‘A Network of Trust’: Measuring and Monitoring Air Pollution in British Cities, 1912–1960

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ABSTRACT

This paper examines the origins and development of the first nationwide air pollution monitoring network of its kind. The Investigation of Atmospheric Pollution was founded in 1912 with less than 30 participating bodies. By the 1960s it had expanded its research activities to involve over 500 cooperating authorities and organisations in almost every major British town and city. The paper is set out in three interrelated parts. Firstly, it explores how central and local government, representatives of industry, and non-governmental organisations worked together to establish an expert body that could gather information on polluted air, despite their different interests and agendas. Secondly, it draws historical attention to the importance (and difficulties) of technical standard-setting in providing reliable and policy-relevant knowledge about environmental pollution. Lastly, it will examine the uses of monitoring in efforts to raise public awareness of the problems caused by coal smoke and its role in supporting action to reduce urban air pollution, particularly after the 1952 London smog disaster.

KEYWORDS

History of air pollution, technical standard setting, environmental monitoring, British environmental history

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INTRODUCTION

By the turn of the twentieth century, high levels of atmospheric pollution from both industrial and domestic sources had enveloped major British cities such as Glasgow, Leeds, London and Manchester in a permanent smoke haze. Legislative and educational measures aimed at controlling urban air pollution had enjoyed little success, in part because of a lack of accurate information on which to ground decision-making and build consensus for meaningful action. While the political, economic, technological and socio-cultural obstacles to smoke abatement have all received scholarly scrutiny, the scientific work that paved the way for effective regulation in the mid-twentieth century has often been overlooked.[1] In this paper I examine a neglected aspect of Britain's urban environmental history, the origins and development of a monitoring network to systematically collect data on atmospheric pollution – the first nationwide investigation of its kind.[2]

The Committee for the Investigation of Atmospheric Pollution, founded in 1912 with less than 30 participating bodies, had by the 1960s expanded its research activities to involve over 500 cooperating authorities and organisations in almost every major British town and city. This study of how a national level investigation of atmospheric pollution was designed and developed is set out in three interrelated parts. Firstly, it will explore how central and local government, representatives of industry, and non-governmental organisations worked together to establish an expert body that could gather information on polluted air, despite their different interests and agendas. Secondly, it will draw historical attention to the importance (and difficulties) of technical standard-setting in providing reliable and policy-relevant knowledge about environmental pollution. Thirdly, it will examine the uses of monitoring in efforts to raise public awareness of the problems caused by coal smoke and its role in supporting action to reduce urban air pollution, particularly after the 1952 London smog disaster.[3]

BUILDING THE NETWORK

Sporadic efforts to measure pollutants in city air had been ongoing in Britain since the late 1840s, when scientist Robert Angus Smith's pioneering work had identified coal combustion as the principal cause of the great acidity of Manchester's rainfall. For example, in 1876 he noted:

> In Manchester, we have rain containing nearly a grain of free sulphuric acid per gallon. Where my laboratory is, by no means in the centre, the rain reddens litmus as it falls as rapidly as vinegar does, and trees and shrubs refuse to grow, even grass looks unhappy ... We do not require chemical works to destroy trees; coal alone is sufficient, although slower, whenever chimneys are sufficient in

> number to produce the acidity spoken of ... and all the coal districts shew this abundantly.[4]

The term 'acid rain' was coined by Smith, Britain's first Chief Inspector of Alkali Works, to describe the deleterious environmental consequences of air pollution in and around Manchester.[5] By the turn of the twentieth century, a number of scientists were actively involved in studying the amount of 'impurity' in the air of Manchester and other British cities, most notably in Glasgow, Leeds and London. Research conducted by the laboratory staff of *The Lancet*, one of the country's leading medical journals, revealed that some 650 tons of soot per square mile fell on the centre of London in 1910–11, together with an 'appalling downpour of chemical substances' that included tar, ammonia, chlorine, sulphate and traces of lead.[6] Work of this kind provided valuable information about atmospheric pollution and its effects in major cities and their hinterlands, but as Britain's scientists each 'did their own thing' it was difficult to compare results and build public confidence in this new knowledge.

For most of the nineteenth century, highly visible emissions from the massed ranks of tall smokestacks that dominated industrial towns were regarded by scientists, engineers, doctors and other specialists involved in anti-pollution activism as being chiefly responsible for a variety of serious problems, including the destruction of vegetation; loss of sunlight; the defacement of monumental architecture; and rising rates of respiratory diseases among urbanites.[7] But by the 1880s, the forceful campaigning of the meteorologist Francis Albert Rollo Russell, son of the former Prime Minister Lord John Russell, and others had begun to attract public attention to the damage that the less visible emissions from private homes caused to human health and the urban environment. Most strikingly, in his influential publication *London Fogs* (1880), Russell charged that the smoke issuing from 'more than a million' domestic chimneys, in combination with prolonged fogs, had 'literally choked to death' some 2,000 Londoners during late January and early February 1880, mainly due to the exacerbation of pre-existing lung conditions.[8] Picked up by the Victorian press, discussion began to centre on whether industries or households were the major polluters of city air. Domestic smoke emissions, unlike those from factory chimneys, were not subject to any form of regulation or legislation. And without reliable statistical information on the sources of urban air pollution, it was difficult for reformers to make a convincing case for political action to interfere with individual freedom and abate smoke from the traditional open coal fire.[9] In 1899, for example, *The Builder* – a journal that was highly supportive of the smoke abatement movement – reported that 'observers all over the country' were confirming domestic fires as the leading cause of the 'smoke nuisance', although it cautioned, 'with what accuracy it is difficult to determine'.[10] Even *The Builder* mistrusted the evidence gathered via the disparate investigations of private individuals.

To compound matters, smoke abatement was still widely considered to be a meddlesome 'aesthetic craze'. In 1922, Ernest Simon, Chairman of the Smoke

Abatement League of Great Britain, emphasised this point when he called for a more 'scientific' approach to the campaign to control smoke in order to win the public's confidence:

> The smoke abater is almost universally regarded as an amiable and unpractical faddist; and when one considers the long and sterile history of the movement, and the methods generally pursued by the smoke abatement enthusiast in the past, one cannot deny that the indictment has at least some justification … The time has come for entirely new methods. The difficulty and complexity of the problem must be recognised ... ignorant propaganda must be replaced by research, by scientific method, by helpful technical advice, and by education of both the manufacturer and of the public.[11]

The early twentieth-century was a period when reformers placed great faith in science, technology and expertise to provide insight into the problems of urban-industrial society.[12] It was becoming clear to many anti-smoke activists that the 'credibility gap' could be bridged through cooperation in the production of new scientific knowledge, along with the standardisation of methods. They recognised a need to transform 'independent and isolated' research that was 'useless for comparative purposes' into a coordinated system for gathering and interpreting 'trustworthy' data, so that the public could better 'see' and understand the smoke problem.[13]

The first step on the road to adopting new methods and practices, and toward credibility in the public domain, had been taken ten years earlier at the International Smoke Abatement Exhibition and Conference, London. Inspired in particular by the studies of *The Lancet* and Julius B. Cohen, Professor of Organic Chemistry at Leeds University, delegates to the London conference – including representatives of several municipal authorities – met to appoint a Committee for the Investigation of Atmospheric Pollution. Its remit was to standardise methods and apparatus, and to codify procedures, for measuring and monitoring smoke in British cities. Founded in 1912, this new voluntary body counted among its members many of the leading figures in atmospheric research and the smoke abatement movement, including Cohen, who was also a member of the Leeds Smoke Abatement Society, Sir Napier Shaw, Director of the Meteorological Office, Dr. Harold A. Des Voeux, Treasurer of London's Coal Smoke Abatement Society, Baillie W.B. Smith, Convenor of the Air Purification Sub-Committee of Glasgow Corporation, and the aforementioned Ernest Simon of the Manchester-based Smoke Abatement League of Great Britain. Bringing together the various actors was a decisive moment in the joint endeavour of designing the research programme and building the network. From the outset the Committee desired not only to determine the origins, nature and extent of urban atmospheric pollution 'for its own sake', but also to use this information to advance the cause of smoke abatement.[14] Its aims were to measure air pollution in towns over time, create reliable and comparable scientific data that would allow the different cooperating bodies to raise public awareness of the 'smoke problem', and ultimately for this knowledge to be used in planning and executing prevention strategies. In order to better understand the development of standards, technologies, data collection practices, and the uses of measuring and monitoring, we must first gain a sense of the organisational evolution and geographical expansion of the network.

Mobilising a nationwide system for the study of air pollution was an expensive undertaking that went through several stages of development. The second report of the Committee for the Investigation of Atmospheric Pollution, issued for the year 1915–16, drew attention to the 'financial difficulties' of designing, fitting out and managing the emerging network. The cost of operating the field stations amounted to around £1,000 per annum, discounting the expense of compiling data and coordinating the investigation. Local authorities and other cooperating bodies met the expense of equipping and running the field stations, while a successful application to the newly established Department of Scientific and Industrial Research (DSIR) for a government grant contributed a further £500 per annum towards the cost of coordinating the research programme and publishing the results.[15] The Committee's work was given 'official approval and status' in 1917, when it was reconstituted as the Advisory Committee on Atmospheric Pollution under the direction of the Meteorological Office. In 1927, the coordination of the network became the responsibility of the DSIR, in order to better support the development of the research side of the work. At the same time, it was renamed the Investigation of Atmospheric Pollution. As well as continuing to fund the field stations, the various collaborating organisations also agreed collectively to match the £500 government grant towards research and central services. All those who contributed were entitled to appoint one or more representatives to a new Standing Conference of Co-operating Bodies, which met twice a year to 'provide an effective opportunity of consultation' and to inform the DSIR of any 'problems or difficulties arising in the work'.[16]

The Standing Conference promoted 'the closest possible contact between the Department, as responsible for the direction of the work, and the representatives of local authorities and industry, as responsible for the practical application of its results'.[17] Although it had no executive power, the Standing Conference gave participants a voice in discussions about how the Investigation should be developed; it promoted mutual assistance and understanding by bringing the various allies together; and it facilitated the communication of up-to-date information to those attempting to solve the smoke problem and related public health questions. The rules and standing orders of the Standing Conference allowed for the discussion of 'remedial measures for dealing with atmospheric pollution' to encourage participation in the Investigation. However, tensions did occasionally surface between the various cooperating bodies. In April 1931, for example, the appointment of the anti-smoke activist Dr. Harold A. Des Voeux as chairman of the Standing Conference was a cause for concern to the DSIR, as it was perceived to be ‘a disadvantage to have as chairman one who is so closely identified with the work of a propagandist organisation’. An attempt in May 1936 by the representative for Glasgow Corporation, Bailie Alex Munro, to raise a deputation from the Standing Conference to wait on the Minister of Health, Kingsley Wood, to press for tougher anti-smoke legislation was also the source of some ‘embarrassment’ to the DSIR. But a confidential DSIR report on the activities of the Investigation found that in general it was ‘working well [and] … This is largely due to the success of the Standing Conference’.[18]

The Standing Conference remained an invaluable forum for collaboration and discussion when the Investigation was merged with the activities of the Fuel Research Station of the DSIR in 1945, to link more effectively with ‘practical work’ on fuel efficiency and smoke prevention. The Chairman of the Investigation's Research Committee, G.M.B. Dobson, had stressed its importance during merger negotiations the previous year:

> We do wish to record our conviction that the contact between research workers and those more directly concerned with the suppression of pollution has been of great value in the past and holds out the promise of even greater value in the future if the research is, as we recommend, to be even more closely related to the avoidance of pollution.[19]

The immediate post-war period saw coal-rationing and fuel shortages that persuaded the government to increase its share of the Investigation's funding. From this time on, it no longer depended on the ‘£ for £ formula’ for equal contributions by cooperating parties which had been in place since 1927. The Investigation now had the full backing of the state, allowing for significant expansion. In 1960, the burgeoning network was reorganised as the National Survey of Smoke and Sulphur Dioxide, again retaining the twice yearly meetings of the Standing Conference that had enabled all sides – central government, local authorities, industry, clean air groups, and other institutions – to work together effectively.[20] Table 1 below outlines the growth of participation in the Investigation of Atmospheric Pollution and the National Survey over almost fifty years.

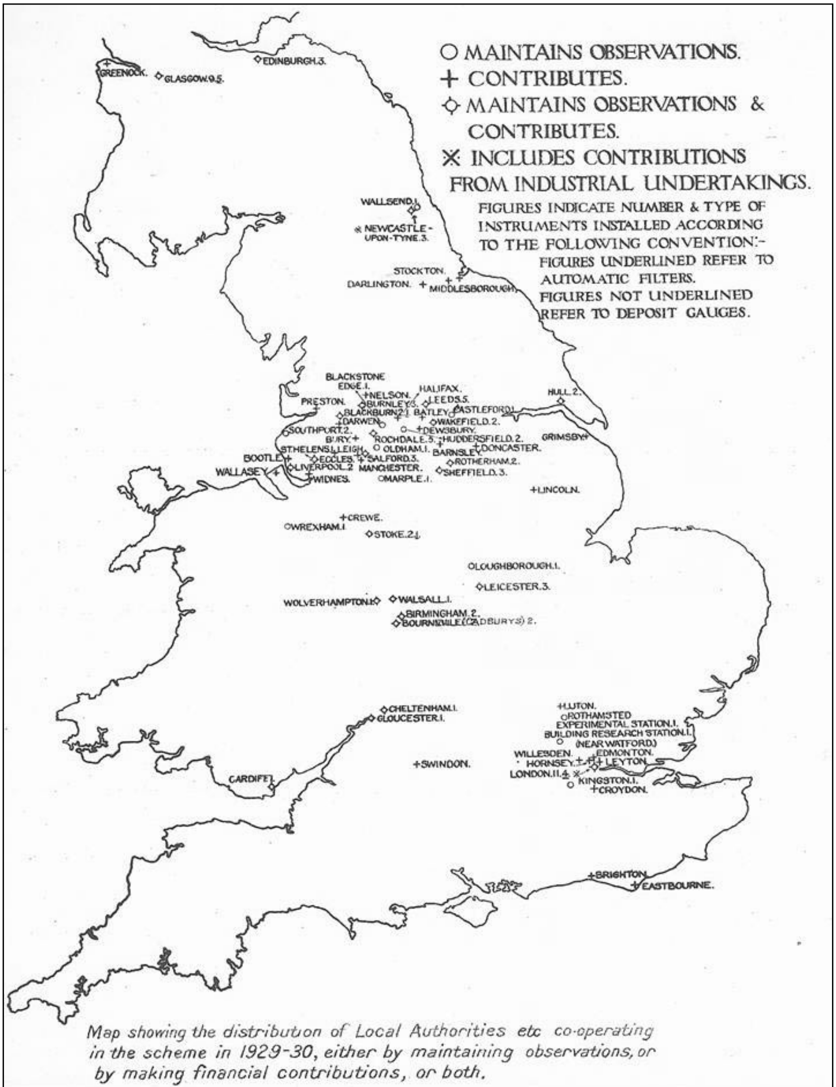
Year	Government Bodies	Local Authorities	Industry	Others	Total
1917	2	17	0	5	24
1925	5	22	3	8	38
1930	6	67	6	3	82
1939	8	77	5	5	95
1954	8	213	16	10	247
1966	13	448	25	43	529

TABLE 1. Growth of Cooperating Bodies in the Investigation.
Sources: Investigation of Atmospheric Pollution Reports

In 1917, the DSIR and Meteorological Office had been the central government's only representatives in the Investigation. By the 1960s, no fewer than thirteen government departments had an interest in the network, including the Ministry of Health, Ministry of Power, Ministry of Technology, and the Forestry Commission. At the outset, municipal participants had tended to be drawn from Britain's major industrial centres, including Birmingham, Glasgow, Leeds, Liverpool, London, Manchester, and Newcastle-upon-Tyne. But the number of local authorities cooperating in the work grew dramatically after 1939, as Table 1 demonstrates, undoubtedly spurred on by the deadly London smog of 1952 and the passage of the Clean Air Act in 1956. However, it should be noted that the post-war government's drive for fuel efficiency, and its emphasis on planning for sunlight and fresh air in rebuilding a 'better Britain', had seen a significant extension of the network well before London's Great Smog disaster (see Table 2 below).[21]

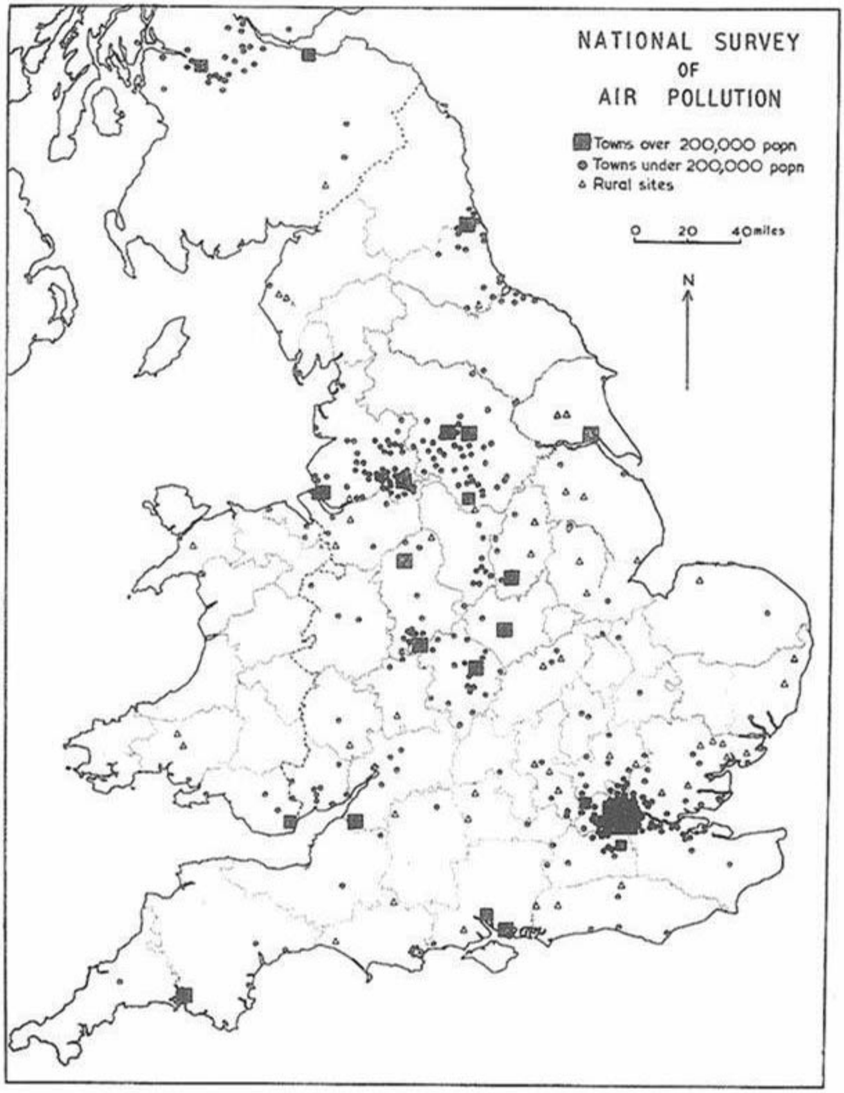
Industrial collaboration had been modest before the Second World War, arising mainly from the gas and electricity industries. However, in 1923 Cadbury's chocolate works at Bournville in Birmingham had joined the Investigation. The owner George Cadbury, who developed Bournville Model Village in order that workers at the factory might enjoy the benefits of 'sun, light and air', had been an active anti-smoke campaigner until his death the previous year. That the company's advertising stressed the purity and wholesomeness of the many products made at 'the factory in a garden' might also help to account for its involvement.[22] The figures in Table 1 chart the growth of business interest in the network, particularly after 1945 from newly-nationalised industries that were large consumers of coal and heavy emitters of atmospheric pollution such as the Central Electricity Generating Board, the Gas Council, the National Coal Board, and British Iron and Steel.[23] Private industry also played its part in the Investigation for similar reasons, with firms wishing to better understand air pollution problems and reduce emissions, such as Lever Brothers (Port Sunlight), Monsanto Chemicals, and Pilkington Glass, becoming actively involved. Where 'others' are concerned, clean air groups maintained a high-profile presence during the period under discussion, being joined by recruits from prestigious institutions such as universities (including Oxford, Birmingham and Durham), and hospitals (including St. Bartholomew's and St. Thomas', London).[24] Overall, the expansion of the network shows that actors with very different interests – usually portrayed as being at loggerheads with each other – could work together in a common cause.[25] Although growth was slow at first, hindered in no small part by the intervention of two World Wars and the Great Depression, after 1945 strong government support for the Investigation, together with the impressive widening of its membership, both increased confidence in the system and helped to boost the status of the smoke abatement movement as a whole.

The growth of the network can also be gauged from the installation of observation stations across the country. During the inter-war years, as Map 1 helps to illustrate, national coverage was uneven to say the least. Stations were most thickly spread over the urban-industrial areas of Lancashire and Yorkshire, through the Midlands, and in and around London. There were numerous appeals by the Investigation for local authorities to fill in the gaps, particularly



MAP 1. Distribution of Observation Stations, 1929–30. Source: Investigation of Atmospheric Pollution, *16th Report, 1929–30* (London: HMSO, 1931).

in Britain's seaside towns and sparsely populated rural districts.[26] While air pollution was rarely a major problem in such localities, it was argued that the data acquired would provide a valuable basis for comparison with urban observation stations.

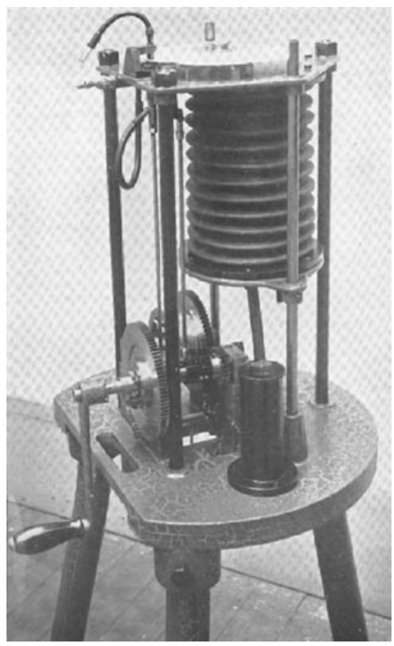


MAP 2. Distribution of Observation Stations, 1966. Source: Investigation of Atmospheric Pollution, *32nd Report, 1958–66* (London: HMSO, 1967). Reproduced under the terms of the Office of Public Sector Information Click-use Licence.

The Superintendent of Observations advised on where a station and its instruments should be placed, and the site details were then recorded and mapped.[27] By the mid-1960s, as Map 2 demonstrates, the distribution of observation stations was far more comprehensive. Although still following the same broad patterns on the ground, the network was deserving of its title of National Survey, having extended substantially in Wales, Scotland, and rural and coastal England.

SETTING STANDARDS

From the beginning, the network was designed to provide a systematic account – rather than a highly accurate picture – of levels of urban air pollution in Britain. Setting standards for the Investigation was recognised to involve the sacrifice of absolute accuracy in favour of uniform measures that could be widely reproduced. To encourage participation in this ambitious nationwide scheme, it was important that methods of measurement should be simple to use, 'robust and reliable', and 'not too costly in time and money'.[28] The technical work of standard setting began with the design and production of standardised instru-



FIGURES 1, 2. Standard Deposit Gauge and Automatic Filter.
Sources: A.R. Meetham, *Atmospheric Pollution: Its Origins and Prevention* (London: Pergamon Press, 1952); Investigation of Atmospheric Pollution, *17th Report, 1930–31* (London: HMSO, 1932).

ments that established uniformity across the network, and produced continuous, consistent, and comparable results. The development of tools to monitor environmental problems, as Hugh Gorman and Erik Conway have recently pointed out, 'suggests that people have already identified what they want to "see"'.[29] In this case, the Investigation directed its attention towards the smoke and sulphur dioxide emissions that were closely associated with smog, acid rain and public health problems.[30] By the 1940s, five main types of apparatus had been developed by a technical subcommittee for the measurement of atmospheric pollution (Figures 1–4):

- *Standard deposit gauge*. This was the first instrument to be standardised for use and it formed the backbone of the inquiry, particularly during the first quarter-century. The standard deposit gauge was essentially a modified rain gauge (long utilised by Britain's meteorologists in compiling rainfall statistics). Its purpose was to collect the total material deposited in a neighbourhood over the period of one month. Its contents were analysed using the following categories: water (including rainfall, dew, frost and melted snow); insoluble matter (including tar, soot and ash); and soluble matter (including acids, ammonia, and sulphur in the form of sulphates). Apart from rainfall, which was measured in millimetres, the results were usually expressed in 'metric tons per hundred square kilometres per month'. After 1951, the deposit gauge was manufactured and operated subject to British Standards Institution specifications (BS 1747).[31]

- *Automatic smoke filter*. Designed in 1916 to measure 'suspended impurity in the atmosphere', this instrument sampled the air of towns on an hourly basis. A fixed volume of air was made to pass through a disc of white filter paper, leaving a circular smoke stain that could be compared with a standard scale of shades. By means of calibration (which converted stain density to an equivalent weight of smoke), the results were usually expressed as 'milligrams per hundred cubic metres of air'. Regulated by a timing mechanism, the filter disc revolved to record 24 smoke stains per day.[32]

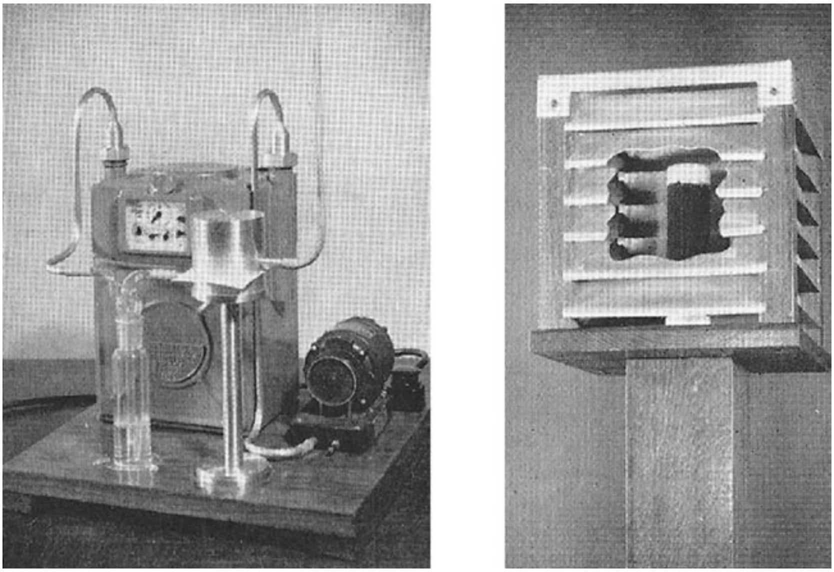
- *Volumetric sulphur dioxide apparatus*. Introduced in 1931, the volumetric apparatus was used to measure concentrations of sulphur dioxide in the atmosphere for periods of 24 hours. A fixed volume of air, measured by a conventional gas meter, was aspirated through a dilute solution of hydrogen peroxide. The amount of retained sulphur was then determined by titration with a standard alkaline solution. The results were usually expressed in 'volumes of sulphur dioxide per 100 million volumes of air'. After 1963, the apparatus was manufactured and operated subject to British Standards Institution specifications (BS 1747, Part 3).[33]

- *Daily smoke filter*. Often used in combination with the volumetric sulphur dioxide apparatus from 1944, this smoke filter sampled the air over a 24-hour period. Air, measured by a conventional gas meter, was drawn through a sheet of white filter paper at the rate of 50 cubic feet per day, forming a single circular smoke stain. The density of the stain was assessed (either using a reflectometer or one's eyes) by comparison with the same set of calibrated standards used for the automatic smoke filter. The results were usually expressed as 'milligrams of smoke per hundred cubic metres of air'. After 1964, the apparatus was manufactured and operated subject to British Standards Institution specifications (BS 1747, Part 2).[34]
- *Lead peroxide 'candle'*. Introduced in 1932, this was another method for determining sulphur dioxide concentrations in a given area. A piece of cotton fabric was coated with a standard paste of lead peroxide (which reacts with sulphur dioxide to form lead sulphate), and wrapped around a porcelain cylinder or 'candle'. The 'candle', housed in a simple louvred shelter for protection against the weather, was then exposed to the ambient air for one month. This method measured sulphur-containing compounds formed on the candle, and the results were usually expressed as 'milligrams of sulphur trioxide per day per 100 square centimetres of lead peroxide surface'.[35]

The work of designing and refining methods of measurement was a crucial part of the enterprise, with some instruments taking decades to evolve. As part of their painstaking work the scientists involved struggled with a basic problem, set out by the Investigation's Research Committee in 1944:

> … the devising of new, or the modification of existing measuring or recording apparatus [must be] so designed that it made the minimum demand on the skill or time of those operating it, since there were few Local Authorities sufficiently well provided with scientifically qualified staff to be able to make use of any but the simpler forms.[36]

The automatic smoke filter was never deployed extensively throughout the network because of the time and trouble involved in taking readings, and its successor – the daily smoke filter – long remained 'unpopular with Local Authorities' for similar reasons.[37] However, despite the care taken over the development of the apparatus used in the Investigation, there were known limitations with regard to the accuracy of the measurements they furnished. For example, results from the deposit gauge varied according to rainfall, wind direction, choice of location, and 'other factors'. Even after 1951, the British standard gauge was considered accurate to only ± 20 per cent.[38] In addition, it should be noted that some lines of research led only into blind alleys. For example, attempts to standardise methods for studying the effects of smoke pollution on visibility and urban sunlight levels were to be largely unproductive.[39]



FIGURES 3, 4. Combined Volumetric Sulphur Dioxide Apparatus and Daily Smoke Filter, and Lead Peroxide 'Candle'. Source: A.R. Meetham, *Atmospheric Pollution: Its Origins and Prevention* (London: Pergamon Press, 1952).

As well as working to standardise the apparatus, the Investigation's technical subcommittee also acted to induce discipline and order where the human parts of the system were concerned. The network had a diverse membership, including: the scientists and engineers who designed the instruments; the public analysts who carried out much of the testing; and the smoke and sanitary inspectors who collected most of the samples. Strict rules and procedures were necessary for the management and harmonisation of the research. The establishment of precise guidelines governing the tasks involved in data collection and analysis, and the routine use of pre-printed forms for recording results, helped to create solid scientific foundations, both facilitating communication between – and restricting the 'interpretive freedom' of – all participants in the network. Detailed guidelines and pre-printed forms were supplied to all cooperating bodies for making their deposit gauge returns, for example, while the calibration of the automatic and daily smoke filters similarly 'locked-in' research personnel to a precise set of instructions to protect the process of data-collection from corruption.[40] Because the day-to-day work took place at many different locations, establishing and embedding such agreed-upon rules for producing and maintaining standards was essential not only to demonstrate good scientific practice, but also to allow routine reproduction, ensuring the integrity of information over time and across the growing network. Table 2 below shows the number and types of instruments maintained by the cooperating bodies between 1917 and 1966.

Year	Standard Deposit Gauge	Automatic Smoke Filter	Volumetric SO_2 Apparatus	Daily Smoke Filter	Lead Peroxide 'Candle'
1917	27	2	0	0	0
1925	48	5	0	0	0
1930	84	11	0	0	0
1935	110	11	11	0	39
1939	128	16	11	0	47
1949	177	9	30	38	272
1954	615	8	52	99	672
1966	1066	0	1222	1282	989

TABLE 2. Growth in Numbers and Types of Instruments. Sources: Investigation of Atmospheric Pollution Reports

As the number of instruments and observation stations expanded, the work involved in providing technical assistance, inspecting sites, and coordinating data-collection efforts escalated. Between 1917 and 1966, the number of scientific personnel employed by the government to direct and service the Investigation of Atmospheric Pollution grew from one to forty, with the bulk of this increase coming after the Second World War.[41] Although measuring and monitoring for the survey was undertaken by local authorities and others, at their own expense, the process of setting standards saw central government officials impose conformance in data-collecting procedures on all interested parties. From an organisational viewpoint then, administrative power and technical expertise gradually coalesced at the centre with the DSIR, limiting the ability of allies – local authorities, industry, and nongovernmental organisations – to act independently.

The information collected using these methods generated 'a mass of knowledge, growing in extent and reliability, about the facts of air pollution' that was widely disseminated in print, lectures and exhibitions.[42] Research findings were discussed regularly in the scientific journals of the day, including: *Nature*; *Quarterly Journal of the Royal Meteorological Society*; and the *American Journal of Public Health*.[43] In 1925 Sir Napier Shaw and John S. Owens, the first Superintendent of Observations for the network, published *The Smoke Problem of Great Cities*, a popular book based on the work of the Investigation. Officials gave public lectures and participated in exhibitions, such as the Smoke Abatement Exhibition held at the Science Museum, London, in 1936, and the Royal Sanitary Institute's Health Exhibition held at Birmingham in 1937. The principal vehicles of dissemination, however, were its *Annual Report*, first issued in 1916, and its monthly journal, *Atmospheric Pollution Bulletin*, established in 1946 and sent to all organisations cooperating in the network. Aimed at a heterogeneous readership, from an early stage of the inquiry committee members were keen that the comparative information presented should be 'easily and immediately intelligible to ... the public at large, and, in particular, by busy members of public authorities and their officials'.[44] But as the Investigation grew, tables of dense statistical data – giving daily, monthly, seasonal and yearly averages of observations for each station – began to dominate the annual reports. By the late 1950s, the view of the DSIR was that this mass of information – gleaned from around 150,000 individual measurements per year – had made the network 'too blunt an instrument'. There were also concerns that the scientific personnel involved in interpreting data were unable to cope with the substantial increase in 'computing work'. It needed to be streamlined if the knowledge generated by the Investigation was to be easily understood by the public and policymakers, and the network was to avoid a 'gradual break down'. In addition, this would help to keep down the cost of compiling and publishing data (the Investigation's annual reports ran to more than 120 pages by the 1950s), and allow information on air pollution trends to be communicated more quickly.[45]

In November 1960 the Standing Conference of Co-operating Bodies endorsed a comprehensive reorganisation of the network, 'so as to get the maximum value with the greatest economy of effort'.[46] It was agreed that a new National Survey should be designed around the use of the daily smoke and sulphur instruments, rather than the deposit gauge (which measured 'sootfall', and not atmospheric pollution), and that a 'scientifically planned' statistical evaluation should be carried out on a 40 per cent 'representative' sample of the 381 towns taking part. The selection of the sample was made on the basis of a number of factors, including geographical location, industrial coal consumption, domestic coal consumption, and population size. Where population was concerned, these 'representative' towns were divided into the following categories: (1) above 100,000 inhabitants; (2) 50,000–100,000 inhabitants; (3) 20,000–50,000 inhabitants; (4) 5,000–20,000 inhabitants; and (5) under 5,000 inhabitants. In large towns and cities, where possible, an observation station was located in each of five different types of district (which helps to account for the explosive growth of instruments at this time, shown in Table 2):

- Residential district with high population density (for example, old-fashioned terraced housing).
- Residential district with low population density (for example, a new council estate).
- Industrial district
- Commercial centre
- Smoke-control area [47]

The National Survey was designed to yield more precise information about pollution patterns over the country as a whole, and to provide a clearer picture of national progress towards clean air. Tables of dense statistics, which in the past had tended to 'obscure the primary purpose' of the Investigation of Atmospheric Pollution, were to be kept to a minimum in its annual reports.[48]

THE USES OF MONITORING

The stress on systematic research as a tool enlisted to advance smoke abatement was plain in the Investigation's first annual report (1914–15); its stated objective was to act as 'an index of present effort and a guide to future action'.[49] On the importance of monitoring, John S. Owens insisted that sound data gathered on smoke was 'often the first step' toward pollution control, as it exerted a 'profound psychological effect upon a city when it has been shown that the air which its inhabitants have to breathe and live in is abnormally dirty'.[50] In addition to generating interest in smoke control, monitoring was generally undertaken for the following purposes: to provide baseline data about levels of urban air pollution in Britain; to identify its origins, patterns and trends, including daily, weekly, seasonal and annual variations in smoke density; to provide information and advice to central government and local authorities on developing pollution control policies; to assess improvements stemming from smoke control initiatives, including conformity to legislation; and to provide reliable systematic data for use in related research projects.[51] However, the Investigation's initial efforts to gain local government support for the research were fraught with difficulty, as observational results could expose some participants in the network to harsh public criticism.

The industrial town of Rochdale, Lancashire, is a good case in point. Despite its manufacturers having spent a 'large amount of money' on the installation of 'smokeless' technologies, after joining the network in 1916 Rochdale was to regularly top comparative 'league tables' compiled for soot, tar and dust deposits. The figures in Table 3 below, for example, compiled using data from the Investigation's standard deposit gauge, showed the total amount of impurities from selected collecting stations, in ranking order of insalubrity, for the winter of 1917–18.

In 1924 the Medical Officer of Health for Rochdale, Dr. Anderson, took up the cudgels in defence of the town's reputation:

> … in Rochdale, like Dr. Owens, [we] wanted to get at facts and figures … But Rochdale rather resented the attempt in some quarters to make comparison as to which town had the cleanest or most polluted atmosphere. Rochdale had simply faced facts. They had placed gauges in the worst parts of the town and published the figures. But that did not justify the statement as made in some quarters that Rochdale was the dirtiest town in England.

Town	**Tons per Square Mile**
Rochdale	90
St. Helens	51
Coatbridge	43
Newcastle	41
Glasgow	38
London	34
Leicester	33
Manchester	28
Malvern	5

TABLE 3. Average Monthly Deposits of Impurities at Selected Stations in English Tons per Square Mile, October to March 1917–18. Source: Sir Napier Shaw and John S. Owens, *The Smoke Problem of Great Cities* (London: Constable & Co., 1925).

For similar reasons, Anderson claimed, several towns in Lancashire had either declined to keep records or 'ceased to publish results'.[52] And when considered from this perspective, it is unsurprising that initially many local authorities saw little advantage in participating. Fears that 'uninformed writers in the Press … mak[ing] play with comparisons between towns' were damaging the Investigation became a prominent theme in its annual reports during the 1930s.[53] It was recognised that each industrial town, whether involved in textiles, mining, or iron and steel, faced its own peculiar set of problems where abating air pollution was concerned – making 'fair' comparisons difficult.

Matters came to a head at a meeting of the Standing Conference in May 1937, when the representative for Liverpool Corporation, Professor W.H. Roberts, announced that it would no longer permit the publication of data from its Netherfield Road observation station. Deliberately located in the 'worst possible position', he complained that the 'Publicity which had been given by the local press to the results from this gauge was considered to be most unfair.' Roberts also pointed out that 'He and his colleagues had been embarrassed by the fact that the 22nd Report had been in the hands of the press before they themselves had seen it'. Councillor C.E. Keene of Leicester City Council, however, reminded representatives at the meeting that 'press publicity was most desirable in the interests of the investigation'. The impact of its work would be limited, he argued, without the oxygen of publicity. But later in 1937 a significant step forward was taken in terms of overcoming mistrust, reducing exposure to criticism, and enlisting more recruits, when the format for presenting comparative information on air quality was changed: the key table on 'sootfall' in the annual report was anonymised to 'afford no direct means of comparing station with station'.[54]

By the mid-1930s, many observation stations had been collecting deposit gauge data for more than a decade and a half. Statistical analysis of the data allowed the Investigation to identify 'real trends' for smoke pollution at each of these sites. The long-term results of monitoring showed that the cities and other places involved in the network fell into 'three distinct groups'. The first, including Cardiff, Glasgow, London, Newcastle and Rochdale, showed a 'definite improvement' in reducing smoke emissions. The second, including Birmingham, Bournville Works, Castleford, Edinburgh and Liverpool, demonstrated 'little or no change in the condition of the air'. The third and smallest group, which included Leeds and Stoke-on-Trent, showed a 'definite deterioration' in air quality since the early 1920s. Although these trends were conflicting when viewed on a national scale, the data indicated that levels of urban smoke pollution were on a downward curve overall (mainly because Britain's industries were generating power more efficiently, and switching from coal to gas and electricity).[55]

During the same period, data gathered from the automatic smoke filter – although based on fewer instruments and sites – helped contemporaries to discern daily and weekly patterns of smoke pollution. Installed in town centres (with the exception of the apparatus at Kew Observatory in Richmond, London), the automatic smoke filter sampled the air on an hourly basis.[56] The results were tabulated in various ways, but they were most commonly divided up as follows: weekdays, when all industries were in operation; Saturdays, when many industries were closed during the afternoons; and Sundays, when almost all industries were closed. This approach was intended to address the thorny issue of whether industrial or domestic chimneys caused most atmospheric pollution by providing a detailed picture of the urban smoke cycle. Its ebbs and flows were found to correspond with coal consumption in factories and private houses. In London, for example, on weekdays and Saturdays smoke emissions increased rapidly between the hours of 6 and 7am, as domestic fires were lit and the chimneys of manufacturing industry – largely dormant at night – belched back into life. The smoke was thickest around 10am, with a subordinate peak at 4–5pm; the latter peak coinciding with the preparation of evening meals. Air pollution gradually waned after this point, as works wound down and domestic fires were allowed to burn low at the end of the day. Smoke emissions were at their lowest ebb between the hours of 10pm and 6am, although it rarely happened that there was no smoke at all during the 24 hours. On Sundays, as workers liked to sleep late on their day off, the peaks of the smoke cycle occurred one or two hours later than on a weekday. In 1921, the Investigation's seventh annual report could now state authoritatively:

> ... it is obvious that there is not a very great difference between the amount of impurity present in the air on ordinary weekdays and on Saturdays or Sundays, and it is fair to conclude from this that since the closing of factories on Sundays does not make a very great difference [to air quality], domestic smoke must be the chief source ... in London, the domestic fire is responsible for something over two-thirds of the total smoke.[57]

In addition, data from the automatic smoke filter were used to construct seasonal averages for smoke emissions, which showed a great increase in the volume of air pollution during the cold winter months when domestic fires were kept burning all day. Very similar patterns emerged in other towns and cities where the apparatus was used, such as Manchester and Rochdale.[58]

This research informed contemporary debates on pollution control legislation. Several of the Investigation's experts, including its Superintendent of Observations John S. Owens, gave evidence to the Committee on Smoke and Noxious Vapours Abatement, which had been set up to examine British legislation on air pollution. Indeed, three members of the Investigation of Atmospheric Pollution – Julius B. Cohen, Baillie W.B. Smith, and W.S. Curphey (Chief Alkali Inspector) – served on this governmental inquiry, which issued its report in 1921. The Newton Report, named after the Committee's chair Lord Newton, denounced domestic smoke thus:

> A number of important witnesses have stated that even in industrial areas domestic chimneys contribute, at the least, 50 per cent of the total smoke nuisance, and that at least 6 per cent of the bituminous coal ordinarily burnt in domestic fireplaces escapes unconsumed into the atmosphere as soot. Taking 40½ million tons as the amount of coal burnt annually in the United Kingdom in its natural condition for domestic purposes, the loss amounts to 2,430,000 tons, or more than half of the total amount of fuel required to heat the Metropolitan area for a whole year. That is to say, nearly 2½ million tons of soot escape into and pollute the atmosphere every year from domestic fireplaces alone.[59]

Satisfied that domestic emissions caused 'serious danger to health and damage to property', the Newton Report concluded that improved technology could address the problem, recommending that 'smokeless' heating systems, such as gas fires and coke-burning stoves, be installed in state-subsidised housing. It also called for 'an extension of research into domestic heating problems generally'.[60] But, as Lord Newton noted, any move to outlaw the traditional open hearth at this time would have been commonly viewed 'in the nature of high treason'. The nation's home fires were left untouched by the provisions of the resulting Public Health (Smoke Abatement) Act of 1926, which tightened the regulation of industrial emissions through the introduction of stiffer fines and a broader definition of the 'smoke nuisance' (which expanded to include soot, ash, grit and non-black smoke).[61]

Given that political interest in air pollution was focused mainly on smoke abatement during the interwar years, the Investigation of Atmospheric Pollution had paid less heed to monitoring the 'invisible evil' of sulphur dioxide produced by coal combustion, whether for domestic or industrial purposes. However, concerns that sulphur fumes had been involved in causing the deaths of around 60 people in December 1930 during the Meuse Valley fog disaster in Belgium attracted its attention to the issue. The damage that sulphurous smoke emissions, particularly from new power stations, caused to buildings and vegetation also acted as a spur to the development in the early 1930s of instruments (the volumetric sulphur dioxide apparatus and the lead peroxide 'candle') to measure and monitor sulphur gases. In 1945 Albert Parker, Director of Fuel Research at the DSIR and leading member of the Investigation, estimated that around 5 million tons of sulphur dioxide were discharged from Britain's chimneys every year, with no less than 80 per cent deriving from industrial smokestacks.[62] The transition to 'cleaner' forms of heat and power in the home and workplace after World War II, such as gas, oil and electricity, had slowly reduced levels of coal smoke, but not sulphur dioxide – a major component of acid rain. Technical fixes that alleviated one environmental problem unintentionally exacerbated another. In 1965, data from the network showed that sulphur dioxide emissions in Britain had risen sharply to 6.32 million tons per annum, with the tall stacks of coal-burning power stations being the biggest polluters (contributing almost 33 per cent of total emissions). By this time, aware of the growing problem, the Central Electricity Generating Board was the biggest collaborator in the National Survey, maintaining over 650 instruments at sites in the vicinity of its power stations.[63] Unlike the downward trend for smoke, emissions of sulphur dioxide were increasing as demand for energy grew and techniques for desulphurising fuel before combustion, or removing it from flue gases afterwards, were considered uneconomic. From the late 1960s and early 1970s, the issue of acid rain began to climb both the British and European political agendas.[64]

From its inception the Investigation not only sought to identify and monitor trends in atmospheric pollution, it also undertook or supported a wide range of experimental research into air pollution and its effects on health and the built and natural environment. Just three short examples will have to suffice here. In the early 1920s, reflecting its close ties to the Meteorological Office, specialised research was carried out in collaboration with the London Electric Supply Company on how coal smoke affected the formation and persistence of fogs.[65] In the late 1930s, in partnership with local authorities, the Investigation attempted to track the 'life history' of smoke emissions by means of an intensive study of the distribution and dispersal of air pollution throughout the city of Leicester: a study that also incorporated research on the efficacy of introducing 'smokeless zones' in urban areas.[66] Data from the network were also used by the medical research community in investigating the effects of air pollution on health, such as the studies undertaken at Sheffield University in the 1950s on morbidity and mortality from bronchitis after severe smog episodes in the city.[67] Taking a leading role in research efforts to better understand the nature of atmospheric pollution problems – often in partnership with influential allies – helped to build confidence in the Investigation's work. For example, both the Royal Sanitary Institute and the Society of Medical Officers of Health enthusiastically endorsed its methods and activities.[68] Moreover, its achievement in being the first organisation to provide detailed scientific information on major smog episodes also enhanced trust in its expertise.

When the lethal smog of 5–8 December 1952 enveloped London causing, according to official estimates, some 4,000 'excess' deaths from lung and heart disorders, data from the Metropolitan nodes of the network revealed that concentrations of smoke and sulphur dioxide had risen to around ten times their normal level in the city centre. While exactly how smog caused these fatalities was not fully understood, the Investigation made available to the British public hard-won information on the 'intensity of pollution' gathered from twelve observation stations in London on a daily basis during the course of this unnatural disaster. Members of the Investigation, such as Albert Parker and Dr E.T. Wilkins, were interviewed both on radio and television, while journalists from several national newspapers visited its base at the Fuel Research Station, Greenwich, to obtain material for articles on London smog and air pollution more generally.[69] As a result of pressure from the public and the press, in 1953 the government set up a committee of inquiry into the catastrophe under Sir Hugh Beaver, and turned to leading members of the Investigation of Atmospheric Pollution for scientific and technical guidance. It furnished five of the twelve personnel who served on the Beaver Committee: Sir Graham Sutton, Director of the Meteorological Office and a leading member of the National Society for Clean Air; Dr. R. Lessing, Chemical Engineer and also a prominent member of the National Society for Clean Air; Mr. Gordon Nonhebel, Head of the Fuel Economy Section, Imperial Chemical Industries; Mr. C.J. Regan, Chemist in Chief, London County Council; and Dr. J.L. Burn, Medical Officer of Health, Salford Borough Council. The Investigation also provided two of the eight assessors to the Committee: W.A. Damon, Chief Alkali Inspector for England and Wales and the aforementioned Albert Parker. In November 1954, Sutton informed the Standing Conference that the Beaver Committee had 'drawn extensively on the knowledge' of the Investigation.[70] It is a reasonable assumption, therefore, that its research and expertise were influential in shaping the Committee's recommendations.

Significantly, little formal evidence was taken by the Beaver Committee, mainly because of the large body of information the Investigation and its allies had already provided on 'the nature and sources of air pollution, its effects and methods of prevention'. The Committee took the view that 'all interests were in agreement as to the objective and therefore it was a matter for joint discussion to find the means'.[71] The main objective of its recommendations, published in 1954, was national legislation that would bring about an 80 per cent reduction of smoke in urban areas within a time frame of ten to fifteen years. Echoing the earlier Newton Report, the Beaver Committee made it clear that 'nearly half of all the smoke in the air comes from domestic chimneys', although the nation's home fires actually consumed less than 20 per cent of its coal supplies. Its report stated forcefully that smoke from all chimneys should be prohibited:

> No cure can, therefore, be found for the heavy smoke pollution of our cities and towns unless the domestic chimney is dealt with. In our view, there would be little justification for requiring industry and commerce to take all possible measures to prevent smoke, often at considerable cost, if the problem of domestic smoke were not also tackled.[72]

The Beaver Report was accepted by the government and welcomed by the press, and most of its recommendations were swiftly carried into law. The 1956 Clean Air Act empowered local authorities to establish smoke control areas and smokeless zones in towns and cities, which for the first time regulated domestic as well as industrial emissions. Shocked by the scale of the London smog disaster, Britain's householders finally accepted the need to give up the traditional open coal fire. There was, however, some criticism of the legislation's failure to tackle effectively the invisible 'sulphur danger … chiefly responsible for respiratory illness and deaths during smog'.[73] The government had rejected the Beaver Report's recommendation to remove sulphur dioxide from power-station emissions on economic grounds, as it would require 'more than reasonable costs'.[74]

The Beaver Report officially endorsed the Investigation's methods and practices in monitoring and measuring air pollution as 'essential both as a basis for preventive action and as a means of assessing the results achieved'.[75] After the passage of the Clean Air Act in 1956, the organisation found that it had gained additional work in the following areas: in assisting local authorities to set up smokeless zones and smoke control areas; in monitoring whether smoke reduction targets were being met (which also helps to account for the impressive growth of instruments in the 1960s, shown in Table 2); and in continuing to set standards for techniques of measuring smoke, such as the Ringelmann Chart (BS 2742: 1958), used by inspectors in enforcing the new legislation.[76] The range and scope of its research work on atmospheric pollution was also extended. By the mid-1960s, the Investigation's data, methods and expertise helped to inform a comprehensive research programme on air pollution in the United Kingdom that involved over fifty major institutions, encompassing everything from the monitoring of airborne radioactive matter, through wind-tunnel simulations of the performance of industrial chimneys, to the study of the effects of motor vehicle emissions in urban areas.[77] An insistence on using rigorous and uniform standards with the ability to extend across time, place, and disciplinary boundaries had helped to create a strong scientific community – a 'network of trust', to borrow Clark Miller's phrase – that could influence public opinion and shape public policy on air pollution.[78]

CONCLUSION

This study makes clear that the design of a system to measure and monitor air quality in Britain during the first half of the twentieth century was not a neutral, value-free endeavour. Although the aim of the Investigation was to obtain scientific information on air pollution, its 'ultimate purpose' was to assist the various cooperating bodies in 'dealing with the smoke problem and other questions of public health'.[79] It also shows the importance of technical standard-setting in producing policy-relevant knowledge about environmental pollution. During the first decades of the twentieth century, the study of air pollution in Britain was transformed. Out of the disorganised investigations of private individuals emerged the Investigation of Atmospheric Pollution, an expanding national network, governed by rules and standards. It provided reliable comparative data on the smoke problem that could be used to inform policy and support regulatory action. From the outset, systematic research was seen by the various allies not only as valuable in itself, but also as a tool to advance smoke abatement. But it is important to note that the government was slow to act against domestic smoke – identified by the Investigation as the leading source of urban air pollution in the early 1920s – because politicians were unwilling to impose unpopular restrictions on individual freedom. Not until after the London smog of 1952, when scientific evidence provided by the network proved crucial to understanding the disaster, did public opinion finally back smoke abatement.

While achieving greater accuracy in measuring and monitoring sulphurous coal smoke was always an important goal for many participants, for much of the period under discussion it was recognised that the best that could be accomplished in practice was to paint a 'rough and ready' picture of the air of towns. As late as 1959, Sir Graham Sutton informed the Diamond Jubilee meeting of the National Society for Clean Air that where the study of atmospheric pollution was concerned, 'it is vain to hope for great precision or accuracy'.[80] However, through an emphasis on proper standards and systematic procedures for data collection and production – and by placing the Investigation at the centre of a network of powerful allies – people began to gain confidence in its work. No longer considered meddlesome 'cranks', by the late 1950s the collaborative work of the Investigation of Atmospheric Pollution was attracting international attention as a model of good scientific practice.[81] But the real accomplishment had been in constructing a monitoring system at relatively low cost that, despite the different interests of its participants, had built up trust within the network, and helped to win both public and parliamentary support for the 1956 Clean Air Act. Over the next two decades, the implementation of the Act – with assistance from the network – dramatically reduced smoke pollution from both domestic and industrial sources, clearing Britain's skies.

NOTES

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[1] See: Stephen Mosley, *The Chimney of the World: A History of Smoke Pollution in Victorian and Edwardian Manchester* (London: Routledge, 2008); Bill Luckin, 'The Heart and Home of Horror: The Great London Fogs of the Late Nineteenth Century', *Social History* 28 (2003): 31–48; E. Melanie Dupuis (ed.), *Smoke and Mirrors: The Politics and Culture of Air Pollution* (New York: New York University Press, 2004); Peter Thorsheim, *Inventing Pollution: Coal, Smoke and Culture in Britain since 1800* (Athens: Ohio University Press, 2006); Eric Ashby and Mary Anderson, *The Politics of Clean Air* (Oxford: Clarendon Press, 1981); Carlos Flick, 'The Movement for Smoke Abatement in 19th-Century Britain', *Technology and Culture* 21 (1980): 29–50. However, there is a useful overview of the Investigation of Atmospheric Pollution in Peter Brimblecombe, *The Big Smoke: A History of Air Pollution in London since Medieval Times* (London: Routledge, 1988), 148–55. On the other side of the Atlantic, scientific research into Pittsburgh's smoke problem is discussed in David Stradling, *Smokestacks and Progressives: Environmentalists, Engineers, and Air Quality in America, 1881–1951* (Baltimore: Johns Hopkins University Press, 1999), 98–100.

[2] Until recently, environmental historians have shown little interest in systems that measure and monitor environmental quality. A start has now been made, and the key themes are surveyed in Hugh S. Gorman and Erik M. Conway, 'Monitoring the Environment: Taking a Historical Perspective', *Environmental Monitoring and Assessment* 106 (2005): 1–10.

[3] This paper draws inspiration from: Clark A. Miller and Paul N. Edwards (eds.), *Changing the Atmosphere: Expert Knowledge and Environmental Governance* (Cambridge: MIT Press, 2001); Karin Knorr-Cetina, *Epistemic Cultures: How the Sciences Make Knowledge* (Cambridge: Harvard University Press, 2000); Theodore M. Porter, *Trust in Numbers: The Pursuit of Objectivity in Science and Public Life* (Princeton: Princeton University Press, 1995); M. Norton Wise (ed.), *The Values of Precision* (Princeton: Princeton University Press, 1995); Joan H. Fujimura, 'Crafting Science: Standardized Packages, Boundary Objects, and "Translation"', in *Science as Practice and Culture*, ed. Andrew Pickering (Chicago: University of Chicago Press, 1992); Susan Leigh Star and James R. Griesemer, 'Institutional Ecology, "Translations" and Boundary Objects: Amateurs and Professionals in Berkeley's Museum of Vertebrate Zoology, 1907–39', *Social Studies of Science* 19 (1989): 387–420.

[4] Robert A. Smith, 'What Amendments are Required in the Legislation Necessary to Prevent the Evils Arising from Noxious Vapours and Smoke?' *Transactions of the National Association for the Promotion of Social Science* (1876): 495–542 (quotation on 516).

[5] Robert A. Smith, 'Some Remarks on the Air and Water of Towns', *Philosophical Magazine* 30 (1847): 478–82; *idem*, 'On the Air of Towns', *Quarterly Journal of the Chemical Society* 11 (1859): 196–235; *idem*, *Air and Rain – The Beginnings of a Chemical Climatology* (London: Longmans, Green & Co., 1872). See also: Eville Gorham, 'Robert Angus Smith, FRS, and "Chemical Climatology"', *Notes and Records of the Royal Society of London* 36 (1982): 267–72; and A. Gibson and W.V. Farrar, 'Robert

Angus Smith, F.R.S., and "Sanitary Science"', *Notes and Records of the Royal Society of London* 28 (1973–4): 241–62; Alan Wellburn, *Air Pollution and Climate Change: The Biological Impact* (Harlow: Longman Scientific & Technical, 1994), 97. For an up-to-date discussion of the establishment of Britain's Alkali Inspectorate, see: Christine Garwood, 'Green Crusaders or Captives of Industry? The British Alkali Inspectorate and the Ethics of Environmental Decision Making, 1864–95', *Annals of Science* 61 (2004): 99–117.

[6] 'The Sootfall of London: Its Amount, Quality, and Effects', *The Lancet*, 6 Jan. 1912, 47–50. See also: Manchester Field-Naturalists and Archaeologists' Society, *The Atmosphere of Manchester: Preliminary Report of the Air Analysis Committee* (Manchester, 1891); *idem, Second Report on the Atmosphere of Manchester and Salford* (Examiner Printing Works, Manchester, 1893); Wilfrid Irwin, 'The Soot Deposited on Manchester Snow', *Journal of the Society of Chemical Industry* 21 (1902): 533; Glasgow Sanitary Department, *Report on the Air of Glasgow* (1877); Julius B. Cohen, *The Character and Extent of Air Pollution in Leeds* (Leeds: Goodall & Suddick, 1896); Julius B. Cohen and Arthur G. Ruston, *Smoke: A Study of Town Air* (London: Edward Arnold, 1912).

[7] Mosley, *Chimney of the World*, Part One: The Nature of Smoke; Thorsheim, *Inventing Pollution*, chapters 3–6; Dupuis, *Smoke and Mirrors*, chapters 4–6.

[8] F.A.R. Russell, *London Fogs* (London: Edward Stanford, 1880), 11 and 27. See also: Thomas C. Horsfall, *The Nuisance of Smoke from Domestic Fires, and Methods of Abating It* (Manchester: John Heywood, 1893).

[9] For a summary of these debates, see: Stephen Mosley, 'Fresh Air and Foul: The Role of the Open Fireplace in Ventilating the British Home, 1837–1910', *Planning Perspectives* 18 (2003): 1–21. For the importance of statistical inquiries to effective government intervention and action, see: M.J. Cullen, *The Statistical Movement in Early Victorian Britain: The Foundations of Empirical Social Research* (Hassocks: Harvester Press, 1975).

[10] 'The Smoke Nuisance', *The Builder* 77 (1899): 143. For a contemporary account that stresses the contribution of industrial chimneys see: 'Soot in London', *The Times*, 5 Jan. 1912, 7.

[11] Ernest D. Simon and Marion Fitzgerald, *The Smokeless City* (London: Longmans, Green & Co., 1922), 1–3.

[12] The rise of urban scientific expertise is comprehensively treated in Sven Dierig, Jens Lachmund, and J. Andrew Mendelsohn (eds.), 'Science and the City', *Osiris* 18 (2003).

[13] 'The Campaign against Smoke', *The Times Engineering Supplement*, 27 Nov. 1914, 146; Advisory Committee on Atmospheric Pollution: Minutes and Papers 1918–24, DSIR 14/72. National Archives, Kew, London.

[14] *Atmospheric Pollution: First Report of the Committee of Investigation, 1914–15* (London, 1916), 1.

[15] *Atmospheric Pollution: Second Report of the Committee of Investigation, 1915–16* (London, 1917), 1. On the establishment and aims of the Department of Scientific and Industrial Research, see: Roy M. MacLeod and E. Kay Andrews, 'The Origins of the DSIR: Reflections on Ideas and Men, 1915–16', *Public Administration* 48 (1970), 23–48; Peter Alter, *The Reluctant Patron: Science and the State in Britain, 1850–1920* (Oxford: Berg, 1986); Andrew Hull, 'War of Words: The Public Science of the British Scientific Community and the Origins of the Department of Scientific and Industrial Research 1914–16', *The British Journal for the History of Science* 32 (1999): 461–81.

[16] *The Investigation of Atmospheric Pollution* (hereafter IAP)*, 14th Report, 1927–28* (London: HMSO, 1930), iv.

[17] Department of Scientific and Industrial Research, *The Investigation of Atmospheric Pollution* (London: HMSO, 1939), p.2.

[18] Standing Conference of Co-operating Bodies: Formation, Standing Orders, etc. 1927–1939, DSIR 14/15; Atmospheric Pollution Research Committee Meetings: Agenda, Minutes, etc. 1936, DSIR 14/13; 'Report by the Atmospheric Pollution Research Committee on the Continuation of its Work for a Further Period', in Co-operative Investigation: Financial Arrangements 1926–52, DSIR 14/29. National Archives, Kew, London.

[19] Atmospheric Pollution Research Committee: Future Research Programme 1944–58, DSIR 14/56. National Archives, Kew, London.

[20] IAP*, 27th Report, 1944–54* (London: HMSO, 1955), 1; IAP, *32nd Report, 1958–66* (London: HMSO, 1967), 75–100.

[21] The Labour Party, *Your Home Planned by Labour* (London: Victoria House Printing, 1943); Helen Meller, *Towns, Plans and Society in Modern Britain* (Cambridge: Cambridge University Press, 1997).

[22] George Cadbury served on the Executive Committee of the Smoke Abatement League of Great Britain until the suspension of its activities on the outbreak of World War 1. For a recent discussion of Cadbury and the Bournville estate, see: John R. Bryson, and Philippa A. Lowe, 'Story-telling and History Construction: Rereading George Cadbury's Bournville Model Village', *Journal of Historical Geography* 28 (2002): 21–41.

[23] The gas and electricity industries marketed their products as the solution to the nation's smoke problem, but were major polluters in their own right. See: Peter Thorsheim, 'The Paradox of Smokeless Fuels: Gas; Coke and the Environment in Britain, 1813–1949', *Environment and History* 8 (2002): 381–401; Stephen Murray, 'Bankside Power Station: Planning, Politics and Pollution', *The Local Historian* 33 (2003): 99–111; John Sheail, *Power in Trust: The Environmental History of the Central Electricity Generating Board* (Oxford: Oxford University Press, 1991).

[24] Standing Conference of Co-operating Bodies: 47th Meeting, 1956, DSIR 14/99. National Archives, Kew, London; IAP*, 27th Report, 1944–54* (London: HMSO, 1955), 188–93; IAP*, 31st Report, 1958* (London: HMSO, 1960), 148–57; IAP*, 32nd Report, 1958–66* (London: HMSO, 1967), Appendix II, Organizations Co-operating in the Investigation of Air Pollution. For business responses to efforts to control pollution more generally, see: Christine Meisner Rosen and Christopher C. Sellers, 'The Nature of the Firm: Towards an Ecocultural History of Business', *Business History Review* 73 (1999): 577–600.

[25] For detailed accounts of political disputes and lobbying activities see: Ashby and Anderson, *Politics of Clean Air*; and *idem*, 'Studies in the Politics of Environmental Protection: The Historical Roots of the British Clean Air Act, 1956', Parts I, II and III, *Interdisciplinary Science Reviews* 1 and 2 (1976 and 1977): 279–90, 9–26, and 190–206.

[26] For examples, see: *Atmospheric Pollution: Sixth Report of the Committee of Investigation, 1919–20* (London, 1921), 1; IAP, *16th Report, 1929–30* (London: HMSO, 1931), 2.

[27] *Atmospheric Pollution: First Report of the Committee of Investigation, 1914–15* (London, 1916), 'Methods of Work', 4–27. See also: IAP*, 15th Report, 1928–29* (London: HMSO, 1930), 2; Inspection and Installation of Deposit Gauges by the Superintendent of Observations 1928–39, DSIR 14/30. National Archives, Kew, London.

[28] Albert Parker, 'Air Pollution Research and Control in Great Britain', *American Journal of Public Health* 47 (1957): 560–61; IAP, *32nd Report, 1958–66* (London: HMSO, 1967), 90.

[29] Gorman and Conway, 'Monitoring the Environment', 8.

[30] Early concerns about the impacts of sulphur dioxide emissions are discussed in: Harold L. Platt, '"The Invisible Evil": Noxious Vapor and Public Health in Manchester during the Age of Industry', in *Smoke and Mirrors*, ed. Dupuis, 27–50. The term smog was neologised in 1905 by Dr Harold Des Voeux of the London-based Coal Smoke Abatement Society to describe the fusion of smoke and fog.

[31] *Atmospheric Pollution: First Report of the Committee of Investigation, 1914–15* (London, 1916), 'Methods of Work', 5–7; Sir Napier Shaw and John S. Owens, *The Smoke Problem of Great Cities* (London: Constable & Co., 1925), chapter 6; J.R. Ashworth, 'Atmospheric Pollution and the Deposit Gauge', *Weather* 3 (1948): 136–40; A.R. Meetham, 'Notes on Atmospheric Pollution and the Deposit Gauge', *Weather* 3 (1948): 140–43. On monitoring Britain's rainfall, see: David E. Pedgley, *A Short History of the British Rainfall Organization* (Reading: The Royal Meteorological Society, 2002). For a discussion of the British Standards Institution, see: C. Douglas Woodward, *BSI: The Story of Standards* (London: British Standards Institution, 1972).

[32] *Atmospheric Pollution: Third Report of the Committee of Investigation, 1916–17* (London, 1918), 17–22; *Atmospheric Pollution: Fourth Report of the Committee of Investigation, 1917–18* (London, 1919), 20–23; Shaw and Owens, *Smoke Problem of Great Cities*, chapter 7.

[33] IAP, *17th Report, 1930–31* (London: HMSO, 1932), Appendix I, Report on the Determination of Sulphur Gases in Air; E.T. Wilkins, 'The Measurement of Air Pollution', in M.W. Thring (ed.), *Air Pollution* (London: Butterworth's Scientific Publications, 1957), 34; Jane Dunmore (ed.), *NSCA Reference Book* (Brighton: National Society for Clean Air, 1985), 118–22.

[34] Department of Scientific and Industrial Research, *Atmospheric Pollution in Leicester: A Scientific Survey* (London: HMSO, 1945), 8–16; IAP, *26th Report, 1939–44* (London: HMSO, 1949), 11–13; Wilkins, 'Measurement of Air Pollution', 34–35; Dunmore, *NSCA Reference Book*, 118–22.

[35] IAP, *20th Report, 1933–34* (London: HMSO, 1935), Appendix I, The 'Lead Peroxide' Method of Measuring Atmospheric Sulphur Dioxide; Wilkins, 'Measurement of Air Pollution', 33–34.

[36] Atmospheric Pollution Research Committee: Future Research Programme 1944–58, DSIR 14/56. National Archives, Kew, London.

[37] Atmospheric Pollution Research Committee: Meetings and AP Papers 1953–54, DSIR 14/63. National Archives, Kew, London.

[38] On the limitations of the various instruments for measuring smoke, see: Brimblecombe, *Big Smoke*, chapter 7; and A.R. Meetham, *Atmospheric Pollution: Its Origins and Prevention* (London: Pergamon Press, 1952), chapter 10.

[39] For examples, see: *Atmospheric Pollution: Seventh Report of the Committee of Investigation, 1920–21* (London, 1922), 27–31; IAP, *19th Report, 1932–33* (London: HMSO, 1934), 17 and Appendix I, Sunlight and Ultra-Violet Light Measurement.

[40] *Atmospheric Pollution: First Report of the Committee of Investigation, 1914–15* (London, 1916), 7; *Atmospheric Pollution: Third Report of the Committee of Investigation,*

1916–17 (London, 1918), 17–22; Shaw and Owens, *Smoke Problem of Great Cities*, 81–83 and 109–12; IAP, *14th Report, 1927–28* (London: HMSO, 1930), Appendix I, Examination of the Scale of Shades for the Automatic Filter; IAP*, 32nd Report, 1958–66* (London: HMSO, 1967), 91–96. For a useful discussion on the importance of calibration to metrology networks, see: Arne Hessenbruch, 'Calibration and Work in the X-Ray Economy, 1896–1928', *Social Studies of Science* 30 (2000), 397–420.

[41] *Atmospheric Pollution: Ninth Report of the Committee of Investigation*, *1922–23* (London: HMSO, 1918), 4; IAP, *32nd Report, 1958–66* (London: HMSO, 1967), 126–27.

[42] IAP, *24th Report, 1937–38* (London: HMSO, 1939), 3.

[43] 'Atmospheric Pollution', *Nature* 122 (1928), 902–3; E.T. Wilkins, 'Air Pollution: Aspects of the London Fog of December 1952', *Quarterly Journal of the Royal Meteorological Society* 80 (1954), 267–71; Parker, 'Air Pollution Research', 559–69.

[44] Shaw and Owens, *Smoke Problem of Great Cities;* IAP, *23rd Report, 1936–37* (London: HMSO, 1938), 2; IAP, *14th Report, 1927–28* (London: HMSO, 1930), v.

[45] IAP, *31st Report, 1957–58* (London: HMSO, 1960), 10; IAP*, 32nd Report, 1958–66* (London: HMSO, 1967), 3; Wilkins, 'Measurement of Air Pollution', 29; Programme and Policy: Arrangements for Future Work 1951–54, DSIR 14/103. National Archives, Kew, London.

[46] IAP*, 32nd Report, 1958–66* (London: HMSO, 1967), 76.

[47] Ibid, 77–81.

[48] Full data sets, however, were available to members of the public free of charge upon request. Ibid, 3–5.

[49] *Atmospheric Pollution: First Report of the Committee of Investigation*, *1914–15* (London, 1916), 1.

[50] John S. Owens, 'Air Pollution', in Smoke Abatement League of Great Britain, *Report of the Smoke Abatement Conference held at the Town Hall, Manchester, November1924* (Manchester: J.F. Tangye, nd), 37.

[51] *Atmospheric Pollution: First Report of the Committee of Investigation, 1914–15* (London, 1916*)*; IAP*14th Report, 1927–28* (London: HMSO, 1930); General Appeal for Support of Investigation into Atmospheric Pollution 1938–39, DSIR 14/39, National Archives, Kew, London; IAP, *32nd Report, 1958–66* (London: HMSO, 1967)*;* See also: Dunmore, *NSCA Reference Book*, 117–18.

[52] Quoted in Owens, 'Air Pollution', 43–44.

[53]IAP, *21st Report, 1934–35* (London: HMSO, 1936), 4; IAP*, 23rd Report, 1936–37* (London: HMSO, 1938), 5 and 8–9.

[54] Reports from the DSIR to the Standing Conference 1928–38, DSIR 14/17, National Archives, Kew, London; IAP, *23rd Report, 1936–37* (London: HMSO, 1938), Figure 1, Total Solids Deposited in 1936–37, 56.

[55] IAP, *22nd Report, 1935–36* (London: HMSO, 1937), 11–15 and 55–58 (quotation on 11); IAP, *21st Report, 1934–35* (London: HMSO, 1936), Appendix, Results of a Statistical Examination of Records of Deposit Gauges.

[56] For a recent discussion of the work undertaken at Kew Observatory, see: R.G. Harrison, 'Urban Smoke Concentrations at Kew, London, 1898–2004', *Atmospheric Environment* 40 (2006), 3327–32.

[57] *Atmospheric Pollution: Seventh Report of the Committee of Investigation, 1920–21* (London, 1922), 22–24.

[58] William Thomson, 'The Smoke-Polluted Atmosphere of Manchester', in *Annual Report of the Manchester and Salford Sanitary Association for 1914* (Manchester: Sherratt and Hughes, 1915), 23–33; J.R. Ashworth, *Smoke and the Atmosphere: Studies from a Factory Town* (Manchester: Manchester University Press, 1933), chapter 5; IAP, *22nd Report, 1935–36* (London: HMSO, 1937), 15–18. For a more detailed discussion of the urban smoke cycle, see: Mosley, *Chimney of the World*, 50–54.

[59] Ministry of Health, *Committee on Smoke and Noxious Vapours Abatement: Final Report* (London: HMSO, 1921), Appendix B, Interim Report (Cmd. 755), 37.

[60] Ibid, 37 and 46.

[61] Quotation from Lord Newton's Preface to Simon and Fitzgerald, *Smokeless City*, vii; Ashby and Anderson, *Politics of Clean Air*, 92–99. For a recent discussion of domestic smoke pollution see: Stephen Mosley, 'The Home Fires: Heat, Health, and Atmospheric Pollution in Britain, 1900–45' in Mark Jackson (ed.) *Health and the Modern Home* (New York: Routledge, 2007).

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[63] IAP, *32nd Report, 1958–66* (London: HMSO, 1967), Table 3, 8, and Appendix II, 108 and 118. See also: Sheail, *Power in Trust,* chapter 15.

[64] Peter Brimblecombe, 'Acid Rain', in *Encyclopedia of World Environmental History*, eds. Shephard Krech, John R. McNeill, and Carolyn Merchant (New York: Routledge, 2004); Lars J. Lundgren, *Acid Rain on the Agenda: A Picture of a Chain of Events in Sweden, 1966–78* (Lund: Lund University Press, 1998).

[65] IAP, *10th Report, 1923–24* (London: HMSO, 1925), 32–35.

[66] Department of Scientific and Industrial Research, *Atmospheric Pollution in Leicester: A Scientific Survey* (London: HMSO, 1945).

[67] J. Pemberton, and C. Goldberg, 'Air Pollution and Bronchitis', *British Medical Journal*, 4 Sept. 1954, 567–69; M. Clifton, D. Kerridge, J. Pemberton, W. Moulds, and J.K. Donoghue, 'Morbidity and Mortality from Bronchitis in Sheffield in Four Periods of Severe Air Pollution', in National Society for Clean Air, *The Proceedings of the Diamond Jubilee International Clean Air Conference, London, October 1959* (London: NSCA, 1960), 189–92.

[68] Letter from the Secretary of the Royal Sanitary Institute, E. White Wallis, dated 10.06.1926 in Co-operative Investigation: Financial Arrangements 1926–52, DSIR 14/29, National Archives, Kew, London; IAP, *19th Report, 1932–33* (London: HMSO, 1934), 2.

[69] Atmospheric Pollution Research Committee: Meetings and AP Papers 1953–54, DSIR 14/63, National Archives, Kew, London; IAP, *27th Report, 1944–54* (London: HMSO, 1955), 5; Ministry of Health, *Mortality and Morbidity during the London Fog of December, 1952* (London: HMSO, 1954). However, new research suggests that around 12,000 people lost their lives. See: Devra Davis, *When Smoke Ran Like Water: Tales of Environmental Deception and the Battle Against Pollution* (Oxford: Perseus Press, 2002), 42–54.

[70] Standing Conference of Co-operating Bodies, 43rd Meeting 1954, DSIR 14/95. National Archives, Kew, London.

[71] *Committee on Air Pollution, Report*, Cmd.9322 (London, HMSO: 1954), 5 and Appendix III.

[72] Ibid, 6 and 21.

[73] Socialist Medical Association, *Death in the Air: The Menace of Air Pollution* (London, c.1956), 8–9; Standing Conference of Co-operating Bodies, 43rd Meeting 1954, DSIR 14/95, National Archives, Kew, London. On the role that mortality data played in changing public views of smoke pollution after the London smog disaster, see: Thorsheim, *Inventing Pollution*, chapter 10.

[74] Maarten A. Hajer, *The Politics of Environmental Discourse: Ecological Modernization and the Policy Process* (Oxford: Clarendon, 1995), 126n.

[75] *Committee on Air Pollution, Report*, Appendix III.

[76] Atmospheric Pollution Research Committee: Meetings and AP Papers 1953–54, DSIR 14/63; Programme and Policy: Arrangements for Future Work 1951–54, DSIR 14/103, National Archives, Kew, London; IAP, *30th Report, 1956–57* (London: HMSO, 1959), 1–16. For a recent discussion of the Ringelmann method of measuring smoke emissions, see: Frank Uekotter, 'The Strange Career of the Ringelmann Smoke Chart', *Environmental Monitoring and Assessment* 106 (2005), 11–26.

[77] See: IAP, *32nd Report, 1958–66* (London: HMSO, 1967), Appendix IV.

[78] Miller and Edwards, *Changing the Atmosphere,* 197.

[79] IAP, *15th Report, 1928–29* (London: HMSO, 1930), 1.

[80] Graham Sutton, 'The Opening Address', in National Society for Clean Air, *Diamond Jubilee International Clean Air Conference,* 17.

[81] See the papers on 'Research and International Cooperation' in Ibid, 185–239. The network still operates today on a smaller number of sites as the UK Smoke and Sulphur Dioxide Network. For more information, see: www.airquality.co.uk