Detailed Dispersion Modelling

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while 1% were planning to change. The remaining few percent did not know either way.

5.1 INTRODUCTION

The atmospheric dispersion of pollution is the process by which pollutants are mixed or diluted and transported in the atmosphere. The pollutant concentration varies in time and space depending on the distribution of pollution sources, meteorology and topography. The actual concentrations which are observed are the result of a balance between a number of competing processes, principally the emissions of compounds into the atmosphere and their subsequent dispersion and removal from the atmosphere. Numerical models can be used to simulate the dispersion process and are very useful tools for predicting the ambient air quality effects of a single pollution emission source or a group of sources.

Three first phase authority groups were specifically tasked with modelling dispersion around industrial sources. These were Ribble Valley where modelling was focused on emissions from sources in Clitheroe, Merseyside where modelling of sources around the Mersey Estuary was carried out and Avon where modelling was undertaken on sources around Avonmouth. Other authorities undertook the larger task of urban area modelling, incorporating all sources in an overall air quality management tool.

Both the Merseyside and Ribble Valley groups carried out dispersion modelling studies using the following widely used models R91, ISC and ADMS. The R91 model is a Gaussian plume model developed by the Working Group on Atmospheric Dispersion. A Gaussian model is one in which the variation in pollutant concentration across the plume profile is a Gaussian (or Normal) curve centred on the plume centre line. The vertical and horizontal standard deviations, σ_z and σ_y increase with distance downwind as turbulent mixing spreads the pollutant through the depth of the boundary layer. The methodology was published by the National Radiological Protection Board (NRPB) as report R91 (Clarke, 1979). The model is presented as a series of nomograms.

The Industrial Source Complex (ISC) version 2 is the US equivalent to the R91 model and was developed by the US Environmental Protection Agency during the 1970s. Like R91, ISC uses a Gaussian plume concentration profile. ISC is used with various modifications to model multiple point source emissions from stacks, stacks that have buildings nearby, area sources and volume sources. The model has 2 versions, ISCLT (long term) and ISCST (short term). The ISCST model includes a short term facility to calculate 1-hour to 24-hour averages, thus enabling an assessment of episodic peak concentrations. The ISCLT model include a long-term average facility to calculate seasonal and annual averages by incorporating long term historical meteorological information. An important difference from R91 is the use of only two surface roughness lengths: urban and rural.

ADMS (version 2) is a dispersion model developed in the UK by CERC (Cambridge Environmental Research Consultants) with support from a number of Government bodies and private companies. It includes a more rigorous treatment of the boundary layer and vertical dispersion, particularly under "unstable" conditions when air at the surface is driven to rise by the solar heating of the ground. In neutral and stable conditions, ADMS treats dispersion as Gaussian. The ADMS treatment of unstable conditions means that the maximum concentrations due to stack emissions are larger and closer to the source than for simple Gaussian models. It is generally accepted that the mathematical model in ADMS is an improvement over the simple Gaussian models for the assessment of stack plume dispersion.

5.2 MODELLING INDUSTRIAL SOURCES IN MERSEYSIDE

This group was asked to undertake a comparison of calculated concentrations of pollutants from industrial sources in the area using three models:

R91, ISC and ADMS (version 2).

5.2.1 Input data requirements

Source data input were very similar for all three models (Emissions data were discussed in Chapter 4). In addition, the three models were similar in their treatment of topographical features in that only a general description of the surrounding landscape is required. The ADMS module for treatment of complex terrain was not used. The Meteorological Office can supply input meteorological data for a large number of locations around the UK and, in general, data from one of these sites will be suitably representative of the modelling site. Longer term meteorological summary data are available in files for direct input to ADMS and to ISCLT. Hourly sequential data can also be obtained from the Meteorological Office for input to the ADMS model for direct estimation of individual hourly averages from which estimates of maximum hourly averages and running averages can be derived.

5.2.2 Model outputs and flexibility

R91 and ISC are simple models to use. ISC was developed by the US EPA to be used by both industry and regulators. It is widely used by industry and environmental consultants in Europe and the UK to predict concentrations from industrial sources. The model processes long term meteorological data at a very fast rate and calculation of annual averages can be very efficient. However, the model cannot predict running averages or percentile values. Although ISC can be downloaded free of charge from the USEPA internet site, this version does not have a user friendly front end so this basic form is unsuitable for use by inexperienced modellers. More user-friendly versions of the model are readily available from model providers listed in the Departments' Guidance document *Dispersion Modelling for Air Quality Review and Assessment* (DETR *et al.,* 1998a).

The number and type of outputs from the ADMS model are clearly greater than with the ISC and R91 models. The ability of the ADMS model to calculate running averages and percentile values is of benefit to end-users whose task it is to compare modelled results with air quality objectives. The ADMS models can also be used in a GIS format which is an advantage if a local authority or the end-user has access to this software. A major drawback of ADMS is the long processing time required, particularly when hourly sequential data are used together with emissions estimates from several sources and a grid of receptor points.

5.2.3 Model Results

ADMS can provide hour-by-hour estimates of pollutant concentrations enabling frequency distributions of concentrations to be derived. Statistical summaries of ADMS-modelled and measured concentrations of SO_2, PM_{10} and VOC are given in Tables 5.1, 5.2 and 5.3. The hour-by-hour predicted and measured hourly average concentrations of sulphur dioxide are shown in Figure 5.1. Industrial emissions of sulphur dioxide are relatively well quantified and are the largest contributor to ambient concentrations. The agreement between ADMS modelled and measured concentrations over the longer term (months) is relatively good, but over the shorter term (hours) the agreement can be poor (correlation co-efficient for hourly data was 0.34). For example, the average ADMS modelled and measured SO_2 concentration over a three month period was very similar (Table 5.1) but, while the maximum hourly modelled and measured concentration was very similar, they did not occur on the same day. The maximum concentrations for R91 and ISC did not compare as well with the maximum measured concentrations.

TABLE 5.1. STATISTICAL SUMMARY OF HOURLY AVERAGE ADMS2-PREDICTED AND MEASURED SO_2 CONCENTRATIONS AT THE AIR QUALITY MONITORING STATION AT SPEKE (JANUARY TO MARCH 1997).

	*Modelled Industrial Emissions SO_2 ($\mu g\ m^{-3}$)**	*Measured SO_2 ($\mu g\ m^{-3}$)*
Maximum	422	427
Mean	23	21
50th percentile	8	12
95th percentile	74	75
98th percentile	114	128
99th percentile	161	150

* Model data filtered to remove zero values

ADMS-modelled concentrations of PM_{10} and VOC and measurements agreed less well. For PM_{10} only primary emissions from industry were modelled and, the modelled average and maximum concentrations were much smaller than measured values. There are many sources

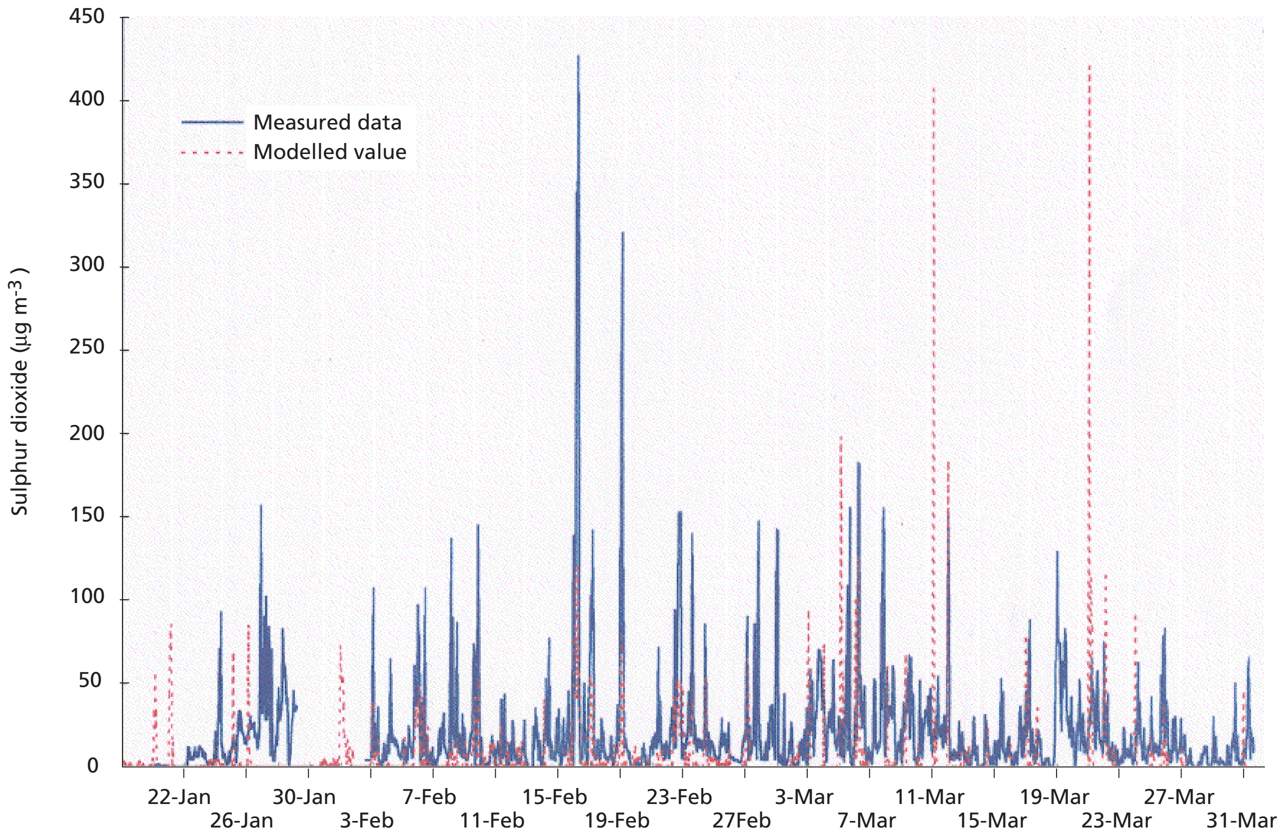

Figure 5.1. Comparison of measured hourly average sulphur dioxide concentrations at Liverpool Speke during January to March, 1997 and the predictions of ADMS-2 using sequential meteorological data. Only contributions from the identified point sources were included in the model calculations.

contributing to ground-level concentrations in addition to industrial sources, including road transport, domestic combustion, mining, quarrying and construction, so this is perhaps not surprising. This illustrated the need to take account of other components of particles to give estimates of ground level concentrations. For VOCs, the modelled concentrations were more than an order of magnitude larger than measured values. This is due to the difficulty of modelling the ambient concentrations due to the emissions from Stanlow refinery. These emissions were available as total VOCs rather than specific compounds and the compounds emitted may have been different from the group of hydrocarbons measured. In addition, VOCs are emitted from multiple sources with the refinery complex and from a range of heights. The details of these release points were not known and the refinery was modelled as an area source with emissions at ground level, very much a worse case. It will clearly be difficult to model the impact of major VOC sources such as oil refineries for review and assessment purposes and direct measurements may be necessary where emissions are a cause of concern.

TABLE 5.2. STATISTICAL SUMMARY OF HOURLY AVERAGE ADMS2-PREDICTED AND MEASURED PM_{10} CONCENTRATIONS AT THE AIR QUALITY MONITORING STATION AT SPEKE (JANUARY TO MARCH 1997).

	Modelled Industrial Emissions PM_{10} ($\mu g\ m^{-3}$)	*Measured PM_{10} ($\mu g\ m^{-3}$)*
Maximum	12	225
Mean	1	21
50th percentile	0.004	17
95th percentile	3	51
98th percentile	4	74

99th percentile	6	92

TABLE 5.3. STATISTICAL SUMMARY OF HOURLY AVERAGE ADMS2-PREDICTED AND MEASURED VOC CONCENTRATIONS AT THE AIR QUALITY MONITORING STATION AT SPEKE (JANUARY TO MARCH 1997).

	Modelled VOC (ppb)	*Measured* VOC (ppb)*
Maximum	16783	188
Mean	245	11
50th percentile	0.5	1.25
95th percentile	1807	27
98th percentile	3862	45
99th percentile	4665	57

* Total hydrocarbons (25 hydrocarbon compounds as defined in national automatic monitoring network.

5.3 MODELLING INDUSTRIAL SOURCES IN RIBBLE VALLEY

The Ribble Valley authority modelled the dispersion of pollutants emitted by the main industrial sources around Clitheroe using ADMS, ISCLT3 and R91. They contracted consultants, CERC, to undertake this task. All three models were used to predict the long term average concentrations of SO_2, particles and NO_2 in a 12 km x 12 km area around Clitheroe for both the current and 2005 cases. Emissions from the major industrial sources are given in Table 5.4.

TABLE 5.4. EMISSIONS OF SO_2 AND NOX (AS NO_2)(g/s) FOR THE CURRENT AND 2005 CASES FROM THE MAJOR SOURCES IN THE RIBBLE VALLEY AREA.

Source	*Emission rate of SO_2 - current*	*Emission rate of NO_2 - current*	*Emission rate of SO_2 - 2005*	*Emission rate of NO_2 - 2005*
Castle Cement	221	89.9	22.1	89.9
Tarmac	9.87	1.1	9.91	1.1
ICI Katalco	3.33	5.55	3.33	2.77

All calculations were carried out in flat terrain in order to compare the results between the three models. The effect of complex terrain on ground level concentrations was not large, except in very stable conditions, and in particular the effect of the quarry was limited (Carruthers *et al.*, 1997).

Only the results from ADMS were compared to the national air quality objectives and the air quality monitoring data from the established station at Chatburn. The other models were not used in this exercise due to practical difficulties in setting up the calculations and a lack of certain modelling features within the available version of each model.

The modelling results show that the national air quality objective (100 ppb [or 267 μg m^{-3}] 99.9th percentile of 15 minute mean concentrations) for SO_2 is exceeded very near to the industrial sources for the current emissions case and may still be very close to the limit for the proposed emissions case, although still in a very localised area (Figure 5.2 and 5.3) Further from the sources the concentration of SO_2 is predicted to be significantly lower in 2005 based on the proposed changes to emissions from the three sources.

Concentrations of NOx resulting from industrial emissions were small for the current case and with the proposed future emissions case, the annual average concentration of NOx is reduced by about 50% (Figures 5.4 and 5.5). This has been achieved mainly by the abatement equipment being installed at ICI Katalco. Some reduction can also be seen in the contribution from Tarmac due to the increased stack heights of three sources.

5.4 URBAN AREA MODELLING IN THE WEST MIDLANDS

The West Midlands Group undertook the task of comparing the performance of two air quality management tools, Indic Airviro and ADMS-Urban for modelling the dispersion of three primary pollutants: carbon monoxide, total oxides of nitrogen and PM_{10}.

Both models require a database of emissions (point, line and area sources) and appropriate meteorological data. Emissions data had been previously collected by the London Research Centre on behalf of DETR (LRC, 1996). The West Midlands is a complex urban area with air pollutant emissions from many industrial point sources as well as the road transport, domestic and other dispersed sources typical of any urban area. The emissions inventory included 3,468 line sources, 1020 point sources and 1,277 area sources. For modelling, additional information was needed. This included stack data (height, heat content and

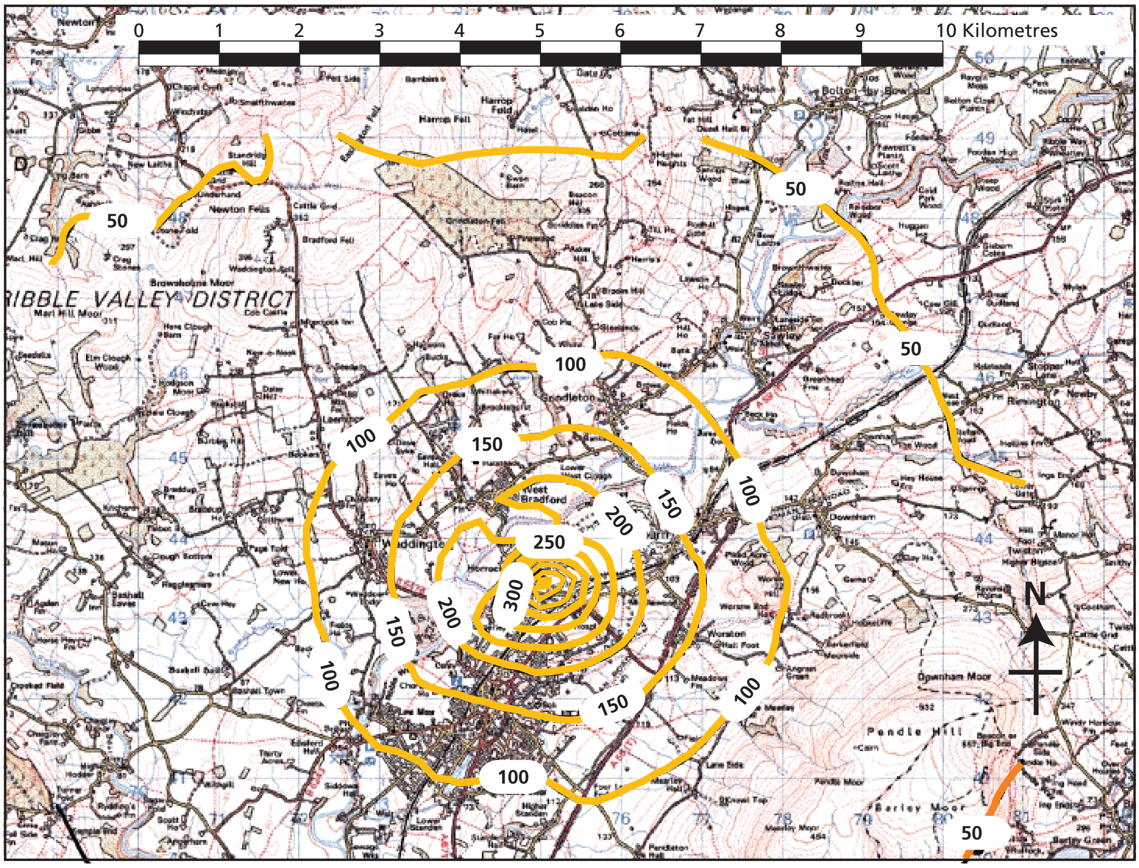

Figure 5.2 Current 99.9th percentile of 15 minute average concentration of sulphur dioxide from all sources (µg m^{-3}) as predicted using ADMS.

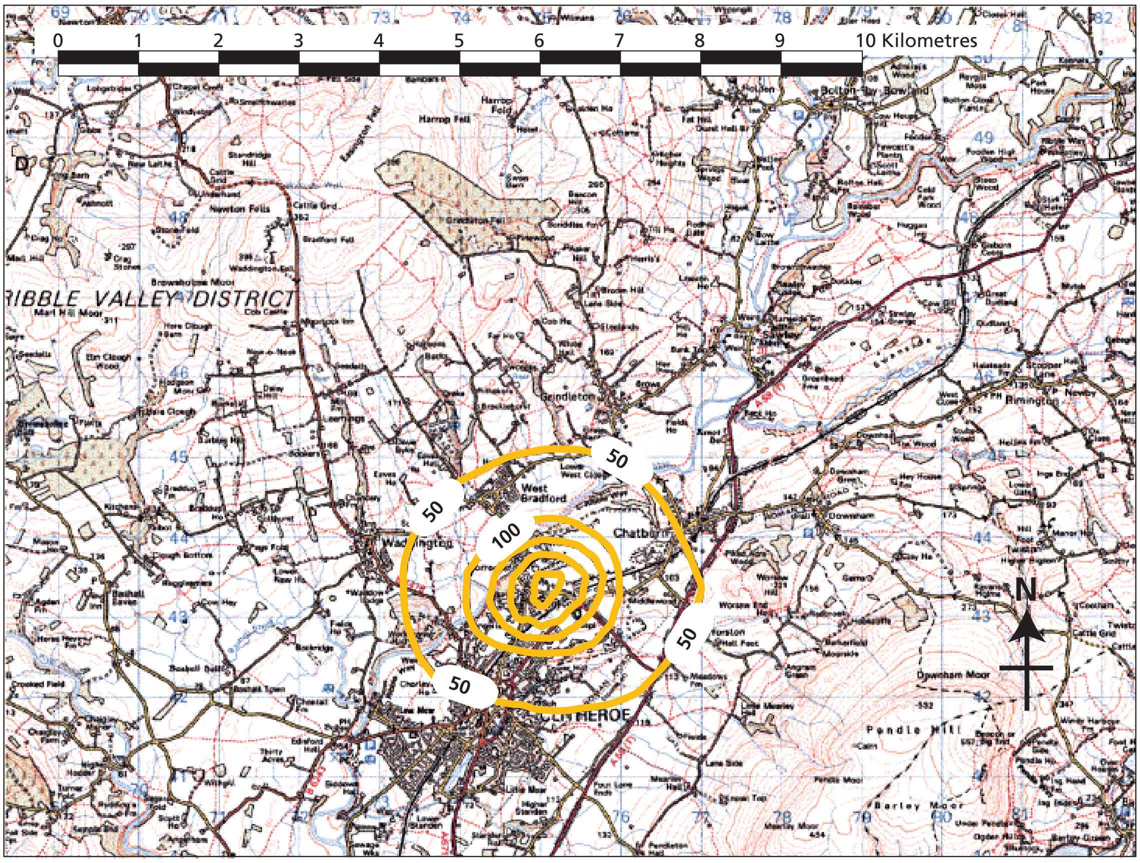

Figure 5.3 2005 99.9th percentile of 15 minute average concentration of sulphur dioxide from all sources (µg m^{-3}) as predicted using ADMS.

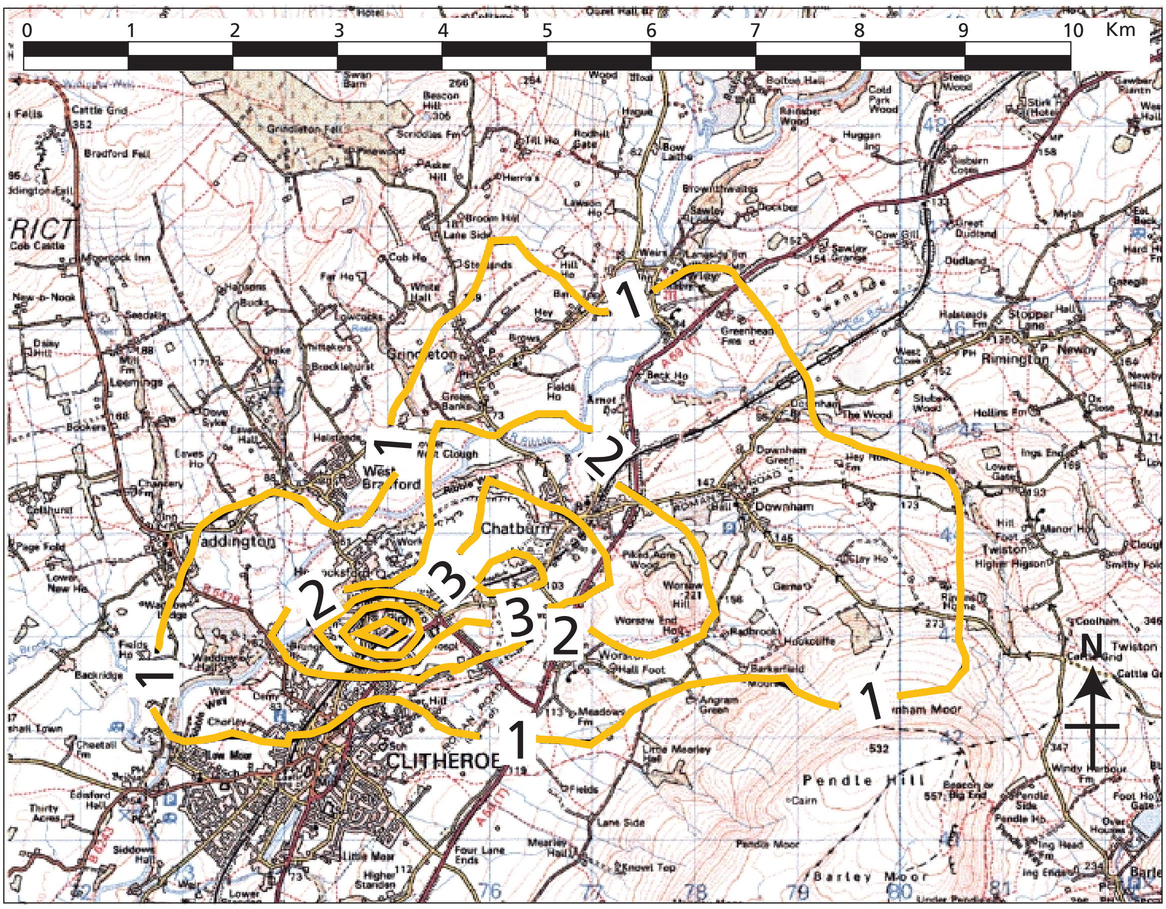

Figure 5.4 Current annual mean concentration of NOx from all sources (µg m^{-3}) as predicted using ADMS.

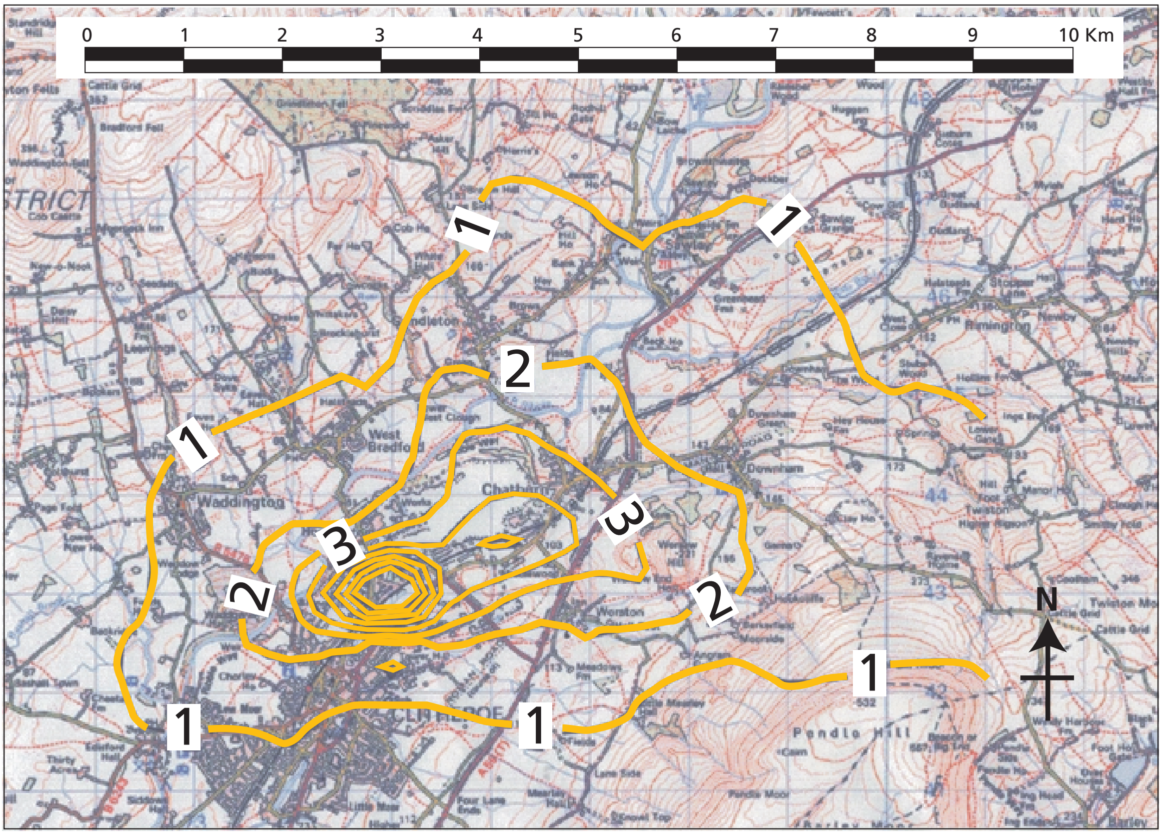

Figure 5.5 2005 annual mean concentration of NOx from all sources (µg m^{-3}) as predicted using ADMS.

so on), process operating times and diurnal variation in traffic flow.
Five years of synoptic meteorological data were obtained from the Meteorological Office and were used to compile summer and winter scenarios for seasonal dispersion modelling.

5.4.1 Emissions data for Airviro

Airviro (Swedish Hydrometeorological Institute), can be used to predict short term air quality (i.e. predictions of ambient concentrations hour by hour) or long term air quality (mean or percentile). It requires a database of emissions (point, line and area) and appropriate meteorology. Airviro works on a UNIX workstation rather than a PC and some aspects of setting it up are therefore relatively complex. The emissions data requirements are also relatively demanding. Once set up, however, the system is potentially a powerful tool for air quality assessment. Like any model. however, the dispersion model contained within the Airviro software suite is subject to error and uncertainty.

Transfer of the urban emissions inventory database into the model was found to be relatively straightforward. Airviro has no fixed limit on the number of sources and a database of the 5699 sources in the West Midlands was created in the modelling software. Information on the release conditions from point sources required for modelling was not available. Thus parameters such as height and temperature of the discharge, efflux velocity and dimensions of neighbouring buildings were estimated. It was noted that these variables are unlikely to change from year to year and collation of these data would improve the accuracy of the modelling results.

Most information on emissions from roads required by the model was available from the DETR West Midlands emissions inventory. The number of lanes was required and was not available in the inventory but a default of 2 was used for most roads, 4 for dual carriageways and 6 for motorways within the model. Eight road types are available which is a more detailed classification system than that used in the emissions inventory.

5.4.2 Emissions data for ADMS-Urban

The West Midlands emissions inventory was input into the model, which uses a Microsoft Access database, by copying and pasting data for groups of sources from the spreadsheet package used by LRC. This model has a limit of 1500 sources which was too restrictive for a large conurbation of over 5000 sources.

As with Airviro, a number of discharge dimension variables are required in the dispersion calculations which were not supplied in the inventory. Most road traffic information required by the model was available in the inventory. However, the following parameters were not available and default settings were used:

- *number of lanes*
- *elevation of road*
- *canyon height*
- *road width*

5.4.3 Comparison with measurements

Two examples of the comparison of hour-by-hour measurements and modelled concentrations are shown in Figure 5.6. Figure 5.6(a) shows hourly mean CO concentrations between November 12 and November 16 1996 at Wolverhampton Centre. The highest concentrations were observed during the morning and evening of November 13 and this was predicted reasonably well by Airviro. ADMS-Urban under-predicted concentrations on this occasion. Figure 5.6(b) shows modelled and measured concentrations of nitrogen oxides at Birmingham West during the same episode. Airviro overpredicts concentrations on the 13th by about a factor of 2. The concentrations at Birmingham West peaked later in the evening on the 13th than at Wolverhampton. This is usually due to very poor dispersion overnight such that any emissions from night-time traffic or other sources have a magnified effect on concentrations. This effect was not reproduced by the models in this case. On the 14th and 15th, measured concentrations were not particularly high but Airviro predicted very high concentrations, up to a factor of 5 too large. ADMS-Urban predicted the morning peak concentrations to within 20% of the measured values on these days.

These examples are typical of the behaviour found at other times and sites. Minor fluctuations in wind direction induced the models to “see” or “miss” an effect from a source at a particular location. Also, it should be noted that the calm conditions that lead to pollution episodes are outside the range of meaningful dispersion calculations and therefore

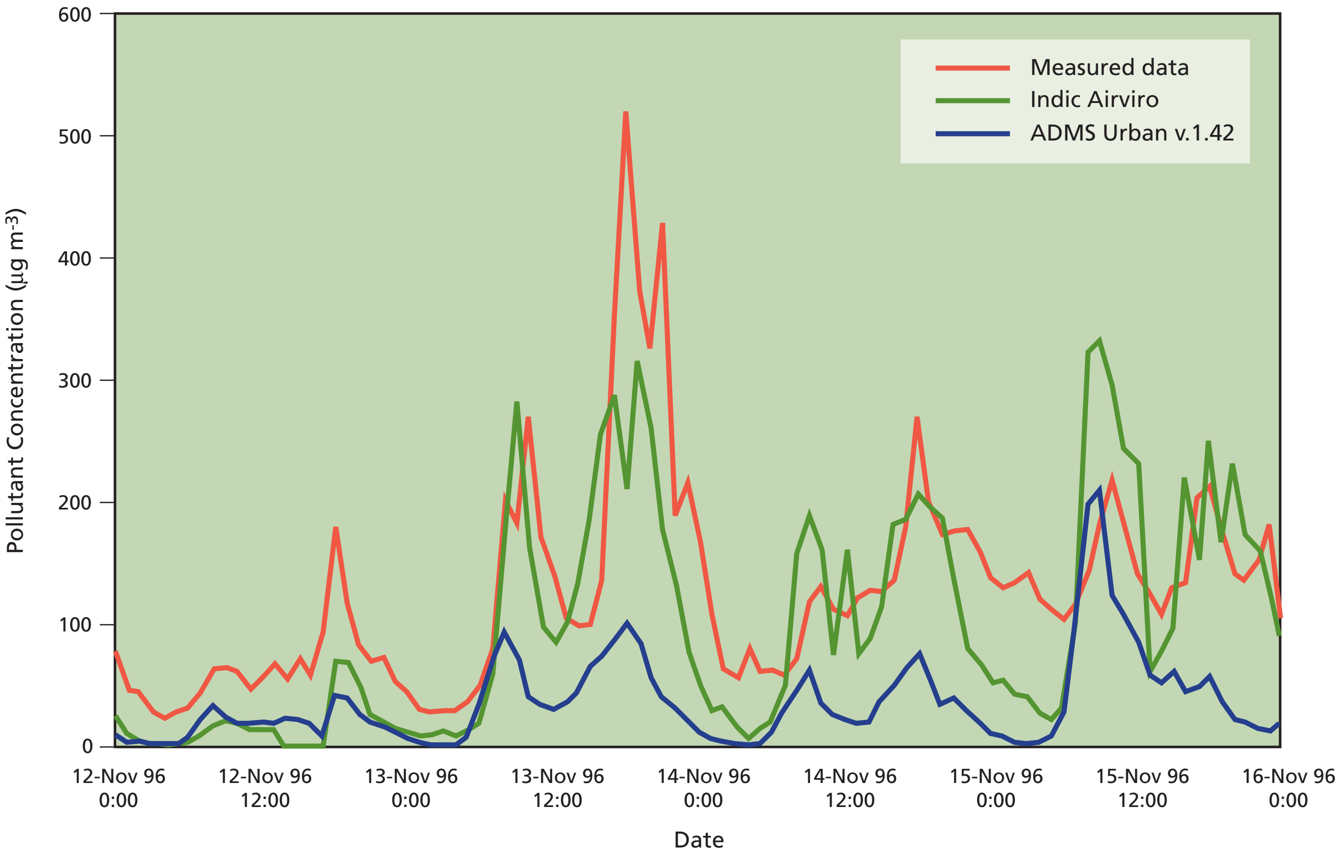

Figure 5.6a Modelled and measured hourly mean concentrations of CO between 12th and 16th November, 1996 at Wolverhampton Centre

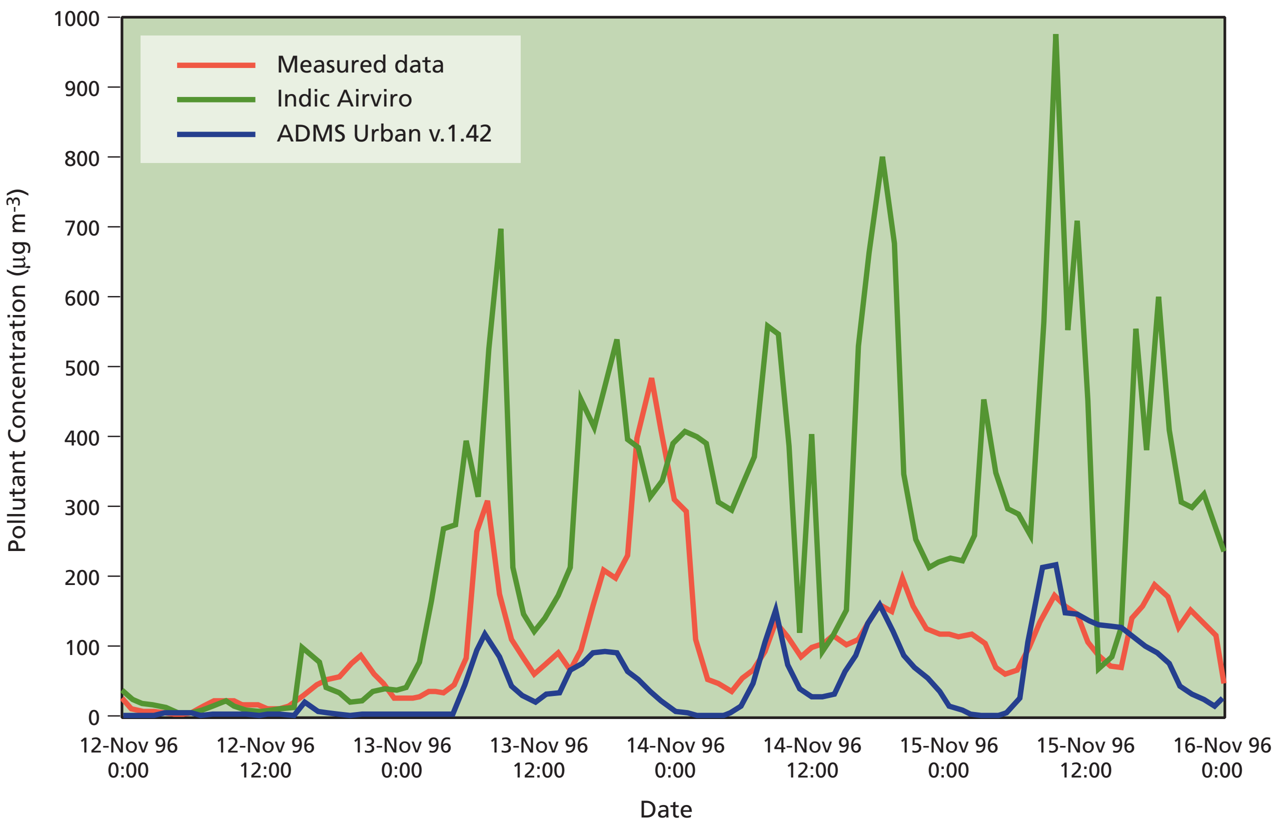

Figure 5.6b Modelled and measured hourly concentrations of NOx between 12th and 16th November 1996 at Birmingham West.

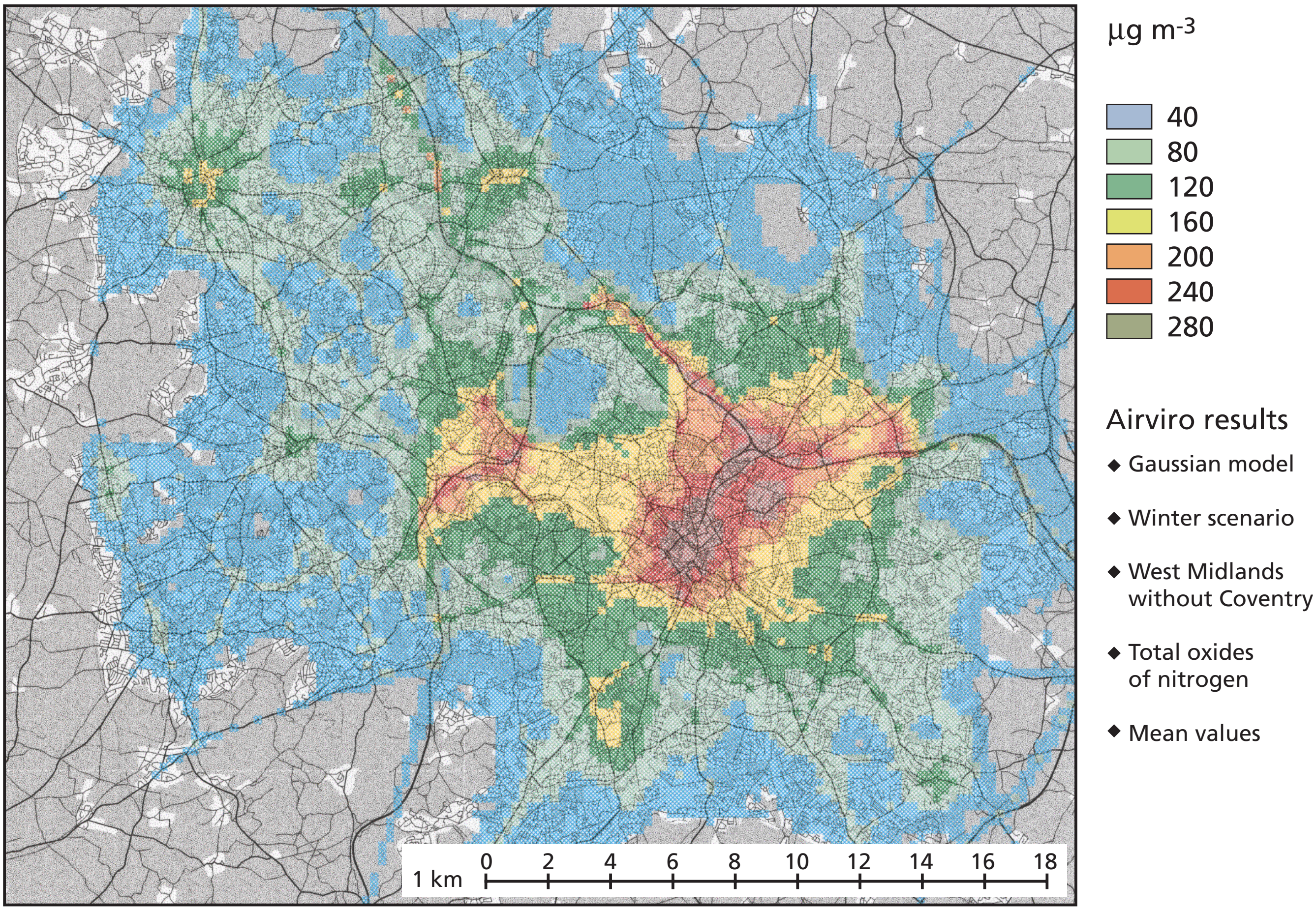

Figure 5.7 Map of West Midlands showing winter mean concentrations of NOx as determined by Airviro.

test the models to the limit. Both models generally followed the patterns of measured values but often not too closely. Sometimes Airviro performed better than ADMS but at other times the performances were reversed. At other times, both models predicted high concentrations which were not recorded by monitoring instruments.
Airviro is capable of providing maps of relevant statistics of the frequency distribution of the concentrations of the pollutants. In the West Midlands study calculations were carried out for oxides of nitrogen, carbon monoxide and PM_{10} particles. For each pollutant, mean, 95th, 96th, 97th, 98th and 99th percentiles were calculated. Figure 5.7 shows the map of winter mean concentration of nitrogen oxides. Point by point comparison with monitoring site results indicates that the mapped winter mean NOx concentrations are about a factor of two too high.

The output from both ADMS-Urban and Airviro in this case highlights the need for model validation with monitoring results in such large conurbations. A key element of the review and assessment of air quality is the use of "screening" tools to assess the risk of specific air quality objectives being exceeded at the end of 2005. Several of the First Phase Authorities tested screening tools including:

- *The Design Manual for Roads and Bridges, a methodology for estimating the impact of major roads on air quality (The Highways Agency, 1994).*
- *AEOLIUS, a model of the effect of street canyons (i.e. where the height of the buildings are significant compared to the width of the road) which was developed by the Meteorological Office.*
- *The preliminary draft review and assessment guidance circulated by the then Department of the Environment prior to the commencement of the First Phase studies.*

5.5 DISPERSION MODELLING IN AVONMOUTH

The Group in Avonmouth also undertook dispersion modelling using Indic Airviro and ADMS-Urban and compared the performance of both models against monitoring data for total oxides of nitrogen.

Like the West Midlands Group, emissions data were input to both models using those data compiled by the London Research Centre (1997) on behalf of the Governments. This urban inventory covered the city of Bristol and surrounding areas including the coastal area of Avonmouth totalling an area of 166 km². Industrial and road traffic emissions were calculated using local data and domestic and other low-level dispersed emissions were added from the National Atmospheric Emissions Inventory.

Results from dispersion modelling were compared with monitoring data from the national automatic

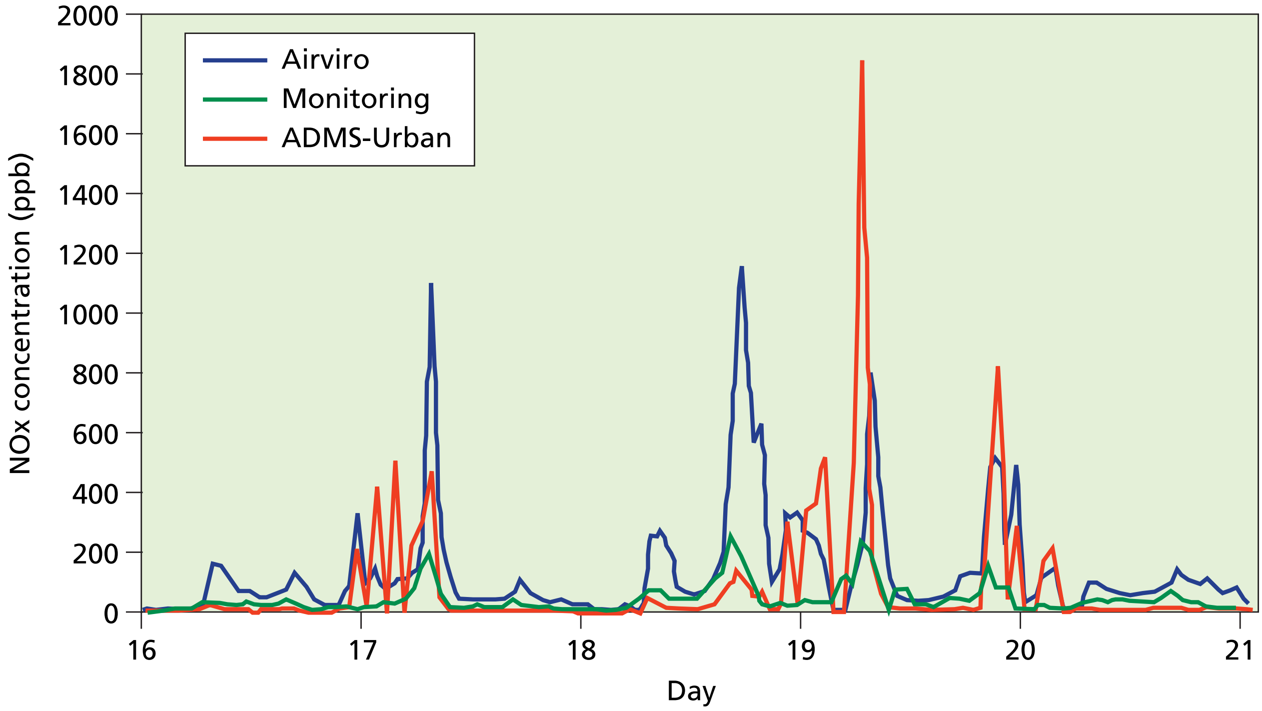

Figure 5.8 Comparison of ADMS-Urban and Airviro predictions with monitoring data (16-21st January 1995).

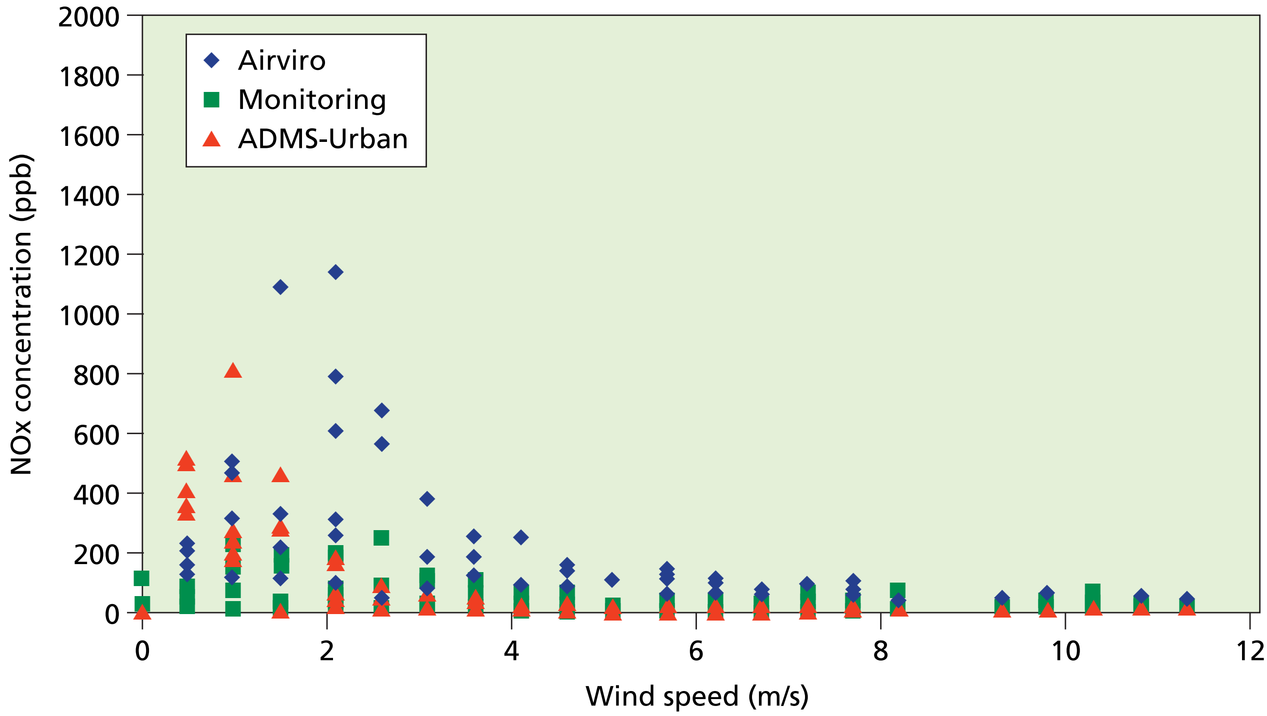

Figure 5.9 Comparison of ADMS-Urban and Airviro predictions with wind speed.

network site at Bristol Centre. This site is representative of the urban centre and is located in a pedestrianised walkway 43 m from a major road. Although both dispersion models used include street canyon options these were not used in this study. Differences in the models resulted in terrain data being input into Indic Airviro but not to ADMS-Urban. Both models are able to process sequential hourly meteorological data.

A scenario was run for a typical week (16th-23rd January, 1995) where predictions were made over the short-term (hours). A diurnal traffic profile was included into the input data which assumed a traffic split of 93% LGV and 7% HGV. Comparison with monitoring data showed that predicted concentrations from both models were of the same order and were of a similar magnitude to the monitored NOx concentrations. Like in the West Midlands study the highest concentrations were, in general, during the morning and evening rush hours but where peaks in the monitoring concentration were seen the predicted concentrations from both models were often much higher, for example, early on 17th, late on 18th, early on 19th (Figure 5.8). On the whole, though, Indic Airviro over-predicted and ADMS-Urban under-predicted the monitored concentrations. Comparisons between predicted concentrations and wind speeds showed that the greatest over-estimates were during periods of relative calm when dispersion models are particularly tested (Figure 5.9). Predicted concentrations are notably high when wind speeds are less than 2 m s^{-1} and it is recommended that wind speeds less than 1 m s^{-1} are not used in ADMS-Urban (CERC, 1997).

5.6 URBAN AREA MODELLING IN LONDON

The London First Phase Group used two models to investigate air quality in the London wide area, Indic Airviro and ADMS-Urban for both NO_2 and SO_2. Comparison with monitoring data from a number of sites was carried out. The modelling was undertaken for two areas of London, Central and the East Thames corridor.

5.6.1 Emissions data

The modelling for this study was undertaken before the publication of the urban inventory for London (LRC, 1998). However, emissions data were supplied by the South East Institute of Public Health which required some manipulation prior to input into the models. Part A point source emission data along with the other required parameters for dispersion modelling, such as stack height, discharge temperature, were readily available but similar information for Part B processes was very limited. Point sources outside the study areas had a significant influence on the region's SO_2 emissions and so were included in the emissions inventory for modelling purposes. Emissions data from roads were calculated using factors from the Design Manual for Roads and Bridges (DMRB). Average traffic flows and speeds for roads with a flow greater than 25,000 vehicles per day were used in the modelling study. A diurnal variation in traffic flow was used for Central London. Background emissions were also input into both models on a 1 km grid square basis.

5.6.2 Predicted results from ADMS-Urban

ADMS was used to calculate hourly averaged concentrations of SO_2 and NO_2 at 5 automatic monitoring sites for every hour in two three month study periods (May-July and October-December, 1995). This allowed the modelled data at each site to be compared with the monitored concentrations over a variety of meteorological conditions. Percentiles of concentration were calculated and compared for each site (Tables 5.7 and 5.8). Typical run times for each of the three month periods were 2-3 hours.

Comparison of the mean and the 95th percentile hourly average concentrations of SO_2 calculated by ADMS with that observed at each of the monitoring sites for both the summer and winter periods generally showed good model performance (Table 5.7). Agreement with the higher percentiles shows more variability and the model often over-predicted up to about a factor of 2. Analysis of the meteorological data suggested that ADMS predicted highest concentrations when the wind was from the east (during the winter) which were caused by emissions from the large power stations along the East Thames corridor which highlighted the need to obtain time-dependent emission data from large point sources.

Nitrogen dioxide concentrations calculated by ADMS generally showed reasonable agreement with measured data, though the model does tend to

TABLE 5.7 SUMMARY MEASURED AND ADMS MODELLED SO_2 DATA (ppb) DURING THE SUMMER AND WINTER PERIODS AT DIFFERENT SITES.

Site	Percentile	Summer Measured concentration	Modelled concentration	Winter Measured concentration	Modelled concentration
Greenwich*	mean	4	5	6	7
	95th	17	22	20	28
	98th	33	33	31	57
	99.9th	106	222	64	227
	100th	178	250	96	230
Bexley	mean	10	7	-	-
	95th	36	29	-	-
	98th	77	49	-	-
	99.9th	254	277	-	-
	100th	304	299	-	-
City*	mean	8	7	9	8
	95th	28	23	24	25
	98th	42	32	31	48
	99.9th	131	456	71	177
	100th	178	429	121	187
Bloomsbury*	mean	8	7	10	8
	95th	26	19	27	23
	98th	38	29	39	39
	99.9th	119	149	83	169
	100th	149	413	104	178
Westminister*	mean	10	6	-	-
	95th	27	15	-	-
	98th	44	28	-	-
	99.9th	96	139	-	-
	100th	141	152	-	-

* Monitored data supplied by South East Institute of Public Health

TABLE 5.8 SUMMARY MEASURED AND ADMS MODELLED NO_2 DATA (ppb) DURING THE SUMMER AND WINTER PERIODS AT DIFFERENT SITES.

Site	Percentile	Summer Measured concentration	Modelled concentration	Winter Measured concentration	Modelled concentration
Greenwich*	mean	23	14	22	8
	95th	48	39	41	22
	98th	64	71	48	41
	99.9th	87	157	83	178
	100th	92	208	89	264
Bexley*	mean	19	11	22	8
	95th	43	47	37	25
	98th	56	93	43	40
	99.9th	86	214	72	142
	100th	128	256	91	306
City*	mean	38	29	64	15
	95th	85	80	100	34
	98th	106	117	121	71
	99.9th	149	293	174	220
	100th	164	341	192	280
Bloomsbury*	mean	34	27	37	15
	95th	66	76	56	38
	98th	88	106	64	65
	99.9th	132	234	85	189
	100th	176	292	112	220
Westminister*	mean	42	25	-	-
	95th	82	68	-	-
	98th	105	96	-	-
	99.9th	182	205	-	-
	100th	246	222	-	-

* Monitored data supplied by South East Institute of Public Health

TABLE 5.9 SUMMARY MEASURED AND INDIC AIRVIRO MODELLED NO_2 DATA ($\mu g\ m^{-3}$) DURING THE SUMMER AND WINTER PERIODS AT DIFFERENT SITES.

Site	Percentile	Summer Measured concentration	Modelled concentration	Winter Measured concentration	Modelled concentration
Bloomsbury	mean	65	91	70	106
	98th	147	400	124	464
Westminister	mean	82	74	69	82
	98th	207	118	374	304
Bridge Place	mean	64	75	65	80
	98th	195	132	120	337
City of London	mean	74	84	123	87
	98th	203	356	232	301
Bexley*	mean	36	41	43	45
	98th	83	115	83	89
Greenwich*	mean	42	45	43	54
	98th	126	76	93	86

* East Thames Corridor monitoring stations

TABLE 5.10 SUMMARY MEASURED AND INDIC AIRVIRO MODELLED SO_2 DATA ($\mu g\ m^{-3}$) DURING THE SUMMER AND WINTER PERIODS AT DIFFERENT SITES.

Site	Percentile	Summer Measured concentration	Modelled concentration	Winter Measured concentration	Modelled concentration
Bloomsbury	mean	22	66	26	86
	99th	132	221	122	262
Bridge Place	mean	58	29	40	34
	99th	144	163	72	149
City of London	mean	22	56	25	60
	99th	137	274	109	224
Bexley*	mean	28	23	19	18
	99th	307	236	127	167
Greenwich*	mean	17	16	18	21
	99th	165	166	104	328

* East Thames Corridor monitoring stations

under-estimate during the winter (Table 5.8). This could be because the NO_2 component of total NOx emissions which was assumed to be 5% for all sources in the modelling was under-estimated when the percentage NOx contribution of non-road sources is likely to be higher. The modelled maximum concentrations are generally over-predicted by about a factor of 2.

5.6.3 Predicted results from Indic Airviro

Indic Airviro was used to model NO_2 and SO_2 over the same three month periods (May - July and October - December 1995). Comparisons between modelled and monitored data were then made. For NO_2 the results showed that for the Central London monitoring stations, the model predictions were up to 34% of monitored concentrations, except at Westminster in summer and City of London in winter where the calculated seasonal mean is less than the measured value (Table 5.9). For the East Thames corridor stations, the model predictions of seasonal means agree very well with the monitoring data. For the Central London stations, the model generally over-predicted the 98th percentile, by factors of 2 - 4. For the East Thames corridor stations, the model is accurate to within 40% for the 98th percentile.

Comparisons between modelled and measured data for SO_2 are shown in Table 5.10 which shows good agreement between the modelled and measured seasonal means for the East Thames corridor stations. It was thought that this may be a result of the SO_2 emissions data for this region being more accurate than for Central London. At Bloomsbury and the City of London sites, the model over-predicted the seasonal means (by up to a factor of 3) whereas at Bridge Place, the model under-predicted (within a factor of 2). During the winter months, the model over-predicted the 99th percentile concentration at all sites, by factors ranging from 1.3 to 3.2. During the summer months, the model over-predicted the 99th percentile at the Central London stations (factors of 1.1 to 2), under-predicted by 23% at Bexley, but gave good agreement at Greenwich.

5.7 DISPERSION MODELLING IN BELFAST

Belfast City Council were asked to predict concentrations of sulphur dioxide and PM_{10} in 2005 under a variety of scenarios and determine if it is likely that the National Air Quality Strategy objectives for these pollutants would be achieved or not. Belfast is unlike many of other cities in the UK in that it experiences high ambient concentrations of SO_2 and PM_{10}. This is principally due to high use of coal, solid fuels and oil within domestic properties. The scenarios modelled include:

A. *High and low uptake of natural gas upon its introduction to Belfast;*
B. *A 15% improvement in the efficiency of Belfast's buildings;*
C. *Zero coal consumption;*
D. *Reduced sulphur emissions, due to a ban on the sale of high-sulphur petroleum cokes and legislation on the sulphur content of oil and diesel;*
E. *The closure of Belfast West power station.*

These scenarios were run for a base period which was winter 1995/96.

An emissions database was compiled by CERC who also undertook the dispersion modelling. Focus was given to domestic emissions but point sources and transport were also included. The information gained during a market survey on the use of solid fuel in Belfast (see Section 4.8) proved useful in determining emissions. Total emissions estimated are shown in Table 5.11 where the majority of the SO_2 and PM_{10} emissions are emitted from the two power stations NIE West and Kilroot.

The dispersion model ADMS-Urban was used in this study together with meteorological data from Belfast International Airport. The prevailing wind direction is generally south to south westerly but the dominant wind direction during this study period was found to be easterly and therefore may not be representative of typical winter conditions.

TABLE 5.11 TOTAL EMISSIONS FROM DIFFERENT SOURCES TYPES ($g\ s^{-1}$) IN BELFAST ESTIMATED FOR WINTER 1995/96

Source	SO_2	PM_{10}
Road Network	3.63	4.84
Stacks < 30 m high	59.3	3.56
Stacks > 30 m high	55.1	3.31
NIE West and Kilroot	927	95
All Point Sources	1040	102
Oil Burning	46.7	3.4
Solid Fuel	94.6	10.2
All Household Fuel Use	141.3	13.5

Belfast is located in between the Antrim hills to the west and the coast to the east. ADMS-Urban can take such complex terrain into account during dispersion calculations using the complex flow model FLOWSTAR. However, this was not used in this study as the run times would have been significantly increased. Alternatively the model was run with a terrain file using a 64 x 64 grid, covering a 39 km x 35 km area, to take into account as much of the surrounding hilly terrain as possible. Model outputs were validated with the monitoring data from the two national monitoring stations, Belfast Centre and Belfast East. For SO_2 the mean modelled concentration at Belfast Centre was within 2 ppb of that measured while the 99.9th percentile of 15 minute means was over-predicted by the model by over 100 ppb, or 42%. Conversely, at Belfast East monitoring site the predicted mean concentration was around 50% of the measurements, while the 99.9th percentile of 15 minute means was under-predicted by almost 80 ppb, or 20%.

Generally, it was found that domestic emissions of SO_2 were by far the greatest contributor to both mean and 99.9th percentile concentrations during the winter study period. Point sources accounted for less than 16% of the mean concentrations while road emissions contributed to about 20%. The power stations, despite having high emissions, did not contribute greatly to the predicted concentrations during the winter as highest concentrations resulting from such large point sources tend to occur in summer when convective atmospheric conditions bring the plume to ground close to source. During the typical stable atmospheric winter conditions such plumes tend to

travel kilometres and significantly disperse before reaching ground level.
Concentrations of PM_{10} were consistently under-predicted in the model output when compared to measured data. However, the model only predicted primary particles and the addition of secondary and coarse particles was not made before comparison of the predictions and measurements were made.

Various scenarios were modelled during this study one of which was the increased use of natural gas (Scenario A). It was thought that the vast majority of conversions to natural gas for domestic heating purposes will be from solid fuel users, especially in the public sector. For commerce, it was expected that there will be 20% conversion from oil to gas amongst the smaller users (less than 75,000 therms per year) and 50% for larger users. This uptake of gas was expected to deliver a 15% reduction in the 99.9th percentile of 15 minute SO_2 concentrations at Belfast Centre. A 30% reduction in energy use in the Belfast housing stock within 10 years, of which 15% will come from reduced fuel use (Scenario B), was predicted to reduce the 99.9th percentile of 15 minute means by 13%. Scenario C was based on zero coal consumption where it was assumed that all domestic coal users would have switched to a non-polluting form of heating, such as gas. Only emissions from oil burning were modelled which resulted in a reduction of the 99.9th percentile of 15 minute averages of 59%. Scenario D was based on reduced sulphur emissions where domestic emissions were recalculated on the basis that no petroleum coke was burnt and that the limit sulphur content in diesel reduces from 0.2% to 0.05% and that the maximum sulphur content in gas oil decreases, also to 0.05%. This resulted in a reduction in the 99.9th percentile of 15 minute averages of 40%. The closure of Belfast West power station (Scenario E) was predicted have no effect on the 99.9th percentile of 15 minute means. Under typical stable winter atmospheric conditions the plume will not impinge on the city.

The assumptions in the scenarios outlined above were combined into a scenario which, it is intended, will be representative of Belfast by 2005, although for domestic emissions it was assumed that there would be a % uptake of natural gas rather than zero coal consumption. It was predicted that the 99.9th percentile of 15 minute averages would reduce by between 49 and 68% depending on the level of uptake of natural gas. Under this basis the National Air Quality Strategy objective is unlikely to be met at either Belfast Centre (111-116 ppb) or Belfast East (190-215 ppb) national monitoring stations.

The predicted concentration of PM_{10} provided similar trends in reductions as seen in the SO_2 predictions, except that the reductions in percentile statistics are generally lower. It was predicted that the National Air Quality Strategy objective for PM_{10} would not be met in 2005. Predictions were 102-109 $\mu g\ m^{-3}$ at Belfast Centre and 66-69 $\mu g\ m^{-3}$ at Belfast East depending on the uptake of natural gas.

The influence of point sources on pollutant concentrations in Belfast is thought to be small compared to the influence from domestic and vehicular emissions. For SO_2, domestic emissions are the dominant contributor.