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MUPPETS: A COMPUTER TOOL FOR MODELLING AND MAPPING EMISSIONS FROM URBAN TRANSPORT AND STATIONARY SOURCES

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Muppets: A Computer Tool For Modelling And Mapping Emissions From Urban Transport And Stationary Sources

Dorota Kupiszewska

This report is the last one in the series of four reports prepared by the author within the Sustainable/Quantifiable City project conducted in 1994-1996 at the Environment Centre. The author wishes to thank the grantholders: Prof. David Kay (Environment Centre), Prof. Tony May (Institute for Transport Studies) and Prof. Mike Pilling (School of Chemistry), as well as Dr Gordon Mitchell (co-researcher, Environment Centre) and Prof. Adrian McDonald (School of Geography) for their support.

A colour version of this report is available on request from the publications secretary at the Institute for Transport Studies, Leeds University.

Other reports in the series are:

Working Paper 519
"Computer implementation of the Quantifiable City Decision Support System (QCDSS)".
A colour version of this report is also available on request from the publications secretary at the Institute for Transport Studies, Leeds University.

Working Paper 520
"Modelling for sustainable cities: Conceptual approach and an audit of existing sectoral models for transport, air pollution, land use, and population modelling", and

Working Paper 521
"Modelling for sustainable cities: the transportation sector".

Contents

A. Introduction to MUPPETS.

MUPPETS is a computer modelling tool for modelling and mapping emissions of pollutants from urban sources. It is composed of two sub-models (Figure 1): MUPPET, which deals with emissions from transport, and MESS, which deals with emissions from stationary sources (anthropogenic and natural). Both models aim to estimate spatial variations in emissions per unit area with a 1 km^2 resolution. They can model a range of pollutants, subject to availability of data on emission rates from various processes. Currently, MESS contains data necessary for modelling emissions of nitrogen oxides (NOx) and volatile organic compounds (VOC). MUPPET uses the SATURN transport model, which has built in formula to calculate emissions of carbon monoxide (CO), nitrogen oxides (NO_x), hydrocarbons (HC) and lead (Pb).

MUPPETS may be used as a support tool for air pollution management: for evaluating the current situation, or for examining impacts of future policies and scenarios. It may be used as part of larger studies, for example for preparing input data for pollution dispersion models.

MUPPETS has been developed as an exemplar model of the Quantifiable City model. As such, it follows the rules defined in the specification of the computer framework for the Quantifiable City Decision Support System according to which sub-models are linked through the common format Database. MUPPETS demonstrates also how to link modelling with geographic information systems. Following the concept of the QCDSS, MUPPETS can be extended with additional sub-models to address a wider range of issues, e.g. it can be coupled with a strategic transport model and/or a population model, or it can be used in a study evaluating impacts of emissions on health. Such a wider modelling structure has been briefly described in (Kupiszewska 1996a), and is presented in Figure 2. The decision to focus the exemplar model on air pollution issues, and on emissions from transport in particular, was not accidental: Traffic related problems have been identified as an issue of particular concern for cities sustainability (Kupiszewska 1996b).

Figure 1. Structure of the MUPPETS modelling system

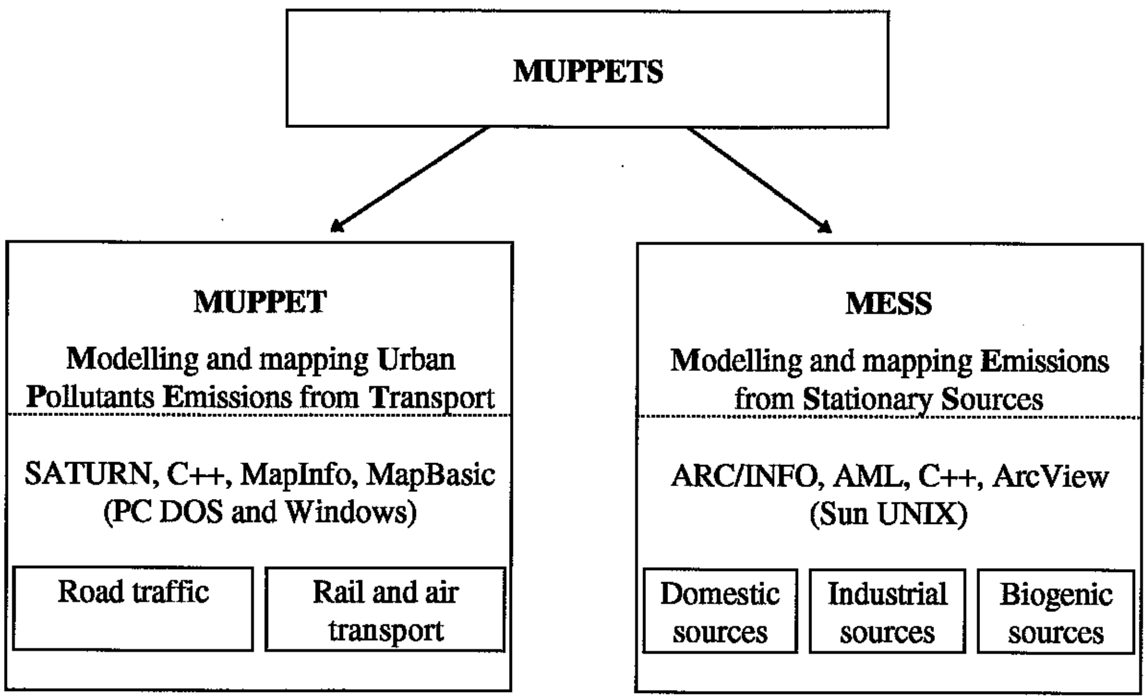
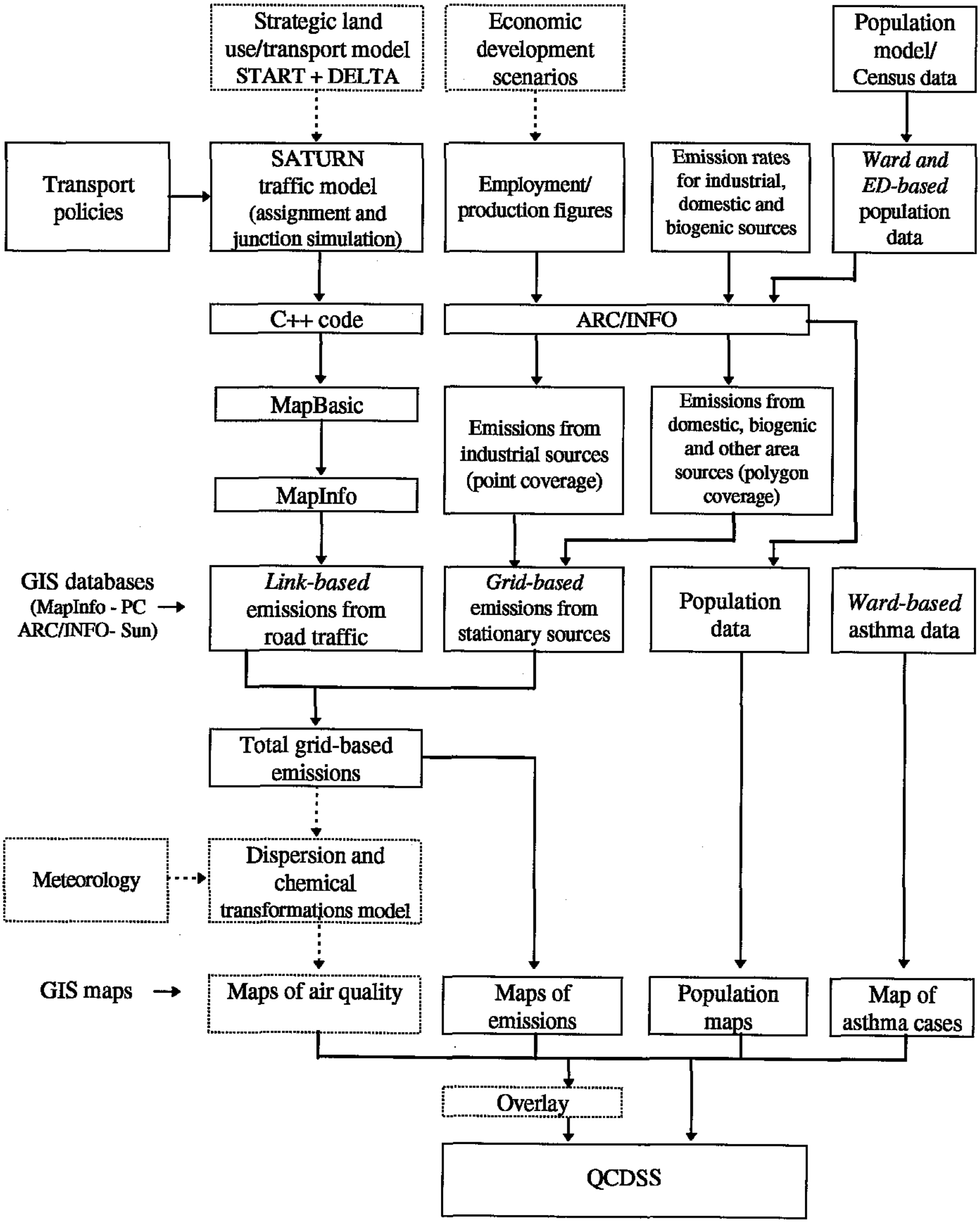


Figure 2. Modelling links between human activities, emissions, air quality, and population exposure to pollutants.



B. MUPPET: Modelling emissions from transport.

MUPPET (Modelling and Mapping Urban Pollutant Emissions from Transport) is, as the name suggests, a tool for modelling emissions from transport. Currently, it covers road traffic, which is the main source of urban pollutants emitted from transport. In future, emissions from rail and air transport might be included, for example using the methodology described by Ko (1995).

MUPPETS has been developed on a PC and tested on data obtained for the morning peak trips in Leeds in 1993. As shown in Figure 1, MUPPETS includes the following sub-modules: the SATURN transport model, C ++ programs, MapBasic programs and the MapInfo GIS. SATURN is used to model traffic flows and to obtain link-based emissions. C++ programs provide the link with the MapInfo and the MapBasic, through the common format Database. Finally, MapBasic and MapInfo are used to calculate emissions from each 1km by 1km grid square, and to produce traffic flow and emission maps. Table 1 lists the main tasks performed within the sub-modules, together with their input and output files for Leeds implementation. Further, all sub-modules will be described in turn, including practical directions for their use, illustrated by examples from the implementation for Leeds.

B.1 Modelling traffic volumes and emissions from traffic using SATURN

B.1.1 Description of the SATURN model

SATURN (Simulation and Assignment of Traffic to Urban Road Networks) is a combined assignment and simulation traffic model developed at the Institute for Transport Studies of the University of Leeds (Van Vliet 1982, Hall *et al.* 1980). It has been used extensively by some 80 UK local authorities, including the Leeds City Council, and in over 30 other countries. As such, it is a convenient transport model to include in a generic modelling structure. SATURN belongs to the category of tactical transport models (Kupiszewska

Table 1. List of programs, and input and output files in the MUPPET model.

Program name	What does program do (main or example tasks)	Input files	Output files
		SATURN	
SATALL	Calculation of traffic flows (all links), fuel use and emissions (simulation links)	lds93am.dat estam10.ufm	lds93am.ufs
SATDB	Manipulation of SATURN results and dumping the output to an ASCII file	lds93am.ufs	lds93am.kp lds93amb.kp
P1X	Analysis of SATURN results using graphical interface	lds93am.ufs	lds93am.xy
MX	Matrix calculations	lds93am.ufs	estam10.kp
		C++ programs	
coord1.cpp	Prepares a file with the co-ordianates of the nodes of all the links	lds93am.xy	nodes.xy zones.xy
class.cpp	Prepares link data (sums traffic and emissions on two-way roads) in the QCDSS Database format.	lds93am.kp lds93amb.kp	data93am.dat node93am.dat data93ab.dat node93ab.dat
map.cpp	Finds co-ordinates of the nodes for the specified links and writes them in the QCDSS Database format.	nodes.xy node93am.dat node93ab.dat	 map93am.dat map93ab.dat
		MapBasic programs	
links.mb	Creates a MapInfo table in British Grid co-ordinate system with line objects representing links, and inputs attribute data into the table	map93am.csv data93am.csv map93amb.csv data93ab.csv	links.tab buflinks.tab
gridlee.mb	Creates a MapInfo table in British Grid co-ordinates with square objects (1km x 1km) covering the requested area.		grid.tab
gridem.mb	Calculates emissions by grid square and creates a table with square object and data on them	links.tab grid.tab	gridem.tab
		MapInfo	
	Data analysis and mapping; Selection and mapping of records fulfilling specified criteria; display of multiple layers of data	buflinks.tab links.tab gridem.tab	bufflows.wor flows.wor flowsbig.tab flowsall.wor emis.wor gridemis.wor

1996c), which means that it aims to estimate traffic volume on each link of the road network assuming a fixed trip matrix. What differs this type of models from assignment models used in strategic transport models is a very detailed representation of the road network and modelling of turning movements at junctions, which results in a detailed modelling of spatial patterns of traffic, a feature important for modelling spatial variations in air quality.

SATURN requires two basic types of input data: (i) a trip matrix, and (ii) road network data. A trip matrix (Table 2), also called an O-D (origin-destination) matrix, expresses the demand for travel and gives the number of trips between pairs of zones, i.e. between trip origins and destinations. Trips are usually expressed in passenger car units (PCU). PCU is defined as equal one for cars and light duty vehicles, 0.5 for motorcycles, and 2 for buses and heavy duty vehicles. Bus trips by public transport are not included in the trip matrix, but in the network data, because they follow fixed routes and cannot be subject to the assignment procedure.

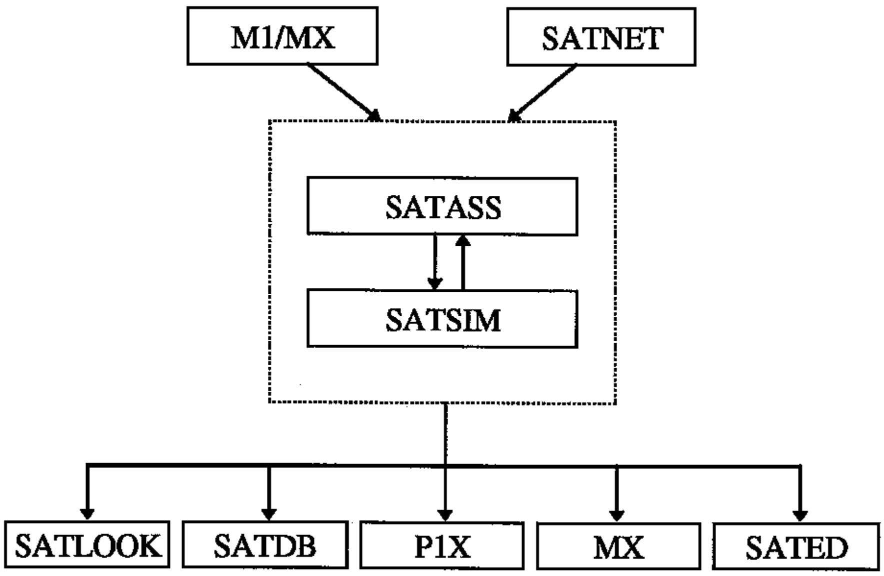
Table 2. The origin-destination matrix.

Zones	1	...	j	...	n	Trip productions $O_i = \Sigma_j T_{ij}$
1	T_{11}	...	T_{1j}	...	T_{1n}	O_1
i	T_{i1}	...	T_{ij}	...	T_{in}	O_i
n	T_{n1}	...	T_{nj}	...	T_{nn}	O_n
Trip attractions $D_j = \Sigma_i T_{ij}$	D_1		D_j		D_n	Total trips $T=\Sigma_{ij}T_{ij}$

In SATURN, a road network may be represented at two levels: as a simulation network, with a full set of detailed data about road links and junctions, and/or as a buffer network (often surrounding the simulation network), with data on roads only. The description of a simulation network includes classification of road intersections into roundabouts, priority and signaled junctions. A number of parameters are required for nodes (junctions), links and turns, e.g. number of links at the node, number of entry lanes for each link, traffic signals data (number of stages, duration of each stage, turning movements allowed at each stage), minimum gap for give-way turns at priority junctions and roundabouts, free-flow speed on the link, link length, saturation flow for each turn. A detailed specification of input data requirements is given in the SATURN manual (Van Vliet and Hall 1995).

The SATURN model is composed of several modules, presented in Figure 3. M1 and SATNET are used to transform input data into binary form. M1 processes the trip matrix, SATNET processes the network data. SATASS and SATSIM, joined into SATALL in SATURN Version 9, are the core of the model, where all calculations are performed.

Figure 3. The structure of the SATURN model.



SATASS and SATSIM are run iteratively. Demand flows generated in the assignment stage (SATASS) are fed into SATSIM, where detailed modelling of the passage of traffic through the network is performed and the delays are calculated. The estimated delays are fed back into SATASS. In SATASS, trips between two zones are assigned to several possible routes in such a way, that the resulting travel costs on each used route are the same and minimum, while all other routes have greater or equal costs. The above rule is known as Wardrop's equilibrium principle and is used in the default assignment option, different assignment are also available to the user. Travel costs are calculated as generalised costs defined by the formula:

$$c = c_1 t + c_2 d,$$

where t is travel time in minutes, d is travel distance in kilometers, c_1 is a user defined cost in pence per minute, and c_2 is user defined cost in pence per kilometre.

The results of modelling include traffic flows on all the links and various measures of congestion and delays. From the point of view of the MUPPET, it is important that values of emissions are also calculated (although for the simulation links only). The emission of pollutant *i* from a link is expressed by the equation:

$$E_i = (a_{i1}\, d + a_{i2}\, t_c + a_{i3}\, t_q + a_{i4}\, s_1 + a_{i5}\, s_2)\, V$$

where:

V is the vehicle flow,

d is the distance traveled on the link,

t_c is the average cruise travel time on the link,

t_q is the time spent in queues at junctions,

s_1 is the number of primary stops per vehicle,

s_2 is the number of secondary stops per vehicle,

and a_{i1}, a_{i2}, a_{i3}, a_{i4}, a_{i5} are the parameters, that can be modified by a user.

Pollutants currently included are : carbon monoxide, nitrogen oxides, hydrocarbons and lead. The default values of parameters are based on (Matzoros and Van Vliet 1992) and are given in the SATURN User's Manual.

The outputs from SATURN may be investigated and processed further using the modules SATLOOK, SATDB, P1X, MX, SATED. For providing data for the other modules of the MUPPET, SATDB and P1X proved particularly useful. SATDB is the data base analysis program and in the MUPPET it is used to prepare data on vehicle flows, fuel use and pollutant emissions and to dump them to ASCII files. P1X is a program for a graphical display of network data, but in the MUPPETS it is used to save nodes and centroids (zone centres) co-ordinates into ASCII files. MX is a matrix manipulation program and it has been used to calculate the total number of trips originating and ending in each zone (the file estam10.kp in Table 1).

B.1.2 Implementation of SATURN for Leeds

Data on the road network and trip matrices in Leeds in 1993 has been obtained from the Leeds City Council. It includes the following files :

Network files	Trip matrices	Description
lds93am.dat	estam10.ufm	Data for the morning peak
lds93ip.dat	estip8.ufm	Data for the interpeak period
lds93pm.dat	estpm10.ufm	Data for the afternoon peak

In addition, data has been obtained for trip matrices forecasted for years 2005, 2015 and 2029, as well as for the road networks planned for these years, which gives the opportunity to test implications of forecasted changes in demand and impacts of new transport plans.

The Leeds SATURN network (Figure 4) is very big (a special version of SATURN code is required to run it) and contains: 1314 intersections, including 327 priority junctions, 17 roundabouts, 133 traffic signals and 534 buffer nodes; 8107 assignment links, including 2143 simulation links and 843 buffer links; and 166 bus routes (with fixed flows). The trip matrix (a.m. peak, 1993) contains altogether 80349 trips between 370 zones.

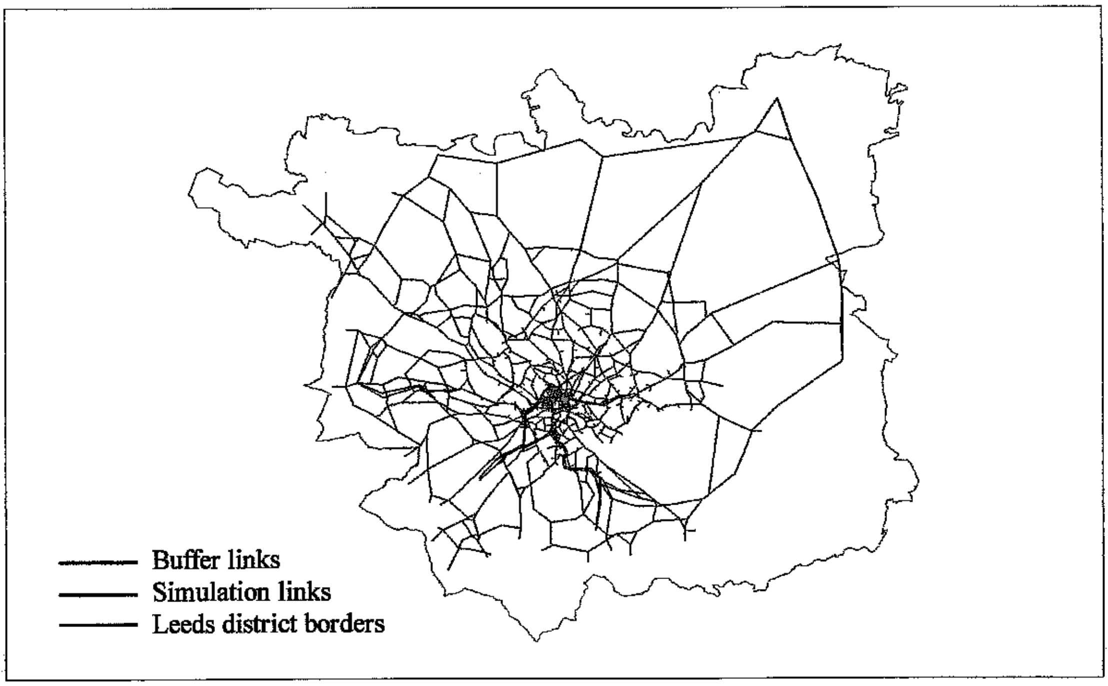


Figure 4. The Leeds SATURN road network

B.1.3 Running the SATURN model

The current PC version of SATURN runs under DOS. The programs have been compiled using Salford FTN77 and require the DBOS memory extender (supplied together with the model). A Windows version of SATURN is under development.

Running the SATURN model involves the following steps (illustrated with data for the morning peak in Leeds, in 1993):

- Run the M1 program with the name of a trip matrix ASCII file as a parameter:

  M1 estam10.dat

  This command results in the transformation of the matrix from the ASCII format into the binary format. The file estam10.ufm is created.
- Run the SATNET program with the name of the network ASCII file as a parameter:

  SATNET lds93am.dat

  As a result, the network data are transformed into the binary format, and the file lds93am.ufs is created.
- Run the SATALL program with the names of a network and matrix files as parameters:

  SATALL lds93am estam10

  This command causes the assignment and simulation loops to be run iteratively. The results are written into the file lds93am.ufs.

B.1.4 Using SATDB to get traffic volumes and emission data

In order to output the results obtained from the SATURN model into an ASCII file, the SATDB menu-driven program must be used. Table 3 shows the SATDB Master Menu. The navigation through the SATDB menus is not very intuitive, so below we have described all the steps needed to get the estimations of traffic flows (for the simulation and buffer links) and emissions of pollutants (available for the simulation links only). The *arial italic* font denotes user inputs, arial condensed font denotes SATDB menus and options.

- From the SATDB Master Menu select Option *2* (Enter the link selection procedure)
- From Link Selection Options select Option *6* (Based on link type)

Table 3. A dump of the screen showing the SATDB Master Menu.

SATDB MASTER MENU:

0 - TERMINATE
1 - FILES MENU
2 - ENTER THE LINK SELECTION PROCEDURE
3 - CANCEL THE CURRENT LINK SELECTION (I.E., INCLUDE ALL LINKS)
4 - READ LINK BASED DATA FROM THE UF FILE(S)
5 - READ NODE BASED DATA FROM THE UF FILE(S)
6 - MISCELLANEOUS DATA INPUT
7 - ASSIGNMENT/TREE-BUILDING OPTIONS
8 - CREATE NEW DATA COLUMNS FROM EXISTING COLUMNS
9 - EXTERNAL DIRECT INPUT AND/OR EDITING
10 - STATISTICAL ANALYSES
11 - REMOVE ONE (OR ALL) DATA COLUMNS

12 - PRINT THE FULL DATA BASE ON THE LINE PRINTER FILE
13 - DUMP THE FULL DATA BASE TO AN ASCII FILE
14 - BASIC HOUSEKEEPING OF THE DATA BASE HEADER RECORDS
15 - DISPLAY/EDIT THE DATA BASE ON SCREEN
16 - CREATE A NEW SATURN UF FILE

17 - SATURN GENERAL PARAMETERS MENU

?

Table 4. A dump of the SATDB screen displaying the selected variables.

SIMULATION/BUFFER			ARRAY/CHANNEL				
ANODE	BNODE	CNODE	A-FLOWS	FUEL CON	CO EMISS	NOX EMIS	HC EMISS
			4513/1	1503/1	1703/1	1723/1	1743/1
5319	598		1542.69	75.59	3.01	1.01	0.00
3065	1000		207.90	4.81	0.61	0.09	0.00
1413	1000		293.94	7.80	0.71	0.16	0.00
1000	1001		501.83	19.65	2.79	0.24	0.00
3047	1002		2690.74	41.44	2.33	0.78	0.00
1412	1002		1197.00	46.93	6.27	0.64	0.00
1001	1002		112.56	2.52	0.34	0.04	0.00
1409	1003		656.37	49.52	6.79	0.53	0.00
1003	1004		39.63	0.12	0.01	0.00	0.00
1002	1005		1287.29	51.27	6.62	0.93	0.01
1005	1006		276.59	8.06	1.08	0.14	0.00
1003	1006		558.96	9.45	1.28	0.25	0.00
1005	1007		974.43	43.78	6.21	0.53	0.00
3048	1008		1059.50	3.49	0.27	0.09	0.00
3049	1009		460.85	2.48	0.20	0.07	0.00
1024	1010		1348.04	4.72	0.23	0.08	0.00
1020	1010		1270.90	8.90	0.54	0.18	0.00
1027	1011		1560.02	16.93	1.32	0.44	0.00
1010	1012		2618.89	19.25	1.12	0.38	0.00
3046	1013		1560.28	51.21	6.42	1.03	0.01

KEYSTROKE PAUSE - RESPONSES ALLOWED: U D HOME END H / Q N Select Order Edit *

- Type *-1* to include simulation links only, or - to include buffer links only
- Type *0* (No more changes) and again *0* (No more tests Option) to come back to the Master Menu
- From the SATDB Master Menu select Option *4* (Read link based data from the UF file(s))
- Select Option *1* (Print all relevant DA codes) to see the list of the codes of variables that can be output. Scroll pressing *Enter*
- For each required variable type the code number followed by *Enter Enter*. The codes relevant to MUPPET are:

  4513 - Actual flows in pcus/h,

  1703 - CO emissions,

  1723 - NOx emissions,

  1733 - Pb emissions,

  1743 - HC emissions.

  All emissions are given in kilograms per link. Other useful variables are: *4503* - Demand flow in pcus/h; and *1503* - Fuel consumption in liters per link. Variable 1713 gives CO_2 emissions in kilograms per link, but we do not recommend to use it (in the current version of SATURN one liter of consumed fuel is assumed to result in one kilogram of CO_2).
- Press *Enter* to come back to the Master Menu
- From the SATDB Master Menu select Option *15* to display the values of the selected variables on the screen. Option *14* might be used first to display only some of the selected variables.
- By default, variables are displayed with two decimal figures and if a value is lower than 0.005, which is often the case for hydrocarbons, it will be displayed as 0.00 (see the last column in Table 4 on the previous page). Use Option *8* (Create new data columns from existing columns) to scale it. For example, if you want to scale values in Column 5 by thousand, do the following:
    - Set Parameter 7 (the column number) to *5*
    - Type *1* (Fortran-style Statement Option)
    - Input the equation: *x5*1000*
- From the SATDB Master Menu select Option *13* (Dump the full data base to an ASCII file) to create a file with selected variables. You will be prompted for the output file name (by

default it has the extension .kp) and the required output format. The output file will contain the following data for each link: A-node (the upstream end of the link), B-node (the downstream end of the link), and the values of the selected variables. Table 5 shows an extract from the file lds93am.kp, that contains data on the simulation links. Note the difference between the values in the last column of Table 5 and Table 4. Data for the buffer links have been saved into the file lds93amb.kp.

Table 5. The extract of the lds93am.kp file (the whole file contains 2143 lines), containing data for the simulation links. Columns contain values of the following variables: A-node, B-node, actual flows (pcus/h), fuel consumption (litres/link), CO emissions (kg/link), NOx (kg/link), HC (g/link).

5319	598	1542.69	75.59	3.01	1.01	3.56
3065	1000	207.90	4.81	0.61	0.09	0.52
1413	1000	293.94	7.80	0.71	0.16	0.76
1000	1001	501.83	19.65	2.79	0.24	2.07
3047	1002	2690.74	41.44	2.33	0.78	2.75
1412	1002	1197.00	46.93	6.27	0.64	4.90
1001	1002	112.56	2.52	0.34	0.04	0.29
1409	1003	656.37	49.52	6.79	0.53	4.65
1003	1004	39.63	0.12	0.01	0.00	0.01
1002	1005	1287.29	51.27	6.62	0.93	5.70
2313	5346	165.45	0.29	0.18	0.06	0.22
2314	5347	401.07	1.68	0.20	0.07	0.24
2315	5348	298.58	2.09	0.25	0.09	0.30
2316	5349	125.65	0.18	0.06	0.02	0.08
2316	5350	5.33	0.01	0.00	0.00	0.00

The sequence of strokes (user inputs) used when running SATDB is automatically written to the SATDB.log file. In order to repeat the same sequence of operations for a new data file (e.g. for the afternoon peak trips, or for a different year) copy the log file to another file (e.g. my_key.key) and use it by typing:

SATDB new_file KEY my_key

Table 6 shows the contents of the log file data.key that could be used to extract data on actual flows, fuel consumption, and emissions of CO, NOx and hydrocarbons.

Table 6. The explanation of the contents of the data.key log file.

	Comments
2	Enter link selection procedure
6	Based on link types
-1	Include simulation links only
0	
0	
4	Read link based data from th UF file
1	See the list of codes
4513	Actual flows
1503	Fuel consumption
1703	CO
1723	NO_x
1743	HC
0	
15	Display data on the screen
13(Ascii key Enter)	
14	Select variables to display
0	
8	Create new data columns
7	Select a column where data will be placed
5	Column number 5
1	Enter the Fortan Statement option
x5*1000	Multiply Column 5 (HC) by thousand (HC in grams instead of kilograms)
0	
15	Display data on the screen
13(Ascii key Enter)	
13	Dump data to an ASCII files
y	
0	two decimal places
1	
0	exit from SATDB
y	

B.1.5 Getting link co-ordinates from SATURN

In order to produce maps of emissions from road traffic, one needs information on the geographical location of all the links. This information can be extracted from the network data file using the P1X program. From the main P1X menu select Option *2* (files), then *11* (Option Dump the co-ordinates to a .xy file). Table 7 shows an extract from the file lds93am.xy containing data on the x and y co-ordianates of nodes and zone centroids for the Leeds network.

Table 7. An extract from the file lds93am.xy, that contains the co-ordinates of nodes and zones of the Leeds network

```
55555
C    14300543344
C    24301243344
C    34297843352
C    44297143352
C    54296043352

C 3684295843323
C 3694300943321
C 3704291543452
  5244354843972
  5264355643826
  5284362143684
  5294370643754
  5304370043558


 53484295343464
 53494301043326
 53504300743321
99999
```

Data are dumped into a .xy file in the same format as they apper in the network input file. The first line (55555) and the last line (99999) mark the beginning and the end of the node and zone co-ordiante data. A "C" in placed in the first column if the data line refer to a zone. The remaining columns contain the following variables:

Columns 2-5 - the zone or node identification number;

Columns 6-10 - the x co-ordinate;

Columns 11-15 - the y co-cordinate.

In the Leeds network, a coordinate value is given as five digit National Grid reference, specifying the location of a node, or a zone centroid in 10 metres units.

B.2 Interfacing SATURN with MapBasic and MapInfo (C++ programs)

The link between the SATURN model and other sub-modules of the MUPPET is provided by the C++ programs that transform outputs from SATURN into the common format specified in the description of the QCDSS Database. The listings of source codes of the programs are included in the Appendix. The programs have been compiled and run using Borland C++, Version 4.51.

The **class.cpp** program takes the SATURN output with the traffic and emission data (lds93am.kp for the simulation links or lds93amb.kp for the buffer links) as an input. It searches the data file for the records referring to two links of two-way roads, and sums traffic flows and emissions from both links. The obtained values, as well as data for one-way roads are written to a space delimited ASCII file. Each record contains the following data: the link (one-way or two-way road section) identifier (an integer number assigned by the class.cpp program), values of up to five real variables. Table 8 shows an extract from the file data93am.dat, containing data on traffic flows, fuel consumption, and emissions of CO, NOx and hydrocarbons for the simulation links. Analogical data for the buffer links has been written into the data93ab.dat file.

Table 8. An extract from the data93.dat file containing data for the simulation links. Columns contain values of the following variables: link identifier, actual flows, fuel consumption, CO emissions, NOx, HC (units as in Table 5).

1	1542.69	75.59	3.01	1.01	3.56
2	207.90	4.81	0.61	0.09	0.52
3	293.94	7.80	0.71	0.16	0.76
4	501.83	19.65	2.79	0.24	2.07
5	2690.74	41.44	2.33	0.78	2.75
6	3887.74	59.74	6.97	0.87	5.72
7	112.56	2.52	0.34	0.04	0.29
1394	1505.61	20.13	2.53	0.48	2.56
1395	91.50	3.63	0.47	0.07	0.43
1396	1375.42	16.89	2.33	0.43	2.41
1397	53.56	1.71	0.22	0.06	0.24
1398	1865.13	14.65	1.85	0.32	1.86

The class.cpp program creates also a second file that contains numbers of nodes (these are numbers used by SATURN) of all the links written into the first file. Both files have identical first columns, that give link numbers. Table 9 shows an extract of the node93am.dat, containing numbers of nodes of the simulation links. The file node93ab.dat contains numbers of nodes of the buffer links.

Table 9. An extract from the file node93am.dat, containing link identifiers, A-nodes and B-nodes of the simulation links of the Leeds network.

1	5319	598
2	3065	1000
3	1413	1000
4	1000	1001
5	3047	1002
6	1412	1002
7	1001	1002
1396	3114	5343
1397	2301	5343
1398	2501	5344

The **coord1.cpp** program reads a file with five-digit Grid Reference co-ordinates dumped from SATURN (e.g. the file lds93am.xy, listed in Table 7). The co-cordinates are transformed into six-digit numbers giving the location in meters, and written into two space-delimited files, one for zone centroids, and a separate one for node co-ordiantes. Table 10 shows an extract from the file nodes.dat containing the co-ordinates of the nodes of the Leeds network.

Table 10. An extract form the file nodes.dat (node number, x, y).

524	435480	439720
526	435560	438260
528	436210	436840
529	437060	437540
530	437000	435580
531	438360	436310
532	437670	433010
5348	429530	434640
5349	430100	433260
5350	430070	433210

The **map.cpp** program takes as an input files created by the class.cpp program (the file with link nodes) and the coord1.cpp program (the file with node co-ordinates). It produces a space delimited ASCII file containing co-ordinates of the link nodes, in the format specified in the description of the QCDSS, i.e. each line of the file contain the following data: the link identifier (as in the output file from class.cpp, containing traffic and emission data on links), x co-ordinate of the A-node, y co-ordinate of the A-node, x co-ordinate of the B-node, y co-ordinate of the B-node. Table 11 shows an extract from the map93am.dat file, containing the co-ordinates of the nodes of the simulation links. The file map93ab.dat contains the co-ordinates of the nodes of the buffer links.

Table 11. An extract form the map93.dat file. The columns contain link identifiers, x and y co-ordinates of A-nodes, and x and y co-ordiantes of B-nodes.

1	432100	429240	432100	429400
2	428530	432720	428640	432800
3	428640	432590	428640	432800
4	428640	432800	428640	432860
5	428690	433020	428690	432930
6	428690	432760	428690	432930
7	428640	432860	428690	432930
1397	430450	433540	430650	433640
1398	430660	433690	430680	433650
1398	430660	433690	430680	433650

The interfacing programs are general, which means that they can be used to process other input data than the test data used in this report. All the user has to do is to edit the "define" lines of a program, specifying the names of the input and output files (in all programs), the maximum number of links (in class.cpp) or nodes (in map.cpp) in the SATURN outputs, and the number of the data columns (in class.cpp).

B.3 Modelling emissions from traffic by grid square using MapInfo and MapBasic

The SATURN model allow to calculate emission from individual links of the road network. A convenient way to use link-based emissions to calculate emissions by grid square is to use a geographic information system, which is by definition designed to process spatial information. In MUPPET, the MapInfo GIS is used (MapInfo 4.0). MapInfo in itself cannot perform automatically the required number of operations, but it has its own programming language, MapBasic, that would do the task.

MapInfo is a vector-type GIS, with four types of objects: regions (polygons, ellipses and rectangles), line objects (lines, polylines and arcs), point objets, and text objects (labels, titles). Objects representing various themes of a map form various layers of the map, and each layer is kept in a separate MapInfo table. A table can store spatial data on the geographical location of map objects, region boundaries, etc; and attribute data characterising each object. Within a layer, each object has a unique identifier, which allows for linking data stored in various tables. When working with MapInfo, four types of windows can be displayed: Browser windows, displaying attribute data; Map windows displaying maps of geographical objects; Graph windows; and Layout windows, where various windows can be combined together as required for printing.

In order to overlay various maps, their projections must be properly defined. Here, the British National Grid co-ordinate system has been used, where co-ordinates are expressed as six digit integer numbers giving the location with the precision of one meter.

To prepare a map of emissions of pollutants from traffic, two map layers are needed:

(i) A layer containing the links of the road network, represented as line objects. This table will have information about the location of all the links, and data on traffic flows and emissions for each link.

(ii)A layer containing grid squares, represented as rectangle objets. This table will initially have only spatial information about the squares. The model should supply attribute data, specifying emissions from each square.

For mapping purposes, it is also useful to have an additional layer with the district and ward boundaries.

B.3.1 Inputting data into MapInfo using MapBasic

In order to create the required map layers, two programs have been written in MapBasic: links.mb and gridlee.mb. The source codes of both programs are included in the Appendix. The programs can be used to process user-supplied data. In order to do this, the source codes should be edited according to the needs of the user (as described in the comments at the top of each file), recompiled under MapBasic to produce executable .mbx files, and run under MapInfo to produce the required tables.

The important thing is that MapBasic requires comma-delimited input, so files stored in the QCDSS Database format (space delimited) have to be edited before use. A quick way of doing this is to open a file in Excel, and use the Save File As CSV (Comma-delimited) Option.

The **links.mb** program takes as an input a file containing the co-ordinates of the link nodes (as produces by the map.cpp program) and a file with link attribute data (as produced by the program class.cpp). An empty, mapable MapInfo table is initially created, with the British National Grid co-ordinate system, and columns to store the required number of data. Line objects are created for all the links and attributed data are written into the appropriate rows of the table. The links.mb program has been used to produce two MapInfo tables:

(i) links.tab was created for the simulation links, basing on the map93am.csv and data93am.csv files; it contains traffic flows and emission data;

(ii)buflinks.tab was created for the buffer links, basing on the map93amb.csv and data93ab.csv files; it contains traffic flow data.

Figure 5 shows two MapInfo Map windows, displaying maps of the buffer and simulation links, and two Browser windows, displaying the attribute data. Figure 4 shows all the links displayed on one map.

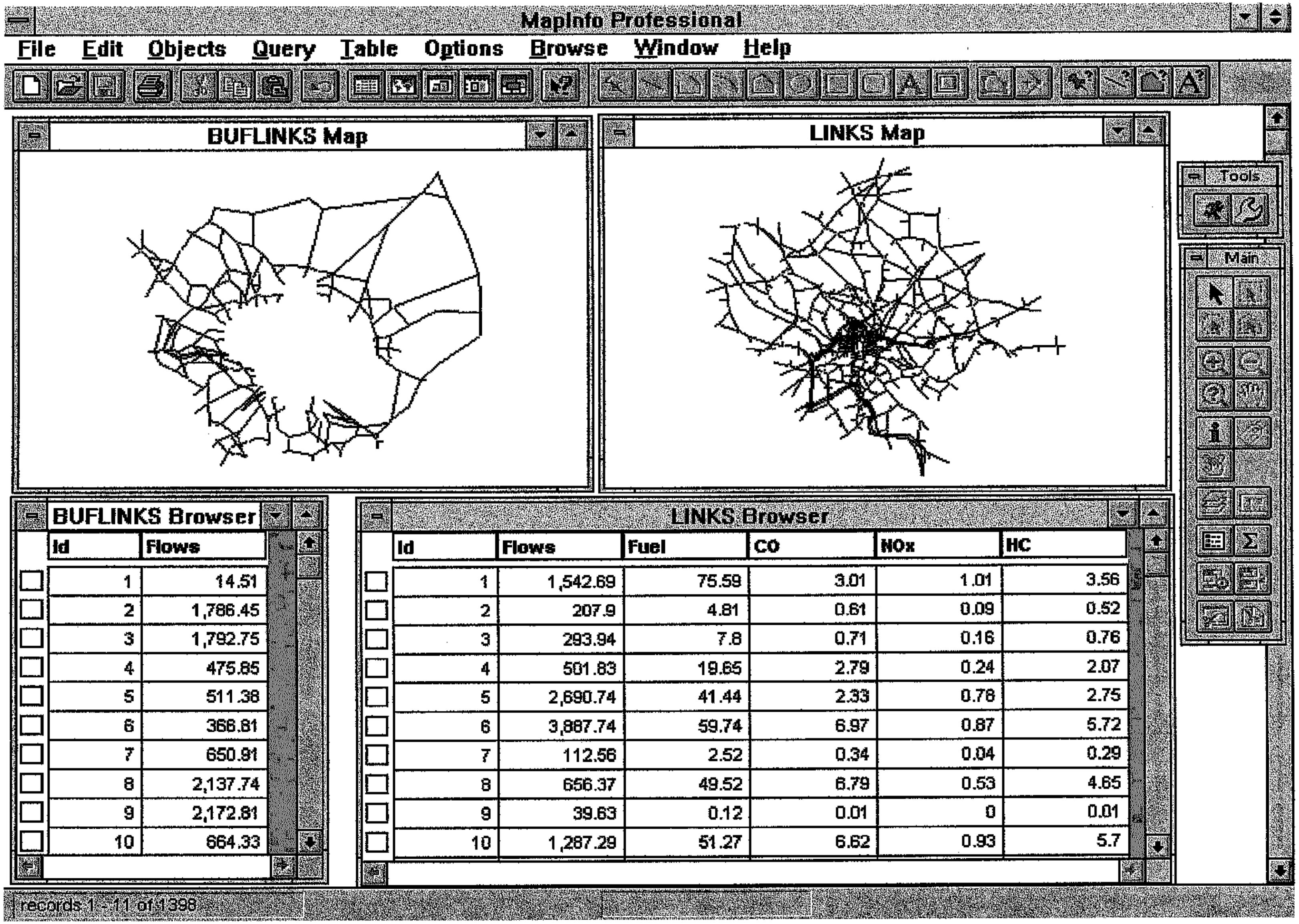


Figure 5. A dump of the screen displaying the MapInfo windows with simulation links and buffer links.

The **gridlee.mb** program creates a MapInfo table containing an array of 1km by 1km squares covering the required area. For Leeds, the table grid.tab has been created covering the following area: The lower left square having the lower left corner at (x1 = 413000, y1 = 422000) and the identifier 4134222; And the upper right square having the lower left corner at (x1 = 446000, y1 = 450000) and the identifier 446450.

Ward and district boundaries have been extracted in the MapInfo Interchange Format (.mif files with graphics and .mid files with textual data) from the Digitised Boundary Data (DBD) for the 1991 Census of Population. They have been downloaded using the UKBORDERS interface from the Edinburgh University Data Library. The 1991 DBD are also available from the Census Dissemination Unit at Manchester Computing Centre.

Figure 6 shows the grid and ward boundaries.

B.3.2 Analysing traffic flows and emissions from links using MapInfo

MapInfo is a convenient tool to analyse data on traffic flows and emissions. Thematic maps can be easily created, where links are displayed in different colours and line styles depending on traffic or emission rates (Figure 7). The Query Menu can be used to select links fulfilling a particular condition, for example links with traffic flow greater than 1000 pcu/h (Figure 8). Various map layers can be displayed on one map, and individual links can be queried by using the Info Tool and clicking on a link in a Map Window (Figure 9). The Layout Window is used to prepare maps for printing (Figure 10). Thematic maps and layouts created during a session can be saved for future reuse in a Workspace file .wor

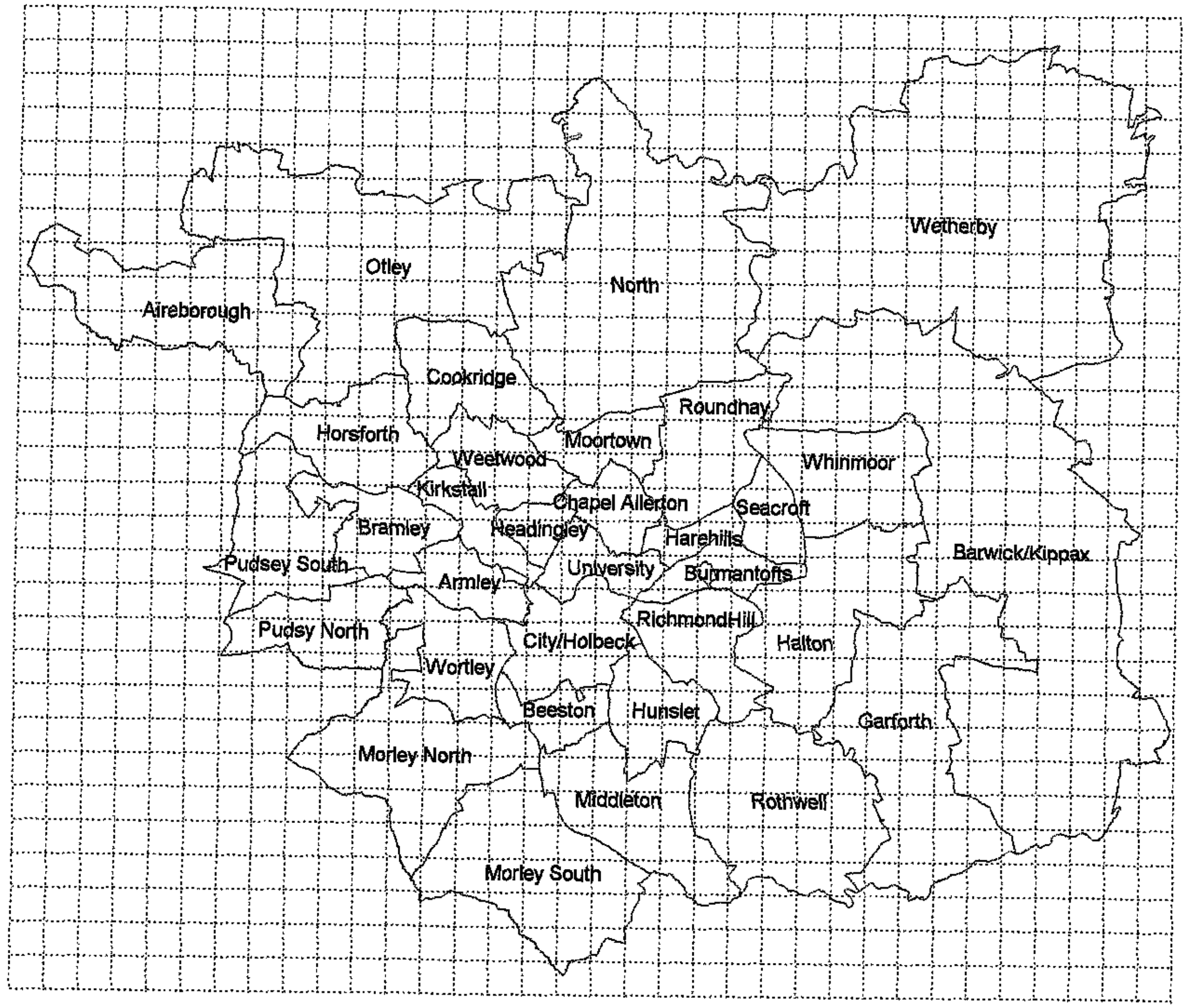
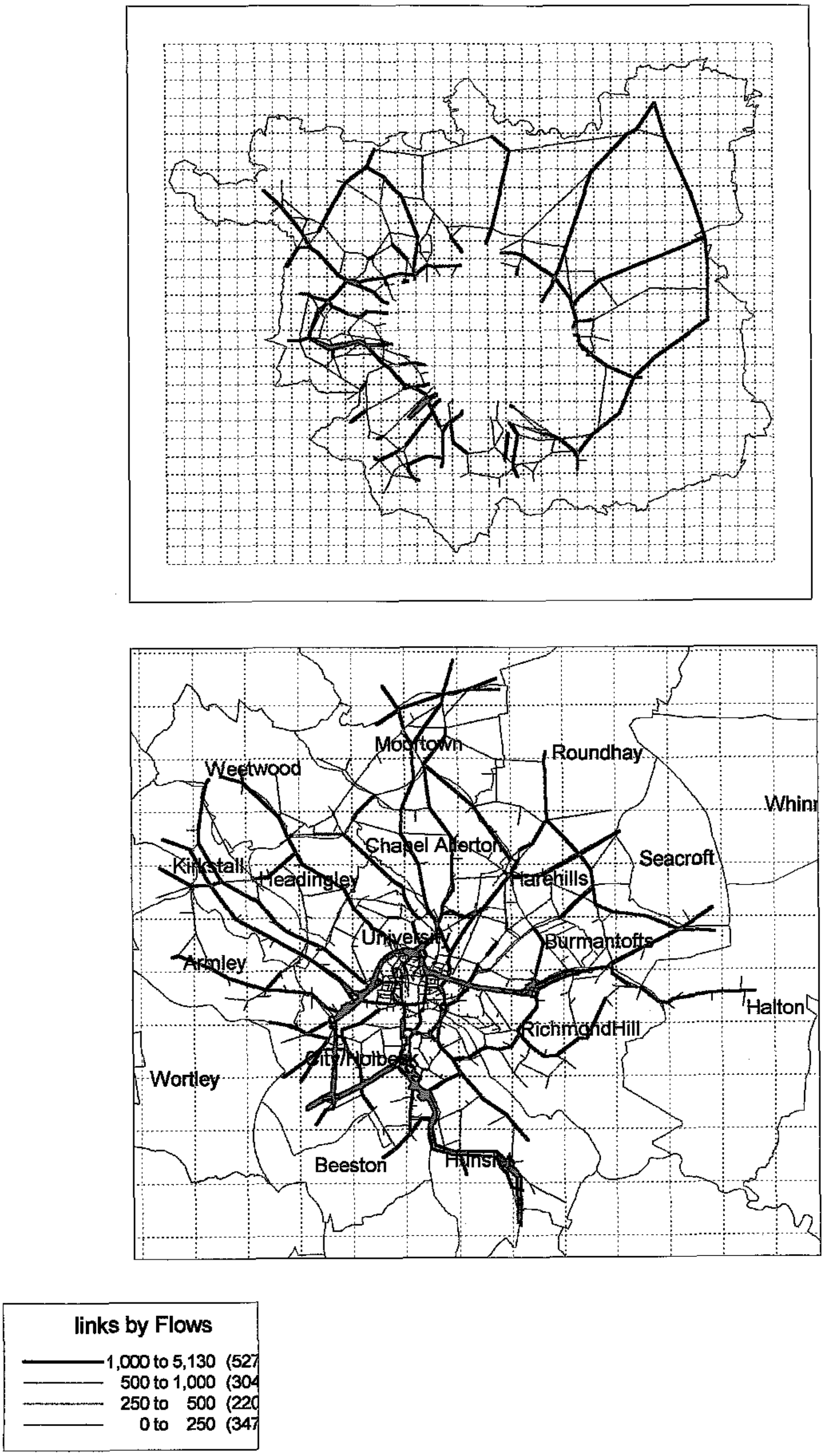


Figure 6. Leeds wards boundaries and the 1km x 1km grid.

Figure 7. Traffic flows on the buffer links and on the simulation links.



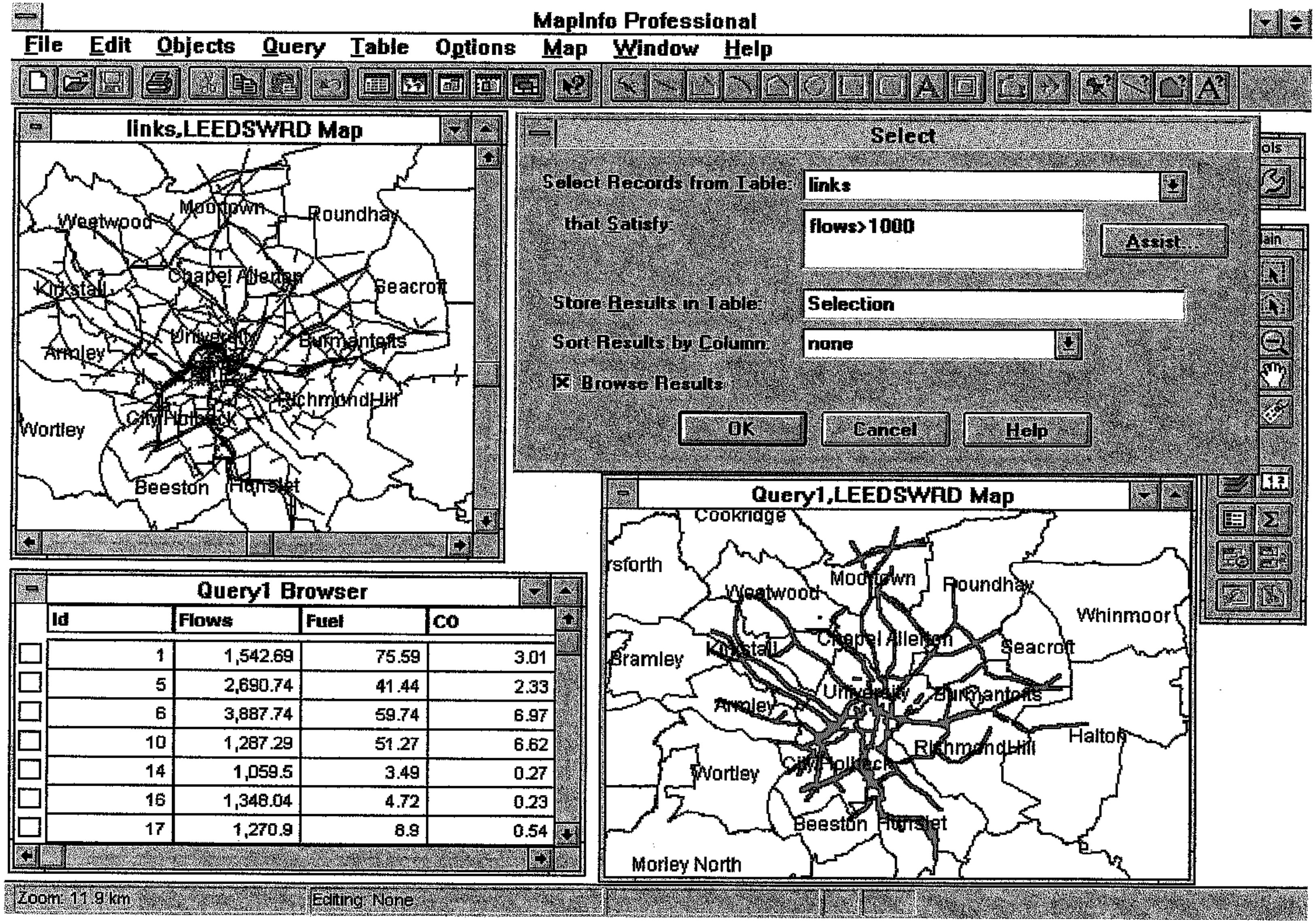


Figure 8. MapInfo: Selecting links with traffic flows exceeding 1000 pcu/h

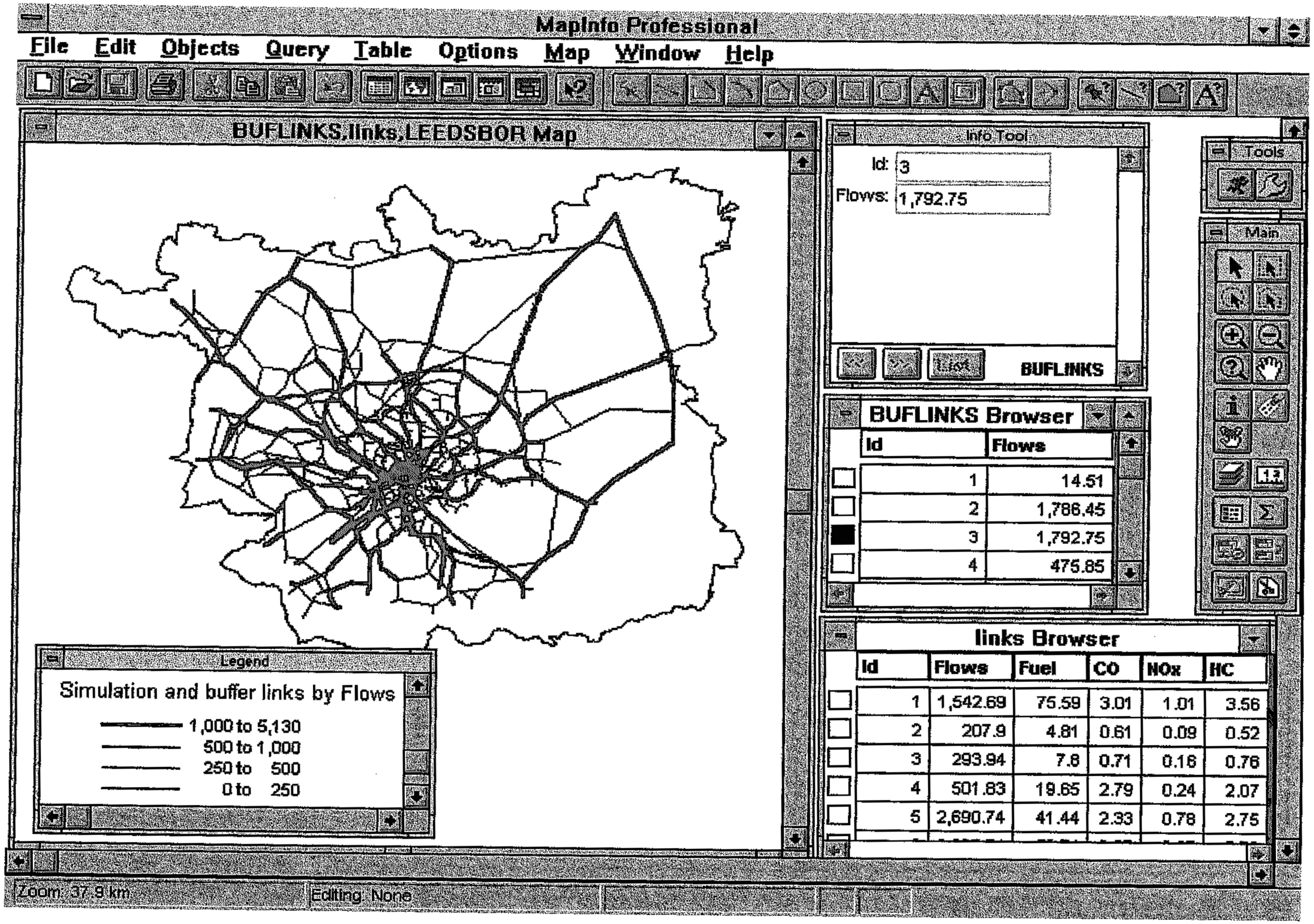


Figure 9. MapInfo: Combining various map layers and using the Info Tool.

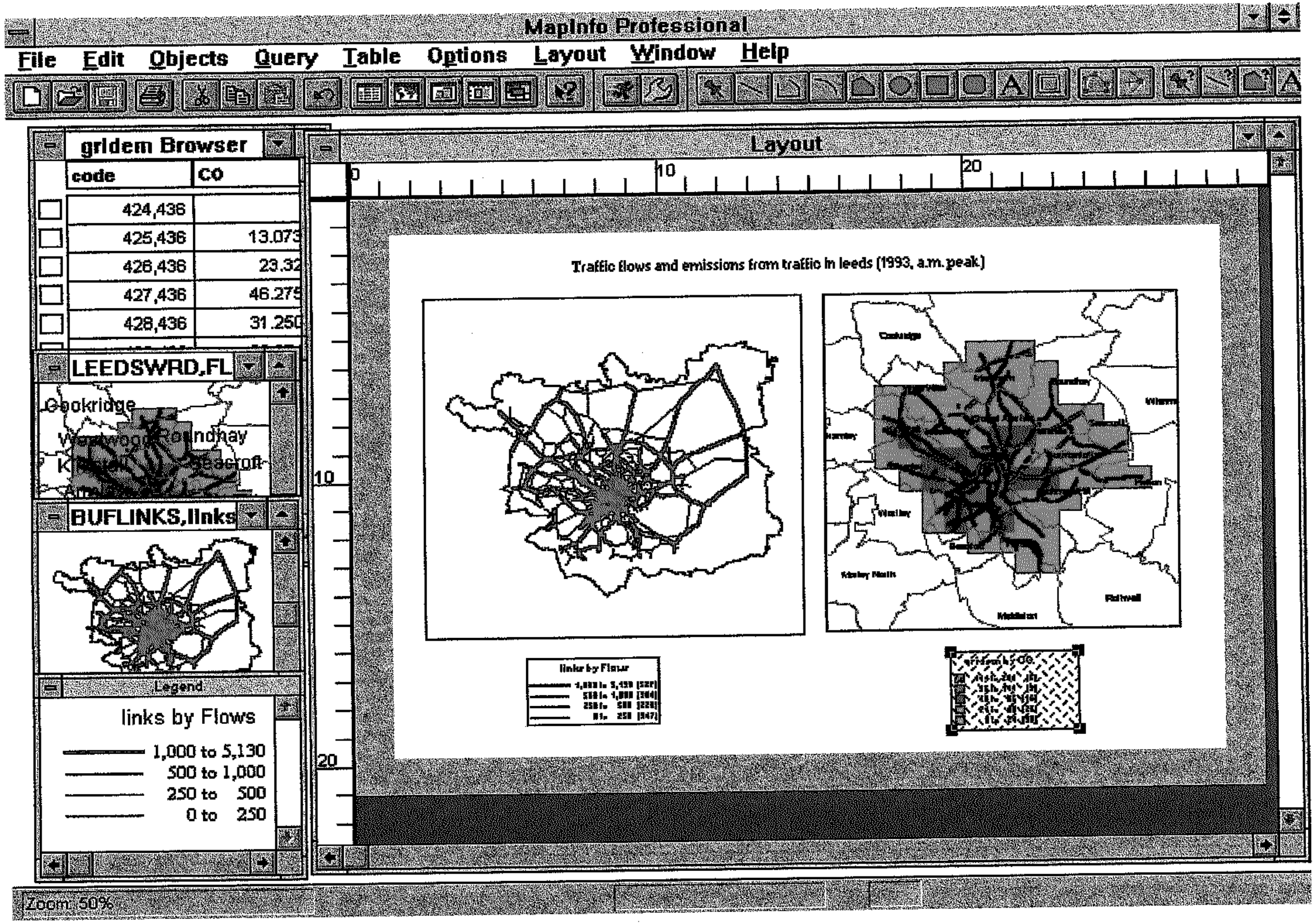


Figure 10. MapInfo: Using the Layout Window to prepare maps for printing.

B.3.3 Calculating emissions by grid square from the data on emissions by link

In order to calculate emissions by grid square, one has to overlay two map layers: the emissions by links map, and the grid map (Figure 11). Emissions from each link have to be assigned to grid squares proportionally to the length of the link section passing through each square. This task is performed by the MapBasic program **gridem.mb** (for a listing of the source code see the Appendix). The gridem.mb program takes the data from the table with link-based emissions produced by the links.mb program (links.tab for Leeds); looks for the intersections of all links with the grid squares from the table produced by the gridlee.mb program (grid.tab); for each grid square calculates the sum of emissions from all the link sections passing through this square; and writes the results into a new table. For Leeds, a table gridem.tab has been created containing grid-based emissions of carbon monoxide, nitrogen dioxide and hydrocarbons. Thematic maps has been prepared for these pollutants using MapInfo (Figure 12-14)

Figure 11. Emissions of carbon monoxide from traffic, by links (Leeds, 1993, a.m. peak).

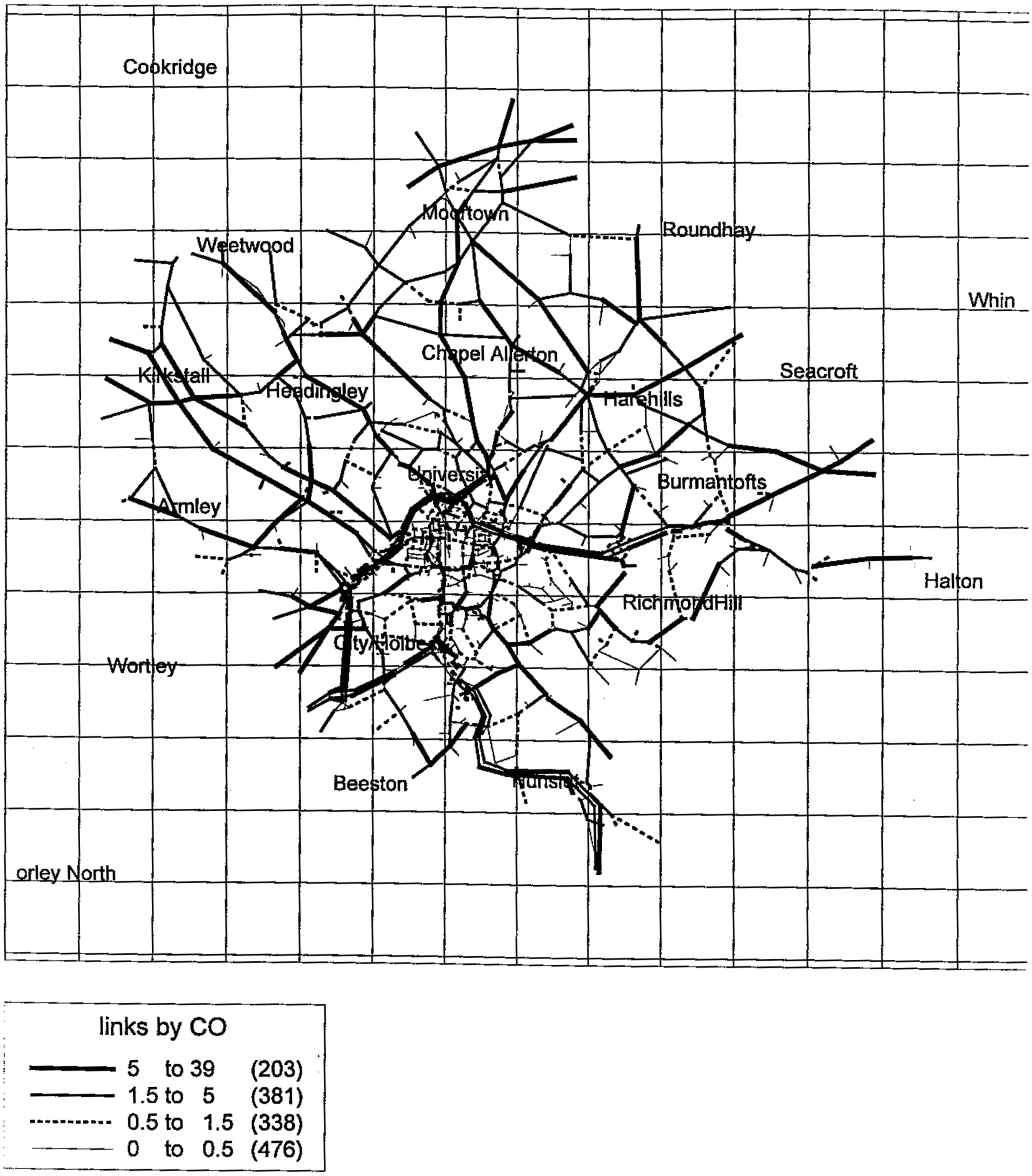


Figure 12. Emissions of carbon monoxide from traffic in Leeds (1993, a.m. peak)

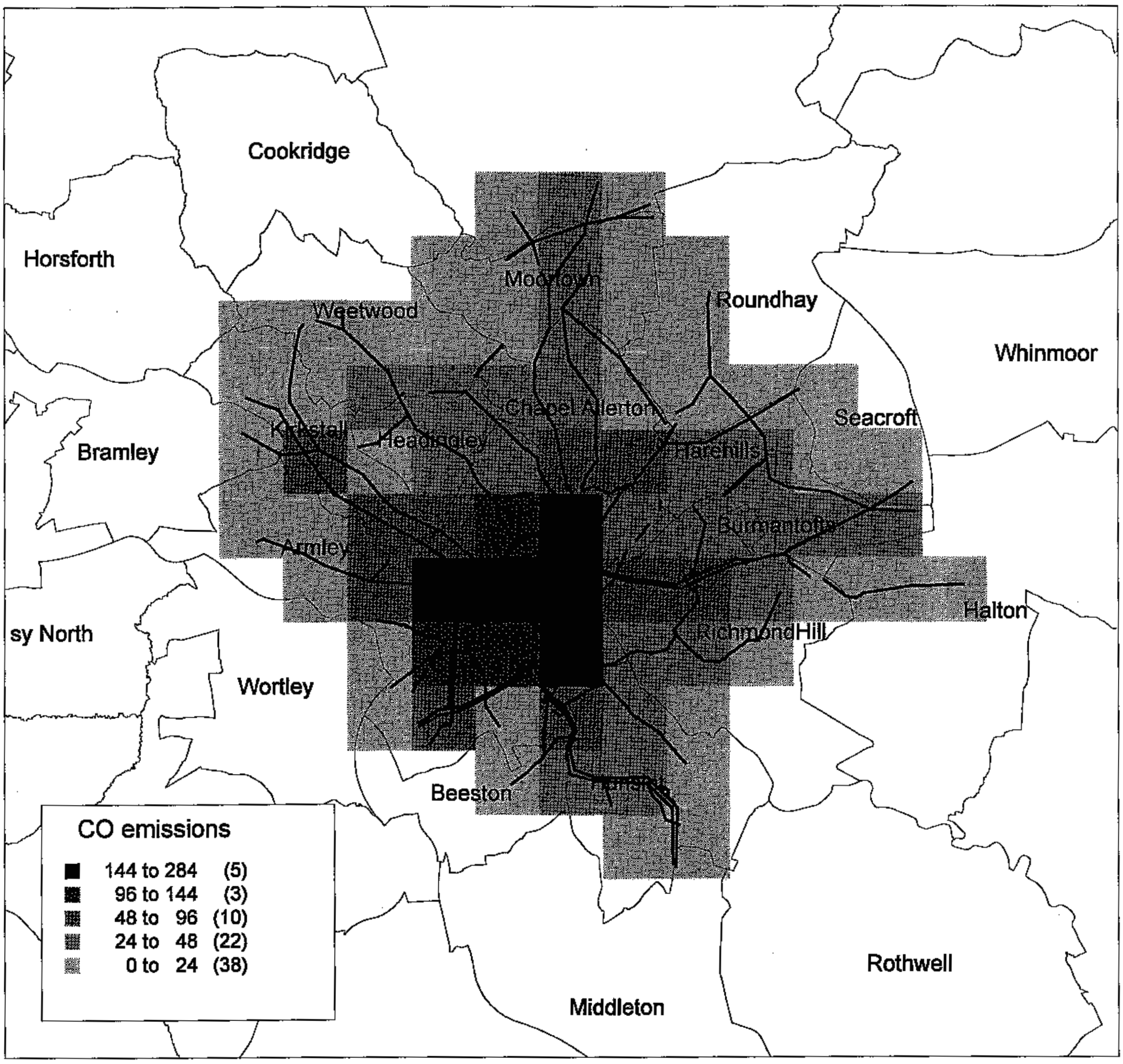


Figure 13. Emissions of nitrogen oxides from traffic in Leeds (1993, a.m. peak).

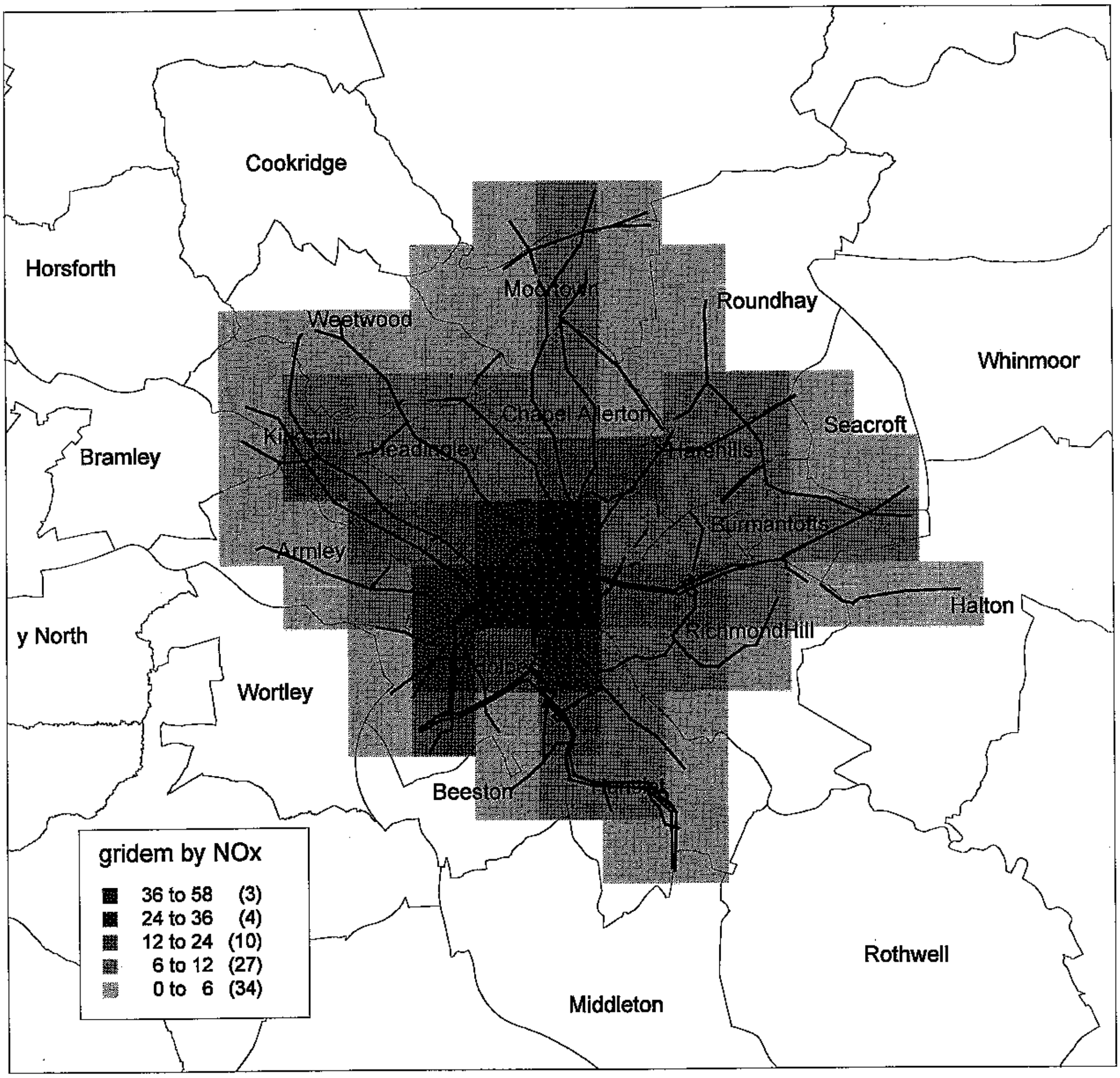
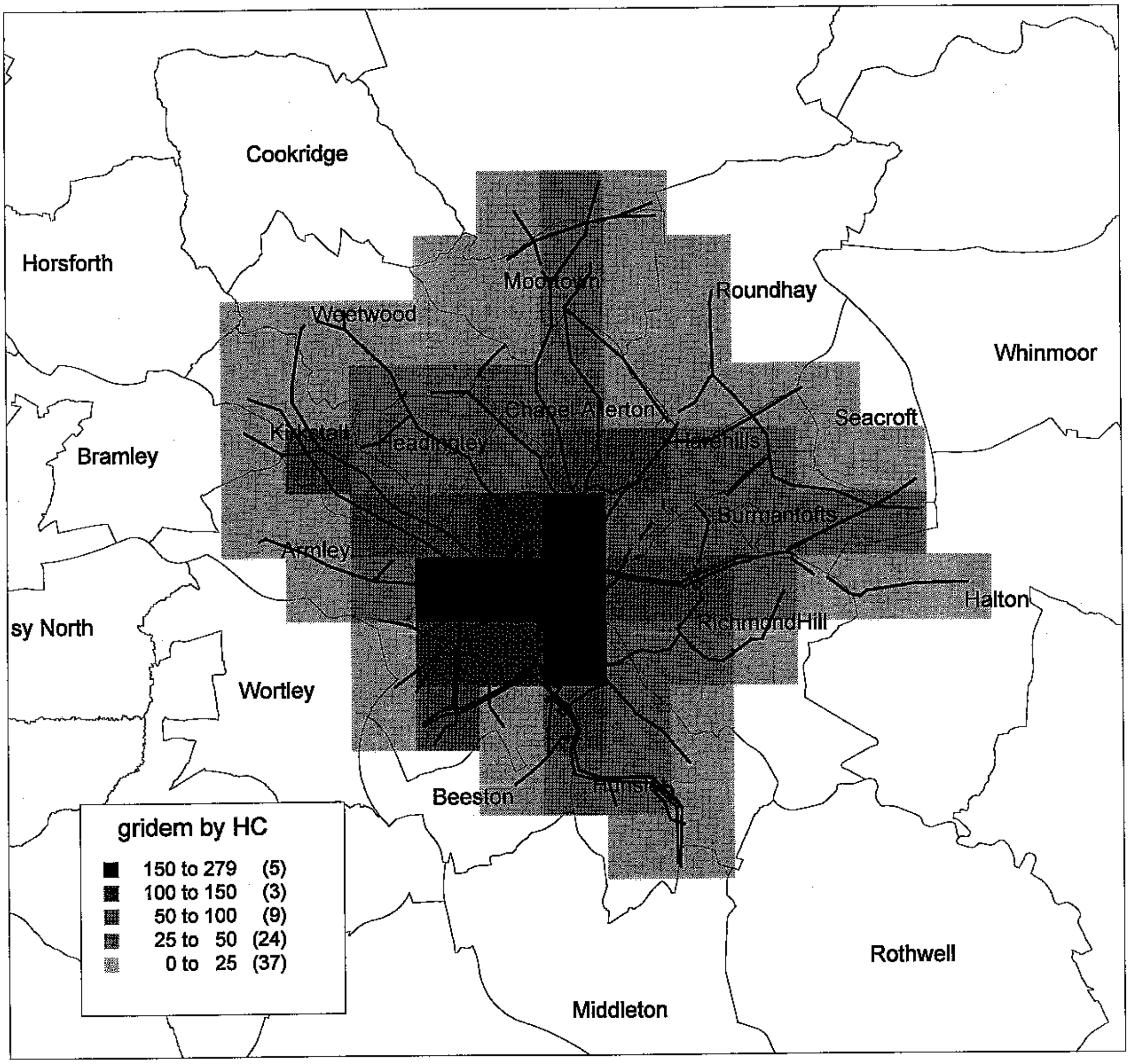


Figure 14. Emissions of hydrcarbons from traffic in Leeds (1993, a.m. peak).



C. MESS: Modelling emissions from stationary sources

C.1 Introduction to the MESS model

The MESS (Modelling Emissions from Stationary Sources) sub-model aims to model and map emissions from stationary sources. Most calculations are performed within the ARC/INFO GIS, with the AML programs allowing for automatisation of certain operations. Maps are prepared in ArcView.

Calculations of emissions from stationary sources cover three types of sources: domestic, industrial and biogenic. Biogenic emissions include both natural sources, and emissions from agriculture. In the MESS model, most calculations are done using a top-down approach that consists in disaggregating emissions for the whole country (or other administrative unit) according to the population share (for domestic sources) or the employment share (for industrial sources) of smaller units. This is equivalent to calculation of emissions by multiplying population or employees number by appropriate emission rates (emissions per capita or emissions per employee).

The calculations are done in the ARC/INFO GIS and data are stored in ARC/INFO coverages of two types: (i) polygon (grid) coverages containing population and land-use data, and calculated emissions; (ii) point coverages containing information on individual manufacturers. Table 12 lists the coverages created within MESS, together with the brief descriptions of their contents and sources. Maps presenting the results of calculations may be prepared either in ARCPLOT or in ArcView. The former, which is a part of ARC/INFO, requires an explicit specification of the characteristics of all the map features. The latter, which has to be bought separately, provides a modern, Windows-type graphical interface and an automatic default specification of map feature characteristics that allows for a relatively fast production of multilayer maps from ARC/INFO coverages.

Table 12. ARC/INFO data files

File	Contents	Source
	Polygon coverages files	
lwards.e00	Leeds wards boundaries in ARC/INFO interchange format	Downloaded from Edinburgh (border.ac.uk) using telnet
leds.e00	Leeds enumeration districts boundaries in ARC/INFO interchange format	Downloaded from Edinburgh (border.ac.uk) using telnet
lwards.pat	Leeds ward boundaries and codes	Created from lwards.e00 using ARC Import command
leds.pat	Leeds enumeration district (ED) boundaries and codes, and ED populations and population densities.	Created from leds.e00 using the ARC Import command. Population data taken from the pop.dat file using the ARC joinitem command. Population density caculated in TABLES.
overlay.pat	Polygons created by an overlay of Leeds EDs with the 1km by 1km grid, including population and population density.	Overlay of leds and lgrid coverages.
pop.dat	Leeds EDs	Population data imported using SASPAC from the 1991 Census of Population Small Area and Local Base Statistics.
	Polygon (grid) coverages files	
lgrid.pat	1km by 1km grid with British National Grid co-ordinates. Population and population density data	Grid created using the generate fishnet command. Population and population density data taken from the sum.dat file using the joinitem command.
sum.dat	Population and population density by grid square.	Calculated using the Statistics command and the overlay.pat file (by summing population of small polygons belonging to the same squares)
llgrid.pat	A subset of lgrid polygons, overlaying the Leeds district. Data on land use, population, and population density.	Data on land use taken from Brooks (1996) (based on Ko 1995). Data on population as in lgrid.pat (item *pop*, and as calculated by Ko (1995) (item *population*)

Table 12 (cont.). ARC/INFO data files.

File	Contents	Source
Polygon (grid) coverages files (cont.)		
emis.pat	Population, land use, and emission data, by grid square. Emission data include NO_x and VOC emissions from domestic and agricultural combustion, VOC emissions from solvent use, gas leaks, and from natural sources.	Calculated in TABLES using emissions factors taken from Ko (1995), and given in Tables 14-16.
Point coverages files		
industry.pat	Data on individual manufacturing companies in Leeds. Includes Standard Industrial Classification (SIC) number, employment, address, type of activity.	Raw data (an ASCII file) obtained from the Leeds Development Agency, and processed in ARC/INFO to extract records with non zero employment figures
Auxiliary files (INFO and ASCII)		
edpop.csv	ED population	Raw data have been imported using SASPAC
gridlbl.txt	Labels of grid squares and their co-ordinates	Created using the gridlbl.cpp program
fueluse.dat	Fuel use factors, by fuel type and user (domestic, agriculture, services)	Own calculations based on Ko (1995). Listed in Table 15.
sicfuel.dat	Fuel use in Leeds, by SIC	Brooks (1996), based on Ko (1995)
emfuel.dat	Factors of emissions of NO_x and VOC from fuel combustion, by fuel type and use.	From Ko (1995). Listed in Table 14.
emvoc.dat	Factors of VOC emissions from domestic use of solvents, domestic gas leakage, animal husbandry and arable farming, and from natural sources.	From Ko (1995). Listed in Table 16.
sicvoc.dat	VOC emission factors, by SIC	Brooks (1996), based on Ko (1995)

C.2 Preparation of the ARC/INFO coverages

Calculations of emissions based on population figures require data on population for each grid square, and these may be calculated in several ways. The method used by Ko (1995) has been based on the 1991 Census data on population by ward and the estimations of residential areas in each ward and grid square. These estimations has been performed "manually" using the Ordnance Survey paper maps (Scale 1:25000). Values of population estimated by Ko for Leeds are in the file llgrid.pat (the item *population*). Here, we have proposed another method. It exploits the geographic analysis capabilities of ARC/INFO, in particular an overlay operation, that allows to accurately and automatically evaluate areas of intersection polygons. This method is generally more accurate because instead of assuming homogenous population density over a ward it uses enumeration districts (EDs) as spatial units (which means 1389 spatial units for Leeds instead of 33). Given the high number of EDs, it would be impossible to perform the calculations manually. Note, that the method might be less accurate if the percentage of the residential area is small in the ED.

The data requirements for calculating population per grid square using the ARC/INFO overlay include:

(i) population by enumeration district (ED);

(ii)digital boundaries of enumeration districts;

(iii)digital boundaries of grid squares.

Digital boundaries of EDs can be obtained in ARC/INFO interchange format (*.e00 files) from the Digitised Boundary Data (DBD) for the 1991 Census of Population, available from the Edinburgh University Data Library and from the Census Dissemination Unit at the Manchester Computing Centre. Population data can be imported as ASCII files from the 1991 Census of Population Small Area and Local Base Statistics using SASPAC (MCC 1992).

Modelling involves the following steps (exemplified with Leeds data files):

- Use the ARC command to import the EDs digital boundaries into INFO format:

```
ARC: Import cover leds.e000 leds
```

  This commands creates the polygon coverage leds. The leds.pat file contains the standard items: *Area, Perimeter, Leds#* (a polygon identifier internal to INFO) and *Leds-id*, and the *Label* item containing ed codes. Area and Perimeter are given in meters, because the coverage uses the six digit National Grid co-ordinates.

- In TABLES, create an empty INFO file to store population data:

```
define pop.dat
        item_name     label
        item_width     8
        output_width  8
        type           C
        item_name     pop
        item_width    4
        output_width  5
        type          B
```

  Read the population data from an ASCII file into the INFO table:

```
select pop.dat
add from edpop.csv
```

  The edpop.csv file must contain two columns: ed code, and population number.

- Join tables leds.pat and pop.dat using *Label* as the relate item:

```
joinitem leds.pat pop.dat leds.pat label label
```

  This command adds the item *pop* to the leds coverage.

- Calculate population density in enumeration districts:

```
additem leds.pat popdens 4 4 F 2 pop
select leds.pat
calculate popdens = pop / area * 1000000
```

  The factor 1000000 is needed to obtain population density in population per km^2 units.

- A map of population density may be produced using ArcView (Figure 15)
- Prepare an ASCII file (gridlbl.txt) with labels of grid squares. This can be done using the short program gridlbl.cpp written in C++, with the appropriately modified parameters defining the grid extent. The source code of the gridlbl.cpp program is listed in the Appendix.

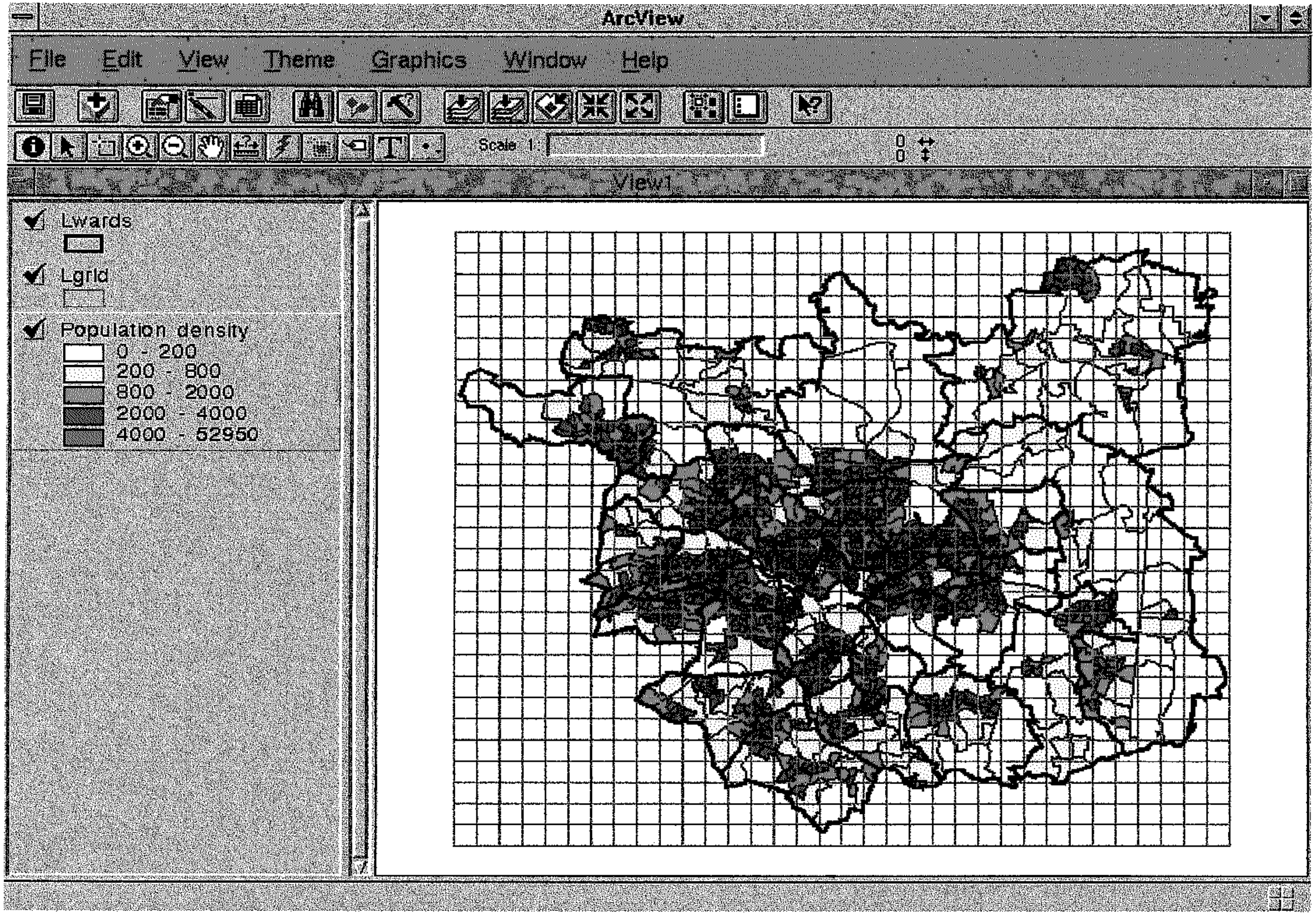


Figure 15. An Arc/View screen displaying the map of population density per enumeration district in Leeds..

- Use the Arc Generate and Clean commands to create a polygon coverage with grid squares:

```
Arc: generate lgrid
Generate:      fishnet nolabels
Fishnet Origin Coordinates (X,Y):   413000 422000
Y-axis Coordinates (X,Y)            413000 451000
Cell Size (Width, Height)           1000   1000
Number of Rows, Columns             29     34
Generate:      input gridlbl.txt
Generate:      points
Generate:      quit

Arc: clean lgrid # # # poly
```

The resulting coverage lgrid has the standard items (*area, perimeter, lgrid#* and *lgrid-id*).

C.3 Modelling population number per grid square using the ARC/INFO overlay

An overlay of two coverages results in the creation of the third coverage where geographic features inherit attributes of the features of the input coverages. Thus, an overlay of a grid coverage (lgrid) and an ed coverage (leds) will produce a coverage composed of a large number of small polygons, with population density (*popdens*) and *grid-id* attributes. By default, areas of all polygons are also given. This allows to calculate population of each small polygon, and then to calculate the population in each grid square, by summing populations of polygons having the same lgrid-id (i.e. contained within the same grid square). The ARC/INFO commands needed to perform all the operations have been written into an AML program overlay.aml listed in Table 13. It can be run by issuing the &RUN directive (&RUN overlay). AML programs are conveniently created using the directives &watch and &conv_watch_to_aml (&cwta).

The first command in the overlay.aml program (identity) performs the overlay operation. Then, the population of each of the 4085 small polygons is calculated into the item *popsmall*. The sum of populations in polygons belonging to the same grid square (*sum-popsmall*) is calculated using the Statistics command and written into the INFO file sum.dat. The same command calculates also the corresponding areas (*sum-area*). Values of *sum-popsmall* and *sum-area* are used to calculate population densities *popdens* in each square (note that although for most squares *sum-area* is equal to 1 km^2, it is smaller in the grid squares crossed by the Leeds district boundary, because we take into account Leeds district population only). Finally, the *sum-popsmall, sum-area* and *popdens* attributes are added to the lgrid coverage using the joinitem command. The Alter command in TABLES can be now used to change the names created by default by the Statistics command. We have changed *sum-popsmall* into *pop* and *sum-area* into *poparea.*

Table 13. The contents of the overlay.aml file.

```
identity leds lgrid  overlay poly
tables
additem overlay.pat popsmall 8 8 F 3
select overlay.pat
calculate popsmall = popsmall * area /1000000
statistics lgrid-id sum.dat
sum popsmall
sum area
end
dropitem sum.dat frequency
additem sum.dat popdens 8 8 F 3
select sum.dat
calculate popdens = sum-popsmall / sum-area * 1000000
q
joinitem lgrid.pat sum.dat lgrid.pat lgrid-id lgrid-id
```

An ArcView map showing population densities calculated using the overlay.aml program is presented in Figure 16.

The lgrid coverage contains grid squares covering a rectangular area, which results in a large number of grid squares with the null population. A new coverage (llgrid) overlaying the district area may be created using the following set of ARCPLOT commands:

```
reselect lgrid poly overlap lwards poly
writeselect llgrid.sel
reselect lgrid llgrid poly llgrid.sel
```

The coverage lwards in the first command contains polygons representing Leeds wards, and was created similarly to the leds coverage.

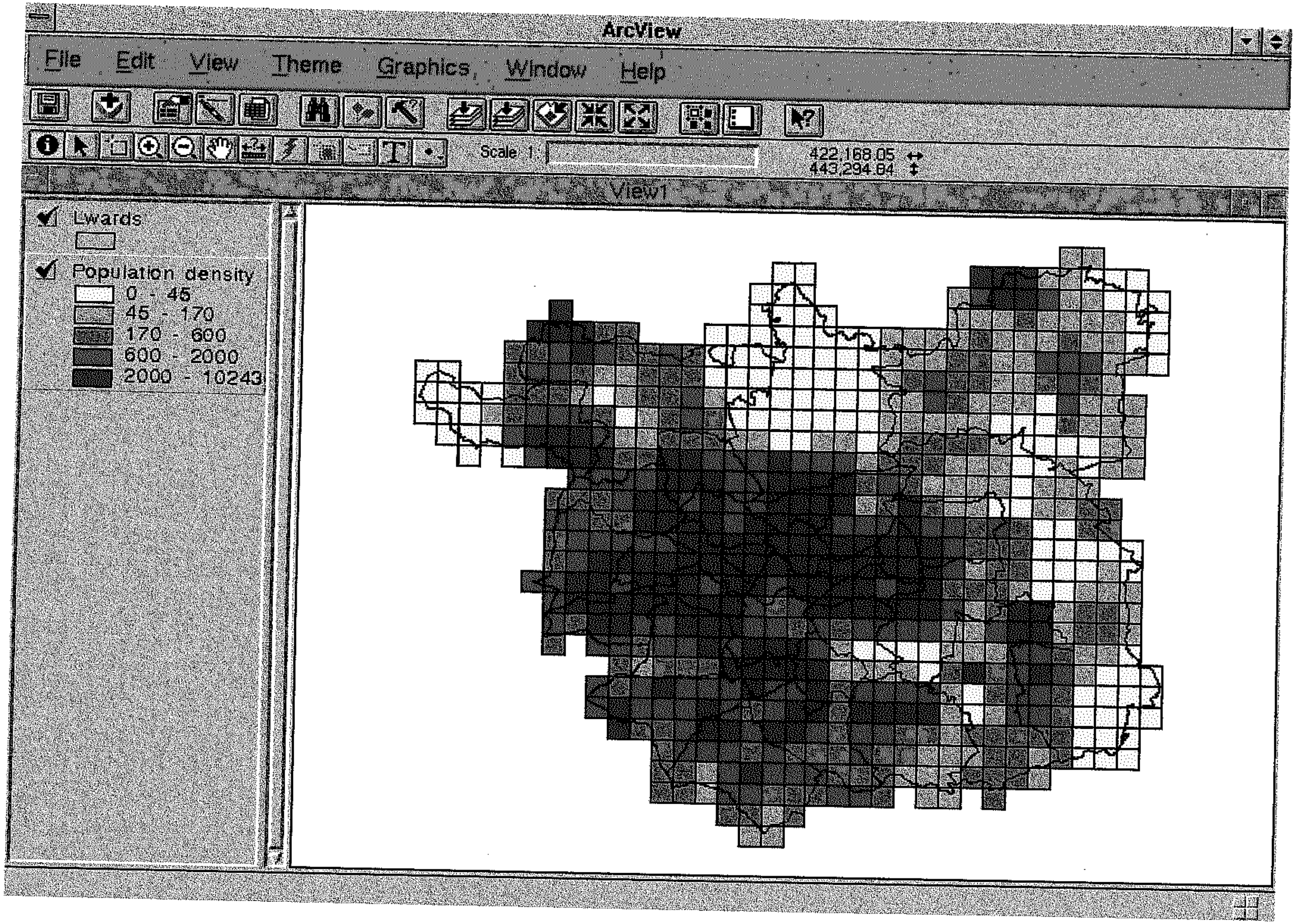


Figure 16. An Arc/View screen displaying a map of population density per 1km by 1km grid square

C.4 Land use data

In order to calculate emissions from natural sources and from agricultural activities, the land use data are required. These might be initially prepared in ASCII format and then read into an INFO file using the Add from command in TABLES. The land use data obtained for each grid square in Leeds and added to the llgrid.pat file include: the area of land used for agriculture (item *agriculture*), the grass land (item *grass*), the area of coniferous and deciduous woods (*conif_woods, decid_wood*), and the area of inland water (*inland_water*). The digital data on land use have been prepared by Brooks (1996), basing on Ko data (Ko 1995) in paper format. Ko has obtained his data by analysing the eight Ordnance Survey maps in the scale 1:25000 covering the Leeds area. A more precise and faster methodology would be based on digital maps. Having a vector map with polygons representing various categories of land use, one could calculate the area of each land use type in each grid square using a technique such as used in the previous section for population calculations.

C.5 Calculation of emissions from domestic and biogenic sources

The MESS implementation for Leeds includes currently the calculations of emissions of volatile organic compounds (VOC) and nitrogen oxides (NO_x) from domestic sources, agriculture, and from natural sources. Data files necessary to calculate VOC and NO_x emissions from industrial sources have also been prepared. (see Section C.6).

NO_x emissions come mainly from combustion of fossil fuels. Volatile organic compounds are emitted in the result of combustion, use of solvents, and from biogenic sources (agriculture and natural sources). The amounts of pollutants emitted from each grid square are expressed by the formula given below.

- Emissions from domestic combustion:

$$E^{j}_{dom.comb.} = \Sigma_i \, (f_i^{dom} \, e^{j}_{i}) \, P.$$

- Emissions from combustion in the agriculture sector:

$$E^{j}_{agric.comb.} = \Sigma_i \, (f_i^{agric} \, e^{j}_{i}) \, A.$$

- Emissions of volatile organic compounds from solvent use and gas leaks:

$$E^{VOC}_{sg} = P\, e_{dom\_solv} + A\, e_{agro\_solv} + P\, e_{gas\_leaks}.$$

- Emissions of volatile organic compounds from natural sources:

$$E^{VOC}_{solv} = \sum_i land\_use_i \; e_{land\_use_i} .$$

In the above formula, the following notation has been used:

j	denotes NO_x or VOC,
f_i^{dom} and f_i^{agri}	gives respectively fuel use per capita and fuel use per hectare for fuel type i (Table 14),
e^j_i	is a factor of emission of pollutant j from combustion of fuel type i (Table 15),
P	is the population of a grid square,
A	is the area of agricultural land in a grid square, in hectares,
e_{dom_solv}, e_{agro_solv}	are factors of VOC emissions from domestic and agrochemical use of solvents (Table 16),
e_{gas_leaks}	is a factor of VOC emissions from gas leaks (Table 16),
$land\_use_i$	is the area of land use type i,
$e_{land\_use_i}$	is a factor of VOC emissions from land use type i (Table 16).

Table 14. The contents of the file fueluse.dat (fuel use by fuel type and user type). Source: Own calculations based on Ko (1995), p. 128.

Use / Fuel type	Domestic (kg or th per capita	Agriculture (kg or th per hectare	Services (kg or th per employee)
Coal	82.149	0.555	87.237
SSF	60.903	11.102	27.172
Burning_oil	35.404	0.555	1.430
Fuel_oil	0.177	6.661	0
Gas_oil	4.603	36.638	0
LPG	3.378	0	0
Natural_gas	205.491	2.110	164.208

Table 15. The contents of the file emfuel.dat, with factors of emissions of NO_x and VOC from fuel combustion, by fuel type and use (in g/kg, except emissions from LPG and natural gas combustion, which are in kg/Mth). Source: Ko (1995), p.141.

Fuel type	NO_x_dom	VOC_dom	NO_x_agr	VOC_agr	NO_x_pstat	VOC_pstat	NO_x_other	VOC_other
Coal	1.5	9.88	4.8	0.069	9.0	0.148	4.8	0.069
SSF	1.5	1.23	4.8	0.069			4.8	0.069
Burning_oil	2.1	0.069	2.1	0.069	2.1	0.069	2.1	0.069
Fuel_oil	7.4	0.059	7.4	0.059	10.7	0.889	7.4	0.059
Gas_oil	4.5	0.069	4.5	0.128	11.4	0.069	4.5	0.069
LPG	5280	834			26400	151	10600	151
Natural_gas	5280	341	10600	151	26400	151	10600	151
DERV							4.5	0.069

Table 16. The contents of the emvoc.dat file, containing factors of emissions from domestic use of solvents, domestic gas leakage, animal husbandry and arable farming, and from natural sources. Emissions from domestic solvents use are given in kilograms per capita; emissions from agrochemical use of solvents, from farming, and from natural sources are given in kilograms per hectare; emissions from animal husbandry are in kilograms per head. Source: Ko (1995), p.146.

Source	Emission factor
solv_use	3.370
agrochem	2.078
gas_leaks	0.338
pigs	0.87
cattle	4.35
calves	1.45
sheep	0.44
lambs	0.15
poultry	0.02
grassland	13.0
pasture	5.4
horticulture	95.0
agriculture	6.7
conif_wood	90.0
decid_wood	26.9
grass	3.3
inland_water	12.7

Assuming the values of fuel use factors and emission factors given in Table 14 and Table 15, one arrives at the following formula for emissions from fuel combustion:

$$E^{dom.comb.}{}_{NOx} = 1.414\,P,$$

$$E^{dom.comb.}{}_{VOC} = 0.962\,P,$$

$$E^{agric.comb.}{}_{NOx} = 0.294\,A,$$

$$E^{agric.comb.}{}_{VOC} = 0.00624\,A.$$

Emissions from other sources are expressed in a straightforward way using the emission factors from Table 16.

In order to perform the calculations for all the grid squares, a new coverage called emis has been created by coping the coverage llgrid (the ARC Copy command) and deleting unnecessary items (the Dropitem command). New items has been added to store the results of calculations. Table 18 list all the attributes stored in the emis coverage. The commands used to perform the calculations of emissions has been saved into the emis.aml file, listed in Table 17.

Maps of pollutant emissions have been prepared using Arc/View. Figure 17-19 show maps of emissions of volatile compound from domestic use of solvents, from natural sources, and from agrochemical use of solvents.

Table 17. The contents of the emis.aml file.

```
tables
select emis.pat
calculate domcombnox = 1.414 * pop
calculate domcombvoc = 0.962 * pop
calculate agricombnox = 0.294 * agriculture
calculate agricombvoc = 0.00624 * agriculture
calculate domsolvvoc = 3.37 * pop
calculate gasleaksvoc = 0.338 * pop
calculate agrovoc = 2.078 * agriculture
calculate naturalvoc =
        3.3 * grass + 26.9 * decid_wood + 90 * conif_wood + 12.7 * inland_water
calculate combnox = domcombnox + agricombnox
calculate combvoc = domcombvoc + agricombvoc
calculate solvvoc = domsolvvoc + agrovoc
calculate totvoc = solvvoc + combvoc + gasleaksvoc
```

Table 18. The structure of the coverage emis containing the input and output data for emissions calculations. All emission data are in kilograms.

Coverage name	emis	
Geographical features	1km by 1 km squares (653 polygons, plus a universe polygon)	
INFO table name	emis.pat	
Feature class	Polygons	
Map units and co-ordinate system	Metres, British National Grid	
Attributes	Attribute description	Attribute format (Width, output width, type and decimals)
AREA	Square area in metres (= 1000000)	4 12 F 3
PERIMETER	Square perimeter in metres (= 4000)	4 12 F 3
EMIS#	Internal number of a polygon	4 5 B -
EMIS-ID	Polygon (grid square) user-defined identifier	4 8 B -
POP	Population number	8 15 F 3
GRASS	Area of grassland in hectares	3 3 I -
AGRICULTURE	Agricultural land in hectares	3 3 I -
CONIF_WOOD	Area of coniferous woods in hectares	3 3 I -
DECID_WOOD	Area of deciduous woods in hectares	3 3 I -
INLAND_WATER	Area of inland waters in hectares	3 3 I -
DOMCOMBNOX	Emissions of NO_x from domestic combustion	8 10 F 2
DOMCOMBVOC	Emissions of VOC from domestic combustion	8 10 F 2
AGRICOMBNOX	Emissions of NO_x from combn in agricult. sector	8 10 F 2
AGRICOMBVOC	Emissions of VOC from combn in agricult. sector	8 10 F 2
DOMSOLVVOC	Emissions of VOC from domestic use of solvents	8 10 F 2
GASLEAKSVOC	Emissions of VOC from domestic gas leaks	8 10 F 2
AGROVOC	Emissions of VOC from agrochemical use of solvs	8 10 F 2
NATURALVOC	Emissions of VOC from natural sources	8 10 F 2
COMBNOX	DOMCOMBNOX + AGRICOMBNOX	8 10 F 2
COMBVOC	DOMCOMBVOC + AGRICOMBVOC	8 10 F 2
SOLVVOC	DOMSOLVVOC + AGROVOC	8 10 F 2
TOTVOC	SOLVVOC + COMBVOC + GASLEAKSVOC	8 12 F 2

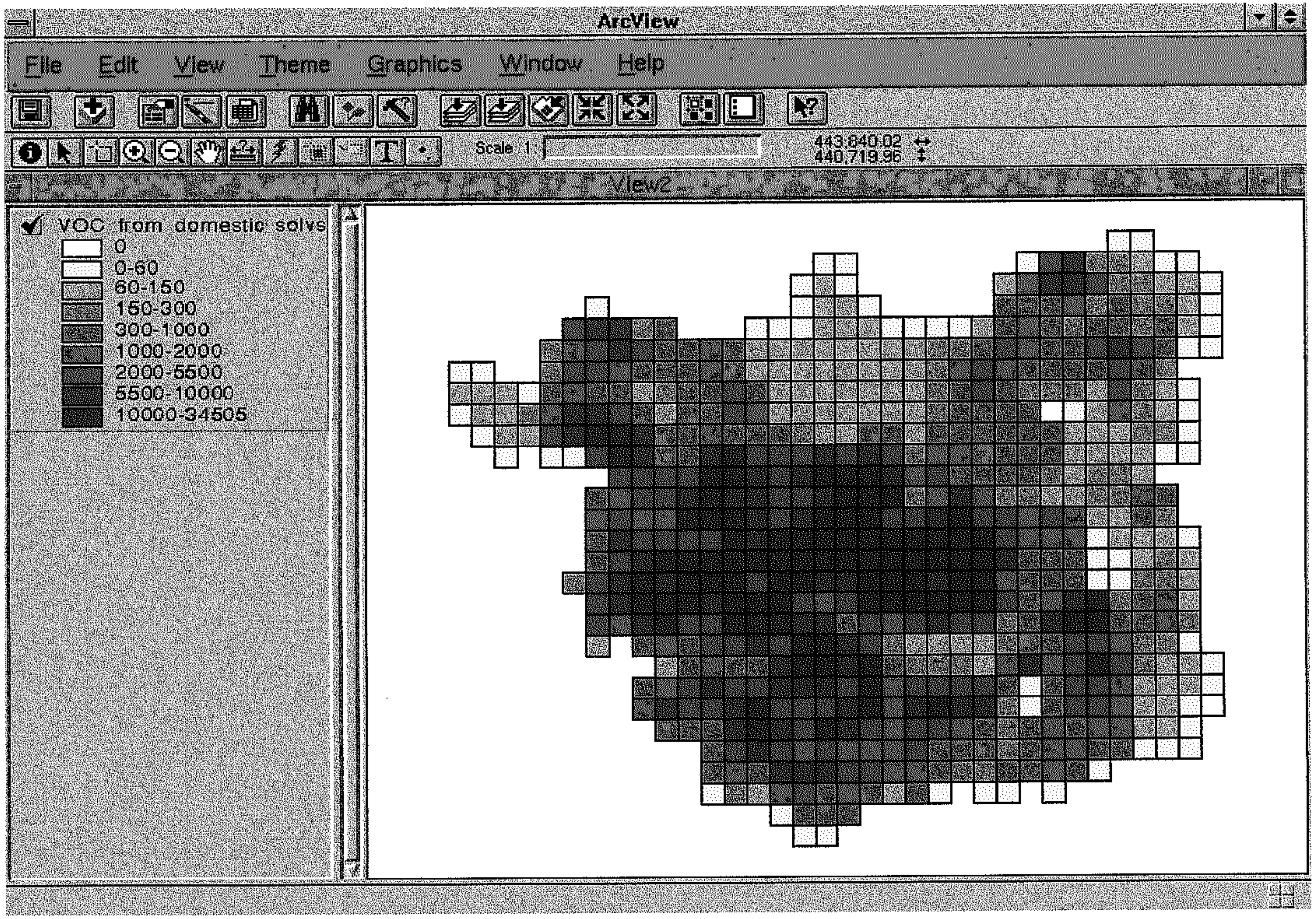


Figure 17. An Arc/View screen displaying a map of VOC emissions from domestic use of solvents.

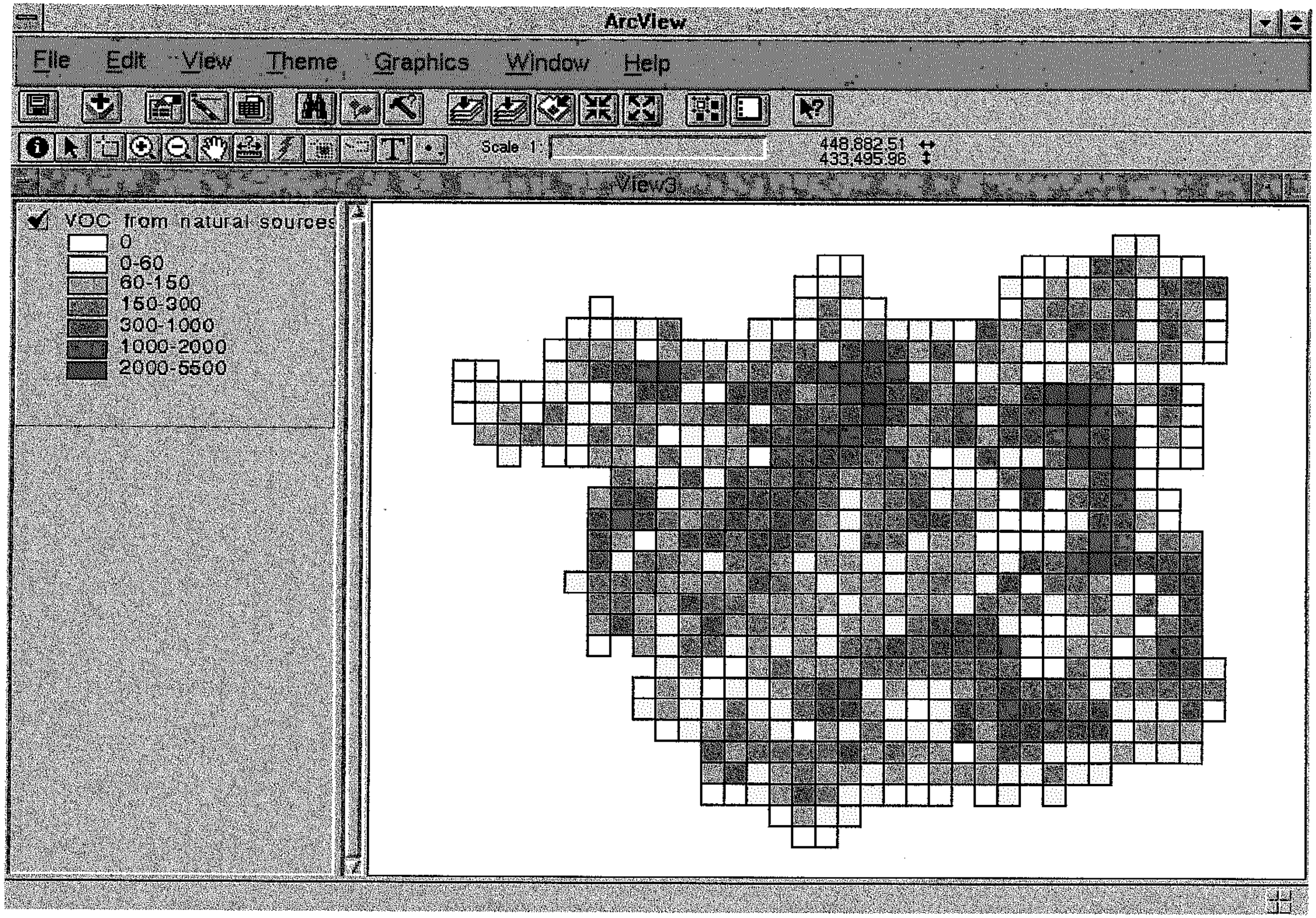


Figure 18. An Arc/View screen displaying a map of VOC emissions from natural sources.

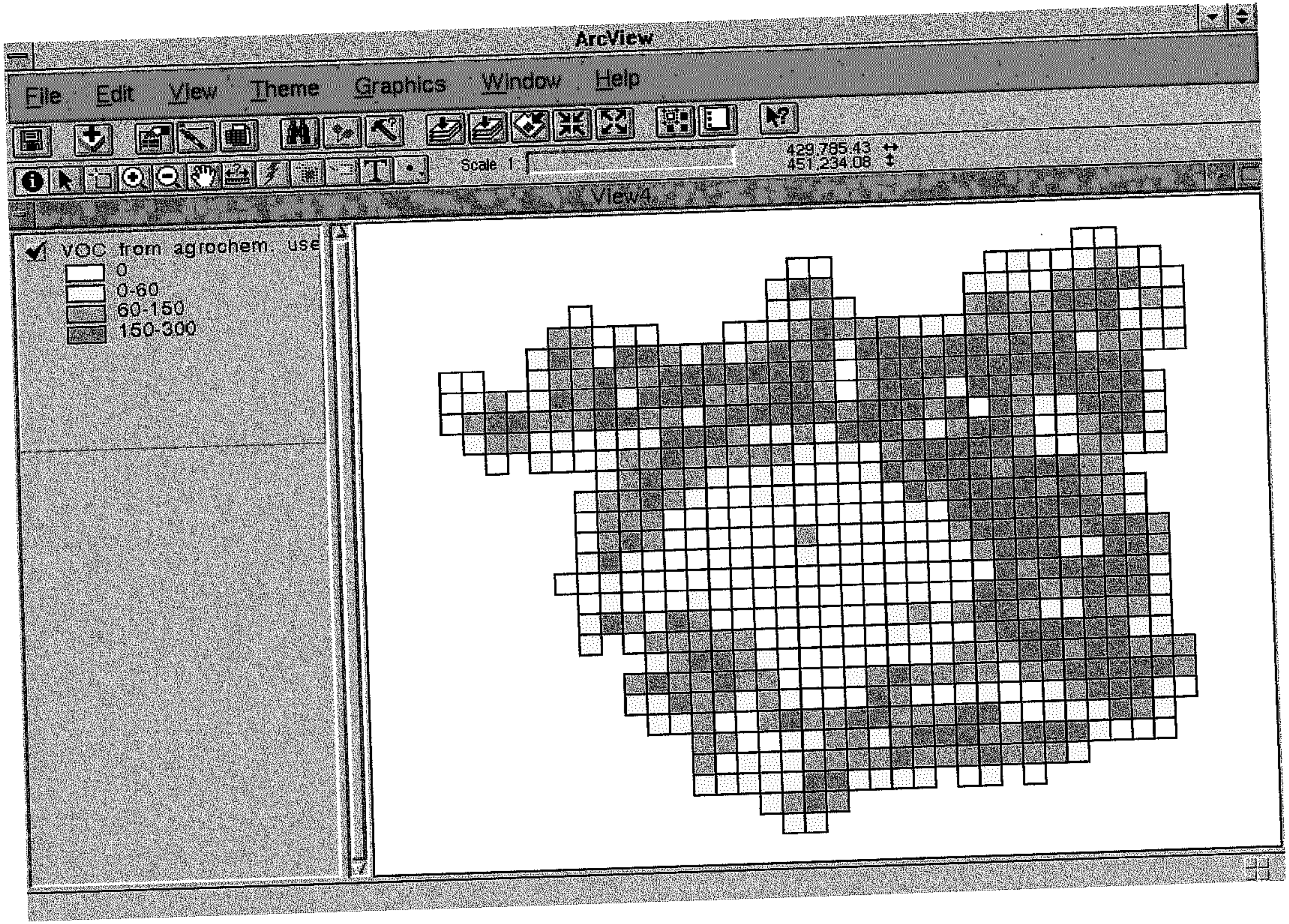


Figure 19. An Arc/View screen displaying a map of VOC emissions from agrochemical use of solvents.

C.6 Preparation of data for calculating emissions from industrial sources

The data requirements for calculating emissions from industrial sources include: (i) employment or production figures, preferably for individual companies, (ii) Standard Industrial Classification (SIC) of each company, (iii) fuel use by fuel type and SIC, (iv) VOC emission factors by SIC. Where data for individual companies are not available, a methodology described by Ko (1995) may be used. For example, number of employees in public services sector per grid square may be calculated pro rata of total employment in services in the city, according to the area of commercial land in a grid square.

For Leeds, data on individual manufacturing companies has been obtained from the Leeds Development Agency. The ARC/INFO point coverage called industry has been prepared, containing the following data: company name, address, postcode, National Grid co-ordinates, SIC, activity type, employment. The coverage contains data on 1736 manufacturers (after removing records with null employment). Figure 20 presents an Arc/View map showing location and number of employees of all companies. Preparation of other files necessary to calculate emissions from industrial sources is in progress.

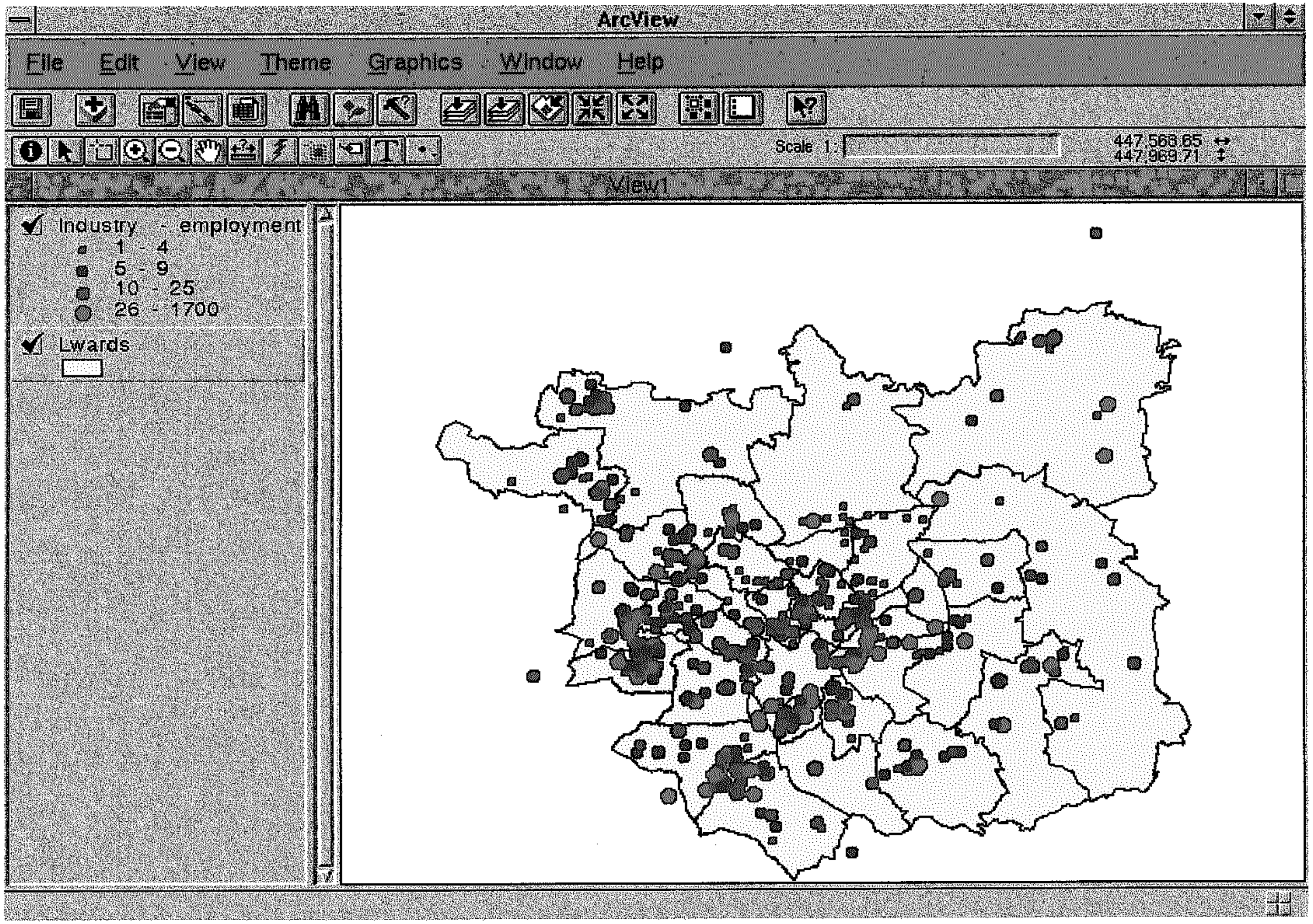


Figure 20. An Arc/View screen displaying a map of manufacturing companies in Leeds (classified by number of employees).

D. Acknowledgments

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The project team would like to thank all collaborators who provided data necessary for the implementation of MUPPETS for Leeds. Mr. Graham Read from the Leeds City Council has provided data for the Leeds SATURN model (data on the road network and trip matrices). Data used in calculations of emissions from stationary sources in Leeds has been collected by Mr. Yun Hwa Ko, under the supervision of Dr. Andrew Clarke from the Fuel and Energy Department of the University of Leeds. Mr. Simon Brooks has helped to transform these data into a digital form. Special thanks are due to Dr. Dirck van Vliet for providing the SATURN model, and to Mr. David Milne for the initial help in running the model.

The digital boundaries of enumeration districts has been extracted from the Digitised Boundary Data, that are Crown and ED-LINE Copyright. The DBD project has been funded by ESRC and JISC.

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F. Appendix

The Appendix contains listings of the source codes of the following programs:

1. C++ programs:

- class.cpp
- coord1.cpp
- map.cpp
- gridlbl.cpp

2. MapBasic programs:

- links.mb
- gridlee.mb
- gridem.mb

To obtain a listing of the source code for any of the programs please contact the author.