# Estimates of Air Pollution in York: 1381 – 1891

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## SUMMARY

Plume dispersion modelling has been used to estimate the smoke and sulphur dioxide concentrations for historic York in five individual years, 1381, 1672, 1841, 1851, and 1891. Historical data concerning population, housing, industrial distribution, fuel imports and exports have been used to generate a source matrix for sulphur dioxide and smoke for the model.

The general levels of pollutants implied by the results seem to be consistent with changes in York over the time-span studied. Maximum annual average sulphur dioxide concentrations (in central York) range between 10 and 120 mgm$^{-3}$ (1672 and 1861 respectively), and for smoke between 5 and 40 mgm$^{-3}$ (1381 and 1861 respectively). The main sources of uncertaintity are implicit in the quality of the data set, which in this case due to certain peculiarities of York record keeping is thought to be good. Sensitivity analyses indicates that because the results of this model are estimates of annual average concentrations, they are likely to be relatively insensitive to changes of up to 20% in up to 15% of the source matrix providing the distribution of the errors in the historical data is random.

## INTRODUCTION

There are two main approaches to modelling the behaviour and dispersion of smoke (or other atmospheric pollutants) in the urban atmosphere. The first is micro-meteorology and involves a detailed knowledge of the terrain and atmospheric conditions at the time of the determination. Although the calculations are very complex it can provide an accurate picture of the fate of smoke or other pollutants on a specific occasion when all the variables are known, i.e. a snapshot. In historical work where many of the key variables have been estimated, and long term averages are required, it is not appropriate to attempt such an analysis. Instead, the second approach, plume modelling has been

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employed. This method attempts to predict the fate of a smoke or pollutant plume in terms of its deposition on the surrounding environment. The bases of plume dispersion models are largely empirical, and although individual models vary in their assumptions and approaches, the main assumptions usually hinge about how the distribution of pollutant within the plume changes with time. It is usually assumed to be Gaussian in either one, two or three dimensions, and the mechanism of this dilution is assumed to be eddy diffusion.

Given this approach, and with information about pollutant source strengths, the heights and locations of those sources, and local meteorology, these models estimate the deposition fluxes (receptor strengths) for the immediate area around the source(s). Intimate knowledge of either the exact topography of the surrounding area or atmospheric conditions is less important. This type of method clearly does not give snapshot pictures with any accuracy, but is very good at giving the general picture over time.

There are a number of types of plume dispersion model, some better for particulates (Brimblecombe, 1992) others for gases. However the main division concerns the type of source that is being treated. One type of model is more or less suited to point sources, very suitable for power stations, large industries i.e. discrete and well defined sources (Scorer and Barrett, 1962). This approach to modelling appears in the preceding article (Newell and Watts, 1996). The second type of model is the area source model, more suited to ill defined diffuse sources, e.g. towns. Pilot work on simple systems showed that the results from the two types of model converged when assemblages of point sources were compared to the more diffuse area source of equivalent total source strength. In this work York is treated as a diffuse area source, because generally it is difficult to be certain about the exact location of all chimneys, and most chimneys (both domestic and industrial) are of similar heights, with few high chimneys. Attempts to model York as an assemblage of point sources rapidly became unfeasible.

The plume dispersion models themselves are alike in that they all give a general picture of pollutant deposition falling with distance away from the source (as would be expected intuitively). However, it has been observed that deposition of pollution (e.g. of radioactivity following the Chernobyl accident) is often not uniform but is affected by local meteorological events such as rainfall. Over long distances these types of events, (as well as the processes generally called Eddy Diffusion), can actually produce concentration of the pollutant as opposed to dilution (Scorer, 1992). Over the small area of a city the size of York however, these effects have been ignored.

Clearly there are major limitations to any study of this sort, some concerning the data, and others the model. In this work the model used describes gaseous processes fairly well, and particulates not at all. In that sulphur dioxide and (to a lesser degree) smoke are both thought of as gases this is not too much of a problem. But there were other particulate species present from the combustion processes which would also be deposited probably fairly close to the sources (i.e. in the city).

## METHODOLOGY

Five individual years were selected for which there were appropriate historical data, (see later). The equation (1) used to calculate the average annual concentrations of sulphur dioxide and smoke (Smith, 1968; Hanna, 1973) necessitated dividing York up onto a 5x5 grid. Each grid square had a side of 300m, and this represents the limit of resolution of the modelling. A constant terrain roughness factor was assumed along with a mean wind speed of 5 $ms^{-1}$ in the city. The rationale for this is that the city acts as its own windbreak, i.e., it is sheltered. It is not possible to take into account explicitly effects of buildings, for example canyon and gully effects, within this type of modelling. A BASIC programme was developed to manipulate and use equation (1):

$$\chi = (2/\pi)^{1/2}\frac{(\Delta x/2)^{(1-b)}}{Ua(1-b)}\left(Q_A(0,0) + \sum_{i=1}^{4}\sum_{j=1}^{4} Q_A(i,j)f(i,j)\left((2r+1)^{1-b} - (2r-1)^{1-b}\right)\right) \quad (1)$$

where:

$\chi$ = annual average surface concentration ($mgm^{-3}$)
$\Delta x$ = grid distance (m), in this case 300m
a,b = vertical dispersion constants, a=0.15, b=0.75, (annual average), implies a mixing layer height of about 200m.
U = wind speed ($5ms^{-1}$)
r = number of grid blocks that square (i,j) is away from central receptor square
f(i,j) = wind frequency distribution, taken from 15 years data (1970-1985) for the town of Church Fenton (data courtesy of Leeds Meteorological Office).
$Q_A$ = source strength ($mgm^{-2}s^{-1}$) calculated from various data, see text.

For each year under study, the deposition flux for both smoke and sulphur dioxide for each square on the grid was determined by moving the central receptor, (denoted by $Q_A$ (0,0) above), around the source matrix and thus determining the deposition flux to each square of the grid, taking into account the contributions from all the other squares.

## DATA

For the five individual years modelled in this work (1381,1672,1841,1851 and 1891) four types of data were required (as below). Much of this information was available in two reports (Brimblecombe and Bowler, 1987; Brimblecombe and Bowler, 1990) and to a large extent provided much of the primary data for our estimations.

*Population*

For each of the five years studied both the population and population distribution in York were required. For 1381 and 1672, the number of hearths per parish (using the Hearth Tax records for 1672) were used to estimate fuel burning in York. For the later years under study, and 19th century census returns, were used to estimate the number of dwellings.

There is little direct data for 1381, but estimates for that year give 1900 mansions/households within the city walls with a population of about 11,000 (Nuttgens, 1976). This compares with 2124 households in York in 1672 (1800 within walls, 330 in suburbs), and a similar population. Hence we have assumed that the number of hearths per parish is similar in the two years. The data actually available is in the form of the hearth density per parish. Knowing the areas of the parishes, the number of hearths per parish was estimated.

The 19th century census returns yield the number of inhabited dwellings per parish. We have assumed that these dwellings are evenly distributed over their respective parishes. Census data is available for 1841 and 1851. There is census data for 1891 but it will not be released to the public until later this year (under the 100 year rule). We have extrapolated from earlier census data (1881). This is not unreasonable as during this period house building was in decline, land within the city walls was saturated with housing and consequently planners used suburban land to house the growing population. It was assumed that on average there were 3 hearths/fireplaces per dwelling (Bowler, 1991), hence the number of hearths per parish was estimated. It was further assumed that each hearth would have consumed about 1 ton of wood/coal per annum.

Previous work (Brimblecombe and Bowler, 1990; Brimblecombe and Bowler 1987) contained much of this data including that from Parish registers and the information about parish boundaries.

*Meteorological data*

We had access (courtesy of Leeds Meteorological Office) to wind speed/ direction data for the 15 years between 1970-85 for the town of Church Fenton. This was used to generate the frequency distributions necessary for the model. The implicit assumption is that no other variable, e.g. climate change, has altered the frequency distributions that were prevalent in the target years from those in the period 1970-85.

*Geogaphical location of industries*

This data was largely extracted from the York Offensive Industries Directories, as well as from previous work (Brimblecombe and Bowler, 1987; Brimblecombe and Bowler, 1990). Major shifts in the geographical location of industry with time have occurred over the period of study. In the 14th century most of the offensive industry (tanners, foundries, bakers) were located on Tanners Row, in the west of the city. By the 17th century many of these industries had moved to the east/south-east part of the city, south of the Minster. By the early the 18th century, there was a decline in the tanning trade, and a subsequent decrease in pollution in the west of the city.

Another change came with the building of the Lendle bridge over the River Ouse in 1863. It is clear that prior to this most of the industry had been concentrated to the south, close to the first bridge. When the new bridge was built the largely marshy ground on the west bank of the Ouse, near the new bridge, became the new industrial area of the city. Another important development as far as the centre of York was concerned was the location of two iron/brass foundries close to the Minster. One was located in Aldwart, and another opened in Stonegate in the 1840s. The location of these foundries in effect means that this area, including the Minster, is always the recipient of large amounts of airborne pollution, almost irrespective of the larger geographical changes in industry.

Other important industries in York were the gas works by Fossbank, northeast of the city, and a glass works at Fishergate, southeast of the city. In 1890 the glass works converted four of its five furnaces to run on gas, which substantially reduced pollution from that source. In 1845/6 the water works moved from a site south of the Minster to Acomb landing (off the grid), again reducing atmospheric pollution within the city.

### *Coal import/export data*

Relative source strengths for the different emitters were gathered in three ways. In some years specific records existed for various institutions of how much coal was burnt. This was very rare however, and mostly we estimated the amounts that an offensive industry might use from either consultation or specific one off records, i.e. all bakers use the same amount. After all the known sinks were accounted for, these were subtracted from the gross import data, and the remainder used to estimate the domestic fluxes of smoke and sulphur. This distribution was weighted according to population.

## RESULTS

Figure 1 shows the calculated annual concentration contoured from the grid for each of the years under study. The immediate observation is that in the later years the amounts of smoke and sulphur increase. This is consistent with increasing population and size of the city. The distributions of both smoke and sulphur seem similar in shape for a given year, which again is reasonable in terms of the model and the similar physical processes that disseminate both pollutants. As time

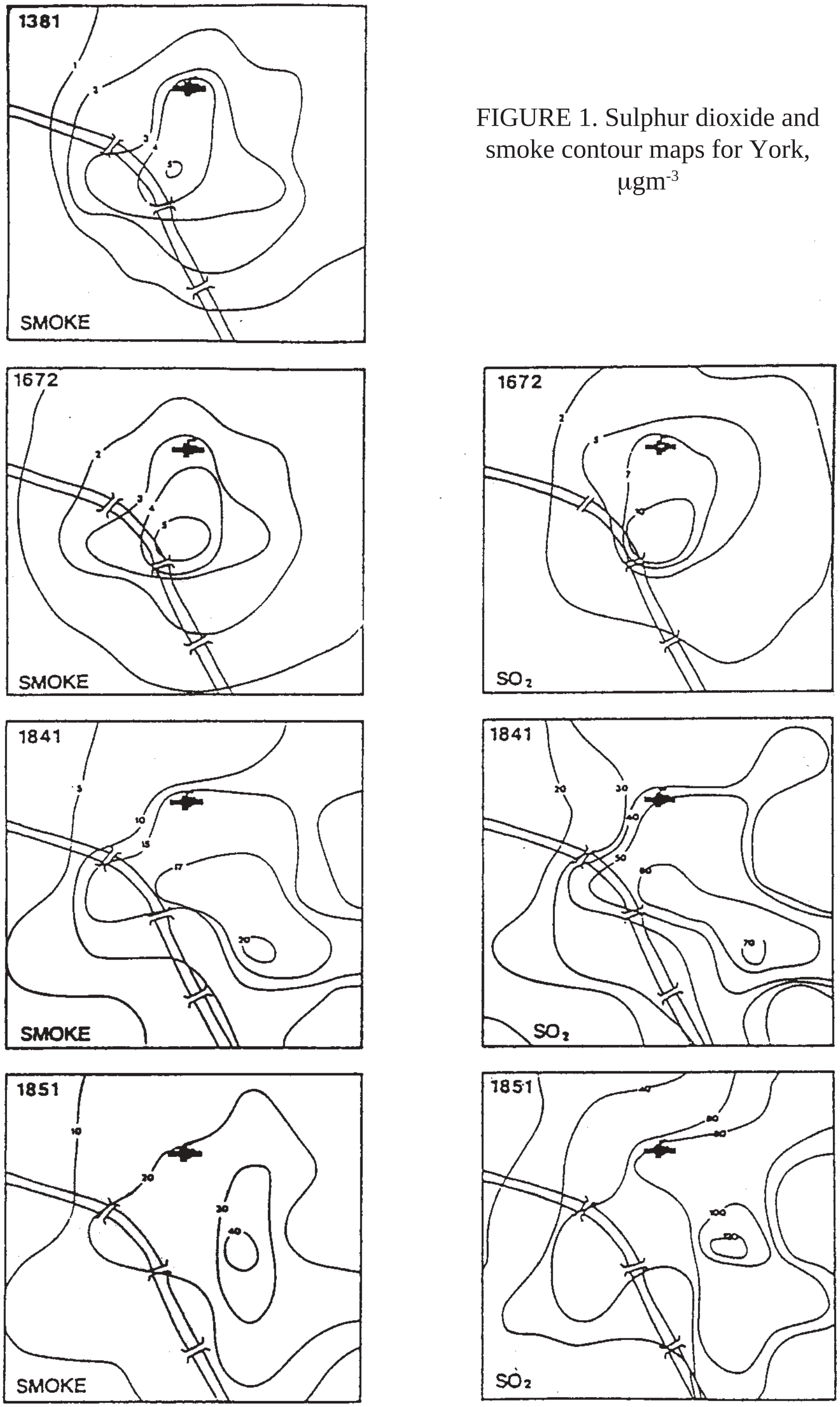
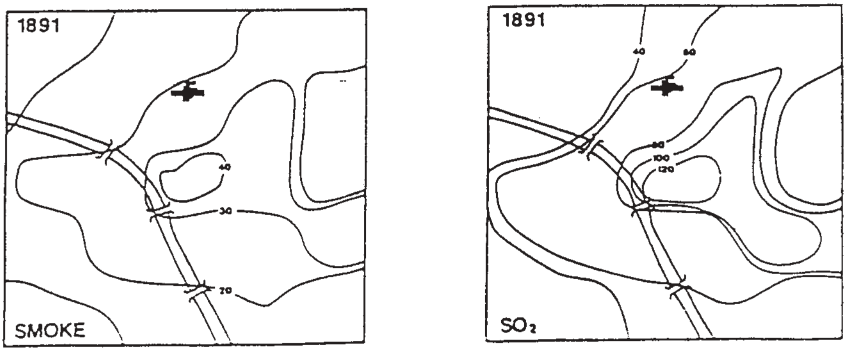



FIGURE 1. Sulphur dioxide and smoke contour maps for York, $\mu gm^{-3}$




passes, the gross shape of the distributions also change, these changes are thought to reflect translocations of industry and domestic dwellings. In the years 1381 and 1672, it is clear that the maximum deposition of smoke and sulphur occurs in the central and central northern parts of the city. In the 17th century much industry moved from the central and west city to the south east of the city. The distributions for 1841 and 1851 reflect this change, and are quite different from the earlier ones. In these later distributions the largest concentrations have moved eastwards and now occur in the central northeastern and southeastern regions. This is thought to be due to the shift in industry referred to above. Between 1841 and 1851 the shift of deposition toward the south progresses even further.

The estimates of sulphur dioxide concentration found in this work compare well with those from previous estimates (Brimblecombe and Bowler, 1990). It is also clear that comparisons of York with other urban/industrial centres at similar times indicate that it was on a par with those places, if not a little more fortunate (Newell and Watts, 1996). Obviously atmospheric levels accepted at that time are very much higher than those that would be tolerated in modern industrial nations. In modern times however, areas of eastern Europe may well have a problem of similar magnitude).

The data set also contains more subtle information. In the earliest year, 1381, the ratio of maximum to minimum concentrations in the grid area is about ten, in the later years however it drops to about six. This could simply be a reflection of the greater amounts and geographical location of the pollutant, i.e. the west of the city is hardly affected by the emissions at all. The wind distribution frequency would further accentuate the very low values in the west. It may also indicate incomplete data sets.

Concern about the affect of air pollution on historic monuments is not an entirely modern thing. In the latter half of the 19th century there were concerns that air pollution was damaging York Minster. The Minster, by chance, happens to be in the central square of the grid, and inspection of Figure 1 shows that it has always been in areas of high pollutant concentrations. In 1381 and 1672 it had almost the largest concentrations of both sulphur dioxide and smoke of any other square on the grid. As time has gone on, the total proportion has decreased, but the amounts have increased six-fold over the period of study. This is due to a large extent to the advent of the iron/brass foundry in the 1840s close to the Minster, in Stonegate. The results of this work might justify those early concerns about the fabric of the Minster.

## EVALUATION OF THE MODEL

The types of errors inherent in work using models concern the performance of the models themselves, as well as the quality of the dataset. The diffuse source model used has been compared to an assemblage of point source models and the results of these two methods converge (Hipkins, 1991). However, the type of model used is very simple and does not comprehend many of the important processes involved plume dispersal or deposition. Many of the deposition processes (e.g. wet deposition) are not dealt with at all (Scorer, 1992), and the plume dispersion parameters assume average Reynolds numbers. The usual way of validating a model is to combine a measurement and modelling programme and compare the results. A more complex but essentially similar plume dispersion model has been subjected to this test, and the results of those comparisons show that long term (e.g. annual) average results at ground level agree well with measured values, except in high pressure inversion situations. Because of the small distances involved in this modelling many of the larger effects can be ignored: but the small grid size (300m squares) does mean that the relative error is likely to be large. Attempts to quantify this by running the model with different grid sizes indicate that an error of 10% is not unreasonable.

The other major source of error in this work is the dataset. Sensitivity analyses indicates that because the results of this model are estimates of annual average concentrations, they are likely to be relatively insensitive to changes of up to 20% in up to 15% of the source matrix providing the distribution of the errors in the historical data is random. We have no way of assessing how good the data set is, and hence it is difficult to estimate an error: a totally arbitary number might be 10%. This may give in all a total error of about 20% on the final estimates of annual average surface concentrations.

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## REFERENCES

Bowler, C. (1992) Personal communication.

Brimblecombe, P. (1992) Personal communication.

Brimblecombe, P and Bowler, C. (1987) *Pollution history of York and Beverley*, University of East Anglia. Report to CEGB on grant RK4229, volume I.

Brimblecombe, P and Bowler, C. (1990) *Pollution history of York and Beverley*, University of East Anglia. Report to CEGB on grant RK4229, volume II.

Hanna, S.R. (1973) Description of ATDL computer model for dispersion from multiple sources. *Ind. Air Pollut. Cont.* 23-32.

Hipkins, S. (1991) Modelling historical variations in York's air pollution. Honours Project, School of Biological and Molecular Sciences, Oxford Polytechnic.

Newell, E. and Watts, S.F. (1996) The environmental impact of industrialisation in South Wales in the nineteenth century: "copper smoke" and the Llanelli Copper company. *Environment and History* **2**: 309-36.

Nuttgens, P. (1976) *York: the continuing city*. London: Faber.

Scorer, R.S. (1992) Deposition of concentrated pollution at large distance. *Atmos. Env.* **26A**: 793-805.

Scorer, R.S. and Barrett, C.F. (1962) Gaseous Pollution from Chimneys *Int. J. Air and Water Pollut.* **6**: 49-63.

Smith, M.E. ed. (1968) *Recommended guide for the prediction of dispersion of airbourne effluents* American Society of Mechanical Engineers, Special Report IX.