MODELLING DUBLIN SMOKE POLLUTION - AN EPILOGUE ?

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INTRODUCTION

The acceleration in industrial growth which occurred in Ireland in the 1970s, the virtual cessation of emigration which it enabled for a time, and the consequent increase in population in the Dublin region which resulted, ushered in problems of pollution and environmental degradation which had not previously been of serious concern. Among the most intractable of these has been that of smoke pollution in Dublin city, a problem further exacerbated by changes in fuel prices and preferences occurring during the late 1970s and 1980s. Though deterioration in air quality was linked in several studies to mortality and morbidity in the city from respiratory and cardiovascular causes, progress in controlling domestic smoke emissions has been limited by political inertia and opposition from commercial interests. The radical decision to ban bituminous coal sales within a designated area from 1st October 1990 has however transformed the situation, and renders compliance likely with EC mandatory limits by the target date of April 1993. This paper charts the turnaround in Dublin air quality and models the meteorological and emission conditions necessary to attain the stricter winter guide values of Directive 80/779.

TRENDS IN DUBLIN WINTER SMOKE CONCENTRATIONS

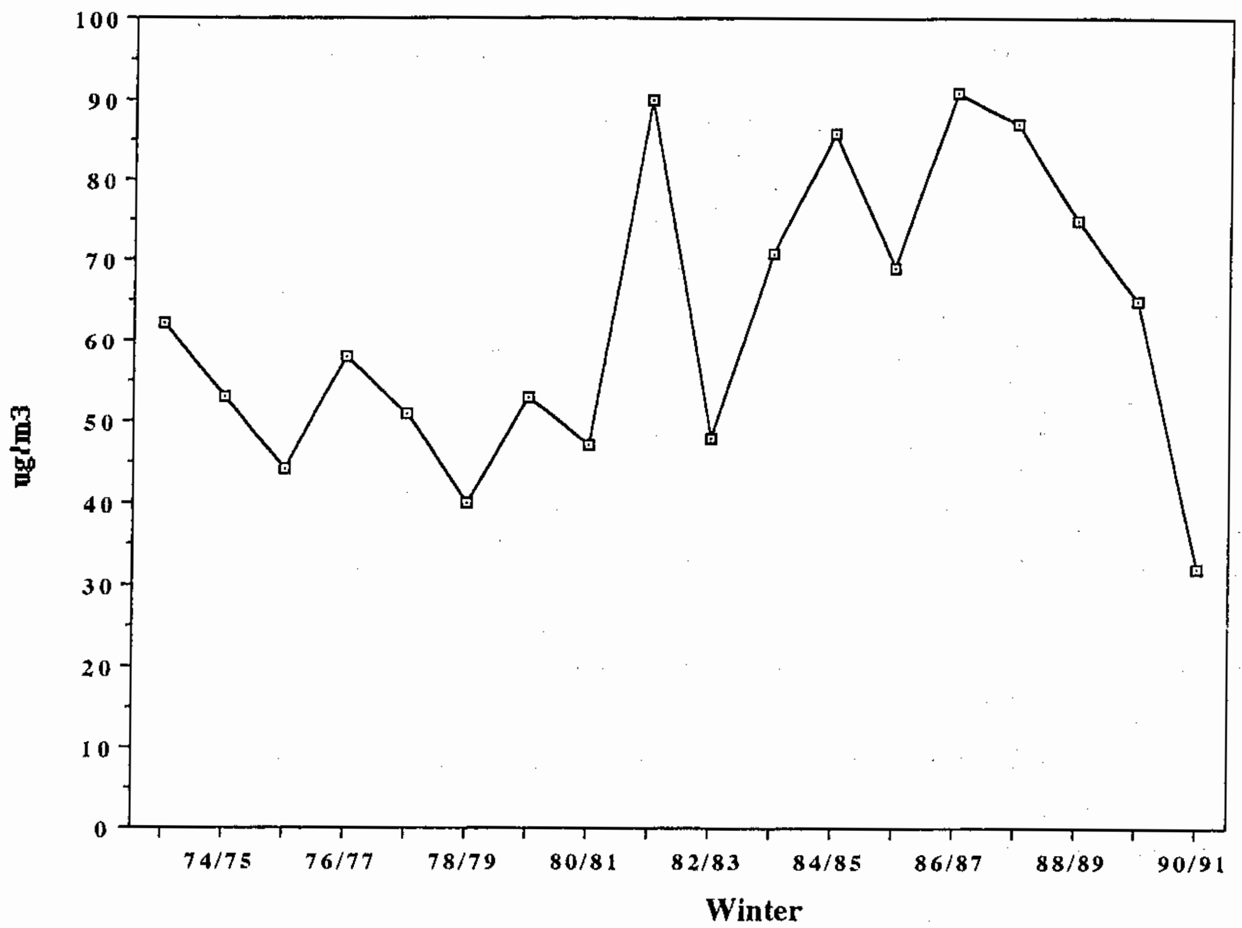
The Decline 1979-1987

Bituminous coal produces about 3.5kg of smoke per 100kg burnt, over seven times as much as anthracite or the various forms of processed coal. The corresponding figure for peat is 2.4kg and for oil 0.1kg/100kg. Changes in domestic fuel preferences to or from bituminous coal can thus be expected to have a rapid and substantial effect on urban smoke concentrations. Throughout the 1970s, advantages in the cost and convenience of oil and electricity meant that domestic consumers in much of Europe were installing oil-fired and electric central heating systems in preference to solid fuel systems. In Dublin, as elsewhere, a decline in smoke concentrations occurred with winter average levels falling to 40μg/m^3 in 1978/79 (Fig. 1). Sulphur dioxide was seen then as the principal concern in Dublin city and significant correlations were detected with respiratory and cardiovascular mortality and morbidity (Kevany *et al.*, 1975).

Following the oil supply crisis of 1979 it became a national priority to reduce dependence on imported oil. Solid fuel became the preferred alternative and grants were issued to enable householders to convert to back-boiler systems and to construct chimneys. For a time it became mandatory that all new housing in the country had a solid fuel based heating system. The impact on air quality in Dublin was immediate, with mean winter smoke concentrations doubling to 90μg/m^3 in 1981/82 and smoke now becoming identifiable as the pollutant most associated with health symptoms (Sweeney, 1982). Indeed, during particularly unfavourable weather conditions when dispersion was inhibited by light winds accompanying a subsidence inversion close to the surface, and emissions were augmented by low temperatures, a build-up in concentrations to alarmingly high levels became noticeable. During one such episode in early 1982 daily concentrations exceeded 1,800 μg/m^3 and this was suggested as a contributory factor in producing 56 excess deaths, predominantly from respiratory causes, at St. James's Hospital (Kelly and Clancy, 1984).

By 1983 smoke emissions in Dublin were estimated to be 16,000 tonnes/annum, almost 80 per cent of which was attributable to domestic coal consumption (Bailey, 1988). This represented an average emission rate of 55 tonnes/km^2/year for Dublin, by comparison with a similar figure of 9 tonnes/km^2/year for London. Individual areas within the city showed substantially enhanced values of over 200 tonnes/km^2/year. These were mostly high density housing areas, within the canals. Surrounding this area the public housing estates, particularly on the western side of the city, were conspicuous also with smoke emission rates of over 100 tonnes/km^2/year. The size of the Dublin coal market was comparable to that of London, a city six times larger, a commercial consideration which was to play an important role in inhibiting control of the problem.

Figure 1: Mean Winter Smoke Concentrations - Dublin Corporation Network.



EC Air Quality Directive

Community countries adopted an EC Directive (80/779) on ambient air quality in 1980, the provisions of which became mandatory on April 1st 1983. This specified limit values and guide values for both smoke and SO_2. The limit values for smoke are 80 (annual median), 130 (winter median), and 250 μg/m^3 (daily average). The latter value may be exceeded on not more than three consecutive days or a total of 7 in the year. Plans to bring air quality within the limit values by 1st April 1993 at the latest were required of member states.

Monitoring results from the Corporation network shows a growing failure to comply with these EC Directive limits during the 1980s. Three breaches of the annual limit have occurred (Ballyfermot, 1986/87/88, Crumlin 87/88) together with several breaches of the winter median limit. However, the principal problem has been short-term high pollution episodes occasioned by blocking anticyclones which restrict dispersal for several days before climatic control from the Atlantic resumes (Sweeney, 1987). These episodes are associated with the numerous breaches of the 250μg/m^3 limit apparent on Fig. 2 and with the peak values shown on Fig. 3. Both diagrams mirror the winter trends already discussed and show the acceleration in deterioration which occurred in the late 1980s. In 1988/89 for example every station except one in Dublin failed the daily limit value and peak levels were again in excess of 1,500μg/m^3.

The Recovery 1987-1992

A commencement order dated 28th July 1987, signed by the Minister, brought into operation the majority of sections of the Air Pollution Act (1987) with effect from 1st September 1987. Although the Act was a necessary piece of enabling legislation to give legal expression to the EC Directive, it meant that for the first time a comprehensive air pollution bill existed on the Irish statute books, one which could be used for the prohibition of certain emissions and the designation of 'special control areas'. During its passage through the Dáil it had suffered many delays and amendments. Winter 1985/86 had been mild, mean levels had fallen and public concerns about smoke pollution had abated. There were those who believed the claims of the coal lobby that unjustifiable hysteria had been generated by irresponsible academics concerning the seriousness of the city's smog problem. One of the most significant amendments to the Act was however proposed by the Minister himself "largely to satisfy the concerns expressed by the Coal Information Services". This entailed the carrying out of a detailed survey by the local authority in each area being considered for designation to confirm that the smoke pollution was caused by solid fuel combustion. This time-consuming exercise not surprisingly revealed that 82.6 per cent of the houses surveyed in the first pilot area (part of Ballyfermot) used solid fuels, a conclusion which could have been drawn from perusal of census data (Brady, 1986).

Figure 2: Daily Smoke Concentrations >250 μg/m3.

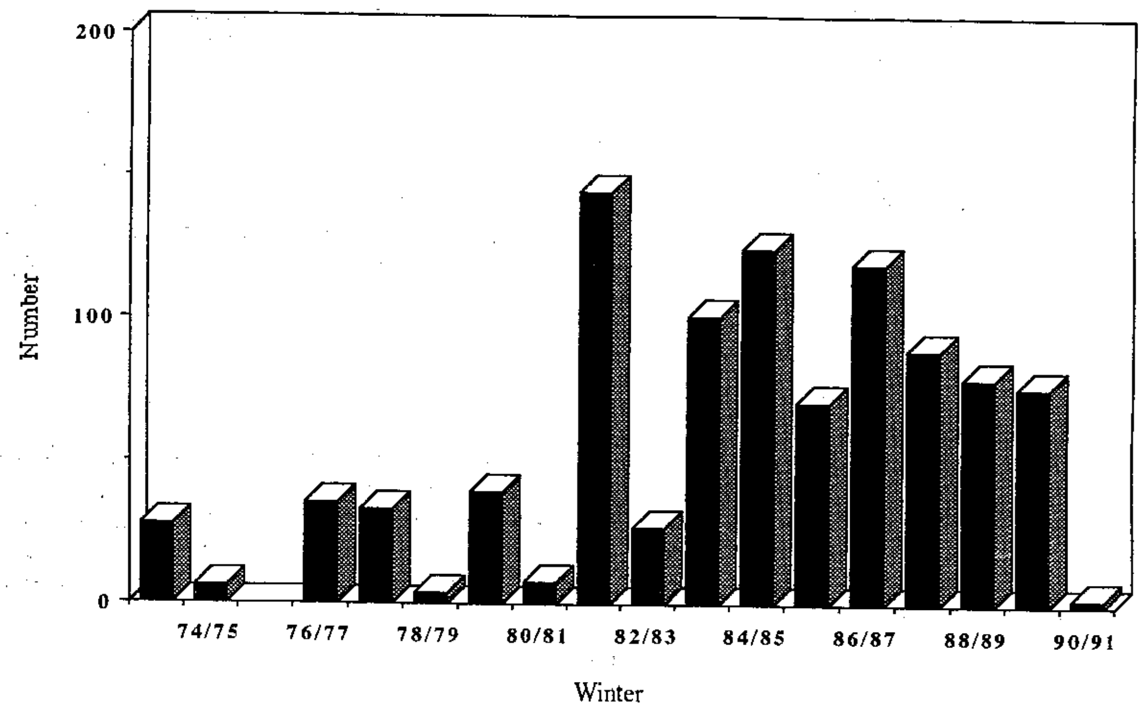
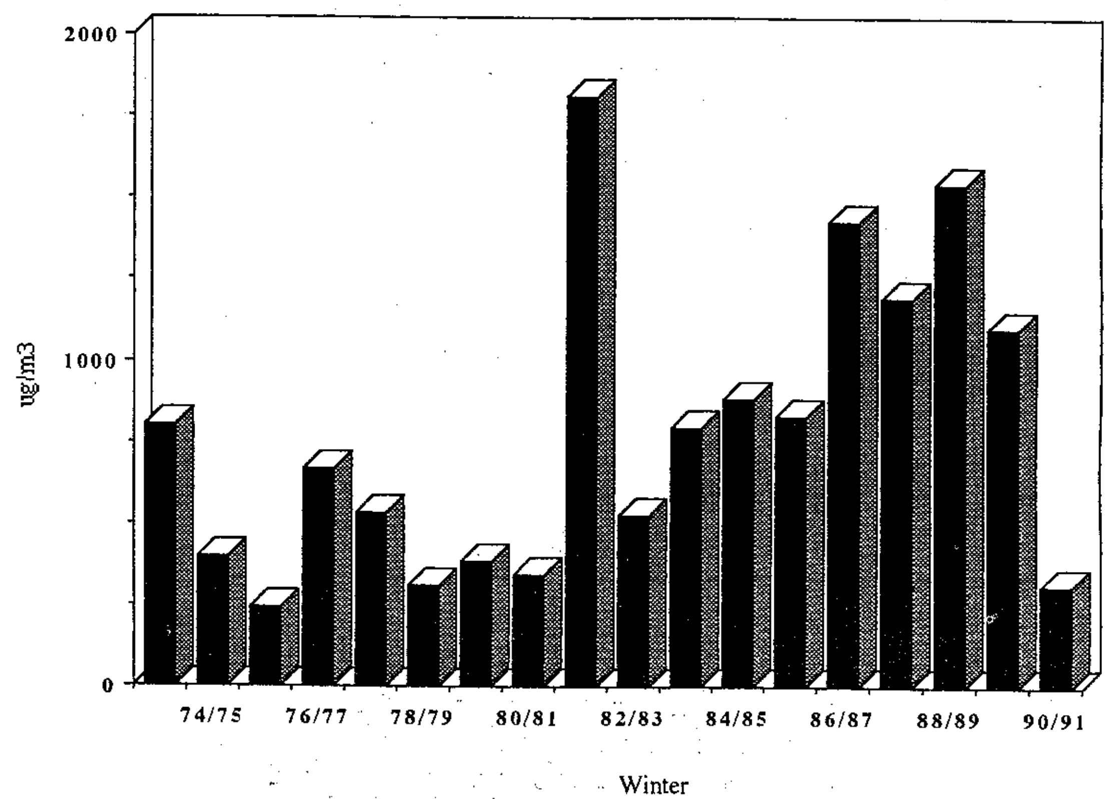


Figure 3: Peak Winter Smoke Concentration.

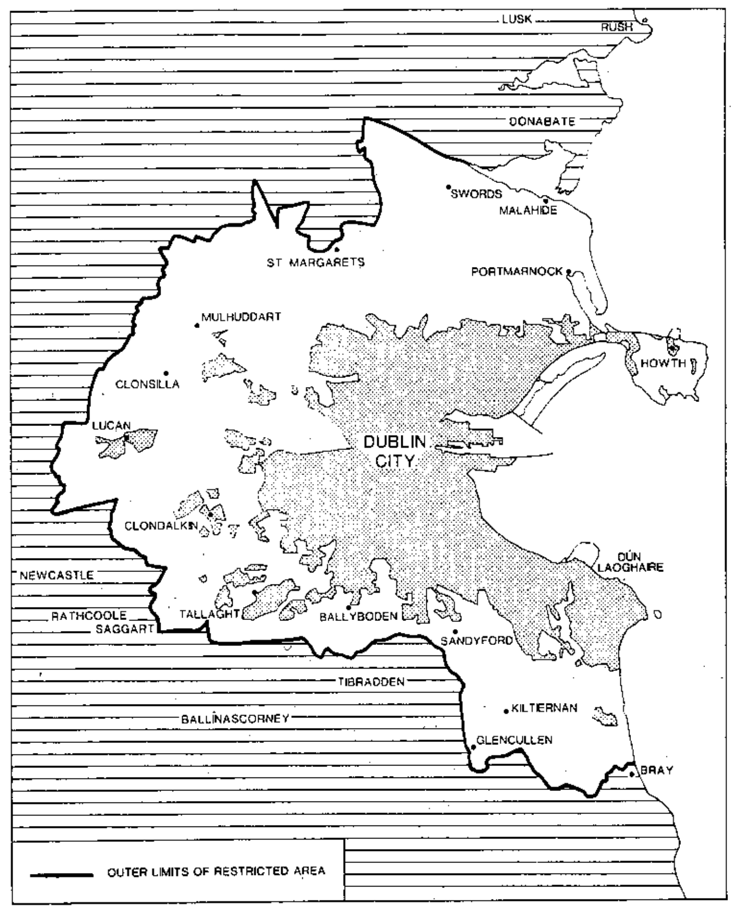


On 18th April 1988 Dublin City Council made an order designating a small part of Ballyfermot, comprising about 900 houses, a special control area. Some 12 objections were made to this, including, not unexpectedly, Coal Distributors Limited - a cartel involving Heitons, MacKenzies and Tedcastles, which had a monopoly of supply of Polish coal to the Dublin market. The oral hearing which lasted from 28th June - 4th July heard of a remarkable new invention from this group - the full burning fire - which, it was claimed, could enable households in special control areas to continue burning bituminous coal. In a ruthless commercial battle to gain a marketing edge in this first special control area a large number of these appliances were donated free to the residents. Pending independent testing the Minister approved the appliance as an "authorised fireplace". Peat briquettes were also approved as an "authorised fuel". Following testing of the "full burning fire" this authorisation was revoked in November 1989. The efforts of Coal Distributors Ltd. to frustrate the extension of special control areas continued with further objections to proposed designations in the western city and it became increasingly clear that compliance with the EC Directive by 1993 was unlikely. In addition, the public had become increasingly sensitised to the issue of smog, especially as a result of a particularly severe episode in late November 1988 when levels comparable to the 1982 episode were reached. It is by individual events such as this that the public consensus of what is 'acceptable' in environmental deterioration, commensurate with a particular standard of living, shifts and, as in London in 1952, the pressure for more radical measures became irresistible.

The Ban on Coal Sales

On 1st October 1990 a prohibition on the sale of bituminous coal within the Greater Dublin area became operative. The area is shown on Fig. 4 as encompassing all of the western suburban area as far as the County Kildare boundary, extending southwards almost to Bray and north to include Swords. Ironically, the action came as smoke emissions were already falling due to the effects of local community action and more importantly a growing penetration of the fuel market by natural gas. As the adverse consumer reaction in the aftermath of a serious gas explosion at Raglan House in Ballsbridge waned, the popularity of natural gas increased. 10,000 new customers were gained in 1988 as sales increased by 15 per cent.

Figure 4



The outcome of this new approach was that mean winter smoke levels in 1990/91 fell to $32\mu g/m^3$, the lowest level since the establishment of the monitoring network. Only two breaches of the $250\mu g/m^3$ limit value occurred and the city complied fully with the Directive for the first time in over a decade. Compliance with the stricter guide values of the Directive (winter mean $40\text{-}60\mu g/m^3$) was also achieved.

The changes in air quality described are a consequence of interacting variations in emission and dispersion conditions. In order to assess the effectiveness of the control policies described it is necessary to take into account meteorological factors. This entails a modelling exercise with the purpose of ascertaining what the likely prognosis is for future air quality under the present policies and what additional steps might need to be taken to ensure compliance with the limit and guide values under various meteorological and emission scenarios.

MODELLING DUBLIN SMOKE POLLUTION

Urban air pollution models are widely used to assess the impact of new sources or to examine the effect of control policies. Frequently these models are based on the Gaussian diffusion principle and vary considerably in complexity (Rao *et al.*, 1989). In an impact assessment of the proposed North Wall power station on Dublin air quality, Warren Spring Laboratory (1983) employed a 'Multiple Source Gaussian Plume Dispersion Model'. This study questioned the efficacy of monitored concentration levels and suggested that the peculiarities of peat smoke may be responsible for underestimating concentration values by a factor of up to 2.5. Calibration tests subsequently carried out (Walsh, 1988) did not confirm this, however.

One of the simplest, yet most successful, models is the Simple Box Model of Gifford and Hanna (1973) which is based on the principle that urban ground level concentrations are a function of source strength and transport by the mean wind.

$$X = \frac{cQ}{u}$$

where: X = concentration (in $\mu g/m^3$)
Q = emission rate (in g/s)
u = wind speed (in m/s)
and 'c' is a dimensionless constant which varies from city to city.

In their work on 44 US cities Gifford and Hanna (1973) found that the value of the constant 'c' for smoke varied from 57 (Cleveland) to 634 (Philadelphia) with a mean of 225. In order to ascertain the appropriate value of the constant for Dublin the winter averages for smoke from the Corporation network and wind speed (Dublin Airport) for the period 1975-1990 were employed. No data relating to winter smoke emissions over the area exist, however, although annual estimates for the early 1980s have been made by An Foras Forbartha (Bailey, 1983).

The estimated proportion of the national population resident in Dublin was used to scale down national energy consumption figures for 'directly consumed coal' for each of the 15 years from 1975 to 1989. To this was added 15 per cent, being the estimate by Warren Spring Laboratory for the contribution to smoke emissions due to motor vehicles (Warren Spring Laboratory, 1983) and a further 8 per cent being the estimate by Bailey (1988) for emissions from peat. The annual total emissions estimated are shown in Fig. 5. These are somewhat higher than a similar exercise carried out by McGovern (1991) and suggest a greater amplitude of variations in emissions than that derived in the An Foras Forbartha study (Bailey, 1983). Coal sales during the months from April to September are broadly equivalent to sales from two winter months and on this basis it was estimated that 75 per cent of annual smoke emissions occur during the six winter months.

The area of Dublin has changed considerably over the 15 year record and satellite-based estimates of the built-up area made by Horner (1990) were used to derive estimates of a real change. These factors were used to reduce the emission data to units of $tonnes/km^2/winter$ (Fig. 6) and subsequently to $g/s/km^2$ as required by the Box Model. Wind speed was obtained from Dublin Airport since urban wind speeds are unduly affected by building geometry.

Using all the data for the period 1975-89 the value of 'c' the dimensionless constant could now be obtained. An average value of 121 was derived which was intermediate to the values obtained by Gifford and Hanna for the cities of Seattle (117) and San Francisco (138). Both these cities are in west coast maritime-dominated climatic locations and also are not too dissimilar from Dublin in population terms.

Figure 5: Estimated Smoke Emissions in the Dublin Area.

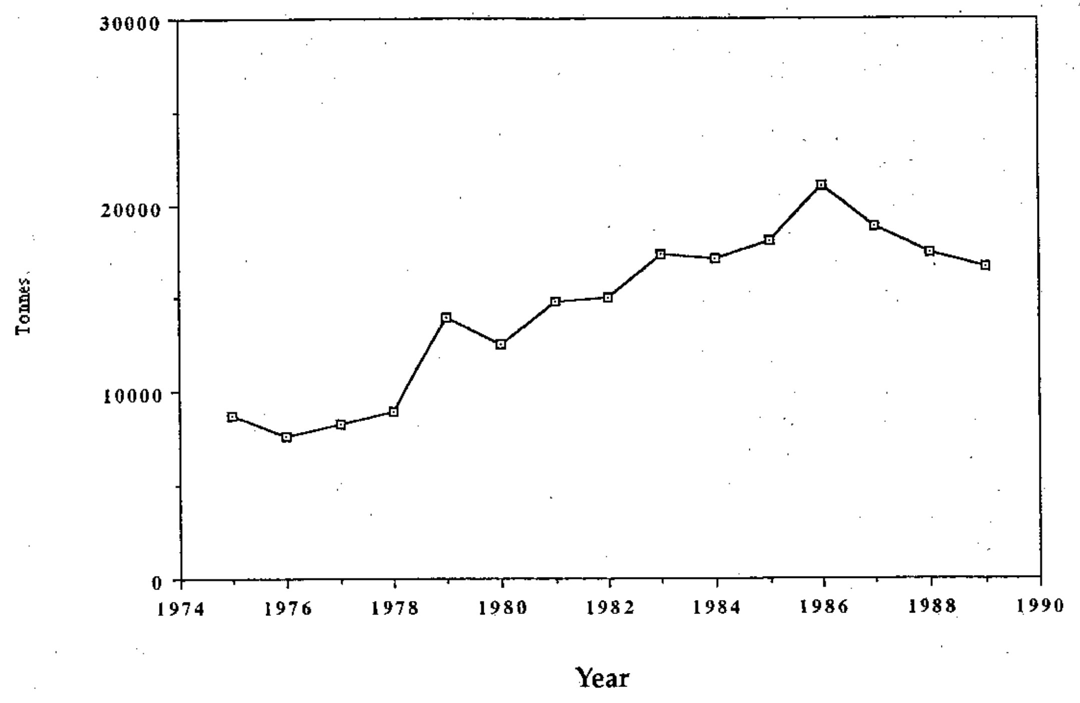
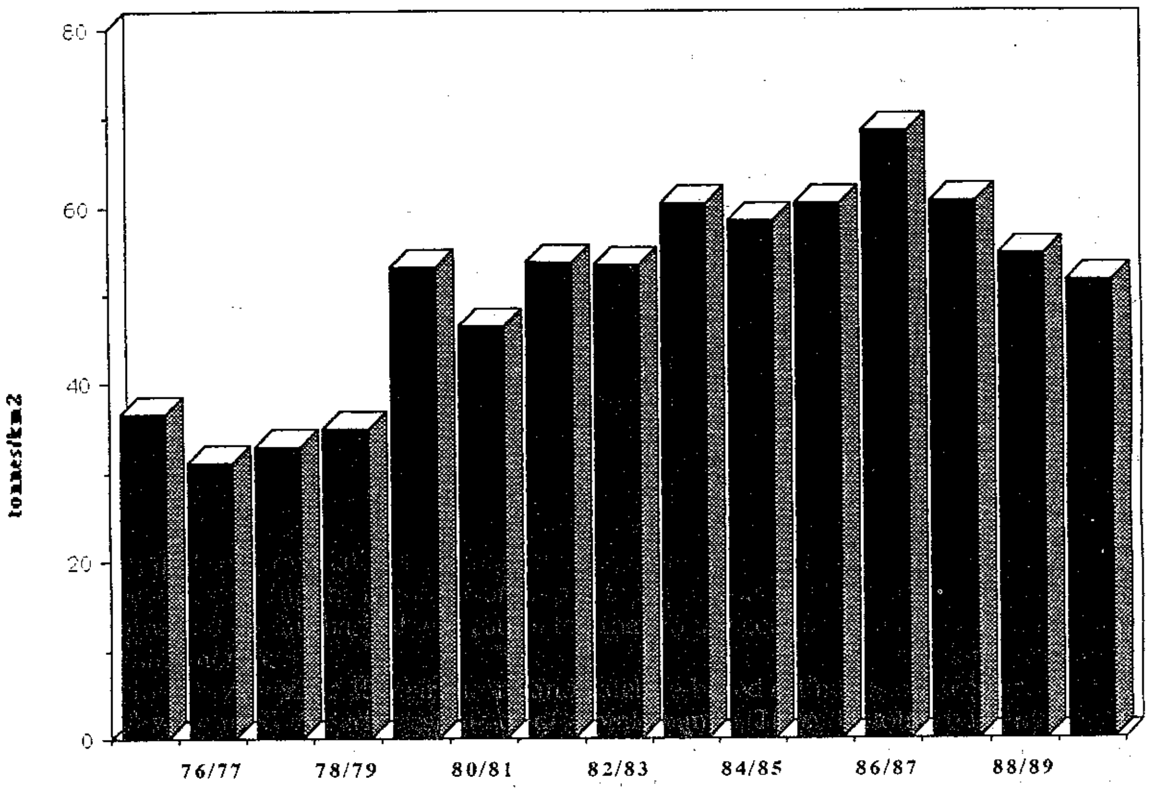


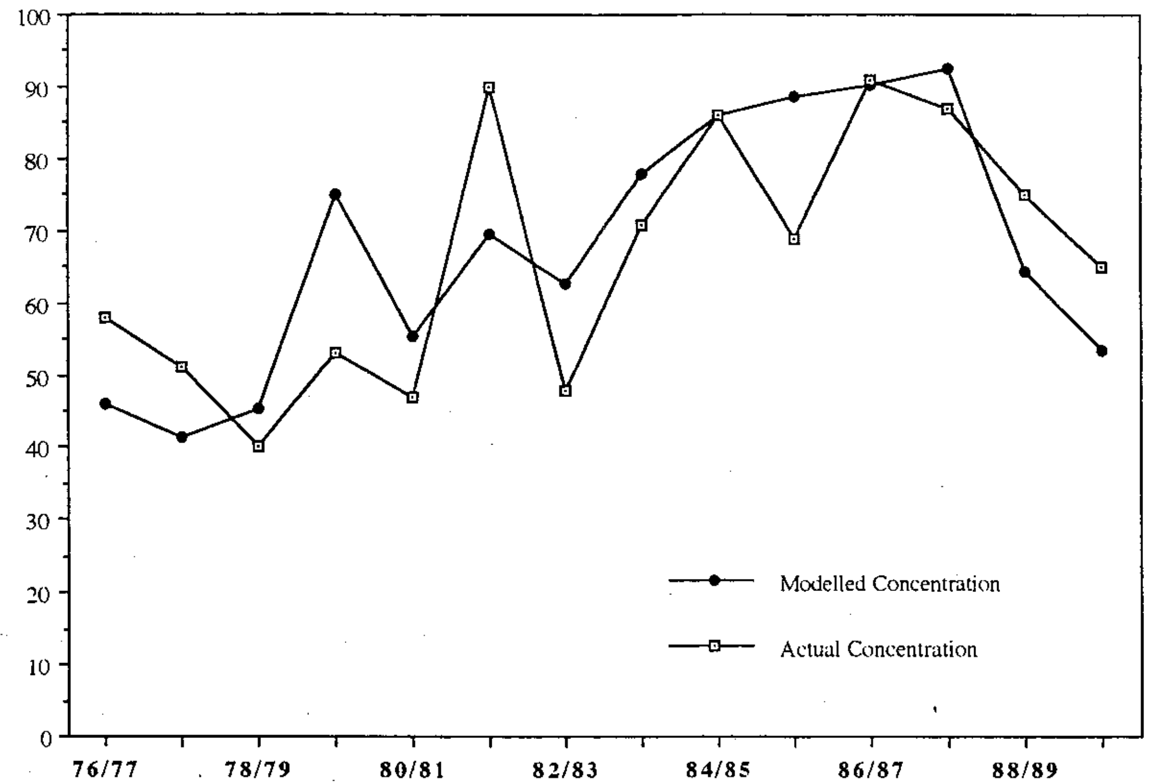
Figure 6: Winter Smoke Emissions in Dublin.



Using the constant thus derived, predictions for concentrations over the period 1975-1989 could be made (Fig. 7). These indicate that quite a high degree of confidence may be placed in the model as a predictive tool with all but one of the actual concentration values falling within one standard deviation of the predicted values.

Since the winter concentration for 1990/91 is now known to have been 32μg/m^3 and windspeed 5.3m/s the model can also be used to provide an estimate of smoke emissions for winter 1990/91. These turn out at 22.2 tonnes/km^2 as compared with 51.7 tonnes/km^2 for the previous winter. An emission reduction of 57 per cent has occurred. This represents a substantial turnaround in such a short period and has been sustained into winter 1991/92 when average smoke concentrations fell further to 23μg/m^3 with an average windspeed of 5.8m/s, equivalent to emissions of 17.7 tonnes/km^2. Smoke emissions in Dublin are now running at only 26 per cent of the 1986/87 values.

Figure 7: Actual v Modelled Winter Smoke Concentrations.



Compliance with EC Guide Values

An ability to predict concentrations with combinations of emissions and meteorological conditions enables estimates to be made of scenarios under which compliance with the EC guide values will and will not be achieved (Table 1). Under present conditions comfortable compliance is anticipated in all but the calmest of winters. Breaches of the daily limit value may from time to time continue to occur, but certainly with much diminished frequency and intensity.

CONCLUSION

While it is too soon to write the epilogue on Dublin's smoke problem, the situation has been transformed within a very short time, an indication of how a small nation can galvanise itself to begin to solve its environmental problems once community sensitisation occurs and the political will to grasp the nettle exists. But Dublin is only part of the Irish smoke problem (Sweeney, 1990) and while things have been improving in the capital further deterioration is evident in medium-sized towns and cities throughout the country. It is clearly time to extend control strategies to such areas. It is also time to remember that other forms of air pollution merit attention, such as oxidants and aerosol sulphates (Leavey and Sweeney, 1990) and in most cases these are not pollutants where changes can be pointed to in such a visible fashion as Dublin smoke. However, these also must be tackled if air quality in Ireland is to be safeguarded.

Table 1: Predicted Winter Smoke Concentrations for Wind Speed and Emission Combinations.

Winter Smoke Emission (Tonnes/km^2)	8.0	7.5	7.0	6.5	6.0	5.5	5.0
70	69	71	76	82	89	97	107
60	57	61	65	71	76	83	92
50	48	51	55	59	64	69	76
40	38	41	44	41	51	56	61
30	29	31	33	35	38	42	46
20	19	20	22	24	25	28	31
10	10	10	11	12	13	14	15

Mean Winter Windspeed (m/s)

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