58	0.45	0.46	0.57	0.78	0.58	0.56		0.58
Grangemouth	$PM_{2.5}$	6	5	9	11	7	6	7	5	14	7	10	7	8
	% data capture	99	61	99	100	72	100	100	90	100	91	95	100	92
	PM_{10}	11	8	14	17	12	10	11	9	18	11	14	11	12

Monitoring Site	Value	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Means
	% data capture	98	86	98	99	92	100	100	88	100	93	95	100	96
	$PM_{2.5}$ / PM_{10} ratio	0.55		0.64	0.65		0.60	0.64	0.56	0.78	0.64	0.71	0.64	0.64

Table A8: Results from SAQD monitoring sites in 2015 for $PM_{2.5}$ & PM_{10} means & % data capture, and monthly & annual calculated $PM_{2.5}$ / PM_{10} ratios

Monitoring Site	Value	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Means
Auchencorth Moss (Partisol - Measured Daily)	$PM_{2.5}$	2	5	6	5	2	2	2	2	3				3
	% data capture	58	100	100	100	97	100	100	97	100				95
	PM_{10}	6	8	9	7	5	5	5	5	5				6
	% data capture	81	100	100	100	100	100	100	97	100				98
	$PM_{2.5}$ / PM_{10} ratio		0.63	0.67	0.71	0.40	0.40	0.40	0.40	0.60				0.53
Inverness (Partisol - Measured Daily)	$PM_{2.5}$	5	6	6	5	3	4	7	8	9				6
	% data capture	97	96	94	100	100	90	74	97	100				94
	PM_{10}	9	12	13	11	8	7	7	8	9				9
	% data capture	97	96	87	83	94	97	97	90	100				93
	$PM_{2.5}$ / PM_{10} ratio	0.56	0.50	0.46	0.45	0.38	0.57		0.50	0.44				0.48
Aberdeen Errol Place	$PM_{2.5}$	8	13	13	10	7	9	6	6	5	8	5	6	8
	% data capture	89	86	99	98	100	100	86	100	68	99	100	99	94
	PM_{10}	10	15	16	11	8	10	10	12	10	16	9	13	12
	% data capture	96	95	100	98	99	90	89	96	99	99	100	100	97
	$PM_{2.5}$ / PM_{10} ratio	0.80	0.87	0.81	0.91	0.88	0.90	0.60	0.50		0.50	0.56	0.46	0.71
	$PM_{2.5}$	10	12	11	9	6	11	12	11	13	13	10	9	11

Monitoring Site	Value	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Means
Aberdeen Union Street Roadside	% data capture	95	99	99	91	77	40	26	97	96	88	90	100	83
	PM_{10}	17	21	22	17	12	11				20	14	14	16
	% data capture	96	99	100	88	78	5				90	91	100	83
	$PM_{2.5}$ / PM_{10} ratio	0.59	0.57	0.50	0.53	0.50					0.65	0.71	0.64	0.59
Auchencorth Moss	$PM_{2.5}$	6	4	5	4	1	2	2	2	3	4	1	2	3
	% data capture	95	92	97	100	99	99	89	88	99	100	100	100	97
	PM_{10}	17	7	9	8	6	8				10	5	7	9
	% data capture	96	94	99	100	100	86				100	100	100	97
	$PM_{2.5}$ / PM_{10} ratio	0.35	0.57	0.56	0.50	0.17	0.25				0.40	0.20	0.29	0.36
Edinburgh St Leonards	$PM_{2.5}$	9	8	8	6	4	5	4	6	8	10	6	5	7
	% data capture	59	95	100	100	100	100	94	63	44	100	100	89	87
	PM_{10}	11	18						6	11	14	9	8	11
	% data capture	92	53						21	93	100	100	88	78
	$PM_{2.5}$ / PM_{10} ratio										0.71	0.67	0.63	0.67
Glasgow Kerbside	$PM_{2.5}$	9												9
	% data capture	17												17
	PM_{10}	16												16
	% data capture	17												17
	$PM_{2.5}$ / PM_{10} ratio													
Glasgow Townhead	$PM_{2.5}$	4	9	9	8	5	6	5	6	7	9	6	5	7
	% data capture	85	76	71	95	100	100	92	93	100	100	100	100	93
	PM_{10}		20	40					9	11	15	11	10	17

Monitoring Site	Value	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Means
	% data capture		46						83	100	100	100	100	88
	$PM_{2.5}$ / PM_{10} ratio								0.67	0.64	0.60	0.55	0.50	0.59
Grangemouth	$PM_{2.5}$	8	11	11	10	6	8	7	8	10	14	9	9	9
	% data capture	89	99	99	98	99	100	91	90	100	100	87	90	95
	PM_{10}	12	15	16	14				10	10	14	9	10	12
	% data capture	89	99	100	98				46	100	100	87	90	90
	$PM_{2.5}$ / PM_{10} ratio	0.67	0.73	0.69	0.71					1.00	1.00	1.00	0.90	0.84
Aberdeen Market Street 2	$PM_{2.5}$										10	6	8	8
	% data capture										98	100	95	98
	PM_{10}	13	22	28	22	15	16	20	24	18	19	14	19	19
	% data capture	99	89	100	97	98	100	97	99	94	98	89	95	96
	$PM_{2.5}$ / PM_{10} ratio										0.53	0.43	0.42	0.46
Falkirk Banknock	$PM_{2.5}$		8	10	8	4	4	4	4	5	8	5	5	6
	% data capture		55	100	100	100	100	100	100	96	100	100	100	96
	PM_{10}	12	12	23	16	9	9	7	8	8	12	8	9	11
	% data capture	86	55	100	100	100	100	100	100	96	100	100	100	95
	$PM_{2.5}$ / PM_{10} ratio			0.43	0.50	0.44	0.44	0.57	0.50	0.63	0.67	0.63	0.56	0.54
Fife Rosyth	$PM_{2.5}$							4	5	6	10	6	6	6
	% data capture							35	100	96	100	100	100	89
	PM_{10}	14	21	21	14	16	17	12	9	10	14	8	10	14
	% data capture	94	98	100	35	92	91	77	100	96	100	100	100	90
	$PM_{2.5}$ / PM_{10} ratio								0.56	0.60	0.71	0.75	0.60	0.64

Monitoring Site	Value	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Means
Glasgow High Street	$PM_{2.5}$	7	12	10	9	6	7	6	7	9	12	9	8	9
	% data capture	16	96	99	99	99	100	90	98	94	100	100	100	91
	PM_{10}	13	20	21	18	14	14	12	13	15	19	16	15	16
	% data capture	16	96	100	100	99	100	90	98	95	100	100	100	91
	$PM_{2.5}$ / PM_{10} ratio		0.60	0.48	0.50	0.43	0.50	0.50	0.54	0.60	0.63	0.56	0.53	0.53
North Ayrshire Irvine High St	$PM_{2.5}$				8	6	6	5	5	7	9	7	8	5
	% data capture				46	87	99	99	100	97	99	100	100	69
	PM_{10}	13	15	19	15	13	11	9	11	13	16	13	16	14
	% data capture	97	98	99	90	87	99	99	100	97	99	100	100	97
	$PM_{2.5}$ / PM_{10} ratio					0.46	0.55	0.56	0.45	0.54	0.56	0.54	0.50	0.52
South Lanarkshire Lanark	$PM_{2.5}$				7	5	6	4	5	6	9	6	7	6
	% data capture				64	99	100	96	100	98	100	100	99	95
	PM_{10}				14	10	10	8	9	10	13	9	11	10
	% data capture				63	99	100	96	100	98	100	100	99	95
	$PM_{2.5}$ / PM_{10} ratio					0.50	0.60	0.50	0.56	0.60	0.69	0.67	0.64	0.59
South Lanarkshire Uddingston	$PM_{2.5}$			14	9	5	5	4	4	5	8	5	5	6
	% data capture			67	100	99	100	100	99	97	99	100	100	96
	PM_{10}			21	16	10	9	9	8	10	12	8	8	11
	% data capture			67	100	99	100	99	99	97	100	100	100	96
	$PM_{2.5}$ / PM_{10} ratio				0.56	0.50	0.56	0.44	0.50	0.50	0.67	0.63	0.63	0.55
West Dunbartonshire Clydebank	$PM_{2.5}$			8	8	5	6	5	5	6	9	6	6	6
	% data capture			41	93	99	100	100	100	98	100	100	100	93

Monitoring Site	Value	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Means
	PM_{10}			12	13	9	9	8	9	9	13	9	9	10
	% data capture			41	94	100	100	100	100	98	100	100	100	93
	$PM_{2.5}$ / PM_{10} ratio				0.62	0.56	0.67	0.63	0.56	0.67	0.69	0.67	0.67	0.63

Table A9: Results from SAQD monitoring sites in 2014 for monthly & annual calculated $PM_{2.5}$ / PM_{10} ratios (to see monthly mean for $PM_{2.5}$ and PM_{10} and capture rates see Table A7)

	MONTHLY MEAN												ANNUAL	
Monitoring Site	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	MEAN	SD
Auchencorth Moss (Partisol - Measured Daily)	0.67	0.50	0.67	0.55	0.57	0.43	0.50	0.50	0.73	0.40	0.83	0.50	0.57	0.13
Inverness (Partisol - Measured Daily)	0.73	0.50		0.50	0.45	0.33	0.50	0.50	0.62	0.63	0.69	0.63	0.55	0.12
Aberdeen Errol Place				0.67	0.63	0.69	0.71			0.73	0.65	1.11	0.74	0.17
Aberdeen Union Street Roadside														
Auchencorth Moss	0.67		1.00		1.00	0.88	0.88		0.92	0.86	0.88	1.00	0.90	0.11
Edinburgh St Leonards	0.60		0.73	0.71	0.75	0.70	0.73	0.70					0.70	0.05
Glasgow Kerbside			0.67							0.65	0.71	0.68	0.68	0.03
Glasgow Townhead			0.60	0.67	0.58	0.45	0.46	0.57	0.78	0.58	0.56		0.58	0.10
Grangemouth	0.55		0.64	0.65		0.60	0.64	0.56	0.78	0.64	0.71	0.64	0.64	0.07
MEANS	0.64	0.50	0.72	0.62	0.66	0.58	0.63	0.57	0.76	0.64	0.72	0.76	0.67	0.11
SD	0.07	0.00	0.14	0.08	0.19	0.19	0.15	0.08	0.11	0.14	0.11	0.24		

Table A10: Results from SAQD monitoring sites in 2015 for monthly & annual calculated $PM_{2.5}$ / PM_{10} ratios (to see monthly mean for $PM_{2.5}$ and PM_{10} and capture rates see Table A8

Monitoring Site	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	MEAN	SD
Auchencorth Moss (Partisol - Measured Daily)		0.63	0.67	0.71	0.40	0.40	0.40	0.40	0.60				0.53	0.14
Inverness (Partisol - Measured Daily)	0.56	0.50	0.46	0.45	0.38	0.57		0.50	0.44				0.48	0.06
Aberdeen Errol Place	0.80	0.87	0.81	0.91	0.88	0.90	0.60	0.50		0.50	0.56	0.46	0.71	0.18
Aberdeen Union Street Roadside	0.59	0.57	0.50	0.53	0.50					0.65	0.71	0.64	0.59	0.08
Auchencorth Moss	0.35	0.57	0.56	0.50	0.17	0.25				0.40	0.20	0.29	0.36	0.15
Edinburgh St Leonards										0.71	0.67	0.63	0.67	0.04
Glasgow Kerbside														
Glasgow Townhead								0.67	0.64	0.60	0.55	0.50	0.59	0.07
Grangemouth	0.67	0.73	0.69	0.71					1.00	1.00	1.00	0.90	0.84	0.15
Aberdeen Market Street 2										0.53	0.43	0.42	0.46	0.06
Falkirk Banknock			0.43	0.50	0.44	0.44	0.57	0.50	0.63	0.67	0.63	0.56	0.54	0.08
Fife Rosyth								0.56	0.60	0.71	0.75	0.60	0.64	0.08
Glasgow High Street		0.60	0.48	0.50	0.43	0.50	0.50	0.54	0.60	0.63	0.56	0.53	0.53	0.06
North Ayrshire Irvine High St					0.46	0.55	0.56	0.45	0.54	0.56	0.54	0.50	0.52	0.04
South Lanarkshire Lanark					0.50	0.60	0.50	0.56	0.60	0.69	0.67	0.64	0.59	0.07
South Lanarkshire Uddingston				0.56	0.50	0.56	0.44	0.50	0.50	0.67	0.63	0.63	0.55	0.07
West Dunbartonshire Clydebank				0.62	0.56	0.67	0.63	0.56	0.67	0.69	0.67	0.67	0.63	0.05
AVERAGE MONTHLY MEAN	0.59	0.64	0.57	0.60	0.47	0.54	0.52	0.52	0.62	0.64	0.61	0.57	0.58	0.11
SD	0.16	0.12	0.13	0.14	0.17	0.17	0.08	0.07	0.14	0.14	0.18	0.14		

Table A11: Results from SAQD monitoring sites in 2014 for data point & annual calculated $PM_{2.5}$ / PM_{10} ratios, including number of data points used and data captured

Monitoring Site	Annual Mean $PM_{2.5}$ / PM_{10} ratio	SD	data points (n)	* Data Captured
Auchencorth Moss (Partisol - Measured Daily)	0.57	0.21	341	93%
Inverness (Partisol - Measured Daily)	0.54	0.19	336	92%
Aberdeen Errol Place	0.65	0.21	5085	58%
Aberdeen Union Street Roadside	0.73	0.15	182	95%
Auchencorth Moss	0.74	0.21	5020	57%
Edinburgh St Leonards	0.66	0.20	4797	55%
Glasgow Kerbside	0.67	0.18	4625	53%
Glasgow Townhead	0.55	0.20	6158	70%
Grangemouth	0.61	0.21	7550	86%
AVERAGE	0.65	0.07	n/a	n/a

* A divsion of data points used to calculate the ratio by maximum number data points during operational days

Table A12: Results from SAQD monitoring sites in 2015 for data point & annual calculated $PM_{2.5}$ / PM_{10} ratios, including number of data points used and data captured

Site Name	Annula Mean $PM_{2.5}$ / PM_{10} ratio	SD	Data Points (n)	* Date Captured
Aberdeen Errol Place	0.91	0.75	7442	85%
Aberdeen Union Street	0.64	0.20	6965	80%
Auchencorth Moss - Partisol	0.55	0.22	233	64%
Auchencorth Moss	0.55	0.56	5353	61%
Edinburgh St Leonards	0.51	0.37	7039	80%
Glasgow Kerbside	n/a	n/a	n/a	n/a
Glasgow Townhead	0.64	0.39	3514	40%
Grangemouth	0.96	0.66	5723	65%
Inverness - Partisol	0.47	0.17	241	66%
Aberdeen Market Street 2	0.50	0.29	2051	23%
Falkirk Banknock	0.57	0.18	7625	87%
Fife Rosyth	0.60	0.16	3890	44%
Glasgow High St	0.55	0.27	7763	89%
North Ayrshire Irvine High St	0.55	0.16	6050	69%
South Lanarkshire Lanark	0.60	0.33	6208	71%
South Lanarkshire Uddingston	0.58	0.18	6968	80%
West Dunbartonshire Clydebank	0.62	0.16	6783	77%
Average	0.61	0.32	n/a	n/a

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