Observations on Air Quality in the UK during the Covid-19 Lockdown, April 2020.

A report submitted to the Air Quality Expert Group by Dr David Muir on behalf of Environmental Protection UK.

Introduction.

This report is submitted in response to the request for evidence issued by the Government's Air Quality Expert Group (AQEG) in April 2020. The basis of the work carried out has been to examine the hourly average concentrations of nitrogen dioxide, total oxides of nitrogen (NO_x), ozone, PM_{10}, $PM_{2.5}$ and carbon monoxide at a total of 40 monitoring sites (listed in Table 1) across the UK from 1 January to 19 April 2020, compared with the corresponding long term hourly average concentrations at each site. The majority of these sites are in the AURN but some data have also been examined from the London Air Quality Network, Air Quality in Scotland and from sites at Heathrow and Birmingham Airports. These sites cover all the main description categories and were selected because they mainly had long term (ideally 10+ years) datasets to calculate the long-term average concentrations of the various pollutants. For the purposes of this study the date for the start of the lockdown is taken as Monday 23 March 2020.

Not all the pollutants mentioned above are measured at all the sites. The inclusion of the Heathrow sites made it possible, albeit to a very limited extent, to include data for PM_1 and Black Carbon (BC) and from sites close to a major airport. A further caveat must be given: at some of the sites there have been equipment changes and this might reduce the validity of comparisons. Finally, at some sites data are not available for all pollutants for all of the period under consideration.

Table 1 Sites examined.

Urban Traffic (8)	Urban Background (19)	Urban/Suburban Industrial (6)	Rural Background (4)	Airport (3)
Camden Kerbside, Dumfries, Enfield Bowes Primary School, Glasgow Dumbarton Road, Knightsbridge, London Marylebone Road, Oxford Centre Roadside, York Fishergate.	Aberdeen, Belfast Centre, Bristol St Pauls, Cardiff Centre, Edinburgh St Leonards, Glasgow Anderston, Hull Freetown, Leamington Spa, Leeds Centre, London Bloomsbury, London North Kensington, Manchester Piccadilly, Newcastle Centre, Norwich Lakenfields, Nottingham Centre, Plymouth Centre, Sheffield Tinsley, Southampton Centre, Stoke-on-Trent Centre.	Billingham, Grangemouth, Horley, Liverpool Speke, Middlesbrough, Port Talbot Margam.	Glasgow Waulkmilglen Reservoir, Lullington Heath, Lough Navar, Narberth.	Birmingham Airport, Heathrow LHR2, Heathrow Oaks Road.

Methodology.

Initially, all available data for 2020 at the selected sites were compared with the long-term average concentrations as simple time series to establish the extent to which concentrations of the five pollutants compared with the long-term averages. Given that, in general, the concentrations of most pollutants have fallen at least to some extent over the years it was felt that the 2020 concentrations would probably be lower than the long-term averages used but that the comparison would still provide a benchmark against which to assess any changes post-lockdown. It is also important to recognise that the 2020 data are provisional and, in some cases at least, might be of questionable reliability as will be shown.

In some cases, simple time series graphs gave a very clear indication of whether or not pollutant concentrations changed after 23 March but in others the degree of variation of hourly average concentrations made for confusion. This led to further, more detailed, work being carried out looking at time series of the hourly average concentrations divided by the corresponding average for that day and hour and by calculating weekly averages of ratios of measured concentrations to averages.

Finally these concentration ratios; NO_2:NO_X, PM_{10}:$PM_{2.5}$, PM_{10}:$NO_2/NO_X/O_3$ and $PM_{2.5}$:$NO_2/NO_X/O_3$ were calculated for each hour of 2020 and, again, compared with the long term average ratios.

Expectations.

The lockdown that followed the outbreak of Coronavirus in the UK resulted in a major change in road traffic. A combination of media reporting and (limited) personal observation suggested that the total amount of traffic fell from mid-March, initially relatively slowly and then more dramatically. Apart from reducing the amount of road traffic this reduction had the side effect that, in theory at least, the remaining traffic would be able to move more smoothly which should have the consequence of decreasing emissions.

The main expectation arising from this combination was that there should be a noticeable improvement in urban air quality, at least so far as the two main pollutants of concern (namely NO_2 and particulate matter (PM)). Further consideration of this potential reduction in emissions, certainly of oxides of nitrogen (predominantly nitric oxide (NO)) suggests that ozone concentrations could rise, at least in urban areas, due to the removal of NO as a sink for ozone.

Observations.

Carbon monoxide.

This is only measured at eight of the sites under consideration here and is of only marginal interest as concentrations of CO are now very low nationally. In spite of that they might still provide some indication of petrol engined vehicle activity albeit to a limited extent.

There is little similarity between the eight sites beyond the fact that CO concentrations were mainly below the long-term averages. The data from the Edinburgh St Leonard's sites are unusable in the current provisional form as there are many negative values. At Belfast Centre concentrations fell from 9 March and at Birmingham Airport 2 there was a marginal increase from late February. At Cardiff Centre there was a marked increase from 23 March and this was even more marked at Leeds Centre where concentrations were higher than the long-term average. At London Marylebone Road concentrations fell whereas at both London North Kensington and Port Talbot Margam they remained steady and often slightly higher than the long-term average.

Ozone.

The data for ozone were sufficiently clear that the examination of the ordinary time series was adequate for this study. At the majority of urban sites ozone concentrations from January to March were slightly higher than the long-term average concentrations. There were, however, two cases (Aberdeen and Belfast Centre) where the 2020 concentrations were markedly lower than the average during this period. There was no particular difference between the various sub-groups of urban sites. At the rural sites concentrations at Lullington Heath approximated to the average but at all others concentrations were higher than average.

From 23 March all the sites, with the exception of Aberdeen, recorded concentrations of ozone higher than average and, to a greater or lesser extent, more so than in the earlier months. This was most marked at London Marylebone Road where in January/February the average ozone concentration was 117% of the average compared with 265% in March/April. The increases in concentrations of ozone were far more marked at the urban sites and it seems likely that this is a consequence of there being less nitric oxide to act as a sink for the ozone. The fact that the largest increase was at London Marylebone Road might add weight to this deduction.

PM_{10} and $PM_{2.5}$.

The initial examination of the time series data for PM_{10} and $PM_{2.5}$ did not appear to show any particular consistency between patterns at the sites investigated. The more detailed examination looking at hourly average concentrations divided by the corresponding long-term average concentrations, especially when the weekly averages were considered, showed very clearly that at all sites concentrations of both PM_{10} and $PM_{2.5}$ increased after 23 March compared with 1 January – 22 March. There were also many differences. At some sites (e.g. Edinburgh St Leonards) concentrations of both remained below average. At others (e.g. Glasgow Dumbarton Road and Waulkmilglen Reservoir PM_{10} remained below average but $PM_{2.5}$ was higher than average. At the majority of other sites, regardless of site type, concentrations of both PM_{10} and $PM_{2.5}$ were higher than average to a greater or lesser extent.

NO_2 and NO_X.

As stated earlier the initial expectation was that the reduction in road traffic would lead to a marked and sustained reduction in the concentrations of both NO_X and NO_2 at least at urban sites. The time series data as plotted for initial examination seemed to suggest that, although NO_X concentrations had fallen and remained relatively low the same might not be the case for NO_2. As the data for NO_2 in particular were very variable, making the longer term plots less clear, the data were subjected to further analysis.

Apart from the examination of hourly $[NO_2]$:$[NO_X]$ ratios (see below) the weekly averages of the concentrations of both NO_2 and NO_X divided by the long term averages were calculated. This showed very clearly that at most non-industrial urban sites, concentrations of both pollutants after 23 March were in general about 40% of the long-term average. One caveat that should be made here is that in a number of cases the earlier data for 2020 were also lower than the long term average. These sites are listed in Table 2 and grouped to identify sites where the 2020 average was <75%, <66% or <50% of the long-term average.

The actual reductions in NO_2 concentrations from 23 March compared to 1 January to 22 March range widely from 59% at Belfast Centre to 7.5% at London Bloomsbury. Some sites even recorded small increases in NO_2 concentrations, Plymouth Centre and Southampton Centre (+7.6% and +0.9% respectively) and Heathrow Oaks Road showed a 35% increase. This, and the Plymouth increase, seem to be the consequence of some very low recorded concentrations in February resulting in especially low average concentrations for the earlier period. Two rural sites, Lullington Heath and Narberth showed even larger percentage increases. Reductions in NO_X concentrations were consistently higher, a 50% reduction in NO_2 typically corresponding to a 70% reduction in NO_X.

Table 2 Sites with lower than average NO_2 and/or NO_X, January – March 2020.

	NO_2	**NO_X**
75%	Birmingham Airport, Edinburgh St Leonards, Grangemouth, Heathrow LHR2, Leeds Centre, Nottingham Centre, Sheffield Tinsley, Southampton Centre.	Aberdeen, Bristol St Pauls, Glasgow Dumbarton Road, Heathrow LHR2, Manchester Piccadilly, Stoke-on-Trent Centre, York Fishergate.
66%	Belfast Centre, Billingham, Bristol St Pauls, Enfield Bowes Primary School, Knightsbridge, Liverpool Speke, London Bloomsbury, London Marylebone Road, London North Kensington, Middlesbrough, Narberth, Oxford Centre Roadside, Plymouth Centre	Birmingham Airport, Cardiff Centre, Edinburgh St Leonards, Glasgow Anderston, Grangemouth, Leamington Spa, Leeds Centre, Liverpool Speke, London Bloomsbury, London Marylebone Road, London North Kensington, Middlesbrough, Narberth, Newcastle Centre, Nottingham Centre, Plymouth Centre, Sheffield Tinsley, Southampton Centre.
50%	Camden Kerbside, Heathrow Oaks Road, Lullington Heath.	Billingham, Camden Kerbside, Enfield Bowes Primary School, Glasgow Waulkmilglen Reservoir, Heathrow Oaks Road, Knightsbridge, Leeds Centre, Lullington Heath. Oxford Centre Roadside.

Heathrow PM and Black Carbon.

In the pre-lockdown period concentrations of PM_{10}, $PM_{2.5}$ and PM_1 were all usually lower than the long-term average. There were, however, two events in late January and early February that appear to be dominated by the $PM_{2.5}$/PM_1 fractions. BC concentrations were also notably elevated during these events.

Following the lockdown PM_{10} and $PM_{2.5}$ behaved in much the same way as at other sites and these were two of the sites where both PM_{10} and $PM_{2.5}$ were markedly higher than average post-23 March.

Data for PM_1 and BC were also examined at these two sites, in part because the author has observed that BC normally correlates well with ultrafine particles (UFP). At the LHR2 site PM_1 behaved in an almost identical fashion to $PM_{2.5}$ both pre and post 23 March whereas BC concentrations were generally about 50% of average with the exception of w/c 20 January. At Oaks Road PM_1 also mirrored $PM_{2.5}$ but BC concentrations, although below average, were close to it. There is a clear difference between these two sites, which are about 3 miles apart, but the reason is unclear. Normally BC concentrations at Oaks Road are lower than at LHR2 (~75%) but during this period they were very similar. Although BC usually correlates well with UFP there is evidence[1] that this is not the case with airport emissions so the Oak Road data suggest another source for the BC measured here.

Ratios.

Earlier work[2] has demonstrated that the ratios of concentrations of pollutants can shed important light on events. That work was aimed at identifying possible sources of PM_{10} during a range of pollution episodes. Here the main emphasis has been on the NO_2:NO_X ratio, largely because of limitation of time. The issues with PM_{10} and $PM_{2.5}$ mean that the ratios of these to other pollutants and to each should be examined to establish possible reasons for the increased concentrations after 23 March. That analysis is being undertaken but will be a lengthy process.

As described above both NO_X and NO_2 concentrations fell after 23 March while ozone concentrations rose. The relationship between the components of NO_X has been the subject of study in the past, notably by Derwent, Dixon and Middleton[3]. One essential element of this work has been that as the total NO_X concentration fell the proportion of NO_2 in that mixture would rise. One way of investigating this hypothesis

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[1] Evaluation of ultrafine particle concentrations and size distributions at London Heathrow Airport; Brian Stacey, Roy M. Harrison, Francis Pope, Atmospheric Environment 222 (2020) 117148.

[2] Muir, D. and Longhurst, J. (2006) Modelling the concentration of PM10 at a roadside using data from a nearby background site. In: Longhurst, J. and Brebbia, C. , eds. (2006) *Air Pollution XIV.* WIT Press, pp. 221-229. ISBN 9781845641658.

Muir, D. (2006) Identification of the possible sources of PM10, PM2.5 and PMCoarse during air pollution episodes in the UK. In: *Air Pollution and Environmental Health. From science to action. 15th IUAPPA Conference*, Lille, France, September 2006.

Muir, D. , Longhurst, J. and Tubb, A. (2005) Characterisation and quantification of the sources of PM10 during air pollution episodes in the UK. *Science of the Total Environment*, 358 (1-3). pp. 188-205. ISSN 0048-9697.

Muir, D, Source Apportionment of PM_{10} During Pollution Episodes, PhD thesis, University of the West of England, 2003.

[3] Derwent R G and Middleton D R, 1996 An empirical function for the ratio NO2:NOx, UK Clean Air, 26, 57-602

Dixon J, Middleton D R and Derwent R G, 2000 Using measurements of nitrogen oxides to estimate the emission controls required to meet the UK nitrogen dioxide standard. Environmental Monitoring and Assessment, 65, 3-11.

Dixon J, Middleton D R and Derwent R G, 2001 Sensitivity of nitrogen dioxide concentrations to oxides of nitrogen controls in the United Kingdom. Atmospheric Environment, 35, 3715-3728.

is to calculate the hourly ratios [NO_2]/[NO_X] and compare them with long-term averages on a site by site basis and this has been done for a selection of sites listed in Table 3.

Table 3 Sites used for NO_2:NO_X ratio analysis.

Urban Traffic (2)	Urban Background (5)	Urban/Suburban Industrial (2)	Rural Background (2)	Airport (2)
Enfield Bowes Primary School, Knightsbridge, London Marylebone Road.	Aberdeen, Belfast Centre, Bristol St Pauls, Cardiff Centre, London North Kensington.	Billingham, Port Talbot Margam.	Lullington Heath, Narberth	Heathrow LHR2, Heathrow Oaks Road.

This analysis shows that in many, but by no means all, cases the [NO_2]:[NO_X] ratio increased after 23 March to a greater or lesser degree and remained higher than average until the end of the period being studied. The greatest increase in the ratio was observed at London Marylebone Road; 1.1 before 23 March and 1.8 after. At other sites (notably Aberdeen and London North Kensington) the difference was marginal.

Discussion.

It is clear that in general the lockdown has resulted in a reduction in concentrations of both NO_2 and NO_X. The fact that the latter decreased to a greater extent than the former indicates the difficulty of achieving the Air Quality Standards for NO_2. At least in part this evidence suggests that NO_2 concentrations are less responsive to reductions in road traffic. Also there are differences between different sites and site types. There are also issues with the fact that at a number of sites concentrations of NO_2 and NO_X in early 2020 were already low. This makes identifying the consequences of reduction of road traffic more difficult.

The increases in concentrations of ozone, especially in urban areas, might be a consequence of meteorological factors but the coincidence of the increases with the fall in NO_X concentrations very strongly suggests that they are a consequence of the reduction in availability of nitric oxide to act as an ozone sink and hence of the lockdown.

There is no single immediately obvious explanation for the increases in concentrations of PM_{10} and $PM_{2.5}$ that were observed. One possibility, given that increases were observed across the UK, is that long range transport and/or secondary particle formation was involved. Another is that non-road traffic sources, such as construction activity or, more probably, domestic and other combustion sources, were the predominant contributors to the observed particles.

From the data available it is not possible at this stage to reach any particular conclusions in relation to pollution arising from airports.

Key questions.

There are two of the key questions on which we would like to comment briefly.

- How might altered emissions of air pollutants over the next three months affect UK summertime air quality?

There would seem to be two aspects to this, one potentially positive, one potentially negative. On the positive side reductions in concentrations of oxides of nitrogen have the potential to reduce the formation of secondary particles. Set against this is the likelihood that reduced concentrations of NO_X will result in increased concentrations of ozone, especially in urban areas.

- Are there any insights that can be gained from aerosol science on possible viral transmission mechanisms?

At least one Italian study[4] suggests that the Covid-19 virus may e carried on fine particles and that this could have been a factor in the higher infection rates in Northern Italy. If this is the case the higher concentrations of PM_{10} and $PM_{2.5}$ in the UK after 23 March could be extremely important.

Suggestion for further work.

There is one vital aspect of air pollution which it has not been possible to examine here and that is what, if any, effect the lockdown has had on ultrafine particles as trying to derive likely concentrations of UFP from other metrics is unreliable. As the measured data for any calendar year are not usually available until about six months after the end of that year it will obviously be some time before this work can be carried out.

Concluding remarks.

It is clear that the changes in societal behaviour resulting from the Covid-19 outbreak have affected air pollution levels in the UK, most notably in the cases of oxides of nitrogen and ozone. There are a number of questions outstanding in relation to particles and a considerable amount of further work is needed in respect of this.

[4] Setti *et al*: https://www.medrxiv.org/content/10.1101/2020.04.11.20061713v1