3.4.3 Summary for Quantity of Air Pollutant Emission

(1) Pollutant Emission Quantity by Source

The pollutant emission quantity by source is shown in Table 3.4.30.

Although the quantity of pollutant emissions shown in the table is used in the air quality simulation, it does not represent the total emission in the Mexico Valley or in AMCM as stated at the beginning of Section 3.4.

The SOx emissions are primarily from stationary sources at 87,146 ton/y of the total of 105,282 ton/y. The CO emission quantity was calculated solely for automobiles and amounts to 1,050,221 t/y.

The NOx emissions are primarily from mobile sources at 41,432 t/y of the total of 65,749 t/y. The HC emission quantity, calculated for reference, for automobiles is 89,189 t/y.

Table 3.4.30 Pollutant Emission Quantity by Source

Classification	Pollutant Sources		SO_x	CO	NO_x	Smoke and Soot
			(Nm^3/h) (ton/y)			(kg/h) (ton/y)
Stationary Sources	Factories	Power Plants	2186.2 54717.4	– –	801.9 14426.3	100.9 883.7
		18 De Marzo Refinery	191.8 4800.9	– –	214.8 3863.3	129.7 1136.4
		10 Major Factories	613.4 15353.2	– –	82.1 1477.7	69.8 611.2
		Other Factories	325.8 8153.5	– –	202.0 3633.4	150.9 1322.5
		Factories Total	3317.2 83025.0	– –	1300.8 23400.7	451.3 3953.8
	Service and Commercial Establishments		164.6 4120.6	– –	50.9 916.3	39.9 349.8
	Stationary Sources Total		3481.8 87145.6	– –	1351.7 24617.0	491.2 4303.6
Mobile Sources	Automobiles	Major Roads	320.7 8025.3	45722 500652	1113.5 20031.4	– –
		Narrower Roads	402.9 10083.7	50189 549569	1179.1 21210.8	– –
		Automobiles Total	723.6 18109.0	95911 1050221	2292.6 41242.2	– –
	Airplanes	Climb Approach/Landing	0.3 8.5	– –	3.2 57.2	– –
		Idling/Taxing Take-off	0.8 19.3	– –	7.3 132.2	– –
		Airplanes Total	1.1 27.8	– –	10.5 189.4	– –
	Mobile Sources Total		724.7 18136.8	95911 1050221	2303.1 41431.6	– –
Total			4206.5 105282.4	95911 1050221	3654.8 65748.6	491.2 4303.6

(2) Regional Distribution of Pollutant Emission

The study area was divided into five regions (NE, NW, C, SE, SW) as shown in Figure 3.4.14, and the emission quantity of stationary and mobile sources for each region is shown in Figure 3.4.13.

Emissions of SOx and NOx from stationary sources are large in NE and NW regions, and those from mobile sources are large in C, SE, and SW regions.

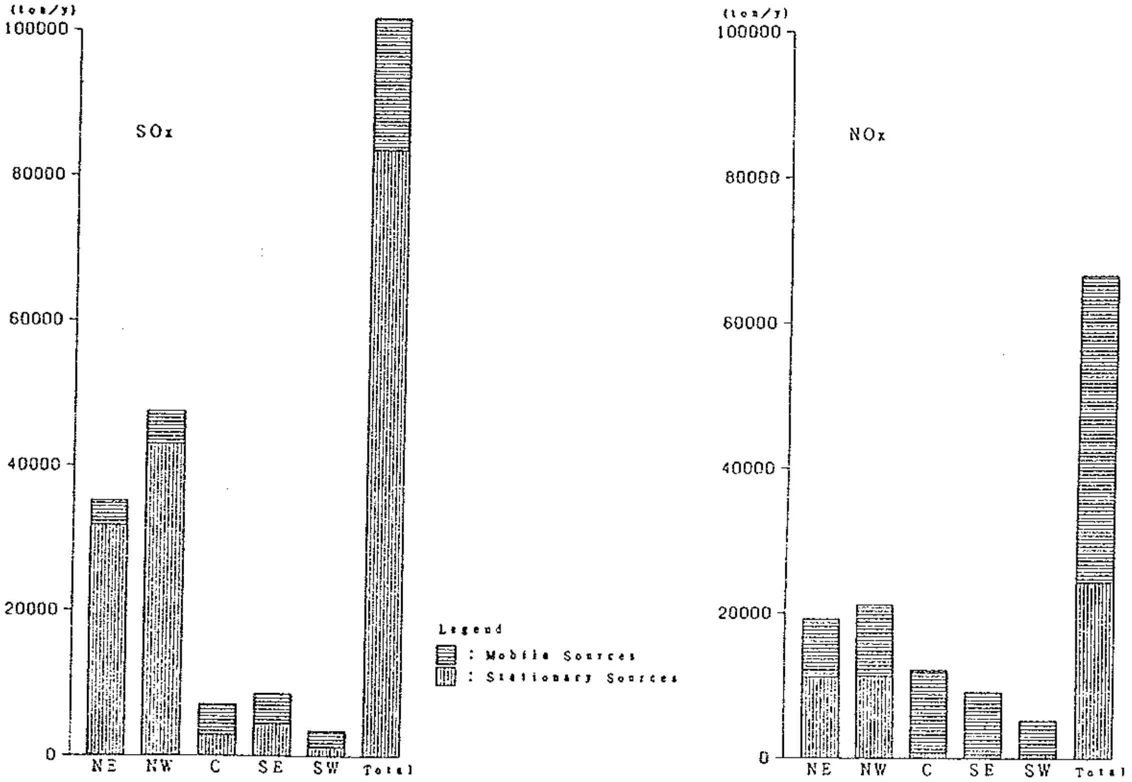


Figure 3.4.13 Pollutant Emission Quantity by Region and by Type of Source

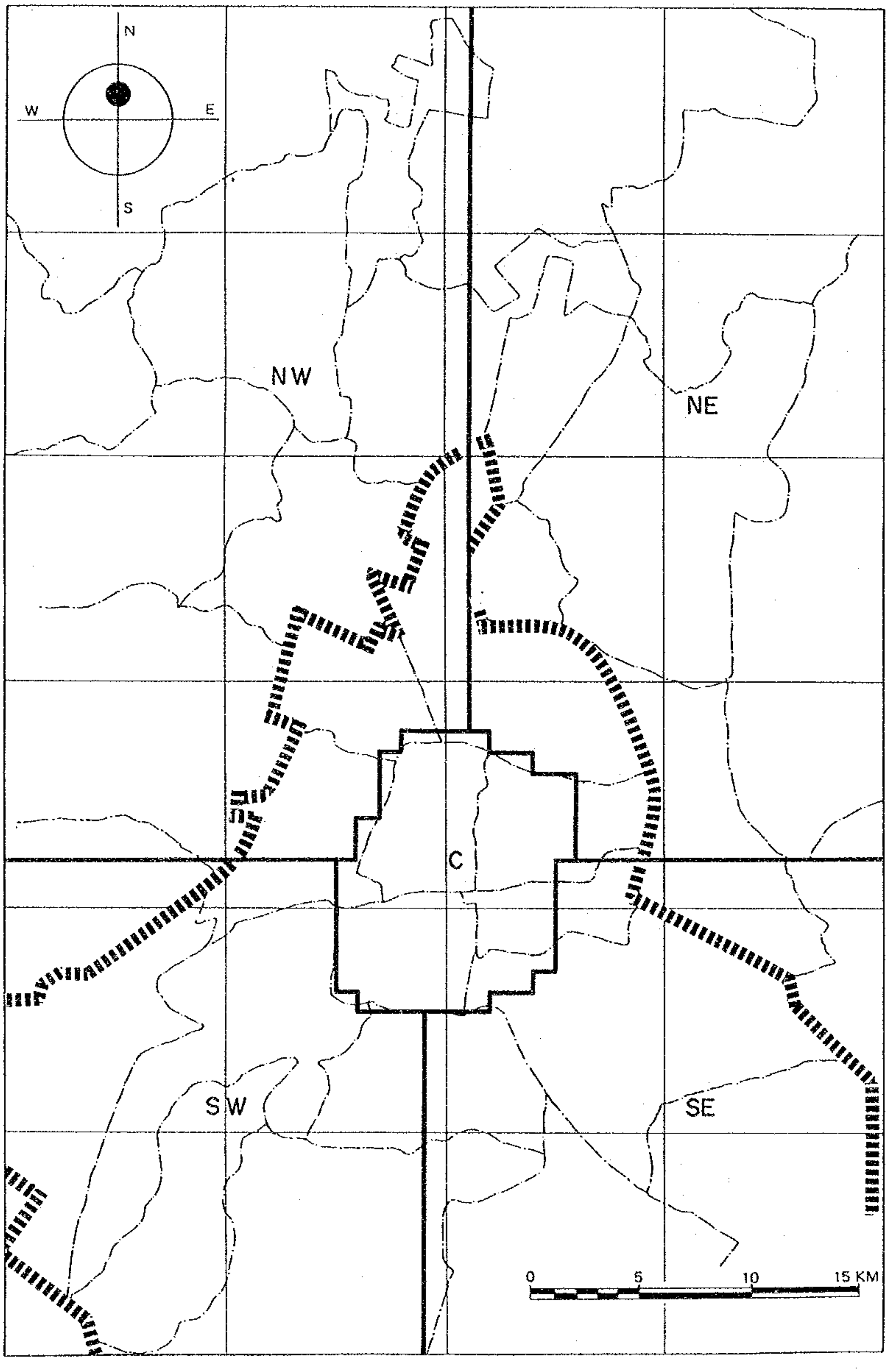


Figure 3.4.14 Division of the Study Area

(3) Areal Distribution of Pollutant Emission

The areal distribution of quantity of pollutant emission is described below.

1) SOx

Figures 3.4.15 and 3.4.16 show the areal distributions of SOx emissions from mobile sources and stationary sources, respectively, and Figure 3.4.17 the total of these.

Emissions from mobile sources are large in the central part of the city and the zones along the road running from urban area to the northeast and southeast.

Emissions from stationary source are large in the northeastern and northwestern areas. In the central area, there are some zones with relatively large emission scattered about.

2) CO

Figure 3.4.18 shows the distribution of CO emissions from automobiles.

Although, the CO emission quantity is larger than that of SOx for mobile sources, the distribution pattern is similar.

3) NOx

Figures 3.4.19 through 3.4.21 show the distribution of NOx emissions from mobile sources, stationary sources, and the total of these, respectively.

The distribution patterns for both mobile sources and stationary sources are similar to those of SOx.

4) Smoke and Soot

Figure 3.4.22 shows the distribution of smoke and soot emissions.

The distribution pattern is also similar to that of SOx from stationary sources.

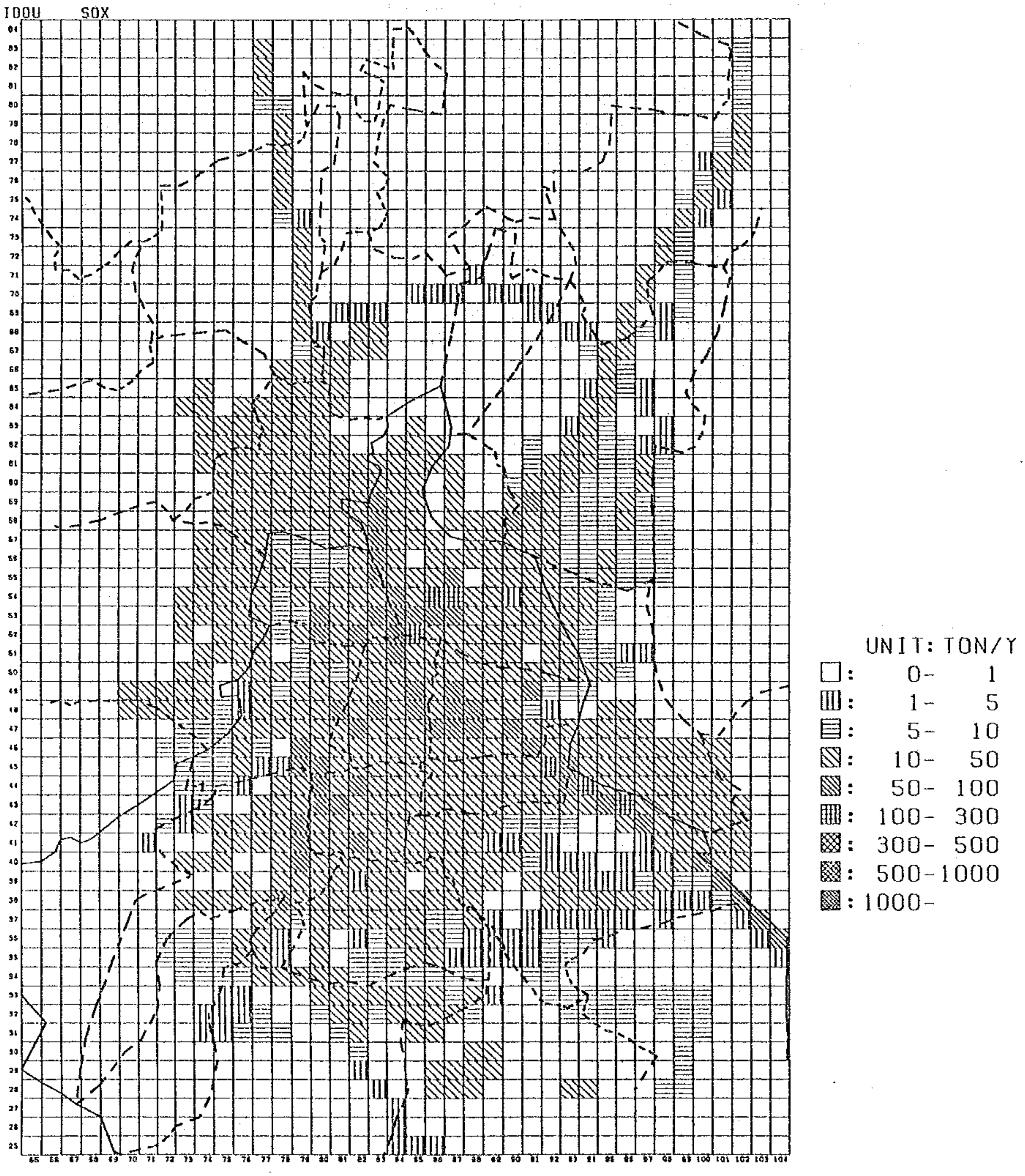


Figure 3.4.15 Distribution of SOx Emissions (Mobile Source)

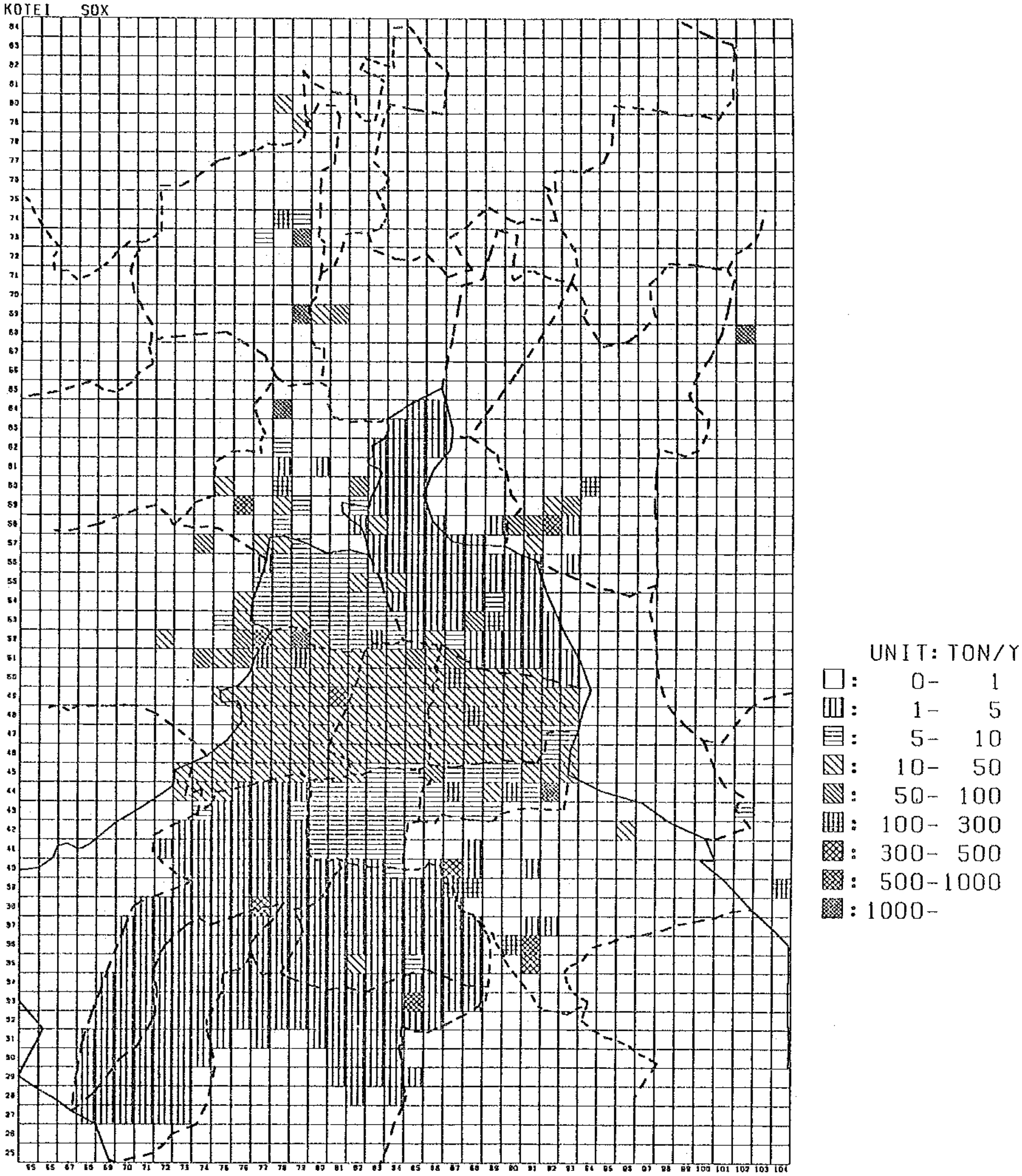


Figure 3.4.16 Distribution of SOx Emissions (Stationary Source)

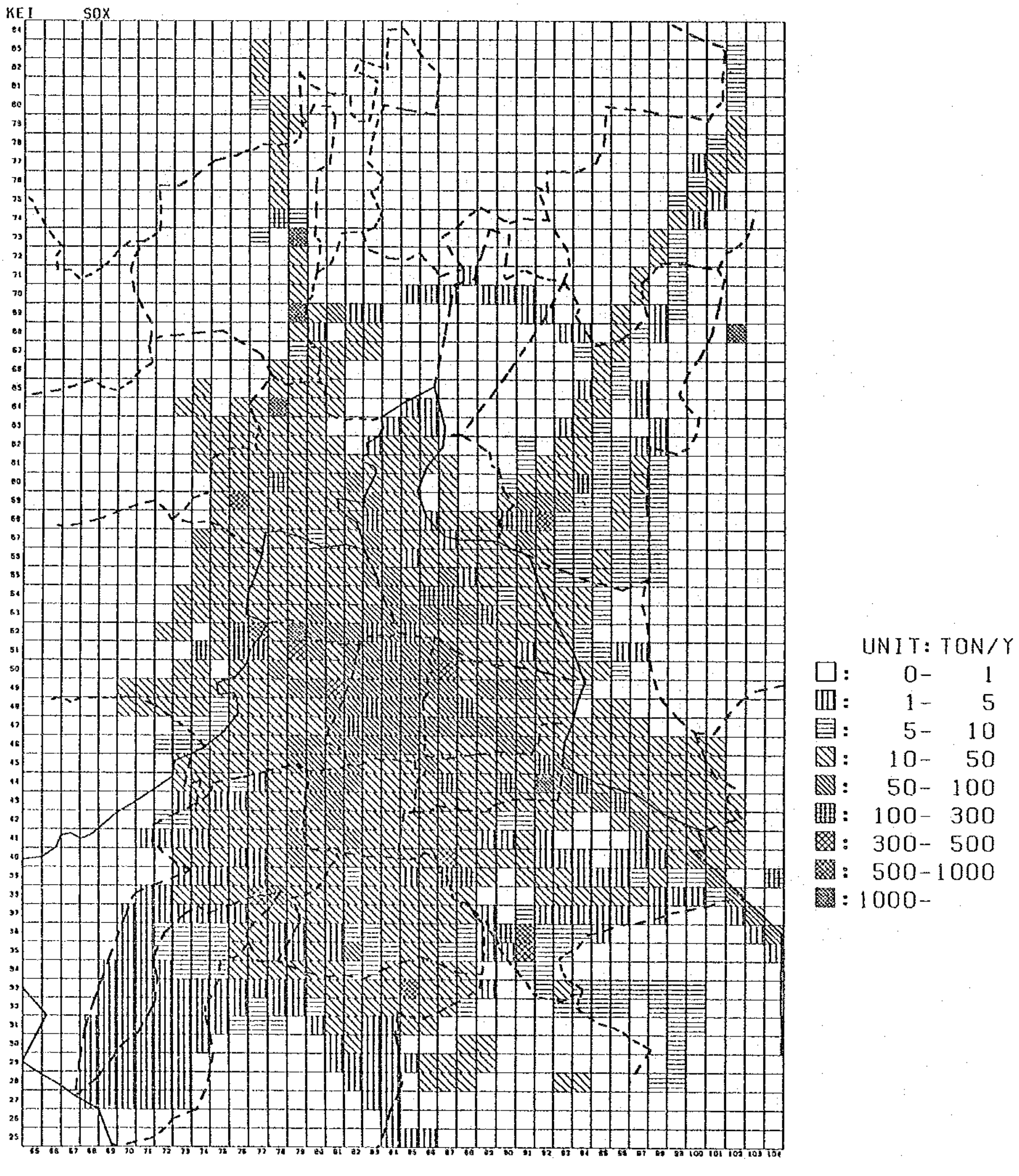


Figure 3.4.17 Distribution of SOx Emissions (Total)

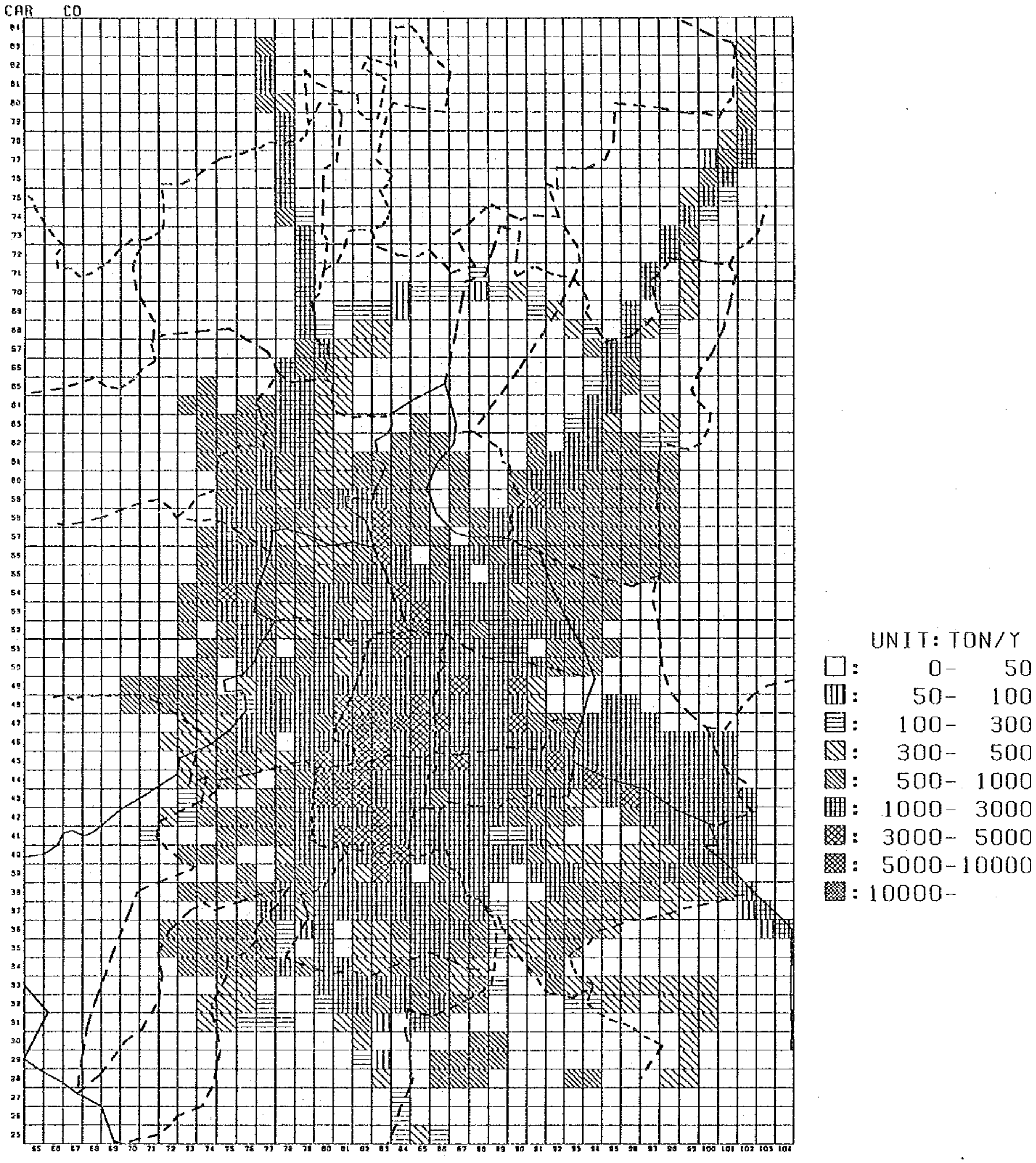


Figure 3.4.18 Distribution of CO Emissions (Automobiles)

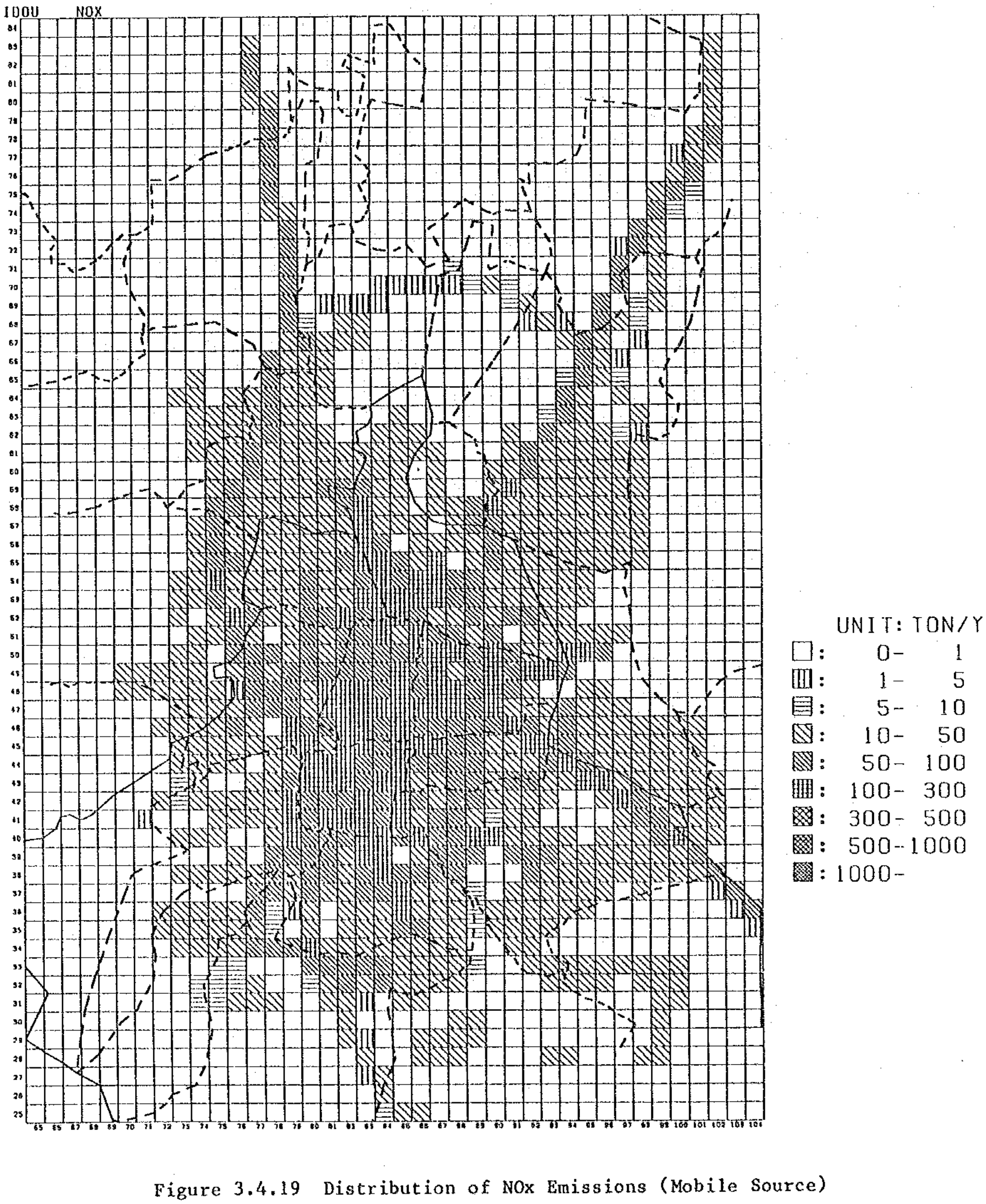


Figure 3.4.19 Distribution of NOx Emissions (Mobile Source)

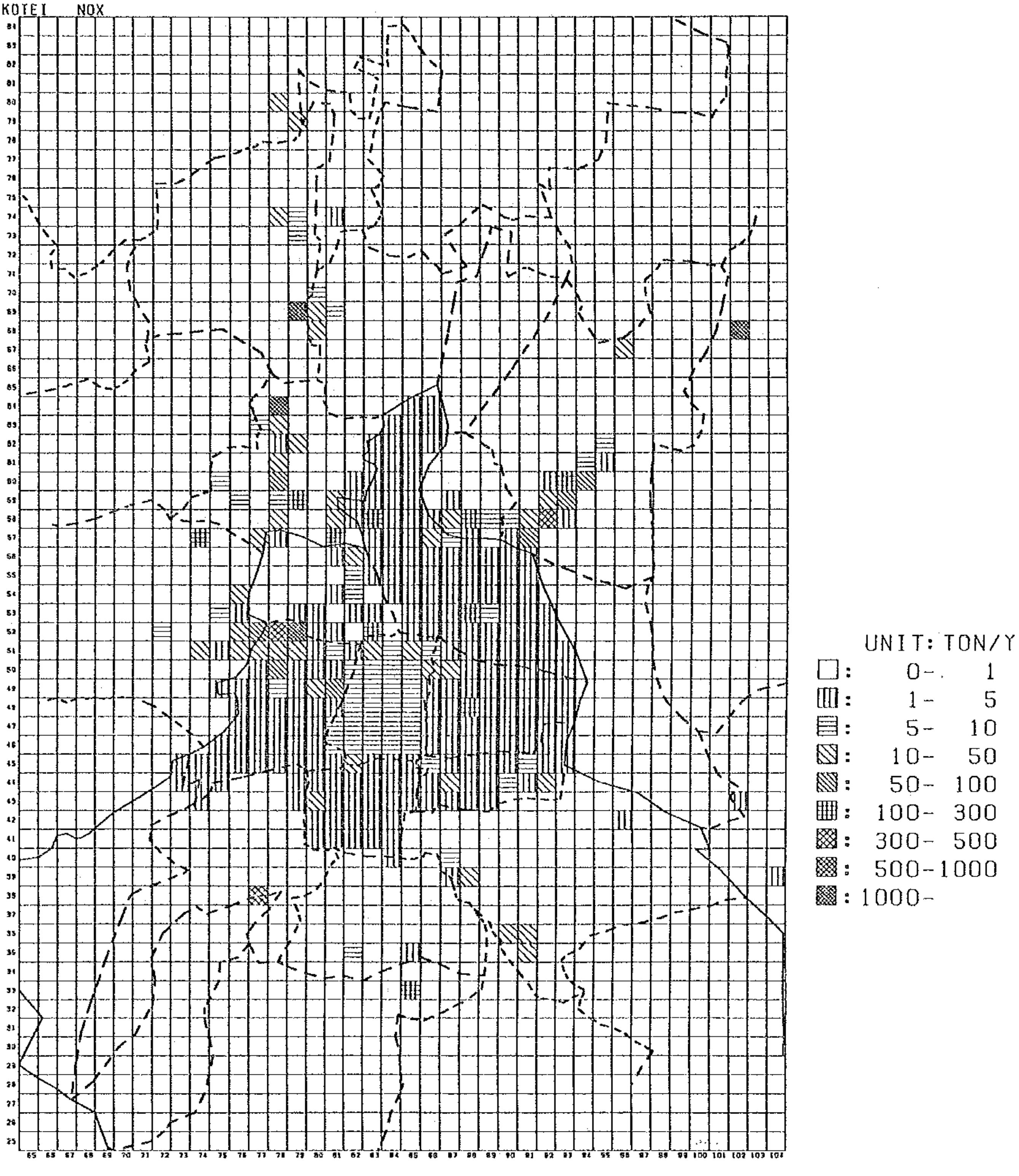


Figure 3.4.20 Distribution of NOx Emissions (Stationary Source)

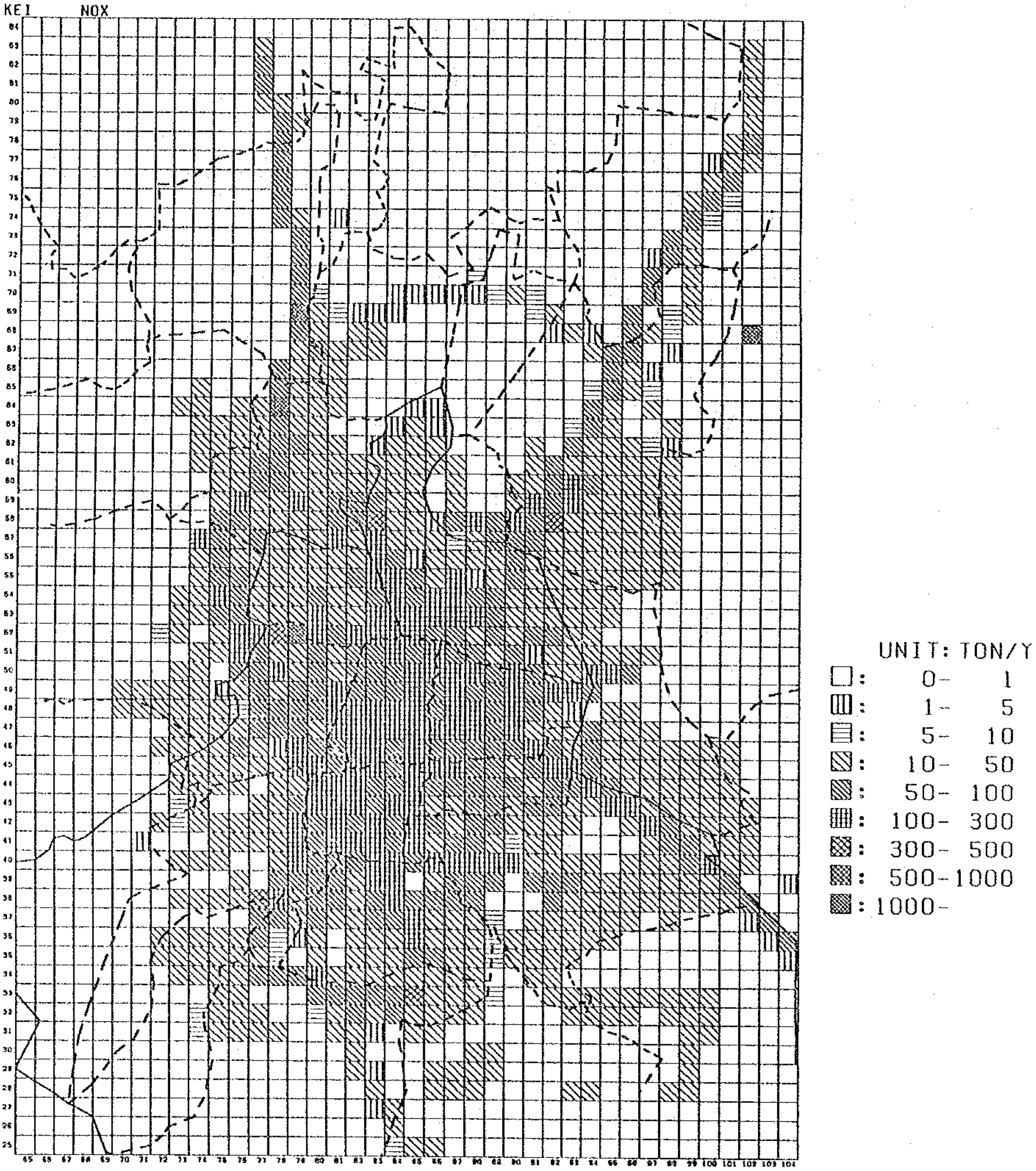


Figure 3.4.21 Distribution of NOx Emissions (Total)

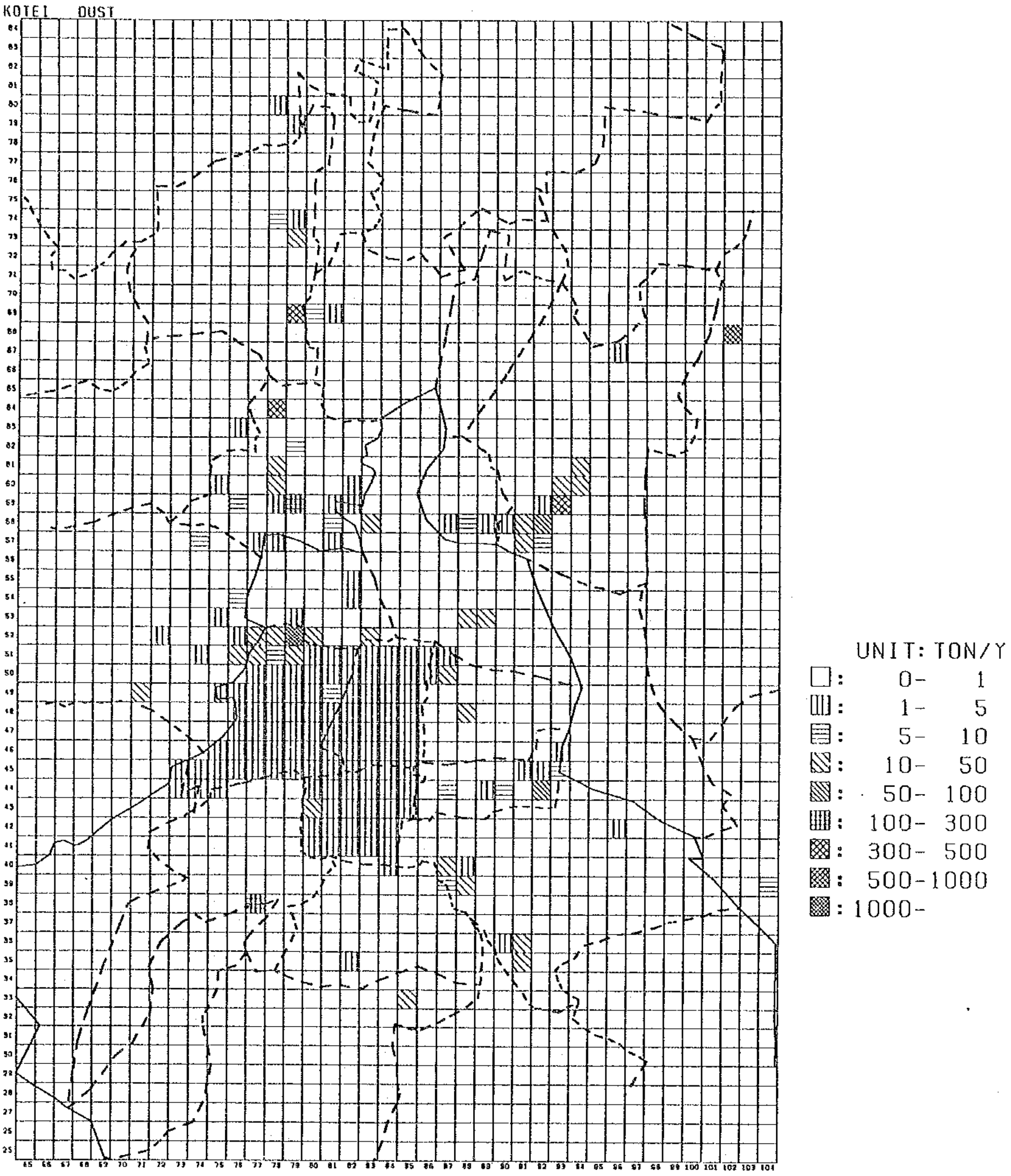


Figure 3.4.22 Distribution of Smoke and Soot Emissions

3.5 Air Quality Simulation Under the Present Conditions

3.5.1 General Consideration

When air pollutants are emitted into the environment, they are transported, dispersed, and/or chemically converted to other forms under the given meteorological and topographic conditions which vary specially and temporally. It is extremely difficult to incorporate all of these factors quantitatively into the mathematical representation of air pollution phenomena. Especially, various chemical reactions taking place in the atmosphere are in a large extent not understood yet on a quantitative basis. In air quality modeling, therefore, some factors that are considered to be essential to describe particular aspects of air pollution phenomena are chosen, and they are represented by simplified forms in mathematical air quality models. Table 3.5.1 summarizes characteristics of various mathematical air quality models.

Ability of the air quality model required in this study include the following:

a. capable to describe geographical distribution of ambient pollutant concentration within the study area in sufficient detail

b. capable to compute long-term average concentration

c. capable to evaluate the degree of contribution of each type of source to the overall concentration

The overall air quality simulation model developed in this study to meet the requirements above consists of a source model, a meteorological model, and a dispersion model.

The dispersion model consists of several equations including a phume equation as the principal equation.

A general plume equation which allows to compute steady-state concentration of a pollutant at downwind zone is as follows:

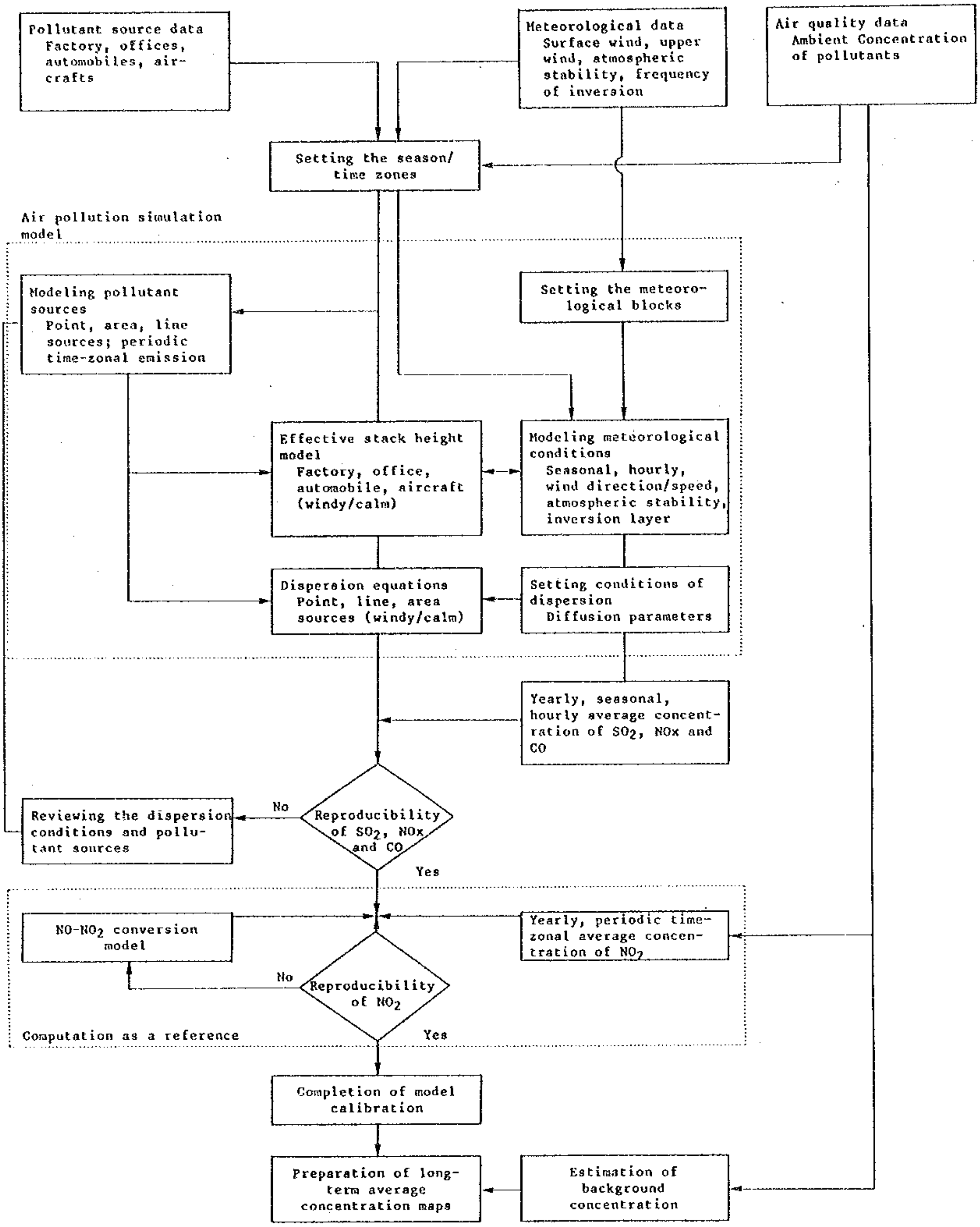


Figure 3.5.1 General Process of Air Quality Simulation

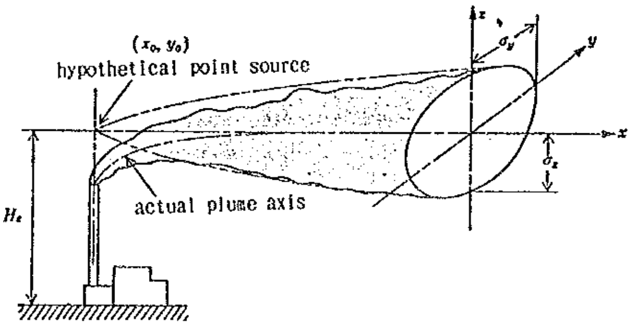
Table 3.5.1 Mathematical Air Quality Models

Category	Name	Characteristics
Dispersion Model	Plume model	Dispersion of continuously emitted stack gas is expressed in terms of smoke plume. Calculation of concentration is simple. This model can be applied for stationary conditions over relatively flat terrain. Long-term average concentration can be obtained by repeated computations.
	Puff model	The dispersion is expressed in terms of a smoke mass emitted instantaneously. Continuous emissions are represented by a procession of puffs. This model can either be applied for non-stationary or calm conditions.
	Box model	Exchange of pollutants between neighboring boxes is calculated. This model is suitable for large-area application, but not for detailed concentration distribution in the area.
	Difference equation model	Differential equations for transport and dispersion are solved numerically. It is suitable for experimental applications. Photochemical reactions and wash-out phenomenon can be also treated.
Statistical Model	Regression model	Relationship between concentration of pollutant and meteorological and other factors is correlated based on the past data by means of multiple regression analysis or control theory to predict the concentration. This model can not be applied when emission source conditions change in the future.
	Grouping model	Past data of concentration and meteorology are classified statistically into groups. Prediction of concentration is made stocastically. This model can not be used under the conditions that are different from those being grouped.

$$C\ (x,y,z) = \frac{Q}{2\pi\sigma_y\,\sigma_z\,U}\exp\left(-\frac{y^2}{2\sigma_y{}^2}\right)\left[\exp\left(-\frac{(z-He)^2}{2\sigma_z{}^2}\right)+\exp\left(-\frac{(z+He)^2}{2\sigma_z{}^2}\right)\right]$$

where,

C : concentration of a pollutant (ppm)
x : downwind distance from the source (m)
y : horizontal distance perpendicular to the x axis (m)
z : height of the point from the ground where the concentration is to be computed (m)
Q : pollutant emission rate (m^3/s)
σ_y : horizontal diffusion paprameter evaluated in terms of downwind distance x (m)
σ_z : vertical diffusion parameter evaluated in terms of downwind distance x (m)
U : wind speed (m/s)
He : effective stack height (m)



Coordinate System for Plume Equation

When the long-term average concentration is considered, an integrated form of the above equation proposed by Holland (1953) as given below may be used.

$$C\ (x,z) = \frac{Q}{\sqrt{2\pi}\ \frac{\pi}{8}\ x\,\sigma_z\,U}\left[\exp\left(-\frac{(z-He)^2}{2\sigma_z{}^2}\right)+\exp\left(-\frac{(z+He)^2}{2\sigma_z{}^2}\right)\right]$$

This equation is used as the basic equation in the dispersion model. Pollutant emission rate (Q) is given based on the results of the source investigation, wind speed and diffusion parameter are determined based on the meteorological information and source characteristics.

Figure 3.5.1 shows the model development procedure.

3.5.2 Development of Air Quality Simulation Model

(1) Condition Setting

Condition setting involves determination of object pollutants, object area, time span and its classification by period and time zone.

1) Basic Scope

a.	Pollutant modeled	Sulfur dioxide (SO_2) and carbon monoxide (CO). Nitrogen oxides (NOx) and nitrogen dioxide (NO_2) are modeled for reference because continuous measurements on these substances are made only at five stations.
b.	Source modeled	Factories, service and commercial establishments, automobiles, jet airplanes
c.	Model evaluation points	Continuous monitoring stations (SEDUE stations)
d.	Concentration averaging time	Evaluation of the model on reproducibility of actual concentration is made on the annual average concentration
e.	Computation area	Area around Mexico City as shown in Figure 3.5.2.

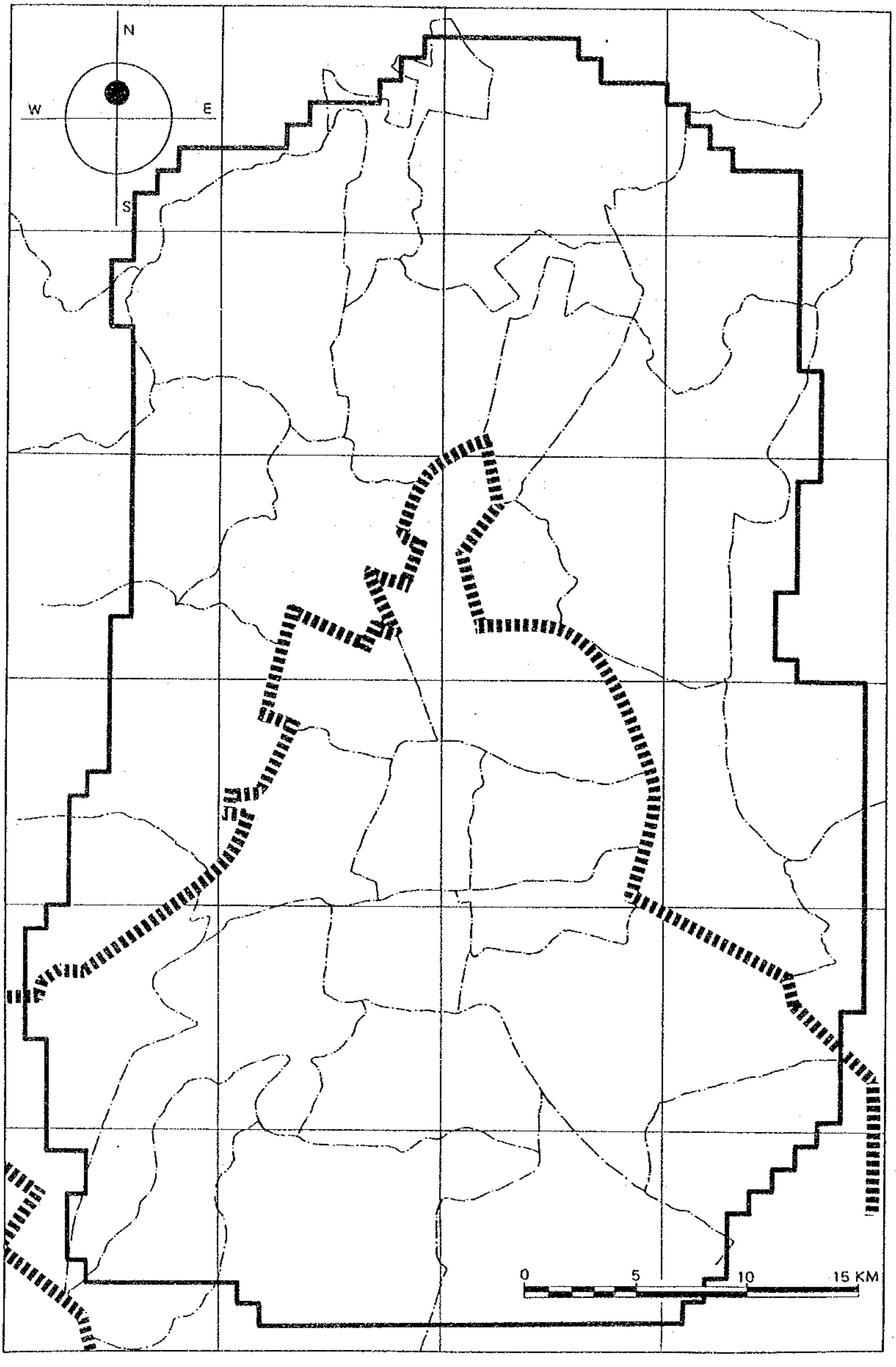


Figure 3.5.2 Area for Computation of Air Pollutant Concentration

2) Classification of Period and Time Zone

Classification of period and time zone is shown in Table 3.5.2. The period classification was made into rainy and dry seasons while the time zone classification was made into 4 zones in view of temporal variation of the ambient concentration and automobile traffic volume.

Table 3.5.2 Period and Time Zone

Period	Rainy	May - September
	Dry	October - April
Time Zone	Morning	7 - 13 hours
	Afternoon	13 - 19 hours
	Evening	19 - 24 hours
	Midnight	0 - 7 hours

(2) Source Model

The source model development consists of arranging types and forms of sources, quantity of emissions and various related information for application to the dispersion model, including averaging of various emission conditions.

Modeling of sources by form was made as shown in Table 3.5.3 for each type of source using technical data for individual sources described in the Section 3.4. The size of an area source was set at 1 km x 1 km.

Table 3.5.3 Number and Form of Pollutant Sources

Type of Pollutant Sources / Item			Number of Source	Form of Source
Stationary Source	Factories		957	Point Source
	Service and Commercial Establishments		919	Area Source
Mobile Source	Auto-mobiles	Major Roads	649	Line Source
		Narrower Roads	750	Area Source
	Airplanes	Idling/Takeoff	7	Area Source
		Climb Landing/Approach	538	Continuous Point Source*

* Point source was placed at every 10 m on the route of takeoff and landing.

(3) Meteorological Model

The meteorological model is a model to set meteorological conditions for application to the dispersion model.

Meteorological items used in the dispersion equation are wind direction and speed, and information concerning diffusion width (diffusion parameter). These data were arranged according to the appearance pattern of wind direction and speed (double cross of wind direction and speed) and set for each dispersion field (each block of the area divided horizontally and vertically according to the difference in wind direction and speed).

Exhaust gas from a source in each dispersion field is assumed to be transported and dispersed according to the appearance ratio of wind direction and speed in the field (source oriented method).

1) Dispersion Field Classification

Table 3.5.4 shows the vertical division of the dispersion field.

Table 3.5.4 Vertical Divisions of Dispersion Field and Corresponding Pollutant Sources

Category of Dispersion Field	Pollutant Sources
Surface Field	Automobiles
Lower Field	Factories (Stack Height Ho $<$ 30m) Service and commercial establishments Airplanes (Taxing/Idling, Takeoff)
Middle Field	Factories (Stack height Ho $\geq$ 30m)
Upper Field	Airplanes (Climb, Landing/Approach)

2) Meteorological Block

Considering the topographical conditions, the result of similarity analysis and reproducibility of the actual pollutant concentration, the computational area was divided into five blocks as shown in Figure 3.5.3. Representative meteorological condition was set for each block.

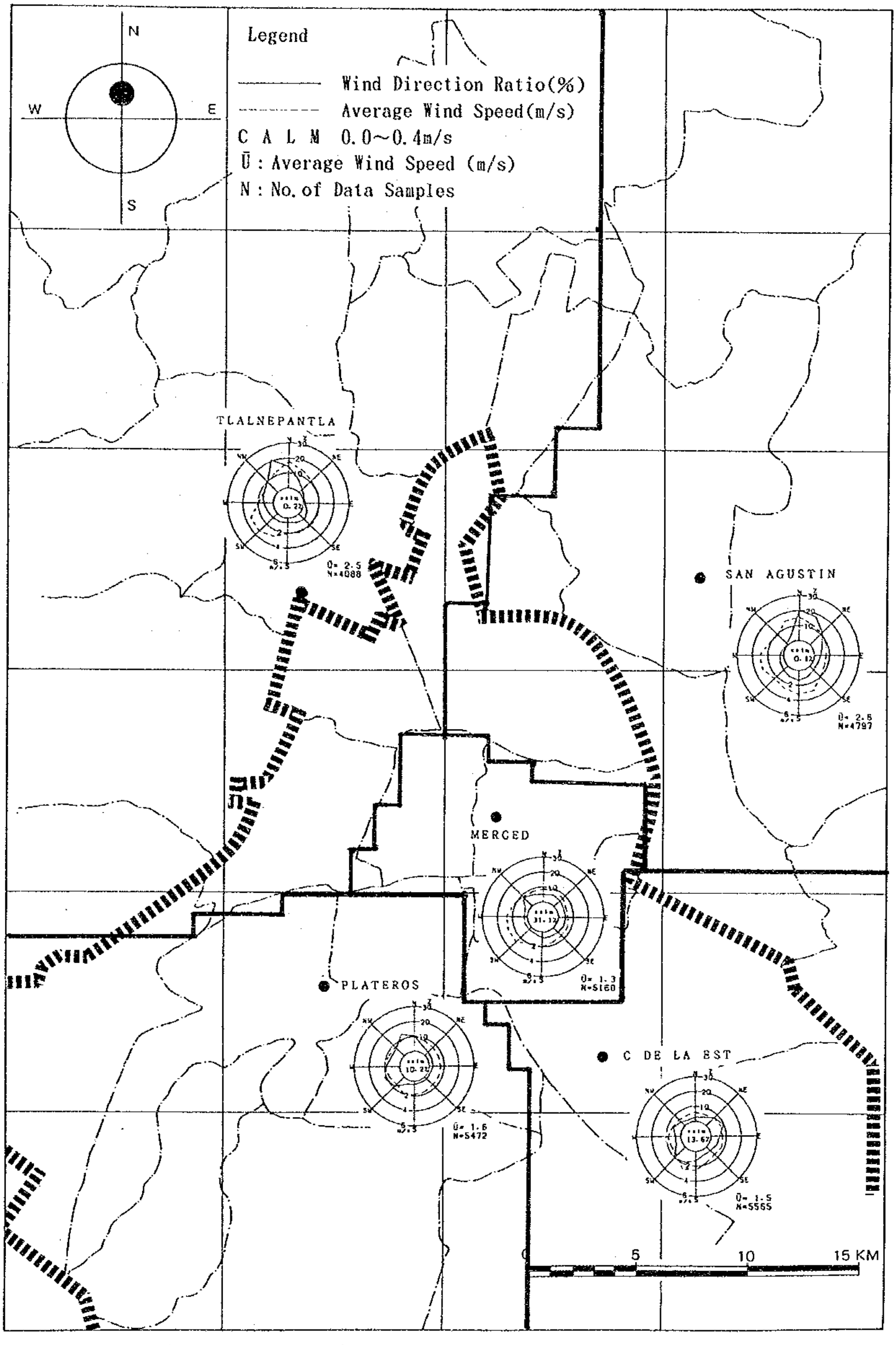


Figure 3.5.3 Meteorological Blocks and Typical Wind Conditions

3) Meteorological Classification

The meteorological data were classified as follows for calculation of the appearance ratio of wind direction and speed:

Wind direction ... 16 directions and calm ($U \leq 0.4$ m/s)

Wind speed ... 8 classes of wind speed as shown in Table 3.5.5

Table 3.5.5 Wind Speed Classification

Class	1	2	3	4	5	6	7	8
Wind speed classes(m/s)	0.4 or less	0.5 to 1.9	2.0 to 2.9	3.0 to 3.9	4.0 to 5.9	6.0 to 7.9	8.0 to 9.9	10.0 or more
Wind speed used (m/s)	0	Average wind speed of each class						

(4) Dispersion Model

The dispersion model consists of the dispersion equations, the effective stack height equations, etc., and allows application of the properly selected equation depending on the form of source, emission conditions, and meteorological conditions. Selection of the diffusion parameter and initialization of diffusion width is also made.

1) Effective Stack Height Equation

The effective stack height equation in the windy condition for the point source factories was selected from those shown in Table 3.5.6 depending on the amount of heat emission.

For the sources modeled as area or line source, the effective stack height was determined considering typical height and situation around the source.

Table 3.5.6 Effective Stack Height Model

Pollutant Source		Form of Source	Windy	Calm
Factories		Point Source	• Large scale stacks (Q_H* $\geqq 2x10^6$Cal/s) Moses&Carson Equation • Medium to small scale stacks (Q_H* $< 2x10^6$Cal/s) CONCAWE Equation	Briggs' Equation with $d\theta/dz$** as, Daytime: 0.003°C/m Nighttime: 0.010°C/m
Service and Commercial Establishments		Area Source	20 m	30 m
Auto-mobiles	Major Roads	Line Source	Center of City: 5 m Outskirts : 2 m	Center of City: 10m Outskirts : 3m
	Narrower Roads	Area Source		
Airplanes	Taxing/ Idling, Takeoff	Area Source	10 m	15 m
	Climb, Landing/ Approach	Continuous Point Source	Height of takeoff and landing route	Height of takeoff and landing route

Note * Q_H : Heat emission due to efflux of stack gases (cal/s)
** $D\theta/dz$: Vertical potential temperature gradient in the atmosphere (°C/m)

2) Dispersion Equation

Dispersion equations used are shown in Table 3.5.7.

As described earlier, the Holland equation was used for windy conditions. This equation was obtained by modifing the original plume equation by grouping wind directions into 16 direction blocks so that the concentration in the Y direction becomes uniform within one direction block ($2\pi/16$). For the area source, the point source equation was integrated over the width of area source (1 km).

The simplified puff equations applied to calm condition are obtained from the original puff equation by setting wind speed to zero and assuming diffusion width being proportional to the time elapsed.

Table 3.5.7 Application of Dispersion Equation

Wind Condition / Form of Source	Windy	Calm
Point source	Plume equation	Simplified puff equation
Area source	Area-source plume equation	Area-source simplified puff equation
Line source	Line-source plume equation	Line-source simplified puff equation

Note: Plume equation shown above is Holland equation applicable when wind directions are grouped into 16 blocks.

3) Diffusion Parameter

The diffusion parameter used in the computation was chosen from the diffusion factor table obtained from the Pasquill-Gifford diagram and Turner diagram.

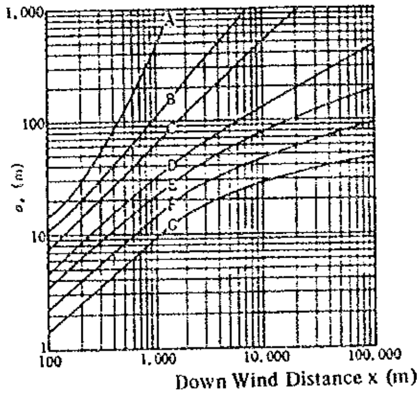


Figure 3.5.4 Pasquill-Gifford Diagram

The diffusion parameter varys with height, period, and time zone. Therefore, the atmospheric stability class to obtain the parameter was set for each period and the time zone as shown in Table 3.5.8 after confirmation of the atmospheric stability appearance pattern and the agreement of computed concentration with measured concentration.

Table 3.5.8 Atmospheric Stability Class to Obtain Diffusion Parameter

Period	Dispersion Field	Time Zone			
		Morning	Afternoon	Evening	Midnight
Rainy	Surface	B	B	CD	D
	Lower	CD	C	D	D
	Middle	D	CD	D	D
	Upper	D	CD	D	D
	Surface	C	B	D	E
Dry	Lower	CD	C	D	D
	Middle	D	CD	D	D
	Upper	D	CD	D	D

In application of the diffusion parameter for windy condition, the initial spread of diffusion parameter due to the effect of wind speed variation and surface roughness was set for each source as shown in Table 3.5.9.

Table 3.5.9 Initial Spread of Diffusion Parameter

Pollutant Source	Initial Spread
Factories (Point Source)	14 - 18 m
Service and Commercial Establishments (Area Source)	20 m
Automobiles (Line Source, Area Source)	Center of City: 10 m Outskirts: 2 m

(5) Conversion of NOx to NO_2

For conversion of concentration from NOx to NO_2, the index approximation model given in "Nitrogen Oxide Total Quality Control Manual, the Environment Agency" was used.

(6) Reproducibility of the Model

Table 3.5.10 shows computed and measured annual average concentration values for SO_2, CO, NOx and NO_2. Figures 3.5.5 through 3.5.8 show the scatter diagram of computed and measured annual averages for SO_2, CO, NOx and NO_2. Table 3.5.11 summarizes the reproducibility of the simulation model.

Requirements for reproducibility of the simulation model include: 1) high correlation coefficient, with the slope of the regression equation being nearly 1, 2) small variation coefficient, and 3) appropriate background concentration. The method of evaluating reproducibility of simulation model is described in the Appendices.

1) Reproducibility of the SO_2 Concentration

Relation between the measured and the computed values for SO_2 concentration indicate the correlation coefficient at 0.595, slope of the regression line at 0.615, variation coefficient at 0.239, and background concentration at 5.87 ppb. The evaluation rank was thus "B."

Note that the evaluation rank of "B" was considered inevitable because the SO_2 measurement was interrupted often (the annual measurement time at each point was about 4000 - 6000 hours out of 8760 hours) and the meteorological data were also insufficient (data quantity about 4000 -5500 hours).

2) Reproducibility of the CO Concentration

Although quantity of the measurement data was almost similar to the case of SO_2, the correlation coefficient is 0.855, slope of the regression line 0.808, variation coefficient 0.195, and background concentration 1.182 ppm. As a result, the evaluation rank was "A."

Table 3.5.10 Computed and Measured Concentration (Annual average)

Receptor	SO_2(ppb)		CO(0.1ppm)		NO_x(ppb)*		NO_2(ppb)*	
	Actual	Estimate	Actual	Estimate	Actual	Estimate	Actual	Estimate
Z. LAGUNILLA	-	-	38.1	25.9	-	-	-	-
E. VALLEJO	56.8	52.0	-	-	-	-	-	-
S. STA URSRA	26.1	24.0	-	-	-	-	-	-
B. TACUBA	56.3	41.5	-	-	-	-	-	-
G. ENEP-ACATLAN	71.7	17.9	-	-	-	-	-	-
M. LOS LAURELES	37.6	18.5	-	-	-	-	-	-
H. LA PRESA	26.2	28.7	-	-	-	-	-	-
J. LA VILLA	43.1	45.8	-	-	-	-	-	-
N. SAN AGUSTIN	26.3	-**	-	-	-	-	-	-
C. ATZCAPOTZALCO	52.6	36.1	-	-	-	-	-	-
F. TLALNEPANTLA	48.6	43.2	31.6	12.3	68.9	38.9	38.7	27.4
L. XALOSTOC	54.8	39.2	39.5	16.4	76.1	-**	28.0	-**
X. MERCED	50.3	52.1	35.2	30.2	90.2	81.4	49.2	59.4
T. PEDREGAL	41.4	22.7	26.0	10.8	55.7	34.3	36.6	26.0
Q. C DE LA EST	32.5	38.6	36.8	13.9	72.1	34.6	38.8	26.4.
U. PLATEROS	-	-	32.1	23.2	-	-	-	-
Y. HANGARES	33.2	40.7	-	-	-	-	-	-
P. UAM-IZTAPALAPA	-	-	18.1	16.5	-	-	-	-
K. ARAGON	-	-	29.3	14.0	-	-	-	-
O. NEZAHUALCOYOTL	-	-	27.1	21.4	-	-	-	-
D. IMP	-	-	31.3	22.0	-	-	-	-
W. BENITO JUAREZ	-	-	33.9	32.3	-	-	-	-
R. TASQUEÑA	-	-	46.4	32.8	-	-	-	-
V. INSRUGENTES	-	-	67.2	58.0	-	-	-	-
A. CUITLAHUAC	-	-	53.6	39.2	-	-	-	-

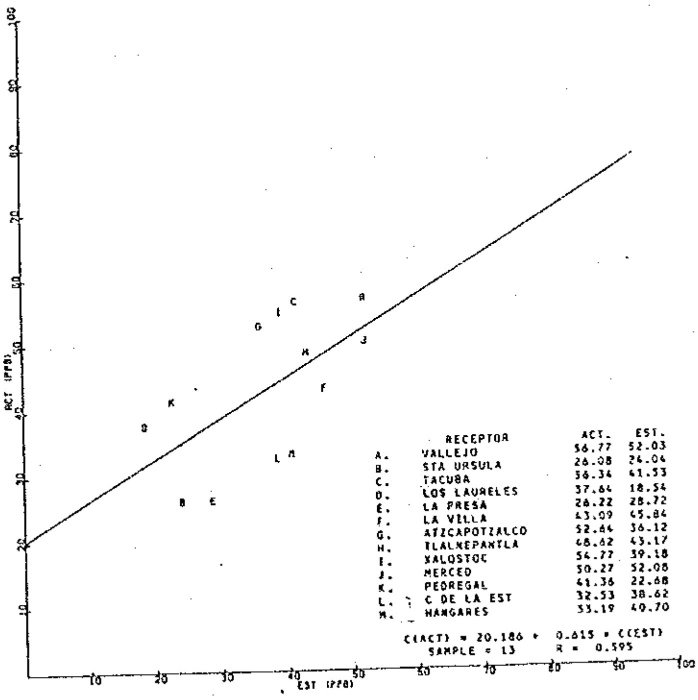
* Computation made for reference

** Not computed because of insufficient annual measurement time

Table 3.5.11 Reproducibility of Simulation Model (Annual Average)

Item	Regression Line	Number of Stations for Evaluation	Correlation Coefficient	Coefficient of Variation	Back-ground	Rank of Evaluation
SO_2	y=0.615X+20.19 (ppb)	13	0.595	0.239	5.87 (ppb)	B
CO	y=0.808X+1.654 (ppm)	15	0.846	0.195	1.182 (ppm)	A
NOx	y=0.547X+45.86 (ppb)	4	0.880	0.211	24.43 (ppb)	B
NO_2	y=0.341X+28.96 (ppb)	4	0.988	0.325	6.06 (ppb)	C

Note: Y = actual concentration, X = estimated concentration

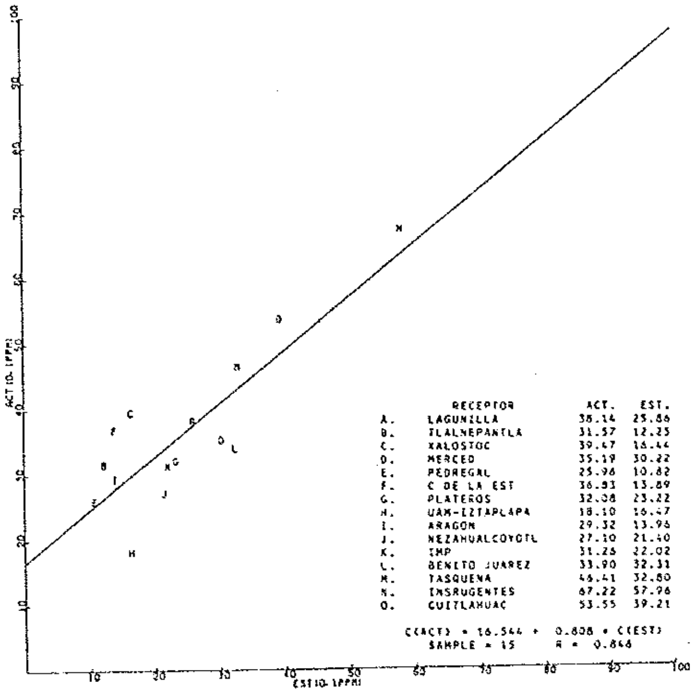


	RECEPTOR	ACT.	EST.
A.	VALLEJO	56.77	52.03
B.	STA URSULA	26.08	24.04
C.	TACUBA	56.34	41.53
D.	LOS LAURELES	37.64	18.54
E.	LA PRESA	26.22	28.72
F.	LA VILLA	43.09	45.84
G.	ATZCAPOTZALCO	52.44	36.12
H.	TLALNEPANTLA	48.62	43.17
I.	XALOSTOC	54.77	39.18
J.	MERCED	50.27	52.08
K.	PEDREGAL	41.36	22.68
L.	C DE LA EST	32.53	38.62
M.	HANGARES	33.19	40.70

C(ACT) = 20.186 + 0.615 * C(EST)
SAMPLE = 13 R = 0.595

Note: Measured data at ENEP-ACATLAN were excluded from evaluation because of instability.

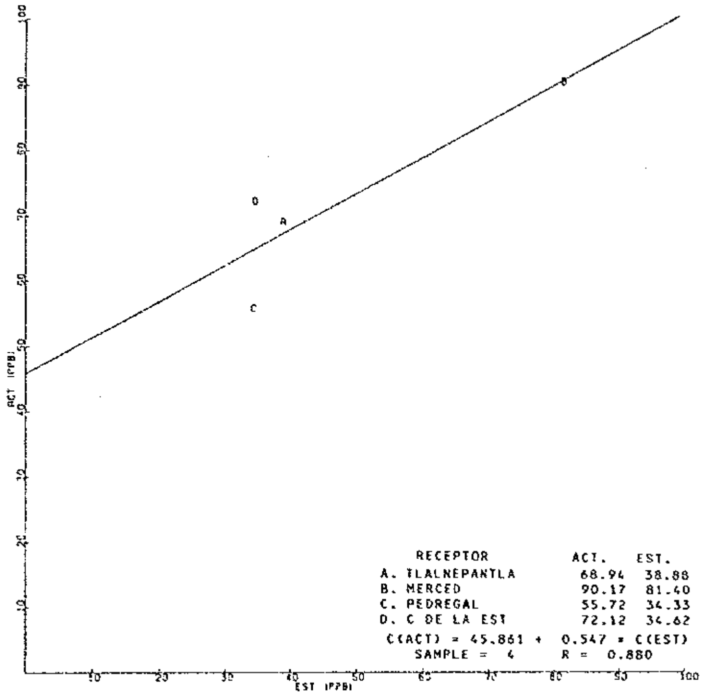
Figure 3.5.5 Scatter Diagram of Actual and Estimated Values (Annual: SO_2)



	RECEPTOR	ACT.	EST.
A.	LAGUNILLA	38.14	25.86
B.	TLALNEPANTLA	31.57	12.25
C.	XALOSTOC	39.47	16.44
D.	MERCED	35.19	30.22
E.	PEDREGAL	25.96	10.82
F.	C DE LA EST	36.93	13.89
G.	PLATEROS	32.08	23.22
H.	UAM-IZTAPLAPA	18.10	16.47
I.	ARAGON	29.32	13.96
J.	NEZAHUALCOYOTL	27.10	21.40
K.	IMP	31.26	22.02
L.	BENITO JUAREZ	33.90	32.31
M.	TASQUENA	46.41	32.80
N.	INSRUGENTES	67.22	57.96
O.	CUITLAHUAC	53.55	39.21

C(ACT) = 16.544 + 0.808 * C(EST)
SAMPLE = 15 R = 0.846

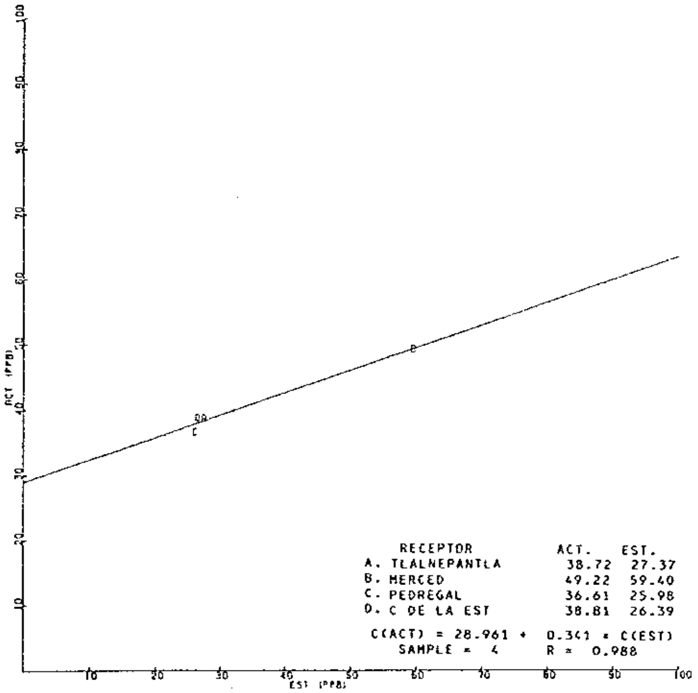
Figure 3.5.6 Scatter Diagram of Actual and Estimated Values (Annual: CO)



RECEPTOR	ACT.	EST.
A. TLALNEPANTLA	68.94	38.88
B. MERCED	90.17	81.40
C. PEDREGAL	55.72	34.33
D. C DE LA EST	72.12	34.62

C(ACT) = 45.861 + 0.547 * C(EST)
SAMPLE = 4 R = 0.880

Figure 3.5.7 Scatter Diagram of Actual and Estimated Values (Annual: NOx)



RECEPTOR	ACT.	EST.
A. TLALNEPANTLA	38.72	27.37
B. MERCED	49.22	59.40
C. PEDREGAL	36.61	25.98
D. C DE LA EST	38.81	26.39

C(ACT) = 28.961 + 0.341 * C(EST)
SAMPLE = 4 R = 0.988

Figure 3.5.8 Scatter Diagram of Actual and Estimated Values (Annual: NO2)

3.5.3 Pollutant Concentration Distribution

(1) SO_2 Concentration Distribution

Figure 3.5.9 shows the distribution of annual average concentration of SO_2 as computed by the simulation model.

Zones exceeding 60 ppb are distributed around DELEGACION CUAUHTEMOC and to the east of DELEGACION IZTACALCO while Cmax (the highest concentration) appeared to the east of DELEGACION IZTACALCO and the concentration is 99.8 ppb.

(2) CO Concentration Distribution

Figure 3.5.10 shows the distribution of annual average concentration of CO as computed by the simulation model.

Zones exceeding 4 ppm are distributed in the DELEGACION CUAUHTEMOC, the area around DELEGACION BENITO JUAREZ, and to the east of DELEGACION IZTACALCO where Cmax of 6.62 ppm appears.

(3) NOx and NO_2 Concentration Distribution

Figure 3.5.11 shows the distribution of annual average concentration of NOx computed, and Figure 3.5.12 that of NO_2. Computations were made only for reference purpose because model calibration could not be made sufficiently due to only a few number of measuring stations.

× Cmax point Unit: ppb

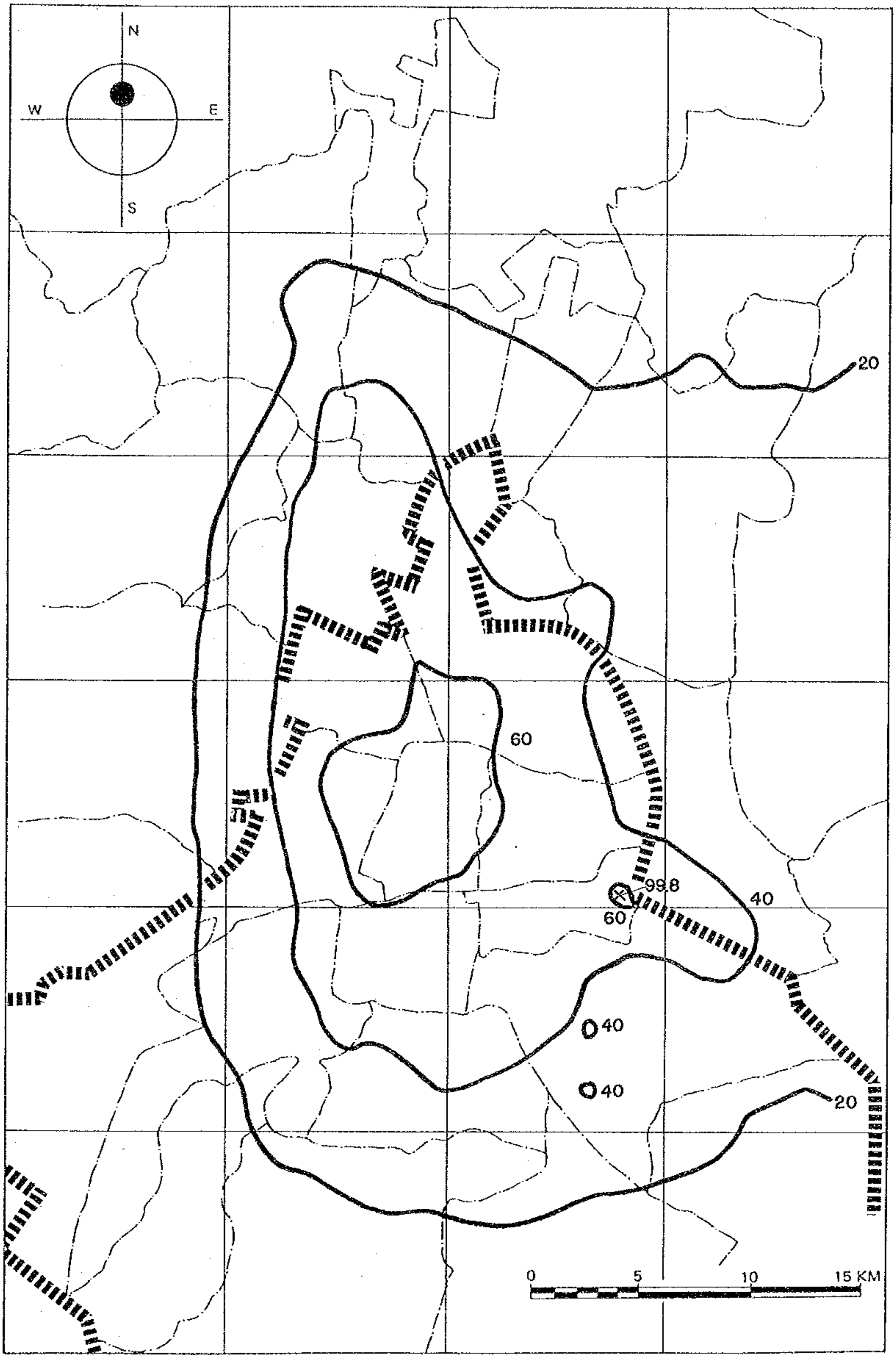


Figure 3.5.9 Annual Average Concentration Ispleths for SO_2 (All Sources)

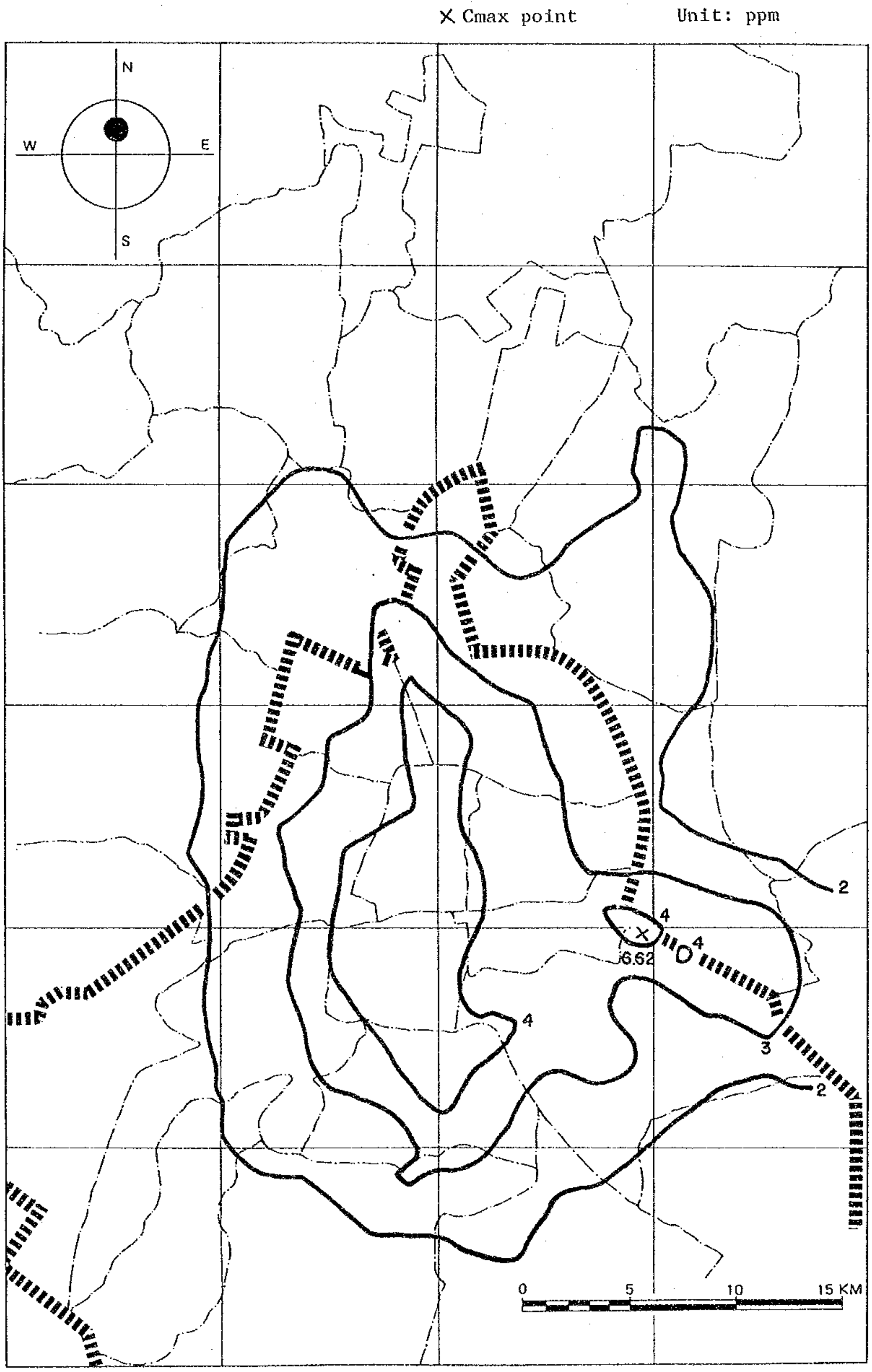


Figure 3.5.10 Annual Average Concentration Isopleths for CO (Automobiles)

3.5.4 Source Contribution

(1) SO_2 Source Contribution

Contribution of sources to the annual average SO_2 concentration at receptors (measuring stations and Cmax point) is shown in Figure 3.5.13 and Table 3.5.12. The concentration at the receptors ranges from 24.41 ppb (LOS LAURELES) to 99.76 ppb (Cmax point).

The contribution of stationary sources shows a range of 22.1 -69.0%, automobiles 17.2 - 71.8%, and airplanes less than 1.0%.

Contribution of stationary sources, automobiles and airplanes to concentration distribution are shown in Figures 3.5.14 through 3.5.16. The contribution of stationary sources (factories and service and commercial establishments) exceeds 40 ppb in DELEGACION CUAUHTEMOC and MIGUEL HIDALOGO and in TULTUITLAN. The Cmax point appears to the north of MIGUEL HIDALGO and the concentration is 55.8 ppb.

The contribution of automobiles exceeds 30 ppb at the southern part of DELEGACION GUSTAVO A. MADERO and at IZTAPALAPA. The Cmax point appeared near the border of IZTACALCO and IZTAPALAPA, with the concentration being 71.7 ppb.

The airplane contribution is small and limitted within the area around BENITO JUAREZ airport with the Cmax point of 1.6 ppb.

× Cmax point Unit: ppb

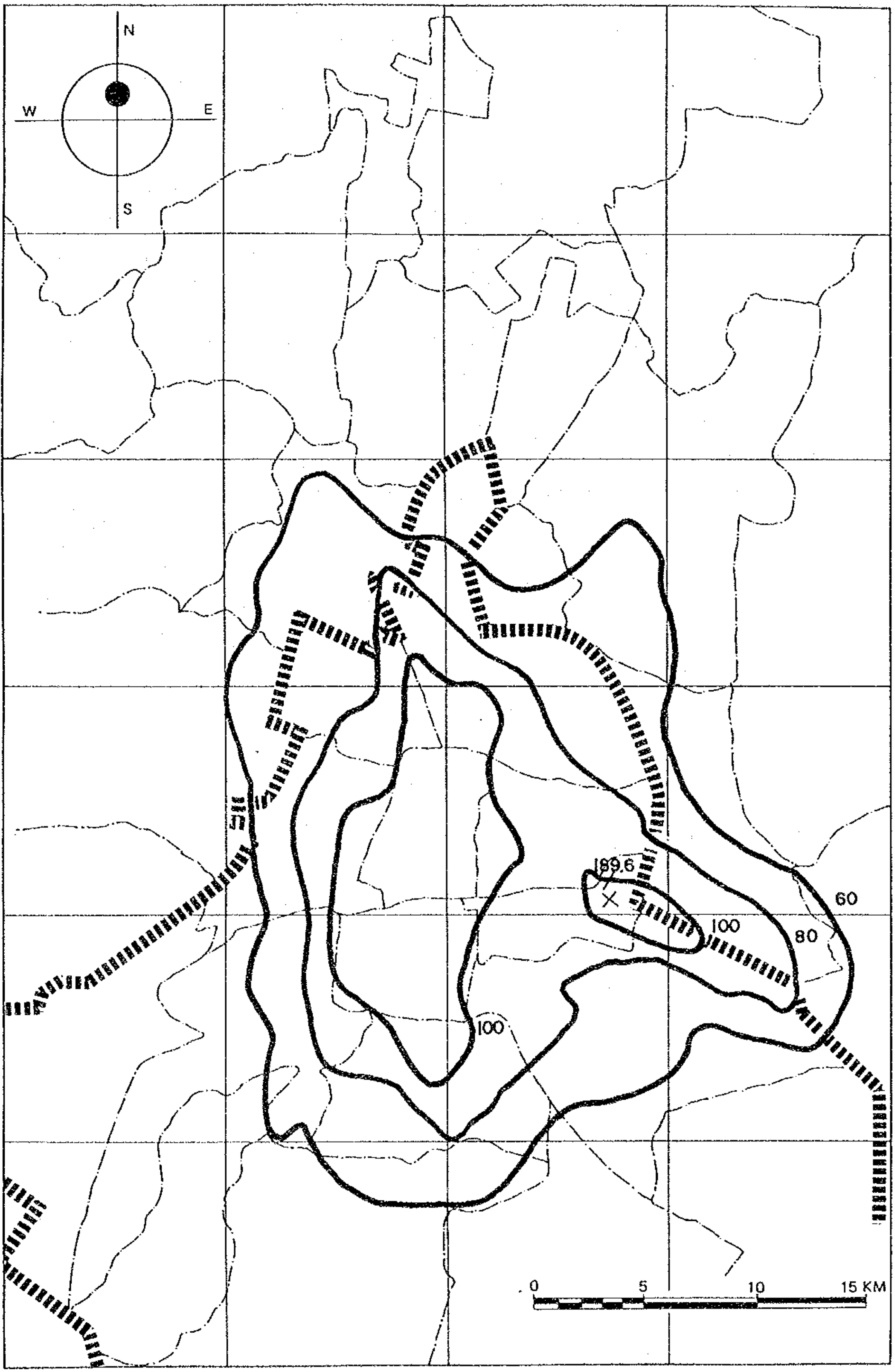
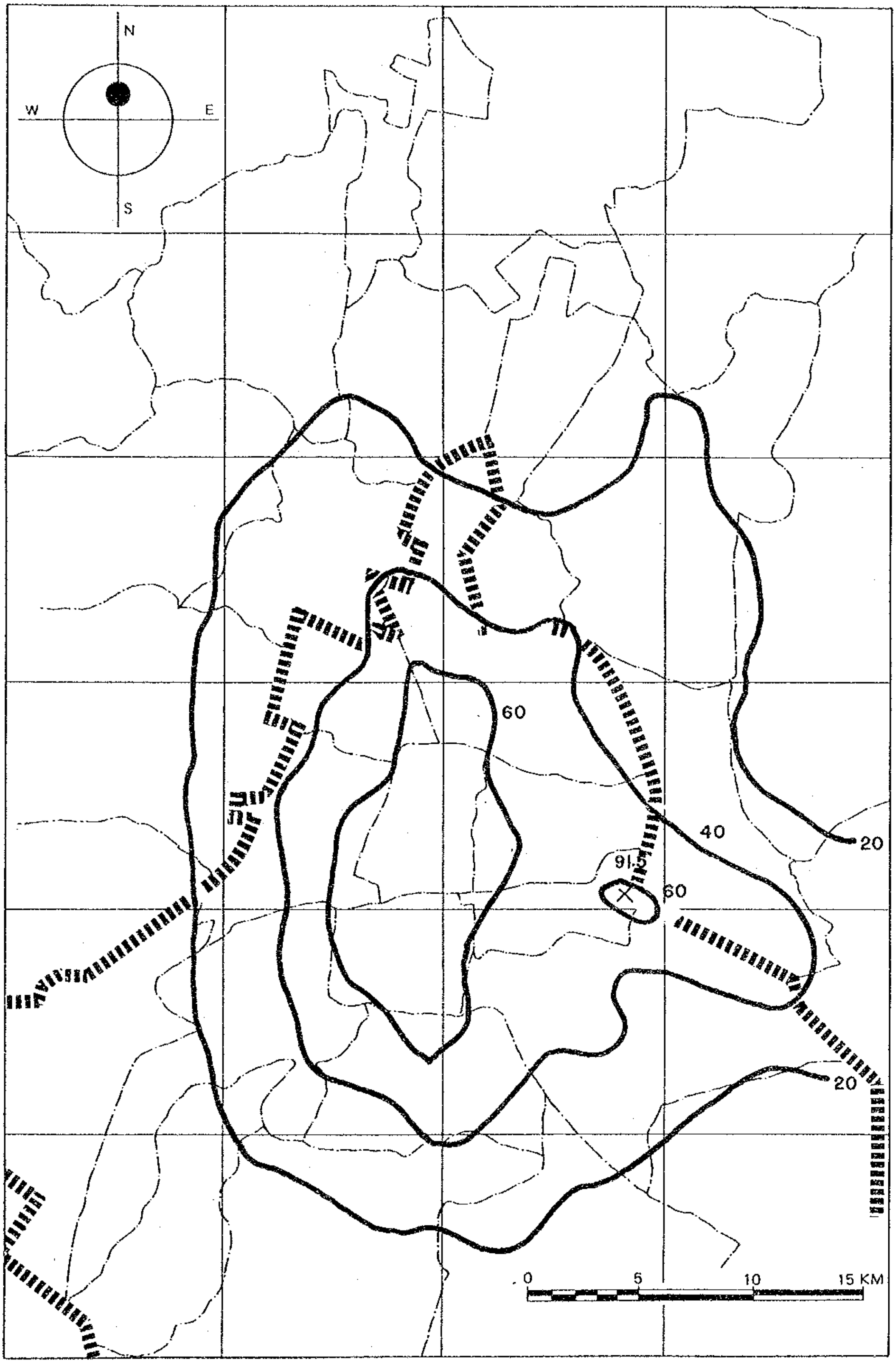


Figure 3.5.11 Annual Average Concentration Isopleth for NOx (All Sources)



× Cmax point Unit: ppm

Figure 3.5.12 Annual Average Concentration Isopleth for NO_2 (All Source)

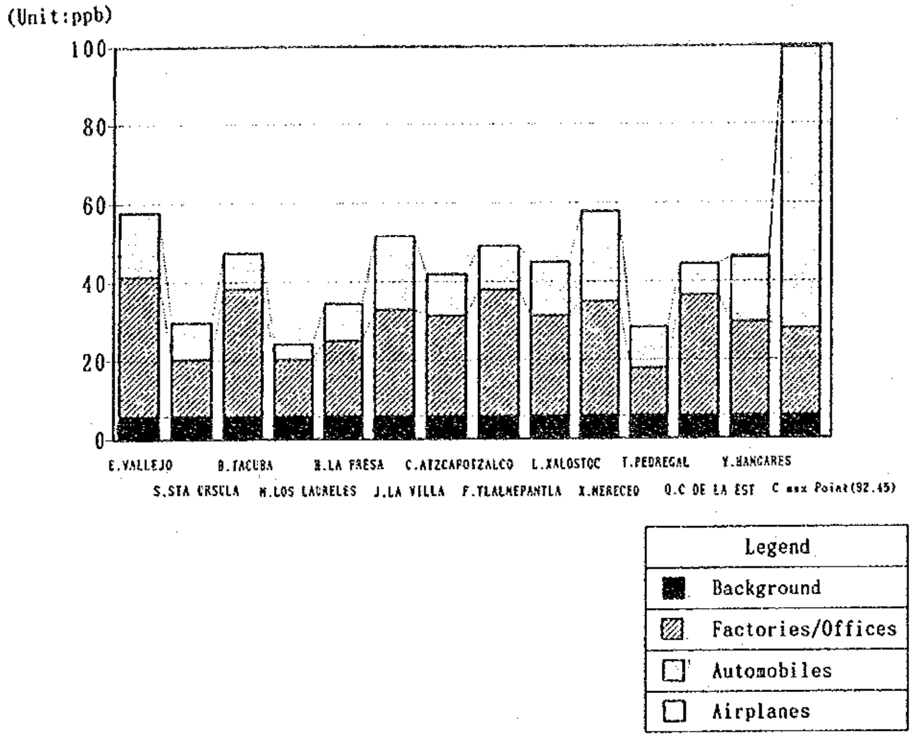


Figure 3.5.13 Contribution of Sources to SO_2 Concentration

Table 3.5.12 Contribution of Sources to SO_2 Concentration

Unit: ppb, (%)

Receptor	Total	Factories/ Offices	Automobiles	Airplanes	Background
E. VALLEJO	57.90	35.72(61.7)	16.31(28.2)	0.00(0.0)	5.87(10.1)
S. STA URSULA	29.91	14.52(48.5)	9.51(31.8)	0.01(0.0)	5.87(19.6)
B. TACUBA	47.40	32.32(68.2)	9.21(19.4)	0.00(0.0)	5.87(12.4)
M. LOS LAURELES	24.41	14.34(58.7)	4.21(17.2)	0.00(0.0)	5.87(24.0)
H. LA PRESA	34.59	19.08(55.2)	9.64(27.9)	0.00(0.0)	5.87(17.0)
J. LA VILLA	51.71	27.12(52.4)	18.69(36.1)	0.03(0.1)	5.87(11.4)
C. ATZCAPOTZALCO	41.99	25.54(60.8)	10.57(25.2)	0.00(0.0)	5.87(14.0)
F. TLALNEPANTLA	49.04	32.09(65.4)	11.07(22.6)	0.00(0.0)	5.87(12.0)
L. XALOSTOC	45.05	25.65(56.9)	13.51(30.0)	0.02(0.0)	5.87(13.0)
X. MERCED	57.95	29.36(50.7)	22.66(39.1)	0.06(0.1)	5.87(10.1)
T. PEDREGAL	28.55	12.20(42.7)	10.48(36.7)	0.00(0.0)	5.87(20.6)
Q. C DE LA EST	44.49	30.70(69.0)	7.92(17.8)	0.01(0.0)	5.87(13.2)
Y HANGARES	46.57	24.07(51.7)	16.30(35.0)	0.32(0.7)	5.87(12.6)
C max Point(92,45)	99.76	22.08(22.1)	71.67(71.8)	0.14(0.1)	5.87(5.9)

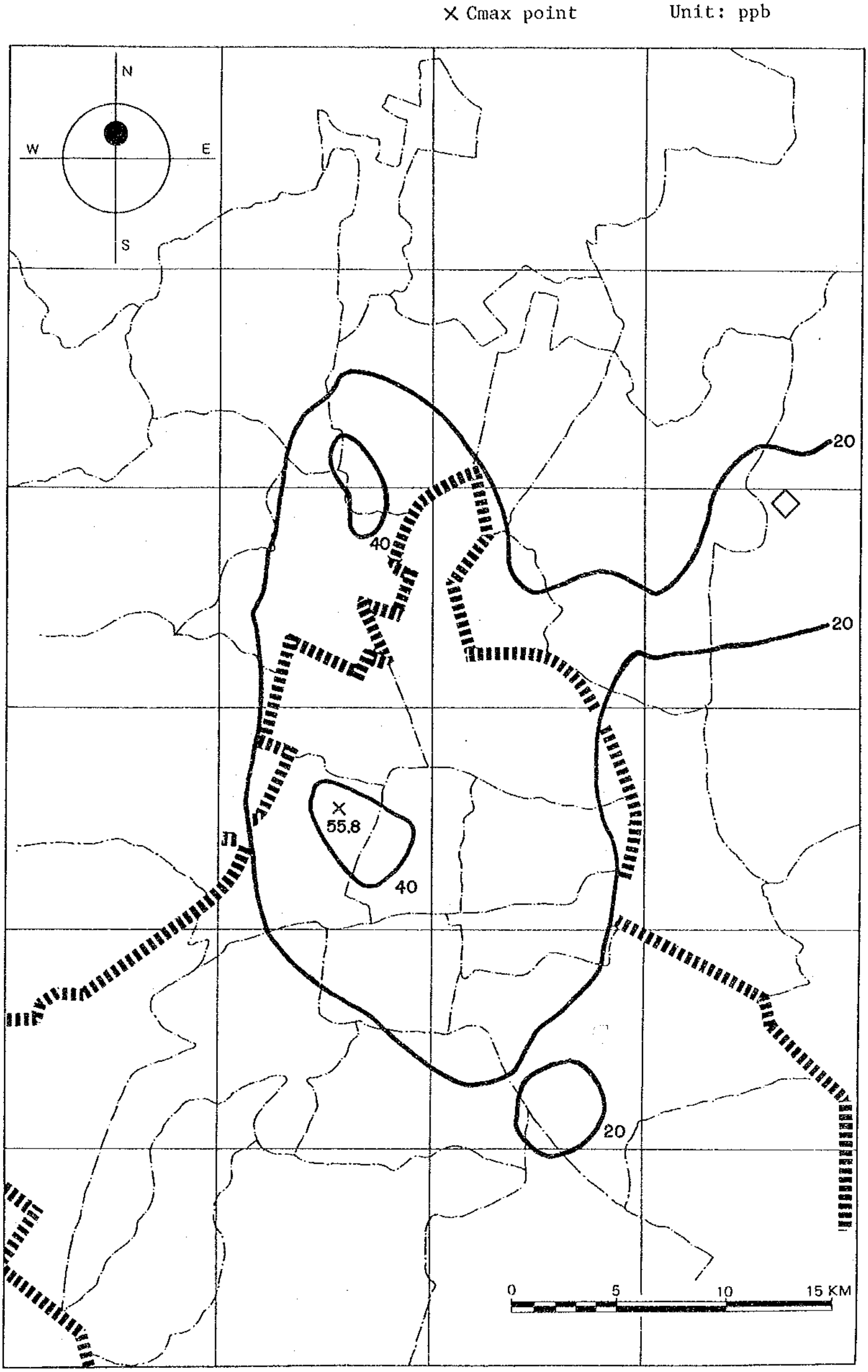
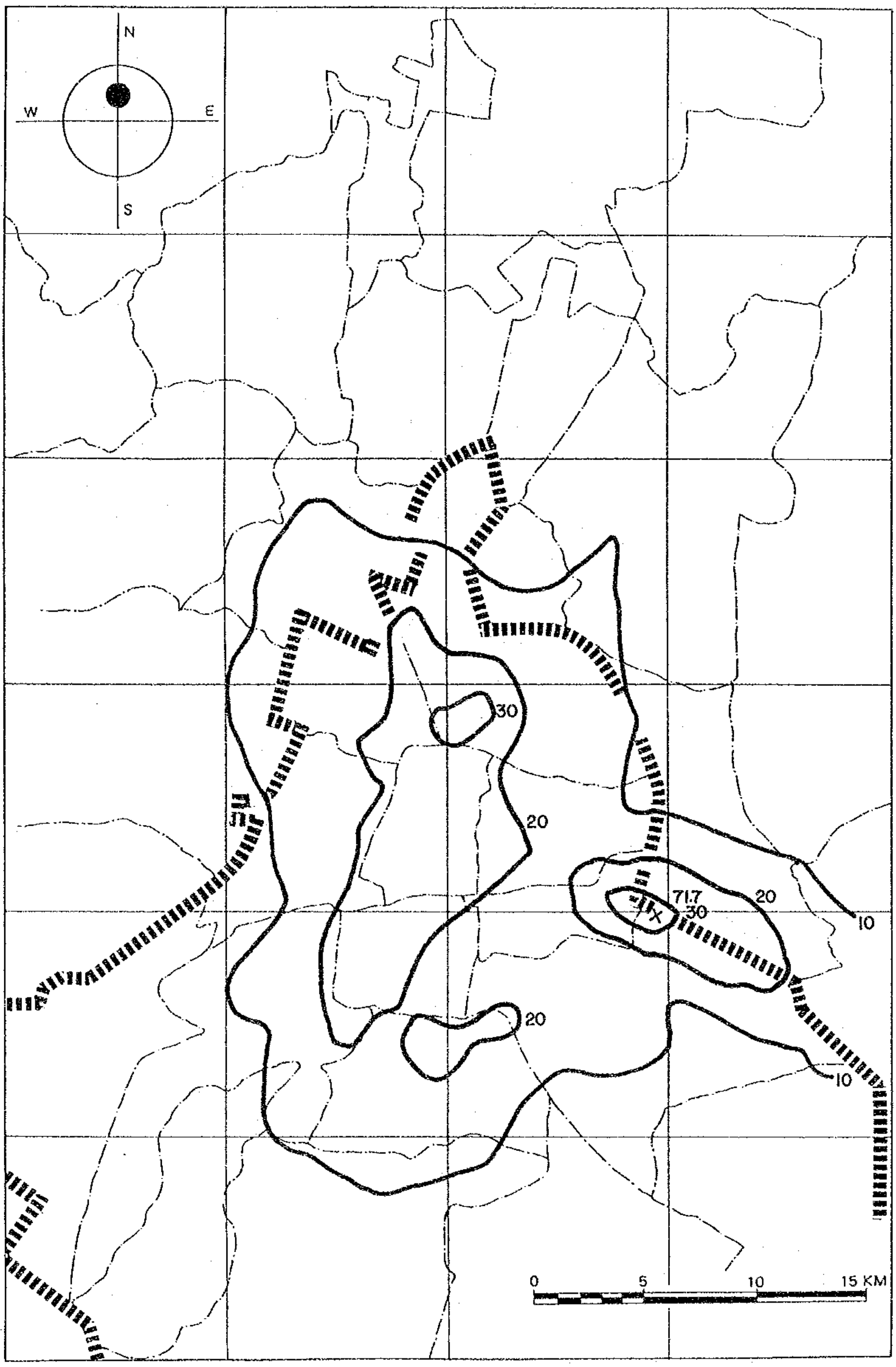


Figure 3.5.14 Contribution of Stationary Sources to Annual Average Concentration of SO_2



× Cmax point Unit: ppb

Figure 3.5.15 Contribution of Automobiles to Annual Average Concentration of SO_2

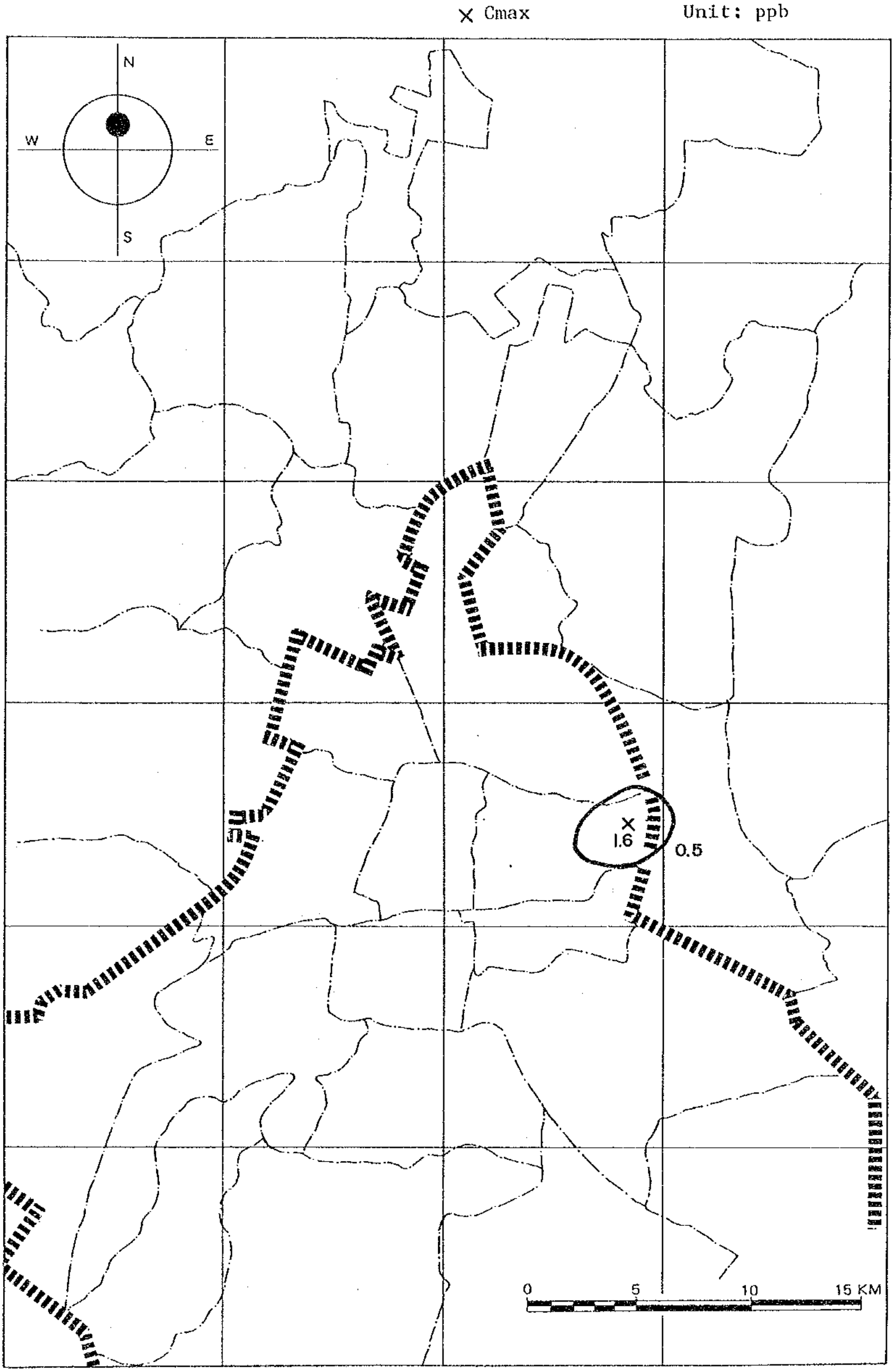


Figure 3.5.16 Contribution of Airplanes to Annual Average Concentration of SO_2

(2) CO Source Contribution

Only automobiles were considered as sources for computation of the annual average CO concentration. The estimated annual average concentration was obtained by adding the background concentration to the automobiles contribution.

The annual average concentration at the receptors and the Cmax point are shown in Table 3.5.13. The values range from 2.26 (PEDREGAL) to 6.98 ppm (INSURGENTES).

Table 3.5.13 Contribution of Automobiles to CO Concentration

Unit: ppm

Receptor	Total	Automobiles	Background
Z. LAGUNILLA	3.77	2.59	1.18
F. TLALNEPANTLA	2.40	1.22	
L. XALOSTOC	2.82	1.64	
X. MERCED	4.20	3.02	
T. PEDREGAL	2.26	1.08	
Q. C. DE LA EST.	2.57	1.39	
U. PLATEROS	3.50	2.32	
P. UAM-IZTAPALAPA	2.83	1.65	
K. ARAGON	2.58	1.40	
O. NEZAHUALCOYOTL	3.32	2.14	
D. IMP	3.38	2.20	
W. BENITO JUAREZ	4.41	3.23	
R. TASQUEÑA	4.46	3.28	
V. INSURGENTES	6.98	5.80	
A. CUITLAHUAC	5.10	3.92	
Cmax Point(94,44)	6.62	5.44	

(3) NOx and NO_2 Source Contribution

Source contribution to the NOx concentration at the receptors is shown in Figure 3.5.17 and Table 3.5.14, and that of NO_2 concentration in Figure 3.5.18 and Table 3.5.15. Contribution to concentration distribution is shown in Figures 3.5.19 through 3.5.24.

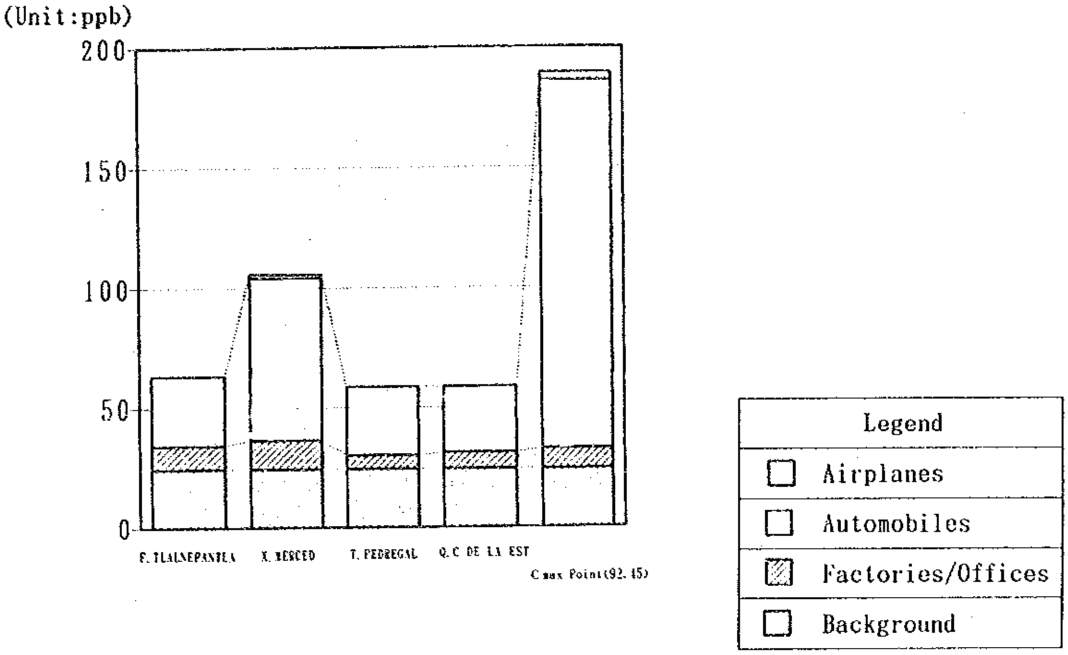


Figure 3.5.17 Contribution of Sources to NOx Concentration

Table 3.5.14 Contribution of Sources to NOx Concentration

Unit: ppb, (%)

Receptor	Total	Factories/ Offices	Automobiles	Airplanes	Background
F. TLALNEPANTLA	63.31	10.03(15.8)	28.82(45.5)	0.03(0.0)	24.43(38.6)
X. MERCED	105.83	12.11(11.4)	67.84(64.1)	1.45(1.4)	24.43(23.1)
T. PEDREGAL	58.76	5.35(9.1)	28.92(49.2)	0.07(0.1)	24.43(41.6)
Q. C DE LA EST	59.05	6.57(11.1)	27.90(47.2)	0.14(0.2)	24.43(41.4)
Cmax Point(92.45)	189.63	7.90(4.2)	153.85(81.1)	3.45(1.8)	24.43(12.9)

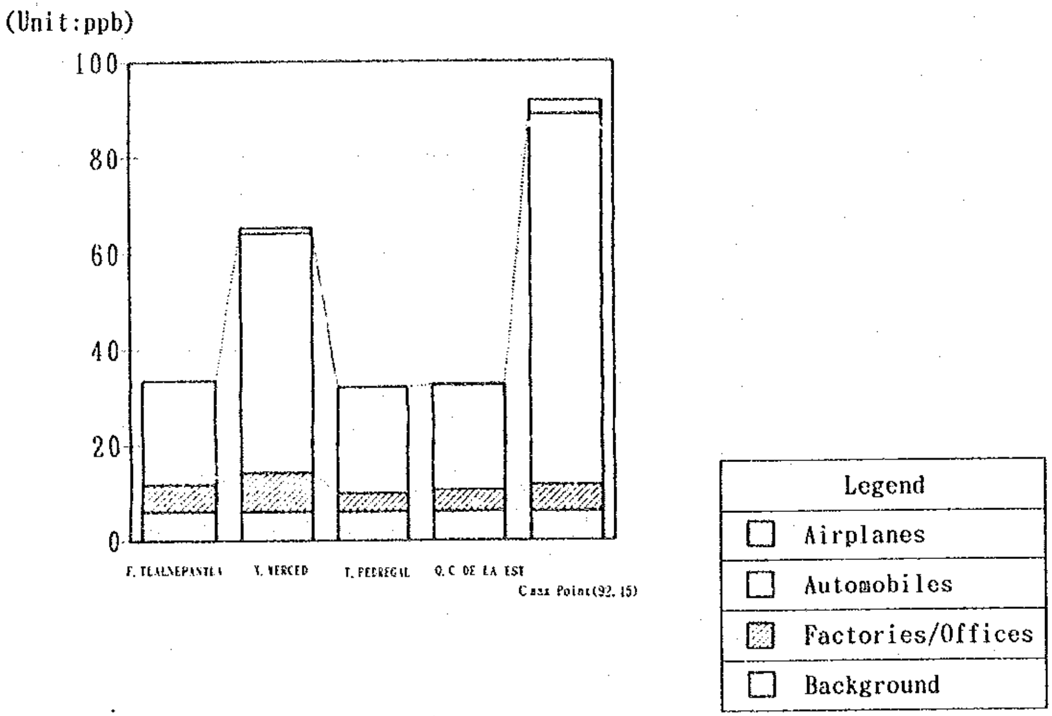


Figure 3.5.18 Contribution of Sources to NO_2 Concentration

Table 3.5.15 Contribution of Sources to NO_2 Concentration

Unit: ppb, (%)

Receptor	Total	Factories/ Offices	Automobiles	Airplanes	Background
F. TLALNEPANTLA	33.43	5.80(17.3)	21.55(64.5)	0.02(0.1)	6.06(18.1)
X. MERCED	65.46	8.22(12.6)	50.05(76.5)	1.14(1.7)	6.06(9.3)
T. PEDREGAL	32.04	3.78(11.8)	22.16(69.2)	0.05(0.2)	6.06(18.9)
Q.C DE LA EST	32.45	4.53(14.0)	21.76(67.1)	0.10(0.3)	6.06(18.7)
C max Point(92,45)	91.54	5.60(6.1)	77.25(84.4)	2.64(2.9)	6.06(6.6)

× Cmax Point   Unit: ppb

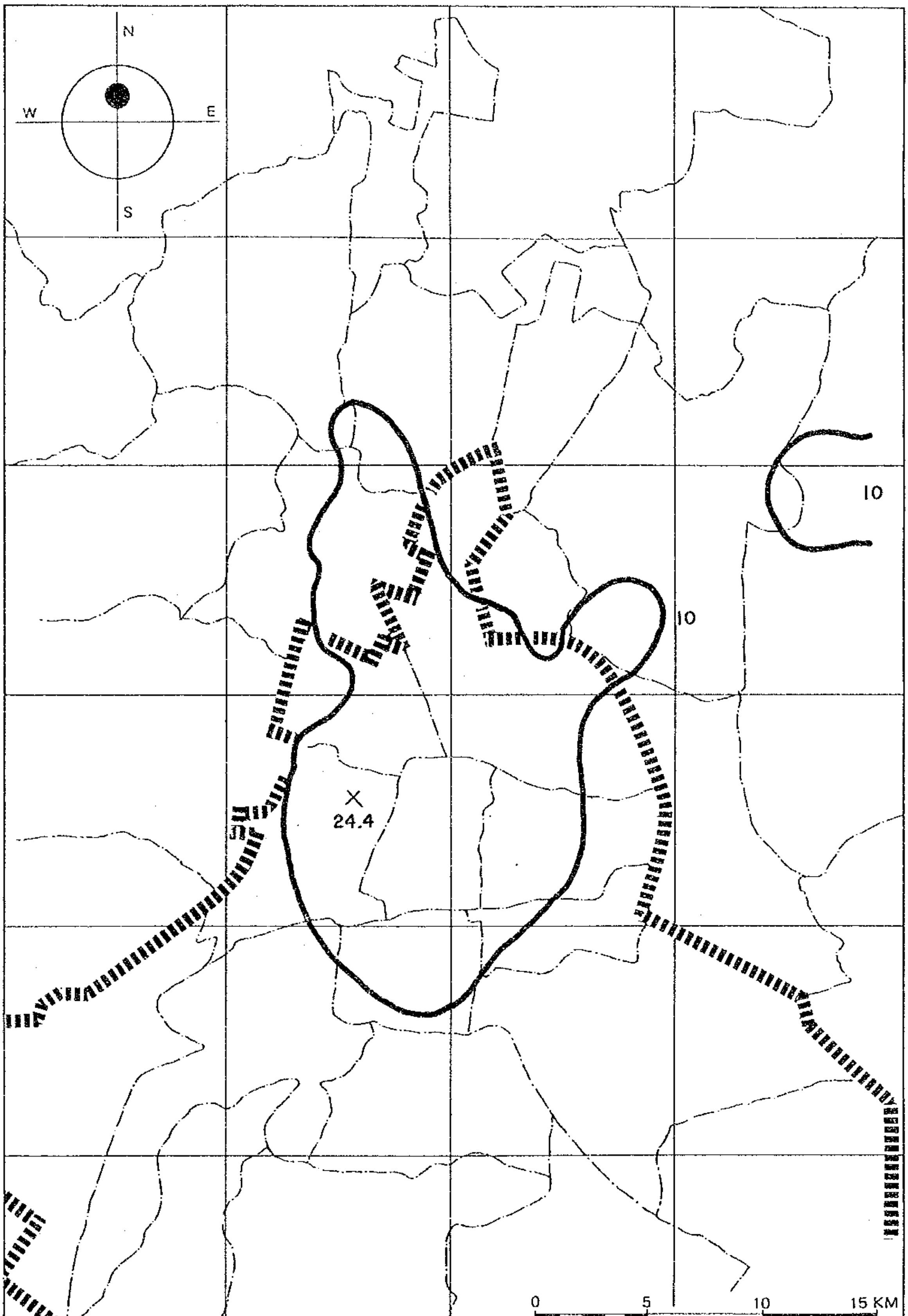


Figure 3.5.19 Contribution of Stationary Sources to Annual Average Concentration of NOx

× Cmax Point   Unit: ppb

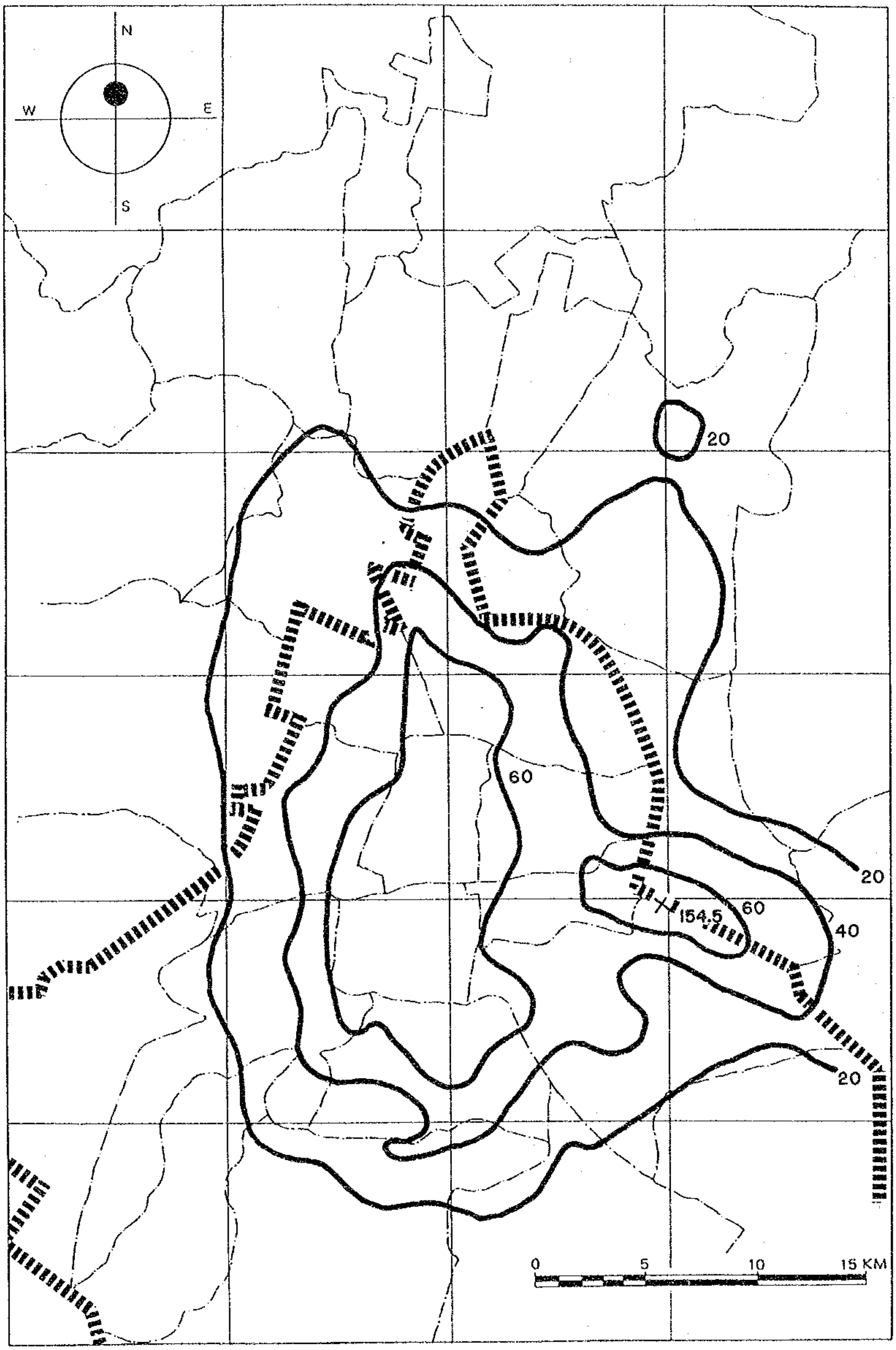
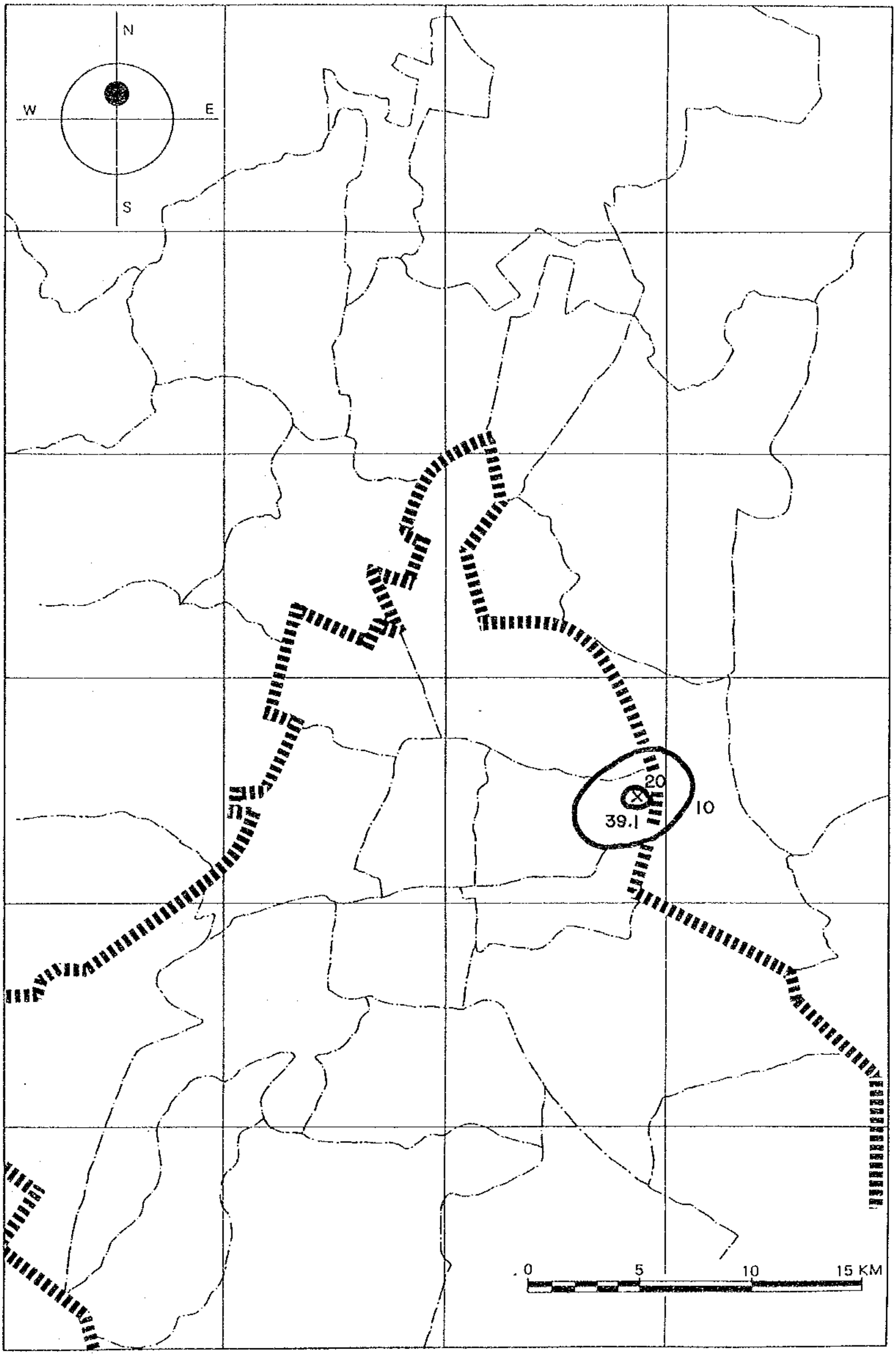


Figure 3.5.20 Contribution of Automobiles to Annual Average Concentration of NOx



× Cmax Point   Unit: ppb

Figure 3.5.21 Contribution of Airplanes to Annual Average Concentration of NOx

X Cmax Point   Unit: ppb

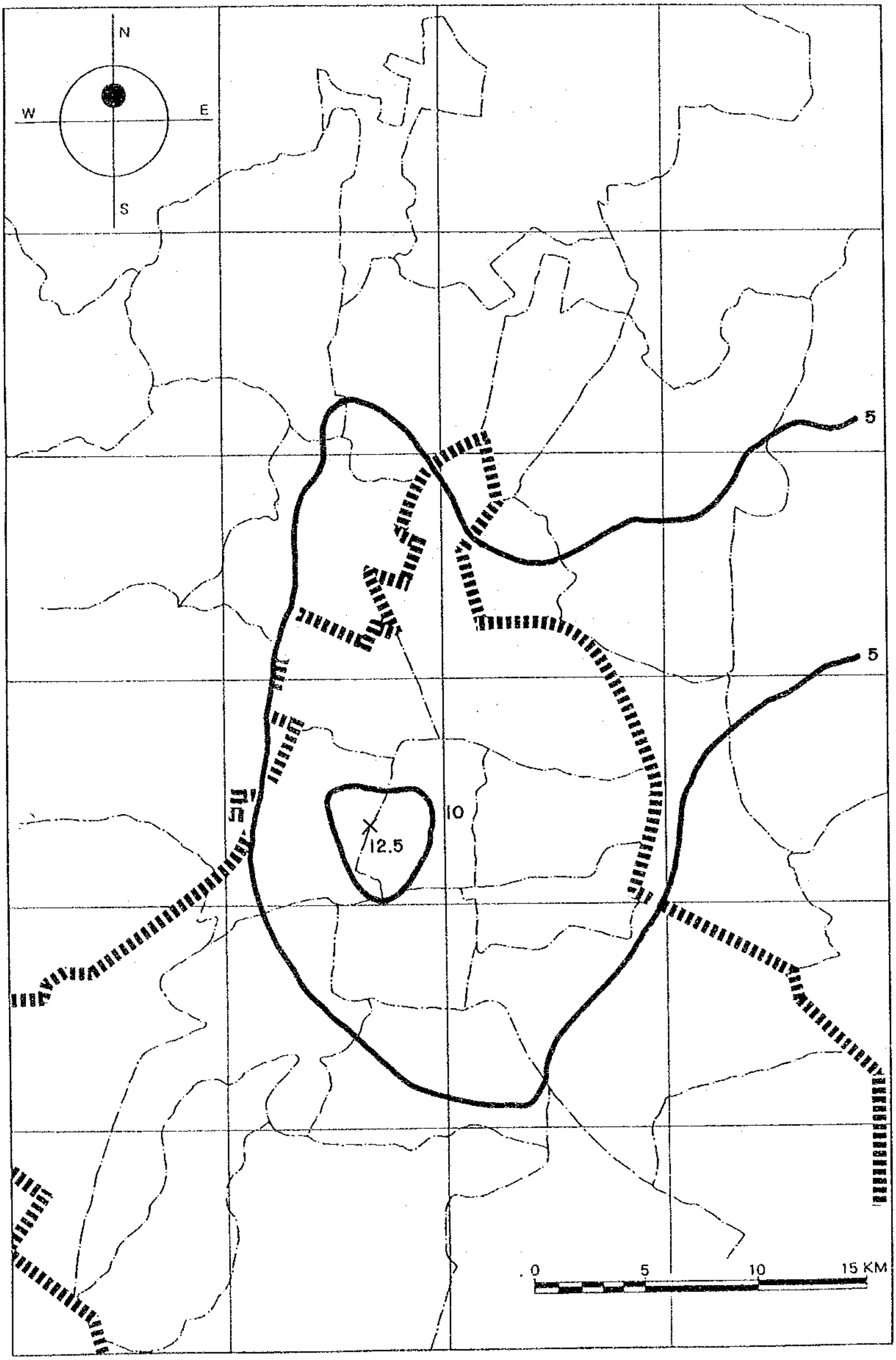


Figure 3.5.22 Contribution of Stationary Sources to Annual Average Concentration of NO_2

× Cmax Point Unit: ppb

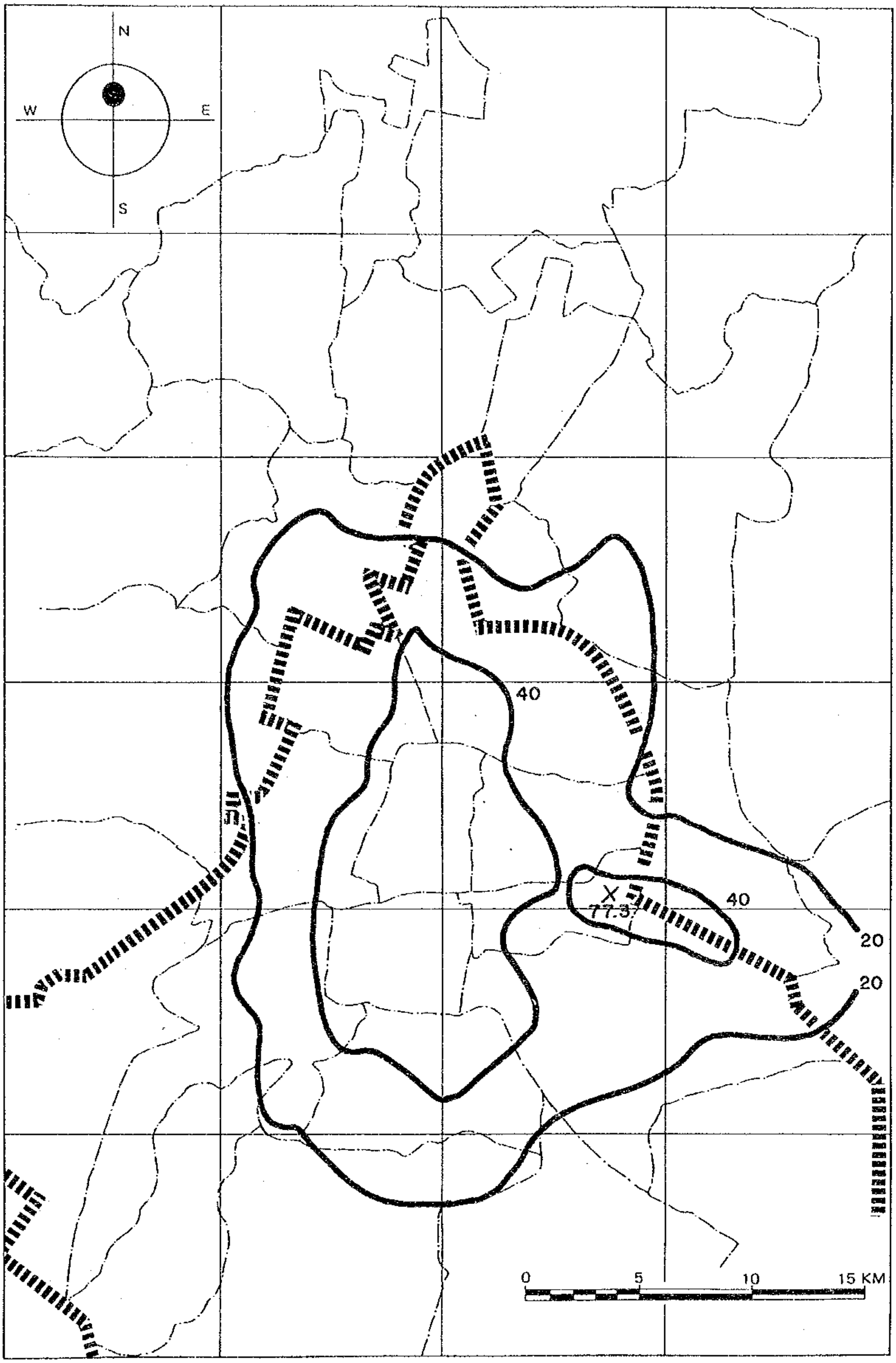
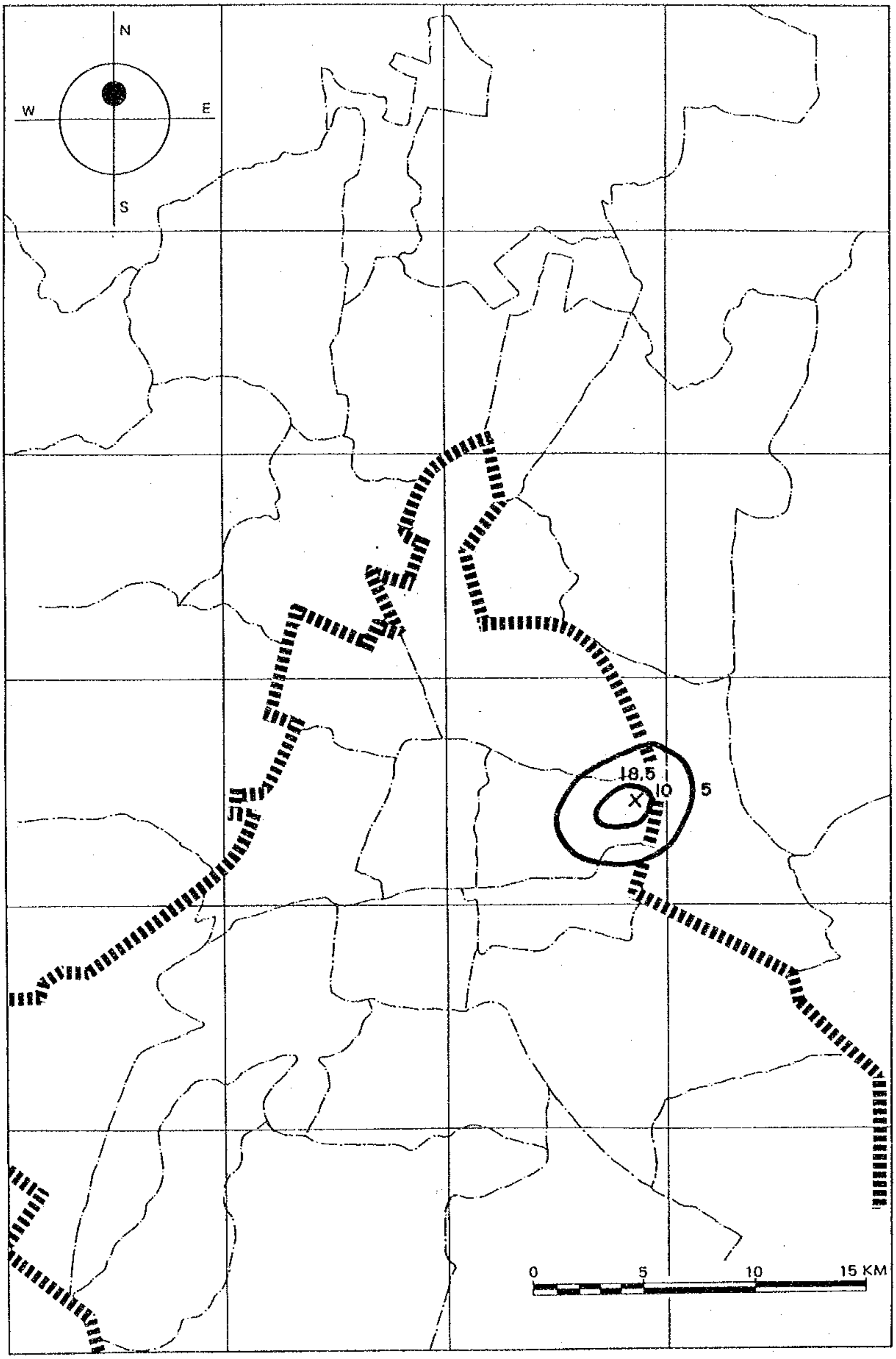


Figure 3.5.23 Contribution of Automobiles to Annual Average Concentration of NO_2



× Cmax Point   Unit: ppb

Figure 3.5.24 Contribution of Airplanes to Annual Average Concentration of NO_2

3.6 Analysis of Sources of Suspended Particulates by Chemical Mass Balance Method

(1) Introduction

Particulate matter suspended in the air originates from man-made sources (factories, automobiles) and natural sources (soil, etc.).

Since reliable methods to simulate dispersion of suspended particulates have not been established yet, the CMB method (Chemical Mass Balance Method) was used to evaluate contribution of sources.

The CMB method utilizes the fact that suspended particulates originate from various sources and that particulates from each type of source have their own characteristics in the element composition. A detailed description of the CMB method is given in the Appendices.

(2) Selection of Elements

Data necessary for this method are content of specific elements in the particulates discharged at sources and that in the particulates suspended in the ambient air.

Elements to be analyzed for their contents in the particulates have to be chosen so that each of them represents a certain types of source. The elements chosen in this study are Fe, Zn, Ni, Pb, V, Mn, Na, Ca, K and Al. Table 3.6.1 shows some types of source that are generally considered to be major origines of these metallic elements.

Table 3.6.1 Major Sources of the Selected Metallic Elements

Element	Source						Standards$^{(1)}$ in Japan (mg/m^3)
	Soil	Sea salt	Steel industry	Fuel oil	Incinerator	Automobile	
Fe	X		X				
Zn			X		X		0.10 - 0.15$^{(2)}$ (Osaka Prefecture)
Ni			X	X			
Pb						X	10 - 30$^{(3)}$ (National)
V				X			0.03$^{(2)}$ (Hyogo Prefecture)
Mn			X				0.025$^{(2)}$ (Osaka Prefecture)
Na		X			X		
Ca			X				
K					X		
Al	X						

Note: (1) Concentration value includes concentration of compounds of the element.

(2) Concentration at the boundary of the site.

(3) Emission standards are specified for three types of facility.

For the analysis of element content of suspended particulates, the TSP samples were taken at the five stations with the Andersen high volume air sampler for about four days a month from September, 1987 to May, 1988. The results of the analysis were presented in Section 3.2.2.

For the sources, the samples were taken at the following sources for the analysis of each element and the average for each type of source was calculated.

Kind of source: Soil (4 points), sintering furnace (one cement plant), glass melting furnace (four plants including glass plants), drying furnace (nine plants including asphalt plants), and metal melting plant (five plants including steel plants), boiler plant (one plant)

(3) Result

Computation of source contribution by the CMB method may produce unreasonable results because least-square approximation has to be made under the various uncertain assumptions.

Consequently, the trial-and-error computations were made for various combinations of element and kind of source. Table 3.6.2 shows the result of the computational case which is considered to be reasonable considering the actual situations in Mexico City.

Table 3.6.2 Contribution of Sources to TSP Concentration Computed by the CMB Method

Unit: $\mu g/m^3$, (%)

Station	Ambient TSP Concent-ration	Source Contribution							
		Soil	Sintering Furnace	Glass Melting Furnace	Drying Oven	Metal Melting Furnace	Boiler	Auto-mobiles	Unknown
O. CENTRAL	183.0	28.2	12.7	1.3	12.3	10.0	-	106.7	11.8
	(100.)	(15.4)	(6.9)	(0.7)	(6.7)	(5.5)	(-)	(58.3)	(6.4)
TACUBA	146.2	10.2	6.1	-2.6	17.6	9.8	-	87.2	17.9
	(100.)	(7.0)	(4.2)	(-1.8)	(12.0)	(6.7)	(-)	(59.6)	(12.2)
ESTRELLA	313.9	115.6	4.5	-	-	4.1	2.0	96.1	91.6
	(100.)	(36.8)	(1.4)	(-)	(-)	(1.3)	(0.6)	(30.6)	(29.2)
Average	185.1	75.8	4.0	-	11.8	7.3	-	28.9	57.3
	(100.)	(41.0)	(2.2)	(-)	(6.4)	(3.9)	(-)	(15.6)	(31.0)

Note: "-" indicates a source excluded from analysis

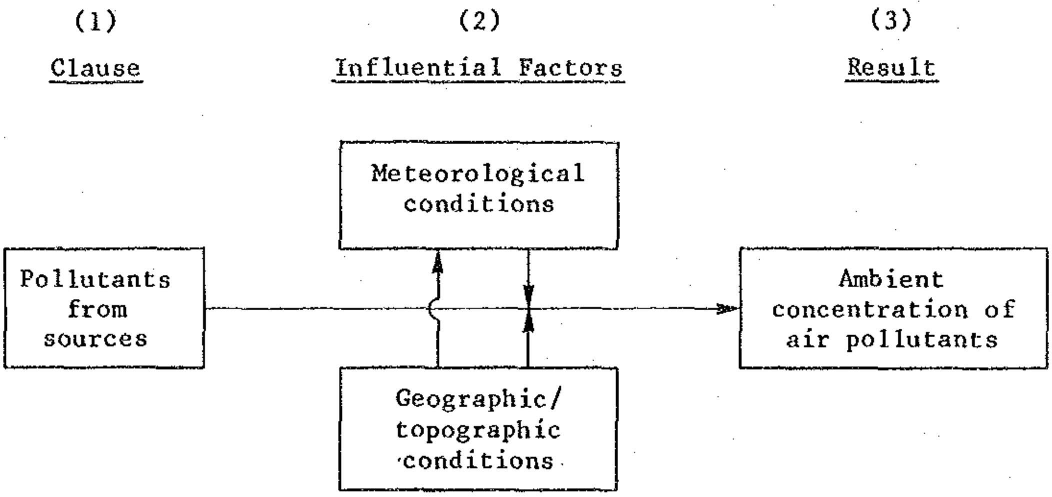
The result indicates that the contribution of automobiles at O. CENTRAL and is more than 50%, followed by soil or unknown source. The contributions of each of various equipment at factories varys between 0.7 - 12.0%.

At ESTRELLA point, the contribution of soil is largest at 36.8%, followed by automobiles at 30.6% and unknown sources at 29.2%. The contribution of factory equipment is small at 0.6 - 1.4%. No reasonable result was obtained at SAN AGUSTIN and PEDREGAL.

The contribution of automobiles exceeds 50% in the urban area near the northern industrial area, followed by contribution of soil. In the southern area having relatively few factories, soil and automobiles are dominant sources.

3.7 Summary

A phenomenon of air pollution involves three major components as shown below in a conceptualized form.



In this Chapter, the results of various surveys and analyses conducted on these three components have been presented to explain the existing state of air pollution in Mexico City.

This Section summarizes the findings of these surveys and analyses.

3.7.1 Ambient Concentration of Air Pollutants

(1) General Level of Pollutant Concentration

When the annual measurement result for each pollutant is compared with the ambient air quality standard value, the following can be said. The concentration of NO_2, SO_2 and CO generally satisfies the air quality standard except that of SO_2 and CO at a few localities.

The concentration of O_3 exceeds the standard level for 3% to 65% of the days of the year, the percentage depending on locality.

When the pollutant concentration levels are compared with those in Japan for reference, SO_2, CO, HC, SPM (suspended particulate matter) and O_3 are higher in Mexico City, and NO and NO_2 are at the similar levels.

(2) Hourly Variation

a. Two-peak pattern

Hourly variation of the concentration of SO_2, NO, NO_2, CO and HC shows a two-peak pattern: the first peak at 8:00 a.m. to 10:00 a.m., and the second peak at 8:00 p.m. to 10: p.m.

b. One-peak pattern

Hourly variation of the O_3 concentration shows one peak at noon to 3:00 p.m.

c. Other pattern

Hourly variation of SPM shows a peak in the morning hours and rises again in the afternoon to a certain level but without a definite peak.

(3) Seasonal Variation

Characteristics of seasonal average concentration of the pollutants are as follows.

a. Pollutants whose concentration is higher in winter than in summer are SO_2, NO, NO_2, CO, HC and SPM

b. The concentration of O_3 is higher in summer than in winter.

3.7.2 Meteorology and Topography

Meteorological and topographic conditions in Mexico City in view of pollutant dispersion can be summarized as follows.

(1) Winds

a. Wind speed is generally low. Consequently, the air in the Mexico Valley is not easily replaced.

b. The wind system around Mexico City is mostly influenced by the local topographic conditions, and the winds are mostly of mountain-valley breezes. Influence of the seasonal geostrophic air currents is very small as indicated by the small atmospheric pressure gradient.

c. Wind speed is lower in the dry season (winter) than in the wet season (summer). In a day, winds are low during daytime and night, and highest at around 6:00 p.m.

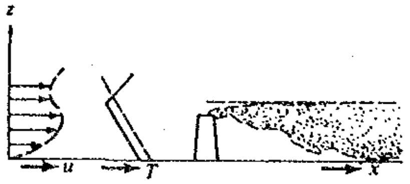
d. Wind speed profile from the ground level to the height of 500m is almost uniform.

(2) Rain

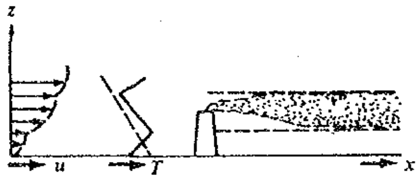
Precipitation is small particularly in the dry season and virtually no effects of washout and rainout are expected in this season.

(3) Thermal Inversion

Occurrence of thermal inversion may have a large influence on the pollutant concentration near the ground level depending on the height of inversion layers. Some examples are shown below.



fumigating



trapping

Characteristics of the thermal inversion observed in Mexico City are as follows.

a. Thermal inversion occurs frequently in the dry season. Inversion layers are formed most frequently at the height between 200 m and 500 m.

b. The inversion often appears at night and sustains until about 10:30 a.m., then begins disappearing with increasing amount of solar radiation.

c. Maximum mixing depth is about 200 m throughout the year. This height is similar to that observed in Japan during the summer.

(3) Conditions for Pollutant Dispersion

Since the wind speed is low, the degree of transport and dispersion of pollutants is generally low. Stable thermal stratification in the atmosphere during the night prevents dispersion of pollutants. But, during the daytime, the increasing solar radiation brings about unstability of the air creating convective air currents which transport pollutants upward.

3.7.3 Pollutant Source

(1) Stationary Sources

a. Although efforts have been made to increase the supply of natural gas, a large amount of heavy oils with the sulfur content more then 3% are still used as fuel. These heavy oils constitute a large portion of origins of SO_2.

b. Because of small height of stacks, pollutants are discharged below the thermal inversion layer.

c. Large-scale factories exist mostly in the northern areas, where increase in population is also significant in recent years. Consequently, industrial zones and residential zones exist adjacent to each others.

(2) Automobiles

a. There exist a considerable number of poorly maintained automobiles such as those with an ill-tuned engine.

b. Incomplete combustion of engine fuels due to the high altitude of the Mexico Valley and the poor engine maintenance causes high levels of CO and HC emissions.

c. Sulfur contained in the gasoline is considerably affecting the SO_2 concentration in certain areas along major roads.

3.7.4 Mechanism of Occurrence of High Pollutant Concentration

A high level of air pollution tends to occur in Mexico City during the dry season: from December to February. The major factors affecting the occurrence of high pollutant concentration are considered to be low wind speed, occurrence of thermal inversion, and little precipitation.

Figure 3.7.1 shows the hourly variation of the wind speed, the height of thermal inversion, and the ambient concentration of pollutants observed on February 22, 1988.

At around 8:00 a.m. to 10:00 a.m., a distinct inversion layer existed at the height between 100 m to 300 m, and the levels of the pollutant concentration were considerably high. The inversion layer

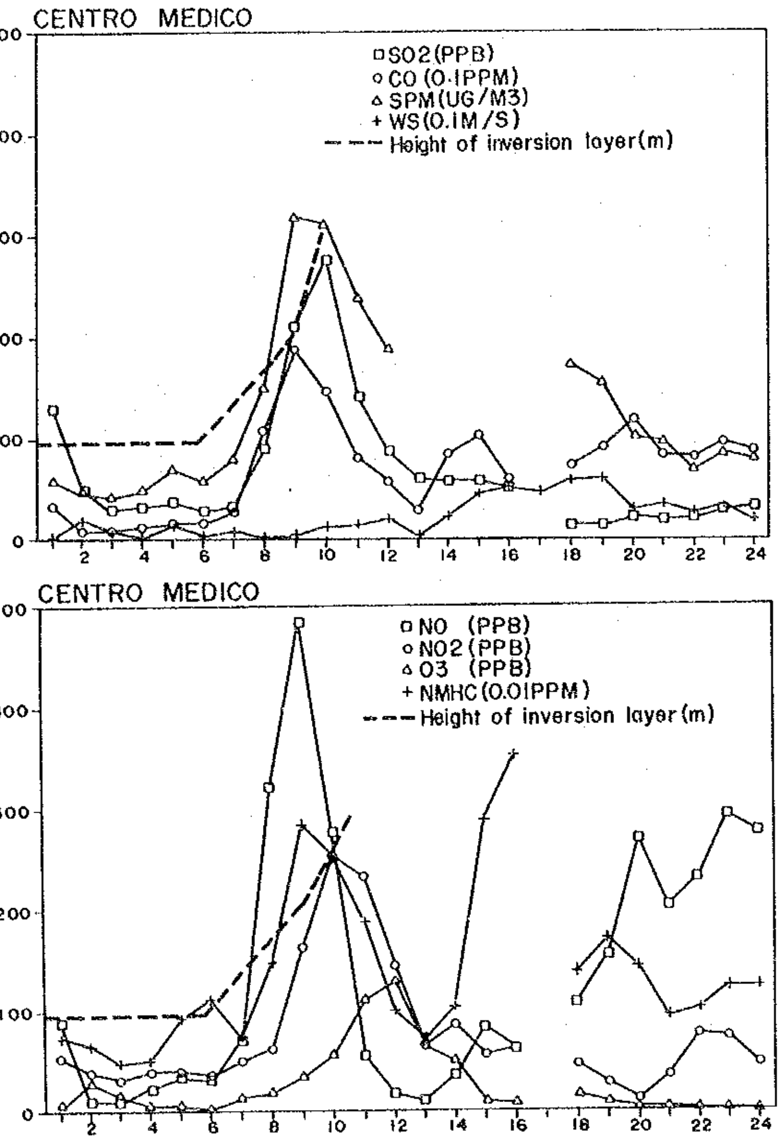


Figure 3.7.1 Example of Occurrence of High Pollutant Concentration in Relation to Meteorological Factors (February 22, 1988)

disappeared at about 11:00 a.m. with the increased solar radiation causing instability of the air and active dispersion of pollutants resulting in the decrease of the concentration of SO_2, NO, NO_2, HC and CO.

However, the concentration peak for O_3 occurred around noon about two hours later than the other pollutants indicating the time required for the reactions involving NO, NO_2 and HC to produce photochemical oxidants.

Then, the wind speed increased and it was maintained at high levels between 3:00 p.m. to 7:00 p.m., and the pollutant concentration levels decreased temporarily. But the concentration of the pollutants that are primarily originated from automobiles such as NO, CO and HC increased again from about 7:00 p.m. with the decreasing wind speed.

The pattern of occurrence of high pollutant concentration described above is considered to be typical of the Mexico Valley, although it is not always the case.

CHAPTER 4 INSTITUTIONAL FRAMEWORK FOR AIR POLLUTION CONTROL IN MEXICO

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4.1 Law

The organic law for the protection of the environment in the United Mexican State is the General Law for Ecological Balance and Environmental Protection (LEY GENERAL DEL EQUILIBRIO ECOLOGICO Y LA PROTECTION AL AMBIENTE: LGEEPA). LGEEPA was promulgated in March 1988, replacing the Federal Environmental Protection Law (LEY FEDERAL DE PROTECCION AL AMBIENTE) introduced in 1982. LGEEPA is aimed at establishing the principle of policies for protection of the ecosystem and environment and coordinating means to put these policies into effect. Assignment of responsibility among federal and local agencies to achieve the purpose has also been defined more clearly in this law than in the preceding one. The functions of the Ministry of Urban Development and Ecology (SECRETARIA DE DESARROLLO URBANO Y ECOLOGIA: SEDUE), an executive agency of this law, include the following:

- Establishment and execution of general environmental policies
- Promulgation of environmental technology standards (NORMAS TECNICAS ECOLOGICAS) and monitoring of compliance with these standards
- Planning and execution of environmental improvement policies for the health of people in coordination with the Ministry of Health
- Decision-making in application of technologies for reduction of atmospheric pollution by vehicles in coordination with the Ministry of Commerce and Industrial Development (SECOFI) and the Ministry of Energy, Mines, and Public Industries (SEMIP)

The above mentioned environmental technology standard is essential for effective operation of this law and, as regards atmospheric pollution, corresponds to the emission standards for the sources. On the basis of the requirements of this standard, SEDUE is drawing up the emission standards for various sources while coordinating with the authorities concerned. Some of such standards have already been made public.

Concerning the air pollution problem in the Federal District (DF), SEDUE and the Department of Federal District (DDF) are respectively assigned the following responsibilities:

SEDUE's functions

- Prevention and control of air pollution by stationary sources other than service and commercial establishments
- Involvement in prevention and control of air pollution by motor vehicles inside DF according to the cooperation agreement with DDF
- Promulgation of air pollutant emission standards for motor vehicles
- Establishment of technical measures to reduce air pollutants from the vehicles in cooperation with SECOFI and SEMIP
- Promulgation of air pollutant emission standards for stationary sources that comply with the quality standards set forth for fuels and energy sources used inside DF
- Installation and operation of the ambient air quality monitoring network

DDF's functions

- Prevention and control of air pollution by stationary pollutant sources of service and commercial industries and all mobile sources in DF
- Establishment and operation of the exhaust gas inspection system for vehicles inside DF, and control of traffic of vehicles which exceeds the emission standards set forth by SEDUE
- Application of traffic and road operation regulations necessary for reduction of pollutant emissions from vehicles
- Inspection of public buses to ensure compliance with the emission standard level
- Operation of the regional network of air pollution analysis laboratories

Since Mexico City Metropolitan Area (AMCM) includes a part of the Mexico State, the government of the Mexico State will also play an important role to improve air pollution control in this area. LGEEPA stipulates the functions of state and municipal governments concerning air pollution control, that includes the following:

- Preventive and control activities against air pollution in the respective area

- Application of general air protection criteria to define the areas allowed for industrial installations that are possible sources of pollution
- Negotiation with those engaged in activities that are possible sources of pollution and, if necessary, obligating installation of preventive devices. If the federal government has jurisdiction, the local government appeal to SEDUE to promote installation of the devices.
- Preparation and updating of the inventory of stationary sources
- Evaluation of the environmental impact of the sources under the jurisdiction.
- Establishment of a vehicle exhaust gas inspection system taking into consideration the SEDUE's technical comments and conduct of the inspection using this system
- Establishment of an air quality monitoring system under technical cooperation and advice of SEDUE, and its operation
- Establishment of requirements and procedures for the control of pollutant emissions from public transport vehicles other than those under the federal jurisdiction, and traffic measures including suspension of the traffic at the time of serious pollution.
- Execution of preventive measures necessary to avoid environmental hazard due to air pollution

4.2 Administrative Organization

The activities concerning air pollution control in Mexico City involve various federal and local governmental agencies. The administrative organizations mainly concerning air pollution control in AMCM include the following:

(1) National Commission for Ecology (CONADE)

The National Commission for Ecology (COMISION NACIONAL DE ECOLOGIA: CONADE) was established in 1985 for the purpose of inter-divisional coordination of policies related to the environment. As shown in Figure 4.2.1, the President acts as a chairman, with members consisting of representatives from various authorities concerned. For air pollution control in the Federal District, the twenty-one policies established by CONADE were promulgated as Presidential decree in February, 1986. CONADE also publicized the 100 Necessary Environmental Measures in January 1987.

(2) Ministry of Urban Development and Ecology (SEDUE)

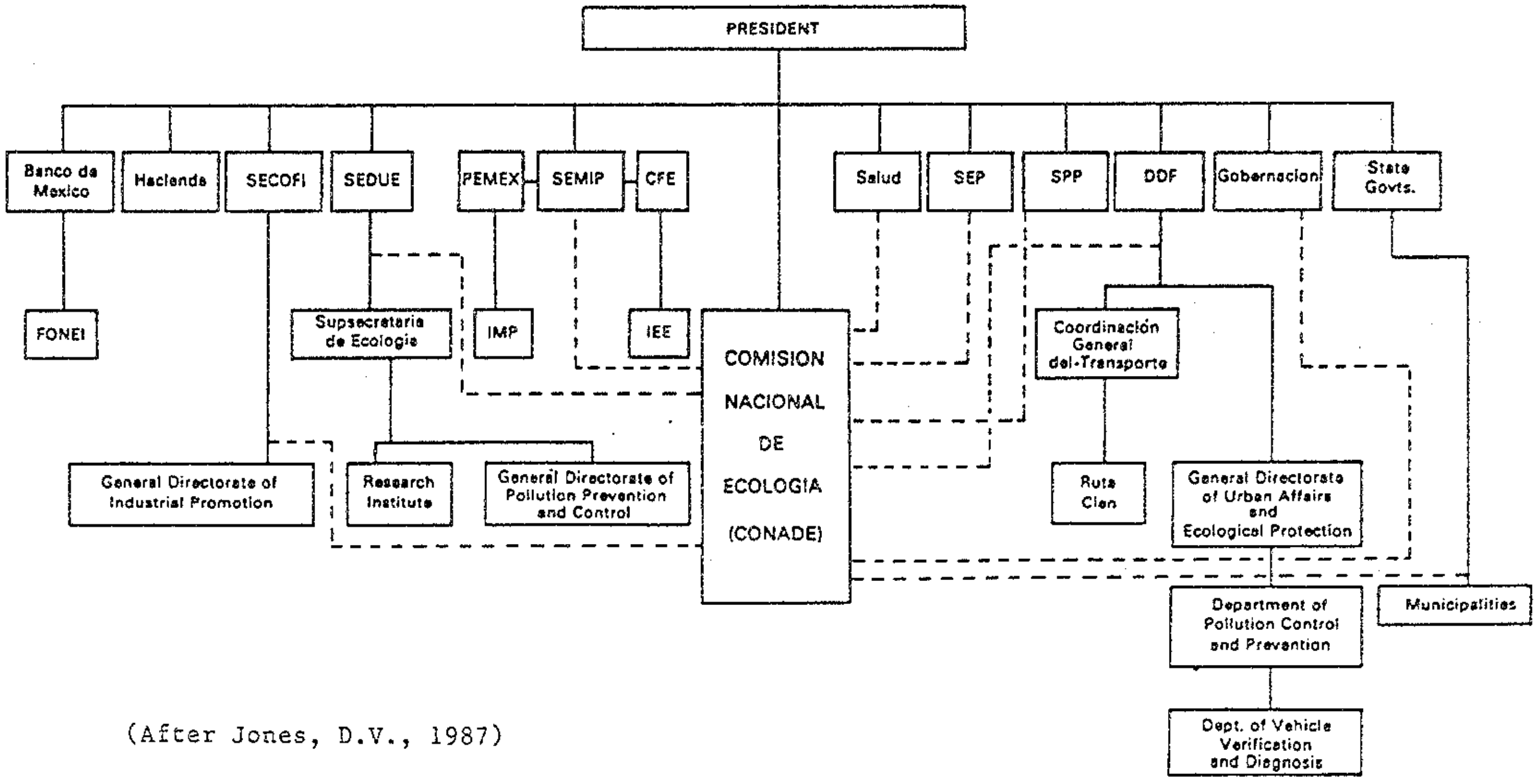
In SEDUE, General Direction for Prevention and Control of Environmental Pollution (DIRECCION GENERAL DE PREVENCION Y CONTROL DE LA CONTAMINACION AMBIENTAL: DGPCCA) is in charge of prevention and control of environmental pollution including air pollution. The organization of DGPCCA is shown in Figure 4.2.2 and consists mainly of three divisions (DIRECCION): technical assistance, investigation, and standards and monitoring. Functions related to air pollution control are shared by these three divisions.

(3) Department of Federal District (DDF)

In DDF, Direction for Prevention and Control of Pollution in the General Directorate of Urban Reordering and Ecological Protection (DIRECCION GENERAL DE REORDENACION URBANA Y PROTECCION ECOLOGICA: DGRUPE) is in charge of controlling environmental pollution including air pollution. Figure 4.2.3 shows the organization of DGRUPE, mainly of the Direction for Prevention and Control of Pollution. The Sub-direction for Air Pollution Prevention and Control is most directly in charge of the air pollution control activities.

(4) State of Mexico

The organization for pollution control in the State of Mexico is as shown in Figure 4.2.4.



(After Jones, D.V., 1987)

Figure 4.2.1 Coordination of Pollution Control Within the Mexican Government

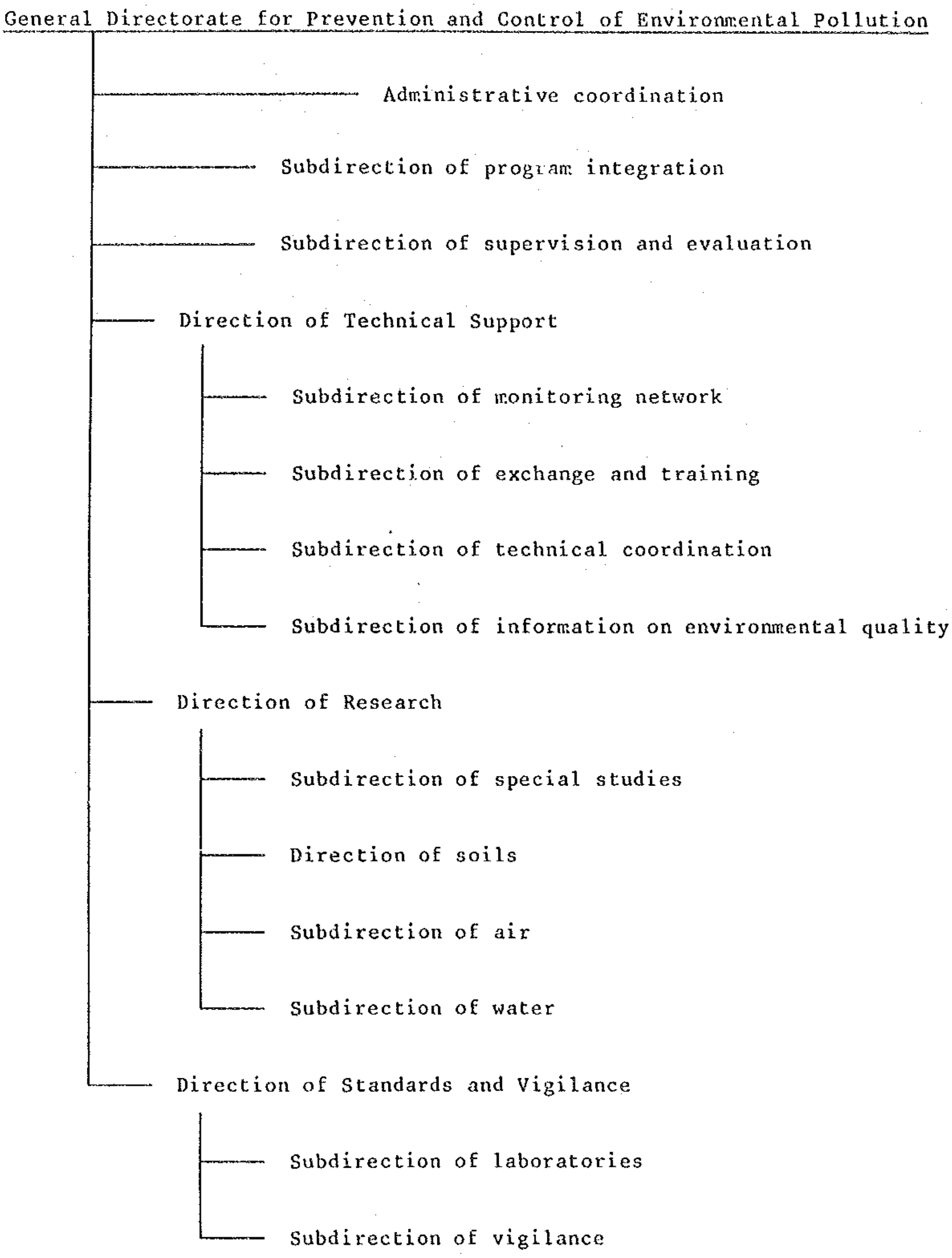


Figure 4.2.2 Organization of DGPCCA in SEDUE

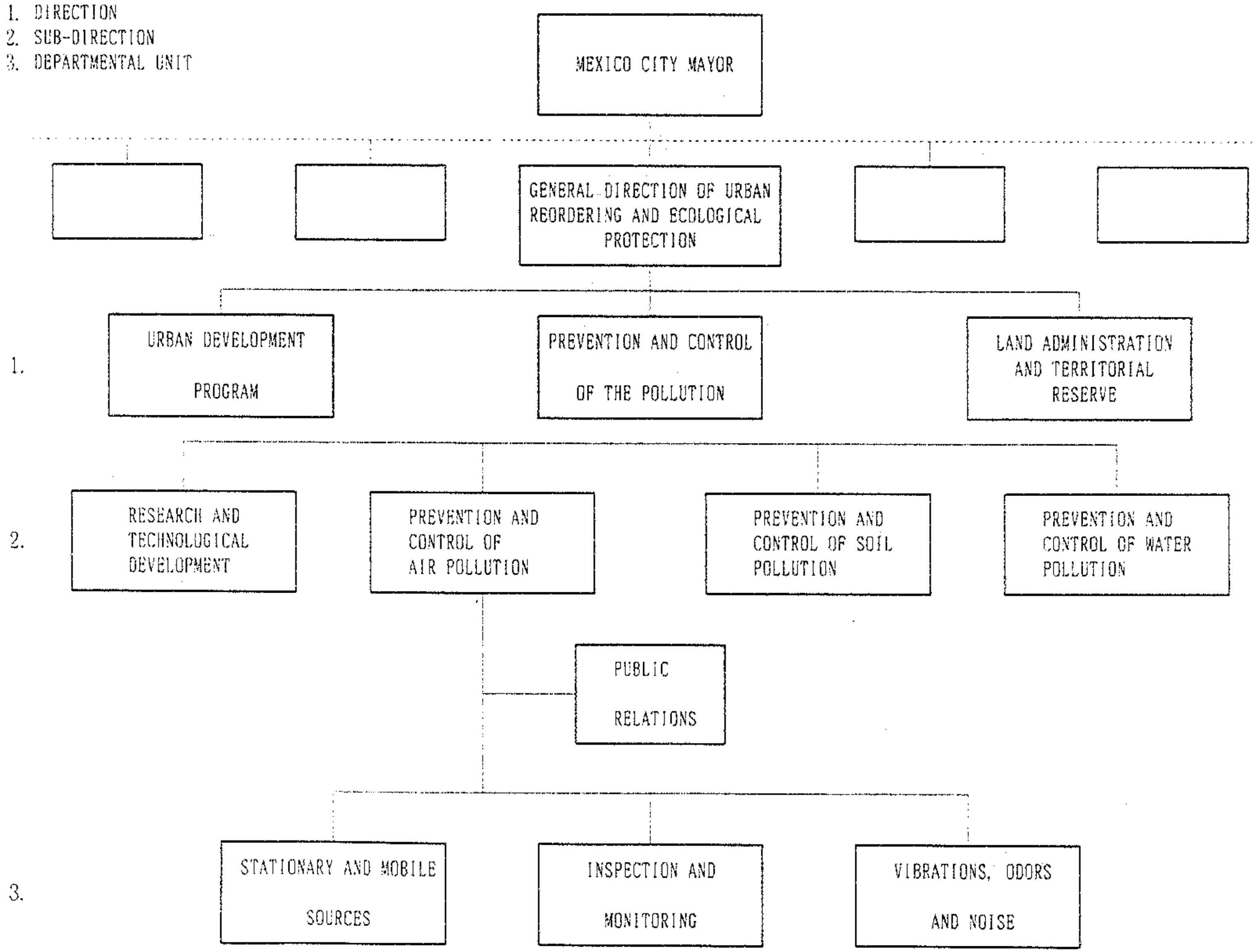


Figure 4.2.3 Organization for Pollution Control Within DDF

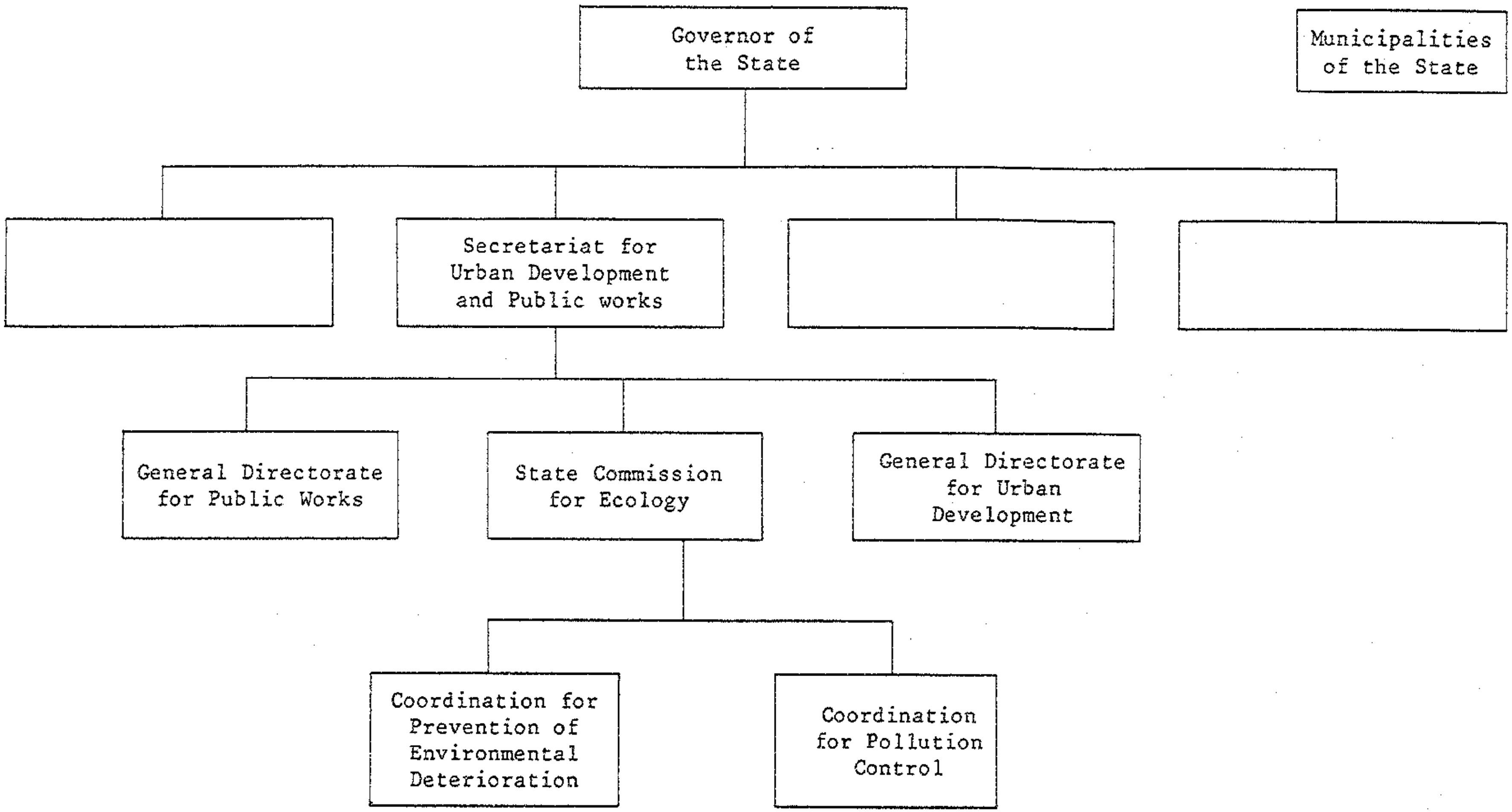


Figure 4.2.4 Organization for Pollution Control in the State of Mexico

4.3 Ambient Air Quality Standards

The ambient air quality standards in Mexico were established in November 1982 for five pollutants as shown in Table 4.3.1.

Table 4.3.1 Ambient Air Quality Standards in Mexico

Pollutant	Averaging time (hr)	Concentration
Total suspended particulates (TSP)	24	275 $\mu g/m^3$
Sulphur dioxide (SO_2)	24	0.13 ppm
Carbon monoxide (CO)	8	13 ppm
Nitrogen dioxide (NO_2)	1	0.21 ppm
Ozone (O_3)	1	0.11 ppm

For convenience of understanding by the general public, SEDUE uses the index called IMECA (INDICE MEXICANO DE LA CALIDAD DEL AIRE) when publishing the daily air quality situation in newspapers. Conversion of each pollutant to IMECA is made as follows:

(1) The concentration of the ambient standard value in Table 4.3.1 is assumed as IMECA 100.

(2) The concentration limit beyond which there is potential hazard to everyone is assumed as IMECA 500. This concentration is determined for each pollutant.

(3) By interpolating linearly the origin and the above two points, the measured concentration is converted to the IMECA value.

4.4 **Air Pollutant Emission Standards**

4.4.1 Automobiles

(1) Gasoline-Powered Automobiles in Circulation

Gasoline-powered automobiles in circulation are under obligation to be inspected for their exhaust gas in the idling mode starting from the summer of 1988. The allowable emission levels for CO and HC in the idling mode are specified as shown in Table 4.4.1.

Table 4.4.1 Maximum Permissible Levels of Emission of CO and HC at Idling from Gasoline-Powered Automobiles in Circulation (NTE-CCAT-003/88)

Model Year	CO (% vol.)	HC (ppm)
1979 and before	6.0 (5.5)	700 (650)
1980 - 1986	4.0	500
1987 and after	3.0	400

Note: The values within the parentheses are applied to the regions with the attitude less than 1500m from the sea level.

Source: DIARIO OFICIAL, June 6, 1988.

(2) New Gasoline-Powered Automobiles

For new gasoline-powered automobiles, the emission standards as shown in Tables 4.4.2 through 4.4.5 are to be applied.

Table 4.4.2 Maximum Permissible Levels of Emission for Gasoline-Powered New Passenger Vehicles

Model year	CO (g/km)	HC (g/km)	NOx (g/km)
1989	22	2.0	2.3
1990	18	1.8	2.0
1991/92	7.0	0.7	1.4
1993 -	2.125	0.25	0.625

Source: SEDUE

Table 4.4.3 Maximum Permissible Levels of Emission for Commercial Vehicles up to 2727 kg

Model year	CO (g/km)	HC (g/km)	NOx (g/km)
1990 - 93	22	2.0	2.3
1994	8.75	0.625	1.44

Source: SEDUE

Table 4.4.4 Maximum Permissible Levels of Emission for Light-Duty Trucks from 2728 to 3000 kg

Model year	CO (g/km)	HC (g/km)	NOx (g/km)
1990/91	35	3.0	3.5
1992/93	22	2.0	2.3
1994	8.75	0.625	1.44

Source: SEDUE

4.4.2 Factories and Others

As regards air pollutants from factories and other stationary sources, the standards by type of facility and by kind of fuel are being established. Tables 4.4.5 and 4.4.6 show respectively the emission standards applicable to plants producing sulphuric acid and the cement industry. Tables 4.4.7 through 4.4.9 show respectively the emission standards applicable to industrial and commercial establishments using natural gas, diesel oil, and heavy oil as fuel.

Table 4.4.10 shows the emission standards for solid particulates applicable to industrial and commercial establishments.

Table 4.4.5 Maximum Permissible Levels of Emission of SO_2, SO_3 and Mist of H_2SO_4 in Plants Producing Sulphuric Acid (NTE-CCAT-001/88)

Plant Capacity (ton/day)		Maximum Permissible Emission (kg of SO_2/ton of 100% H_2SO_4)	
		Critical Zones	Other Regions
Existing plants	1 - 500	17.5	28.0
	501 - 700	13.0	20.0
	701 - 1000	9.0	14.0
	1000 -	4.0	7.0
New plants	1 - 500	13.0	
	500 -	3.0	

Source: DIARIO OFICIAL, June 6, 1988

Table 4.4.6 Maximum Permissible Levels of Emission of Particulates From Calcination Furnace of Cement Industry (NTE-CCAT-002/88)

Type of Facility	Region	Maximum Permissible Emission (kg/h)		
		$(P) < 300$	$300 \leq (P) \leq 366$	$366 < (P)$
New	Urban	$16.264x(P)^{0.18}$	$0.150x(P)$	$0.150x(P)$
	Non urban	$28.975x(P)^{0.18}$	$18.975x(P)^{0.18}$	$0.150x(P)$
Existing	Urban	$16.264x(P)^{0.18}$	$0.150x(P)$	$0.150x(P)$
	Non urban	$21.685x(P)^{0.18}$	$21.685x(P)^{0.18}$	

Note: (P) = Production (ton/h)
Source: DIARIO OFICIAL, June 6, 1988

Table 4.4.7 Maximum Permissible Levels of Emission of Particulates, CO, SO_2 and NOx for Combustion of Natural Gas in Industrial and Service Establishments (NTE-CAT-001.003/88)

Pollutant	Maximum Permissible Emission ($kg/10^6m^3$)
Particulates	100
CO	(a) 500
	(b) 640
SO_2	10
NOx*	(a) 2250
	(b) 8800

Note: * Expressed as NO_2

(a) For combustion equipment of the capacity up to 106 x 10^9 joules/h. (3000 c.c.)

(b) For combustion equipment of the capacity greater than 106 x 10^9 joules/h. (greater than 3000 c.c.)

Source: SEDUE

Table 4.4.8 Maximum Permissible Levels of Emission of Particulates, CO, SO_2 and NOx for Combustion of Diesel in Industrial and Service Establishments (NTE-CAT-001.005/88)

Pollutant	Maximum Permissible Emission (kg/m^3)	
	Critical zones	Other regions
Particulates	0.250	0.275
CO	0.600	0.665
SO_2	17.0	34.0
NOx*	2.40	2.76

Note: * Expressed as NO_2
Source: SEDUE

Table 4.4.9 Maximum Permissible Levels of Emission of Particulates, CO, SO_2 and NOx for Combustion of Heavy Oil in Industrial and Service Establishments (NTE-CAT-001.005/88)

Pollutant	Maximum Permissible Emission (kg/m^3)	
	Critical zones	Other regions
Particulates	4.860	7.99
CO	0.600	0.660
SO_2	57.00	114.00
NOx*	(a) 6.6 (b) 8.0	(a) 6.6 (b) 8.0

Note: * Expressed as NO_2

(a) For combustion equipment of the capacity up to 106 x 10^9 joules/hr. (3000 c.c.)

(b) For combustion equipment of the capacity greater than 106 x 10^9 joules/hr. (greater than 3000 c.c.)

Source: SEDUE

Table 4.4.10 Maximum Permissible Levels of Emission of Solid Particulates from Industrial and Service Establishments (NTE-CAT-001.008/88)

a) Maximum Permissible Emission According to Amount of Production

Production (P) (kg/h)	Maximum Permissible Emission (g/h)	
	Critical zones	Other regions
$P \leq 8000$	$78.8 \times (P)^{0.52}$	$118.2 \times (P)^{0.52}$
$P > 8000$	$1781.93 \times (P)^{0.173}$	$2672.90 \times (P)^{0.173}$

b) Maximum Permissible Emission According to Amount of Exhaust Gas

Maximum Permissible Emission (mg/hr)	
Critical zones	Other regions
$3020 \times (C)^{-0.42}$	$4529.7 \times (C)^{-0.42}$

Note: (C) = Exhaust gas flowrate (m^3/min) at 25°C and 760 mmHg

Source: SEDUE

4.5 Air Pollution Monitoring

4.5.1 Pollutant Source Monitoring

(1) Monitoring of Stationary Sources

SEDUE is responsible for monitoring air pollutant emissions from factories. Specific factories with a large pollutant emission conduct measurement of the exhaust gas quantity and pollutant concentration according to the agreement with SEDUE and submit the results to SEDUE. For general factories, only smoke color and smoke and soot concentration were specified by the emission standards until recently, and accordingly, the Ringelmann method has been employed. Because of the shortage in manpower available within SEDUE, DDF personnel also conduct inspection in response to the demand from representatives of inhabitants of DF . About 400 demands were presented in 1987 and three to four staffs of DDF carried out the measurement.

Under the current situation, progress in installation of automatic monitoring devices is expected at large pollutant sources. Since the monitoring items are increased also for smaller factories along with the establishment of new emission standards, strengthening of the monitoring system for these sources is an important subject for the future.

There are about 5500 service and commercial establishments with facilities emitting smoke in DF, which are under the jurisdiction of DDF. Those in the State of Mexico will be under jurisdiction of the state government. It is therefore necessary for DDF and the government of the Mexico State to establish their own systems to monitor emissions from these establishments.

(2) Monitoring of Automobile Exhaust Gas

The Subdirection for Prevention and Control of Air Pollution in DDF-GDRUPE has been conducting measurement of CO and HC in automobile exhaust gas at twelve centers and by eighteen diagnostic vehicles. Location of eight diagnostic centers is shown in Figure 4.5.1. This measurement has been made during idling operation on voluntarily submitted automobiles. The results of measurement for the past several years are summarized in Table 5.2.5 in the following Chapter.

These centers plan to inspect about 2 million automobiles for compliance with the idling standards shown in Table 4.4.1 for three years from August 1988.

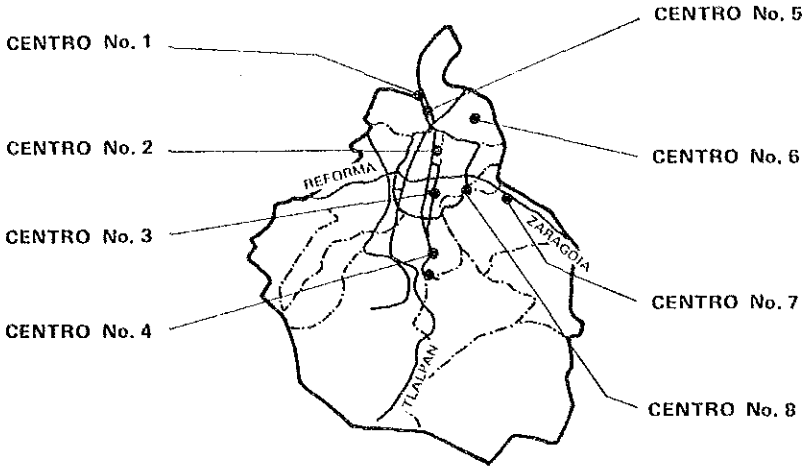


Figure 4.5.1 Location of the Centers for Verification and Diagnosis of Automobiles in the Federal District

4.5.2 Ambient Air Quality Monitoring

SEDUE is carrying out automatic measurement of ambient concentration of pollutants at the stations shown in Table 3.3.1 and Figure 3.3.1. Starting in January 1986, data from the monitoring stations are transmitted online to the monitoring center. In addition, there are 16 non-automatic monitoring stations which have been operated to measure SO_2 and TSP. The method of measurement for each pollutant is as shown in Table 4.5.1.

Table 4.5.1 Methods of Measurement at SEDUE Stations

	Items	Methods
Automatic Monitoring Stations	TSP	Optical scattering
	Ox	Ultraviolet fluorescence
	CO	Infrared absorption
	SO_2	Ultraviolet fluorescence
	NOx	Chemilluminescence
	NMHC	Flame ionization detection
Non-automatic Monitoring Stations	SO_2	Ultraviolet fluorescence
	TSP	Gravimetry

CHAPTER 5 STUDY AND EVALUATION OF SOURCE CONTROL MEASURES

CHAPTER 5 STUDY AND EVALUATION OF SOURCE CONTROL MEASURES

5.1 Stationary Source Control Measures

5.1.1 Stationary Source Control Technologies

Generally speaking, most of air pollutant reduction measures involve a considerable cost, which varies depending on the country. It is therefore essential to review the measures from an economical point of view. Though it is desirable to select the reduction method which is technologically most efficient, the actual method selected must be practically feasible and acceptable under the social and economic conditions.

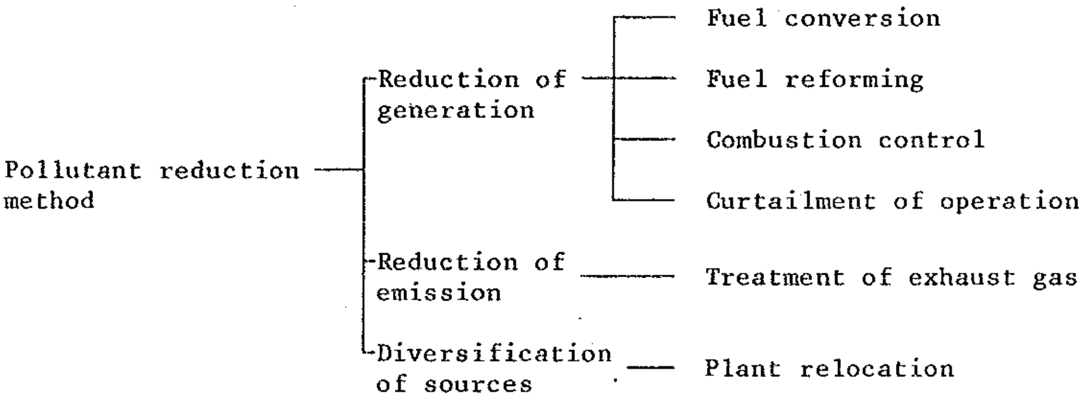


Figure 5.1.1 Pollutant Reduction Method for Stationary Sources

As shown in Figure 5.1.1, pollutant reduction methods are roughly classified into reduction of generation, reduction of emission, and diversification of sources.

Some of the above methods can be independently applied, but most of them are combined with other methods to enhance the reduction effect.

(1) Conversion of Fuel

Theoretically, burning of 1 ton of heavy oil with a sulfur content of 3.5% produces 70 kg of SO_2. Natural gas, however, produces virtually no SO_2 because of low sulfur content. The use of fuel containing less sulfur content is most effective for reduction *of SO_2 emission, and this reduction ratio is proportional to the reduction of sulfur content.*

The use of good quality fuel also allows a substantial decrease in generation of soot. Ranks of fuels in order of less soot production is shown in Table 5.1.1. Any carbon particle in the flame in the course of burning produces soot, which in turn acts as a nucleus to adsorb sulfuric acid produced from sulfur in fuel during burning and grows like snow. This is called "snow smut" and when discharged from a stack causes air pollution nearby because of its heavy weight.

Table 5.1.1 Ranks of Fuels in Order of Less Soot Production

Rank	Fuel	Rank	Fuel
1	*Natural gas*	7	*Coke*
2	Liquified petroleum gas	8	Lignite
3	Other petroleum gas	9	Bituminous coal with low volatile content
4	Coal gas	10	Heavy oil
5	Kerosene	11	Bituminous coal with high volatile content
6	Light fuel oil	12	Tar

The sales price of fuels in 1987 in Mexico City is shown in Table 5.1.2. Though the fuel conversion is accompanied by a rise of the fuel cost and a need for reconstruction or new installation of the burning equipment or storage facility, use of a low-sulfur fuel is most effective for reduction of SO_2 and soot.

Table 5.1.2 Fuel Sales Price in Mexico City

Kind of Fuel	Pesos per Unit Quantity	Pesos per 10^3 Kcal
heavy oil	47,000/ton	452
fuel oil	47,202/ton	454
fuel oil special	47,288/ton	455
kerosene	126/liter	1503
diesel	187/liter	2055
liquified petroleum gas	140/kg	1273
natural gas	$77/m^3$	902

Source: PEMEX, April 1987

Note that, in Table 5.1.2, the price of diesel is higher than that of kerosene because the former includes a production tax.

(2) Fuel Reforming

To obtain low-sulfur heavy oil, the use of crude oil with low sulfur content is recommended. If such crude oil is not produced in sufficient quantity, desulfurization of heavy oil itself often proves advantageous.

Heavy oil is desulfurized either by hydrogenation or gasification. Desulfurization by hydrogenation is further classified into indirect method and direct method. The desulfurization rate of the indirect method is around 40%, and that of the direct method greater than 70% although it varys with the quality of crude oil.

Nitrogen in fuel is partially transformed into NO_x through burning, which is called fuel NO_x. Accordingly, conversion to quality fuel with less nitrogen is an effective measure to reduce NO_x. Note, however, that not all of nitrogen compounds in the fuel are transformed into NO_x: the ratio of nitrogen transformed into the fuel NO_x ranges between 12% - 50%.

The nitrogen content in petroleum fuels is about 300 -2,200 ppm in crude oil, 20 - 140 ppm in diesel oil, and 1,000 -4,000 ppm in fuel oil (equivalent to the C oil in the Japanese standard). There exists a correlation between nitrogen content and sulfur content of fuels.

There are various processes (desulfurization, refining, and cracking) developed to remove sulfur and metals in crude oil. However, denitriding of heavy oil is only incidental to desulfurization by hydrogenation. In general, the rate of denitriding in this case is low.

Nitrogen compounds in petroleum oil are distributed mostly in the heavier portion. When residual oil is carbonized at 500°C, these nitrogen compounds are concentrated in residual carbon because of high thermal stability, and thus difficult to separate as gases. This may be a reason for difficulty of denitration as compared with desulfurization. As of the present, no denitriding technology for heavy oil has yet been developed.

(3) Combustion Control

With the increasing use of liquid fuels, the automatic combustion control has come to be employed. And, the appropriateness of the design of the heating system is now an important factor, leaving less room for combustion control. Yet combustion control in a wider sense of the word, including the use of proper fuel and maintenance of the entire heating system, or the equipment control is still important. Particularly, under the present situation where fuel reforming is of not much significance for reduction of NO_x, proper management of combustion including the equipment and combustion techniques will prove vital for reduction of NO_x.

Fuel saving resulting from optimization of combustion control leads to reduction of pollutants (SO_x, smoke and soot) proportional to the amount of fuel saved, thereby serving to promote economy.

Methods available for fuel saving are shown in Table 5.1.4. The equipment to be used differs among these methods, and the effect in saving fuel or power effect varies also.

Table 5.1.3 Various Fuel Saving Methods

Method	Fuel saving ratio (%)	Applicable facility
Coal economizer	6	Boiler
Air preheater	8	Boiler
Drain reclaimer	30	Boiler
Low-oxygen burning (Improvement of air ratio)	40	Boiler, Industrial furnace
Blower control	(Electric power saving)	Boiler
Waste heat recovery	30	Industrial furnace
Saving of heat radiation	30	Industrial furnace, Boiler
Improvement of burner	10	Industrial furnace, Boiler

Note 1) The fuel saving ratio shown above is for reference only.
2) Various methods are often combined.

Fuel saving requires various equipment and instruments, thus incurring expenses. When properly planned, these expenses are usually paid off in about two years. The economizer and air preheater are mostly installed as equipment necessary for the boiler. For drain recovery, the recovered hot water is either reusable as boiler water or not reusable because of contamination.

The air ratio control for low-oxygen combustion is also an effective method to reduce NO_x and for fuel saving. Table 5.1.4 shows a typical example of fuel saving through correction of the air ratio in the industrial furnace using heavy oil.

Table 5.1.4 Fuel Saving (%) Through Correction of the Air Ratio

Exhaust gas temperature (°C)	Air ratio before correction	Air ratio after correction			
		1.30	1.20	1.10	1.00
700	1.40	3.76	7.27	10.5	13.5
	1.30		3.65	7.01	10.1
	1.20			3.48	6.7
	1.10				3.3
900	1.40	5.94	11.27	16.0	20.2
	1.30		5.66	10.7	15.2
	1.20			5.29	10.1
	1.10				5.0
1,000	1.40	9.43	17.3	23.8	29.4
	1.30		8.67	15.9	22.1
	1.20			7.91	14.7
	1.10				7.36
1,300	1.40	15.7	27.2	35.9	42.7
	1.30		13.7	23.9	32.1
	1.20			11.9	21.3
	1.10				10.7

Another meaning of combustion control is reduction of NO_x. As mentioned before, a portion of NO_x produced through combustion originates from the nitrogen content in fuel (fuel NO_x). The other portion is produced through the reaction between nitrogen and oxygen during combustion at high temperature. This NO_x is called "thermal NO_x".

To cut down the fuel NO_x, (1) fuel with less nitrogen should be used or (2) air should be reduced during initial stage of combustion to obtain the reducing atmosphere in which nitrogen in fuel is transformed into nitrogen gas (N_2).

Countermeasures against thermal NO_x include (1) decrease in the oxygen concentration in the combustion zone, (2) shortening of the combustion gas detention time in the high-temperature zone, and (3) reduction of the combustion temperature. In particular, the local high-temperature zone should be eliminated. All these measures depend on improvement of combustion.

Typical examples of NO_x reduction through improvement of combustion are shown in Tables 5.1.5 and 5.1.6.

Table 5.1.5 Typical Example of NO_x Reduction Through Improvement of Combustion of the Power Generation Boiler

(Unit: NO_x ppm)

	Gas*	Oil**	Coal***
No combustion improvement	250 - 300	300 - 400	500 - 800
FGR[a]	160 - 200	200 - 250	400 - 600
TSC[b]	200 - 250	250 - 300	300 - 500
FGR + TSC	120 - 150	150 - 200	250 - 400
FGR + TSC + LNB[c]	60 - 90	80 - 130	150 - 300

Note: *5% O_2 base, **4% O_2 base, ***6% O_2 base,
a Exhaust gas circulation, b Two-stage combustion
c Low-NO_x burner

Table 5.1.6 Effect and Equipment Cost for Combustion Improvement (1978)

(Mainly, existing oil-burnt and gas-burnt industrial boilers)

Type	No. of boilers applied	Mean NO_x reduction ratio (%)	Mean Equipment cost (yen/Nm^3/h)
OSC*	24	18	26
LNB	80	27	129
TSC	72	27	292
FGR	25	32	
LNB + OSC	17	25	
LNB + TSC	32	34	480
TSC + FGR	92	42	
LNB + TSC + FGR	16	44	657
Others	31	41	

Note: * Off-stoichiometric combustion. Others same as Table 5.1.5

(4) Curtailment of Operation

Although curtailment of operation leads to the proportional reduction of pollutants, a thorough socio-economic review is required.

(5) Treatment of Exhaust Gas

When the measures to reduce generation of pollutants alone are proved to be insufficient for the control of air pollution, treatment of exhaust gas is necessary.

Exhaust gas treatment includes flue gas desulfurization, dust collection, and flue gas denitration. Each of these can be applied independently, but it may prove more effective when combined.

1) Desulfurization of exhaust gas

The rate of sulfur removal by flue gas desulfurization is generally 85% or more. This method is widely employed in Japan and other countries, as shown in Table 5.1.7.

Table 5.1.7 Approximate Number of Exhaust Gas Treatment Facilities (1987)

	Japan	USA	West Germany	Total of other countries	Remarks
Exhaust gas desulfurization	1,600	300	30	30	
Exhaust gas denitration	250	10	10	10	Ammonia catalyst process

Flue gas desulfurization can be classified into wet and dry types as shown in Table 5.1.8. The wet type is used mostly at present. In particular, the wet lime/limestone process which uses limestone or slaked lime slurry as absorbent and produces gypsum as a byproduct is and will continue to be the major desulfurizing method.

Table 5.1.8 Classification of Flue Gas Desulfurization Processes

Type	Absorbent or adsorbent	Byproduct
Wet	Aqueous solution of sodium hydroxide or sodium sulfite	Sodium sulfite, sodium sulfate, SO_2, gypsum
	Aqueous solution of sodium acetate	Gypsum
	Aqueous solution of ammonia	Ammonium sulfate, gypsum, SO_2, S
	Lumestone or slaked lime slurry	Gypsum
	Magnesium hydroxide slurry	Sulfuric acid, magnesium sulfate
	Mixed slurry of magnesium sulfite and calcium sulfite	Gypsum
	Aqueous solution of basic aluminum sulfate	Gypsum
	Diluted sulfuric acid	Gypsum
Dry	Activated carbon	Sulfuric acid, gypsum
	Limestone or slaked lime	Gypsum
	Alkaline metal compound	S
	Oxide of metal	Ammonia sulfate

a. Wet type with lime/limestone

The current mainstream process in the world is the wet type lime/limestone process, in which SO_2 is absorbed by lime or limestone powder slurry and oxidized by air to produce gypsum.

Limestone exists in large quantity in many countries including Japan, and gypsum can be used for various purposes and is also favorable for disposal in terms of physical and chemical characteristics. Figure 5.1.2 shows typical wet type lime/limestone processes.

Type I is an absorption-disposal method in which resultant sulfite sludge is disposed. This is advantageous in its simplicity of the process, but a large settling pond is necessary. Accordingly, this is rarely employed except in USA.

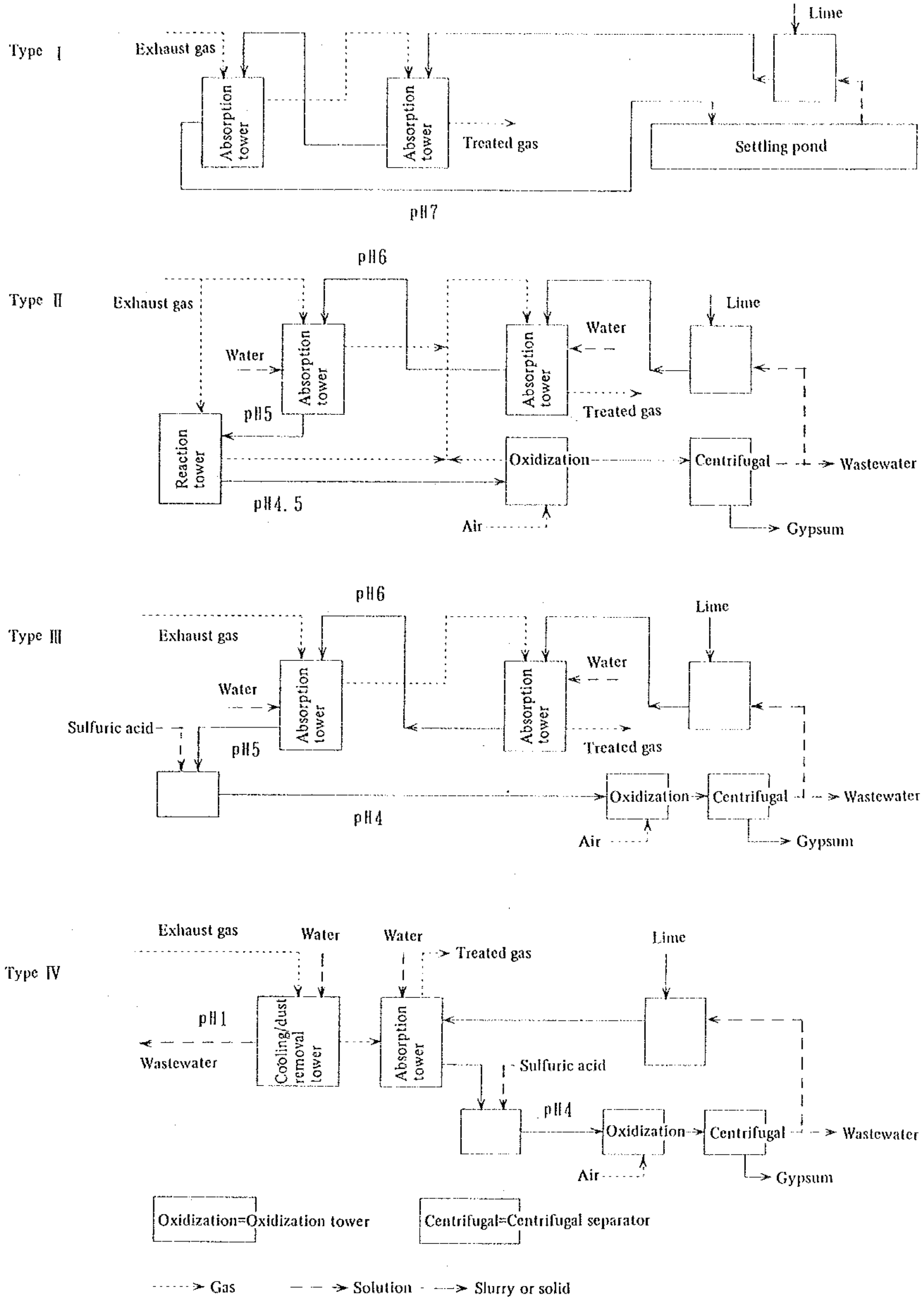


Figure 5.1.2 Typical Wet Type Lime/Limestone Processes

Types other than Type I use limestone as absorbent, with gypsum produced as a byproduct.

Type II has two absorption towers to facilitate oxidation by lowering pH of sulfite lime slurry from the absorption tower. The pH control tower and reaction tower incorporated are also used to absorb SO_2.

Type III has one or two absorption towers, in which sulfuric acid is added to lower pH of slurry. This type is simpler in construction than Type II.

In Type IV, exhaust gas washed in the cooling and dust removal tower by water enters the absorption tower. Sulfuric acid is used for pH control. Sulfite lime slurry is oxidized after lowering pH by the addition of sulfuric acid. The cooling and dust removal tower allows minimizing scaling (solidification of gypsum) and corrosion which are problems of the conventional wet type lime/limestone method, while contributing to enhancement of the purity of byproduct gypsum. This Type presents least problem in operation and is widely employed, but the cost is relatively high.

b. Dry type

The dry types of desulfurization include absorption with activated carbon, lime injection into the furnace, and absorption with metal oxide.

The method of absorption with activated carbon is advantageous in that no gas reheating is necessary and has been attempted in various countries. But this method is not so popular now because of the expensiveness of activated carbon, large pressure loss of exhaust gas, relatively large power consumption, and use of large quantity of water. Recently developed is a method of using inexpensive activated carbon of coal for absorption of SO_2 to be utilized for production of sulfuric acid and sulfur.

The method of limestone injection into furnace is the simplest method applicable to coal combustion. Limestone powder is injected into the furnace via a burner and excess lime is collected together with fly ash by a bag filter for further desulfurization on this filter. Because the desulfurization rate is 50% at most, this method is not widely used in Japan. However, considering the advantages over the wet types such as no wastewater generation and possible low cost, this method may be successfully applied in the case when higher rate of desulfurization is not required and disposal site for byproduct is available.

c. Other methods

Recently, the spraying dryer method has begun to be disseminated as a semi-dry method. In this method, lime slurry is sprayed into the tower for absorption of SO_2 at about 70 - 90%. Powder products dried with the reaction heat and exhaust gas heat are collected with the bag filter. In this bag filter, some degree of desulfurization is attained by the excess lime. This method is advantageous in that there is no need of exhaust gas reheating and waste water treatment. But it is difficult to achieve the desulfurization rate of 90% or more.

2) Dust Collection

Various principles are applied for the collection of dust in exhaust gas.

Dust collectors can be classified into six types as shown in Table 5.1.9: gravity, inertia force, centrifugal force, washing, filtration, and electrostatic.

Table 5.1.9 Practical Range of Various Dust Collectors

Classification	Type	Applicable particle size (μm)	Pressure loss (mm H_2O)	Dust collection rate (%)	Equipment cost	Operating cost
Gravity type	Settling chamber	1000-50	10- 15	40-60	Small	Small
Inertia force type	Louver type	100-10	30- 70	50-70	Small	Small
Centrifugal type	Cyclon	100- 3	50-150	85-95	Medium	Medium
Washing type	Venturi scrubber	100-0.1	300-900	80-95	Medium	Large
Filter type	Bag filter	20-0.1	100-200	90-99	Medium	Medium and beyond
Electrostatic precipitator	Dry or wet type	20-0.05	10- 20	90-99.9	Large	Small to Medium

Among types listed above, gravity and inertia force types are low in the dust removal rate and hardly used.

The greatest of factors governing the dust removal rate is the particle size distribution of smoke and soot or fine dust. The particle size collectable depends on the principle employed. Dust mostly of several μm or more can be efficiently handled with the centrifugal type. For the range principally of several μm or less, the washing or filtration type, or electrostatic precipitator may be necessary. Consequently, it is essential to know the particle size distribution for selection of the type. Table 5.1.10 shows the size characteristics of particulates generated in the mining industry.

Table 5.1.10 Size Characteristics of Particulates Generated in the Mining Industry

Source of particulates	Medium size d_p50 (μm)	Ratio of particle size 10 μm or less(%)
Dust from steelmaking electric arc furnace (O_2 blowing)	0.11	100
Producer gas	0.13	100
Open-hearth furnace (Charging)	0.21	100
do. (Refining)	0.24	100
Lead refining	0.37	100
Titanium oxide	0.65	100
Dust from steelmaking electric arc furnace (Melting)	2	88
Tin oxide	7.2	70
Heavy oil burning boiler	12.5	63-32
Fine coal burning boiler	13-40	40- 5
do. (VDI 2091)	6-28	65-25
Solid waste incinerator (Primary dust collection inlet)	15-22	65
do. (Secondary dust collection inlet)	5.7	38-28
Flyash (UOP)	17	33
Cupola (casting plant)	17	25
Alumina kiln	17.4	23
Aggregate dryer	23	32
Stoker burning boiler	up to 30	30- 8
Grinding dust (casting plant)	40	11

The next important point is the exhaust gas conditions including quantity, temperature, pressure, and components. These are closely related to the performance and capacity of the dust collector, thereby exerting a noticeable influence on the selection of type and determination of the capacity.

Table 5.1.11 shows the basic flow velocity of each type.

Table 5.1.11 Basic Flow Velocity of Dust Collector by Type

Classification	Type	Basic flow Velocity
Gravity	Settling chamber	1- 3 m/s
Inertia force	Louver type Multi-baffle type	- 15 m/s 1- 5 m/s
Centrifugal	Tangential inflow type Axial flow inversion type	7- 15 m/s 8- 13 m/s
Washing	Cyclon scrubber, spray tower Filling tower Theisen washer Jet scrubber Venturi scrubber	1- 2 m/s 0.5- 1 m/s 300-750 rpm 10- 20 m/s 60- 90 m/s
Filter	Bag filter Air cleaner	0.3- 10 cm/s 2- 4 m/s
Electrostatic precipitator	Wet type Dry type	1- 3 m/s 0.5- 2 m/s

(6) Relocation of Factories

Although a large cost is incurred to relocate a factory, it is desirable to relocate those emitting a large amount of pollutants in an orderly manner to the districts having favorable conditions for pollutant dispersion. Relocation becomes necessary not only due to air pollution, but also water pollution, offensive odor, noise, and vibration. This means that careful pollution control at a relocated place is necessary.

5.1.2 Control Measures Adopted or Considered by the Mexican Government

In the United Mexican States, the Presidential decree called "The Twenty-one Measures Against Environmental Pollution" was promulgated in 1986 on the basis of the decision of the National Commission for Ecology, for the mitigation of the air pollution in AMCM. In addition, the National Commission for Ecology announced in 1987 the "100 Necessary Measures on Ecology". At present, the Government of Mexico is reviewing methods of implementing these pollution control measures and has actually put into practice some of them.

Stationary air pollutant source control measures currently undertaken or planned by the Government are described below.

(1) Power Plants

At present, there are two thermoelectric power plants (VALLE DE MEXICO and JORGE LUQUE) in AMCM that supply 25% of power consumption of Mexico City. Air pollution control measures for these power plants being adopted or considered are as follows:

(A) Stepwise changeover of fuel from heavy oil to natural gas
(B) Flue gas desulfurization
(C) Curtailment or suspension of operation
(D) Installation of exhaust gas monitoring system

At VALLE DE MEXICO power plant, the fuel has been partially changed over from heavy oil to natural gas since 1987. For facilities where the fuel changeover to natural gas is not made, the use of low-sulfur fuel as well as introduction of the flue gas desulfurization system are planned. The automatic exhaust gas monitoring instruments will also be installed for the continuous monitoring of SO_2 and NO_x in the exhaust gas.

For JORGE LUQUE plant, the operation will be stopped during the winter of 1988/89 in the case when the use of natural gas in 100% is not possible. After the winter of 1988/89, the operation will be interrupted when the effluent pollutant concentration exceeds the emission standard level. The flue gas desulfurization system will not be introduced for this plant because of financial reasons. These measures for JORGE LUQUE plant is intended to secure supply of natural gas to other industries in winter when the air pollution tends to become serious.

(2) Oil Refinery

There is one oil refinery (18 DE MARZO) within AMCM, with the rest of the refineries being outside the Valley of Mexico.

The air pollution control measures for this refinery are as follows:

(A) No future expansion of the refinery
(B) Fuel changeover to low-sulfur fuel

(C) Repair of the storage facilities to prevent evaportation of hydrocarbons

It is also planned to proceed with improvement of the plant to supply low-sulfur, high quality oil products.

(3) Ten Major Factories

For ten major factories (two for soap and detergent, one for cement, two for paper, one for glass, one for steel, two for chemicals, and one for brewing), the following air pollution control measures are planned:

(A) Changeover from heavy oil to natural gas
(B) Seasonal curtailment of operation
(C) Installation of exhaust gas monitoring system

Fuel changeover from heavy oil to natural gas will be made with priority given to these ten factories.

As in the case of JORGE LUQUE power plant, operation of these ten factories during winter will be curtailed by 30% even if the pollutant emission concentration is within the emission standard level.

Automatic monitoring systems for SO_2 and NO_x will be installed to maintain the continuous monitoring of exhaust gases.

(4) Other Factories

Two basic measures are to be taken for other factories. One is the use of reformed fuel oil. The current sulfur content of heavy oil at about 3.0 - 3.4% will be reduced to about 1%. The sulfur content of diesel will also be reduced from about 1% to 0.5%, and further to 0.3% in future. Reduction of pollutant emissions is expected by the use of these reformed fuels.

Another measure is relocation of factories. Fourteen factories including foundries have completed their relocation to date.

Some sites for new industrial complexes outside AMCM have been determined for relocation of factories. Preferential taxation will be applied to factories that move out to these places. Also, measures to encourage installation of pollution control devices will be taken.

Also reviewed is the measure to prohibit construction of new plants and expansion of existing facilities in the urban district.

(5) Service and Commercial Establishments

Of service and commercial establishments within Mexico City, about 5,500 have boilers. Heavy oil presently used in these facilities will be switched to diesel to reduce air pollutant emissions.

5.2 Control Measures for Automobile Exhaust Gas

Air pollution by automobiles is influenced by pollutants discharged from automobiles, structure of roads and meteorological conditions. Consequently, control measures can be reduced to:

(a) Reduction of pollutants emitted from automobiles
(b) Facilitating dispersion of pollutants

Measures categorized into (a) can be further divided into two groups, i.e., 1) control of pollutants discharged per automobile, and 2) reduction of gross amount of pollutants by changing traffic volume and traffic flow. This Section deals with the former.

5.2.1 Automobile Emission Control Technologies

Principal pollutants from automobiles are CO, HC, NO_x, and particulates, which are emitted as follows:

(a) Emission from the exhaust pipe after combustion in the engine (CO, HC, NOx, etc.)

(b) Gasoline vapors from gasoline tanks and carburetors (mainly HC)

(c) Blow-by gases leaking through gaps between engine piston and cylinder (mainly HC)

(d) Particulates produced from fuel combustion, metal components in fuel and tire abrasion

Measures against (a) above will be mainly considered in the following description.

(1) Processes of Pollutants Production

CO, HC, and NO_x production processes are described.

1) CO Production Mechanism

Incomplete combustion of carbon in gasoline due to insufficient supply of air produces CO.

$$2C + O_2 \longrightarrow 2CO$$

Complete combustion, in contrast, produces harmless CO_2.

$$C + O_2 \longrightarrow CO_2$$

2) HC Production Mechanism

HC is discharged as unburnt raw gas resulting from incomplete combustion of fuel. The following three causes may be considered:

a) A quenching zone, in which the flame ignited by the spark plug inside the cylinder is not propagated, is formed and the unburnt raw gas in this quenching zone is forced out by the piston during the exhaust stroke.

b) Return of the throttle valve to the idle position during deceleration causes a sudden increase in negative manifold pressure resulting in the too rich air-fuel ratio. Unburnt gas is discharged as a result.

c) Overlap of suction and exhaust valves causes blow-by of the drawn mixture, resulting in discharge of unburnt gas.

3) NO_x Production Mechanism

NO_x is the general symbol for nitrogen oxides which are generally produced when a substance is burned at high temperature.

NO forms when both N_2 and O_2 exist at high temperature:

$$N_2 + O_2 \longrightarrow 2NO$$

NO converts to NO_2 when it contacts O_2 in air:

$$2NO + O_2 \longrightarrow 2NO_2$$

4) Effect of the Air-fuel Ratio on Pollutant Production

Production of pollutants in the exhaust gas is influenced by the air-fuel ratio, temperature, and engine structure. The air-fuel ratio, which is most influencial among these factors, is discussed below.

Change in concentration of CO, HC, and NO_x in the exhaust gas in relation to air-fuel ratio is shown in Figure 5.2.1. Generally, CO and HC decrease when the actual air ratio is slightly lower than the stoichiometric ratio.

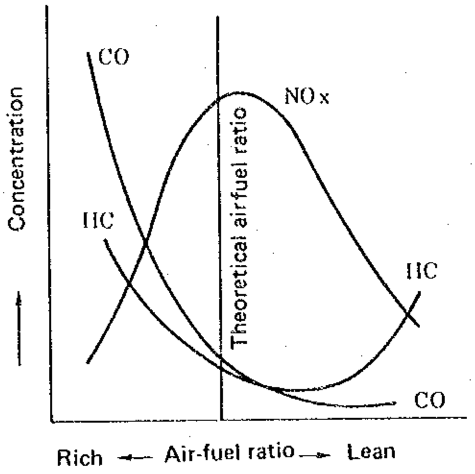


Figure 5.2.1 The Effects of Air/Fuel Ratio on Pollutant Emissions

In turn, such air-fuel ratio causes increased NO_x concentration. NO_x decreases when the air-fuel ratio is further shifted toward the lean. But there exists a high possibility that CO and HC will increase due to ignition failure. This indicates that CO and HC run counter to NO_x. Such antipodal relationship must be taken into consideration when any measures against exhaust gas are to be taken, and it represents one of the difficulties encountered when appropriate measures are to be taken.

(2) Countermeasure Against Exhaust Gas

As described above, the NO_x production process is quite opposite to that of CO and HC. Correspondingly, combined use of several devices is required to comply with increasingly severe emission standards. Methods to control emissions of CO, HC and NO_x are described below.

1) Control of CO and HC

CO is generated through incomplete combustion while HC is a fuel component discharged in an unburnt state. Since CO and HC emissions tend to become large when engine braking is applied, emission control during deceleration is important.

Following measures are taken to control emissions of CO and HC:

(a) Carburetor improvement to ensure supply of satisfactory (properly lean) mixture

(b) Use of electronic fuel injector (EFI) to ensure ready control of air-fuel ratio

(c) Heating of air to improve carburetion of gasoline

(d) Shaping of manifold to improve distribution of air-fuel mixture to each cylinder

(e) Turbulence of mixture to improve combustion

(f) Prevention of sudden closing of the throttle valve of the carburetor during deceleration. This is to prevent shortage of air.

(g) Induction of air or mixture into manifold during deceleration to obtain the state ready for combustion

(h) Stopping of fuel supply during deceleration

(i) Reshaping of the combustion chamber to facilitate combustion

(j) Changing of valve timing to prevent escape of unburnt gas during valve overlap

(k) Powerful ignition system

(l) Delay of ignition timing to raise exhaust gas temperature, thereby aiding recombution of unburnt gas

(m) Improvement of exhaust manifold to facilitate burning of unburnt components of exhaust gas

(n) Introduction of air into the exhaust system for burning of unburnt components and catalytic oxidation or reduction

2) Control of NO_x

Emission of NO_x is large at or near the stoichiometric air-fuel ratio, as shown in Figure 5.2.1. Namely, the emission of NOx increases with increasing combustion efficiency (combustion temperature).

Following measures are generally taken to control NO_x emission:

(a) Supply of the air-fuel mixture considerably leaner than the stoichiometry

(b) Supply of the mixture richer than the stoichiometry

(c) Use of exhaust gas recirculation (EGR) system to lower the combustion temperature

(d) Changing valve timing to lower the combustion temperature

(e) Increasing turbulence of the mixture to achieve quick combustion, thereby shortening period of maximum temperature

(f) Reshaping of the combustion chamber for quick combustion (short maximum temperature period)

(g) Use of the catalyst to reduce NO_x in exhaust gas

Table 5.2.1 shows specific technologies for the measures described above. Automobile manufacturers in various countries attempt to meet the exhaust gas regulations by using the devices listed in Table 5.2.2.

Table 5.2.1 Concept of Countermeasures Against Exhaust Gas (Gasoline Engine)

Component	Production Mechanism	Characteristic	Basic Concept	Specific Concept	Specific Countermeasure	Demerits	Countermeasure Against Demerits	Remarks
CO	Incomplete burning of fuel ↑ Shortage of O_2	Generally determined from air-fuel ratio (A/F)	Lean A/F	Adaptive control of A/F	o Adaption of carburetor, improvement of precision control o Improvement of carburetor (quick choke) o Employment of EFI	Drop of output Poor combustion → Operability lowered, Increase in HC and NOx	Improvement of combustion	Somewhat favorable as far as fuel economy is concerned
				Improvement of atomization and distribution of fuel (Quality and variance of mixture)	o Employment of hot air intake o Reshaping of the intake manifold o Improvement of the intake manifold heating method o Improvement of carburetor (fine particle of fuel, etc.) o Employment of EFI			Including the variable Venturi carburetor, etc.
				Improvement of the ignition capacity (Expansion of ignition limit)	o High-energy ignition device			
				Improvement of combustion - mainly increase in the combustion speed and improvement of ignitability	o Laminated combustion · Tube type · Auxiliary chamber type o Soaking combustion · Auxiliary chamber type · Powerful swirl type · Squish head · Reshaping of the combustion chamber (flame propagation distance) · Multiple ignition	Mostly accompanied by output drop. Deterioration of the fuel economy to a certain extent is therefore inevitable		
		Oxidized at high temperature and when O_2 exists	Recombustion in the exhaust system	Hot insulation of the exhaust gas and extension of the high temperature retention time	o Port liner o Siamese type exhaust port o Dual exhaust pipe o Capacity-increasing-type exhaust manifold o Thermal reactor	Output drop, deterioration of fuel economy		
				Air supply to exhaust system	o Secondary air injection system (AI) o Secondary air suction system (AS)	Output loss → change in fuel economy		
				Oxidation using catalyst	o Oxidation catalyst converter o Three-way catalyst converter · Open loop · Closed loop	Overheating of exhaust system	Various overheating preventive systems and heat shields	Deterioration of the fuel economy may be said to be not very severe because the engine is not under heavy load.
HC	o Unburnt fuel is discharged o Incomplete combustion of fuel	Rich A/F causes increase in HC — Shortage of O_2	Employment of lean A/F (in a range not causing ignition failure	Same as for CO				
		Poor combustion state causes ignition failure or flame OFF, resulting in discharge of unburnt HC	Improvement of ignitability	Same as for CO				
			Improvement of combustion	Same as for CO				
		Quenching by combustion chamber wall, resulting in flame OFF	Reduced quench zone	Reduction in S/V ratio of combustion chamber	o Reshaping of combustion chamber	Increase in NOx		
			Reduction in flame OFF distance	Increase in wall temperature	o Increase in thermostat temperature			
				Increase in turbulance inside combustion chamber	o Identical to item on improvement of combustion			
		Large quantity of HC is discharged due to ignition failure during deceleration	Increase in volume efficiency	Slightly open throttle lever immediately after sudden deceleration	o Throttle positioner (TP), throttel opener (TO) o Dash pot (DP) o Vacuum limiter	Deterioration of operability (engine brake) and fuel economy		

Component	Production Mechanism	Characteristic	Basic Concept	Specific Concept	Specific Countermeasure	Demerits	Countermeasure Against Demerits	Remarks
HC		- Ignition failure due to shortage of mixture - Overheating due to evaporation or suction of liquid fuel in manifold		Supply of mixture from a separate system immediately after deceleration				
			Fuel cut after deceleration		o Deceleration fuel cut system			
			Prevention of smoke through development of liquid fuel	Supply of air to the intake chamber	o Mixture control valve (MC valve)			
				Prevention of accumulation of liquid fuel	o Improvement of the intake manifold heating method o Reshaping of intake manifold	Output drop		
		New air blow-by during valve overlap	Reduce blow-by of new air		o Reduce valve overlap	High-level output drop, increase in NOx	Principal cause for large quantity of HC in 2-cycle engine	
		Oxidation reaction in expansion and exhaust processes, and exhaust system in case of high temperature and O_2	Recombustion in the exhaust system	Increase in exhaust temperature	o Delay of ignition timing · Change of the distributor angle characteristic · Ignition timing control device	Output drop and deterioration of fuel economy		
				Hot insulation of exhaust gas	Same as for CO			
				Supply of air to the exhaust system	Same as for CO			
				Oxidation with catalyst	Same as for CO			
NOx	Oxidation reaction of N_2 in burnt gas and flame plane (N_2 is produced mainly from reaction in burnt gas).	Increases exponentially along with rising combustion temperature (primarily maximum temperature)	Lowering of the maximum combustion temperature	Angle of ignition timing	o Change of distributor angle o Ignition timing control device	Output drop, deterioration of fuel economy		
				Recirculation of exhaust gas (inert gas) to intake for cooling	o Exhaust gas recirculation device (EGR)	Deterioration of combustion → Operability lowered, Increase in HC	o Improvement of combustion Same as for CO o Employment of rich A/F → Deterioration of fuel economy	
				Increase in residual gas quantity in the cylinder	o Change of valve timing · Increase in valve overlap	Deterioration of fuel economy		
				Employment of extremely lean A/F (Improvement of the combustion method)	o Laminated combustion o TGP o Powerful swirl, etc.			
			Cooling of burnt gas	Cooling with the combustion chamber wall	o Reshaping of the combustion chamber (Increase in the S/V ratio)	Deterioration of HC		
		NO production increases with increasing surplus O_2	Employment of rich A/F	A/F	o Adaption of carburetion	Deterioration of fuel economy, increase in CO and HC		
				A/F control appropriate to the operation state	o Smoke fuel ratio control device			
		Large quantity of NO production in initial burnt portion	Rich A/F for initial burnt portion	Improvement of the combustion method	o Laminated combustion			
			Temperature drop of initial burnt portion	Improvement of the combustion method	o Auxiliary chamber combustion (TGP, etc.) o Reshaping of the combustion chamber	Output drop		
		Reduction using proper catalyst and reducing atmosphere present	Reduction in the exhaust system	Reduction with catalyst	o Reduction catalyst converter o Three-way catalyst converter	Deterioration of fuel economy		

Table 5.2.2 Emission Control Devices Adopted by Some Countries

Country	Control Device	HC	CO	NOx
ECE 15	PCV	x		
	TP or DP	x	x	
	SC	x		x
	Lean-Set Carb		x	
SWEDEN	PCV	x		
	TP or DP	x	x	
	SC	x		x
	EGR			x
	Al or AS	x	x	
CANADA	PCV	x		
	EVAP	x		
	TP or DP	x	x	
	SC	x		x
	EGR			x
	Al or AS	x	x	
	OC	x	x	
US '83	PCV	x		
	EVAP	x		
	DP	x	x	
	EGR			x
	TWC	x	x	x
	EFI		(Back up TWC)	
JAPAN 53	PCV	x		
	EVAP	x		
	DP	x	x	
	EGR			x
	TWC	x	x	x
	EFI		(Back up TWC)	

Note:
PCV: Positive Crankcase Ventilation System
TP : Throttle Positioner System
DP : Dash Pot System
SC : Ignition Timing Control System
EGR: Exhaust Gas Recirculation System
AI : Secondary Air Injection System
AS : Secondary Air Suction System
EVAP: Fuel Evaporation Emission Control System
OC : Oxidizing Catalyst System
TWC: Three-Way Catalyst System
EFI: Electronic Fuel Injection System