4.5 Distribution of Air Pollutant Emissions

Figures 4.5.1 through 4.5.10 show areal distribution of emission of SOx, NOx and Dust by various sources.

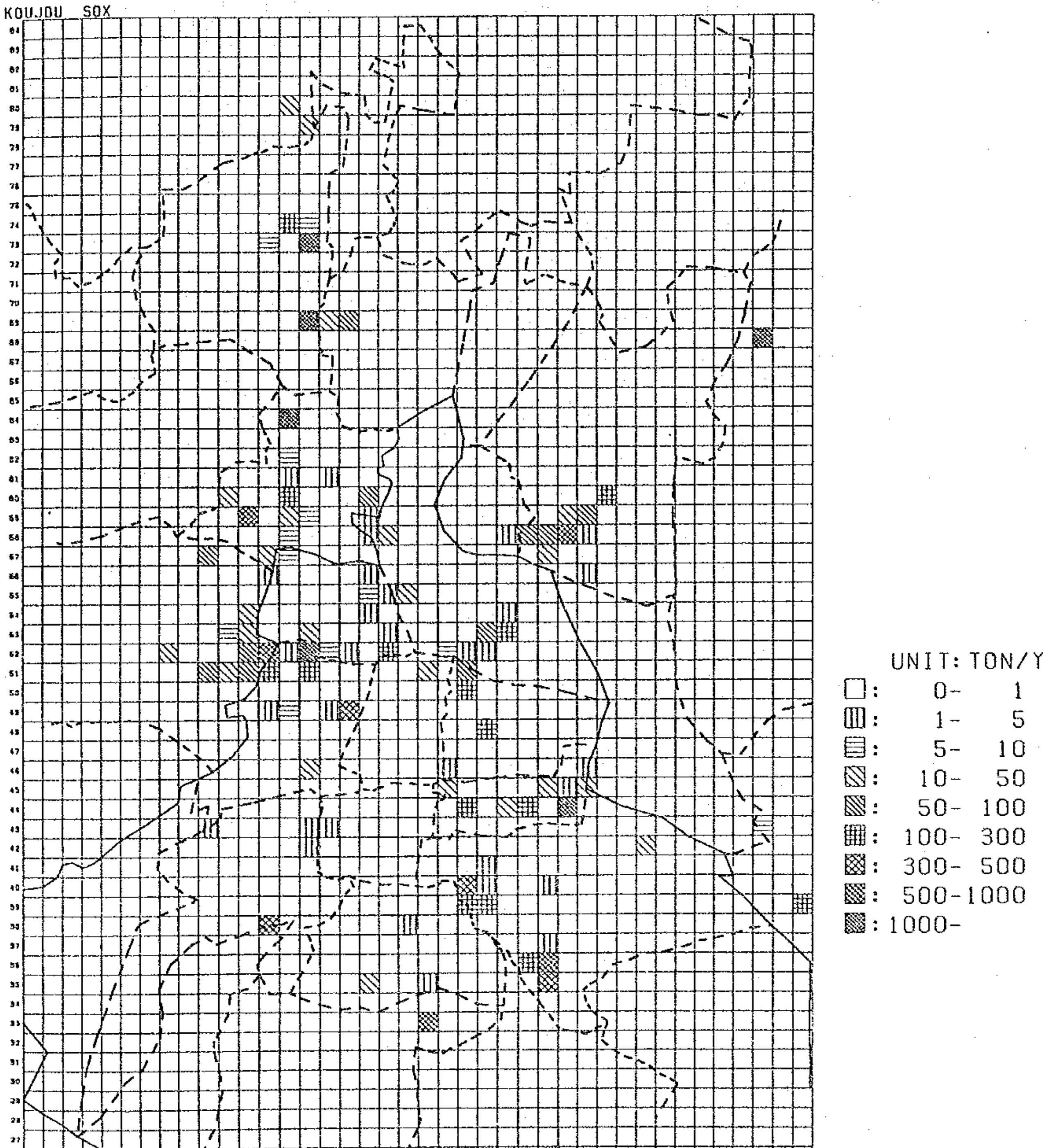


Figure 4.5.1 Distribution of SOx Emission From Factories

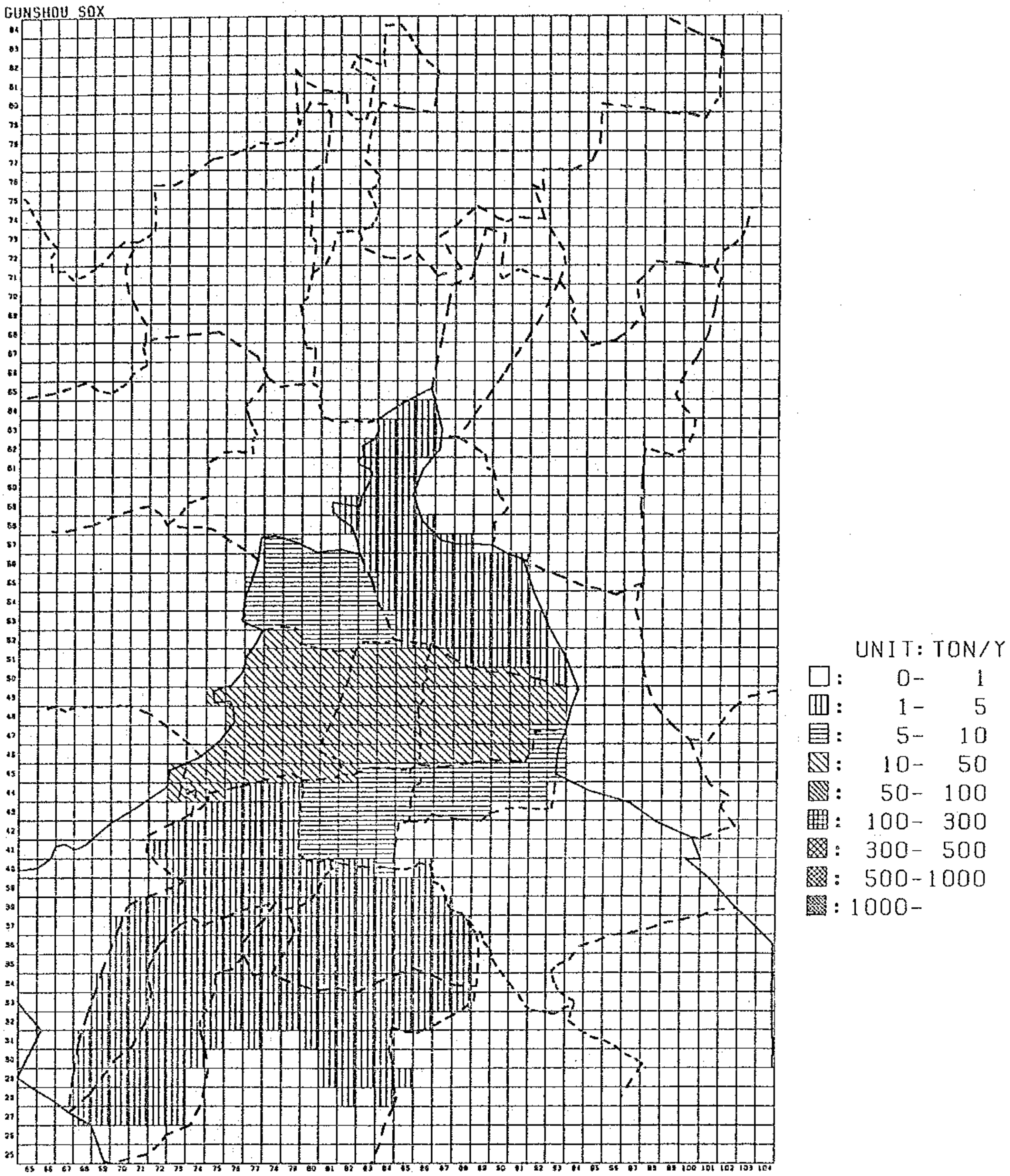


Figure 4.5.2 Distribution of SOx Emission From Service and Commercial Establishments

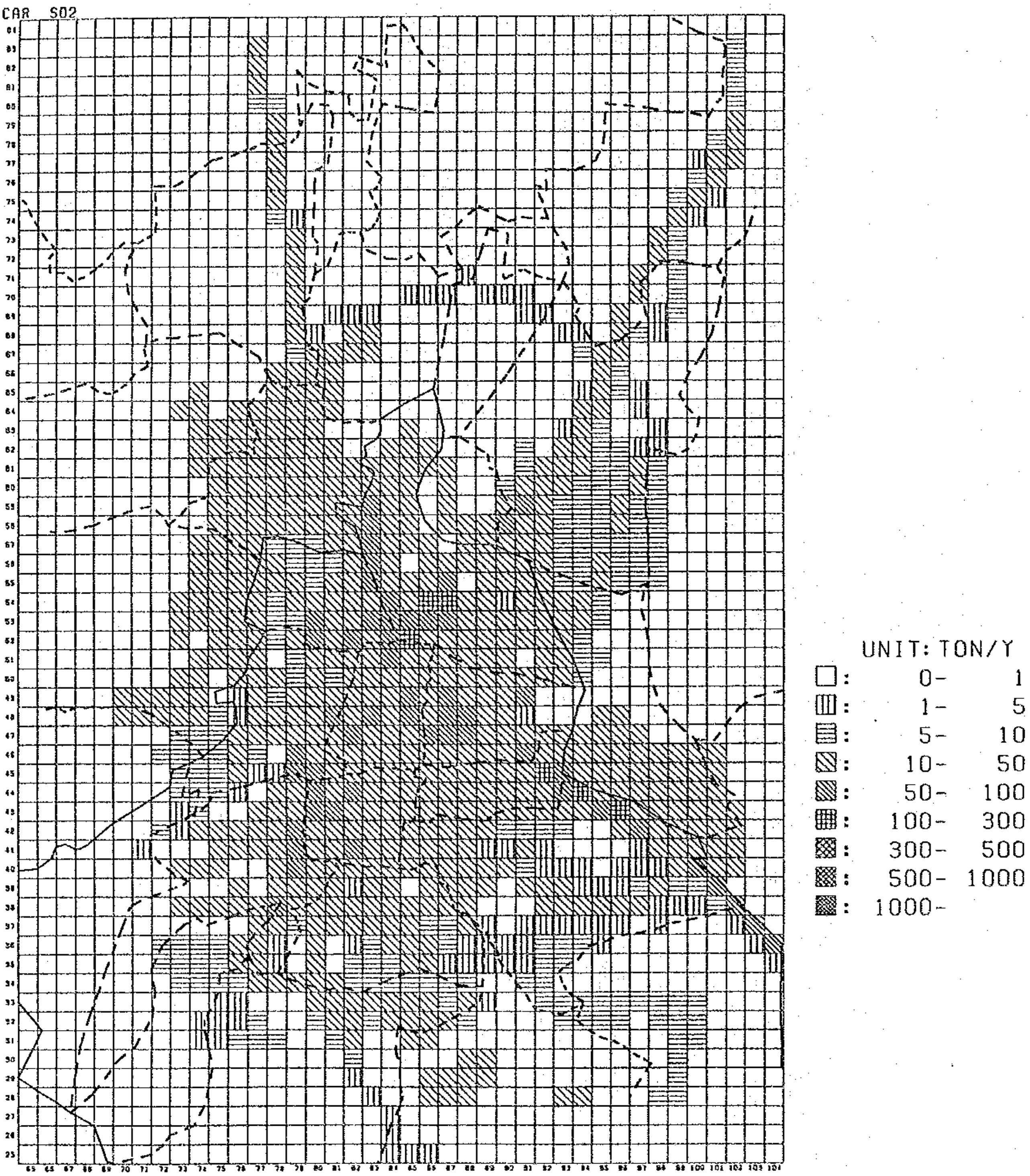


Figure 4.5.3 Distribution of SOx Emission From Automobiles

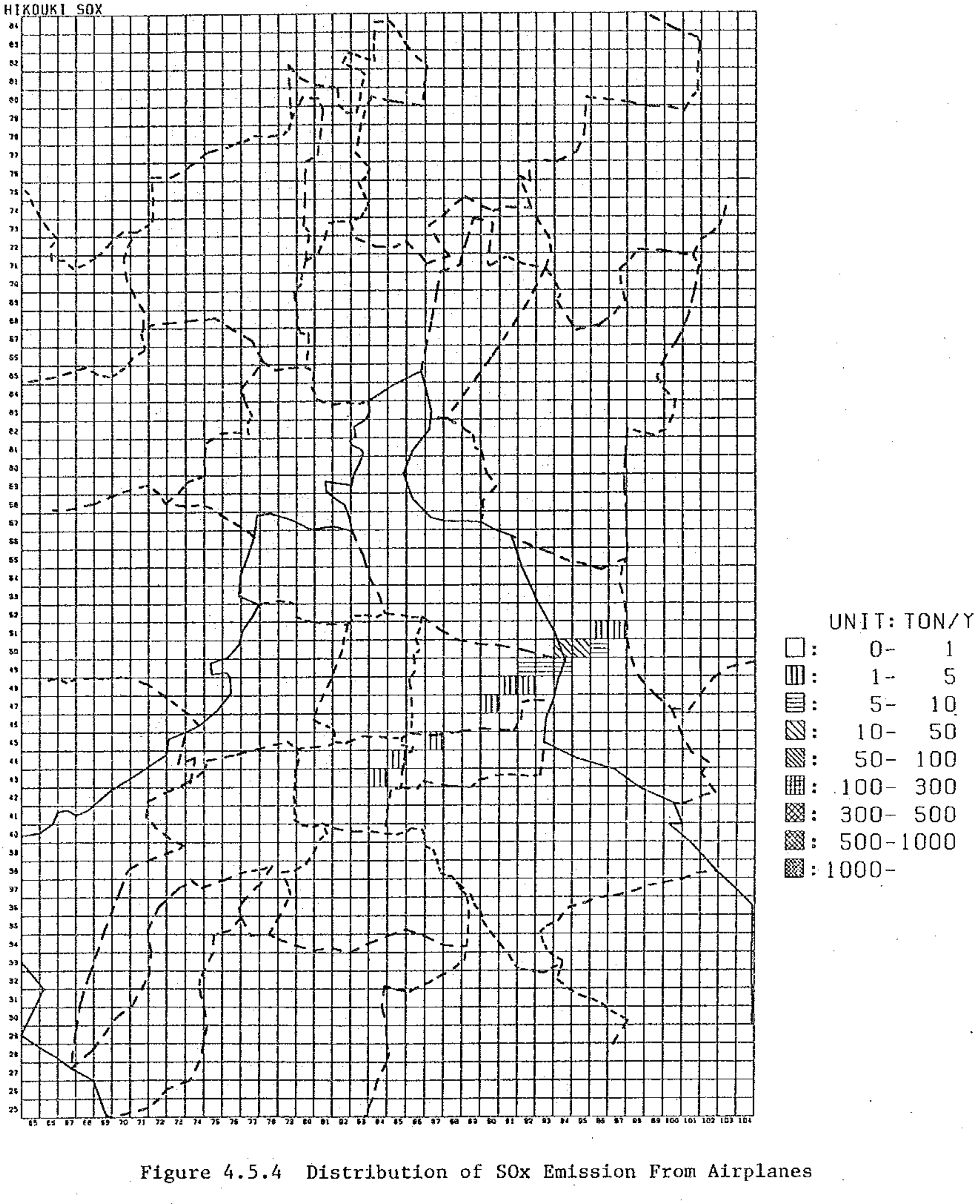


Figure 4.5.4 Distribution of SOx Emission From Airplanes

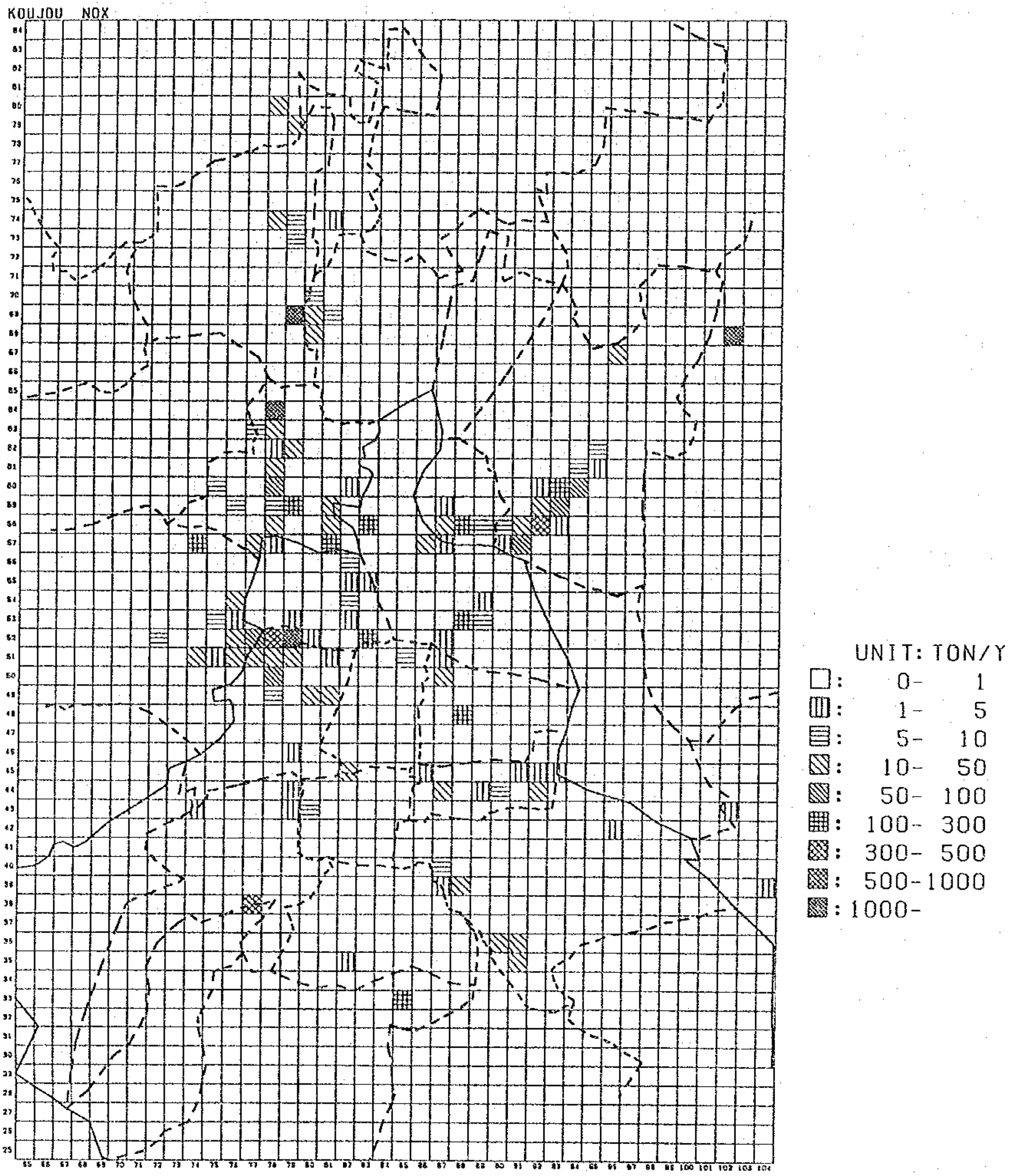


Figure 4.5.5 Distribution of NOx Emission From Factories

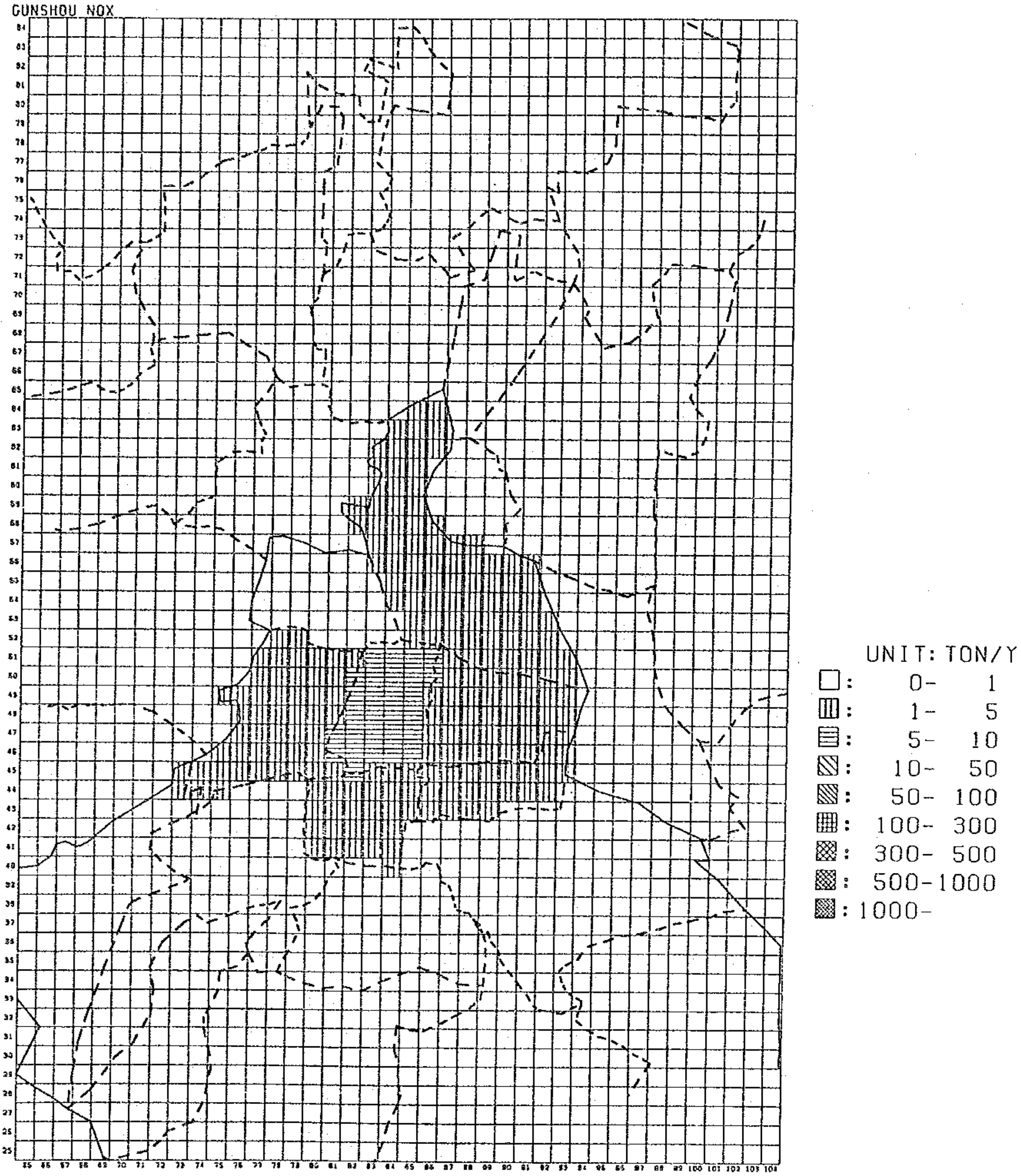


Figure 4.5.6 Distribution of NOx Emission From Service and Commercial Establishments

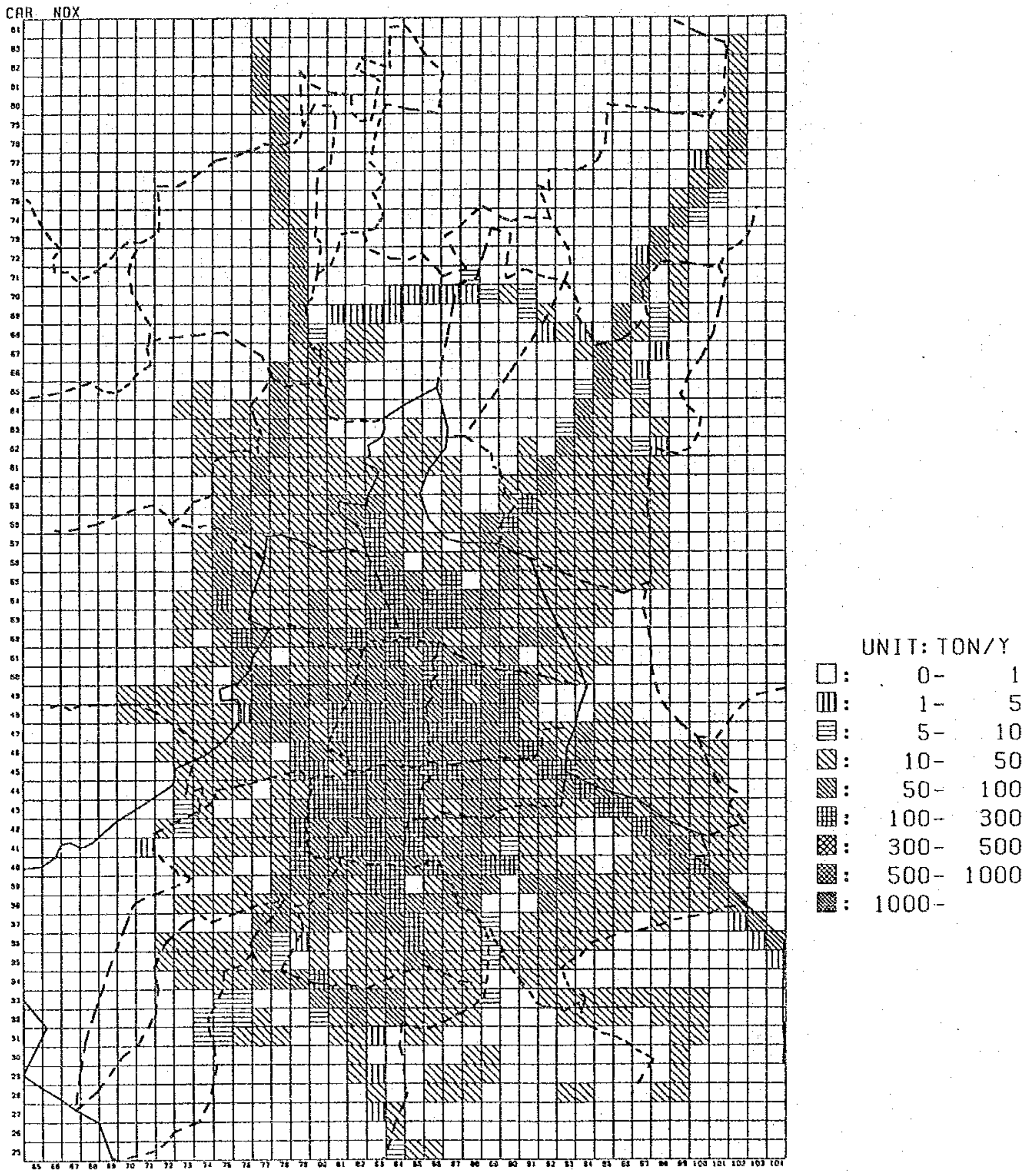


Figure 4.5.7 Distribution of NOx Emission From Automobiles

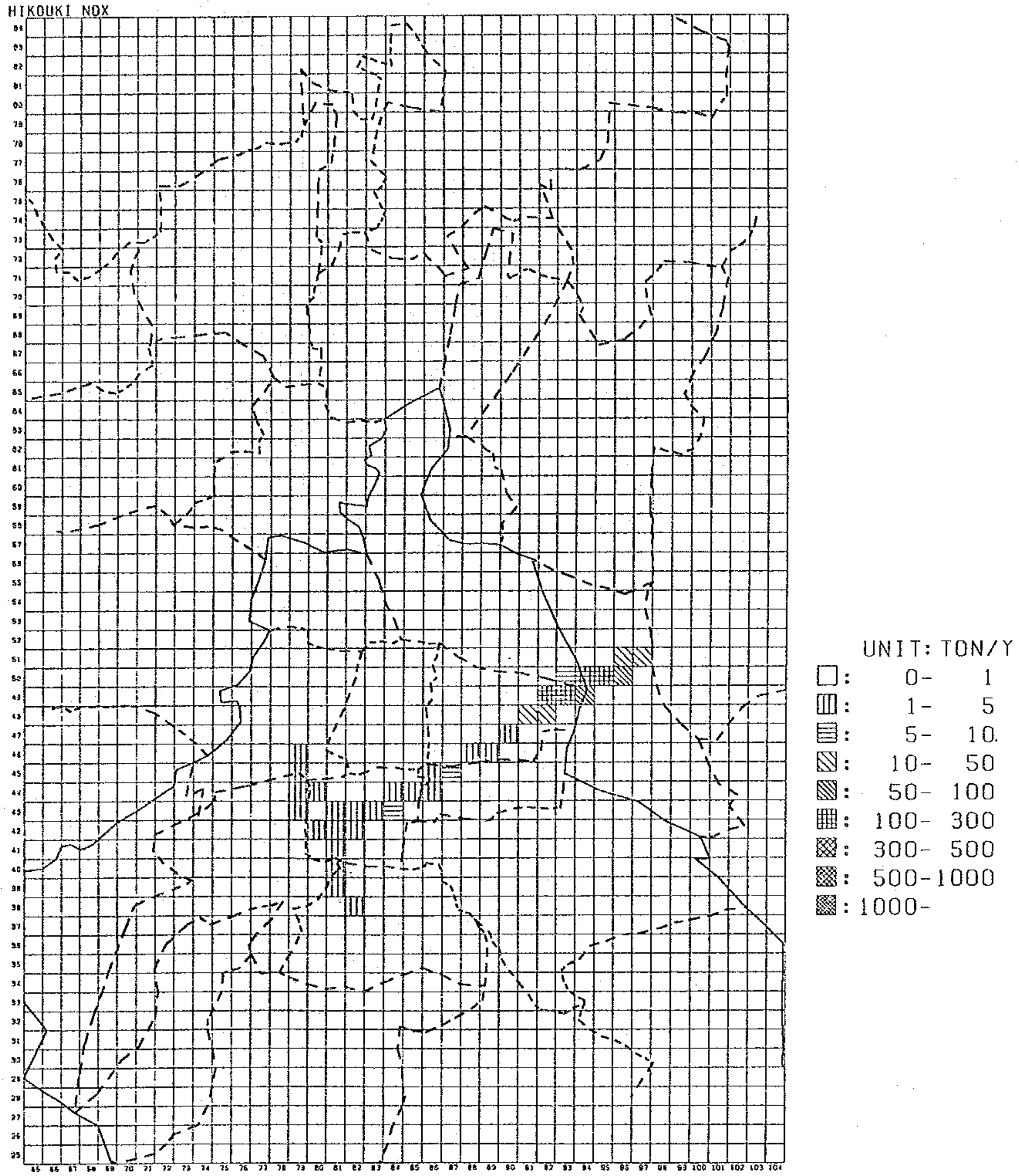


Figure 4.5.8 Distribution of NOx Emission From Airplanes

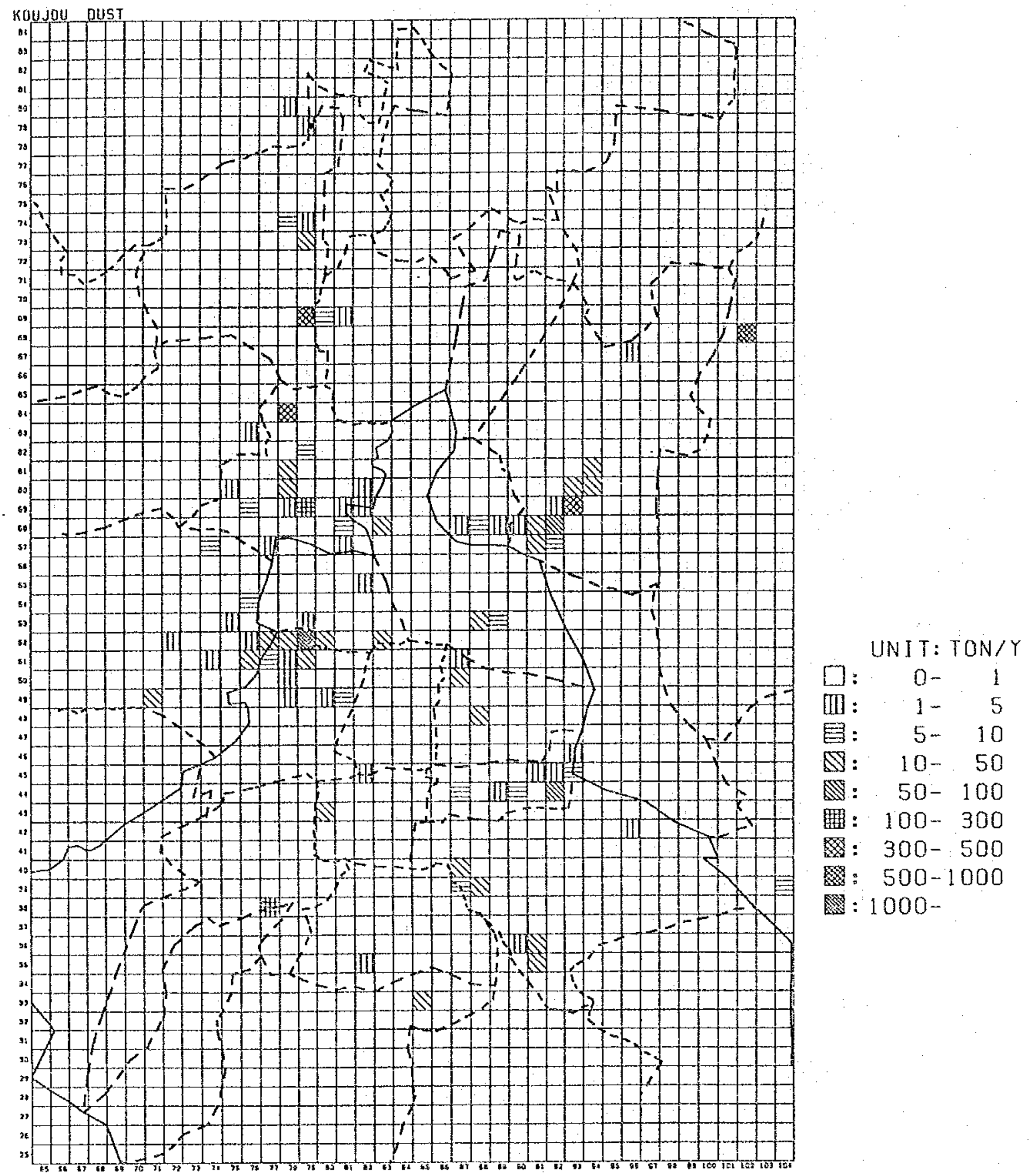


Figure 4.5.9 Distribution of Dust Emission From Factories

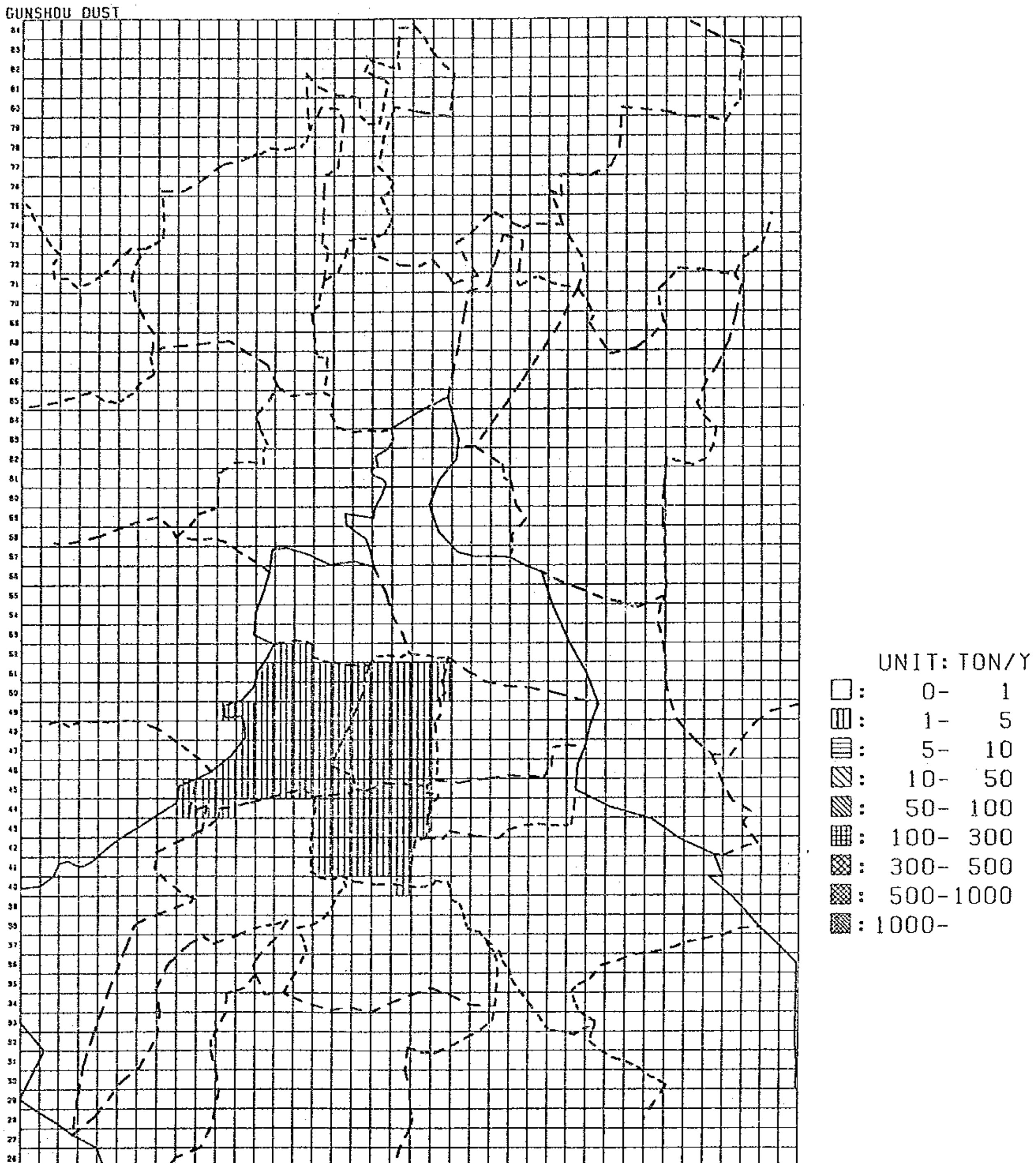


Figure 4.5.10 Distribution of Dust Emission From Service and Commercial Establishments

PART 5 AIR QUALITY SIMULATION

5.1 Air Quality Simulation Under the Present Conditions

5.1.1 Dispersion Model

(1) Effective Stack Height Model

Effective stack height of a source is determined as follows:

$He = Ho + \Delta H$

He: effective stack height (m)
Ho: actual stack height (m)
ΔH: rise of stack gas (m)

ΔH is computed by the following methods.

1) Windy condition

For large scale stacks ($QH \geq 2 \times 10^6$ cal/s), the Moses & Carson equation is used.

$$\Delta H + (C_1 V_s D + C_2 Q_H^{1/2})/u$$

Atomospheric Stability	C_1	C_2
Unstable	3.74	0.33
Neutral	0.35	0.171
Stable	-1.04	0.145

For medium to small scale stacks ($Q_H < 2 \times 10^6$ cal/s), the CONCAWE equation is used.

$$\Delta H = 0.175\ Q_H^{1/2} u^{-3/4}$$

2) Calm condition

The Briggs equation is used.

$$\Delta H = 1.4\ Q_H^{1/4} (d\theta/dz)^{-3/8}$$

QH : Heat emission due to efflux of stack gases (cal/s)
ρ : Density of emitted gases at 0°C ($\simeq 1.293 \times 10^3$ g/m^3)
Q : Emission rate of gaseous effluent (Nm^3/S)
C_p : Specific heat at constant pressure (0.24 cal/°K·g))
ΔT : Difference between the temperature of emitted gas (Tg) and that of atmosphere (°K)
u : Wind speed at the top of stack (m/s)

$d\theta/dz$: vertical potential temperature gradient of atmosphere ($^{o}K/m$) (to be set at 0.003 for daytime and 0.010 for nighttime)

Γd : Adiabatic lapse rate in the atmosphere (0.0098 $^{o}K/m$)

Vs : Stack gas exit velocity (m/s)

D : Inside stack diameter (m)

(2) Dispersion Equation

Dispersion equations applied for point source, area source, and line source are as follows.

1) Point Source Equation

When windy (u >0.4 m/s), the following plume equation is used.

$$C(R,z)=\frac{Qp}{\sqrt{2\pi}\,\frac{\pi}{8}R\sigma z u}\cdot\left[\exp\left(-\frac{(z-He)^2}{2\sigma z^2}\right)+\exp\left(-\frac{(z+He)^2}{2\sigma z^2}\right)\right]$$

C(R,z) : Concentration at the location (R,z)

R : Horizontal distance (m) from a point source to a computation point

z : z coordinates (m) of the computation point (along height)

Qp : Point source intensity (Nm^3/s)

u : Wind speed (m/s)

He : Effective stack height (m)

σz : Vertical diffusion parameter (m) (using the Pasquill-Gifford chart)

When calm ($u \leqq 0.4$ m/s), the following puff equation is used.

$$C(x,y,T)=\frac{1}{(2\pi)}\int_0^T\frac{2Qp}{\sigma y^2\sigma z}\exp\left(-\frac{(x-ut)^2}{2\sigma y^2}-\frac{y^2}{2\sigma y^2}-\frac{He^2}{2\sigma z^2}\right)dt$$

A steady-state solution for the calm condition was applied after integrating the above equation up to $t=\infty$, with $u=0$, $\sigma y=\alpha t$, and $\sigma z=\gamma t$.

$$C(R,z)=\frac{Q_p}{(2\pi)^{3/2}\gamma}\cdot\left\{\frac{1}{R^2+\frac{\alpha^2}{\gamma^2}(z-He)^2}+\frac{1}{R^2+\frac{\alpha^2}{\gamma^2}(z+He)^2}\right\}$$

$$R^2=x^2+y^2$$

α , γ : Diffusion parameters for calm

$\sigma x=\sigma y=\alpha\cdot t$

$\sigma z=\gamma\cdot t$

t : Time lapse (s)

2) Area Source Equation

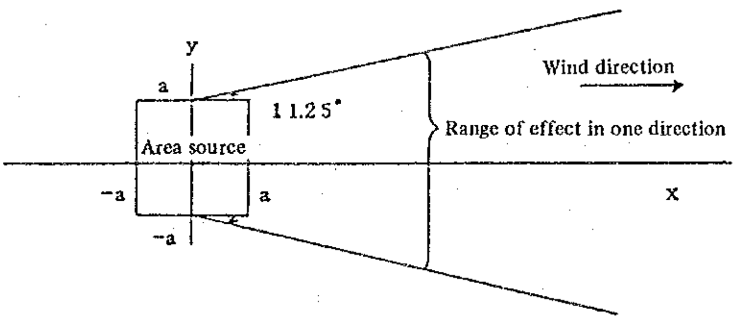
When windy, the plume equation applicable to long-term average concentration is used, assuming that a square area source with a side 2a long is present in isolation.

$$C=\frac{Q_A}{\sqrt{2\pi}\,u}\int_{x-a}^{x+a}\frac{2a}{(\frac{\pi}{8}\xi+2a)\,\sigma z(\xi)}\cdot[F]\;d\xi$$

$$[F]=\exp\left\{-\frac{(z-He)^2}{2\sigma z(\xi)^2}\right\}+\exp\left\{-\frac{(z+He)^2}{2\sigma z(\xi)^2}\right\}$$

QA	: Area source intensity (Nm^3/s)
u	: Wind speed (m/s)
He	: Effective stack height (m)
σ z	: Vertical diffusion parameter (m)
2a	: Length (m) of a side of a square area source

A conceptual diagram of area source dispersion model is shown below.



When calm, the following equation is used by applying the simplified puff equation (steady-state solution) to a circular area source that has the same area as a square area source with a side 2a long.

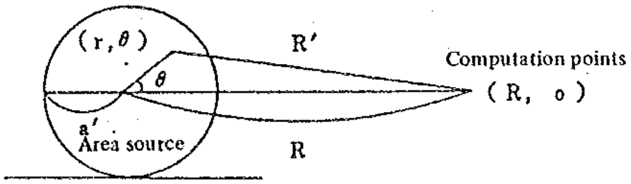
$$C = \frac{Q_A}{(2\pi)^{3/2}\gamma} \int_0^{a'} \int_0^{2} \left(\frac{1}{R'^2 + b_1^2} + \frac{1}{R'^2 + b_2^2} \right) r \cdot dr \cdot d\theta$$

$$a' = \frac{2a}{\sqrt{\pi}}$$

$$R' = (r^2 + R^2 - 2rR\cos\theta)^{1/2}$$

$$b_1 = \frac{\alpha}{\gamma}(z - He), \quad b_2 = \frac{\alpha}{\gamma}(z + He)$$

A conceptual diagram of area, source diffusion model is shown below.



3) Line Source Equation

When windy, the $2\pi/16$ equation which brings uniform concentration in the direction of y is used.

$$C = \int_{r_1}^{r_2} \frac{Q_L}{\sqrt{2\pi} \cdot \frac{\pi}{8} \, r \, \sigma z(r) u} \cdot \left[\exp\left\{ -\frac{(z - He)^2}{2\sigma z(r)^2} \right\} + \exp\left\{ -\frac{(z + He)^2}{2\sigma z(r)^2} \right\} \right] \cdot dr$$

z : z coordinate (m) at the computation point

r : Distance (m) from the computation point to a line source

r1, r2: Integration interval (m) of a line source

QL : Line source intensity (Nm^3 / s.m)

u : Wind speed (m/s)

He : Effective stack height (m)

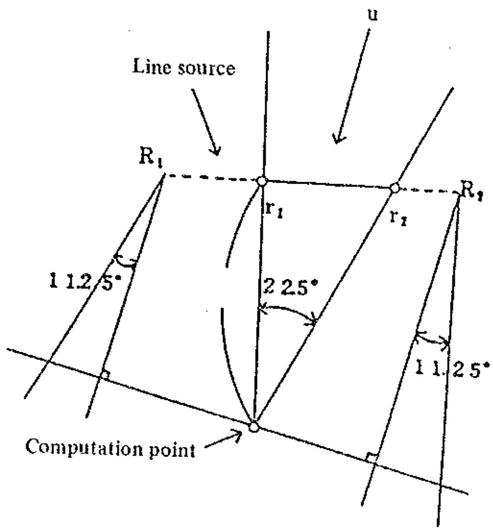
σ z : Vertical diffusion parameter (m)

When calm, the following equation is used.

$$C=\int_{R_1}^{R_2}\frac{Q_L}{(2\pi)^{3/2}r}\left(\frac{1}{r^2+b_1^2}+\frac{2}{r^2+b_2^2}\right)dr$$

$$b_1=\frac{\alpha}{\gamma}(z-He) \qquad b_2=\frac{\alpha}{\gamma}(z+He) \qquad r^2=x^2+y^2$$

R1, R2: Integration interval (m) of a line source as shown below



(3) NO-NO_2 Conversion Equation

For NO-NO2 conversion, the following exponential analogue equation will be used.

$$[NO_2] = [NOx]_D \left[1 - \frac{\alpha}{1+\beta}\{\exp(-Kt)+\beta\}\right]$$

$$K = k \cdot u\,[O_3]_B$$

α : Initial ratio

β : Coefficient to approximate equilibrium condition

k : Reaction constant

$[O_3]_B$: Background concentration of O_3 (ppm)

Parameters were set as shown below:

α:	Factories Service and commercial establishment Airplanes	0.83
	Automobiles	0.80
β:	Day time	0.3
	Night time	0.0
k:	Factories Airplanes (Climb, Approach/Landing)	0.0062
	Service and Commercial Establishment Airplanes (Taxing/idling, Take-off)	0.062
	Automobiles	0.23

Background concentration of O_3 is set as shown in Table 5.1.1.

Table 5.1.1 Background Concentration of O_3

Background Concentration of O_3 (Unit:PPM)

Wind Speed Classes (m/s)		〜 0.4	0.5 〜 1.9	2.0 〜 2.9	3.0 〜 3.9	4.0 〜 5.9	6.0 〜 7.9	8.0 〜 9.9	10. 〜
Period	Time Zone								
Rainy	Morning	0.041	0.041	0.054	0.039	0.039	0.039	0.039	0.039
	Afternoon	0.067	0.067	0.054	0.046	0.036	0.036	0.036	0.036
	Evening	0.012	0.012	0.017	0.021	0.029	0.020	0.020	0.020
	Midnight	0.013	0.013	0.014	0.021	0.021	0.021	0.021	0.021
Dry	Morning	0.043	0.043	0.056	0.050	0.035	0.035	0.035	0.035
	Afternoon	0.081	0.081	0.072	0.050	0.042	0.039	0.034	0.032
	Evening	0.014	0.014	0.020	0.022	0.024	0.027	0.027	0.027
	Midnight	0.013	0.013	0.017	0.024	0.030	0.030	0.030	0.030

5.1.2 Evaluation of the Dispersion Model

The conditions given in Table 5.1.2 can be used to judge the agreement between computed and measured values, thereby evaluating the credibility of the dispersion mode. The SEDUE data of 1986 may be used as measured values, but these data are not enough to ensure adequate calibration of the model because of insufficient measuring achievements (the measurement time reached only about 6,000 hours a year even in a measuring station with good achievements). Therefore, the evaluation conditions in Table 5.1.2 will be regarded as the goal toward which efforts should be made.

Table 5.1.2 Conditions for Evaluation of the Accuracy of the Dispersion Model

- Individual conditions pertaining to the conformity between calculated and measured values.

①. $a_0 \leq 1/5\,(\overline{Y} - BG) + BG$

②. $a_0 \leq 2/5\,(\overline{Y} - BG) + BG$

③. The inclination of a regressing line shall range from 0.8 to 1.2 and be as close to 1 as possible. In addition, the correlation coefficient shall be at least 0.71 and should possibly exceed 0.8.

④. $s'/\overline{Y} \leq 1/5$

⑤. $s'/\overline{Y} \leq 1/4$

⑥. $s'/\overline{Y} \leq 1/3$

$\overline{Y}$: Mean measured value available from a measuring station
$\overline{X}$: Mean computed value for the measuring station
a_0 : $\overline{Y} + \overline{X}$
BG : Background values in the nature
s'/Y : Variation coefficient obtained from $\overline{Y} = \overline{X}/a_0$

- Accuracy ranking pertaining to the conformity between computed and measured values

(a) Rank A

Either the conditions ①, ③, and ⑤, or ① and ④, stated above, be satisfied. Even if the conditions 1 and 4 are satisfied, the inclination of a regressing line should be as close to 1 as possible.

(b) Rank B

The conditions ② and ⑤ shall be satisfied.

(c) Rank C

The conditions ② and ⑥ shall be satisfied.

Note : It is desired that the inclination of regressing lines should also be as close to 1 as possible in the caseses of Ranks B and C.

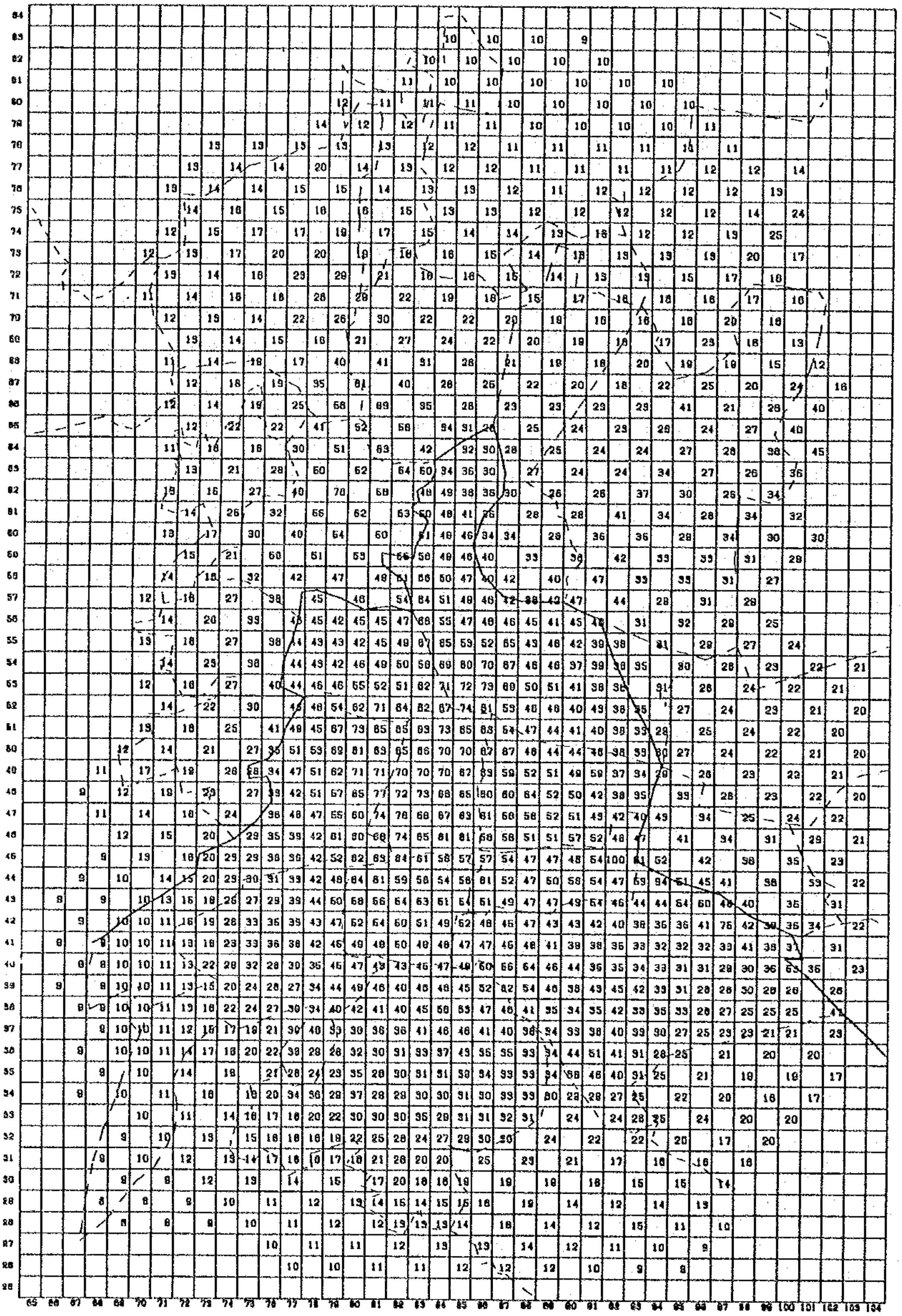
5.1.3 Computation Results for Present Ambient Air Quality

Figures 5.1.1 shows computed ambient concentration of SO_2 corresponding to all the sources. Figures 5.1.2 through 5.1.4 show contribution of each category of source to SO_2 concentration.

Figure 5.1.5 shows computed ambient concentration of CO corresponding to automobile emissions.

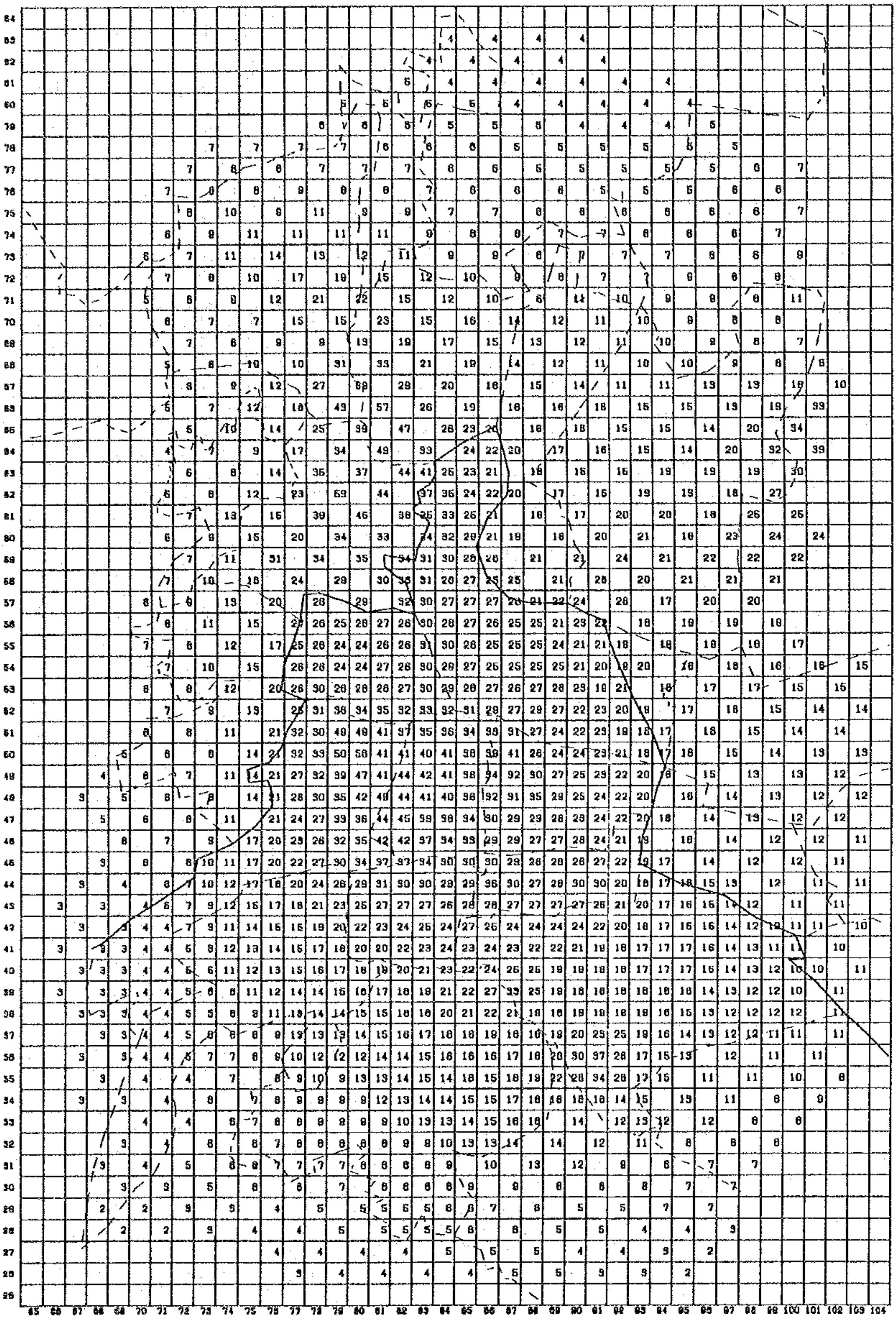
Figure 5.1.6 shows computed ambient concentration of NOx corresponding to all the sources. Figures 5.1.7 through 5.1.9 show contribution of each category of source to NOx concentration.

Figure 5.1.10 shows computed ambient concentration of NO_2 corresponding to all the sources. Figures 5.1.11 through 5.1.13 show contribution of each category of source to NO_2 concentration.



Unit: ppb

Figure 5.1.1 Ambient Concentration of SO_2 (Present, All Sources)
(Background concentration of 5.87 ppb included)



Unit: ppb

Figure 5.1.2 Contribution of Stationary Sources to SO_2 Concentration (Present)

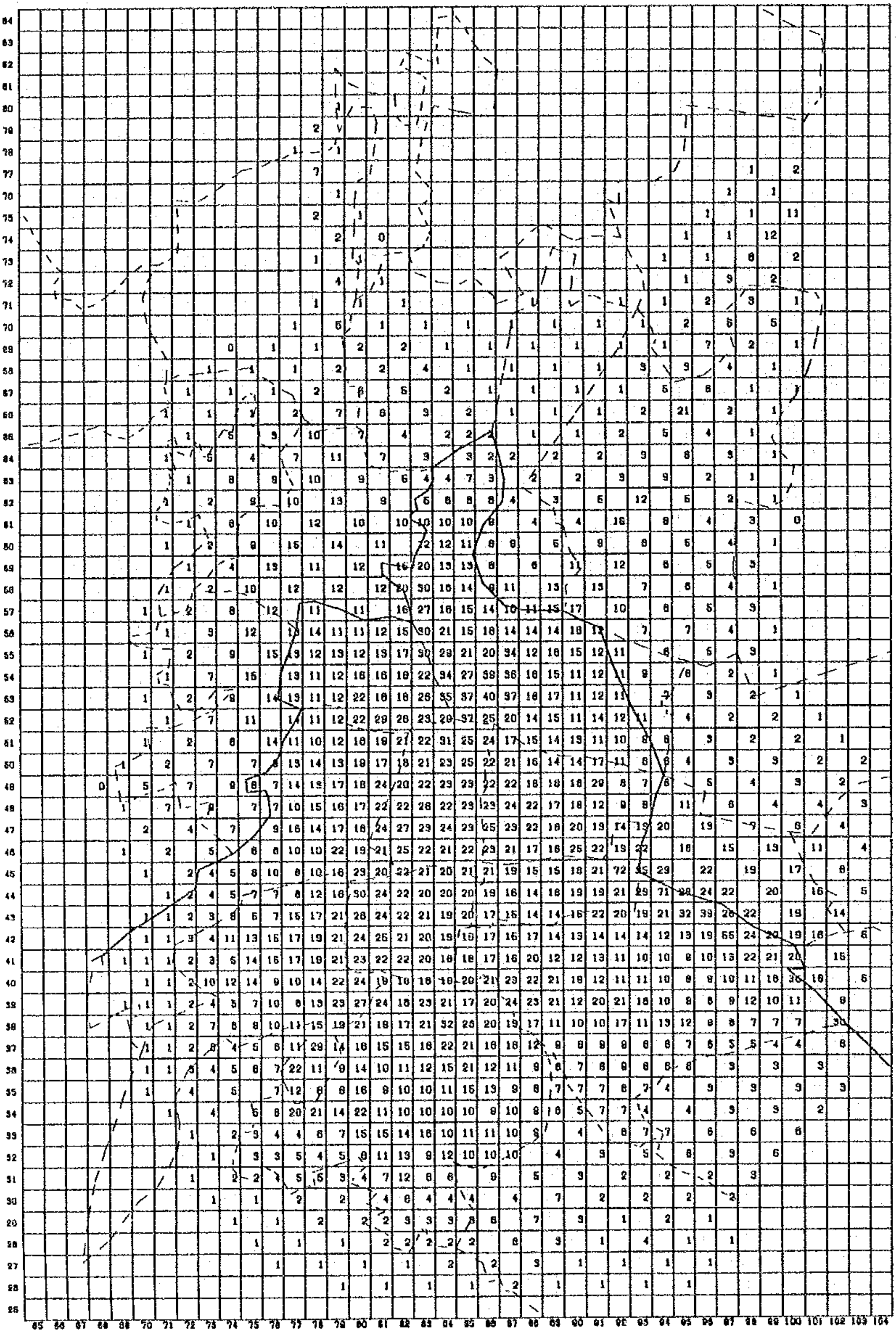
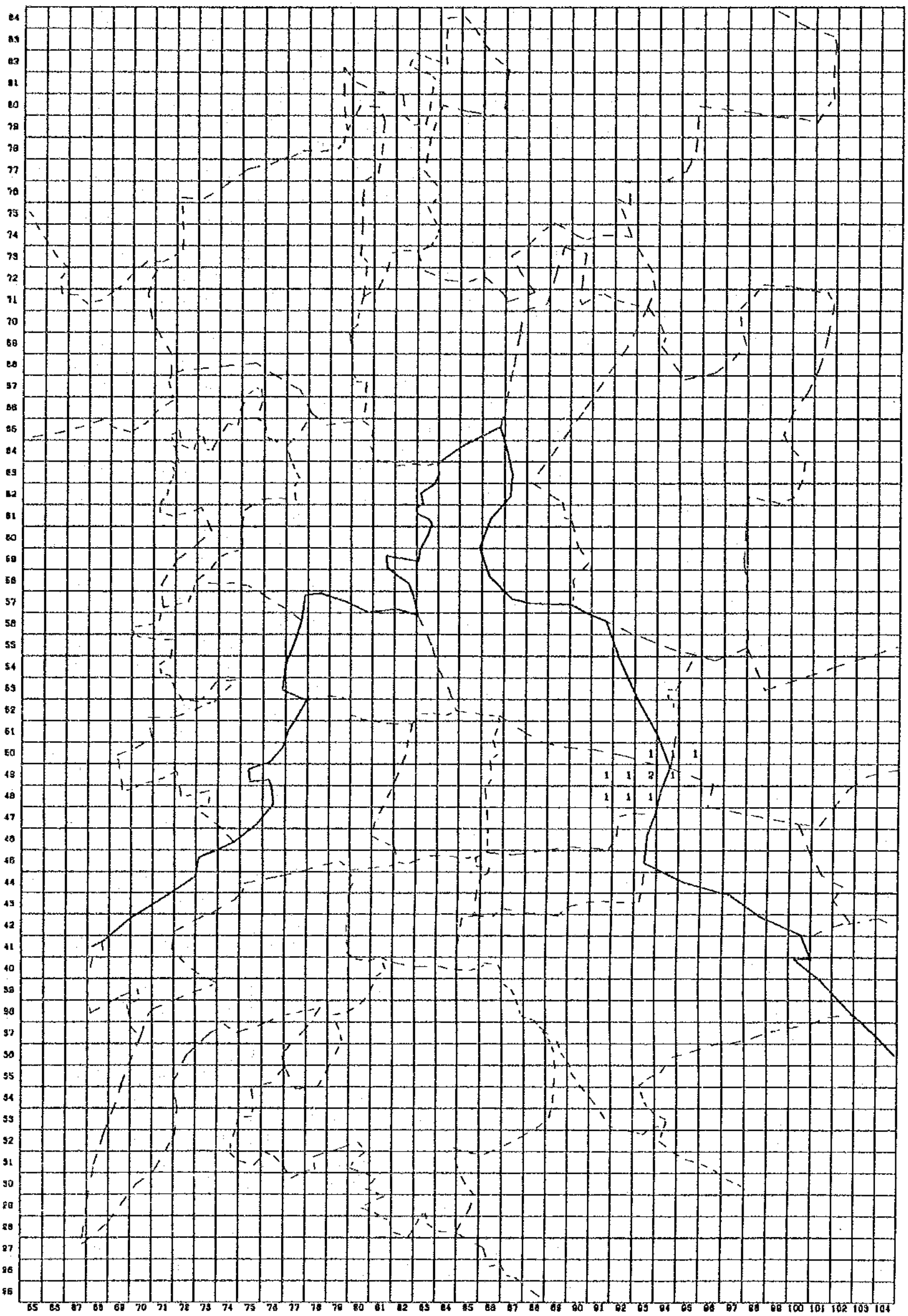
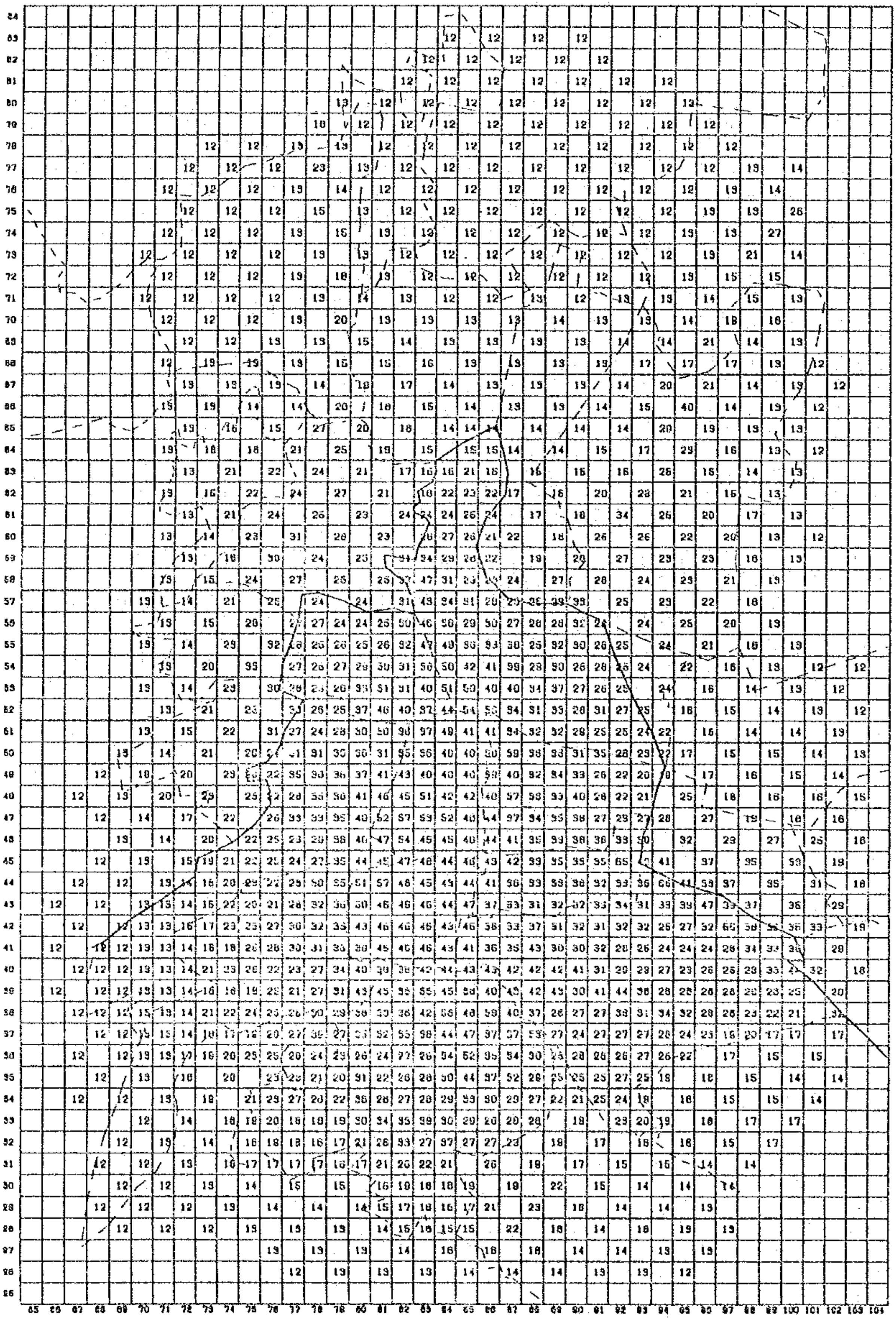


Figure 5.1.3 Contribution of Automobiles to SO_2 Concentration (Present)



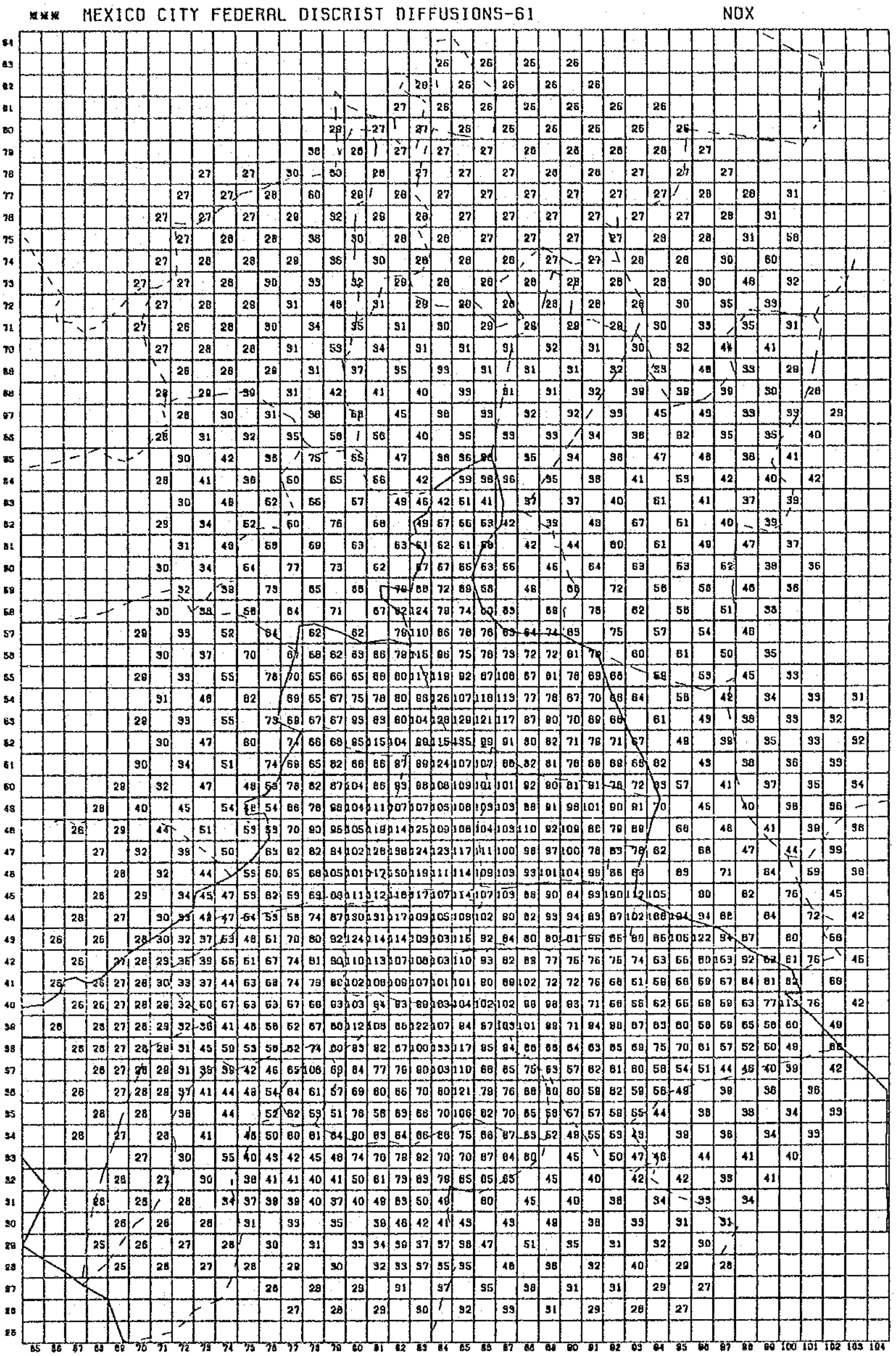
Unit: ppb

Figure 5.1.4 Contribution of Airplanes to SO_2 Concentration (Present)



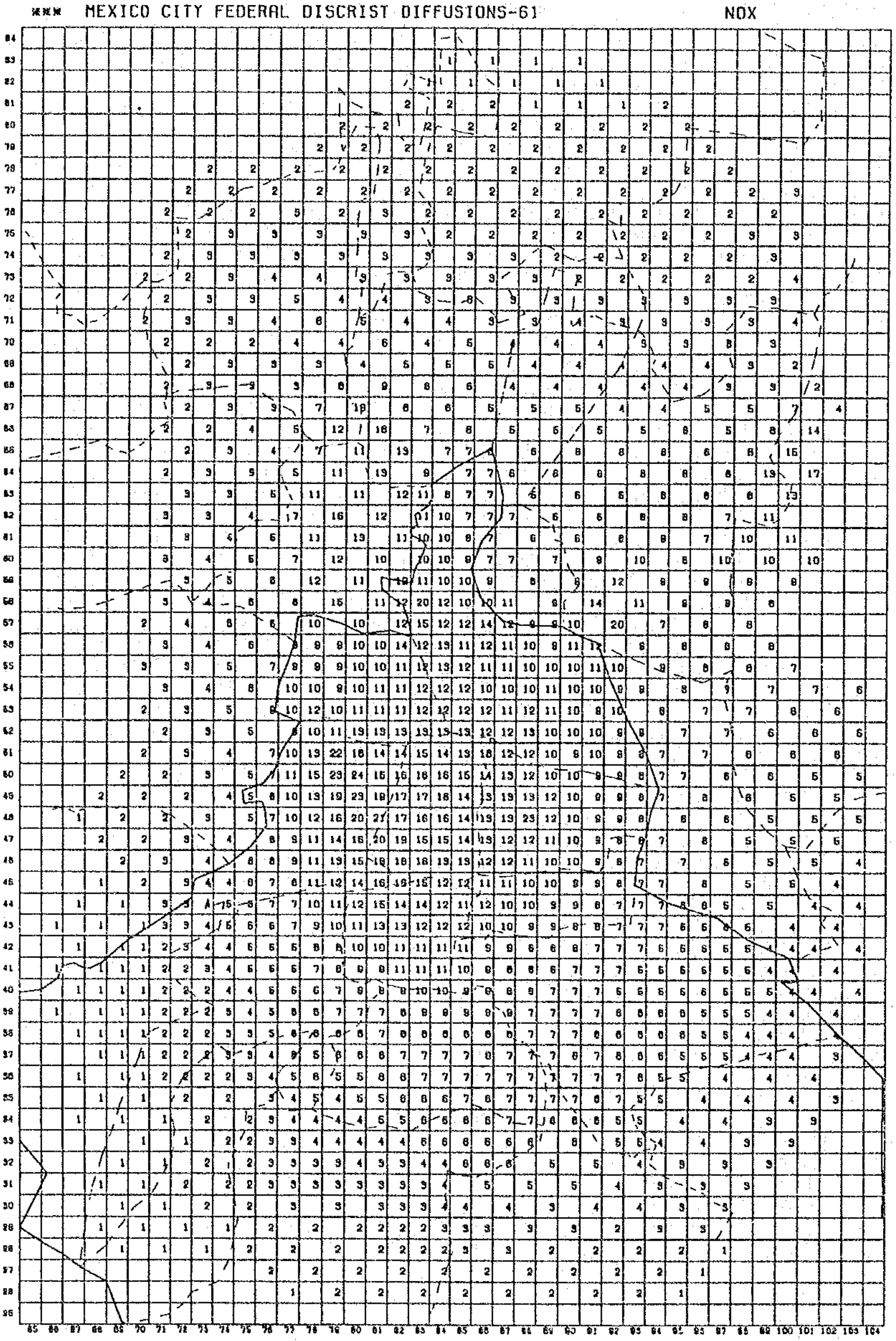
Unit: 0.1 ppm

Figure 5.1.5 Contribution of Automobiles to CO Concentration (Present)
(Background concentration of 1.182 ppm included)



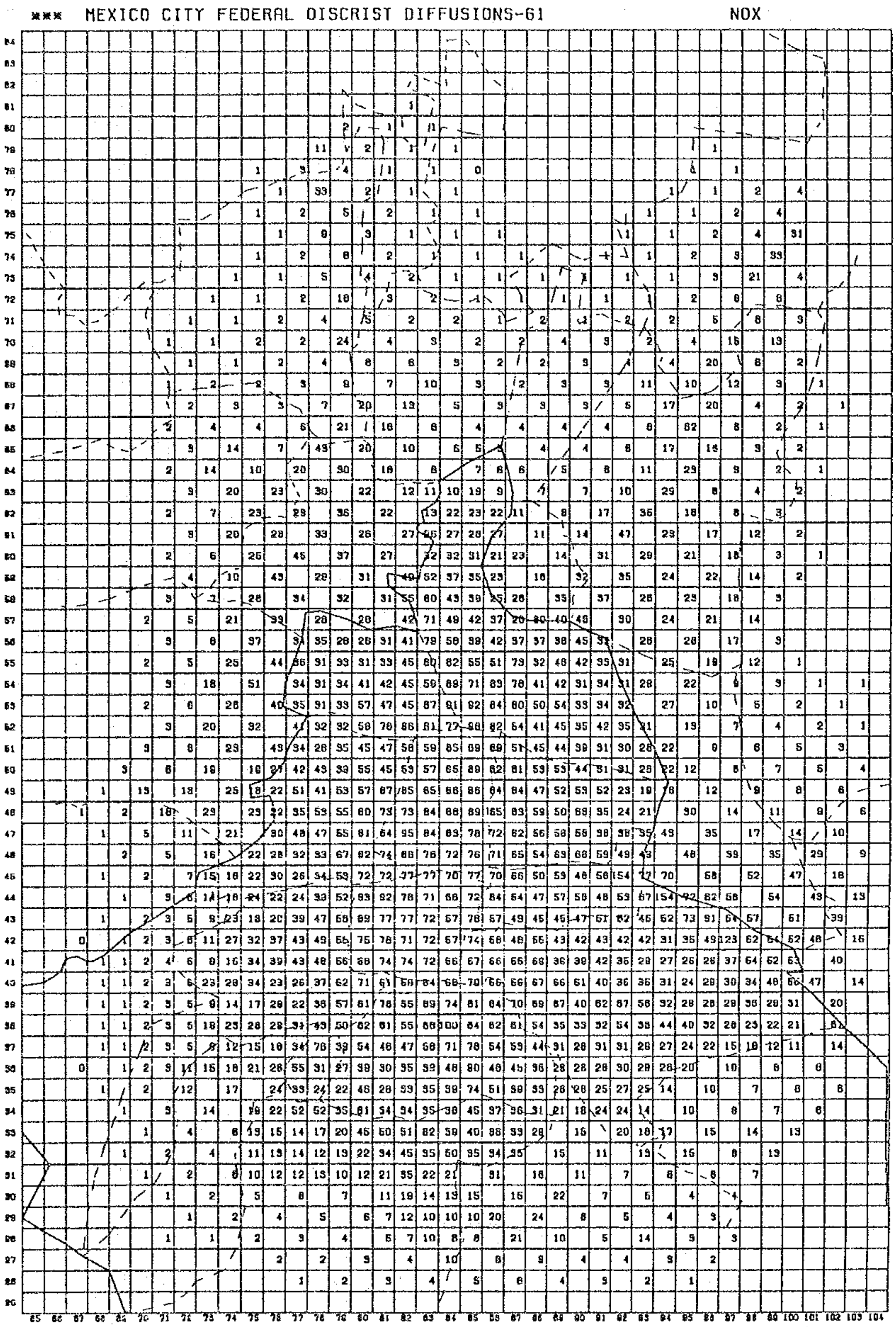
Unit: ppb

Figure 5.1.6 Ambient Concentration of NOx (Present, All Sources)
(Background concentration of 24.43 ppb included)



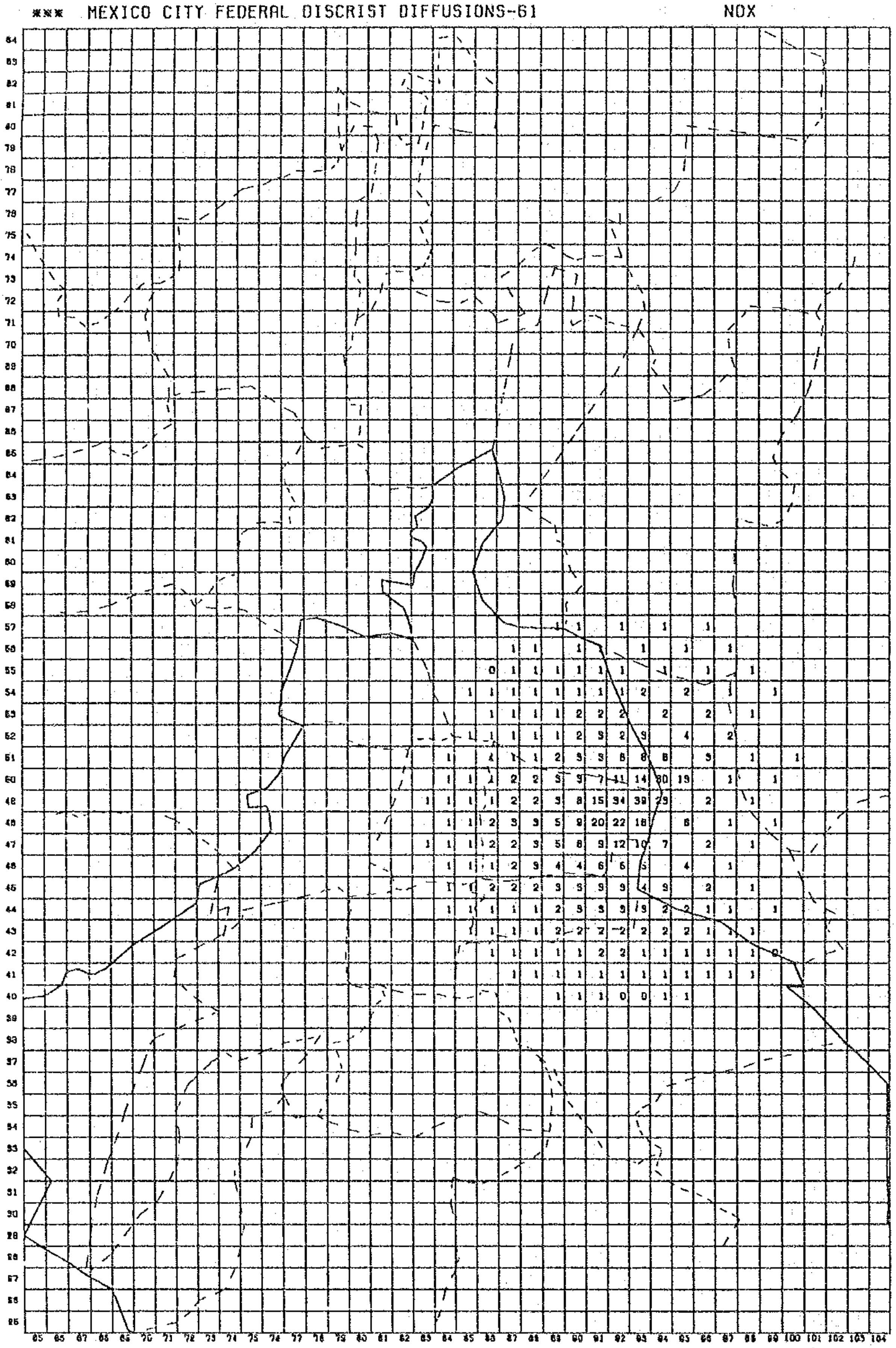
Unit: ppb

Figure 5.1.7 Contribution of Stationary Sources to NOx Concentration (Present)



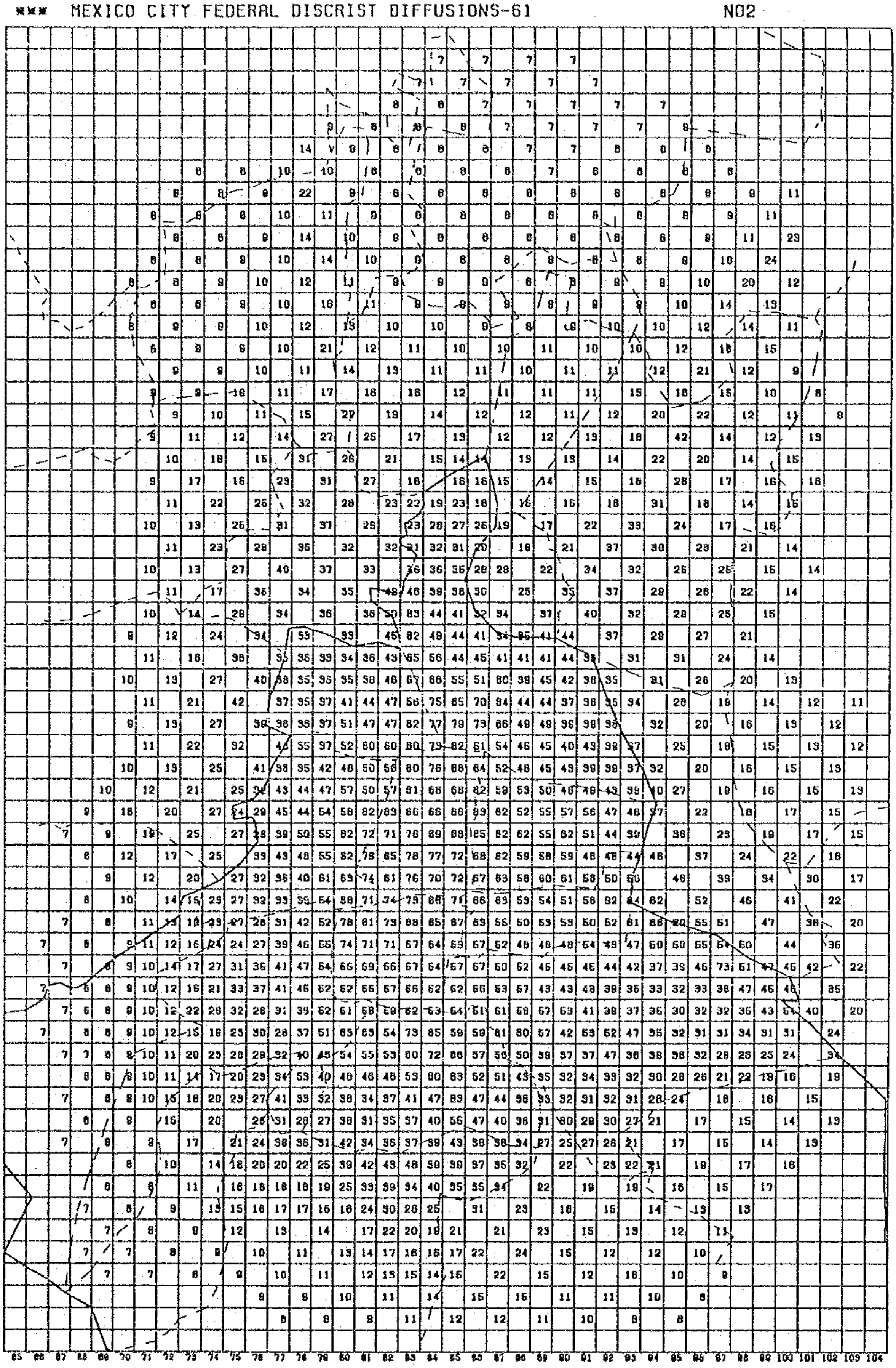
Unit: ppb

Figure 5.1.8 Contribution of Automobiles to NOx Concentration (Present)



Unit: ppb

Figure 5.1.9 Contribution of Airplanes to NOx Concentration (Present)



Unit: ppb

Figure 5.1.10 Ambient Concentration of NO_2 (Present, All Sources) (Background concentration of 6.06 ppb included)

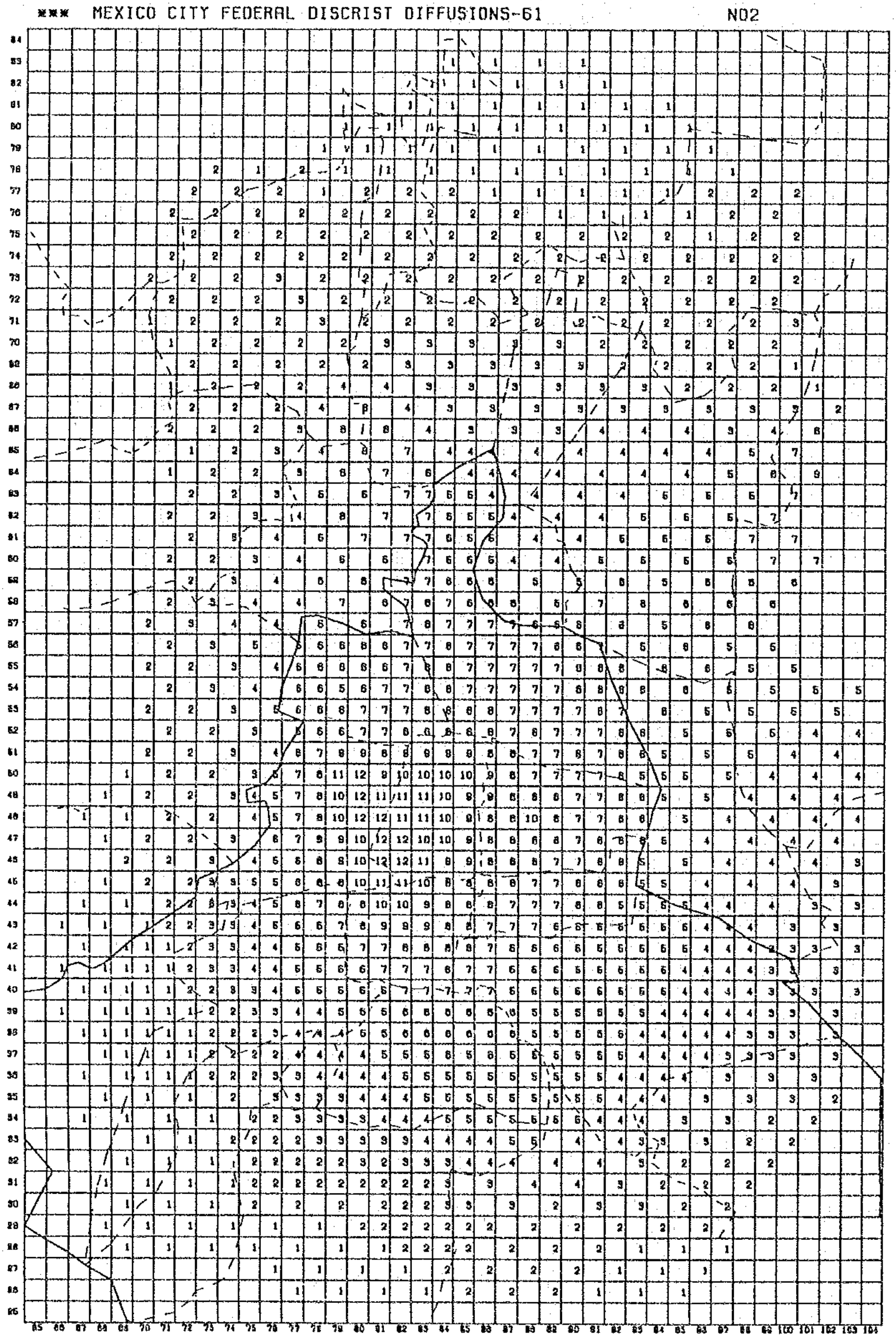
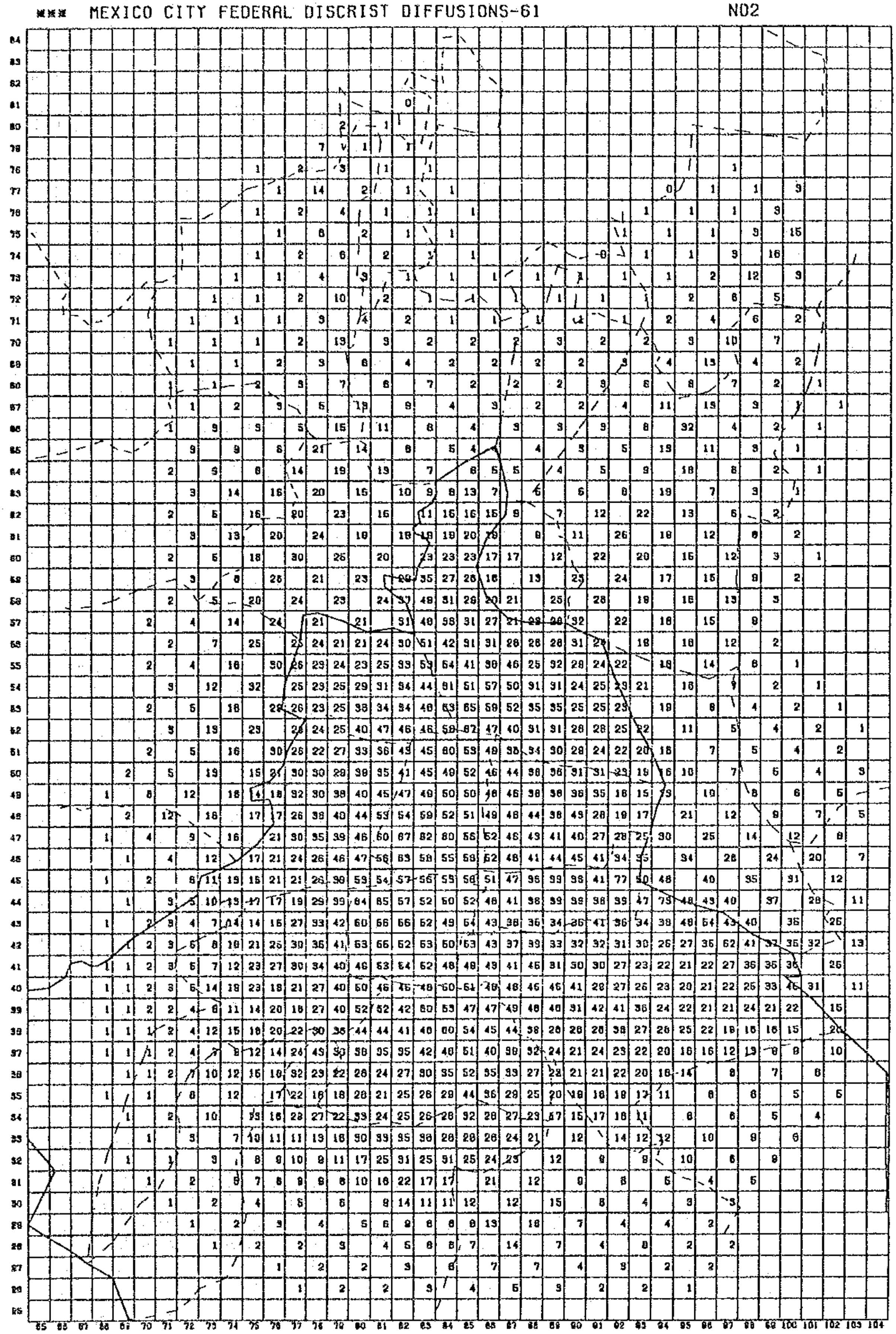
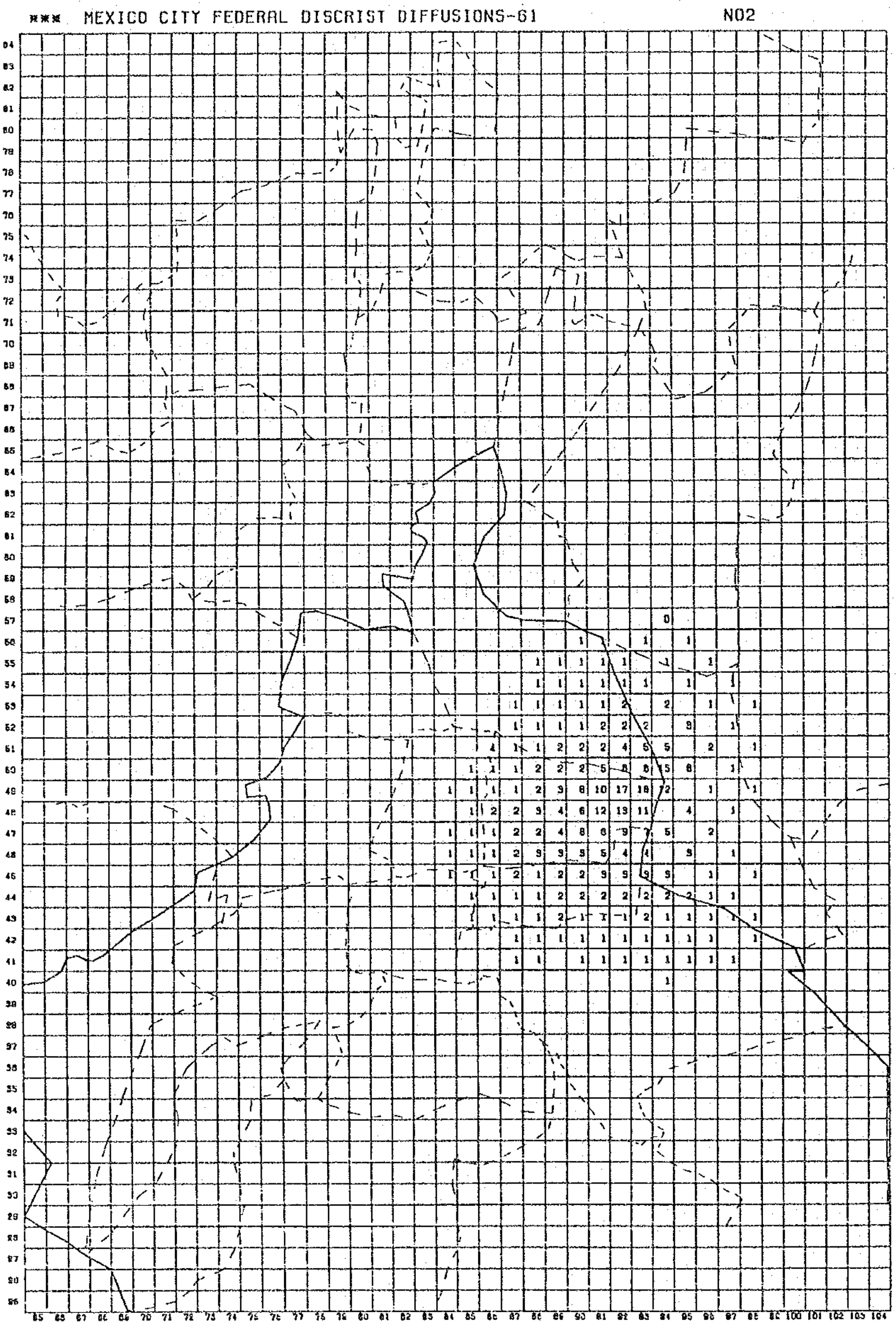


Figure 5.1.11 Contribution of Stationary Sources to NO_2 Concentration (Present)



Unit: ppb

Figure 5.1.12 Contribution of Automobiles to NO_2 Concentration (Present)



Unit: ppb

Figure 5.1.13 Contribution of Airplanes to NO_2 Concentration (Present)

5.2 Chemical Mass Balance Method for Analysis of TSP Sources

(1) Method of Analysis

Ambient concentration Ci of an element i can be expressed as follows:

$$C_i = \sum_{j}^{p} m_j \cdot x_{ij} \cdot \alpha_{ij}$$

m_j : Ambient concentration contributed by the source j ($\mu g/m^3$)

X_{ij} : Ratio of the element i in particulates emitted from the source j (g/g)

$_{ij}$: Coefficient for fractionation of the element i emitted from the source j in the course it reaches the ground

When several elements whose fractionation coefficient is assumed to be 1 are selected, the above equation reduces to the following. Knowing Ci and X_{ij}, contribution of the source (m_j) can be obtained through the least-square method.

$$C_i = \sum_{j}^{p} m_j \cdot x_{ij}$$

The following weighted least-square equation is used.

$$x^2 = \sum_{i=1}^{n} \frac{(C_i - \sum_{j}^{p} m_j \cdot x_{ij})^2}{C_i^{-2}}$$

(2) Input Data

1) Metallic Element Composition of Suspended Particulates

TSP samples collected by Andersen high volume air sampler at the 5 stations for 4 days monthly are analyzed for 10 selected metallic elements. Concentration of the elements and TSP in each station averaged over the entire period is shown in the following Table.

Metallic Element Composition of Suspended Particulates at Each Station ($\mu g/m^3$)

Element	O.CENTRAL	TACUBA	SANAGUSTIN	PEDREGAL	ESTRELLA
Fe	3.53	2.15	3.50	2.45	3.24
Zn	0.65	0.68	0.41	0.19	0.41
Ni	0.01	0.01	0.01	0.01	0.01
Pb	1.03	0.52	0.34	0.40	0.41
V	0.09	0.11	0.05	0.05	0.06
Mn	0.11	0.13	0.10	0.06	0.07
Na	2.04	1.07	1.46	0.66	0.65
Ca	4.12	2.04	3.70	1.99	4.08
K	0.91	0.33	1.10	0.60	0.78
Al	2.03	1.79	4.76	2.04	3.32
TSP	183.0	146.2	182.6	110.0	313.9

2) Metallic Element Composition of Particulates at Various Sources

Dust samples were collected at various sources in Mexico City as shown below. Content of each element was determined for these samples using an atomic absorption spectrophotometer.

Soil : Cement (Rotary kiln)
Sintering furnace: One rotary kiln for cement
Melting furnace : 4 glass melting furnaces
Drying oven : 9 ovens of various types
Metal smelting furnace : One electric furnace and 4 cupolas
Boiler : One 45 ton/hr boiler
Automobiles : Exhaust particulates from automobiles in Mexico City

Content of the elements in particulates sampled at the above mentioned sources is shown in the following Table.

Metallic Element Content in Particulates at Various Sources (%)

Element	Soil	Cement sintering furnace	Glass melting furnace	Drying oven	Metal smelting furnace	Boiler	Automobiles
1 Fe	1.7800	0.8360	1.0200	0.5040	8.7000	0.7460	0.0055
2 Zn	0.0071	0.5190	0.2300	0.1620	5.4900	0.0023	0.1340
3 Ni	0.0022	0.0000	0.0706	0.0639	0.0118	0.2830	0.0002
4 Pb	0.0020	0.4390	2.2900	0.1170	5.8800	0.0105	0.0660
5 V	0.0032	0.0000	0.0000	0.3870	0.0000	0.7490	0.0180
6 Mn	0.0347	0.0585	0.0308	0.0032	1.1700	0.0062	0.0000
7 Na	0.2090	0.0000	39.4000	8.1100	1.8100	0.1150	0.5050
8 Ca	2.6200	22.7000	0.4020	0.0842	3.3200	0.0000	0.0073
9 K	0.3050	0.1730	3.2100	0.2800	2.7900	0.0059	0.0447
10 Al	2.7200	1.4500	5.8500	10.5000	2.2300	0.0894	0.1010