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EVALUATION OF AIR QUALITY PROGRAMS FOR A COMBINATION OF SOURCE CATEGORIES

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ABSTRACT

The contribution of air pollution from car traffic, home heating and industry to the population exposure in Oslo is determined by calculations based upon data for emission and dispersion.

The calculations are carried out in a 1 km^2-grid with special calculations for roads with high traffic and for large point sources. Based on data for pollution advection into each km^2, on local contribution and on the concentrations close to streets with high traffic, estimates are made of the cumulative spatial distribution of air pollution within each km^2.

The number of people living in each km^2 combined with the spatial concentration distributions are used to summarize the population exposure to 24 hour mean episodic concentrations values.

Future air quality as a result of alternative emission situations is evaluated in terms of population exposure curves for SO_2, NO_2, CO and particulate matter. Considering emission data and results of dispersion calculations in different urban areas in Norway it is seen that the data for emission from car traffic may limit the accuracy of the emission survey.

CONTENTS

EVALUATION OF AIR QUALITY PROGRAMS FOR A COMBINATION OF SOURCE CATEGORIES

1 INTRODUCTION

To control future air quality in Oslo the Norwegian State Pollution Control Authority in Norway initiated and coordinated studies to provide data for evaluating the benefit of improved air quality versus the cost of emission reduction.

Alternative air quality programs may be developed to reduce air pollution on local, urban and regional scale. On a local scale (10-1000 m) elevated point sources, urban area sources and nearby auto traffic cause high concentrations of sulphur oxides, particulate matter, carbon monoxide and nitrogen oxides. In an urban area a pollution problem may be resolved by considering a number of local problems. However, an urban scale problem (10-40 km) may be developed as a result of multiple point sources and low level area sources. An urban scale problem often include sulphur oxides, particulate matter, nitrogen oxides and in some areas photochemical oxidants. Air quality measuring programs in several urban areas (Grønskei, 1976, Hagen, 1985, Larssen, 1986) have indicated that a combination of local and urban scale source distribution cause pollution concentrations exeeding air quality standards e.g. in the neighbourhood of streets with high traffic.

For practical reasons dispersion calculations are carried out with one minimum scale resolution i.e. selection of grid size in an urban scale model. To clarify the importance of an air quality program for a combination of source categories descriptions of pollution emission and dispersion on different scales have to be combined. When an urban area is considered, many local scale problems may have to be summarized in statistical distribution functions.

The number of people living in areas polluted above air quality standards were used to compare the effect of alternative emission reduction programs. Source oriented dispersion calculations are used to provide data on location and concentrations in polluted areas.

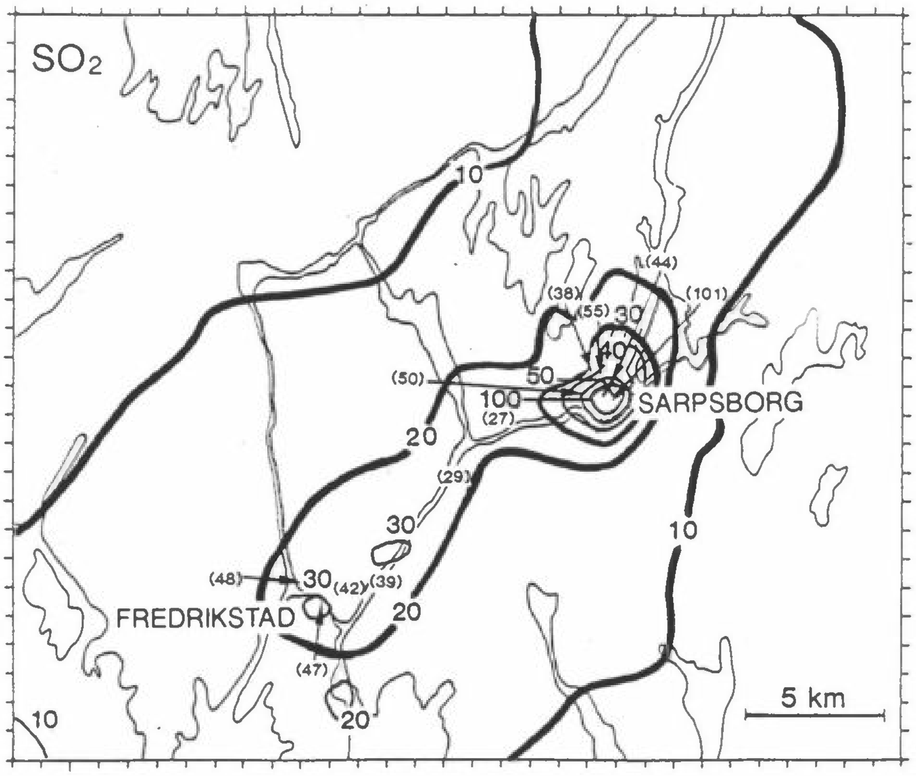
A model resolving the dilution on different scales is described and exemplified by some results on the evaluation of alternative air quality programs in Oslo. Comparing concentration measurements with results of dispersion calculations for different urban areas in Norway, the accuracy of the emission-dispersion model is discussed with particular emphasis on the emission from car traffic.

2 RESULTS OF DISPERSION CALCULATIONS FOR DIFFERENT AREAS

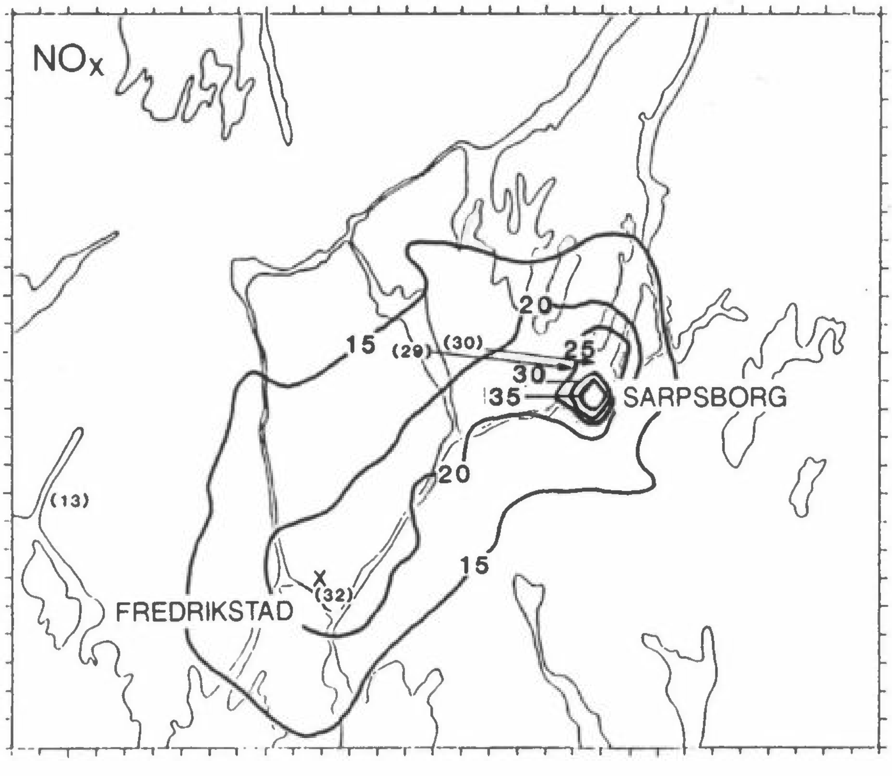
As a part of the air pollution control system in Norway extensive studies in urban areas are carried out one after the other e.g., Sarpsborg/Fredrikstad (Hagen, 1985), Bergen (Larssen, 1986), Mo i Rana (Sivertsen, 1987) and Drammen (Hagen, 1987), as a basis for selecting control programs. These investigations include a description of the interrelation between emission and observed pollution concentration. The interrelation is described by dispersion calculation for winter average concentrations (Gram, 1988). In some investigations dispersion calculations for air pollution episodes were carried out as suggested by Grønskei and Gram (1984).

The same procedure for collecting emission data and for performing dispersion calculations has been followed in the respective areas. The calculations for SO_2-concentrations have compared well with measurements in the different urban areas. Considering other pollution components i.e. nitrogen oxides and particulate matter dispersion calculations have resulted in consistently lower values than observed in Sarpsborg/Fredrikstad and Bergen.

The dispersion calculations in Sarpsborg/Fredrikstad were performed in a 1 km^2-grid. Average calculated and observed values for the winter-period October 1981-March 1982 are shown in Figure 1. A reasonable correspondence was found for SO_2 while the components originating from car traffic were underestimated. Taking into account that observed values for nitrogen oxides are compared with calculated NOx-values, it is seen that the calculations of nitrogen oxides are seriously underestimated. The same discrepancies were found for short term average values (see Figure 2). Calculated hourly values for SO_2 and NOx are compared with observed concentrations. The station locations are marked by crosses in Figure 1.

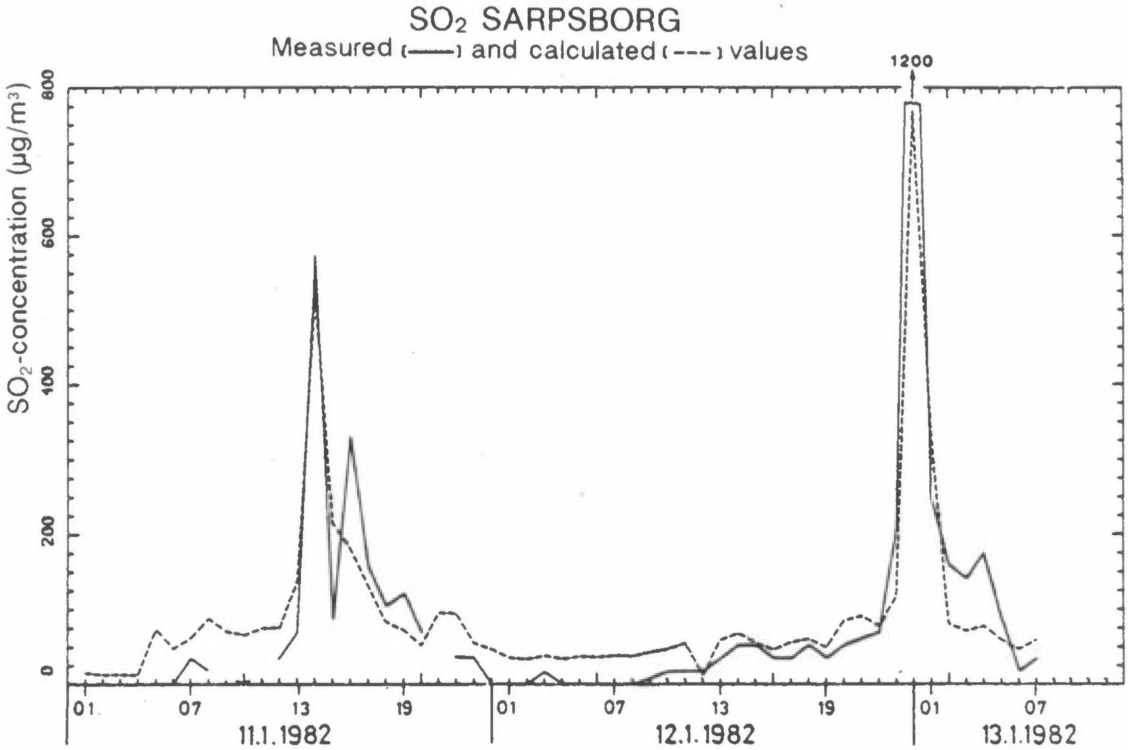


X: Kirkegt. in Sarpsborg.



X: City hotel in Fredrikstad.

Figure 1: Calculated and measured concentrations of SO_2 (upper) and NOx (lower) in Sarpsborg/Fredrikstad for the period October 1981-March 1982. The measured values are given in brackets. For the nitrogen oxides the calculated values applies for NOx while the measurements only applies for NO_2. Unit: $\mu g/m^3$.



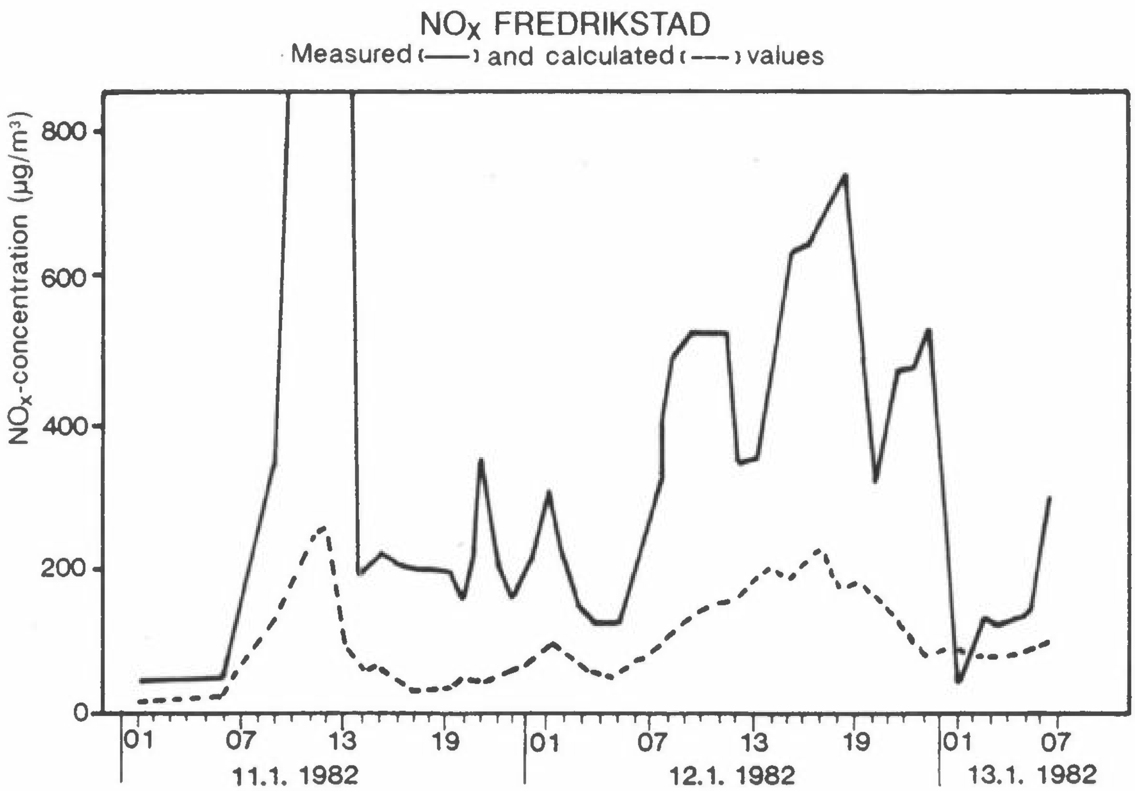


Figure 2: Calculated and measured hourly SO_2 and NOx concentrations in Sarpsborg/Fredrikstad.
Unit: $\mu g/m^3$.
a) SO_2 in Kirkegt., Sarpsborg, 11-13.1.1982.
b) NOx at City Hotel, Fredrikstad, 11-13.1.1982.

The same consistent underestimation is found for NOx in Fredrikstad (Figure 2). The underestimation was particularly large when the wind came from a nearby road as a result of the particular station location.

Performing the next study in Bergen the grid distance was reduced from 1 km to 0.5 km to obtain a better resolution. Dispersion calculations shown in Figure 3 and Figure 4, gave similar results as in Sarpsborg/Fredrikstad. A reasonable correspondence is found for SO_2 and the calculated NOx-concentrations, corresponding with the observed NO_2-concentrations, underestimate the observed NOx-values. At the main measuring station (marked by a cross in the figures) measurements show that NO_2-values were less than 50% of the NOx-values.

Emission factors based on the ECE driving cycles for urban areas have been used for emission calculations. It is possible that the specific driving cycle is not representative for all urban areas. However, the streets with high traffic will be characterized by high concentrations of exhaust gases, higher than average values in grid-squares. In an urban area it is difficult to locate a measuring station that is not influenced by emissions in a nearby street. Accordingly, this effect should be taken into account both in short term and long term average concentration calculations.

Figure 4 shows calculated and measured values for components originating mainly from car traffic. As shown in the figure, it was found necessary to specify the contribution from nearby roads. The underestimation, however, was consistant for all pollution components of car exhaust in Bergen. More details about the calculations are reported by Grønskei (1986).

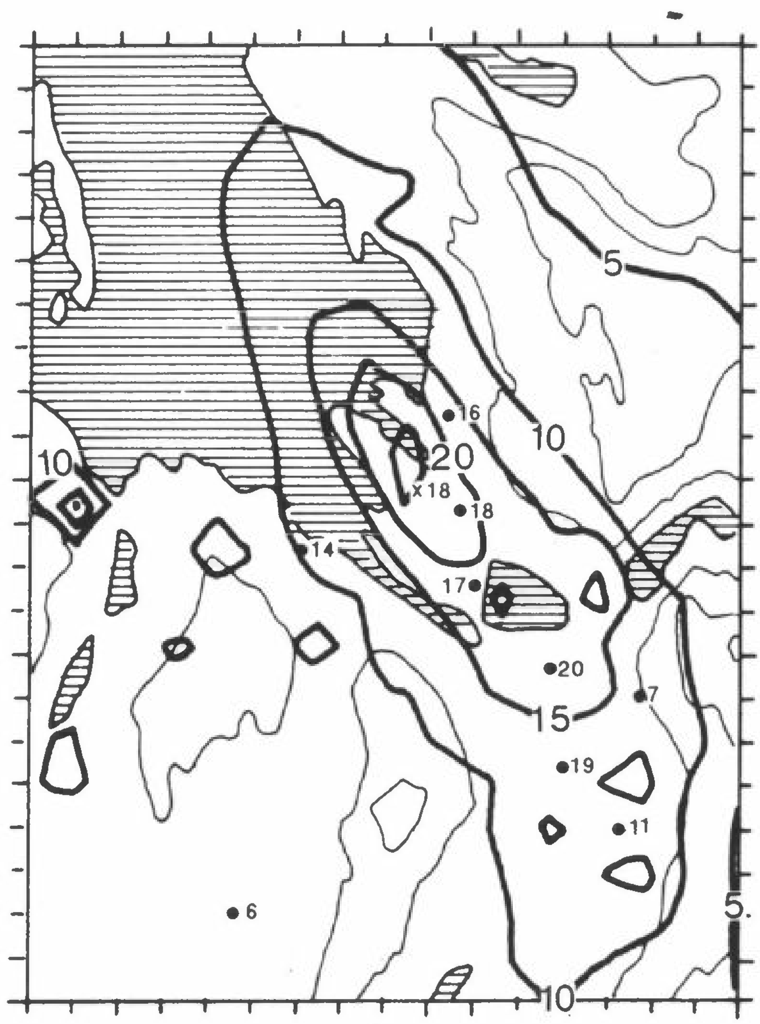


Figure 3: Calculated and measured SO_2-concentrations for the period December 1983-February 1984 in Bergen.
Unit: $\mu g/m^3$.
X: DNS. The main measuring station.

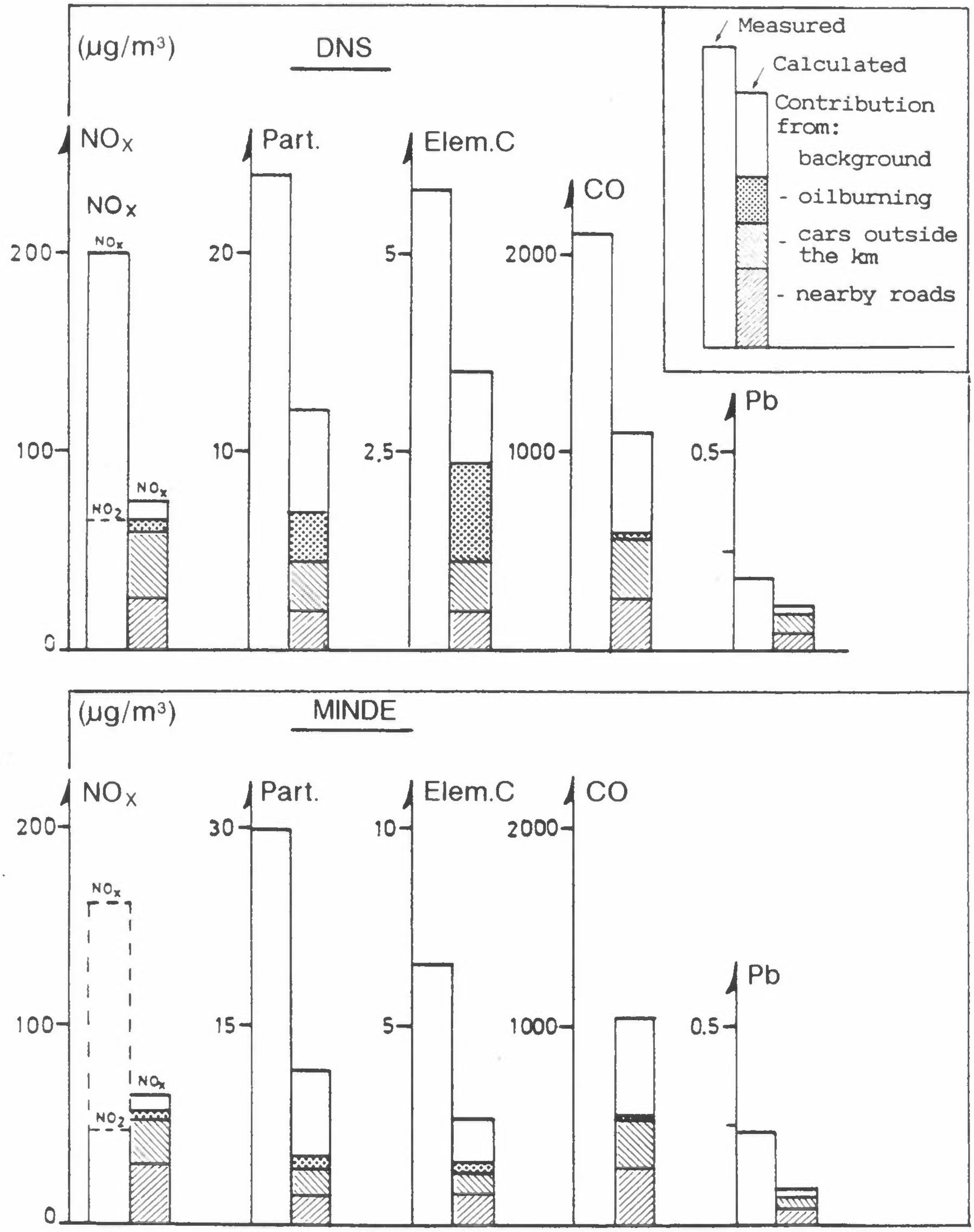


Figure 4: Calculated and measured concentration of pollutants originating mainly from car traffic in Bergen. For calculated values the contributions from different groups of sources are specified (Larssen, 1986).
Unit: $\mu g/m^3$.

Systematic measuring errors explaining the discrepancies are not likely, and the explanation has to be found in the emission data or in the dispersion model.

As an alternative to defining one typical driving cycle for emission calculations in urban areas, the laboratory in Studsvik, Sweden measuring car exhaust constituents, has determined emission as function of driving speed and acceleration. Car driving in urban areas may be decomposed in time in each of these groups of driving condition.

The statistics of urban driving may differ from one urban area to another, from one type of road to another. In Stockholm the percentage of time in each group of driving condition has been developed by Persson (1980). Combining the statistics on driving conditions (Figure 5) with the emission matrix renders an emission coefficient depending on average driving speeds of cars as shown in the Figures 6 and 7. The average emission factors used in concentration calculation for Sarpsborg/Fredrikstad and for Bergen are marked in the figures.

Preliminary calculations for Oslo did show that the pollution components in car exhaust would be underestimated in the same way as in the other urban areas. The Swedish method of emission calculation would give much better correspondence between observed and calculated values in these areas. Based on these results the Swedish methods were selected. The methods require information on driving conditions expressed as average driving speed.

In Appendix A results of average speed and CO-measurements along the main roads in Oslo are presented.

In addition to information about the traffic on the main roads, it is important that emissions along the small, local roads are taken into account. The traffic work on the local roads amounts to about 15-25% of the total traffic work for an area. The speed is normally lower than for the main roads, further the traffic is characterized by few trucks, and in the rush hours (morning and evening) the percentage of cars with cold engines is higher than the average. The numbers in Tables 3 and 4 illustrate this.

As a preliminary approach to evaluate alternative air quality programs in Oslo the following precautions were made in order to avoid systematic underestimations of the contribution from car traffic:

1) Selection of emission factors for automobile traffic that took variation in driving conditions into consideration.

2) Estimation of spatial concentration distribution function for each km^2 (grid square) to account for the high concentrations in streets with high traffic.

3 THE EMISSION SURVEY

The emission inventory for Oslo is characterized by a discription of emissions from many small sources with low emission height. Four categories are listed in a sequence according to their importance for the air pollution situation in Oslo:

1 Fuel combustion in mobile sources.
2 Oil combustion in stationary sources.
3 Combustion of wood and solid fuel including solid waste.
4 Industrial processes.

3.1 EMISSION FROM CAR TRAFFIC

The exhaust emissions from different cars are measured under laboratory conditions and the measurements are carried out and presented in two ways:

- by defining emission factors for representative driving cycles for the area under consideration.
- by defining intensity of emission in different driving modes characterized by speed and acceleration.

A selection of cars representative for the traffic has to be taken into account in both methods. Further the definition of a representative driving cycle is difficult, and this method may not be flexible to provide information on local emissions.

The second method provides basic data to define local emission when the statistics on local traffic are available.

In a street cross-section the emission intensity is integrated over the distribution of cars passing the section to obtain the local emission intensity q (x).

$$q(x) = \int_N \frac{e(V,a)}{V} dN(V,a) + \frac{e(0,0)}{L_o} \cdot f(x) \qquad (1)$$

q(x) : emisssion intensity per length unit of the road.

e(V,a) : emission per time unit for one car as a function of speed (V) and acceleration (a).

N(V,a) : the cumulative distribution of cars as a function of driving conditions past a cross section of the road (x).

N : the total number of cars per time unit (hour).

L_o : average length between idling cars.

f(x) : percentage of time a car is idling in position x.

To obtain integrated emissions over an urban area (Q), the equation (1) has to be integrated over the whole road system with length L:

$$Q = \int_L \left(\int_N \frac{e(V,a)}{V} dN(V,a)\right)dx + \frac{e(0,0)}{L_o} \cdot \int_o^L f(x)dx \qquad (2)$$

Estimation of the different terms in the equations (1) and (2) indicates that emission from idling cars contribute significantly to the local emission of carbon monoxide in stop zones. Integrated over an urban area the emission from idling cars is less important except in congested traffic situations. More data is needed on driving statistics in different traffic situations to estimate the effect of traffic regulations on pollution emission in different areas.

As the evaluation of air quality programs in Oslo is not concerned with detailed emission in specific road intersections, the driving conditions are assumed to be a function of average driving speed over a distance of one to two kilometers. Results of measurements of carbon monoxide concentrations and average driving speeds in Oslo are shown in Appendix A.

Tables 1 and 2 show typical car emissions per length unit of the road ($\frac{e(V \cdot a)}{V}$) for carbon monoxide and nitrogen oxides as determined in Studsvik (Persson, 1980) for a selection of cars typical for the traffic in Sweden. The cars were driven with warm engines in an air temperature of zero degree centigrade. This is considered to be typical for the exhaust emission in Oslo during wintertime.

Table 1: Carbon monoxide emission ($\frac{e(V \cdot a)}{V}$) as a function of driving speed and acceleration. Unit: g/km. Idling emission intensity is given in mg/s.

Acceleration (m/s^2) / Speed (km/h)	-1.8	-1.2	-0.6	0	0.6	1.2	1.8
0 (idling) unit (mg/s)				103			
0-15	39	39	49	53	88	130	99
15-30	13	13	16	17	28	43	48
30-45	9	9	12	14	19	39	48
45-60	6	7	8	13	19	50	69

Table 2: Nitrogen oxides emission ($\frac{e(V \cdot a)}{V}$) as a function of driving speed and acceleration. Unit: g/km. Idling emission intensity is given in mg/s.

Acceleration (m/s^2) / Speed (km/h)	-1.8	-1.2	-0.6	0	0.6	1.2	1.8
0 (idling) unit m/s)				2.1			
0-15	0.48	0.48	0.53	2.0	3.3	17.1	7.7
15-30	0.16	0.16	0.18	2.6	4.0	6.3	8.2
30-45	0.36	0.37	0.18	2.3	5.2	7.4	8.7
45-60	0.25	0.27	0.73	2.8	6.0	8.3	6.8

Similar tables have been prepared for cars with cold engines i.e. typical emissions during the first 6 minutes after the car has started with cold engine.

In order to characterize the driving conditions in Oslo the statistics for the centre of Stockholm were used. The percentage of time in different modes of driving are shown in Figure 5. The driving conditions are grouped as a function of speed and acceleration representing average conditions in the city centre.

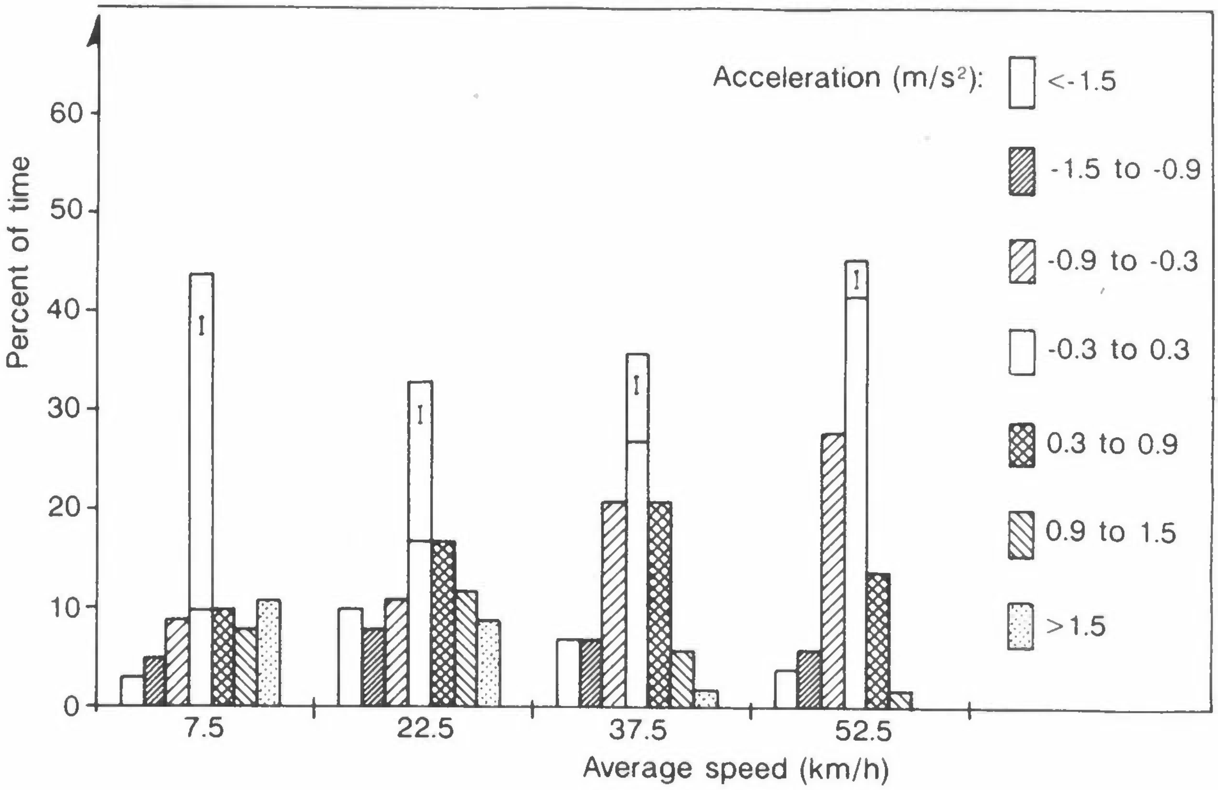


Figure 5: The percentage of time in different driving modes as a function of average driving speed. I = idling.

The time of idling in each class of average speed is also presented.

The figure shows an overload of deceleration in the two highest groups of driving speed denoted by 37.5 and 52.5 km/h. Further it is an excess of time in the acceleration phase when the driving speed is denoted by 7.5 and 22.5 km/h. The statistics represent staggered driving typical for urban centres. Further it is seen that the emission intensity is particularly dependent on the percentage of time in acceleration modes and that it is important to know excess time of idling for cars in certain regions i.e. before light regulated road intersections. In the stop zones of a street the emission intensity is further increased by the accelerations. These zones are considered as hot spots considering exhaust pollution.

To develop driving statistics for an urban area one or several cars may follow urban traffic. Recording percentage of time in groups of driving conditions characterized by speed and acceleration, the measurements may be used to estimate total emission in an urban area by equation 3.

$$Q = [\sum_{k,l} e(V_k, a_e) \Delta t_{k,l}] N \cdot L \qquad (3)$$

$\Delta t_{k,l}$: percentage of time in different driving groups characterized by driving speed V_k and acceleration a_e.

$N \cdot L$: traffic work in an area.

Based on driving statistics from Stockholm (Figure 5) and on the emission matrixes determined in Studsvik, emission factors depending on driving speed were determined, as shown in the Figures 6 and 7. These factors were used for emission calculations.

3.2 EMISSION FROM OIL AND SOLID FUEL COMBUSTION IN STATIONARY SOURCES

Burning of oil in small furnaces.

The Norwegian State Pollution Control Authority has collected data on emission and emission conditions for the large point sources in the Oslo area. Norwegian Institute for Air Research (NILU) has developed an emission survey based on data for oil consumption in each km^2 and emission factors for oil burning. The data for oil consumption in each km^2 is based on

- data from the oil companies on the amount of oil delivered in each km^2
- data from the Norwegian Petroleum Institute on the total sale in the area
- data from the Fire Brigade on oil burning equipment and the area to be heated in each km^2.

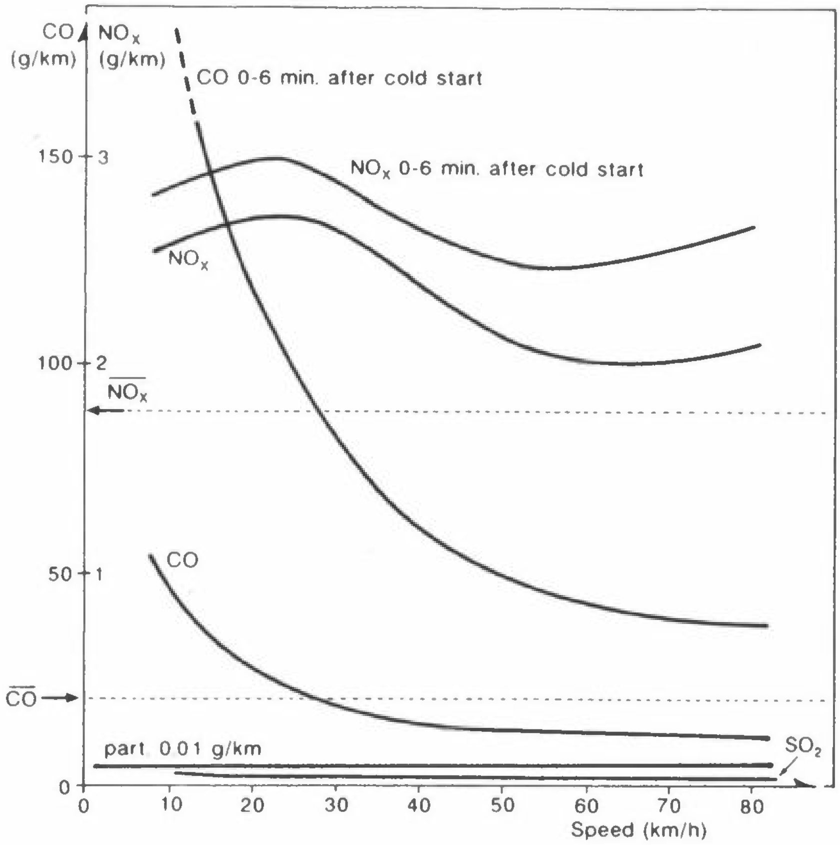


Figure 6: Average emission (Q) of carbon oxide, nitrogen oxides, soot (part.) and sulphur dioxide from gasoline cars as a function of average driving speed. Unit: g/(km·car).

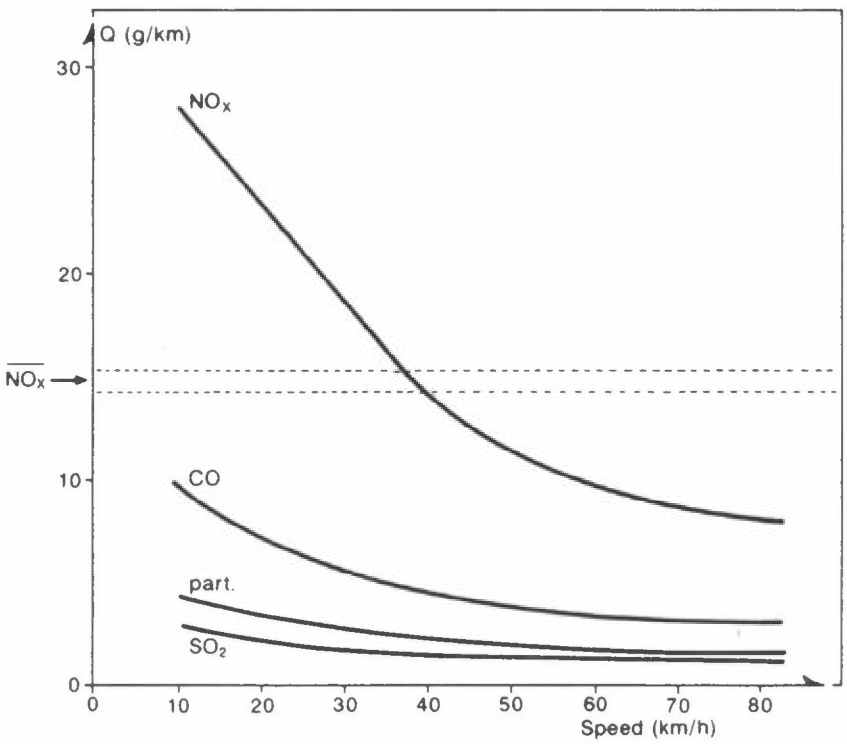


Figure 7: Average emission (Q) of carbon monoxide, nitrogen oxides, soot (part.) and sulphur dioxide from diesel cars as a function of average driving speed. Unit: g/km·car.

Burning of wood, coke and coal

Data has been collected for selected regions of the area and further generalized for the Oslo area by an Environment group at the University of Oslo in co-operation with the State Norwegian Pollution Control Authority.

Emission data for other sources

Emission data for other sources of less importance has been estimated by NILU using information from previous projects e.g. emission from Fornebu Airport and from the harbour.

Future emission

Emission effects of centralized heating systems in the different areas have been provided by Norsk Energi in co-operation with NILU. Data on future changes in activity and emission have been developed by the Norwegian State Pollution Control Authority in co-operation with the technical divisions in the local administration of Oslo.

Concerning the assumptions on future emissions different opinions have been expressed, and the numbers used in this report should only be considered as a possible future emission situation.

3.3 THE TOTAL EMISSION SURVEY AND DISCUSSION OF UNCERTAINTIES.

Total emission from different groups of sources in 1985 is shown in Table 3. Estimated emission in 2000 is given in Table 4. The tables show that the total SO_2 emission is expected to increase by 90% from 1985 to 2000, mainly due to an expected shortage of low-sulphur fuels.

Domestic heating is the dominating source for SO_2, while car traffic produce most of the CO, NOx and particulate pollution.

Table 3: Average emission of air pollution in the Oslo-area, winter 1985. Unit: kg/h.

	SO_2	NOx	CO	Part.
Single sources	160.2	93.9	20.1	5.7
Area sources	201.6	120.5	111.6	10.2
Oil burning	361.8	214.4	131.7	15.9
Main roads				
Gasoline	5.2	472.1	4777.6	11.7
Diesel	29.1	280.3	92.1	44.7
Small roads				
Gasoline	1.3	89.7	1677.4	2.1
Diesel	5.1	54.0	16.5	7.7
Car traffic	40.7	905.2	6563.6	66.2
Airport + harbour	51.4	27.9	32.2	7.6
Coke and coal	3.7	0.3	23.1	1.4
Wood	3.3	5.9	843.4	84.9
Solid fuel	7.1	6.2	866.5	86.3
Total emission	460.9	1153.7	7494.1	176.1

Table 4: Expected emission of air pollution in the Oslo-area, winter 2000. Unit: kg/h.

	SO_2	NOx	CO	Part.
Single sources	231.1	111.2	29.5	14.1
Area sources	538.2	168.2	124.8	19.0
Oil burning	769.3	279.4	154.3	33.1
Main roads				
Gasoline	1.3	120.4	1885.6	2.9
Diesel	40.8	372.7	126.4	61.7
Small roads				
Gasoline	0.4	30.3	864.2	0.7
Diesel	6.5	67.7	21.1	9.9
Car traffic	48.9	590.8	2897.2	75.1
Airport + Harbour	51.4	27.9	32.2	7.6
Coke and coal	3.7	0.3	23.1	1.4
Wood	4.0	8.7	927.3	91.7
Solid fuel	7.7	9.0	950.4	93.1
Total emission	877.3	897.1	4034.1	208.8

The increase in traffic volume in Oslo by 30% in the period are not excepted to increase pollution emission. The introduction of the catalytic converter is expected to decrease exhaust pollution substantially, in particular for carbon monoxide from gasoline cars.

In the year 2000 home heating will still be the main cause of SO_2-pollution. Without the catalytic converter the increase in car traffic is expected to cause a substantial increase in emission of exhaust pollution (CO, NOx and particulates) from cars. The introduction of the catalytic converter on cars with gasoline engines will gradually decrease the CO-problem from 1988, while the NOx and particulate emission from diesel cars will characterize the exhaust pollution in 2000.

Based upon NILU´s experience with calculation of air pollution concentrations in other urban areas (see Chapter 2), the largest uncertainties are expected to be in the model for the emission of exhaust pollution.

A velocity dependent emission factor for car traffic improve the correspondence between calculated and observed concentrations. However, it is not likely that the driving statistics from the centre of Stockholm are representative outside urban centres with many intersecting streets, e.g. the driving statistics on highways with or without traffic congestion follow other driving statistics. To reduce emission uncertainty for exhaust emission more data on driving statistics is needed. In particular it is important to get reliable data on frequency and duration of strong accelerations, on idling time in stop zones as a function of traffic intensity, and in queue zones during rush hours.

4 DISPERSION CALCULATIONS

Pollution problems with different spatial scales may be combined by estimating spatial distribution functions for each grid-square.

In Oslo the dispersion calculations are carried out in a 1 km x 1 km grid with a description of high concentrations in areas with high traffic. To be consistent with available data on car traffic, average

24 hour mean values are considered. Short term episodes occurring during the winter are also important for the air pollution problems in Oslo.

4.1 DILUTION OF EMISSIONS FROM AREA AND POINT SOURCES

The pollution contribution from a large number of small sources in each km^2 (an area source) is taken into account by considering 100 point sources evenly distributed over the square-km (Fortak, 1970). The contribution from the area source is tabulated as a function of distance, wind speed and dispersion conditions. Actual concentrations are calculated by interpolation between tabulated values.

For each point source the narrow plume hypothesis (Calder, 1974) is applied in 12 windsectors of 30 degrees. The average contribution from one point source is described by the following formula:

$$C_i(x,y,o) = \frac{n}{2\pi} \sum_{k=1}^{n} \sum_{l=1}^{4} \sum_{m=1} Q_i \cdot f(k,l,m) \cdot S_{i,k} \cdot D_{l,m}(d_i)$$

$C_i(x,y,o)$: Concentration from source number i at ground level in location (x,y), referring to a co-ordinate system with origin located at the source number i.

Q_i : The emission intensity of source number i [g/s].

n : Number of windsectors (12).

f(k,l,m) : Conditional frequency of hourly wind observations in twelve windsectors (k=1,...,12), four wind speed classes (l=1,...,4) and four dispersion classes (m=1,...,4).

$S_{i,k}$: sector discriminator i.e.

$$S_{i,k} = \begin{cases} 1 & \text{if receptor point is within the windsector k from source number i} \\ 0 & \text{otherwise} \end{cases}$$

$D_{l,m}(d_i)$: Dilution factor i.e.

$$D_{l,m}(d_i) = \frac{1}{d_i} (\sqrt{\frac{2}{\pi}} \cdot \frac{0.5 \cdot (1+\alpha)}{U_l \cdot \sigma_m} \exp((H/\sigma_m(d_i))^2)$$

d_i : The distance from the source number i to the receptor location x,y i.e.

d_i $= \sqrt{x^2 + y^2}$

$\sigma_m(d_i)$: The standard deviation in the Gaussian concentration distribution along the vertical axis.

α : Reflection factor i.e. the vertical concentration distribution are influenced by reflection at the ground and total reflection was used in the calculations.

U_1 : The average wind speed in wind speed class number 1 [m/s].

H : The effective source height [m].

4.2 DILUTION OF EMISSION FROM CAR TRAFFIC

The method for calculating concentrations in urban streets is based on the S.R.I. model (Johnson, 1970). The description of concentration in a street consists of three terms:

C_o : Concentration in the air entering the street [µg/m^3].

ΔC_L : Concentration on leeward side of the street [µg/m^3].

ΔC_W : Concentration on the windward side of the street [µg/m^3]

C_o : The background concentration (C_o) is calculated by the area and point source model not taking into account the emission from the street under consideration.

$$\Delta C_L = \frac{K \cdot q_s}{(u+u_0)[(x^2+z^2)^{0.5}+L_0]}$$

$$\Delta C_W = \frac{K \cdot q_s (H-z)}{(u+u_0) \cdot H \cdot W}$$

q_s : Rate of emission in the street [g/m·s].

K, L_0, u_0 : Empirical constants used to get correspondence between observed and calculated concentration values close to the traffic lanes (L_0) and during low wind conditions (u_0).

In the Nordic method of calculation (Nordisk ministerråd, 1984) an empirical model is developed based on SRI framework using

- The procedure for calculating emission far from road intersections, described in the previous chapter.
- Series of concentration values measured in urban areas under consideration (i.e. Stockholm, Oslo and some smaller towns).
- The empirical parameters K, L_0 and u_0 are determined to develop a model for episode concentration values (99 percentile value) to be compared with air quality standards.

To estimate the reduction in concentration as a function of distance from the road the emission is integrated over the road i.e. when the wind is perpendicular to the road:

$$C(X_0) = \sqrt{\frac{2}{\pi}}\,\frac{q_i}{B \cdot u} \int_{X_0}^{X_0+B} \frac{dx}{(a+bx)^c}$$

q_i : Emission intensity along the road segment (i).
X_0 : Distance from the road.
u : Wind speed.
B : Road width.
a, b and c: Empirical parameters.

On the leeside of the road the concentration will fall according to the following formula:

$$C(x) = \sqrt{\frac{2}{\pi}}\,\frac{q_i}{B \cdot u}\,F_B(x)$$

$$F_B(x) = \frac{1}{(1-c)\cdot b}\,[(a+b(B+x))^{1-c} - (a+bx)^{1-c}]$$

In order to avoid the definition of wind speed perpendicular to the road, the ratio between the concentration at a distance x from the road and the concentration at the road is expressed by f(x) given in the following expression:

$$f(x) = \frac{F_B(x)}{F_B(0)} = \frac{(a+b(B+x))^{1-c} - (a+bx)^{1-c}}{(a+bB)^{1-c} - a^{1-c}}$$

Calculating the decay curve the parameters given in Table 5 were used according to General Motors´ investigation of dispersion downwind of roads (Chock, 1977).

Table 5: Parameters describing dispersion downwind of a road with high traffic.

$$\sigma_m (x) = (a+bx)^c$$

m		a[m]	b	1-c
1	Unstable	1.14	0.05	-0.33
2	Neutral	1.14	0.10	0.03
3	Stable	1.49	0.15	0.23

The decay curve calculated for neutral atmospheric conditions (m=2), is shown in Figure 8 together with results of simultaneous measurements at different distances from the road.

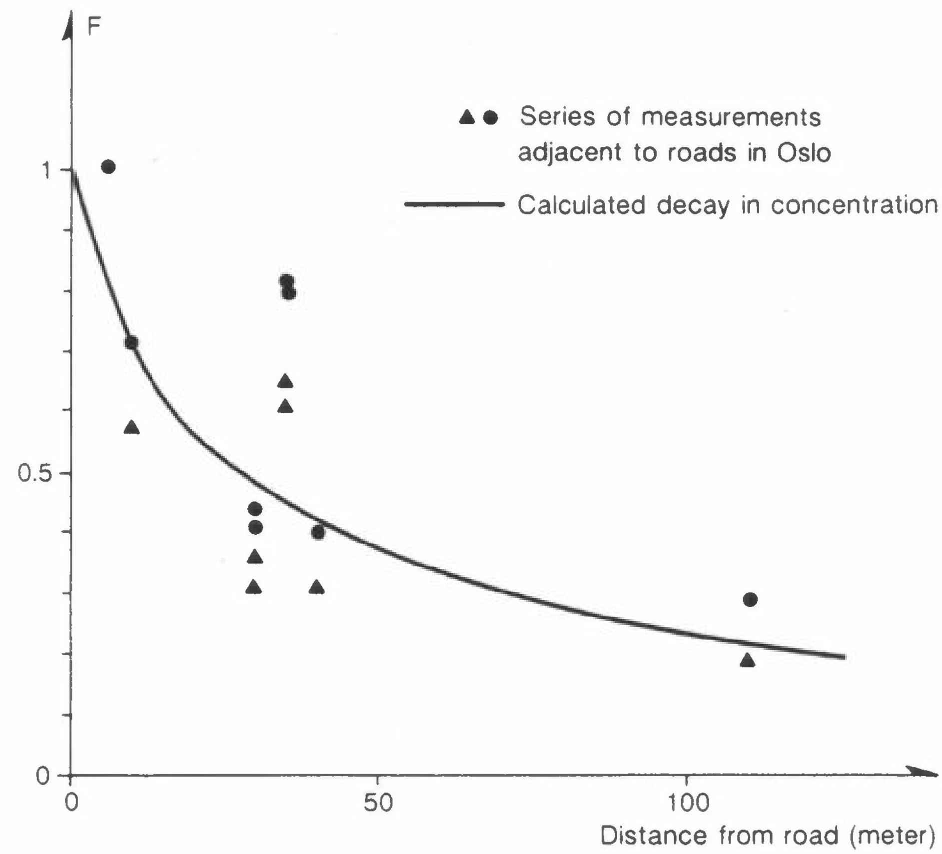


Figure 8: The decay in concentration as a function of distance from the road.

The figure shows variable results from different series of measurements. Detailed data on local dispersion is not available and the calculated decay curve is accepted as an overall characterization of the reduction in concentration with distance from the road.

5 SPATIAL CONCENTRATION DISTRIBUTION FOR EXPOSURE ESTIMATION

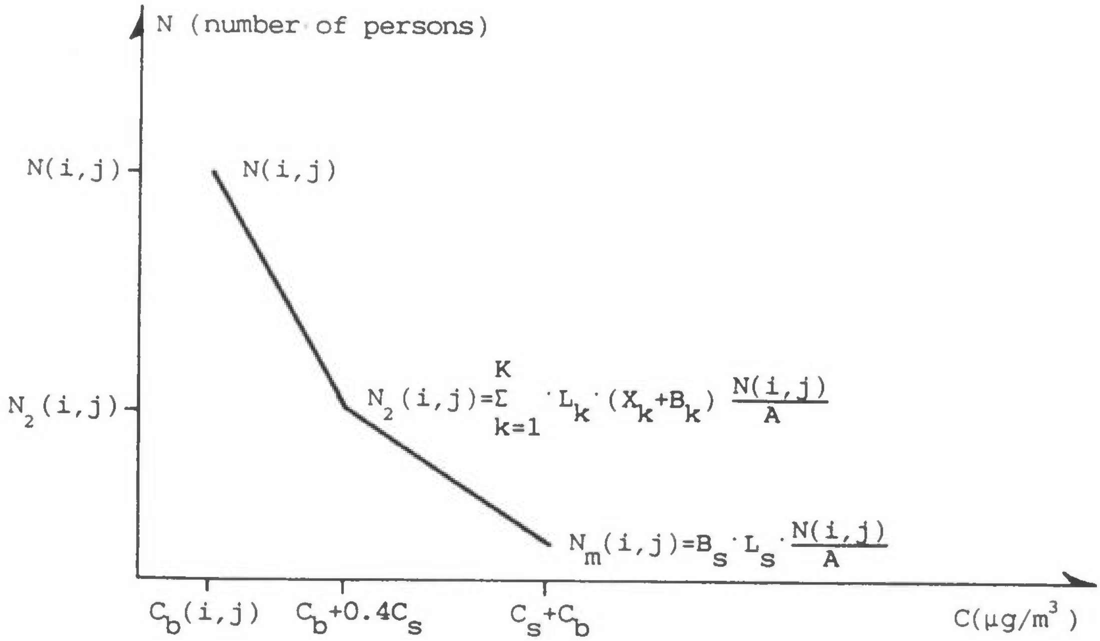
The local air pollution concentration in an urban area consists of the following additive contributions

- the contribution from neighbouring square-km areas: c_0
- contribution from local street emissions: c_s
- contribution from other sources within the square-km: c_a.

The concentrations within a street (C_s) are calculated by the street canyon model and the concentration by the area sources are calculated by the square-km model (C_b).

The spatial concentration distribution within each square-km is characterized by a minimum concentration that all people are exposed to and a maximum concentration affecting only few people. The background concentration (C_b) are calculated by the square-km model. In this way two points on the cumulative exposure curve are determined. A third point is found by calculating the area of the zone around local streets where the concentration exceedes the area source contribution (C_b) pluss 40 per cent of the maximum street concentration from local street emission. When developing the simplified model it was found that the 40% concentration value gave a reasonable approximation of the exposure curve as shown in Figure 9. When the population exposure is summarized for the Oslo area the curve become continuous and represents a combination of models on two different scales.

The function N (i,j) is used to account for differences between square-km areas considering air quality impact. In Oslo the residential distribution of people is used. The distribution of people in the urban area during the working hours would be different and the residential distribution is only applicable to study the impact of long term average concentration distribution.



$N_{(i,j)}$: total number of people living in a square-km
C_b : background concentration in the square-km
C_s : the maximum street concentration in the square-km
B_s, L_s : the width and the length of the street segment with maximum street concentration C_s.
X_k, L_k : the width and the length of the zone adjacent to the street segment k where the concentration is higher than 0.4 C_s.
B_k : width of the street segment k.

Figure 9: Estimated number of people living in areas where the pollution concentration is higher than the values given along the horizontal axis. One such curve applies for each square-km.

6 RESULTS OF POPULATION EXPOSURE CALCULATIONS

The Figures 10-13 show the cumulative distribution of people living in areas of Oslo with observed concentrations above values given along the horizontal axis.

Figure 10 shows results for sulphur dioxide pollution.

The distribution curves appear as straight lines on Gaussian distribution paper. Distribution lines are given for SO_2-pollution in 1985, for SO_2-pollution in 2000 provided no further air quality programs are accomplished and for SO_2-pollution in 2000 if a centralized heating system is developed (C.H.-2000). The SO_2-emissions from low level area sources will be replaced by emissions in a few high stacks. The estimated trend from 1985 to 2000 indicates a considerable increase in the SO_2-pollution. The future problem may be avoided by the construction of a centralized heating system in different areas of the city.

Figure 11 shows results for nitrogen dioxide.

The calculated trend from 1985 to 2000 indicate a considerable reduction of the NO_2-problem. The expected reduction is a result of the introduction of catalytic converters installed in new gasoline cars from 1988. If the catalytic converter was not installed, a further increase in the NO_2-problem would occur. This curve is marked UKAT-2000. Based on other calculations the Norwegian Institute for Transport Economy (TØI) has proposed a combination of traffic regulations to restrict the use of cars in the city centre. The effect on NO_2-pollution is indicated by the curve marked TRAF-RED-2000.

As for the SO_2-pollution the NO_2-curves appear as straight lines on the probability paper.

Figure 12 shows results for CO-concentrations.

Unlike the results for SO_2 and NO_2 the CO-curves contain a tail towards high concentrations. The tail is a result of high concentrations in streets with high traffic and the curves appear as straight lines on a log-normal paper. The curves show that the carbon monoxide problem in 1985 will disappear with the introduction of catalytic converter. The problem would increase if the converter were not installed.

Figure 13 shows results for the particulate pollution.

Particulate pollution is a result of emissions of small particles from several groups of sources and the distributions do not resemble normal or log-normal simplifications.

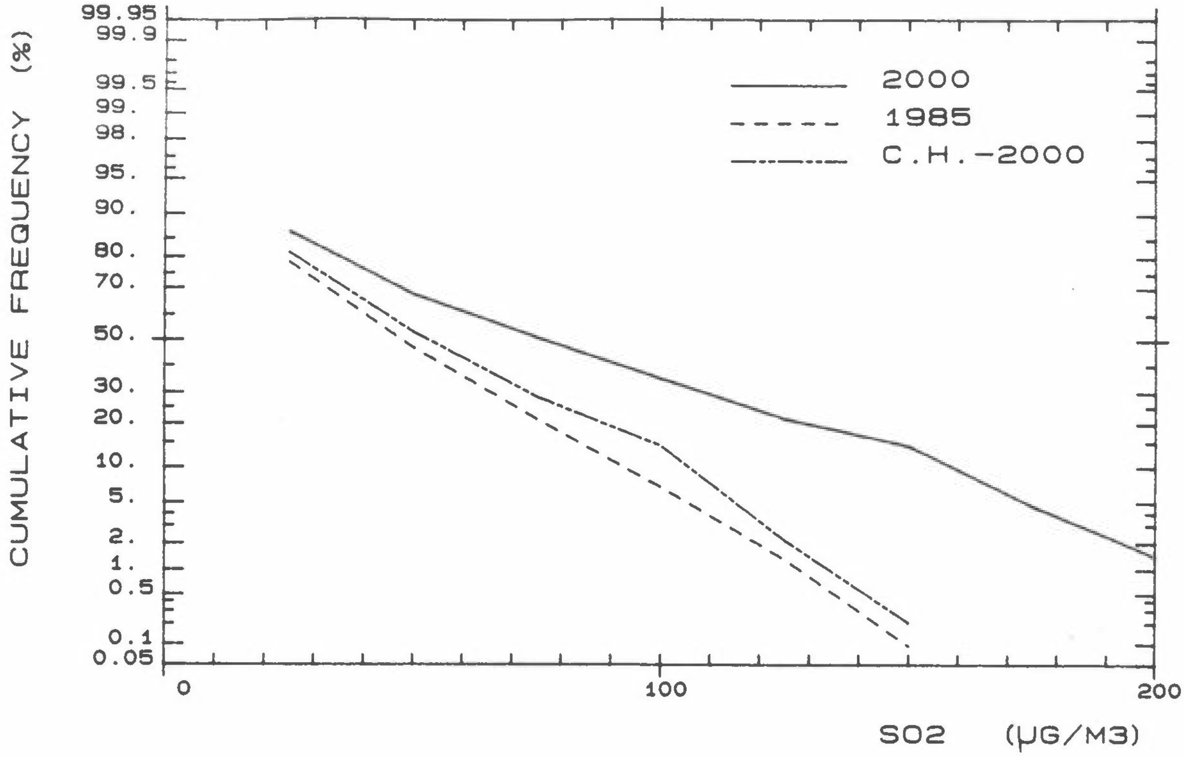


Figure 10: The distribution of inhabitants in Oslo living in areas with maximum 24-hour mean SO_2-concentration above given values.

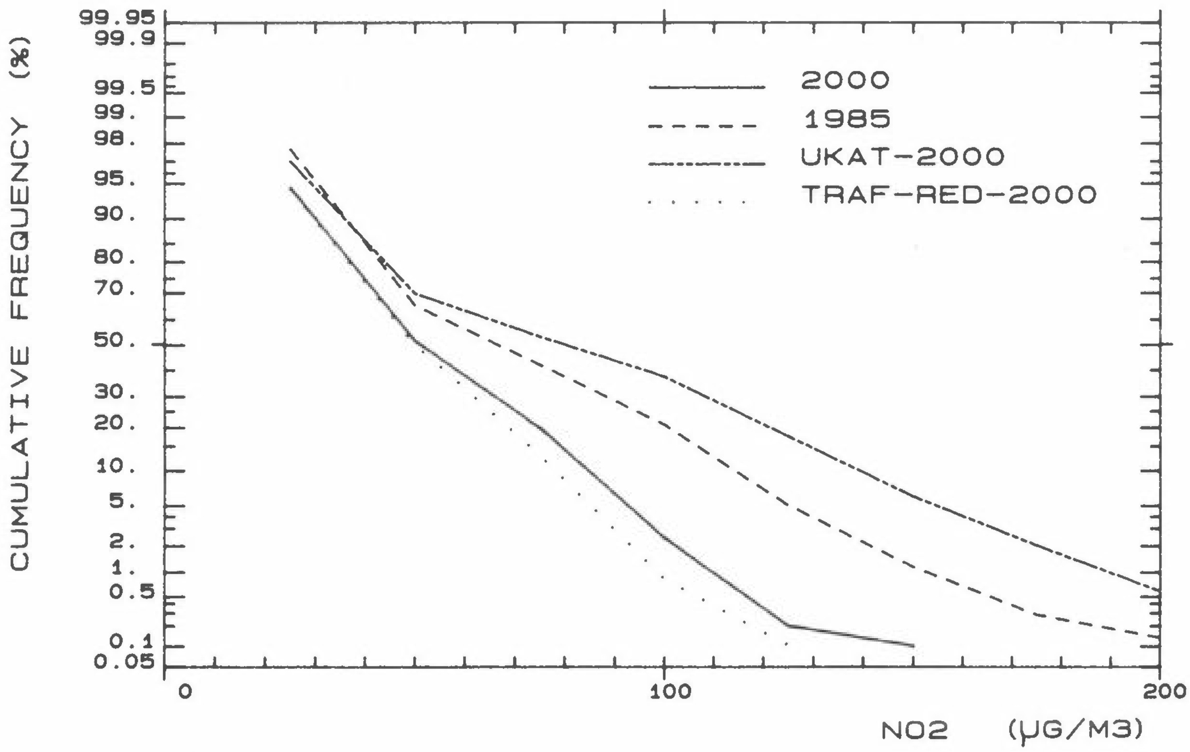


Figure 11: The distribution of inhabitants in Oslo living in areas with maximum 24-hour mean NO_2-concentration above given values.

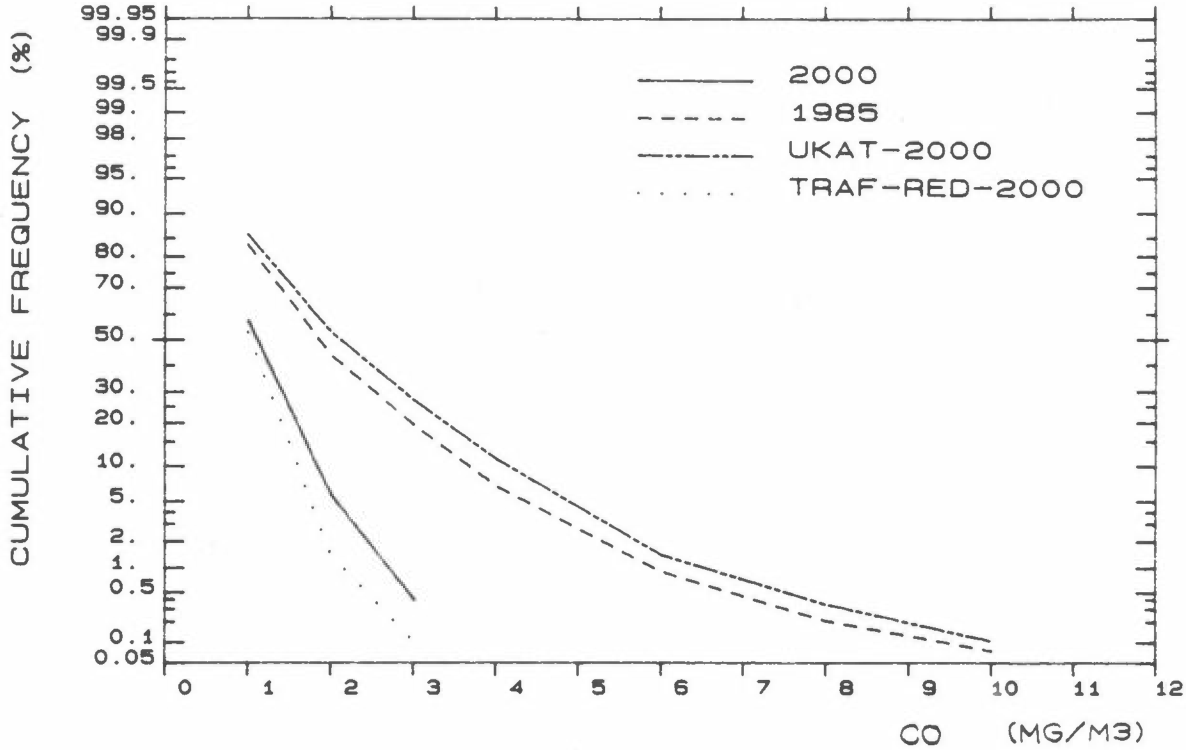


Figure 12: The distribution of inhabitants in Oslo living in areas with maximum 24-hour mean CO-concentration above given values.

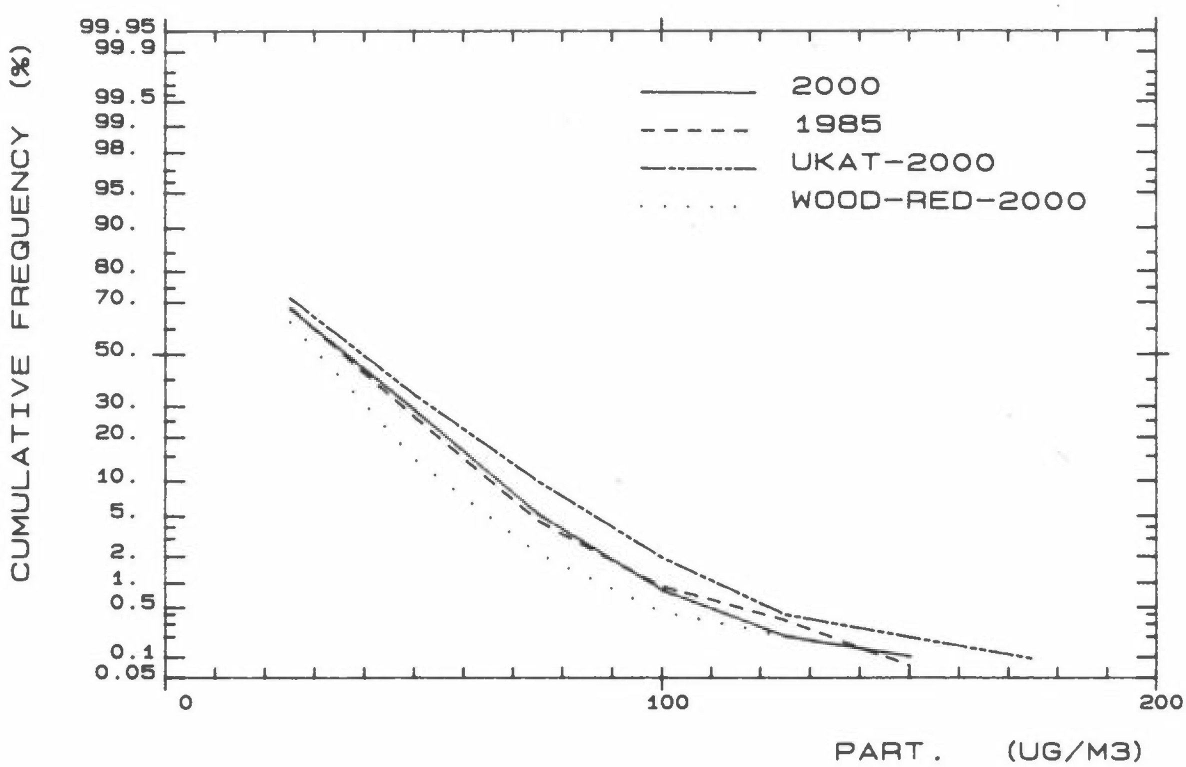


Figure 13: The distribution of inhabitants in Oslo living in areas with maximum daily particulate-concentration above given values.

The introduction of catalytic converter will reduce the problem slightly from 1985 to 2000. The introduction of a centralized heating system has a minor effect on the particulate problem. Some improvement, however, may be obtained by restrictions on the use of wood in small furnaces. The maximum effect is shown in the distribution curve marked WOOD-RED-2000.

It is further seen that the tail of the curve is only influenced to a minor extent. To reduce the number of people influenced by high concentration, reduction of the emissions from the diesel cars seems to be the most effective method.

7 DISCUSSION OF RESULTS

When several groups of sources contribute to an urban air pollution problem, planning of air quality programs should be based on knowledge of the influence from each group to the human exposure. This information may be obtained by collecting data on emission and dispersion.

Description of emission

The two main source categories in Oslo are burning of oil for heating purposes and exhaust emission from car traffic. Dispersion calculations in different urban areas indicate that the intrinsic uncertainties in the methods to estimate emission from car traffic are limiting the accuracy of the emission survey. The uncertainty is probably reduced in Oslo by the introduction of emission factors depending on driving speed. The emission factors, however, are based on limited data for driving statistics, and more data are also needed for the distribution of driving speeds in Oslo. Missing data for car traffic in rush-hours including data for the stop zones was the main reason for restricting the calulations to 24 hour mean values.

The exhaust pollution in rush-hours constitute an important part of the pollution problem in Oslo. Further the increase in traffic during the rush-hour provide information on how the road system will function in the future with an increasing traffic volume.

Emissions from oilburning furnaces are estimated by collecting data on the usage of oil and emission factors. Considering SO_2, it is believed that the data for the sulphur content in oil provide relevant data for the emission distribution. Considering emission of nitrogen oxides and particulates these emissions are also dependent on the burning conditions in the different furnaces. As these data are not available, additional uncertainties has to be taken into account, and the emission data base is not satisfactory to explore the effect of improved maintainance of oil furnaces. In addition to the main groups of sources there are several smaller groups, e.g. the use of wood, the airport and the harbour.

Description of dispersion and exposure

The spatial concentration distribution in an urban area is usually complex and the maximum-zones become particular important when violation of air quality standards are used for the evaluation of pollution effects. To perform relevant dispersion calculations two different scales were taken into account by calculating average pollution concentration for each square in a grid-system and estimating spatial distribution parameters for each square using information of the traffic intensity. The pollution distribution curves (Figure 10-Figure 13) may be used in further analysis to select optimum air quality programs based on cost-effect evaluation. The cost-effect analysis of 38 measures to reduce air pollution in Oslo were performed by the State Pollution Control Authority.

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APPENDIX A

Measurements of average CO-concentrations
and driving speeds along main roads
and streets in Oslo

MEASUREMENTS OF AVERAGE CO-CONCENTRATIONS AND DRIVING SPEEDS ALONG MAIN ROADS AND STREETS IN OSLO

EPA´s monitors were used in six cars to measure average CO-concentrations along main roads in Oslo. The cars followed driving routes with specified road segments. Average CO-concentrations and driving speeds were recorded along the road segments.

The measurements went on continuously during the following time periods:

August 20, 1987 1300-1700
August 21, 1987 0700-0930

For data reduction the rushhours (1500-1630) and (0730-0900) characterized by reduced driving speed were extracted. The time periods before and after the afternoon rushhour and after the morning rushhour gave the additional data to evaluate the effect of increased traffic intencity and reduced driving speeds.

Table A1 shows data on wind direction, wind speed and traffic intensity as average values for the periods of measurements.

Table A1: Data on wind and traffic intensity.

	August 21, 1987						August 22, 1987			
	1300-1500		1500-1630		1630-1730		0730-0900		0900-1000	
Valle Hovin	260	1.1	250	1.5	250	1.2	210	2.0	220	2.1
Kontraskjæret	260	1.2	230	1.6	200	1.3	200	1.1	200	1.4
Nordahl Bruns gt										
Hourly traffic	% 152		% 192		% 193		% 144		% 128	

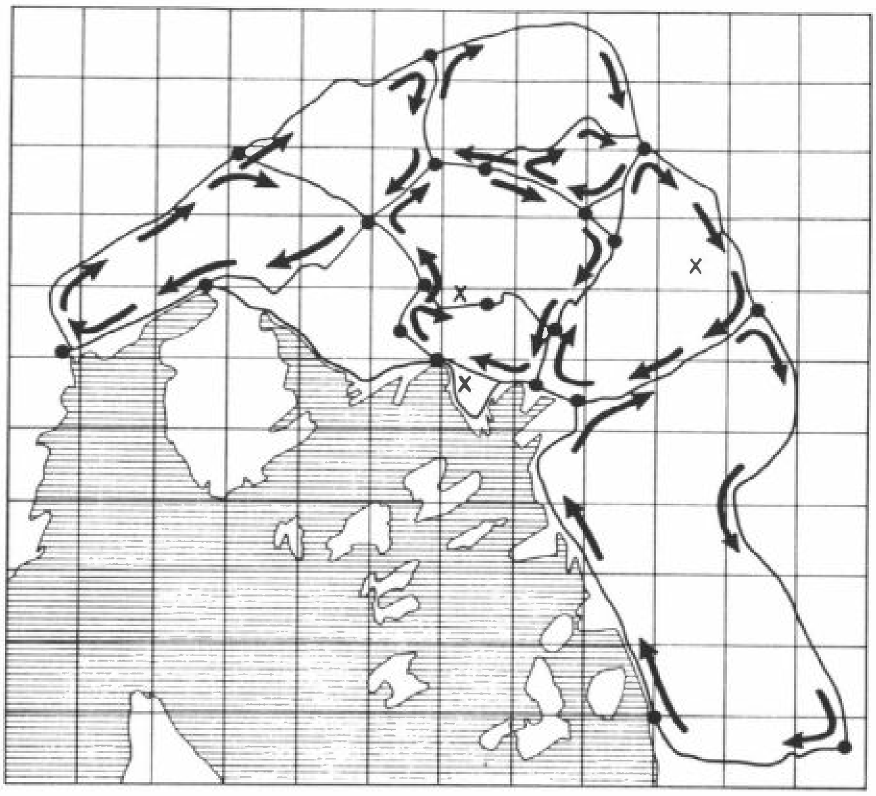

Figure A1: Driving cycles in Oslo for measuring average CO-concentrations and average driving speed. The locations of windstations are marked.

Figure A1 shows the direction of driving along the different routes and the location of wind measuring stations. Figure A2 shows the measuring results before (-15h) and within (1500-1630) the rushhour August 20. As urban values the traffic intencity increased by 26% and the wind speed by 35%. The combined effect on the CO-concentration should be small values for concentration and average driving speeds shown in the figures for the different driving periods are based on measurements from 2-5 driving cycles. The road segments in the city centre were short and the values for average driving speed became inaccurate to reduce the errors in the determination of average driving speed. Only one value was given for the city centre in each driving period. Along each road segment the average CO-concentration is given as a single value in a frame.

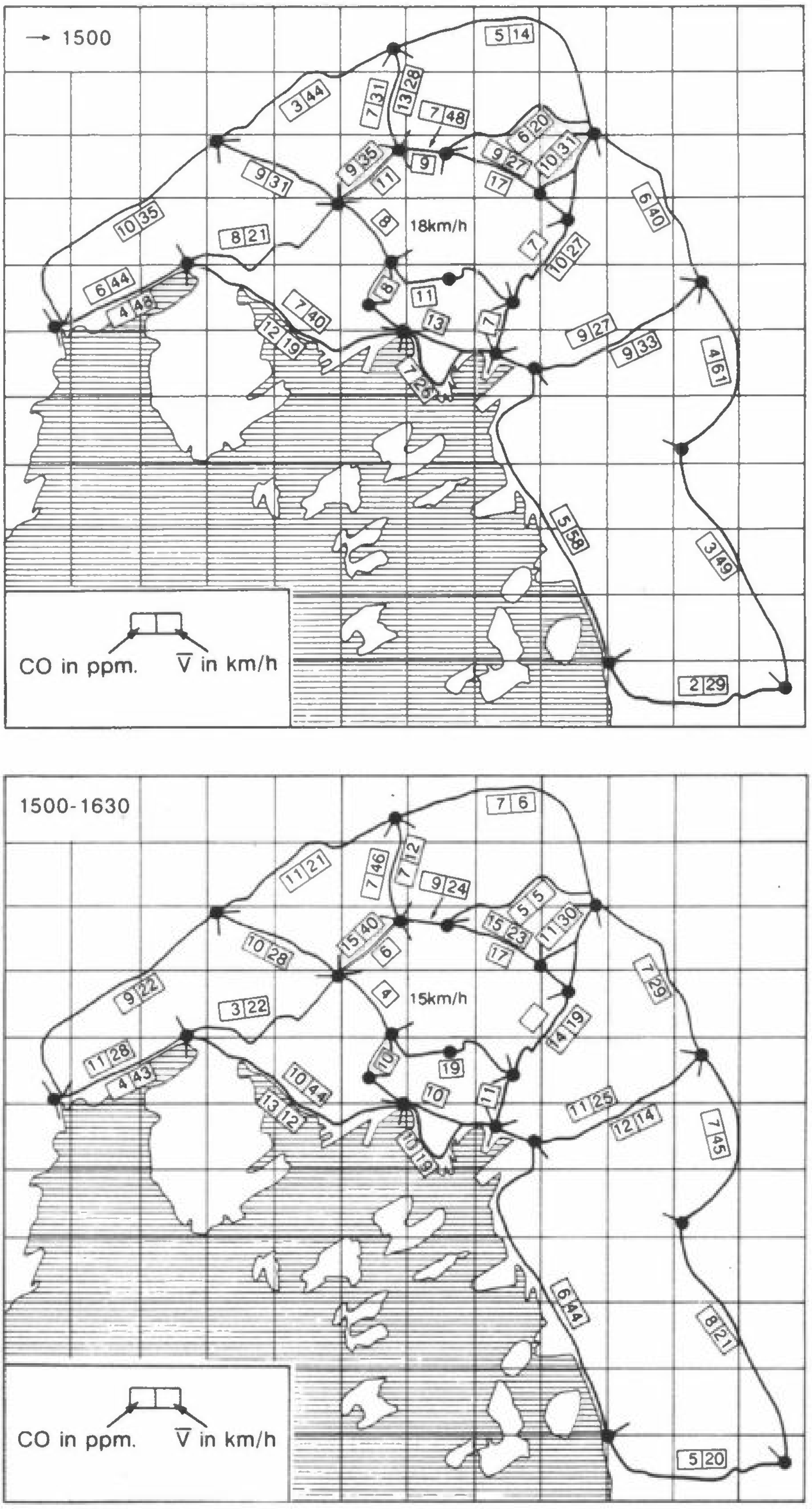

Figure A2: Average concentration of (CO) and average driving speeds ($\bar{V}$) measured along road segments before the rushhour (→1500) and during the rushhour (1500-1630) in Oslo August 20, 1987.

The measurements show that average driving speed are reduced along every segment and that the CO-concentration becomes larger than expected from the increased traffic intensity compensated by the increased wind speed. On the main roads around the city centre the CO-concentration increased by nearly 50 percent. In the city centre the reduction in CO-concentration was not so large. In order to explain the increased CO-concentration the increased emission as a result of decreased driving speed has to be taken into account.

As a first estimate the ratio of concentration in the rushhour (C_r) and the concentration before the rushhour (C) may be estimated as

$$\frac{C_r}{C} = \frac{e(V_r) \cdot N_r \cdot (u_r+u_o)}{e(V_1) \cdot N_1 \cdot (u_1+u_o)} \approx 1.04 \cdot \frac{e(V_r)}{e(V_1)}$$

The average driving speed is reduced by 17% in the city centre and by 39% around the city centre.

The data further indicate that the traffic flow and the emission of exhaust pollution in an urban area is influenced by many factors and that many areas should be treated separately.

The results of this short study shows that it is possible with simple equipment to get valuable information about driving speeds and CO-concentrations. It is necessary to extend the study in order to get better information for selected driving routes, and to compare the results with the driving statistics from Stockholm.

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2001 Lillestrøm

3 STIKKORD (à maks. 20 anslag)

Emission	Dispersion	Exposure

REFERAT

Forurensninsbidrag fra bileksos, boligoppvarming og fra industri til befolkningseksponeringen i Oslo er beregnet på grunnlag av data for utslipp og spredning. Beregningene er utført i km^2-ruter med spesielle beregninger for veier med høy trafikk og for punktkilder. Antall personer som bor i hver km^2-rute kombinert med den romlige fordelingen av forurensninger i hver km^2 er benyttet til å oppsummere befolkningseksponeringen på grunnlag av midlere 24-timers konsentrasjon.

ABSTRACT (max. 300 characters, 7 lines)

The contribution of air pollution from car traffic, home heating and industry to the population exposure in Oslo is determined by calculations based upon data for emission and dispersion.
The calculations are carried out in a km^2-grid with special calculations for roads with high traffic and for large point sources. Based on data for pollution advection into each km^2, on local contribution and on the concentrations close to streets with high traffic, estimates are made of the cumulative spatial distribution of pollution within each km^2.
The number of people living in each km^2 combined with the spatial concentration distributions are used to summarize the population exposure to 24 hour mean episodic concentrations values.

* Kategorier: Åpen - kan bestilles fra NILU A
Må bestilles gjennom oppdragsgiver B
Kan ikke utleveres C