Ricardo Energy & Environment

PM2.5 Network in Scotland

$PM_{2.5}$ Network in Scotland

Investigation of current PM_{10} and $PM_{2.5}$ monitoring network within Scotland to help inform the future development of the network

Report for the Scottish Government

ED57729

The Scottish Government

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Executive Summary

The Scottish Government has committed to aligning the Scottish Air Quality Objectives for particulate pollution with the World Health Organization (WHO) guideline values. This would entail:

- Increasing the Objective for annual mean PM_{10} from 18 µg m^{-3} to a less stringent 20 µg m^{-3}
- Reducing the Objective for annual mean $PM_{2.5}$ from 12 µg m^{-3} to a more stringent 10 µg m^{-3}

These changes would have numerous potential implications for air quality management in Scotland, including 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. With respect to the need to establish a $PM_{2.5}$ monitoring network, this report evaluates different options regarding the design and implementation of a future $PM_{2.5}$ monitoring network for Scotland.

This report looks at the current $PM_{2.5}$ network as it stands; the type of analysers available to measure $PM_{2.5}$ fraction and monitoring site locations. It also looks at the current PM_{10} network and reviews the potential to upgrade or supplement this network to include $PM_{2.5}$ monitoring. The report also evaluates the cost implications of upgrading to $PM_{2.5}$ monitoring network, the imperative for such an upgrade and the limitation of the current and future network.

The main findings are as follows:

- There are currently many fewer $PM_{2.5}$ monitoring sites in the Scottish Air Quality Database (SAQD) Network than there are PM_{10} monitoring sites: at the time of writing, 16 $PM_{2.5}$ instruments compared to 76 PM_{10} throughout the SAQD. (Prior to 2015 the $PM_{2.5}$ instruments within Scotland were mostly due historic regulations requirements, and not any objectives to measure $PM_{2.5}$)
- Geographical coverage of $PM_{2.5}$ monitoring is uneven, with sites concentrated around the major cities particularly in the Central Belt of Scotland. There are few (only four) $PM_{2.5}$ instruments within the 21 PM_{10} Air Quality Management Areas within Scotland,
- Based upon modelling data from Scottish and UK pollution climate mapping programmes, and on estimates of $PM_{2.5}$ concentration using typical annual mean $PM_{2.5}/PM_{10}$ ratios from sites in Scotland where both metrics are measured, it has been estimated that numerous PM_{10} AQMAs might also have exceedances of the proposed $PM_{2.5}$ Objective.
- The recent increase in the number of $PM_{2.5}$ monitoring sites within Scotland has been partly brought about by the replacement of aging instruments, but also increased take-up of a new analyser which has been shown to reduce costs (whilst measuring both $PM_{2.5}$ and PM_{10}), thus giving added information at little or no additional cost.
- The financial pressure on Local Authorities is likely to significantly influence the acquisition of new instruments, thus this expansion of the $PM_{2.5}$ network is unlikely to continue due to market forces alone, and will probably require some influence from the local and national Government.
- The majority (66% for $PM_{2.5}$ and 87% for PM_{10} respectively) of SAQD sites are roadside or kerbside, with the others mainly urban background.
- Instrument types also varied across the network, as did their age, TEOM FDMS and the newer FIDAS instruments dominated $PM_{2.5}$ analysers, whereas for PM_{10} monitoring, older instruments such as the TEOM and BAM were also numerous.
- The age of instruments ranged from a few months to 15 years.
- Of these instruments all but one type demonstrate equivalence, though some require corrections for equivalence according to Defra and EU standard, but not necessarily MCERTS. The FIDAS is type-approved and certified by TUV to EN 16450, and is undergoing PM UK MCERTS. Although it is possible to simply and inexpensively retrofit most PM_{10} analysers to measure $PM_{2.5}$, there is likely to be a requirement to measure PM_{10} at the same location.
- Installing an additional PM analyser might not always be cost effective if a larger enclosure is required.
- A number of instruments can measure both $PM_{2.5}$ and PM_{10} simultaneously, requiring little or no modification of the enclosure. The 10 year overall cost of such a two-metric analyser ($PM_{2.5}$ and PM_{10}) starts from approximately £70,000, whereas only one instrument measuring PM_{10} or $PM_{2.5}$ costs £54,000. Thus with one exception the two metric system costs less overall than those measuring just one metric. The expansion of the $PM_{2.5}$ network is likely to be a costly exercise and the figures below give an indication of the costs involved:
  - A new analyser costs between £15,000 and £34,000

  - Annual costs (servicing, consumable and electricity etc.) are between £3,500 and £10,300 pa
  - 10 year overall costs (which includes the analyser & installation, and 10 years of annual cost) are between £54,000 and £120,000
  - Instruments measuring both $PM_{2.5}$ and PM_{10} simultaneously offer comparative savings, with 10 year overall costs of between £35,000 & £58,000 per metric
  - Some sites cannot accommodate a second new analyser without a new enclosure, with the associated cost in the region £75,000. Systems measuring 2 metrics are unlikely to need this upgrade.
  - Time and money to develop AQMAs and AQAPs for local authorities (LAs) to meet these objectives assuming they fail to meet the current or proposed objectives.
- If the $PM_{2.5}$ objective is reduced to 10 µg m^{-3} and Scottish Government wish to expand the $PM_{2.5}$ network to capture compliance (especially considering the current geographical limitation of the network), then it is recommended that a strategy to increase the number of sites with $PM_{2.5}$ analysers needs to be considered.
- The initial focus should be to cover areas with currently no $PM_{2.5}$ monitoring, especially those with current AQMAs for PM_{10}. Additionally a further expansion of the $PM_{2.5}$ network should look to mirror, to some extent, the current PM_{10} network within Scotland, with consideration to an area having both roadside, urban background and rural sites. The finding of this review suggests the following requirements :

- **Possible requirements 1 (roadside / within PM_{10} AQMAs): Expansion of $PM_{2.5}$ network into areas with no current monitoring**
  i. One or more new monitors in both Perth and Dundee within current PM_{10} AQMAs. (**minimum two monitors**)
  ii. Roadside sites within current PM_{10} AQMAs, for example those that have an annual PM_{10} greater than 13 or 14 µg m^{-3}, which give an estimated $PM_{2.5}$ of at least 8 µg m^{-3} (**13 monitors**)
  iii. Review of requirements in Edinburgh which has no current PM_{10} AQMAs, but has four PM_{10} sites exceeding 13 or 14 µg m^{-3} (at least **one roadside monitor**)

Thus it is estimated that the number of required roadside/kerbside $PM_{2.5}$ monitors within Scotland's town and cities is a **minimum of 16 additional analysers**

- **Possible requirements 2 (Background and Rural): Expansion of $PM_{2.5}$ network for urban background and rural locations**
  i. Five additional urban background (UB) monitors to measure $PM_{2.5}$ and to match the current PM_{10} UB network (currently three cities have $PM_{2.5}$ urban background (UB) monitoring, therefore a minimum of **five UB monitors** are required)
  ii. It is recommended that consideration should be given to expanding the current rural monitor number, with careful attention to the location. Currently there is an AURN site at Auchencorth Moss, to the South of Edinburgh, though this might be considered too close to Edinburgh when the wind is from a Northerly direction. Following this review Ricardo Energy & Environment recommends at least **three rural monitors** in well research rural locations so as to take into consideration the following:
     a. one or more monitors to detect influx of $PM_{2.5}$ and PM_{10} particulates from the South and South East thus giving an early warning of elevated particulate events, from continental Europe, England or further afield.
     b. two monitors to detect volcanic particulates from Iceland, these need to be in the far North West of Scotland, for example Durness and NW Lewis.

Thus the required number of urban background / rural $PM_{2.5}$ monitors across Scotland is considered to be a minimum of **eight analysers.**

- The **estimated number** of necessary analysers is in the order **of 24** throughout Scotland (expanding from 15 sites to 39 sites)
- It might be considered that the roadside sites are more important, thus it is proposed replacement of current PM_{10} analysers within AQMAs might be a priority (requirement 1 above). As noted above the cost would be appreciable, with the 10 year overall cost of a new analyser measuring both $PM_{2.5}$

and PM_{10} of at least £70,000. Thus 24 new analysers would cost a total of £1.68 million not including any new (or modified) enclosures that might be required. Some newer PM_{10} instruments could be adapted to measure $PM_{2.5}$ at little expense if there is room in the enclosure and it only requires a new inlet.

- Spending could be phased with older instruments being replaced first, with perhaps incentives to change to a two-metric system, and instrument at the roadside sites being replaced first. Another option is to use a semi-permanent or moveable instrument to carry out a short-term survey of $PM_{2.5}$ for up to six months. This would enable a detailed understanding of the local needs within an AQMA, and save the expense of buying a new instrument if not required. The instruments would need to be hired or purchased, but with the possibly to be used permanently within the network following their temporary deployment.

Appendices

1 Introduction

1.1 Background

The Scottish Government document "*Cleaner Air for Scotland*" 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 & 12 µg m^{-3}. 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".

The Scottish Government has committed to aligning Scotland's air quality objectives with the WHO guidelines[1], as follows:

1. Increasing the Scottish annual mean PM_{10} objective 18 µg m^{-3} to 20 µg m^{-3}
2. Reducing the annual mean $PM_{2.5}$ objective from 12 µg m^{-3} to 10 µg m^{-3}.

These proposed changes would have numerous potential implications for air quality management in Scotland. These would include:

- the need to develop a $PM_{2.5}$ monitoring network in Scotland;
- the impact on Air Quality Management Areas across Scotland;
- the impact on Air Quality Action Plans.

With respect to the need to establish a $PM_{2.5}$ monitoring network, this report evaluates different options regarding the design and implementation of a future $PM_{2.5}$ monitoring network for Scotland, considering:

- Number and geographical spread of existing $PM_{2.5}$ monitoring sites across Scotland;
- Number and geographical spread of existing PM_{10} monitoring sites across Scotland, including site type (kerbside, roadside, urban background, background) type and age of equipment, scope for modification of site to incorporate a new analyser or retrofit existing analyser;
- The types of $PM_{2.5}$ analysers and retrofits that are compliant with the requirements of the Air Quality Strategy – options and associated costs (both capital costs and maintenance);
- Development of recommendations and options for phased network development. Consideration of existing monitors and infrastructure together with proposed geographical coverage, associated costs and limitations of a new network.

It is provisionally recommended that where possible, monitoring sites are designed to meet the requirements of the Air Quality Directive 2008/50/EC[2] (and subsequent revision of annexes under 2015/1480/EC). This would enable the data generated to be reported to the European Commission for compliance monitoring purposes.

Since the commissioning of this report the Cleaner Air for Scotland (CAFS)[1] document has been published. This document states the intentions of the Scottish Government to:

- "*Include in legislation as Scottish objectives World Health Organisation guideline values for PM_{10} and $PM_{2.5}$*"

Hence it is the intention to develop legislation and policy to support these proposed values by:

- Implementing a refocused Local Air Quality Management system;
- Establishing a $PM_{2.5}$ monitoring network;
- Producing revised and updated Scottish action plans to demonstrate how compliance with the EU Ambient Air Quality Directive will be achieved.

[1] Scottish Government (2015) *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] European Parliament (2008) *Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe*. Available at: http://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:32008L0050.

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 particles which pass through a size-selective inlet with a 50 % efficiency cut-off at 10 µm aerodynamic diameter, similarly $PM_{2.5}$ has a mean aerodynamic diameter of 2.5 µm, though most 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 died worldwide prematurely due to air pollution[3]. 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"[4]. "Diseases caused by $PM_{2.5}$ exposure include stroke, ischaemic heart disease, acute lower respiratory disease, chronic obstructive pulmonary disease, and lung cancer"[5]. 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)[6]

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

A 2011 air quality report[7] by the UK government stated "*The burden of particulate air pollution (specifically $PM_{2.5}$) was estimated to be an effect equivalent to about 29,000 deaths, or a loss of life expectancy from birth of 6 months*", The data were partly based upon the Sniffer project[8]. In Scotland in 2010 it was estimated that around 2,000 premature deaths were associated with fine particulate matter[1], with health and economic impacts likely to be in the order of billions of pounds. The report noted the following:

- There is no currently identified safe threshold for concentrations of PM.

[3] 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/.
[4] 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.
[5] 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.
[6] 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.
[7] UK Government (2011) *House of Commons - Environmental Audit Committee - Ninth Report*: The Committee Office, House of Commons, UK Government. Available at: http://www.publications.parliament.uk/pa/cm201012/cmselect/cmenvaud/1024/102405.htm (Accessed: 27/01/16.
[8] 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.

- 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 often considered to be 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 injurious to health.

2.1.3 PM components & sources

PM is made of both solid and liquid material of various sizes[9]. It also comprises 'primary' components – those emitted directly from sources into the air – and 'secondary' components, which are formed in the air. Sources of the primary components include the combustion of fuels, from mobile sources such as transport, or stationary sources such as domestic, commercial or industrial uses. Natural sources (sea salt and dust) and other anthropogenic sources (quarrying and construction) can also contribute. Primary components include; sodium chloride, elemental carbon, trace metals, mineral components and organic carbon.

Secondary components are formed within the atmosphere by chemical reaction from precursor pollutants (see Table A1 in the appendix), many of which are released from farming practices. Secondary components include: Sulphate; nitrate; water & organic carbon (for more details see Table A2 in the appendix).

The Sniffer project[8] quantified the sources of particulate matter including:

- *"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)[10]

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[10] 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.

Reductions of primary $PM_{2.5}$ emissions in the UK deliver reductions in $PM_{2.5}$ mass predominantly in areas of higher population density, while ammonia reductions lead to decreases mainly in non-urban areas. 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 by tackling of PM within urban areas by local councils[10].

[9] 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.
[10] 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 Objectives prior to Air Quality (Scotland) Amendment Regulations 2016

Prior to the publication of the Air Quality (Scotland) Amendment Regulations 2016 on the 26th march 2016, Scotland's Air Quality Objectives for particulate matter were as follows[11]:

- 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 was an objective it was not incorporated into LAQM Regulations and authorities had no statutory obligation to review or assess air quality against this objective.

(The Air Quality Objectives for PM applicable in the rest of the UK come from the UK Air Quality Strategy. They are in line with the Air Quality Directive limit values[12], and are less stringent than the Scottish Air Quality Objectives.)

2.2.2 Particulate Matter Measurement

Ambient particulate matter is measured throughout the country using a network of urban traffic (roadside and kerbside), urban background and rural background fixed monitoring stations, which form part of the Scottish Air Quality Database (see details about the SAQD & sites at http://scottishairquality.co.uk/, and more about the sites in the appendices, Table A5 & Table A6).

As of January 2016 75 sites were actively measuring PM_{10}, 15 also included hourly $PM_{2.5}$ measurement, whilst two further sites monitored daily mean $PM_{2.5}$ using a gravimetric technique (see Table A5 & Table A6 in Appendix).

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, see Figure 2-1.

The 2015 annual mean PM_{10} concentration, averaged over all of Scotland's 75 monitoring sites is shown in Table 2-2. The annual average PM_{10} is greater than $PM_{2.5}$ this is to be expected as $PM_{2.5}$ is a subset of PM_{10}. Roadside PM concentrations were on average greater than those at urban background sites. Rural background sites on average recorded the lowest concentrations. 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 (see Table 2-3). The overall 2015 $PM_{2.5}$ & PM_{10} concentrations exhibit the lowest annual mean for a number of years. (Please note, data from the SAQD are ratified in three-month batches, in arrears. At the time of writing, some data from the final three months of 2015 were still provisional pending the completion of the ratification process).

[11] Air Quality in Scotland (2015) *Standards - Air Quality in Scotland*. Available at: http://www.scottishairquality.co.uk/air-quality/standards (Accessed: 08/10/15.
[12] European Parliament (2015) *Air Quality Standards*. Available at: http://ec.europa.eu/environment/air/quality/standards.htm (Accessed: 27/1/16.

Table 2-2: Average annual PM concentrations (µg m^{-3}) from 2014 & 2015 from different types of SAQD monitoring sites in Scotland

	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 $PM_{2.5}$ & site number for 2014	12.0	3	9.0	3	8.0	1	5.5	2	**9.1**	**9**
Annual Mean $PM_{2.5}$ & site number for 2015	7.3	9	7.5	3	9.3	1	4.9	1	**7.3**	**14**
Annual Mean PM_{10} & site number for 2014	15.7	62	14.0	11	12.0	1	9.0	3	**15.1**	**77**
Annual Mean PM_{10} & site number 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

Figure 2-1: $PM_{2.5}$ and PM_{10} monitoring sites (in highlighted in orange) and PM_{10} only (red) in Scotland operating between January 2014 and 2016.

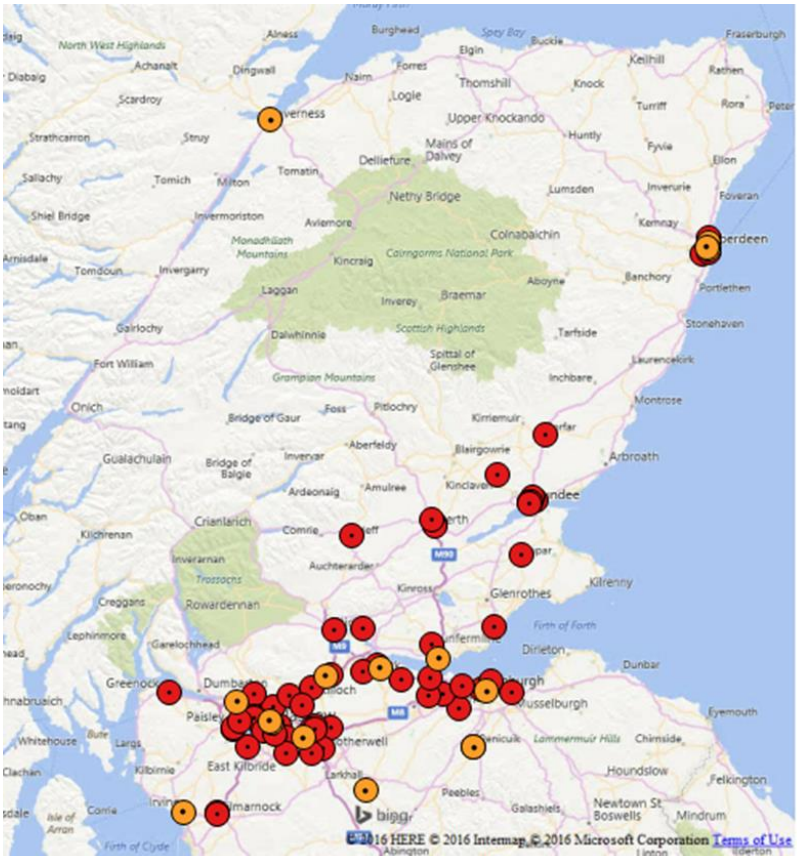


Table 2-3: Average annual $PM_{2.5}$ & PM_{10} concentrations (µg m^{-3}) from selected SAQD monitoring sites in Scotland 2008 to 2015

		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

2.2.3 Particle Mapping

As well as the monitoring described above, PM_{10} is also modelled and mapped throughout Scotland[13], using a Scotland-specific pollution climate mapping method. This enables compliance with air quality objectives to be assessed by modelling, at locations where fixed monitoring is not possible. The modelling is carried out for both background and roadside PM_{10} (see Figure 2-2). The model produces concentrations for 1 km^2 grid squares. Nineteen 1 km^2 grid squares had modelled annual mean PM_{10} concentrations in exceedance of 18 µg m^{-3} (out of a total of 83956 km^2), though some of these were thought to be anomalies. There were modelled annual mean roadside concentrations greater than 18 µg m^{-3} alongside 262 road links, more than half of which were located in the Glasgow Urban Area.

PM_{10} and $PM_{2.5}$ Pollution Climate Mapping model data from 2014 are also available, see Figure 2-3. The Pollution Climate Mapping (PCM) model calculated that the 2014 mean background PM_{10} concentration in Scotland was 9.3 µg m^{-3}, and the corresponding mean $PM_{2.5}$ concentration was 5.9 µg m^{-3}. These averages, and the highest and lowest modelled concentrations are shown in Table 2-4.

Table 2-4: PCM annual $PM_{2.5}$ & PM_{10} concentrations (µg m^{-3}) from 2014 PCM data

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

[13] 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.

Table 1-5 shows the PCM modelled annual average $PM_{2.5}$ and PM_{10} concentrations from 2011 to 2030. It shows that over the 15 years from 2015 to 2030, average $PM_{2.5}$ and PM_{10} concentrations are predicted to decrease from 5.92 µg m^{-3} and 9.23 µg m^{-3} respectively, to 5.62 µg m^{-3} and 8.89 µg m^{-3} respectively – a decrease of approximately 5% in $PM_{2.5}$ and 3.6% in PM_{10}.

Table 2-5: PCM annual $PM_{2.5}$ & PM_{10} concentrations (µg m^{-3}) from 2011-2030 PCM data

	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

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

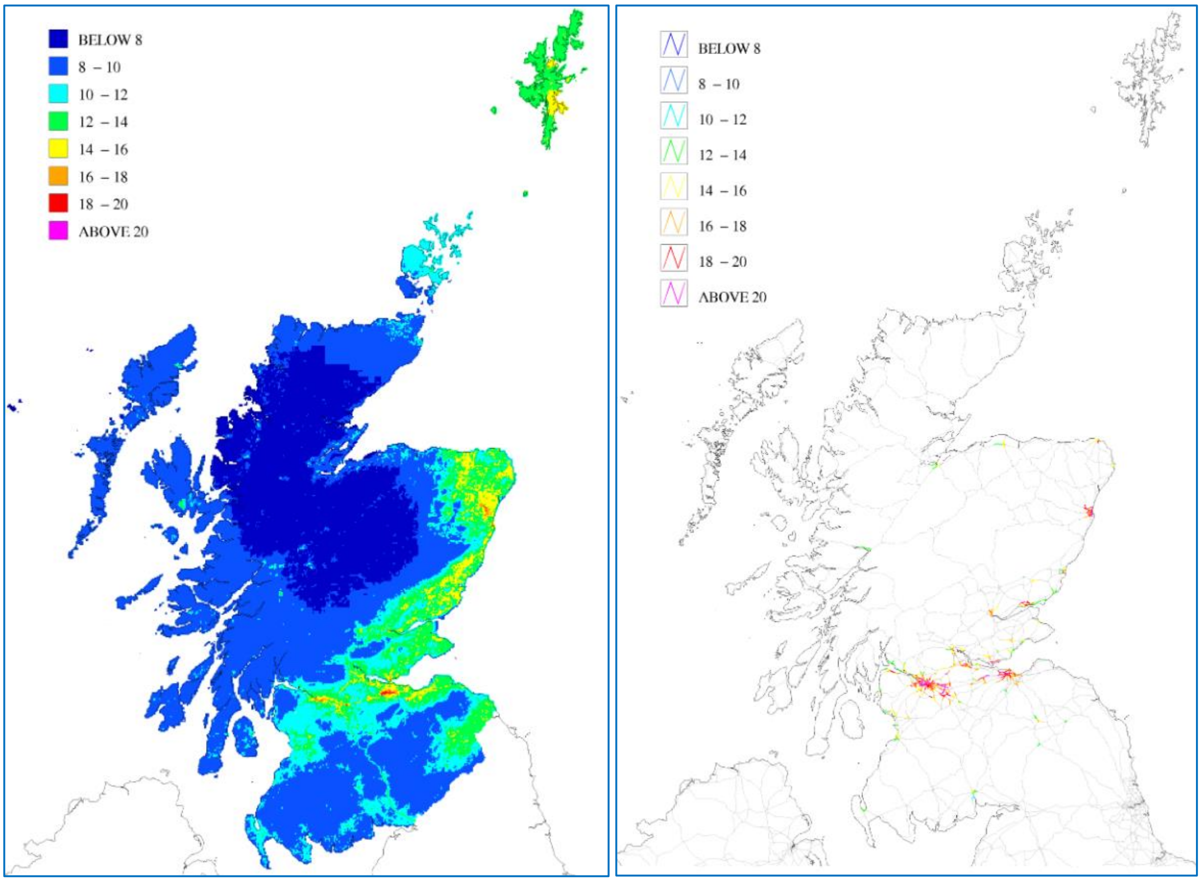
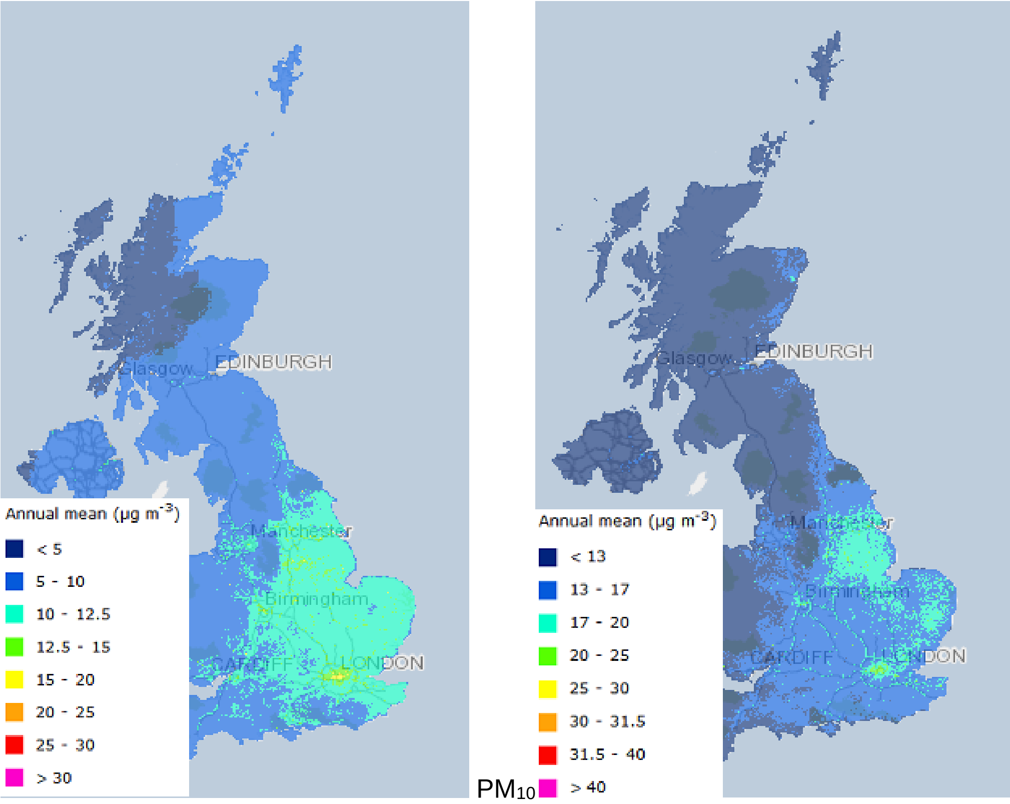


Figure 2-3: Background $PM_{2.5}$ and PM_{10} annual mean modelled maps for the UK



$PM_{2.5}$ PM_{10}

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

The ratio of $PM_{2.5}$ to PM_{10} could be used to approximately estimate $PM_{2.5}$ concentrations from PM_{10} data thus supplementing the limited $PM_{2.5}$ dataset. This methodology was used in a sister report to better understand the likely implication of changes in the $PM_{2.5}$ and PM_{10} objectives.[14]

A number of methods were investigated to derive the ratio of $PM_{2.5}$ to PM_{10}, with the data from the nine SAQD sites from 2009-2015 for sites with more than 75% of days data, giving best estimate for this ratio.

Analysis using the ratio of 0.63 was used to estimate of $PM_{2.5}$ from 6 other sites which only began monitoring both metrics in recent years, most using the FIDAS analyser. Because 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 2-6 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 2-6 Testing the 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 0.63 (difference to actual in brackets)	Actual mean measured $PM_{2.5}$ µg 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)

[14] Sykes, D. (2016) *PM2.5 and PM10 in Scotland: An investigation of concentrations and ratios on PM2.5 & PM10 across Scotland to help inform potential changes to LAQM and AQMAs in Scotland.*

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)
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 **$[PM_{2.5}] \approx 0.63\ [PM_{10}]$**, 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 (data not shown) was used of **$[PM_{2.5}] \approx 0.58\ [PM_{10}]$**, then the estimated $PM_{2.5}$ might be closer to the actual mean measure concentration for $PM_{2.5}$

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.

2.4 Exceedances of Objectives

2.4.1 Measured Exceedances

At the time of reporting (with non-ratified data) 11 SAQD sites exceeded the Scottish Air Quality Objective for annual mean PM_{10} concentration (18 µg m^{-3}), in 2015 with the highest site's annual mean being 22.7 µg m^{-3}. No sites exceeded the Scottish AQS objective for $PM_{2.5}$ of 12 µg m^{-3} in 2015, which is an improvement over the previous year. The proposal to bring Scotland in line with the WHO guideline[6] for PM_{10} and $PM_{2.5}$ concentrations of 20 µg m^{-3} and 10 µg m^{-3}, based on 2015 data, would result in eight fewer exceedances for PM_{10} (see Table 2-7). However there would be one more exceedance at with the lower $PM_{2.5}$ objective.

Table 2-7: Exceedances for 2014 & 2015 of AQ objectives with changes to concentrations

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

Dataset provisional for 2015 due to it not being fully ratified

2.4.2 Modelled Exceedances

No local authority's average annual mean concentrations as modelled by the PCM exceeded either the Scottish objectives for 2015, or the proposed revised objectives. However, some individual 1 km^2 grids within some LA areas did exceed these PM objectives (see Table 2-8). With the objectives brought in line with WHO guidelines the $PM_{2.5}$ exceedances would increase significantly from zero to 22 in 2015. However it should be noted that the number of exceedances are expected drop by 2030.

Table 2-8: Modelled Exceedances of 2015 objectives and proposed revised Scottish AQS Objectives for 2011 – 2030 based on 1 km^2 PCM data

	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

2.4.3 Estimated $PM_{2.5}$ Exceedances Based on SAQD PM_{10} Data

As explained above, the ratio of $PM_{2.5}/PM_{10}$ concentration was calculated as 0.63, based on SAQD sites that measure both these PM metrics. By applying this value to the 2015 annual mean PM_{10} concentrations from SAQD sites, it is possible to *estimate* the number of exceedances of the current and proposed Scottish AQS Objective for $PM_{2.5}$ at all 75 sites in the SAQD that monitor PM_{10}. As shown in Table 2-9, by using the average $PM_{2.5}/PM_{10}$ ratio of 0.63 the number of exceedances of the current $PM_{2.5}$ objective (12 µg m^{-3}) is estimated as five. If the $PM_{2.5}$ objective was reduced to 10 µg m^{-3} the number would increase to 27 (all at roadside and kerbside sites).

Table 2-9: Estimated exceedances of $PM_{2.5}$ annual mean objective using 2015 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

2.4.4 Estimated Impact of Reducing Scottish $PM_{2.5}$ Objective on Number of Exceedances

The number of exceedances of Scottish AQS Objectives, based on any data set (SAQD, PCM or estimated by applying the typical $PM_{2.5}/PM_{10}$ ratio to measured PM_{10} data) can be seen to change (sometimes substantially) if the objectives are altered in line with the proposed WHO guidelines. Hence, such an alignment is likely to impact on the Air Quality Management Areas across Scotland and most probably the Air Quality Action Plans that have been developed by local authorities to improve local concentrations of PM_{10}.

2.5 Summary of Changes to Scotland's PM objectives

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 may be prudent to consider delaying the introduction of the revised PM_{10} objective. 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.

3 Approach and Methodology of Study

3.1 Approach

The study used data from:

1. The SAQD for fixed monitoring sites for both $PM_{2.5}$ and PM_{10}
2. The AQMAs for PM_{10} within the Local Authorities
3. The costs and details of the instruments / analysers that are or could be used within the SAQD to monitor PM.

The information and data gathered were used to develop requirements for expansion of the $PM_{2.5}$ network.

3.2 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 a further 61 just PM_{10}. Data from these sites were publicly available online, via the Scottish Air Quality Website at http://www.scottishairquality.co.uk/, details of the sites and instruments used can be found in the appendix Table A5 & A6.

3.3 AQMAs and AQAPs

Information and data were taken from the Air Quality for Scotland website[15] about Air Quality Management Areas and Action Plans for PM_{10}. This information and data were assessed to determine the effect of the proposed changes on these plans.

3.4 Instruments

Detailed information about the instruments that are currently used within the SAQD and that could be used to measure $PM_{2.5}$ was gathered from both manufacturer's websites and local suppliers within the UK.

3.4.1 Instruments currently used within the SAQD

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

- Thermo Scientific TEOM and 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 some models Filter Dynamics Measurement System (FDMS) to provide measurements with of short-term precision and account for volatile and nonvolatile PM[16].
- 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[17].
- 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[18].

[15] 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.
[16] 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.
[17] Thermo Scientific (2016b) *Partisol™ 2025i Sequential Air Sampler*. Available at: http://www.thermoscientific.com/en/product/partisol-2025i-sequential-air-sampler.html.
[18] Palas GmbH (2016) *Fidas ® 200 - Product Lines - Palas*. Available at: http://www.palas.de/en/product/fidas200 (Accessed: 22/1/16.

- Met One BAM (various models), measures either $PM_{2.5}$ or PM_{10} as a single channel instrument. The instrument uses stepwise semi-continuous beta attenuation mass measurement method for PM[19]

Other instruments not currently used within the SAQD network were also reviewed, these were included within the details about instrument costs.

3.4.2 Further details about instrument

Instrument equivalence and details about certification was taken from the government website[20]

Details about instrument costs were from contacts within the two main UK suppliers of air monitoring equipment, these are Enviro Technology[21] and Air Monitors[22].

3.5 Plotting of Sites using GIS

QGIS[23] was used to plot the various monitoring sites and represent their positioning within Scotland.

[19] Met One Instruments (2016) *Air Quality Monitors & Ambient Particulate Counters | Met One*. Available at: http://www.metone.com/particulate.php (Accessed: 11/3/16.

[20] Defra (2015a) *Certification - MCERTS for UK Particulate Matter*: 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/networks/monitoring-methods?view=mcerts-scheme (Accessed: 21/1/16.

[21] Enviro Technology (2016) *Particulate Monitoring*. Available at: http://www.et.co.uk/products/air-quality-monitoring/particulate-monitoring/ (Accessed: 11/3/16.

[22] airmonitors (2016) *Air Monitors - Air Quality Monitoring Technology Specialists - Home Page - Particulates / Dust Monitors*. Available at: http://airmonitors.uk/air_quality_monitors___particles (Accessed: 11/3/16.

[23] QGIS (2016) *Welcome to the QGIS project!* Available at: http://www.qgis.org/en/site/ (Accessed: 25/01/16.

4 Review of Monitoring Sites and Instruments

4.1 $PM_{2.5}$ Monitoring Sites across Scotland

4.1.1 Number of $PM_{2.5}$ instruments (including associated PM_{10} instruments)

As of January 2016 there were 15 $PM_{2.5}$ monitoring sites in Scotland. All 15 $PM_{2.5}$ monitoring sites also measures PM_{10}. In some cases this is done using a pair of co-located analysers of the same type (both TEOM-FDMS, or both Partisol gravimetric samplers). In other sites FIDAS instruments were used, these provide simultaneous measurement of both PM_{10} and $PM_{2.5}$ (see Table 4-1 below & Table A5 in the appendix). One site, Auchencorth Moss, has four co-located instruments: a pair of FDMS analysers and a pair of Partisols. Each pair measures PM_{10} and $PM_{2.5}$.

There were 10 roadside / kerbside $PM_{2.5}$ sites, three urban background sites, one urban industrial site and one rural site. The instrument types are mainly TEOM FDMS or the more recent FIDAS, which measure hourly data, but two instruments are gravimetric filter-based Partisols at Inverness and Auchencorth and measure daily $PM_{2.5}$ & PM_{10} values.

Table 4-1: SAQD monitoring sites, including site & instrument type with measurement start date & instrument installation date, as of January 2016 for $PM_{2.5}$ and PM_{10}

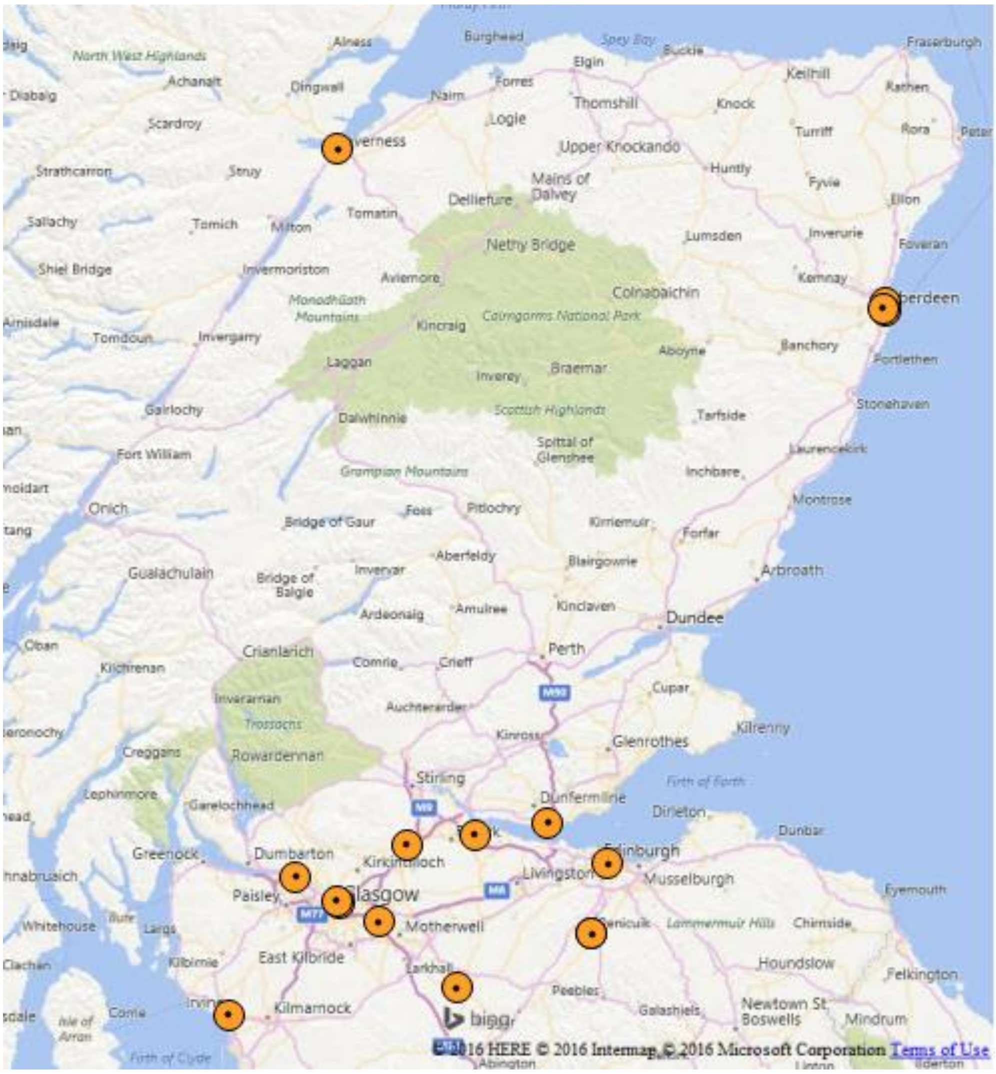
Site Name	Site Type	Instrument Type	Instrument Installation Date ($PM_{2.5}$)	Start of $PM_{2.5}$ measurement	Instrument Installation Date (PM_{10})	Start of PM_{10} measurement
Aberdeen Errol Place	URBAN BACKGROUND	TEOM FDMS	20/02/2009	20/02/2009	20/02/2009	18/09/1999
Aberdeen Union Street	ROADSIDE	TEOM FDMS-DF	11/04/2014	11/04/2014	11/04/2014	01/01/2005
Auchencorth Moss 1	RURAL	Partisol	01/01/2006	01/01/2006	14/08/2007	14/08/2007
Auchencorth Moss 2	RURAL	TEOM FDMS	01/12/2006	01/01/2006	17/12/2006	14/08/2007
Aberdeen Market Street 2	ROADSIDE	FIDAS	30/09/2015	29/09/2015	30/09/2015	27/11/2012
Edinburgh St Leonards	URBAN BACKGROUND	TEOM FDMS	01/10/2008	01/10/2008	10/07/2007	24/11/2003
Falkirk Banknock	ROADSIDE	FIDAS	28/01/2015	28/01/2015	28/01/2015	01/01/2013
Glasgow High Street	ROADSIDE	TEOM FDMS	27/01/2015	27/01/2015	27/01/2015	27/01/2015
Glasgow Townhead	URBAN BACKGROUND	TEOM FDMS	07/10/2013	07/10/2013	07/10/2013	07/10/2013
Grangemouth	URBAN INDUSTRIAL	TEOM FDMS	03/12/2008	03/12/2008	16/04/2009	01/01/2001
Inverness	ROADSIDE	Partisol	01/06/2008	01/06/2008	11/07/2001	11/07/2001
North Ayrshire Irvine High St	KERBSIDE	FIDAS	16/04/2015	16/04/2015	16/04/2015	12/02/2009
Fife Rosyth	ROADSIDE	FIDAS	20/07/2015	20/07/2015	20/07/2015	13/03/2008
South Lanarkshire Lanark	ROADSIDE	FIDAS	10/04/2015	10/04/2014	10/04/2015	10/04/2015
South Lanarkshire Uddingston	ROADSIDE	FIDAS	04/03/2015	04/03/2015	04/03/2015	04/03/2015
West Dunbartonshire Clydebank	ROADSIDE	FIDAS	13/03/2015	13/03/2015	13/03/2015	01/02/2007

4.1.2 Geographical spread of $PM_{2.5}$ instruments (including associated PM_{10} instruments)

As discussed previously, the majority of monitoring sites are situated near centres of urban population. As such they are concentrated in and around Scotland's cities and towns as illustrated in Figure 3-1. Aberdeen has three $PM_{2.5}$ instruments within the city, whilst Glasgow has two. Two instruments are situated in the rural location of Auchencorth Moss and are part of the AURN network.

Currently, $PM_{2.5}$ monitoring sites are predominantly situated within AQMAs, however not all towns and cities with AQMAs have $PM_{2.5}$ instruments, for example both Perth and Dundee have no means to monitor $PM_{2.5}$. This inconsistency is again illustrated in Figure 4-1 and Figure 4-2 where the disparity between PM_{10} and $PM_{2.5}$ site spread is evident.

Figure 4-1: $PM_{2.5}$ monitoring sites in Scotland as of January 2016 (each site also measures PM_{10})



4.2 Number, Geographical Spread, and Further Information about Existing PM_{10} Monitoring Sites across Scotland

4.2.1 Number of PM_{10} instruments (excluding those co-located with $PM_{2.5}$ instruments)

As of January 2016 there were 60 PM_{10} monitoring sites in Scotland (excluding those which were co-located with $PM_{2.5}$ instruments) (see Table 4-2 below & Table A6 in the appendix). Including those co-located that would increase to 75 sites and 76 instruments.

Table 4-2: SAQD monitoring sites, including site & instrument type with measurement start & instrument installation date, as of January 2016 PM_{10} only

Site Name	Site Type	Instrument Type	Instrument Installation Date	Start of PM_{10} measurement
Aberdeen Anderson Dr	ROADSIDE	TEOM	01/01/2005	01/01/2005
Aberdeen Wellington Road	ROADSIDE	TEOM	01/01/2008	01/01/2008
Aberdeen King Street	ROADSIDE	BAM	25/11/2008	25/11/2008
Angus Forfar Glamis Rd	ROADSIDE	TEOM FDMS	23/10/2015	23/10/2015
Alloa A907	ROADSIDE	TEOM FDMS	14/01/2015	14/01/2015
South Ayrshire Ayr High St	ROADSIDE	TEOM FDMS	11/09/2007	11/09/2007
West Lothian Broxburn	ROADSIDE	TEOM FDMS	01/01/2008	01/01/2008
Fife Cupar	KERBSIDE	TEOM FDMS	25/06/2009	19/12/2005
Dundee Mains Loan	URBAN BACKGROUNE	TEOM	28/03/2006	28/03/2006
Dundee Union Street	KERBSIDE	BAM	19/02/2013	01/01/2006
Dundee Broughty Ferry Road	ROADSIDE	TEOM	01/01/2006	01/01/2006
Dundee Seagate	KERBSIDE	BAM	09/05/2011	09/05/2011
Dundee Lochee Road	KERBSIDE	BAM	08/04/2011	08/04/2011
Fife Dunfermline	ROADSIDE	TEOM FDMS	01/04/2011	01/04/2011
Dundee Meadowside	ROADSIDE	BAM	15/06/2011	22/06/2011
Ayrshire Kilmarnock St Marnock	ROADSIDE	TEOM FDMS	01/11/2013	17/02/2012
Edinburgh Glasgow Road	ROADSIDE	TEOM	04/09/2012	04/09/2012
Edinburgh Currie	SUBURBAN	TEOM	01/01/2013	01/01/2013
Edinburgh Queen Street	ROADSIDE	TEOM	01/01/2007	01/01/2007
Edinburgh Salamander St	ROADSIDE	TEOM	17/09/2009	17/09/2009
Edinburgh Queensferry Road	ROADSIDE	TEOM FDMS	01/01/2011	01/01/2011
East Dunbartonshire Bishopbrigg	ROADSIDE	BAM	04/12/2003	04/12/2003
East Dunbartonshire Bearsden	ROADSIDE	BAM	01/11/2005	01/11/2005
East Dunbartonshire Kirkintilloch	ROADSIDE	TEOM FDMS	03/08/2007	03/08/2007
East Dunbartonshire Milngavie	ROADSIDE	TEOM FDMS	01/08/2011	01/08/2011
South Lanarkshire East Kilbride	ROADSIDE	TEOM FDMS	01/01/2008	13/03/2008
Falkirk Haggs	ROADSIDE	TEOM	01/01/2013	01/01/2013
Falkirk West Bridge Street	ROADSIDE	TEOM	16/09/2009	16/09/2009
Falkirk Grangemouth MC	URBAN BACKGROUNE	TEOM	01/01/2003	01/01/2003
Glasgow Abercromby Street	ROADSIDE	TEOM FDMS	16/03/2007	16/03/2007
Glasgow Nithsdale Road	ROADSIDE	TEOM FDMS	23/03/2007	23/03/2007
Glasgow Broomhill	ROADSIDE	TEOM FDMS	23/10/2007	23/10/2007
Glasgow Burgher Street	ROADSIDE	TEOM FDMS	20/07/2011	28/07/2011
Glasgow Dumbarton Road	ROADSIDE	TEOM	21/11/2012	21/11/2012
Glasgow Byres Road	ROADSIDE	TEOM FDMS	16/06/2011	01/01/2005
Glasgow Waulkmillglen Reservoi	RURAL	TEOM	01/01/2005	01/01/2005
South Ayrshire Ayr Harbour	ROADSIDE	TEOM FDMS	05/05/2012	05/05/2012
Inverclyde Greenock A8	ROADSIDE	TEOM	18/03/2014	18/03/2014
Fife Kirkcaldy	ROADSIDE	TEOM FDMS	08/02/2011	08/02/2011
ast Lothian Musselburgh N High	ROADSIDE	BAM	01/05/2011	01/05/2011
N Lanarkshire Coatbridge Whiffle	URBAN BACKGROUNE	TEOM	01/01/2007	01/01/2007
North Lanarkshire Kirkshaw	URBAN BACKGROUNE	BAM	01/04/2015	28/06/2014
N Lanarkshire Chapelhall	ROADSIDE	TEOM	01/01/2005	01/01/2005
N Lanarkshire Croy	ROADSIDE	TEOM	01/01/2006	01/01/2006
N Lanarkshire Motherwell	ROADSIDE	TEOM	30/10/2007	30/10/2007
Lanarkshire Shawhead Coatbrid	ROADSIDE	BAM	16/06/2009	16/06/2009
N Lanarkshire Moodiesburn	ROADSIDE	BAM	08/10/2008	08/10/2008
Paisley Gordon Street	ROADSIDE	TEOM FDMS	01/01/2008	01/01/2006
Paisley St James St	ROADSIDE	TEOM FDMS	19/08/2010	19/08/2010
Perth Crieff	ROADSIDE	BAM	01/04/2010	01/04/2010
Perth Atholl Street	ROADSIDE	TEOM	28/07/2004	28/07/2004
Perth Muirton	URBAN BACKGROUNE	TEOM FDMS	05/07/2012	05/07/2012
Perth High Street	ROADSIDE	TEOM	11/06/2003	11/06/2003
Renfrew Cockels Loan	ROADSIDE	TEOM FDMS	04/06/2014	26/09/2013
South Lanarkshire Rutherglen	ROADSIDE	TEOM FDMS	01/01/2011	01/01/2011
South Lanarkshire Hamilton	ROADSIDE	TEOM FDMS	16/10/2013	16/10/2013
South Lanarkshire Cambuslang	ROADSIDE	TEOM FDMS	18/02/2015	18/02/2015
Stirling Craig's Roundabout	ROADSIDE	TEOM	01/01/2009	01/01/2009
/est Lothian Linlithgow High Stree	ROADSIDE	TEOM FDMS	25/10/2013	25/10/2013
West Lothian Newton	URBAN BACKGROUNE	TEOM FDMS	23/05/2012	23/05/2012

4.2.2 Geographical spread of PM_{10} instruments (excluding those co-located with $PM_{2.5}$ instruments)

Again geographical spread is as discussed previously, with the majority of the monitoring sites situated near centres of urban population, as such they are concentrated in and around Scotland's cities and towns. However, there is one further rural location at Glasgow Waulkmillglen Reservoir (see Figure 4-2,

Figure 4-3 & Figure 4-4). See Figure 2-1 above for details of all instruments including those co-located with $PM_{2.5}$ monitoring instruments.

Figure 4-2: PM_{10} monitoring sites in Scotland as of January 2016 (excluding those measuring both $PM_{2.5}$ and PM_{10})

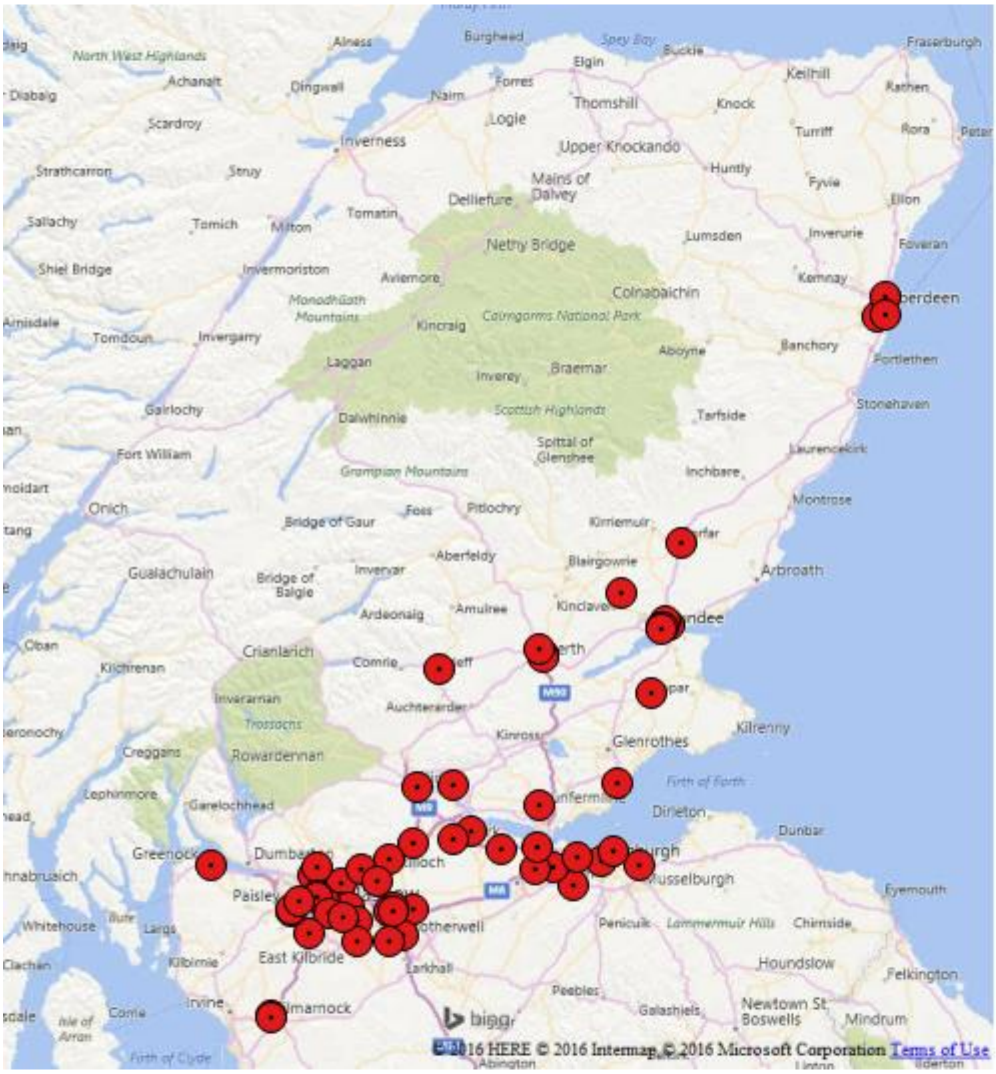


Figure 4-3: PM_{10} monitoring sites in NE region of Scotland as of January 2016 (excluding those measuring both $PM_{2.5}$ and PM_{10})

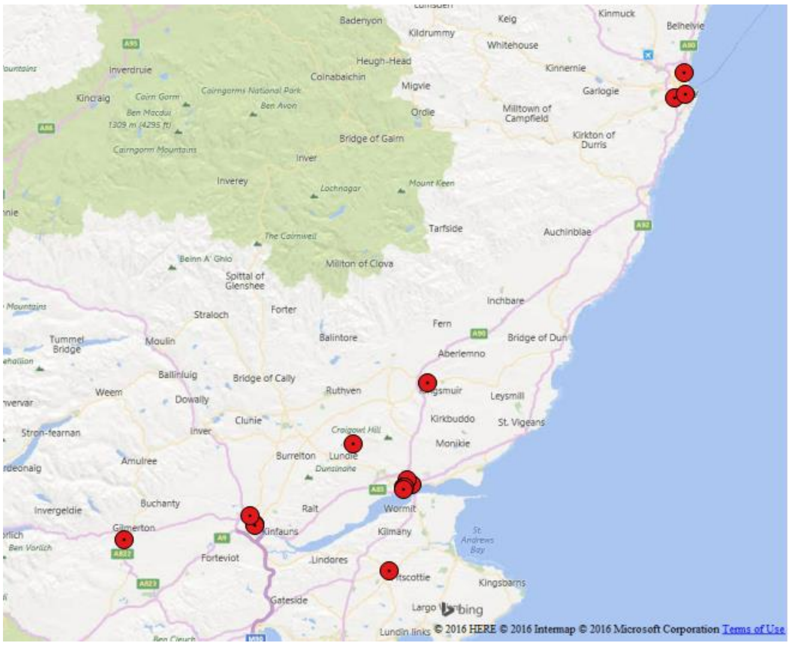
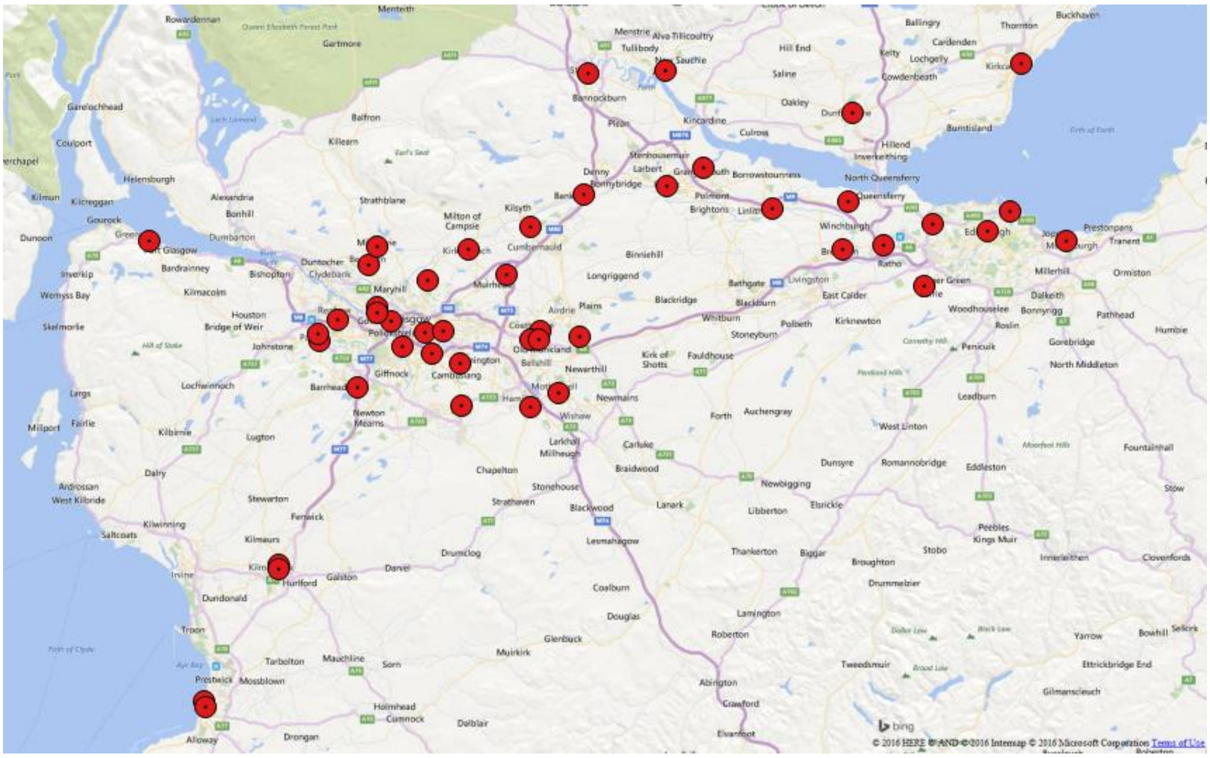


Figure 4-4: PM_{10} monitoring sites in and around central belt of Scotland as of January 2016 (excluding those measuring both $PM_{2.5}$ and PM_{10})



4.2.3 Details of PM_{10} instruments

Site and instrument type as well as measurement start dates for sites across Scotland can be seen in Table 4-2 above. Amongst the 60 SAQD sites, there are 52 roadside / kerbside sites, seven urban background and suburban sites and one rural site. Including co-located instruments these numbers are: 62, 10 & two rural sites respectively, with one urban industrial site.

The PM_{10} instrument types (including co-located instruments) are:

- TEOM FDMS = 34
- TEOM = 21
- BAM = 12
- FIDAS = 7
- Partisol =2

Table 3-2 & Table 4-3 show the differing ages of the analysers within the network. The ages vary considerably with the oldest being installed in 2001 (Partisol) and the newest (FIDAS) 2015. The average age of the PM_{10} network is five years and 10 months, the $PM_{2.5}$ network three years and 8 months.

Table 4-3: PM_{10} instrument age (data extracted from Table 4-2)

Instrument	TEOM FDMS	TEOM	BAM	FIDAS	Partisol
Youngest	23/10/2015	18/03/2014	01/04/2015	30/09/2015	14/08/2007
Oldest	17/12/2006	01/01/2003	04/12/2003	28/01/2015	11/07/2001

4.2.4 AQMAs for PM_{10} across Scotland and measured/calculated $PM_{2.5}$ within these AQMAs

There are 11 Local Authorities in Scotland with AQMAs (see Figure 4-5) and a total number of 21 AQMAs for PM_{10} [24] (see Table 4-4). Of these only four AQMAs have $PM_{2.5}$ monitors, whilst many also are AQMAs for nitrogen dioxide.

Using PM_{10} concentrations from monitoring sites within the AQMAs it is possible to estimate the $PM_{2.5}$ concentration using the average annual mean $PM_{2.5}$ to PM_{10} ratio (see Section 2.3 above). Table 4-5 shows the both the measured and estimated $PM_{2.5}$ values. Annual mean concentrations range from 6 to 14 µg m^{-3} with an average of 9.6 µg m^{-3}. Based on this approach, seven monitoring sites within AQMAs have estimated annual mean $PM_{2.5}$ concentrations greater than 10 µg m^{-3}, indicating that many PM_{10} AQMAs might also exceed the proposed $PM_{2.5}$ objective.

[24] 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.

Figure 4-5: Local Authorities with PM_{10} AQMAs in Scotland[24]

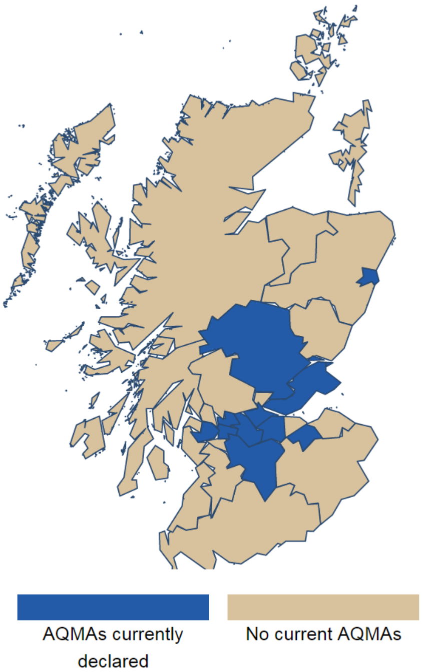


Table 4-4: AQMAs within Scotland for PM_{10}

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 4-5: Measured or Estimated $PM_{2.5}$ from measured PM_{10} data within Scotland's AQMAs for PM_{10}

AQMA	Measured Annual PM_{10} in 2015	Measured / Estimated $PM_{2.5}$ in 2015
Aberdeen City City	n/a	11
Aberdeen City Anderson Dr	14	9
Aberdeen City Wellington Rd	22	14
Dundee City	16	10
East Dunbart. Kirkintilloch Rd	17	11
East Dunbart. A809	14	9
Falkirk Centre	18	11
Falkirk Banknock	11	6
Fife Bonnygate	17	11
Glasgow City Centre	16	9
North Lanark. Coatbridge	14	9
North Lanark. Chapelhall	n/a	n/a
North Lanark. Motherwell	n/a	n/a
North Lanark. Moodiesburn	10	6
North Lanark. Croy	14	9
Perth	17	11
Perth No 2	14	9
Renfrew. Paisley Town	13	8
South Lanark. Whirlies	16	10
South Lanark. Rutherglen	18	11
West Lothian	15	9

Dataset provisional for 2015 due to it not being fully ratified

(Estimated annual mean concentrations are shown in red.)

4.3 Equivalent / Compliant $PM_{2.5}$ Analysers and Retrofits

UK air quality objectives (including those applicable to Scotland) are based upon measurements carried out using the European reference sampler. This is a gravimetric device where the particles are collected onto a filter over a 24 hour period. Most of the instruments used in the SAQD are automated continuous analysers (the TEOM-FDMS and FIDAS), in order to provide up-to-date (near-real-time) data. To ensure these automated analysers provide measurement with an uncertainty equivalent to the European reference sampler they must comply with equivalence tests set out by the UK Government and the Devolved Administrations

There are a number of compliant $PM_{2.5}$ monitors (see Table A7 in the appendix for Defra approved equipment) that can be used within the $PM_{2.5}$ network, these are:

- Thermo Partisol 2025 (gravimetric)
- FAI SWAM 5a (SC and DC)
- FAI SWAM 5a (Hourly and daily averages)

- Met-One BAM1020 (Smart heated version, automatic)
- Thermo 1405-F FDMS
- Thermo 1405-DF FDMS
- Opsis SM200

The Thermo 1405-DF FDMS, Opsis SM200 and the FAI SWAM instruments measure both $PM_{2.5}$ and PM_{10} simultaneously. There is one 1405-DF instrument within the SAQD at present, Aberdeen Union Street site. An Opsis was previously sited at Glasgow Airport. Both the FDMS & SWAM instrument only require one inlet (the Opsis may require two inlets) and take one space in a cabinet. The other instruments would need to be duplicated, one measuring $PM_{2.5}$ and one measuring PM_{10}: they would thus require two inlets, two spaces in a cabinet, increased energy and air conditioning needs and the associated enclosure (and conditions) to house them.

Another instrument, the PALAS FIDAS has in the last year been deployed across the SAQD (seven instruments were deployed in 2015), and although it has not been certified to MCERTS for UK particulate matter[25] or deemed equivalent by Defra, it is type-approved and certified according to latest EN requirements prEN16450 with TUV & NPL, allowing its use in Germany, the UK application is pending (and is likely to get approval by end of March 2016). The FIDAS can measure both $PM_{2.5}$ & PM_{10} simultaneously via just one inlet.

The demonstration of equivalence[26] of $PM_{2.5}$ instruments (according to the EN standard method for $PM_{2.5}$ reference sampler – EN 12341) has a Data Quality Objective for expanded uncertainty of 25% at target value of 25 µg m^{-3}, or ± 6.25 µg m^{-3}. This means that if an equivalent sampler gives a value of 25 µg m^{-3}, then the actual value (after uncertainty is considered for the instrument) may be between 18.75 and 31.25 µg m^{-3}. This concentration range is effectively fixed by the performance of the analyser and is unlikely to reduce in magnitude at lower concentrations. Therefore, if this uncertainty of ± 6.25 µg m^{-3} is applied to the proposed objective of 10 µg m^{-3} then the actual value might be between 4 and 16 µg m^{-3}, and therefore 60% uncertainty.

It is possible to retrofit some single channel instruments (measuring just one PM size) so they can measure $PM_{2.5}$ instead of PM_{10}; normally this simply involves changing the inlet head to provide a sharper cut of the coarse fraction of the particulate matter. However, in most cases it will be necessary to measure both PM_{10} and $PM_{2.5}$, thus two instruments are still required using this solution, with the associated increased maintenance and energy costs. The cost of each instrument, its maintenance and energy cost, and various options are discussed in more detail in Section 3-4.

4.4 Costs Associated with a New Analyser & Installation

4.4.1 Cost of analysers including maintenance and energy usage

Analyser capital costs range from more than £15,000 to over £30,000. These figures do not include one-off installation costs, annual energy, and consumable or maintenance fees. Costs for these services range from £3,500 to £10,000 per annum. Thus, assuming a 10 year life-span, a 10 year overall costs range from £51,000 to £120,000. However, if you consider that some instruments measure two metrics (both PM_{10} and $PM_{2.5}$) this range is reduced to a figure of £35,000 or more for a 10 year period. A summary of the costs is presented in Table 4-6 and Table 4-7 (a full breakdown of the cost for all instruments is shown in the appendix, see Table A8).

To install a new $PM_{2.5}$ analyser to supplement a PM_{10} analyser already on site (assuming there is space within the enclosure, and any other requirements are met) would cost between £51,000 and £120,000 over 10 years. Ideally this instrument should be of the same type as the PM_{10} analyser on site, as per the Local Authority Air Quality Management Technical Guidance LAQM.TG(09)[27], as this minimises any errors associated with differences between measurement methods and produces more reliable datasets.

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[25] CSA group (2016) *MCERTS Certified Products*. Available at: http://www.csagroupuk.org/services/mcerts/mcerts-product-certification/mcerts-certified-products/ (Accessed: 22/1/16.

[26] EC Working Group 2010. Guide to the Demonstration of Equivalence of Ambient Air Monitoring Methods.

If an equivalent PM_{10} analyser is relocated from another site and updated to measure $PM_{2.5}$ this could offer a saving, though this would be at the expense of another site's PM measurement capability.

The overall cost of an instrument (including installation, maintenance and energy costs), which could measure both $PM_{2.5}$ and PM_{10} is between £70,000 and £116,000 for 10 years. This includes purchase of the instrument, installation, servicing and energy and other ongoing costs. If two new analysers were purchased to measure $PM_{2.5}$ and PM_{10} then the cost would be between £110,000 and £240,000, without considering the enclosure costs, which may need modification or renewal.

Table 4-8 shows the 10-year cost of a new instrument or instruments (both with and without a new enclosure). The best $PM_{2.5}$ instrument on cost alone is the BAM1020 (heated), whereas for an instrument that measures two metrics ($PM_{2.5}$ and PM_{10}) the most economical instrument is the Palas FIDAS 200s. Buying one FIDAS or one TEOM1405-DF instrument is cheaper than buying two BAM1020 instruments; the case is even more compelling when considering a new enclosure, which may be required when two instruments are required to measure $PM_{2.5}$ and PM_{10}.

Table 4-6: Simplified details of instrument, maintenance and energy costs for instruments measuring PM_{10} or $PM_{2.5}$ Prices are in £.

Manufacturer	Met-One	Met-One	Thermo	Thermo	Thermo	Thermo
Type	BAM	BAM	Partisol	TEOM	TEOM FMDS	TEOM FMDS
Model	BAM1020 unheated	BAM1020 heated	Partisol 2025 (gravimetric)	TEOM 1400*	TEOM 1400 FDMS 8500	TEOM 1405-F PM2.5 FDMS
UK supplier	ET or Air Monitors	ET or Air Monitors	Air Monitors	Air Monitors	Air Monitors	Air Monitors
PM measured	PM10	PM10 or PM2.5	PM10 or PM2.5	PM10	PM10 or PM2.5	PM10 or PM2.5
Metrics Measured (Just PM10 or PM2.5 = 1, or both =2)	1	1	1	1	1	1
Convertible to PM2.5?	NO	YES	YES	YES	YES	N/A
Equivalence	YES (after correction)	YES	YES	NO - but meets after correction	YES	YES
MCERTS	NO	YES	YES	NO	NO	YES
COSTS						
Capital	15295	18495	16990	16320	16320	23875
Annual costs (including maintenance, consumable and energy)	3589	3589	10338	6202	6202	6026
10 year cost (assuming no changes and capital cost over this period)	**51185**	**54385**	**120370**	**78340**	**78340**	**84135**

* TEOM 1400 has been discontinued and will not have parts to support it from 2018

Table 4-7: Simplified details of instrument, maintenance and energy costs for instruments measuring PM_{10} and $PM_{2.5}$. Prices in £.

Manufacturer	Thermo	FAI	PALAS	Opsis
Type	TEOM FMDS	SWAM	FIDAS	Opsis
Model	TEOM 1405-DF PM2.5 FDMS	SWAM 5a DC hourly	200(S)	SM200
UK supplier	Air Monitors	ET	Air Monitors	ET
PM measured	PM2.5 & PM10	PM2.5 & PM10	PM2.5 & PM10	PM2.5 & PM10
Metrics Measured (Just PM10 or PM2.5 = 1, or both =2)	2	2	2	2
Convertible to PM2.5?	N/A	N/A	N/A	NO
Equivalence	YES	YES	NO	YES
MCERTS	YES	YES	NO	YES
COSTS				
Capital	28135	33660	22490	28020
Annual costs (including maintenance, consumable and energy)	6828	7243	4742	8823
10 year cost (assuming no changes and capital cost over this period)	**96415**	**106090**	**69910**	**116250**
10 year cost per metric (assuming no changes and capital cost over this period)	**48208**	**53045**	**34955**	**58125**

Table 4-8: 10-year costs for PM_{10} and $PM_{2.5}$ instruments, including installation, maintenance and energy costs. With and without new enclosure costs comparing best value options. Prices in £.

			10 year cost with new enlcosure *	
Instrument	10 year cost for $PM_{2.5}$ instrument only	10 year cost for $PM_{2.5}$ & PM_{10} instrument(s)	$PM_{2.5}$ instrument only	$PM_{2.5}$ & PM_{10} instrument(s)
BAM1020 heated	54385	108770	129385	183770
Partisol 2025	120370	240740	195370	315740
TEOM 1400 FDMS 8500	78340	156680	153340	231680
TEOM 1405-F PM FDMS	84135	168270	159135	243270
TEOM 1405-DF PM FDMS	n/a	96415	n/a	171415 ^
FIA SWAM 5a	n/a	106090	n/a	181090 ^
Palas FIDAS 200(S)	n/a	69910	n/a	144910 ^
Optis SM200	n/a	116250	n/a	191250 ^

* Assumed price of an enclosure at £75,000

^ Added for completeness, but unlikely to be required as should simply replace previous PM_{10} monitor

Best value option with lowest overall cost for 10 years (green) — Next best value option with lowest overall cost for 10 years (yellow)

4.4.2 Site Modifications and Costs

The site enclosure (cabinet or cabin) may require modification (or replacement) to fit two analysers: this may include two inlets, upgraded air conditioning and improved electricity supply. Site photos below illustrate for indicative purposes the multiple inlet heads and increased size of enclosures required when two analysers are used (see Figure 4-6), compared to smaller single inlet units in the second set of photos, which measure both $PM_{2.5}$ and PM_{10} but using a single analyser (see Figure 4-7).

The cost of a new site was estimated in 2009 to be £50,000-75,000 [27] (however this figure may no longer be accurate). Updating a site to include a new PM analyser may only require the adding of an extra inlet and cage to the enclosure (assuming the enclosure is large enough), which would have a small associated cost, (approximately £1000-£2000). However, if the enclosure required additional

[27] Defra (2009) *Local Air Quality Management Technical Guidance LAQM.TG(09)*, Department for Environment, Food and Rural Affairs, Nobel House, 17 Smith Square, London SW1P 3JR, Telephone 020 7238 6000, Website: www.defra.gov.uk. Available at: https://www.gov.uk/government/publications/local-air-quality-management-technical-guidance-laqm-tg-09.

electricity, telephone lines, air conditioning the cost may increase significantly. If the enclosure is not large enough and required replacing, then the cost would be similar of the building of a new site, depending on the additional electricity, telephone lines and air conditioning costs.

Conversely, a site that already contains a single PM analyser would be adequate to install an analyser which can measure both $PM_{2.5}$ and PM_{10} simultaneously, i.e. FIDAS or the FDMS dual flow, therefore would require limited or no modification (just the new cage as discussed above).

Figure 4-6: Site photos of enclosures housing two analysers to measure PM_{10} and $PM_{2.5}$

Figure 4-7: Site photos of enclosures housing a single analyser to measure PM_{10} and $PM_{2.5}$

5 Recommendations and Options for Phased Network Development

There are still relatively few $PM_{2.5}$ monitoring sites in Scotland compared to the number of PM_{10} sites: in 2015 there were only 16 $PM_{2.5}$ instruments compared to 76 PM_{10} throughout the SAQD. Most $PM_{2.5}$ instruments within Scotland exist to meet historic regulation requirements, rather than to monitor compliance with the objective for $PM_{2.5}$.The number of sites monitoring $PM_{2.5}$ within Scotland has increased in the past two years: this has been partly brought about by the replacement of aging instruments, but also because a new analyser has become available, which has been shown to reduce costs (whilst measuring both $PM_{2.5}$ and PM_{10}), thus giving added information at little or no additional cost.

The financial pressure on Local Authorities is likely to significantly influence the acquisition of new instruments; thus the expansion of the $PM_{2.5}$ network is unlikely to continue due to market forces alone, and would probably require some influence from the Scottish Government.

The geographical spread of Scottish sites monitoring $PM_{2.5}$ is limited, with the majority of sites within Scotland's larger towns and cities; currently there are no instruments in and around Dundee and Perth region for example. Certainly there are few (only four $PM_{2.5}$ instruments) within the 21 PM_{10} AQMAs within Scotland, and calculated $PM_{2.5}$ concentrations suggest that many of these AQMAs would exceed the proposed $PM_{2.5}$ limit of 10 µg m^{-3}. This has obvious limitations, with only estimates using PCM or a calculated $PM_{2.5}$ concentration from the $PM_{2.5}/PM_{10}$ ratio to fill the gaps.

Using the $PM_{2.5}$ to PM_{10} ratio to predict $PM_{2.5}$ concentration, as reported extensively in the sister report[14] can give reasonable indicative estimates of $PM_{2.5}$ concentration, both at a local and regional level, similarly to the use of PCM data. Such data could be used in the short term if the decision to expand the $PM_{2.5}$ network was taken to supplement data, or indeed in the longer term if the expansion network is delayed.

As noted above the ideal situation is that market forces determine the development of the network, however, this might lead to slow uptake of the technology, especially if LAs have recently purchased new equipment and considering the financial restrictions on councils at present.

In view of:

- The limited geographical spread of $PM_{2.5}$ monitors,
- The lack of $PM_{2.5}$ monitors in the PM_{10} AQMAs,
- The potential exceedances of the proposed objective within these AQMAs, and
- The likelihood that there is increased attention to a $PM_{2.5}$ targets (from EU and UK governments),

The further expansion of a $PM_{2.5}$ network seems prudent. Additionally, the continued evidence that $PM_{2.5}$ is more important than PM_{10} with respect to health, and the possible greater concentration of $PM_{2.5}$ as reported in the sister report[14] using the ratio data also points to the expansion of the $PM_{2.5}$ network. Such a network would also require the development of AQMAs and AQAPs, especially considering the proposed $PM_{2.5}$ objective of 10 µg m^{-3}. However, it is important to understand the limitations of the instruments being deployed, especially considering the uncertainty at 10 µg m^{-3} is likely to be high.

The expansion of the $PM_{2.5}$ network is likely to be a costly exercise:

- A new analyser costs between £15,000 and £34,000
- Annual costs are between £3,500 and £10,300 pa
- 10 year overall costs are between £54,000 and £120,000
- Instruments measuring both $PM_{2.5}$ and PM_{10} simultaneously offer comparative savings, with overall 10 year costs of between £35,000 & £58,000 per metric
- Some sites could not accommodate a second new analyser without a new enclosure, and this is thought to cost in the region £75,000, though systems measuring 2 metrics are unlikely to need this upgrade

- Time and money to develop AQMAs and AQAPs for local authorities (LAs) to meet these objectives assuming they fail to meet the current or proposed objectives.

It is recommended that if the $PM_{2.5}$ objective is reduced to 10 µg m^{-3}, and Scottish Government wish to expand the $PM_{2.5}$ network to capture compliance (especially considering the current geographical limitation of the network), then a strategy to increase the number of sites with $PM_{2.5}$ analysers needs to be considered, with an initial focus to cover areas with currently no $PM_{2.5}$ monitoring, especially areas with a current AQMA for PM_{10}. Then, a *further* expansion of the $PM_{2.5}$ network should look to mirror to some extent the current PM_{10} network within Scotland, with consideration to an area having both roadside, urban background and rural sites. Phases and numbers might look like the following:

Possible requirement 1 (roadside / within PM_{10} AQMAs): expansion of $PM_{2.5}$ network into areas with no current monitoring -

i. At least one new monitor in both Perth and Dundee (**minimum two monitors**) within current PM_{10} AQMAs
ii. Roadside sites with PM_{10} AQMAs which have an annual PM_{10} greater than 13 or 14 µg m^{-3}, which give a calculated $PM_{2.5}$ of at least 8 µg m^{-3} (**13 monitors excluding** the two above)
iii. Review of requirements in Edinburgh which has no current PM_{10} AQMAs, but has four PM_{10} sites exceeding 13 or 14 µg m^{-3} (at least **one roadside monitor**)

Thus the required number of required roadside/kerbside $PM_{2.5}$ monitors within Scotland's town and cities is a minimum of **16 analysers.**

Possible requirement 2 (background and rural): further expansion of $PM_{2.5}$ network for urban background and rural locations

i. At least one new monitor to match current urban background PM_{10} monitors throughout Scotland's towns and cities (currently three cities have $PM_{2.5}$ urban background (UB) monitoring, whilst five further areas have PM_{10} UB sites, thus a minimum of **five UB monitors** are required)
ii. It is recommended that consideration should be given to expanding the current rural monitors, with careful attention of location. Currently there is an AURN site at Auchencorth Moss, to the South of Edinburgh, though this might be considered too close to Edinburgh when the wind is from a Northerly direction. It might be worth considering at least **three rural monitors** in other locations.
    a. one or more monitors to detect influx of $PM_{2.5}$ and PM_{10} particulates from the South and South East thus giving an early warning of elevated particulate events, from continental Europe, England or further afield.
    b. two monitors to detect volcanic particulates from Iceland. These need to be in the far North West of Scotland, for example Durness and North West Lewis. Some of this data could be supplemented with data from the Faroe Isles which have two FIDAS PM_{10} / $PM_{2.5}$ monitors

Thus the required number of urban background / rural $PM_{2.5}$ monitors across Scotland is considered to be a minimum of **eight analysers.**

Therefore considering each possible requirement, then the number of necessary analysers is in the order of 24 throughout Scotland. This would expand the current network from 15 sites to 39 sites, which is a little over half the size of current PM_{10} network. The phasing of such a network would be dependent upon numerous factors, chief amongst these would be cost and lack of current $PM_{2.5}$ instrument in a particular area. It might be considered that the roadside sites are more important, thus it is proposed replacement of current PM_{10} analysers within AQMAs might be a priority (requirement 1 above).

As noted above the cost would be appreciable, with the minimum cost of a new analyser that measures both $PM_{2.5}$ and PM_{10} at ~£70,000. Thus 24 new analysers would cost a total of £1.68 million without any consideration to new enclosures that might be required, though this would likely only be required where there is currently no PM_{10} monitoring.

It is possible some newer instruments that measure PM_{10} could be adapted to measure $PM_{2.5}$ at little expense assuming the proposed cabinet could house the extra analyser and only requires a new inlet. This could save the buying of new instruments in some cases, but needs to be researched more fully to review the cost saving. Spending could be phased with older instrument being replaced first, with perhaps incentives to change to a two-metric system, also as per the requirements, with instrument at the roadside sites being replaced first.

Another option is to review the use of a semi-permanent or moveable instrument, which has the capability of measuring $PM_{2.5}$ for an extended period of up to six months, enabling a detailed understanding of the local needs within an AQMA, thus saving the expense of buying a new instrument if not required. This option would require a number of these instruments to be hired or purchased, but it may be possible to use these instruments permanently within the network following their temporary deployment.

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Appendices

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

$PM_{2.5}$ monitoring network evaluation

The Scottish Government's intentions to include a 10 µg m^{-3} annual mean $PM_{2.5}$ objective 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 $PM_{10.}$ With respect to the need to establish a $PM_{2.5}$ monitoring network it is proposed that a network evaluation is undertaken to evaluate different options regarding the design and implementation of a future $PM_{2.5}$ monitoring network for Scotland. This evaluation would consider:

- Number and geographical spread of existing $PM_{2.5}$ monitoring sites across Scotland
- Number and geographical spread of existing PM_{10} monitoring sites across Scotland, including site type (kerbside, roadside, urban background, background) type and age of equipment, scope for modification of site to incorporate a new analyser or retrofit existing analyser.
- Compliant $PM_{2.5}$ analysers and retrofits – options and associated costs (capital and maintenance)
- Development of recommendations/ options for phased network development. Considering existing monitors and infrastructure together with proposed geographical coverage, associated costs and limitations of a new network.

It is provisionally recommended that where possible sites are designed to meet the requirements of the Air Quality Directive 2008/50/EC, and thus any data generated could also be used to report to the European Commission.

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 $PM_{2.5}$

Table A3: Source attribution for annual average $PM_{2.5}$[10]

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 µg 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.

Appendix 4: Effect of reductions in primary PM and SIA precursors on $PM_{2.5}$ mass (AEI) concentrations

Table A4: Effect of reductions in primary PM and SIA precursors on $PM_{2.5}$ mass (AEI) concentrations[10]

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 5: Tables 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 PM2.5 measure	End of PM2.5 measure	Start of PM10 measure	End of PM10 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	

Site Code	Site Name	Pollutants Measured	Latitude	Longitude	Type	Currently Operational	Start of PM2.5 measure	End of PM2.5 measure	Start of PM10 measure	End of PM10 measure
WDB3	West 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}

Table A6: 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 PM10 measure	End of PM10 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	

Site Code	Site Name	Pollutants Measured	Latitude	Longitude	Type	Currently Operational	Start of PM10 measure	End of PM10 measure
DUN5	Dundee Seagate	PM_{10}	56.462381	-2.967379	KERBSIDE	Yes	09/05/11	
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	
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	

Site Code	Site Name	Pollutants Measured	Latitude	Longitude	Type	Currently Operational	Start of PM10 measure	End of PM10 measure
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
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	

Site Code	Site Name	Pollutants Measured	Latitude	Longitude	Type	Currently Operational	Start of PM10 measure	End of PM10 measure
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	
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

Site Code	Site Name	Pollutants Measured	Latitude	Longitude	Type	Currently Operational	Start of PM10 measure	End of PM10 measure
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	
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	

Appendix 6: Defra approved equipment

The table below summarises the status of particulate matter methods for use in the UK in terms of which have been approved by Defra as equivalent for use in the UK. This considers separately the instruments which were deemed equivalent by Defra and approved as equivalent based on upheld decisions predating the MCERTS for UK Particulate Matter, and instruments which are formally certified to MCERTS for UK Particulate Matter. Also included are those instruments that have MCERTS certificates but are not approved by Defra for use within the UK for particulate matter monitoring.[28]

Table A7: Defra approved equipment

Instrument Type	Species	Deemed equivalent by Defra	Certified to MCERTS for UK Particulate Matter	Certified to MCERTS for CAMs of Particulate Matter
Thermo Partisol 2025 (gravimetric)	PM_{10}	Defra approved: Meets equivalence criteria	No	No
Thermo Partisol 2025 (gravimetric)	$PM_{2.5}$	Defra approved: Meets equivalence criteria	Yes	Yes
Thermo TEOM 1400 (automatic)	PM_{10}	Failed equivalence criteria[1]	No	No
Thermo TEOM 1400 with FDMS 8500 (automatic)	PM_{10}	Defra approved: Meets equivalence criteria[2]	No	No
Thermo TEOM 1400 with FDMS 8500 (automatic)	$PM_{2.5}$	Defra approved: Meets equivalence criteria[2]	No	No
Opsis SM200 (automatic)[3]	PM_{10}	Defra approved: Meets equivalence criteria	No	Yes
Opsis SM200 (gravimetric)	PM_{10}	Defra approved: Meets equivalence criteria (after correction)	No	Yes
Met-One BAM1020 (unheated version)(automatic)	PM_{10}	Defra approved: Meets equivalence criteria (after correction)	No	Yes

[28] Defra (2015a) *Certification - MCERTS for UK Particulate Matter*: 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/networks/monitoring-methods?view=mcerts-scheme (Accessed: 21/1/16.

Instrument Type	Species	Deemed equivalent by Defra	Certified to MCERTS for UK Particulate Matter	Certified to MCERTS for CAMs of Particulate Matter
FAI SWAM 5a (SC and DC)	PM_{10} & $PM_{2.5}$	Defra approved: Meets equivalence criteria	Yes	Yes
FAI SWAM 5a (Hourly and daily averages)	PM_{10} & $PM_{2.5}$	Defra approved: Meets equivalence criteria	Yes	Yes
Opsis SM200 (beta)[3]	$PM_{2.5}$	Not tested in 2004 to 2006 trials	No	Yes
Thermo Sharp 5030	PM_{10}	Not tested in 2004 to 2006 trials	No	Yes
Thermo Sharp 5030	$PM_{2.5}$	Not tested in 2004 to 2006 trials	No	Yes
Met-One BAM1020 (Smart heated version) (automatic)	PM_{10}	Defra approved: Meets equivalence criteria (after correction)	Yes	Yes
Met-One BAM1020 (Smart heated version) (automatic)	$PM_{2.5}$	Defra approved: Meets equivalence criteria	Yes	Yes
Grimm EDM180	PM_{10}	Not tested in 2004 to 2006 trials	No	Yes
Grimm EDM180	$PM_{2.5}$	Not tested in 2004 to 2006 trials	No	Yes
Thermo 1405-F FDMS	PM_{10}	Defra approved: Meets equivalence criteria	Yes	Yes
Thermo 1405-F FDMS	$PM_{2.5}$	Defra approved: Meets equivalence criteria	Yes	Yes
Thermo 1405-DF FDMS	PM_{10} & $PM_{2.5}$	Defra approved: Meets equivalence criteria	Yes	Yes

Notes:

[1] While the TEOM 1400 PM10 analyser failed demonstration of equivalence even with linear correction for slope and offset, data can be corrected using the Volatile Correction Model and demonstrate equivalence to the Reference Method

[2] FDMS 8500 units in the AURN are currently fitted with B- or CB-type dryer modules

[3] The Opsis SM200 appears to be a combined instrument measuring both $PM_{2.5}$ and PM_{10} automatically, it may also have MCERTS for UK particulate matter but this isn't noted above, but can be seen on both the manufacturers[29] and resellers[30] webpages

[29] Opsis (2016) *SM200 Particulate Monitor*. Available at: http://www.opsis.se/Products/ProductsAQM/SM200ParticulateMonitor/tabid/1059/Default.aspx (Accessed: 10/2/16.
[30] EnviroTechnology (2016) *OPSIS SM200 Beta-attenuation Particulate Monitor / Gravimetric Sampler**. Available at: http://www.et.co.uk/products/air-quality-monitoring/particulate-monitoring/opsis-sm200-beta-attenuation-particulate-monitor-gravimetric-sampler/ (Accessed: 10/2/16.

Appendix 7: Cost of instruments

Table A8: Comprehensive list of instrument and annual costs

Manufacturer	Met-One	Met-One	Met-One	Thermo	Thermo	Thermo	Thermo	Thermo	Thermo	Thermo	Thermo	FAI	PALAS	Opsis
Type	BAM	BAM	BAM	Partisol	Partisol	TEOM	TEOM FMDS	TEOM FMDS	TEOM FMDS	TEOM FMDS	TEOM FMDS	SWAM	FIDAS	Opsis
Model	BAM1020 unheated	BAM1020 heated	BAM1020 heated	Partisol 2025 (gravimetric)	Partisol 2025 (gravimetric)	TEOM 1400	TEOM 1400 FDMS 8500	TEOM 1400 FDMS 8500	TEOM 1405-F PM10 FDMS	TEOM 1405-F PM2.5 FDMS	TEOM 1405-DF PM2.5 FDMS	SWAM 5a DC hourly	200(S)	SM200
UK supplier	ET or Air Monitors	ET or Air Monitors	ET or Air Monitors	Air Monitors	Air Monitors	Air Monitors	Air Monitors	Air Monitors	Air Monitors	Air Monitors	Air Monitors	ET	Air Monitors	ET
PM measured	PM10	PM10	PM2.5	PM10	PM2.5	PM10	PM10	PM2.5	PM10	PM2.5	PM2.5 & PM10	PM2.5 & PM10	PM2.5 & PM10	PM10
Metrics Measured (Just PM10 or PM2.5 = 1, or both =2)	1	1	1	1	1	1	1	1	1	1	2	2	2	1
Convertible to PM2.5?	NO	YES	N/A	NO	N/A	NO	YES	N/A	YES	N/A	N/A	N/A	N/A	NO
Equivalence	YES (after correction)	YES	YES	YES	YES	NO - but meets after correction	YES	YES	YES	YES	YES	YES	NO	YES
MCERTS	NO	YES	YES	NO	YES	NO	NO	NO	YES	YES	YES	YES	NO	NO
COSTS														
Capital	15295	18495	18615	16445	16990	16320	16320	16320	23875	23875	28135	33660	22490	28020
Annual costs (including maintenance, consumable and energy)	3589	3589	3589	10338	10338	6202	6202	6202	6026	6026	6828	7243	4742	8823
10 year cost (assuming no changes and capital cost over this period)	51185	54385	54505	119825	120370	78340	78340	78340	84135	84135	96415	106090	69910	116250
10 year cost (assuming no changes and capital cost over this period)	51185	54385	54505	119825	120370	78340	78340	78340	84135	84135	48207.5	53045	34955	116250

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