3.8   Future Distribution of Air Pollutant Emission by Source

       (1)   SOx (Factories)

       (2)   SOx (Mobile Sources)

       (3)   SOx (All Sources)

       (4)   *CO (Motor Vehicles)*

       (5)   NOx (Factories)

       (6)   NOx (Mobile Sources)

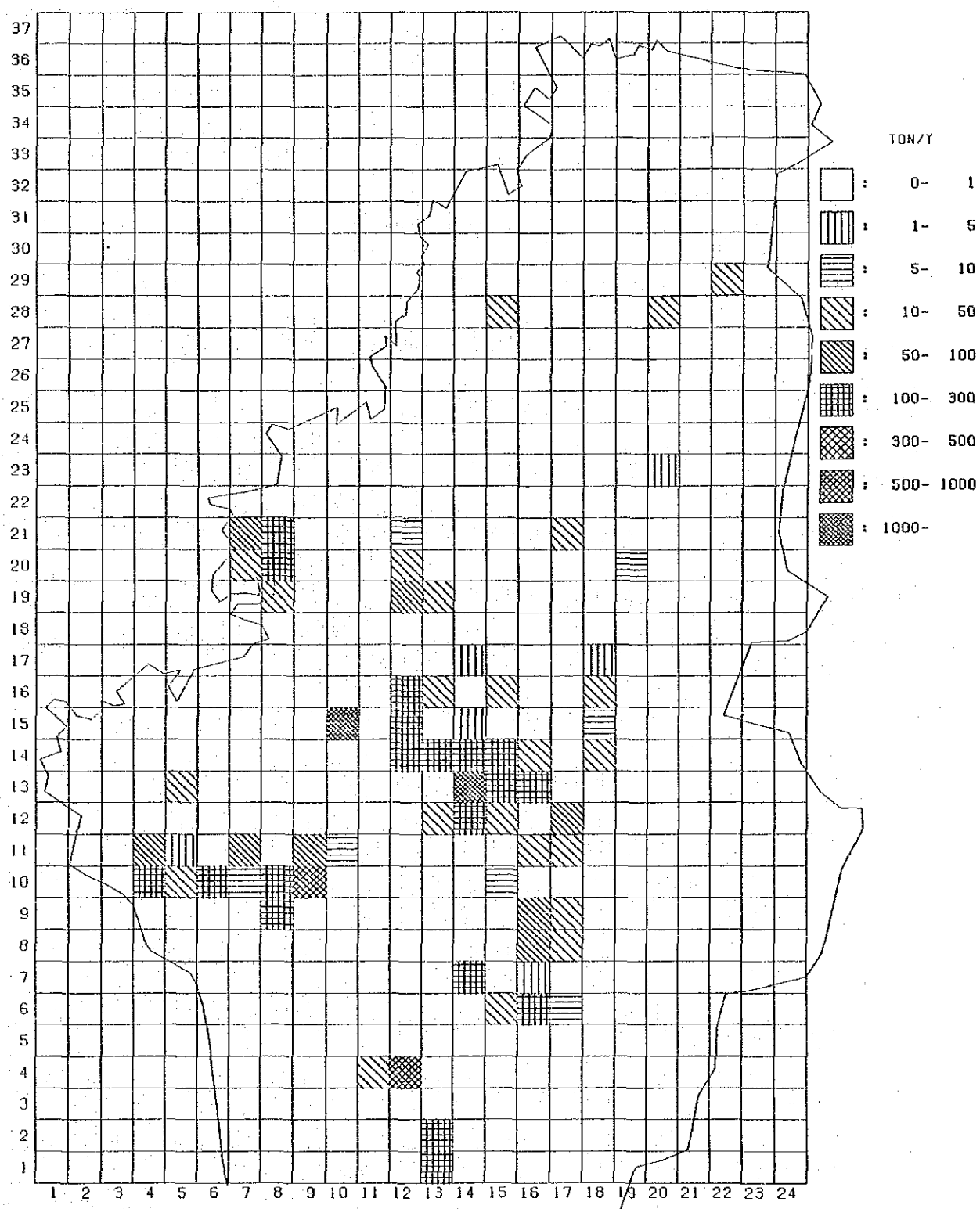   (7)   NOx (All Sources)

       (8)   Dust (Factories)

Fig. 3.8.1 Distribution of SOx Emission from Factories
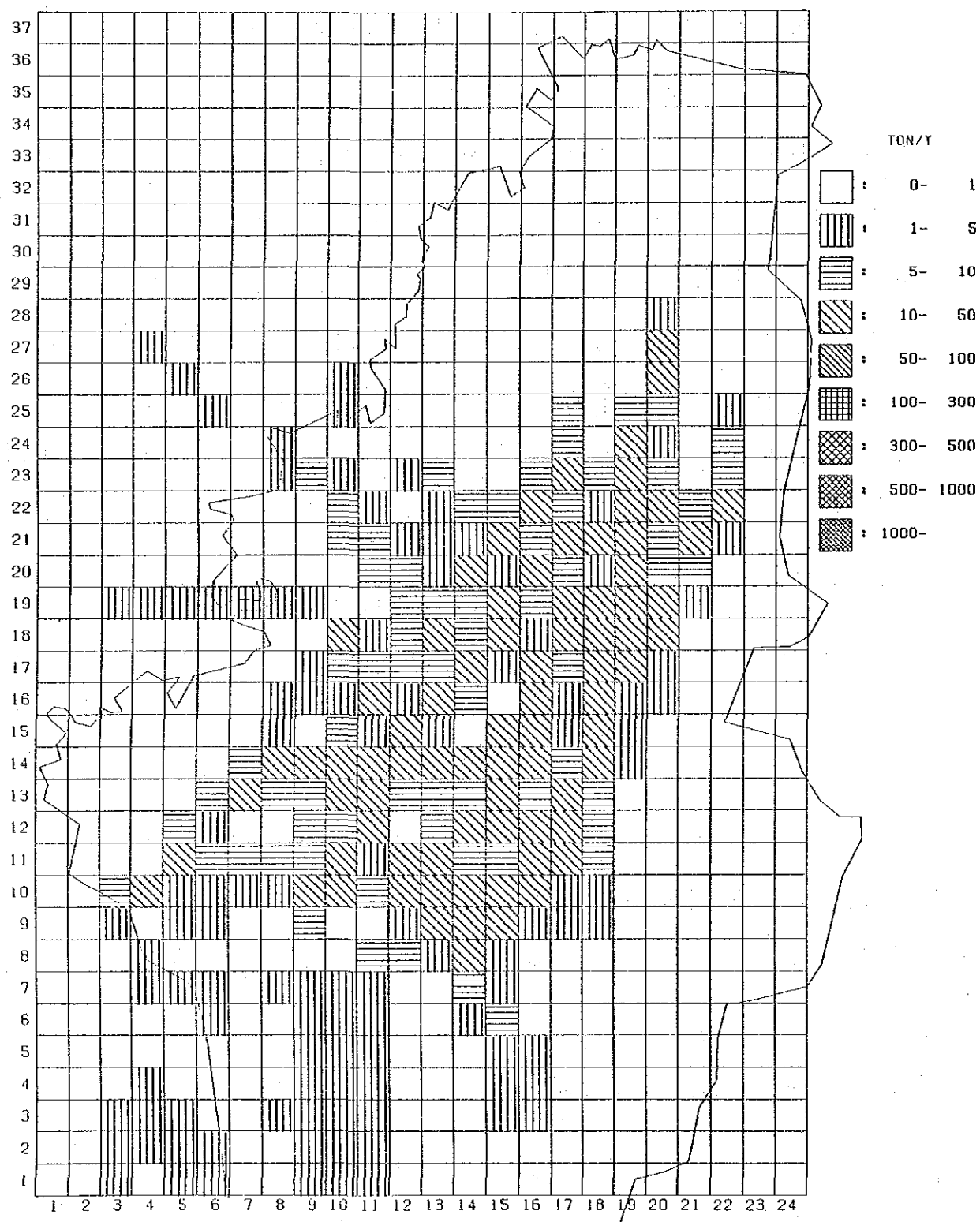without Control Measures in 2001

Fig. 3.8.2　Distribution of SOx Emission from Mobile Sources
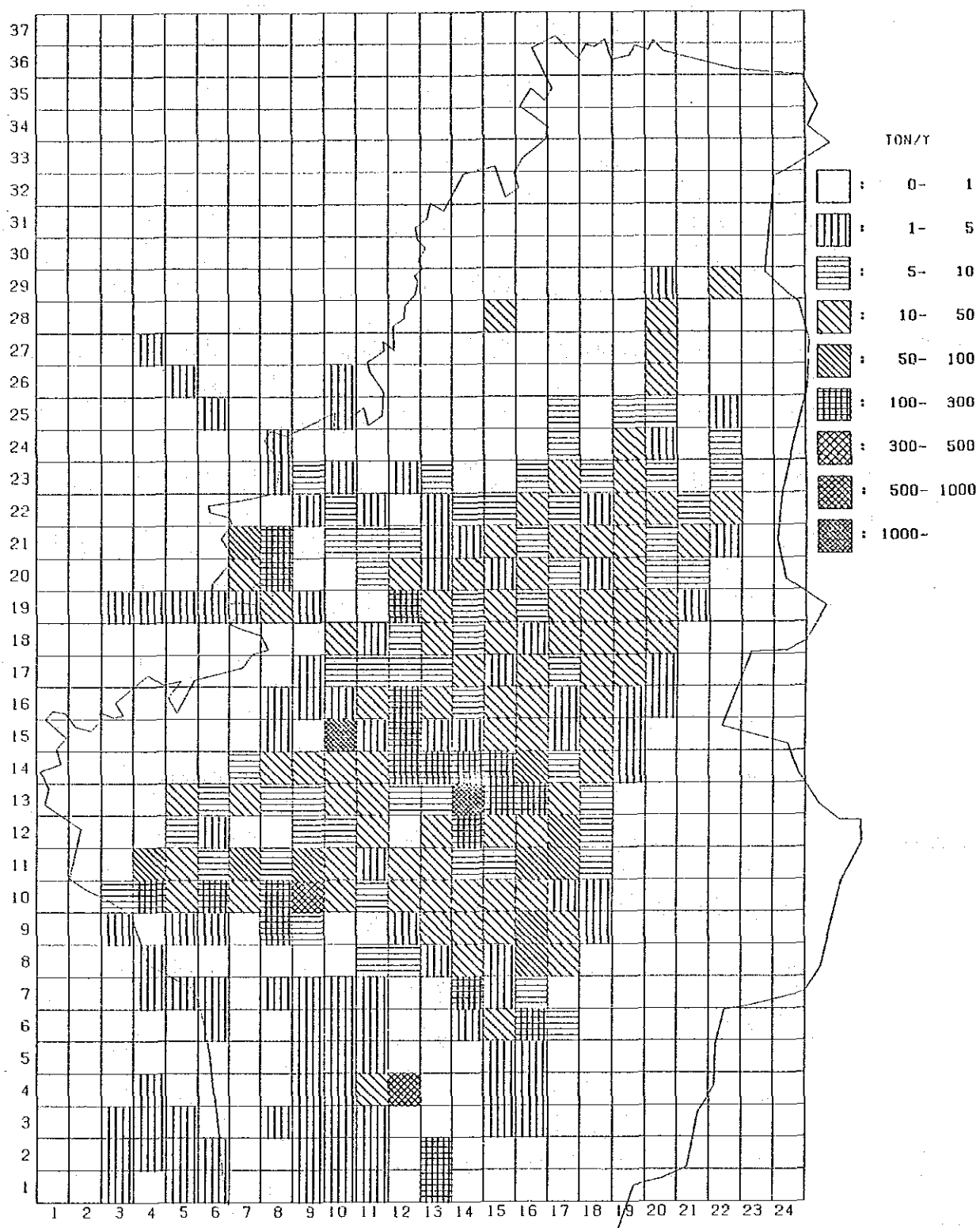without Control Measures in 2001

Fig. 3.8.3   Distribution of SOx Emission from All Sources without Control Measures in 2001

Fig. 3.8.4   Distribution of CO Emission from all sources (Motor Vehicles)
without Control Measures in 2001

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TON/Y

☐ : 0- 1

▥ : 1- 5

▤ : 5- 10

▨ : 10- 50

▨ : 50- 100

▦ : 100- 300

▩ : 300- 500

▩ : 500- 1000

▩ : 1000-

Fig. 3.8.5   Distribution of NOx Emission from Factories
Without Control Measures in 2001

Fig. 3.8.6   Distribution of NOx Emission from Mobile Sources
Without Control Measures in 2001

Fig. 3.8.7   Distribution of NOx Emission from All Sources
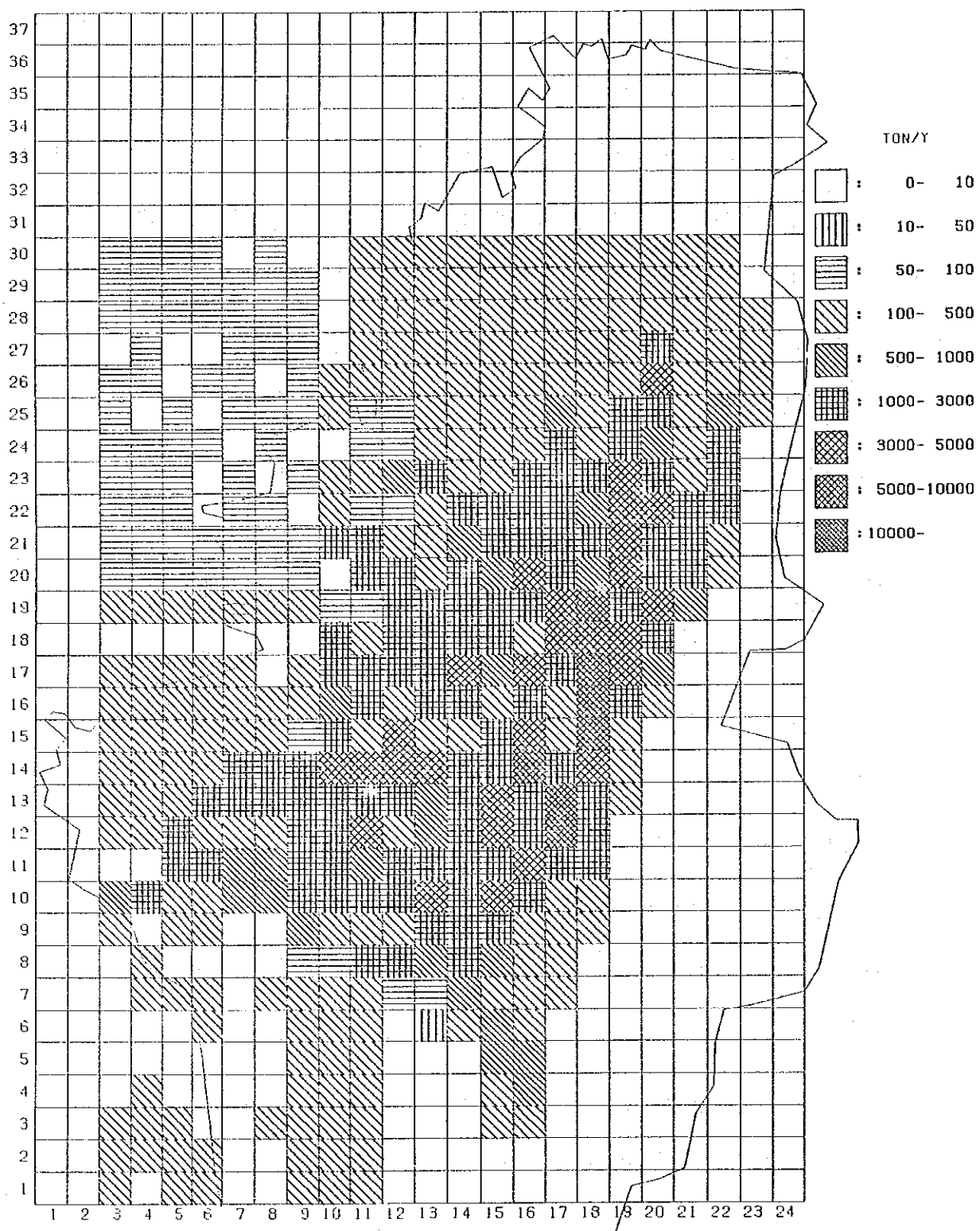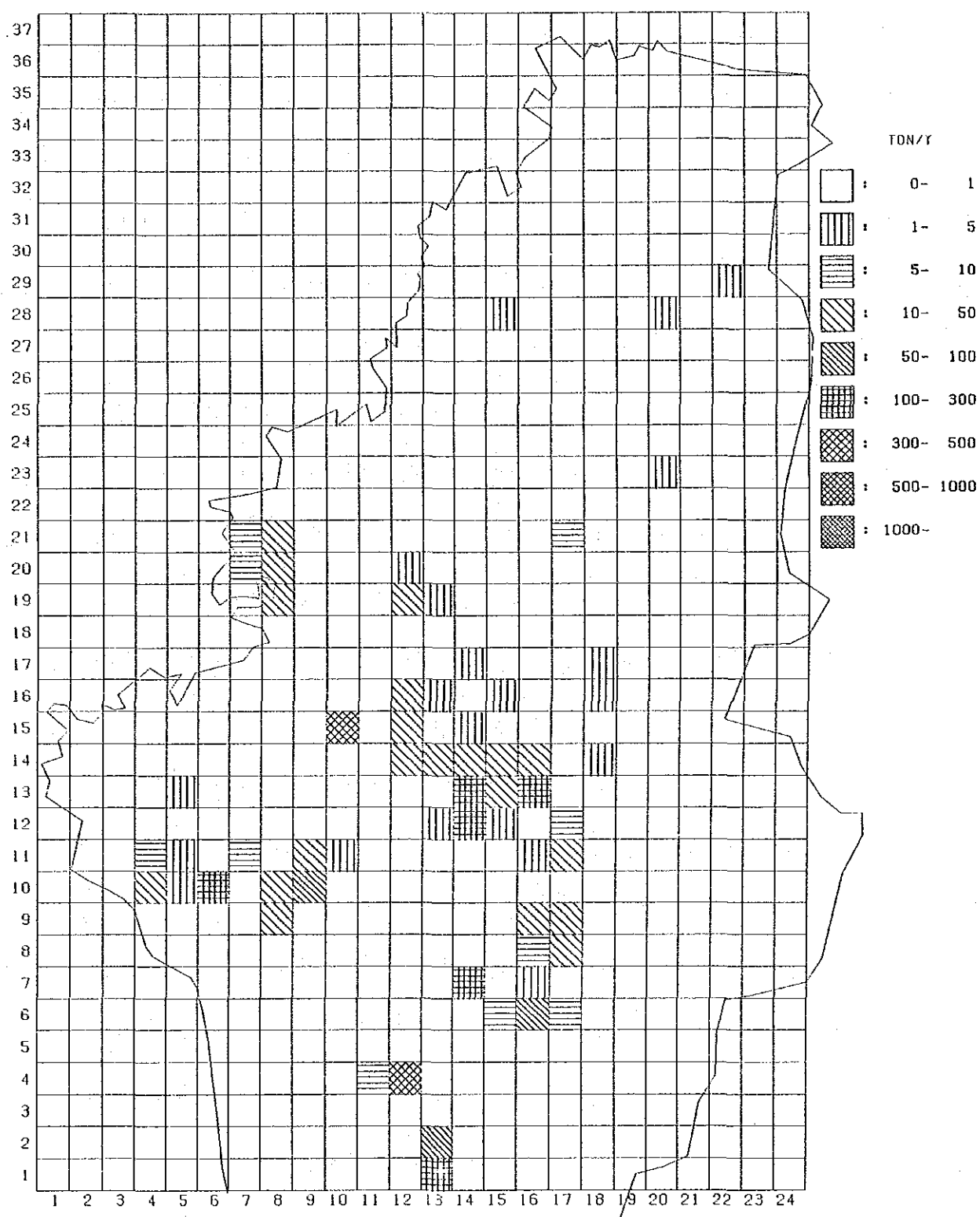Without Control Measures in 2001

Fig. 3.8.8   Distribution of Dust Emission from All Sources (Factories)
Without Control Measures in 2001

3.9   Future Distribution of Air Pollutant Emission by Source with Control Measures

   (1)   SOx (Factories)

   (2)   SOx (Mobile sources)

   (3)   SOx (All Sources)

   (4)   CO (Motor Vehicles)

   (5)   NOx (Factories)

   (6)   NOx (Mobile Sources)

   (7)   NOx (All Sources)

   (8)   Dust (Factories)

Fig. 3.9.1   Distribution of SOx Emission from Factories
with Control Measures in 2001

Fig. 3.9.2 Distribution of SOx Emission from Mobile Sources
with Control Measures in 2001

Fig. 3.9.3　Distribution of SOx Emission from All Sources
with Control Measures in 2001

Fig. 3.9.4   Distribution of CO Emission from All Sources
(Motor Vehicles) with Control Measures in 2001
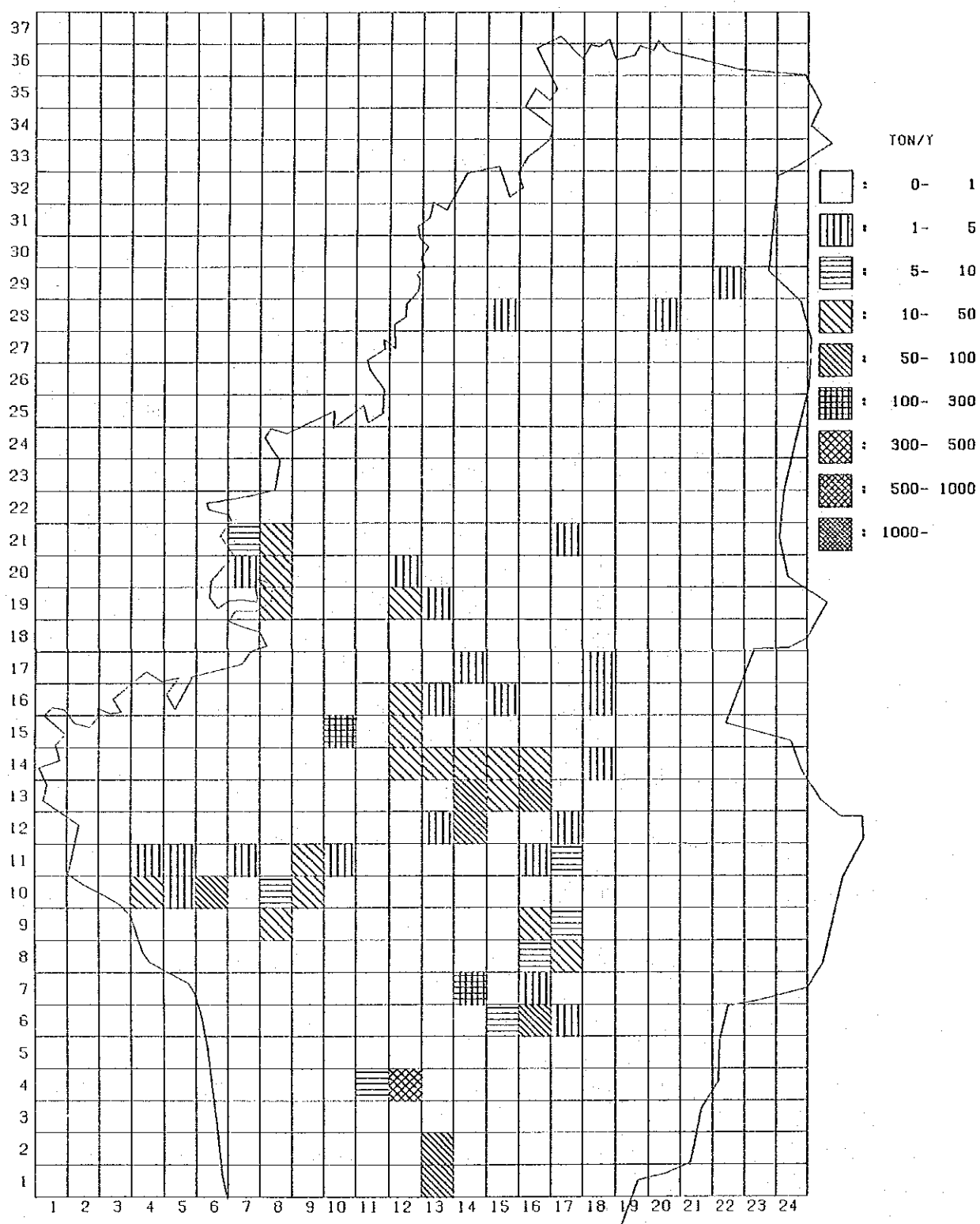
Fig. 3.9.5   Distribution of NOx Emission from Factories
with Control Measures in 2001
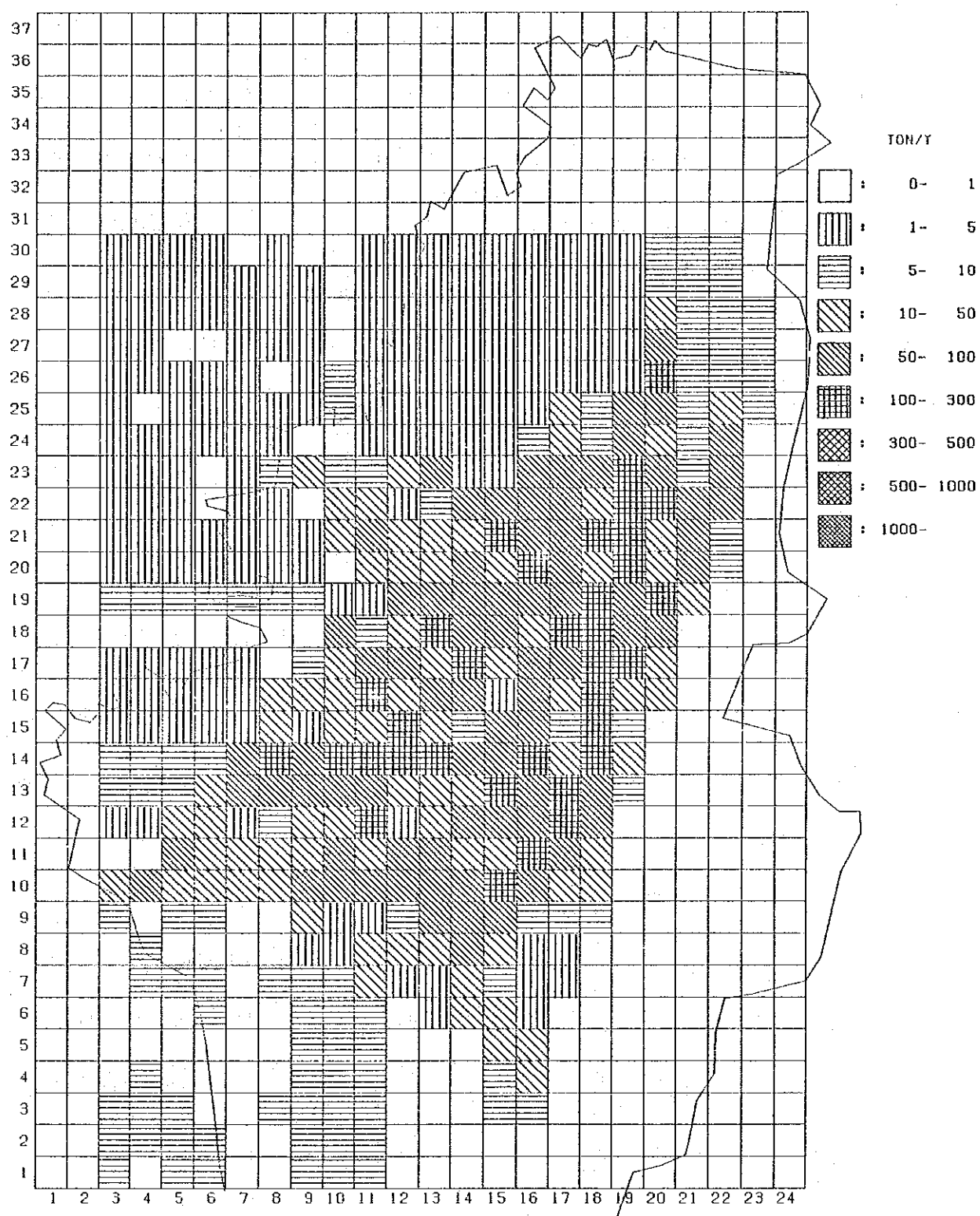
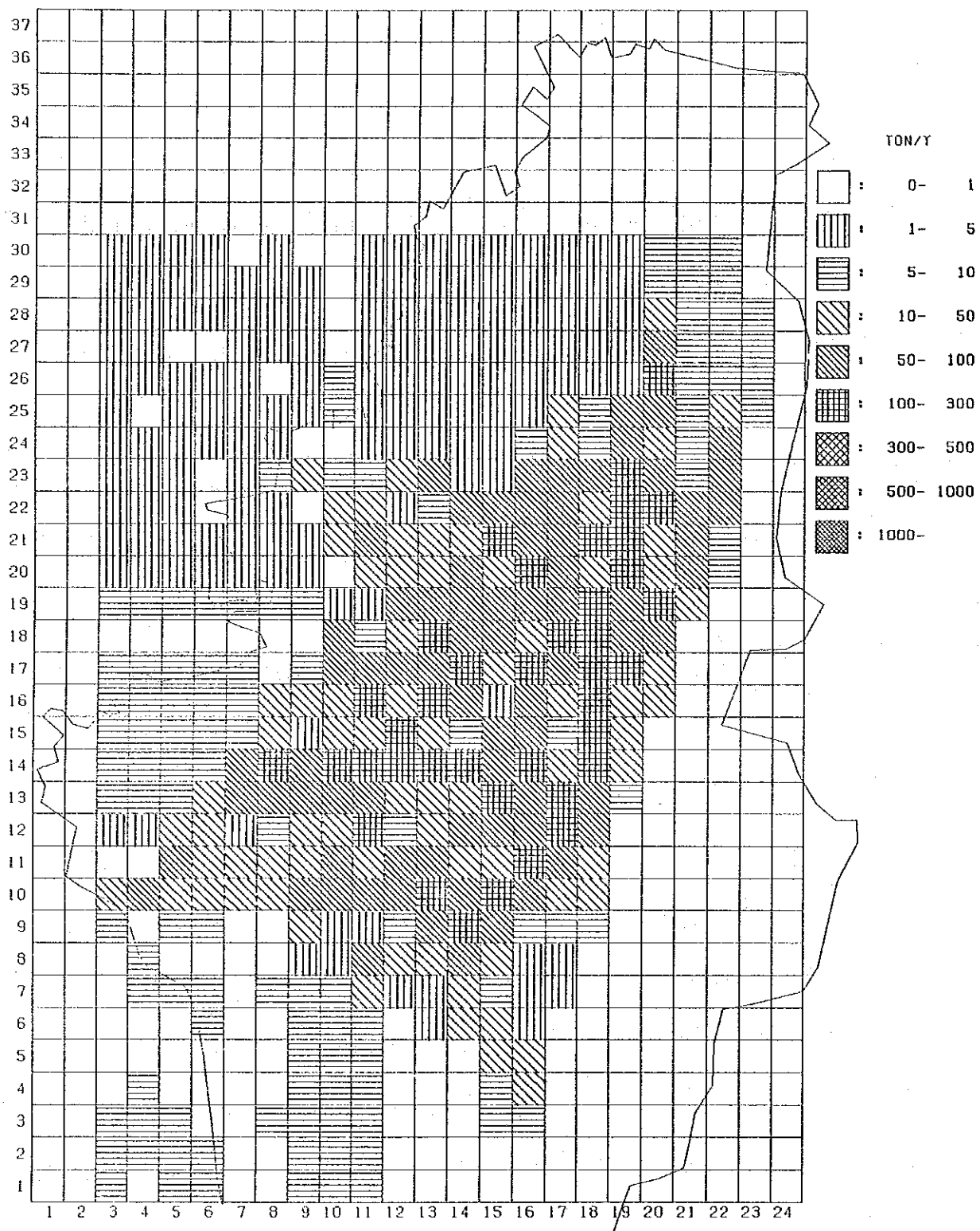Fig. 3.9.6 Distribution of SOx Emission from Mobile Sources
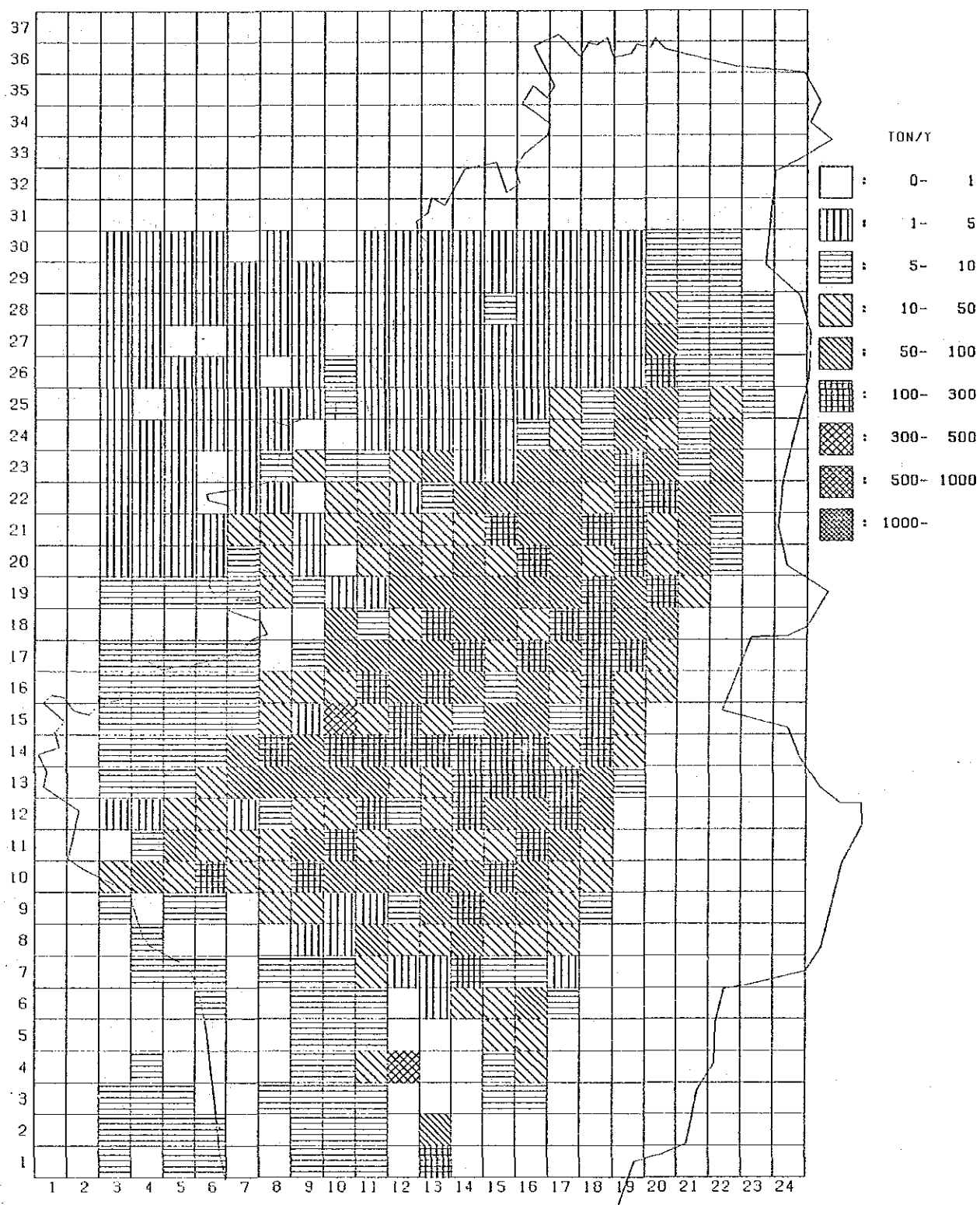with Control Measures in 2001

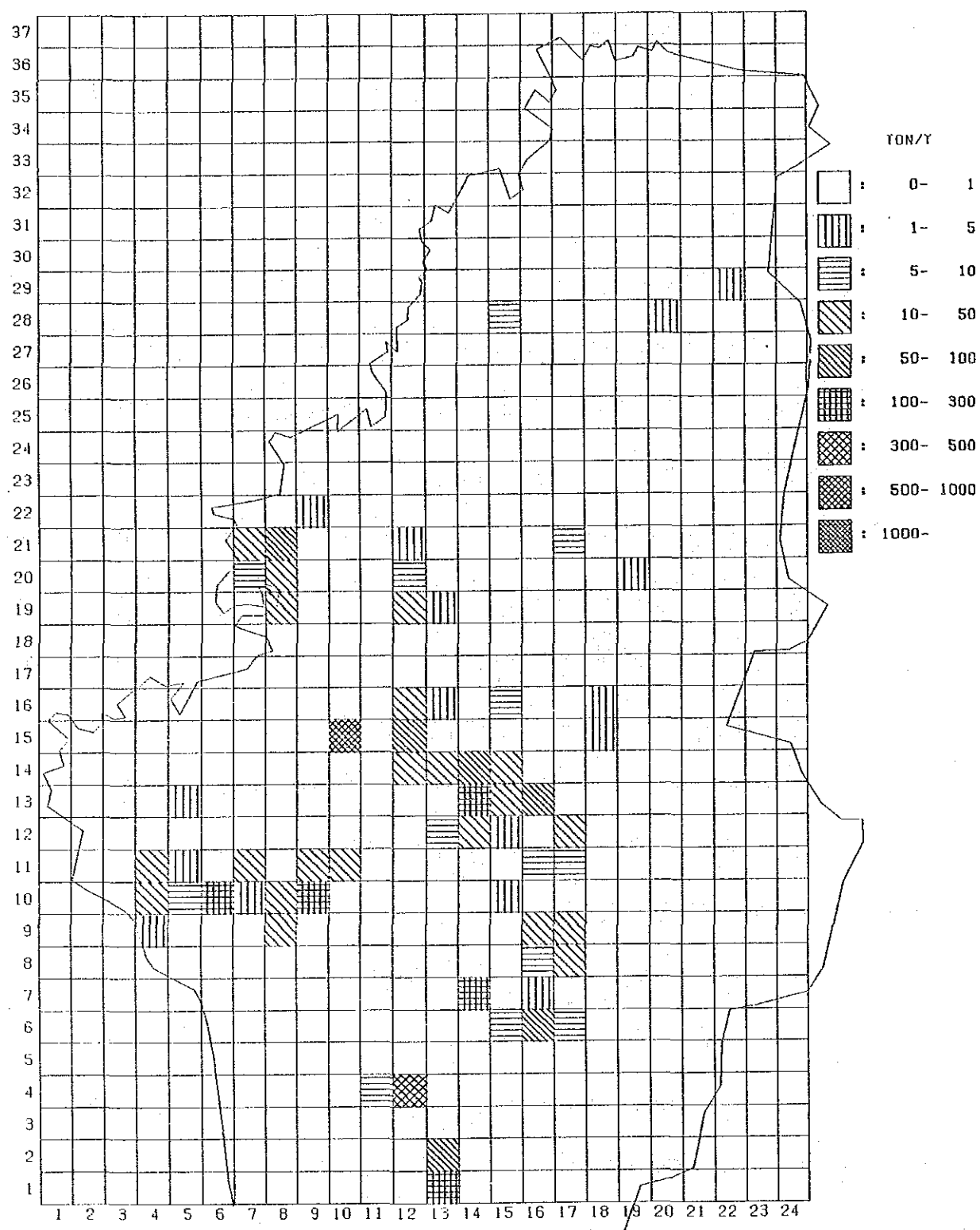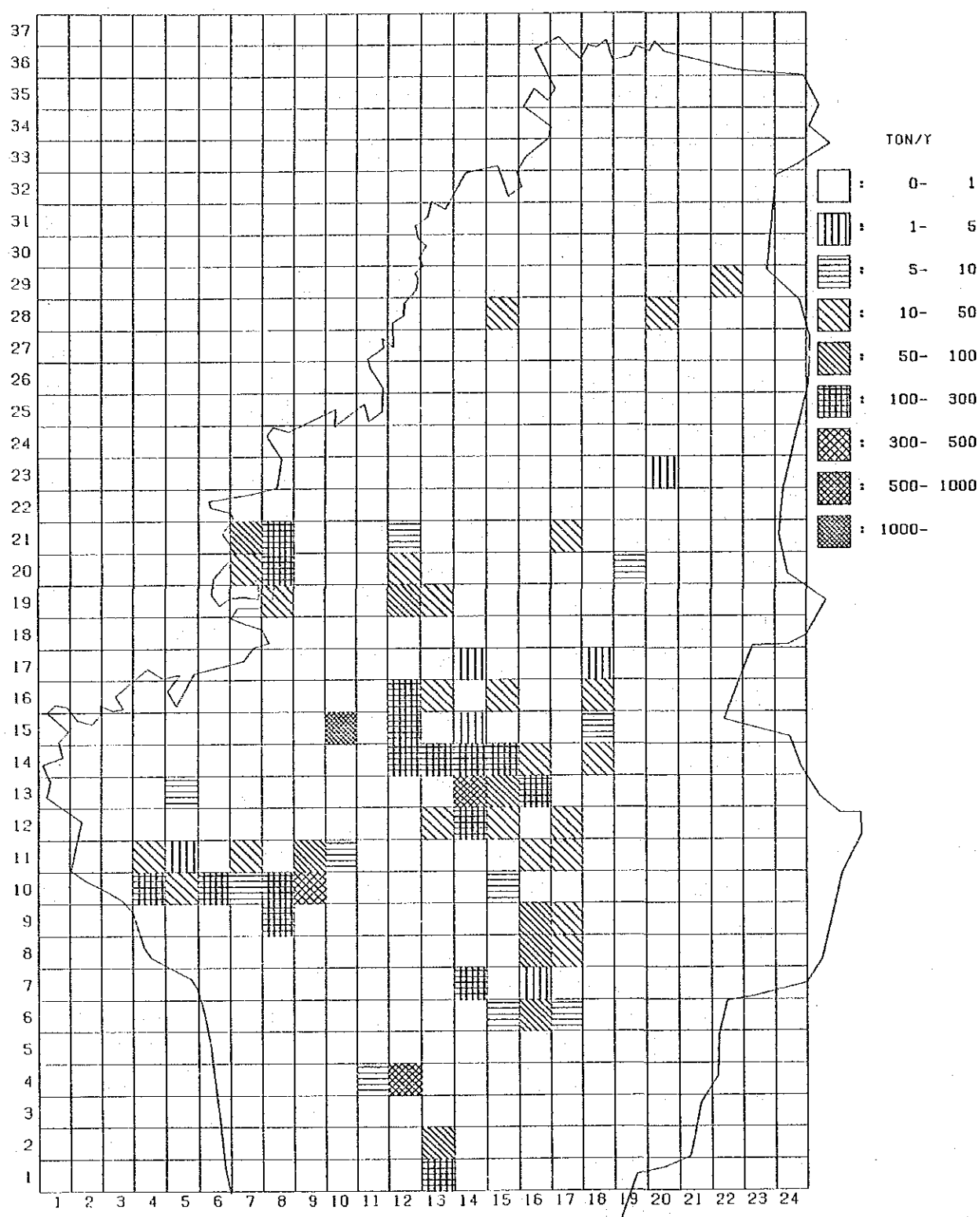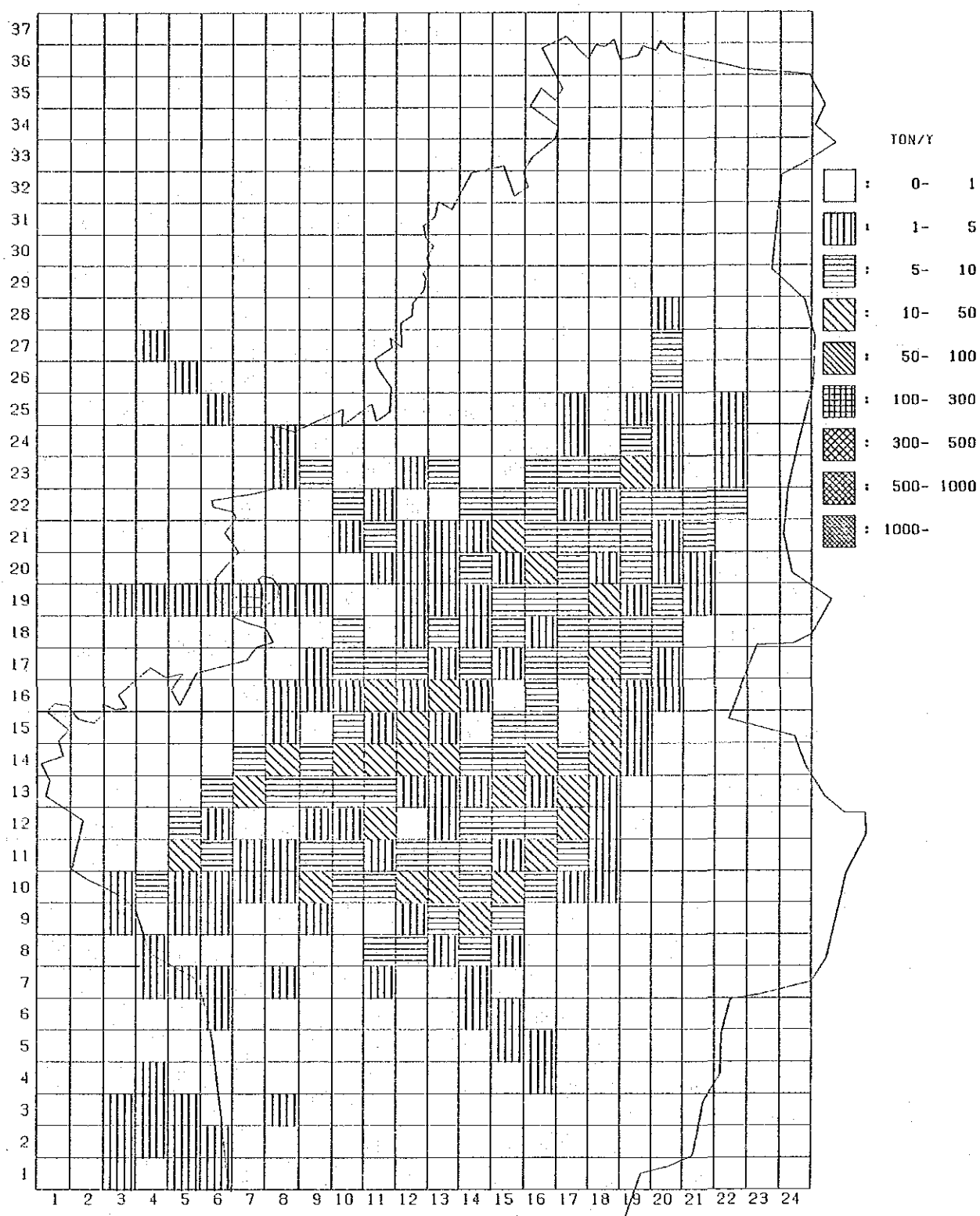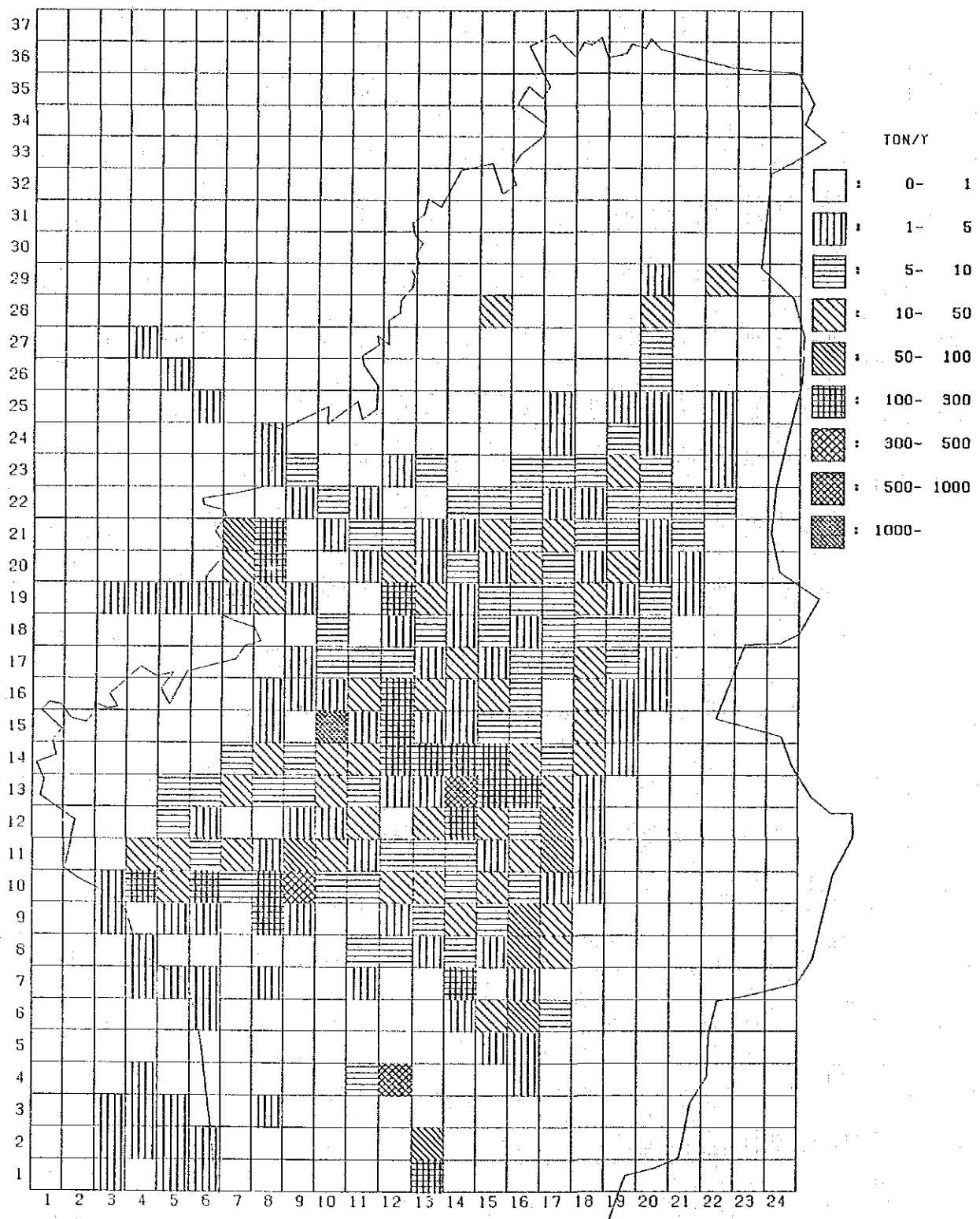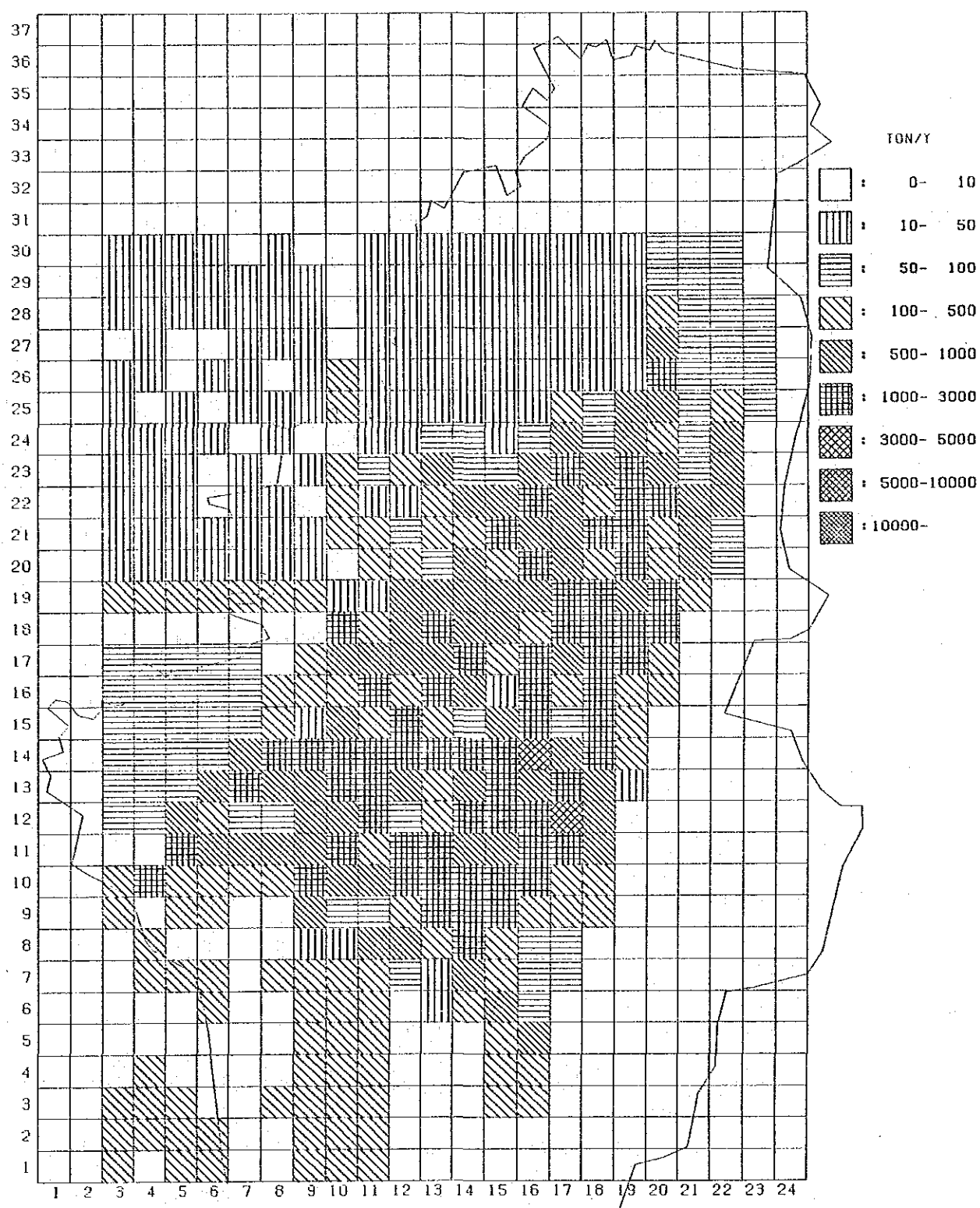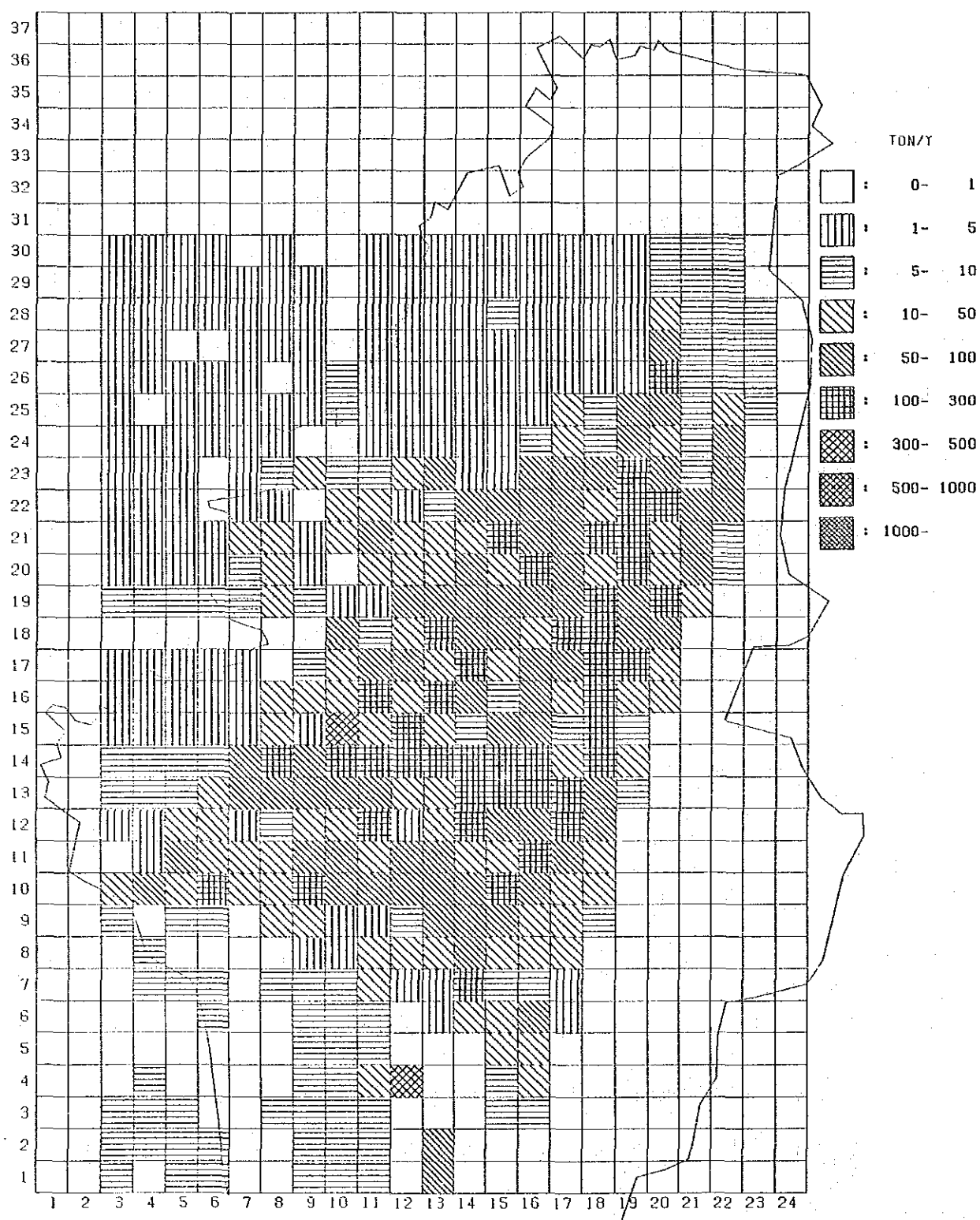Fig. 3.9.7 Distribution of SOx Emission from All Sources with Control Measures in 2001
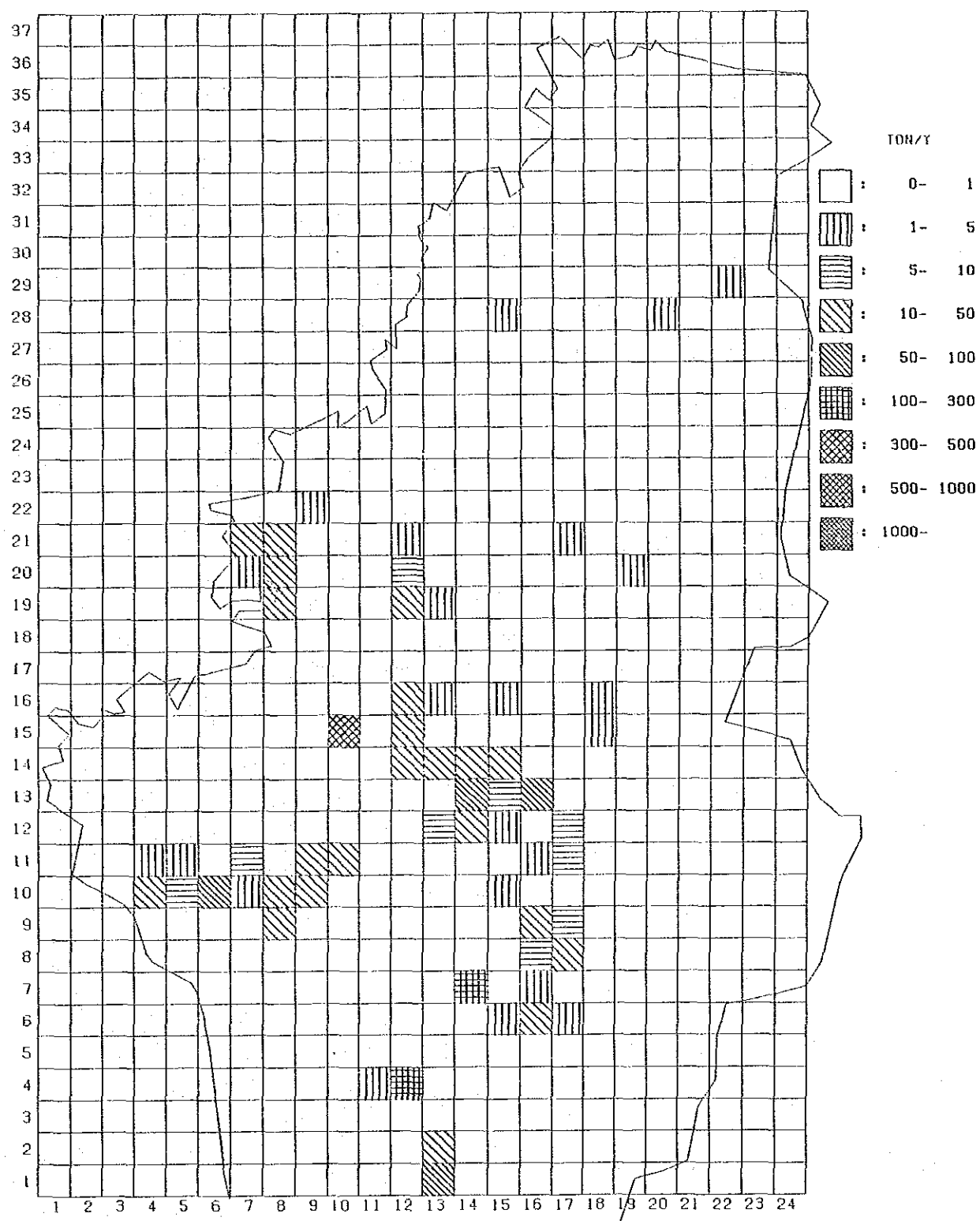
Fig. 3.9.8 Distribution of Dust Emission from All Sources
(Factories) with Control Measures in 2001

PART 4   AIR QUALITY SIMULATION

4.1 Air Quality Simulation by Dispersion Model

4.1.1 Dispersion Equation

(1) Point source Equation

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

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

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)

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

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

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

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

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

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

a , γ : Diffusion parameters for calm

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

$\sigma z = \gamma \cdot t$

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)

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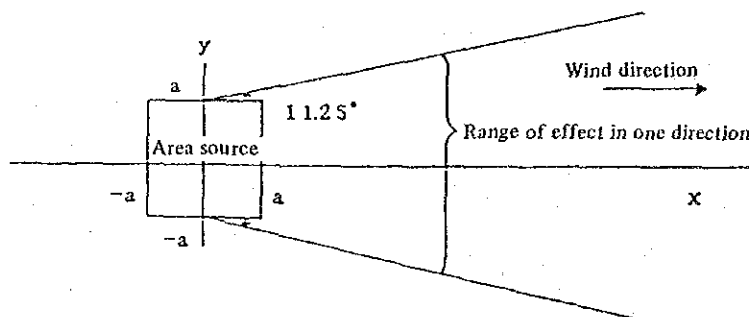
When calm, the following equation is used by applying the simplified puff equation (steady-state solution) to a circular area source that has the same area as a square area source with a side 2a long.

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

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

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

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

A conceptual diagram of area source diffusion model is shown below.
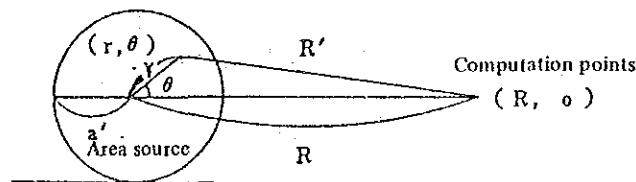
(3) Line Source Equation

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)

σz : Vertical diffusion parameter (m)

When calm, the following equation is used.

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

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

R1, R2: Integration interval (m) of a line source as shown below
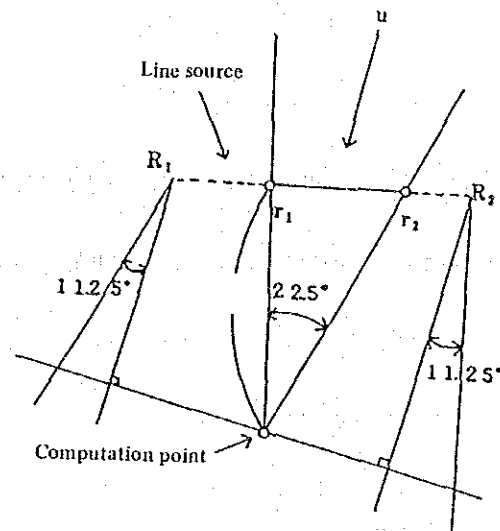
4.1.2 Calculation Method for Correlation Coefficient and Coefficient of Variation

Calculation Method for Correlation Coefficient is as follows.

$$r = \frac{Sxy}{\sqrt{Sxx \cdot Syy}}$$ Correlation Coefficient

$$\overline{Y} = \frac{1}{n} \sum_{i=1}^{n} Yi$$

$$\overline{X} = \frac{1}{n} \sum_{i=1}^{n} Xi$$

$$Sxy = \sum_{i=1}^{n} (Xi - \overline{X}) \cdot (Yi - \overline{Y})$$

$$Syy = \sum_{i=1}^{n} (Yi - \overline{Y})^2$$

$$Sxx = \sum_{i=1}^{n} (Xi - \overline{X})^2$$

Calculation Method for Coefficient of Variation is as follows.

$$Ei = Yi - Y'i \quad \text{------- Error}$$

$$S'_E = \sum_{i=1}^{n} (Yi - Y'i)^2 \quad \text{------- Sum of error squares}$$

$$= \sum_{i=1}^{n} \left\{ Yi - (a_0 + Xi) \right\}^2$$

$$= \sum_{i=1}^{n} \left\{ Yi - (\overline{Y} - \overline{X} + Xi) \right\}^2$$

$$= \sum_{i=1}^{n} \left\{ (Yi - \overline{Y}) - (Xi - \overline{X}) \right\}^2$$

$$= \sum_{i=1}^{n} (Yi - \overline{Y})^2 - 2 \sum_{i=1}^{n} (Yi - \overline{Y}) \cdot (Xi - \overline{X}) + \sum_{i=1}^{n} (Xi - \overline{X})^2$$

$$= Syy - 2 Sxy + Sxx$$

$$s'_E = \frac{S'_E}{n-2} \quad \text{------- Unbiased variance of error}$$

$$s' = \sqrt{s'_E} \quad \text{------- Coefficient of variation}$$

4.1.3 Setting of Background Concentration

Background concentration was set as shown in Table 4.1.1 in estimating the concentration of present state, in future and with control measure.

Part of background concentration excluding in natural in future and with control measure was supposed to change according to the change of air pollutant volume from all sources.

Table 4.1.1

Estimating case	Item	Air pollutant volume [1] (ton/year)	Background concentration [2]		
			In natural	Unknown	Total
Present state	SO$_2$	7,802	2.0	0.4	2.4
	NO$_x$	11,064	1.5	0.3	1.8
	CO	288,744	0.3	1.0	1.3
In future	SO$_2$	11,161	2.0	0.6	2.6
	NO$_x$	16,473	1.5	0.5	2.0
	CO	398,376	0.3	1.4	1.7
With control measure	SO$_2$	8,669	2.0	0.4	2.4
	NO$_x$	15,046	1.5	0.4	1.9
	CO	193,183	0.3	0.7	1.0

Note: (1 Volume is from all sources.

(2 Units are SO$_2$ → ppb, NO$_x$ → ppb, and CO → ppm.

4.1.4 Cotribution Concentration by Air Pollutant Sources

(1) Cotribution Concentration at Monitoring Stations and Maximum Concentration Point

Estimated cotribution concentration at monitoring stations and maximum concentration point by sources is shown in Table 4.1.2 - Table 4.1.4.

Table 4.1.2 Cotribution Concentration by Sources

(Present state)

Items	Souces Stations	Stationary sources	Mobile Sources	Back-ground	Total
SO$_2$ (ppb)	A.Servicio de Salud	4.8	6.6	2.4	13.8
	B.Laboratorio	8.1	4.4		14.8
	C.Puente Aranda	14.2	4.2		20.8
	D.El Tunal	5.6	1.1		9.1
	E.San Juan de Dios	5.9	9.9		18.2
	Cmax Point (12,15)	19.6	10.3		32.3
NO$_x$ (ppb)	A.Servicio de Salud	1.2	64.0	1.8	67.1
	B.Laboratorio	2.3	43.4		47.6
	C.Puente Aranda	3.6	42.3		47.8
	D.El Tunal	2.4	11.2		15.5
	E.San Juan de Dios	1.9	93.4		97.1
	Cmax Point (16,14)	2.6	104.4		108.8
CO (ppm)	A.Servicio de Salud	–	3.89	1.29	5.18
	B.Laboratorio	–	2.49		3.78
	C.Puente Aranda	–	2.09		3.38
	D.El Tunal	–	0.57		1.86
	E.San Juan de Dios	–	4.99		6.28
	Cmax Point (16,14)	–	5.66		6.96

Table 4.1.3 Cotribution Concentration by Sources

(In future)

Items	Stations	Stationary sources	Mobile Sources	Back-ground	Total
SO₂ (ppb)	A.Servicio de Salud	5.5	10.7		18.8
	B.Laboratorio	10.2	7.0		19.8
	C.Puente Aranda	17.7	6.9	2.6	27.2
	D.El Tunal	7.5	1.9		12.0
	E.San Juan de Dios	7.6	16.4		26.6
	Cmax Point (12,15)	24.1	17.0		43.7
NOₓ (ppb)	A.Servicio de Salud	1.4	94.9		98.4
	B.Laboratorio	2.8	64.4		69.3
	C.Puente Aranda	4.5	64.0	2.0	70.6
	D.El Tunal	3.0	16.9		22.0
	E.San Juan de Dios	2.3	138.3		142.7
	Cmax Point (12,15)	5.6	155.7		163.3
CO (ppm)	A.Servicio de Salud	–	5.41		7.08
	B.Laboratorio	–	3.46		5.13
	C.Puente Aranda	–	2.85	1.67	4.52
	D.El Tunal	–	0.78		2.45
	E.San Juan de Dios	–	6.88		8.55
	Cmax Point (16,14)	–	7.91		9.58

Table 4.1.4 Cotribution Concentration by Sources

(With control measure)

Items	Stations	Stationary sources	Mobile Sources	Back-ground	Total
SO₂ (ppb)	A.Servicio de Salud	4.6	6.4		13.4
	B.Laboratorio	8.5	4.2		15.1
	C.Puente Aranda	14.7	4.6	2.4	21.7
	D.El Tunal	6.1	1.3		9.8
	E.San Juan de Dios	6.3	11.4		20.1
	Cmax Point (12,15)	20.3	11.8		34.6
NOₓ (ppb)	A.Servicio de Salud	1.2	87.8		90.9
	B.Laboratorio	2.1	60.3		64.3
	C.Puente Aranda	3.3	60.8	1.9	66.0
	D.El Tunal	2.4	15.8		20.1
	E.San Juan de Dios	1.8	126.5		130.2
	Cmax Point (12,15)	3.9	148.2		154.1
CO (ppm)	A.Servicio de Salud	–	2.50		3.46
	B.Laboratorio	–	1.66		2.62
	C.Puente Aranda	–	1.42	0.96	2.38
	D.El Tunal	–	0.41		1.37
	E.San Juan de Dios	–	3.95		4.91
	Cmax Point (12,15)	–	3.46		4.42

(2) Plane Distribution of Cotribution Concentration by Air
Pollution Sources

1) Present State

Estimated plane distrubution of cotribution concentration of
present state by sources is shown in Fig. 4.1.1 - Fig.
4.1.4.

2) In Future

Predicted plane distrubution of cotribution concentration in
future by sources is shown in Fig. 4.1.5 - Fig. 4.1.8.

3) With Control Measure

Predicted plane distrubution of cotribution concentration
with control measure by sources is shown in Fig. 4.1.9 -
Fig. 4.1.12.
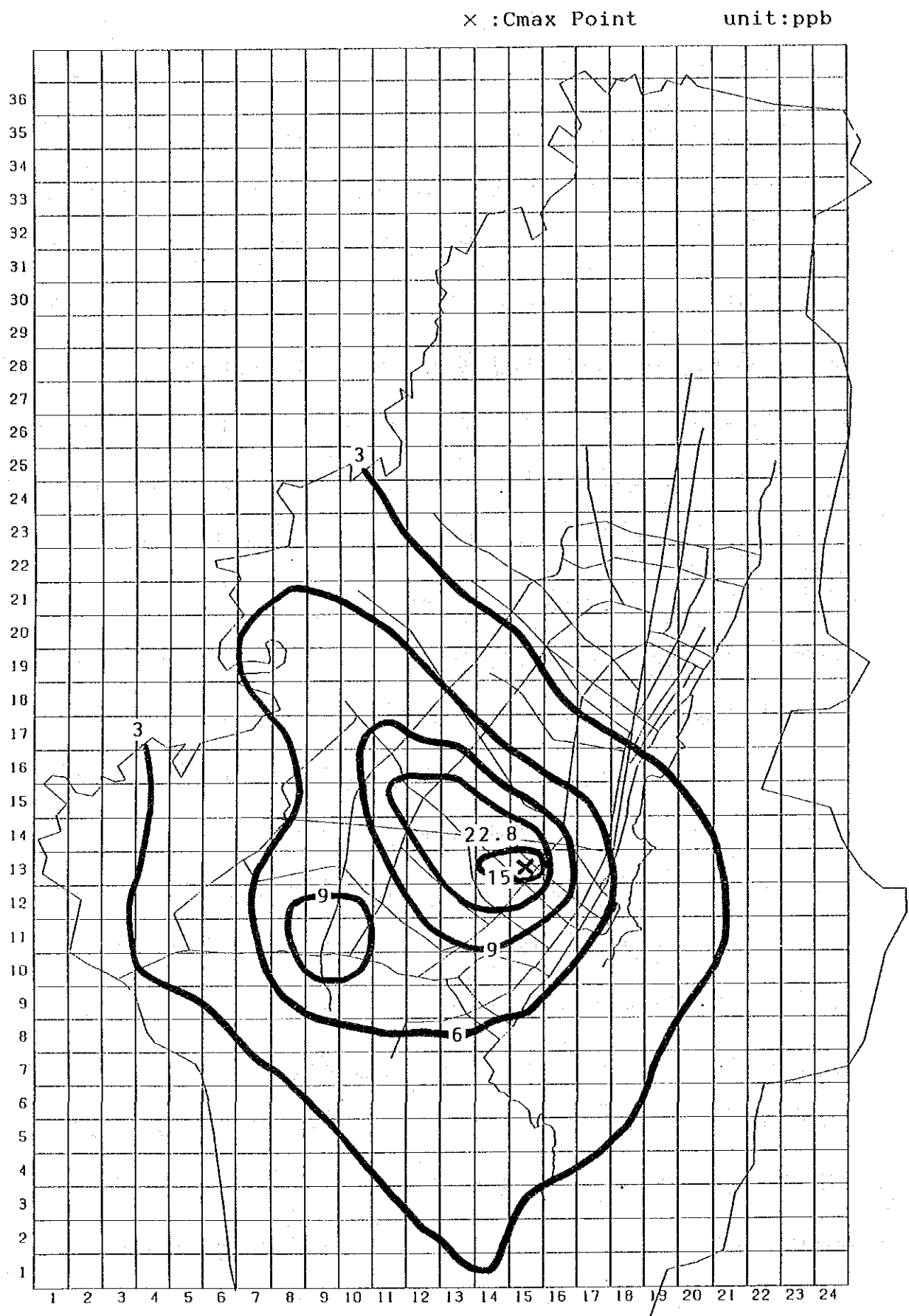
Fig. 4.1.1 Contribution of Factories to Annual
Average Concentration of SO₂ (Present)

× :Cmax Point   unit:ppb
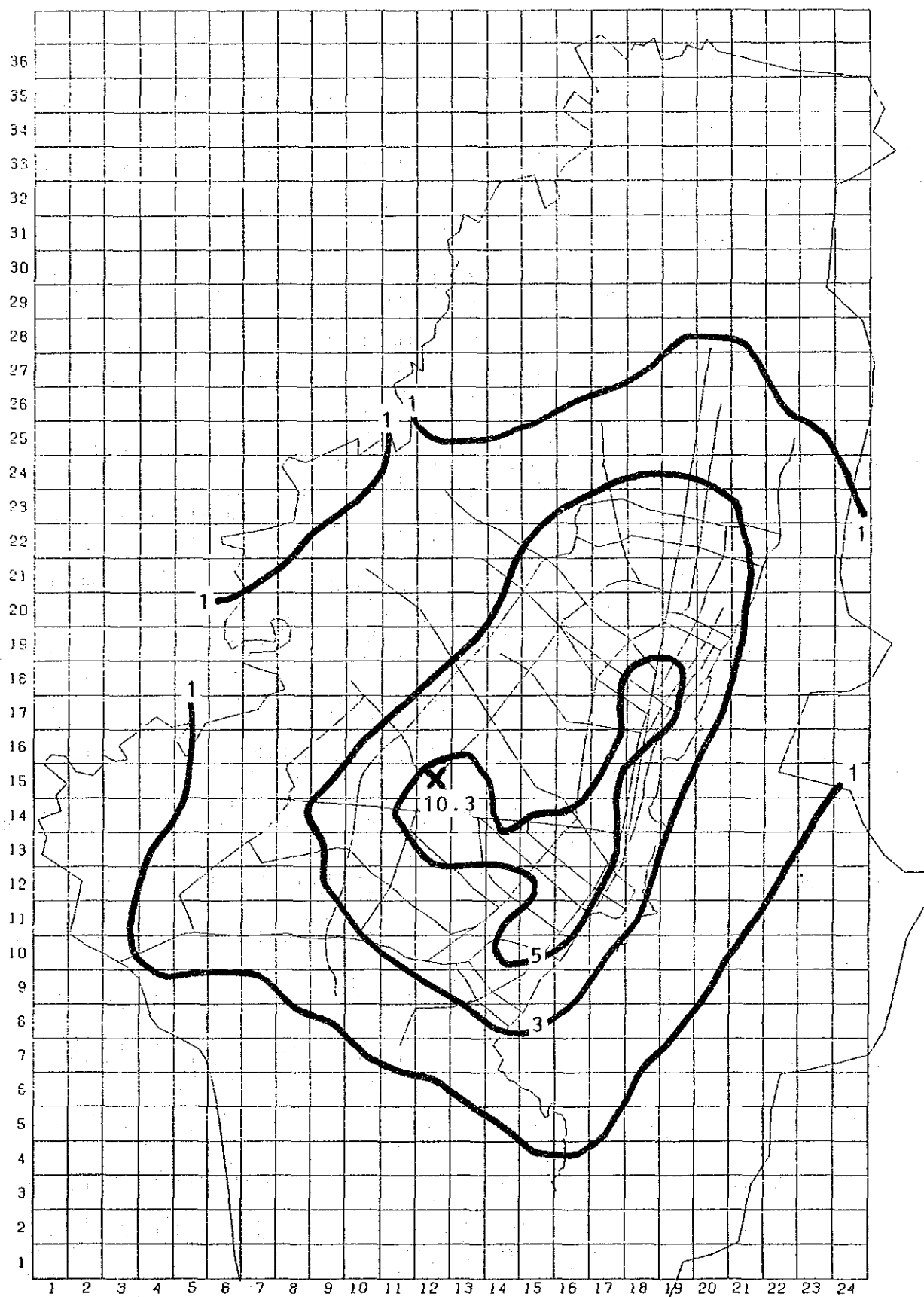
Fig. 4.1.2 Contribution of Automobiles to Annual
Average Concentration of SO_2 (Present)
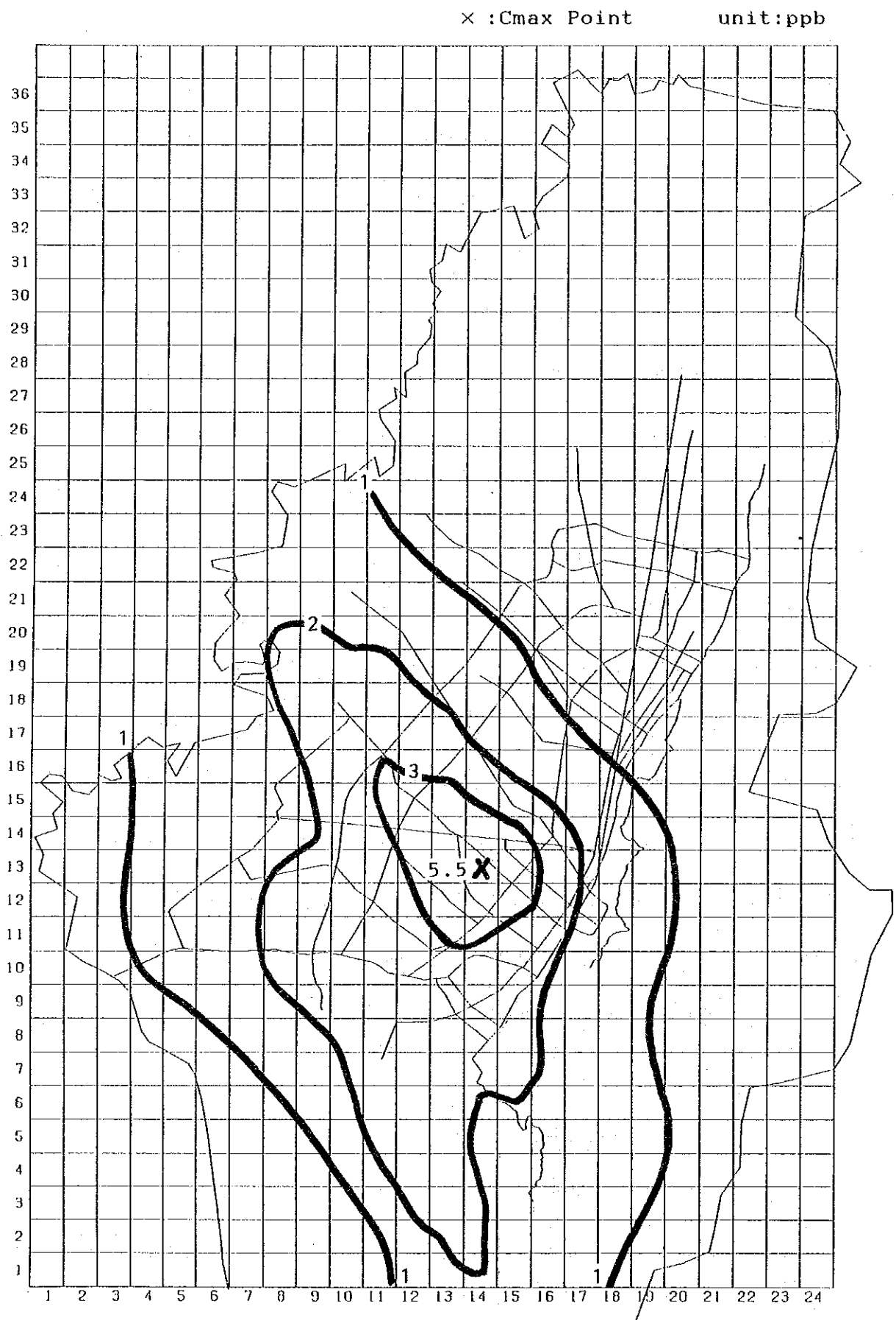
Fig. 4.1.3 Contribution of Factories to Annual
Average Concentration of NOx (Present)
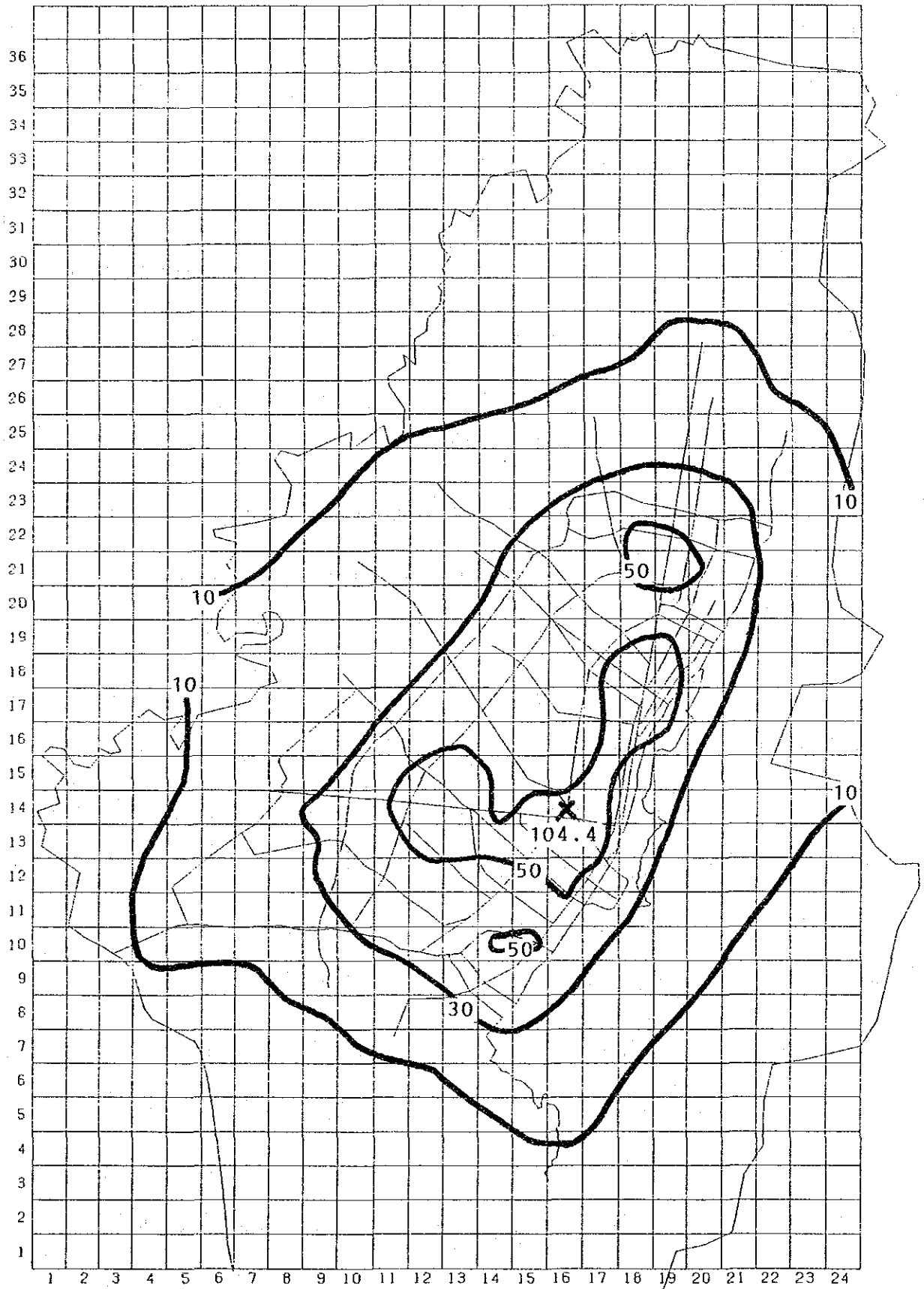
Fig. 4.1.4 Contribution of Automobiles to Annual
Average Concentration of NOₓ (Present)
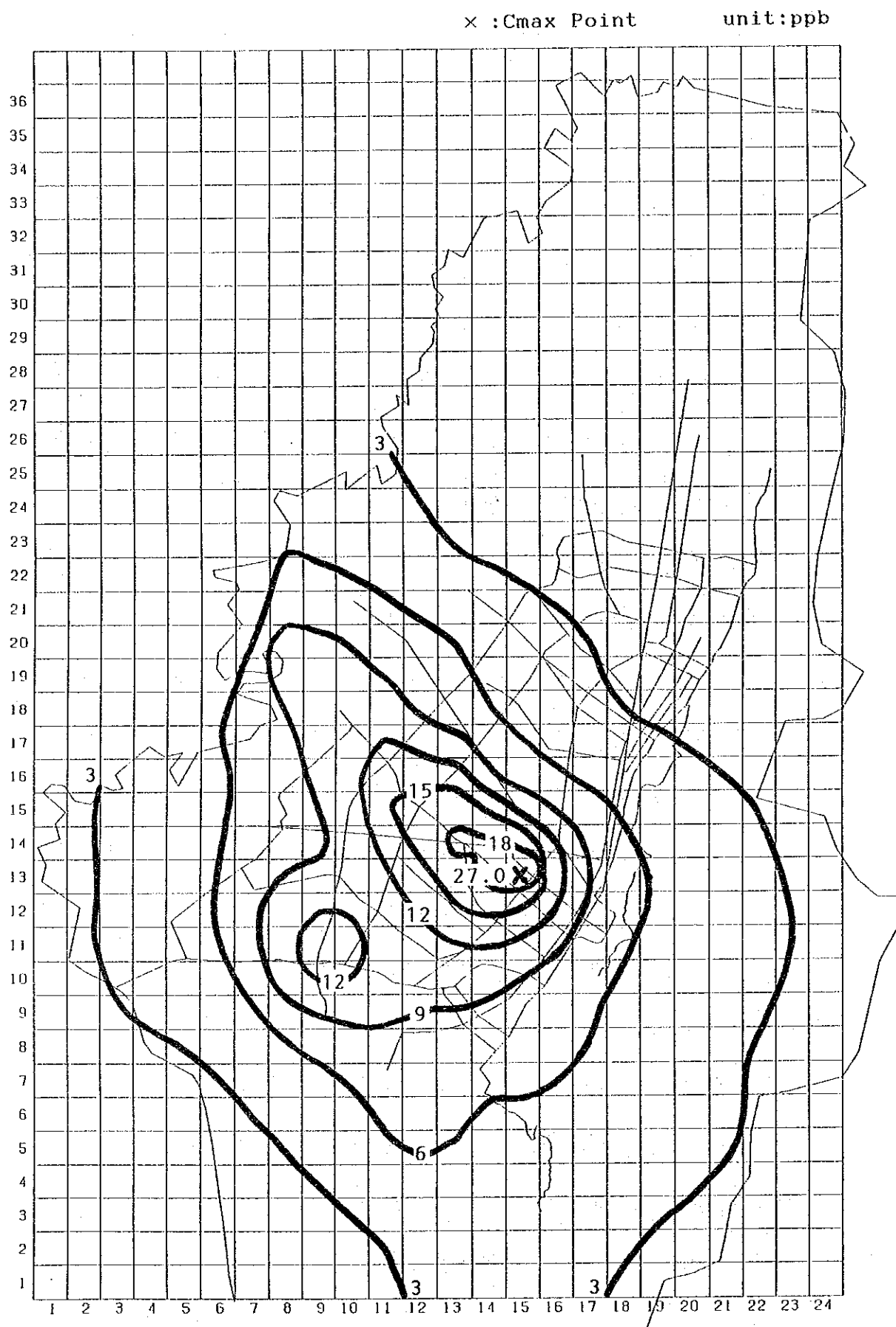
Fig. 4.1.5 Contribution of Factories to Annual
Average Concentration of SO₂ (Future)
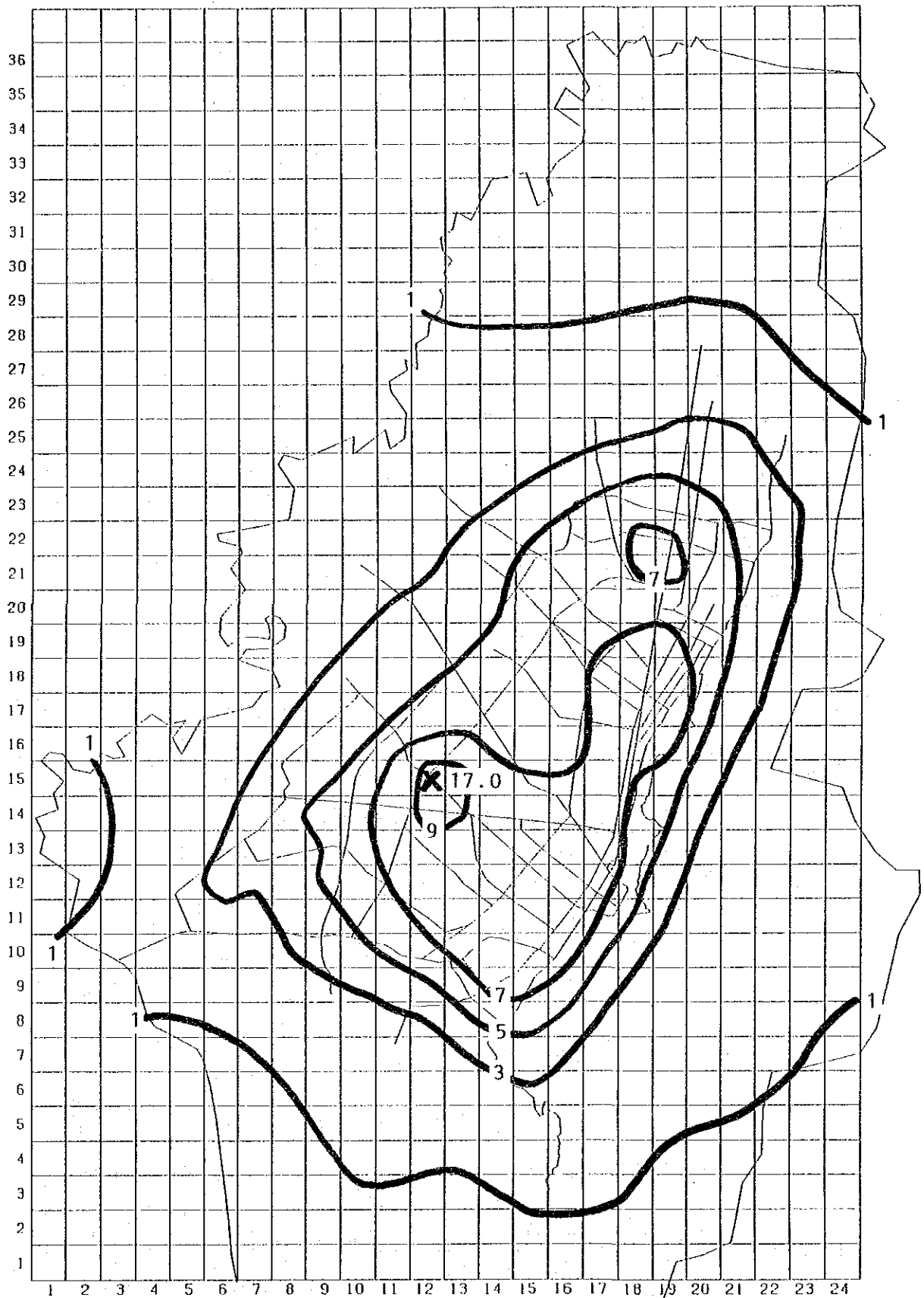
× :Cmax Point   unit:ppb

Fig. 4.1.6 Contribution of Automobiles to Annual
Average Concentration of SO₂ (Future)

×：Cmax Point   unit:ppb
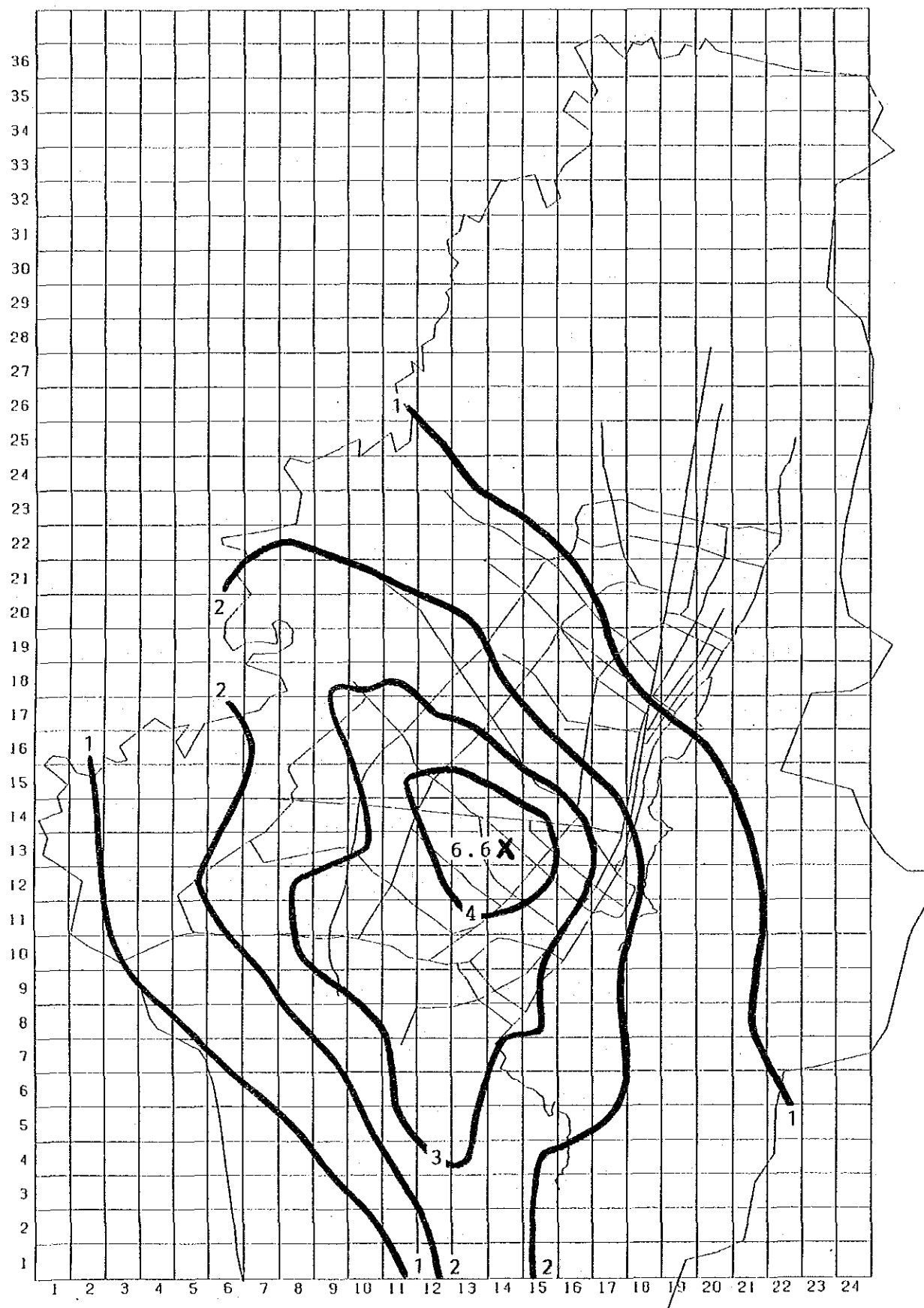
Fig. 4.1.7 Contribution of Factories to Annual
          Average Concentration of NOₓ (Future)

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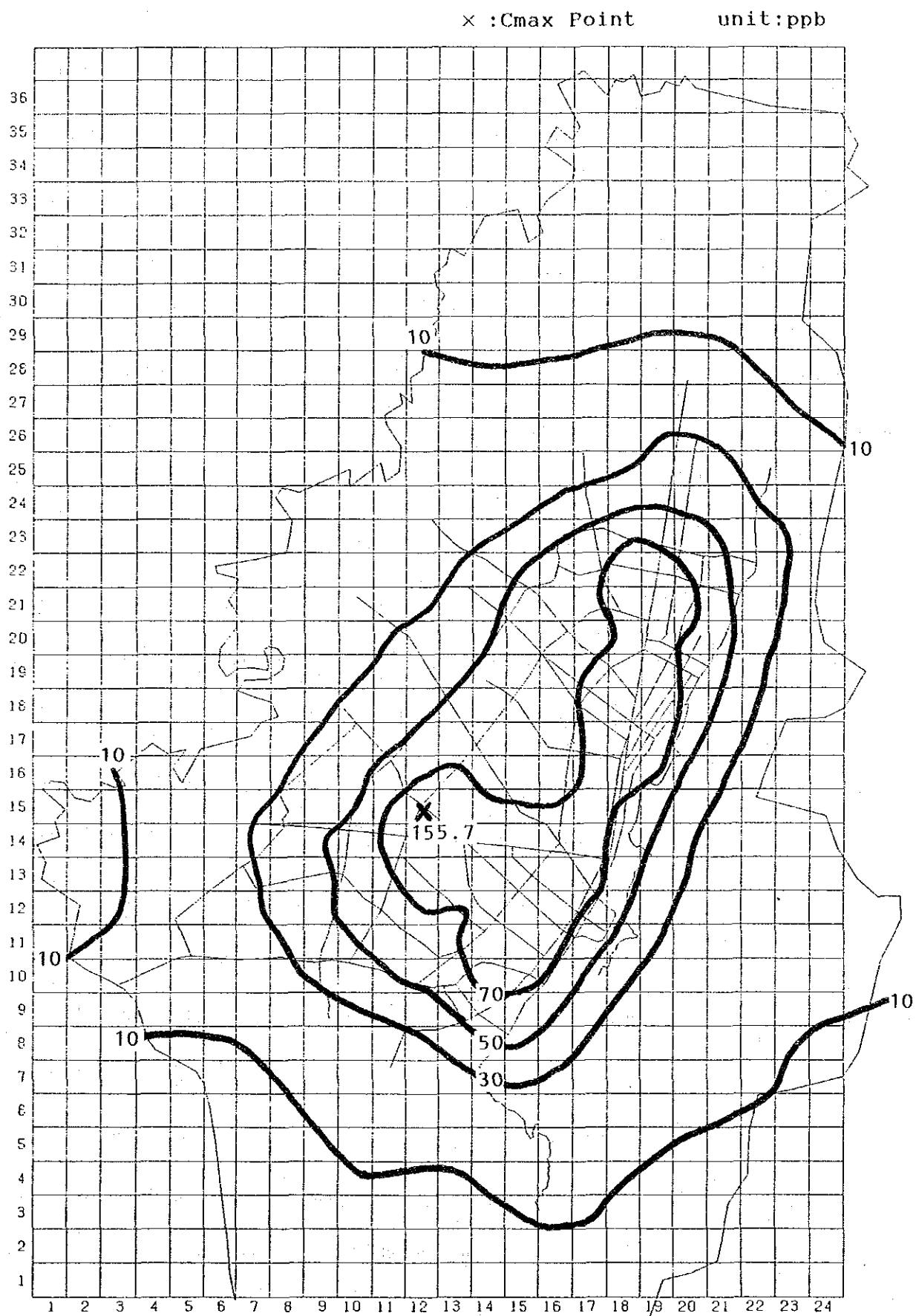
Fig. 4.1.8   Contribution of Automobiles to Annual
Average Concentration of NO$_x$ (Future)
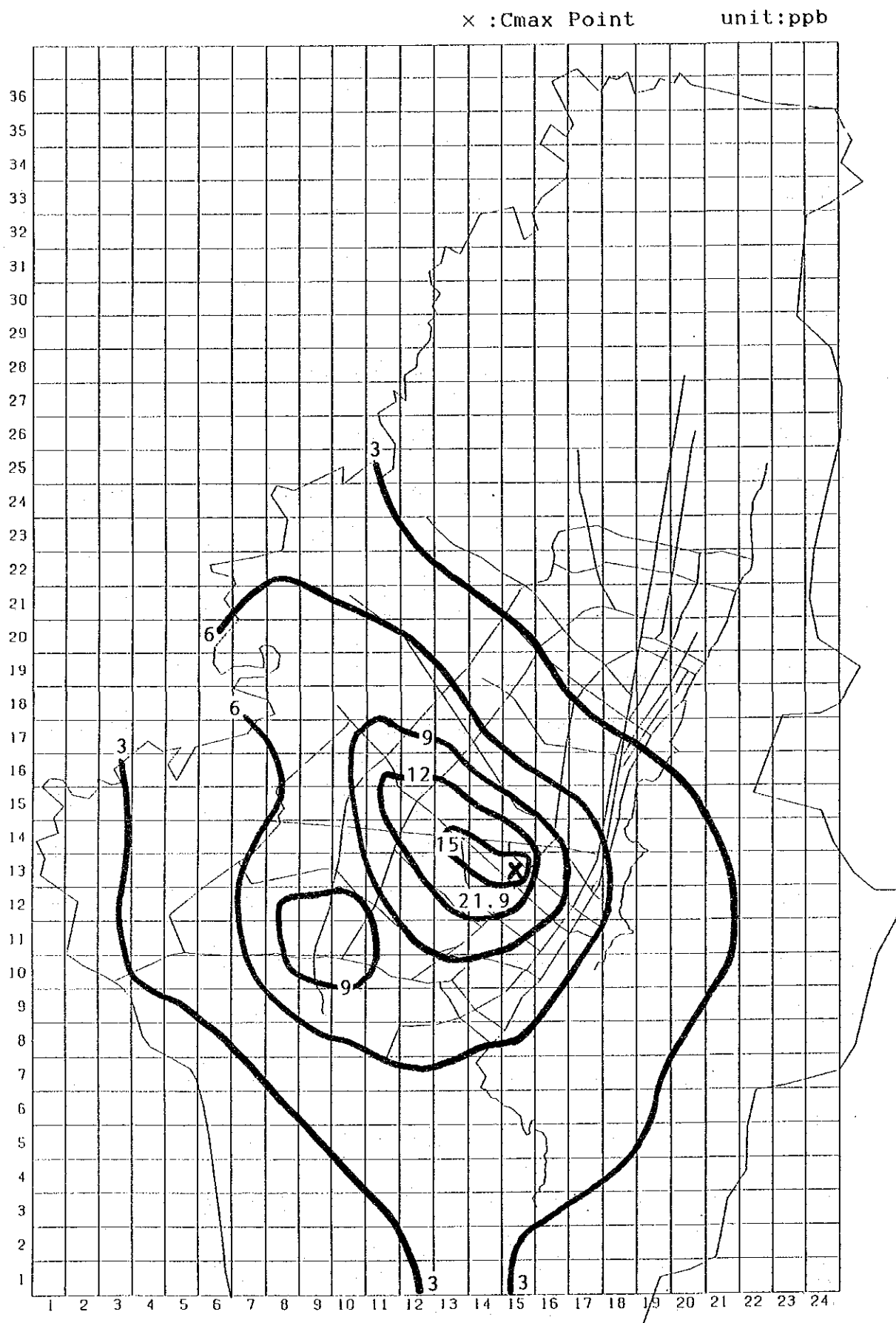
× :Cmax Point   unit:ppb

Fig. 4.1.9 Contribution of Factories to Annual
            Average Concentration of SO₂ (With Control Measures)

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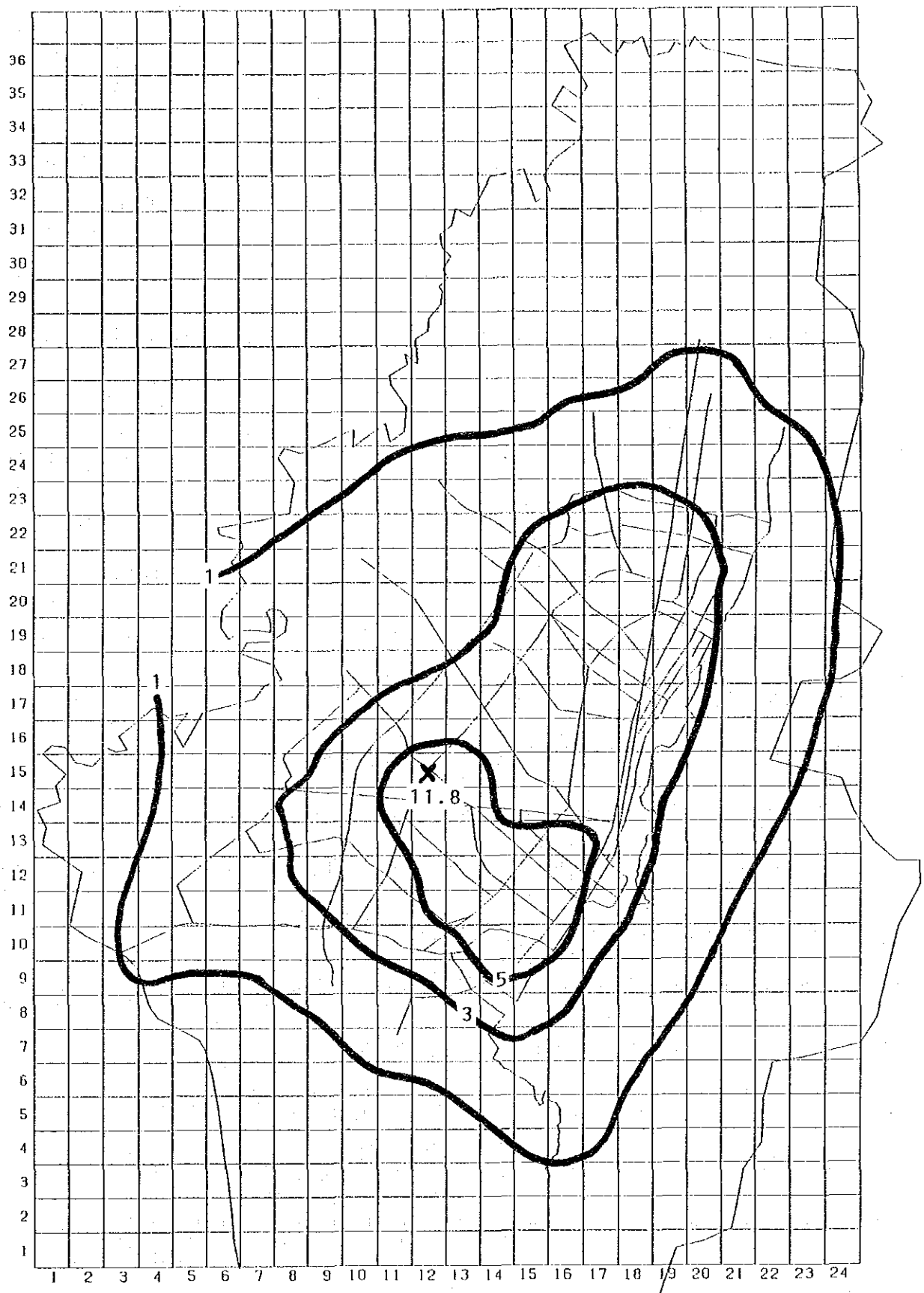
× :Cmax Point   unit:ppb

Fig. 4.1.10 Contribution of Automobiles to Annual
            Average Concentration of SO₂ (With Control Measures)

X :Cmax Point　　　　unit:ppb
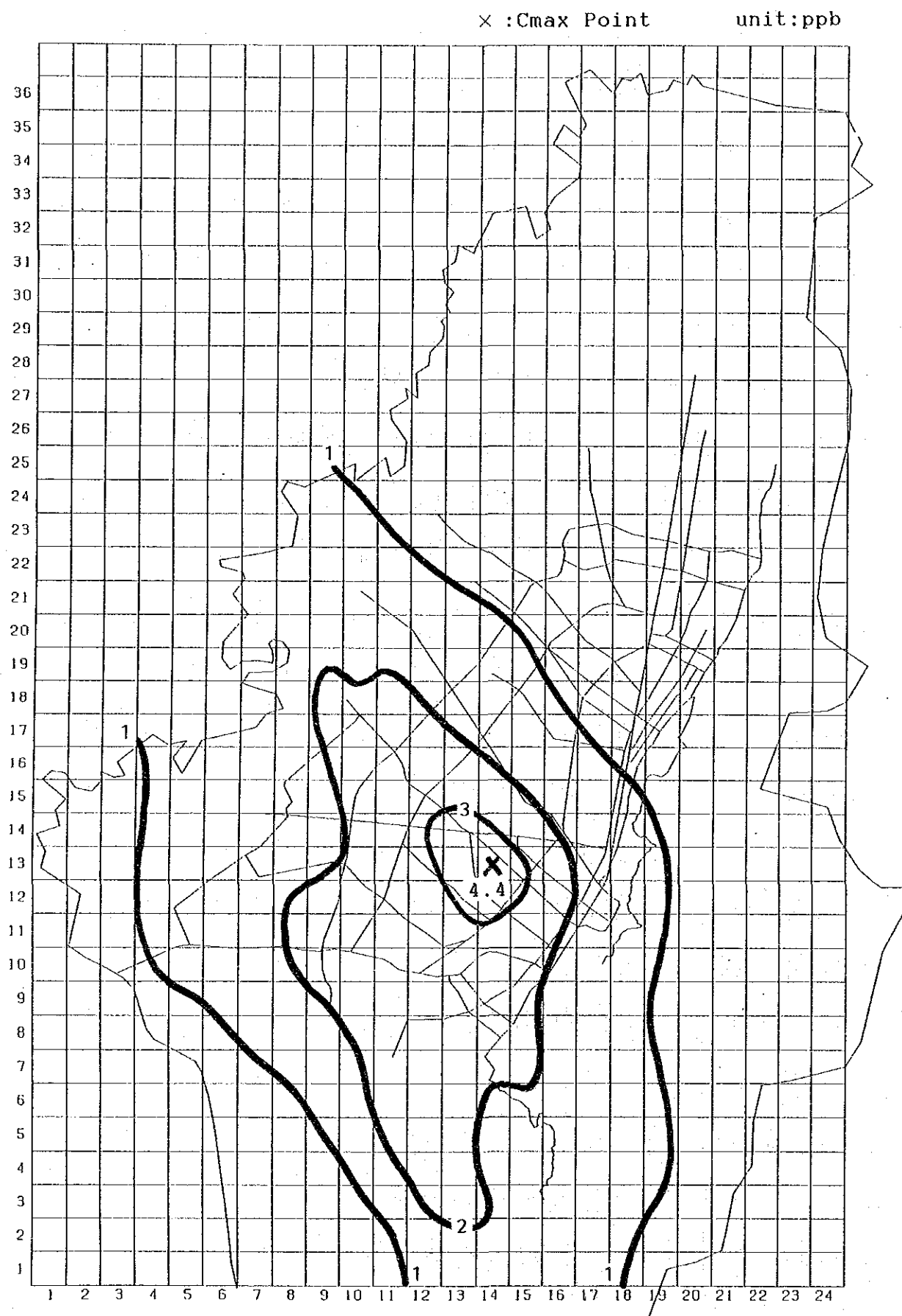
Fig. 4.1.11 Contribution of Factories to Annual
　　　　　Average Concentration of NO$_x$ (With Control Measures)

- 241 -
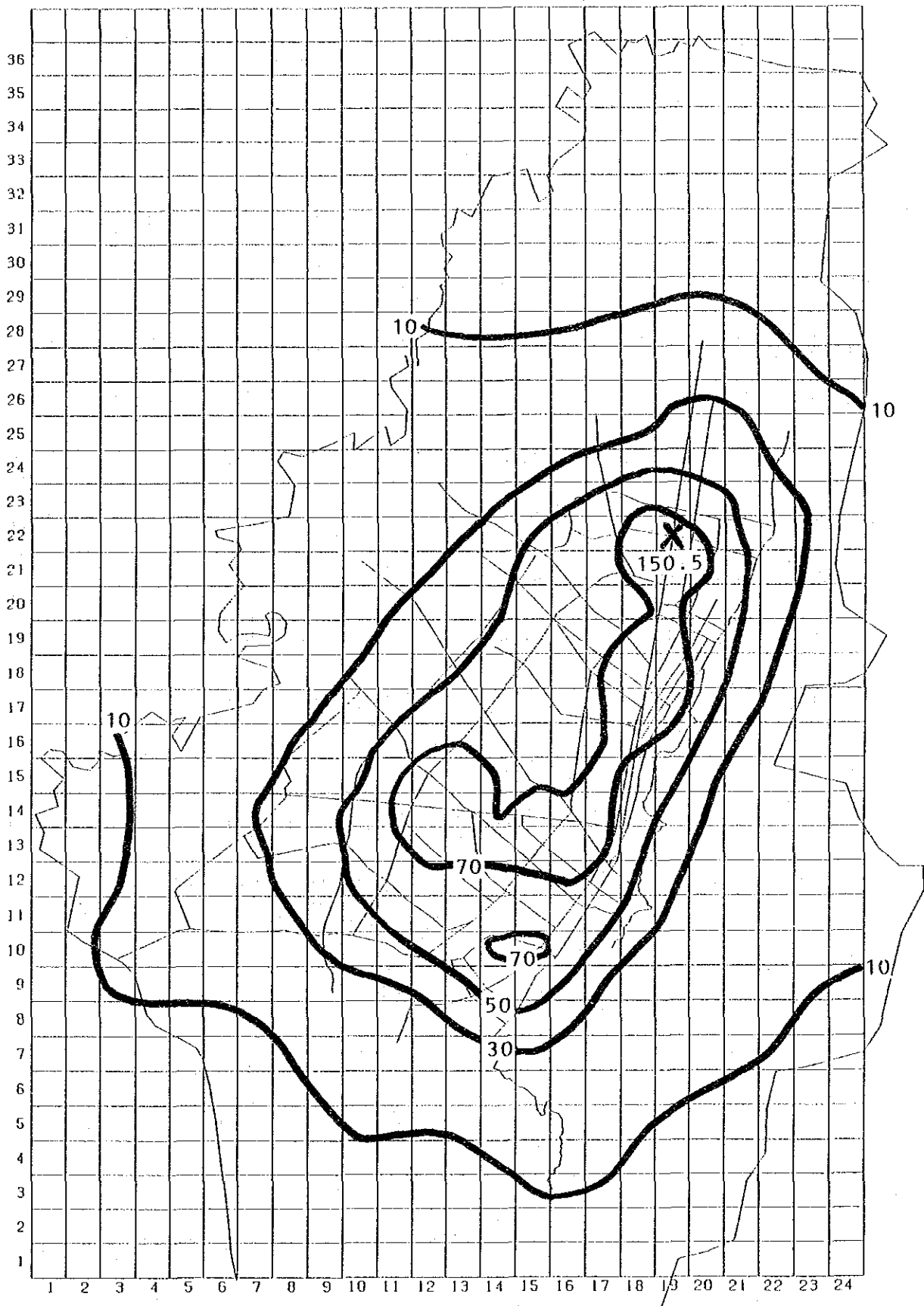
Fig. 4.1.12 Contribution of Automobiles to Annual
Average Concentration of NOx (With Control Measures)

4.2 Chemical Mass Balance Method for Analysis of SPM Sources

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)

α_{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.

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

PART 5 CONTROL MEASURES AGAINST POLLUTANT SOURCES

5. Control Measures against Pollutant Sources

5.1 Control Measures against Factories

5.1.1 Emission Standard in Future

Table 5.1.1   Emission Standard (Draft) in Future

1. Emission Standard for Boiler

Fuel	X	Dust				NOx				SOx				
		Current	Short-term	Medium- to short-term	O2	X	Short-term	Medium- to long-term	O2	Theoretical value	Short-term	Medium-term	Long-term	O2
	kg/10⁶kcal	kg/10⁶kcal	kg/10⁶kcal	kg/10⁶kcal	%	ppm	ppm	ppm	%	ppm	ppm	ppm	ppm	%
Mixed oil	1.14	(1.42)	1.18	0.60	4	240	500	250	4	1,340	1,250	1,200	1,060	4
A C P M	-	-	-	-	-	214	400	300	4	-	-	-	-	-
Carbon	0.77	1.68	1.39	0.97	6	213	420	350	6	353	330	320	280	6
Otros	-	(1.61)	1.34	0.84	6	-	400	300	4	1,340	1,250	1,200	1,060	4

X : Measured value
On : Oxygen concentration to be used as standard
( ) : Assumed value

2. Other Facilities

(1) The emission standard is set for brick/clay pipe kilns and asphalt plants only, and the standard value is to be same as for coal firing boilers.

(2) Emission Standard for NOx and SOx

Facilities	Fuel	NOx			SOx				
		Short-term	Medium- to long-term	O2	Theoretical value	Short-term	Medium-term	Long-term	O2
		ppm	ppm	%	ppm	ppm	ppm	ppm	%
Kilns for bricks and clay pipes	Carbon	450	350	16	118	110	100	90	16
Heating furnace	ACPM	280	200-	15	-	-	-	-	-
Asphalt plant	Crudo	250	230	16	395	370	360	310	16
Incinerator	ACPM	300	250	12	-	-	-	-	-
Direct heating furnace	ACPM	220	170	6	-	-	-	-	-

5.1.2 Control Technology

(1) Improvement of Combustion Method

Combustion control is to make reasonable selection of fuel, equipment and combustion method, which requires proper use of the right measuring instrument.

① Combustion with low excess air

Combustion with a certain degree of excess air will bring complete combustion, but causes (1) temperature drop, (2) increase in waste heat, and (3) increase in ventilation resistance. On the other hand, combustion with low excess air causes increase in the unburnt fuel. Therefore, there should be the optimum air ratio at which a total of waste heat and loss due to unburnt fuel will be minimum. But the optimum value varies depending on the combustion method, and the furnace internal temperature rises with growing boiler efficiency as the optimum value decreases. Generally speaking, combustion with low air ratio proves effective in reducing emission of Dust and NOx.

Combustion with low air ratio will be recommended also because it will bring substantial fuel saving as shown in Table 5.1.2.

Table 5.1.2 Fuel Saving by Correcting the Excess Air

(Unit: Saving percentage %)

Flue gas temperature (°C)	Excess gas before correction	Excess air 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
9800	1.40	5.94	11.27	26.0	20.2
	1.30		5.66	10.78	25.2
	1.20			5.29	120.1
	1.10				5.0
1,000	1.40	9.43	17.3	23.8	29.5
	1.30		8.67	15.9	22.3
	1.20			7.91	14.7
	1.10				7.36
1,300	1.40	15.7	27.2	25.9	42.7
	1.30		13.7	23.9	32.1
	1.20			11.9	21.3
	1.10				10.7

Note: Fuel used was heavy oil, Type 1, No.1.

The practically applicable air ratio was generally 1.2 ~ 1.4 for liquid fuel, 13 ~ 1.5 for coal stoker combustion, and 1.6 ~ 2.0 for coal hand firing.

② Optimization of calorific capacity of the combustion chamber

Excessively large heat generation per unit volume of the combustion chamber leads readily to generation of unburnt gas or dust. On the other hand, excessively small heat generation leads to abnormally high furnace internal temperature, which in turn causes adverse effect on the furnace wall and heat transmission surface, resulting in trouble during operation. Accordingly, this value must be kept at the optimum level.

The adequate value is $18 \sim 35 \times 10^4$ kcal/m^3·h for stoker combustion and $20 \sim 400 \times 10^4$ kcal/m^3·h for small heavy-oil combustion boilers.

The optimum excess air and calorific capacity of the combustion chamber are determined in general by the combustion unit and

combustion chamber. Actually, however, combustion control should be made while taking into account the substantial effect of the atomized particle size (oil drop included) and mixing with air, secondary/tertiary air supply method, etc.

③ Steam injection method

The steam injection method is intended to suppress NOx generation by increasing the heat capacity of combustion gas and decreasing the combustion gas temperature. What is suppressed is thermal NOx only, and the suppression effect is shown in Fig. 5.1.1.

Steam injection proves more effective as its position is nearer to the burner and the maximum, limit of steam injection rate is considered to be 0.5 kg/1,000 kcal. Note that this method suffers more or less degradation of the heat efficiency because the flue gas retaining heat increases.
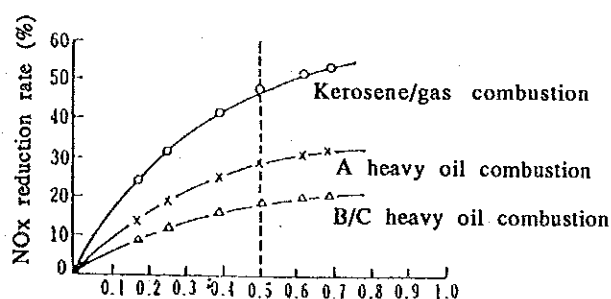
Note: a heavy oil and B/C oil corresponds to ACPM and fuel oil.

Fig. 5.1.1 Steam Injection Rate (kg) per 10,000 kcal of
Heat Quantity Generated by Fuel

④ Change of coal loading method

This is a technology applicable to hand firing of coals, which is intended to minimize pulsation due to intermittent coal feeding as much as possible, thereby enhancing utilization of the combustion air, preventing temperature drop in a furnace, and suppressing generation of dust.

Alternate, stripe, and dotted burning methods are available to achieve this purpose. Alternate burning is used mostly for small units while

stripe burning for units with large fire grate area such as an externally-fired horizontal fire tube boiler.

It is recommended to set the ventilation area for the fire grate surface at 20 ~ 50% and uniform coal grain size within a range from 25 ~ 10mm. The dust suppression effect is nearly proportional to the number of divided cal supply surfaces and is reported to achieve reduction by one half when this method was applied practically to a kiln.

⑤ Stoker combustion

The stoker combustion method is frequently used in medium-sized boilers. Spreader, underfeed, and movable fire grate types are available, and the underfeed stoker is suitable and actually applied in certain cases in Bogota.

The spreader stoker allows supply of lump coal and small coal separately and can have dust and NOx suppressed when equipped with steam injection. The underfeed stoker is applicable for units with relatively small capacity, with coal feed made by screw. Forced ventilation over the coal feed surface also helps achieving complete combustion. However, this type of stoker requires selection of proper coals because burning small coals results in increase in fly ashes and the use of caking coals causes increase in ventilation resistance and produces clinker when the ash melting temperature is low, presenting troubles during operation. If the combustion load is adequate with this type of stoker, the gas released through a stack will become nearly colorless.

(2) Combustion System

① Measuring instruments for combustion control"

Measuring instruments for combustion control include the fuel analyzer, gas analyzer, thermometer, flow meter, liquid level meter, pressure gauge, weighing instrument, soot densitometer, water quality gauge, and automatic controls.

Among instruments listed above, the gas analyzer, thermometer, and flow meter are not provided to the combustion system, but anyway required.

The gas analyzer is used to calculate the excess air and either an Orsat analyzer or O_2 meter is enough. Gas analysis need not be made at all time and is needed only when the fuel or combustion conditions are changed. In this sense, the Orsat analyzer is indispensable.

The thermometer is necessary when the preheating temperature of liquid fuels or radiation is to be controlled. A bar thermometer is enough for low temperature portions and a thermoelectric type indicator for high temperature portions.

The flow meter is used to know the fuel consumption or material balance, the steam generation rate, etc.

Flow meters for fuel and steam are indispensable instruments among those described above and a simple integrating meter will prove helpful.

The O_2 meter to be used should be of paramagnetic method.

② Low-NOx burner

NOx in the combustion flue gas contains NO and NO_2, but the NO_2 content is 10% or less and exists as a mixture of thermal NOx and fuel NOx, making respective identification impossible.

Factors to generate thermal NOx are (1) O_2 concentration in the combustion range, (2) combustion temperature, and (3) stay period in the high temperature range. Fuel NOx characteristics include (1) suppression at low excess air, (2) increase with growing N content in fuel, and (3) increase in generation as mixing of air and fuel is satisfactory.

The suppression method for NOx generation are described below.

① Reduction of O2 concentration in the combustion range: Low excess air combustion
Two-stage combustion off-stoichiometric combustion

② Decrease of flame temperature: Flue gas recirculation
Steam injection
Water spray

③ Decreasing the stay period at   Rapid mixing combustion
   high temperature: High speed injection low-NOx
                                        burner
④ Decrease in N content of the   Conversion to good quality fuel
   fuel:

Though various types of low-NOx burner are available, there are burners as listed below suitable for small and medium combustion units.

Table 5.1.3   Low-NOx Burner

Name of technology	Reason of suppress	Features	Problem factors	Application
Low-NOx burner				
① Promoted mixing, flame quenching type	Decreasing the stay period Lowering the flame temperature	Enhancement of efficiency of thermal unit	Applicable only to boilers	Boiler
② Split flame type	Decreasing the stay period Lowering the flame temperature	Enhancement of efficiency of thermal unit	Increase in Dust and CO	Boilers and industrial furnaces
③ Self-recirculation type	Lowering the flame temperature	Reduction in Dust	Difficult to turn down	Boilers and industrial furnaces
④ Two-stage combustion	Low O2, and lowering the flame temperature	Effective for suppression of fuel NOx NOx reduction possible by preheating the air	Increase in flame length Increase in dust and CO	Boilers, industrial furnaces, oil heating furnaces
⑤ Off-stoichiometric	Low O2, lowering the flame temperature	Effective for suppression of fuel NOx	Increase in flame length, increase in dust and CO	Boilers and industrial furnaces
⑥ Water or steam injection type	Low O2, lowering the flame temperature	Reduction in Dust	Degradation of thermal efficiency	Boilers and industrial furnaces

Control technologies	NOx reduction rate (%)
	0 10 20 30 40 50 60 70
Low NOx burner (LB)	LPG 18 42 58
	Kerosene 11 39 54
	A heavy oil 8 33 52
	B heavy oil 10 28 48
LSC	C heavy oil (1) 11 26 36
	C heavy oil (1) 24 32 44
	C heavy oil (2) 12 28 45
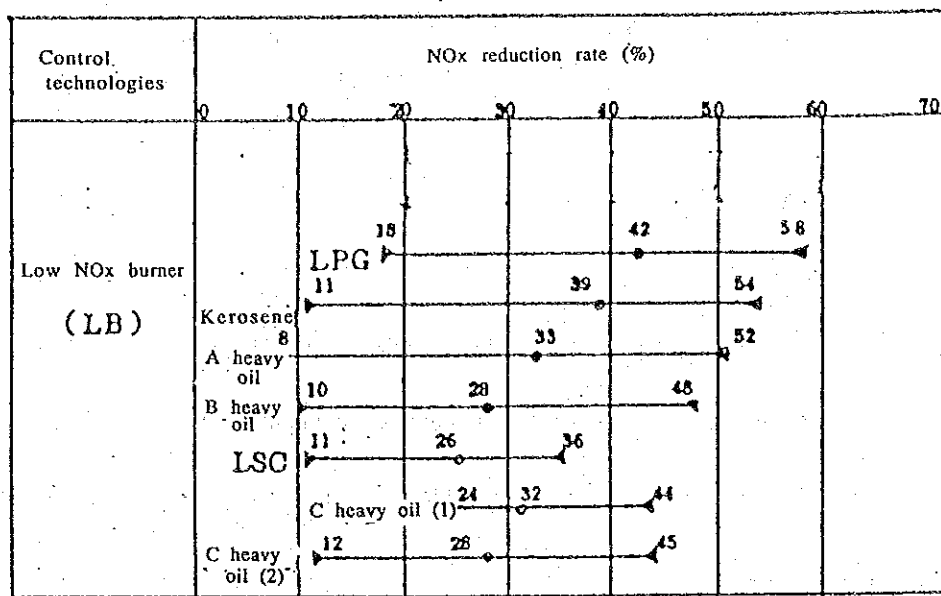
Fig. 5.1.2 NOx Reduction Rate in Existing Water Tube Boiler, Flue-fire Tube Boiler, Hot Water Boilers

The quality of heated material is of importance in the case of industrial furnaces the flame shape is desirable to be unchanged when the burner is changed.

Accordingly, the low NOx burner of a two-stage combustion is most suited.

③ Dust collector

The dust collector is available in types shown in Table 5.1.4. But the size of dust grains that can be collected with a dust collector is limited. Collection becomes easier as the grain size increases.

Table 5.1.4   Comparison of practical Performance among Dust Collectors

Classification	Type	Applicable grain size (m)	Pressure drop (mmAq)	Dust collection rate (%)	Equipment cost	Operation cost
Gravitational dust collector	Dust settling chamber	1,000!2-	10~15	4~~60	Minor	Minor
Inertial dust collector	Louver type	100~20	30~80	50~70	"	"
Centrifugal dust collector	Cyclone type	100~5	100~200	770~95	Medium	Medium
Scrubbing dust collector	Venturi scrubber	100~0.1	400~850	80~95	"	Major
Filter dust collector	Bag Filter	20~0.1	100~200	90~99	"	Medium or above
Electrostatic precipitator		20~0.05	10`20	80~99.9	Major	Small & medium

When fine particles of 1μn or less are to be collected, dust collectors other than a filter dust collector or electrostatic precipitator or a scrubbing dust collector cannot achieve satisfactory result.

Most of dust collectors currently installed in Santa Fe de Bogota City are independent cyclones which are less effective for fine particles with the dust collection efficiency estimated at around 50 ~ 60%. The Dust grain size produced from combustion is mostly very small ranging from about 40 ~ 50 μm. Accordingly, it will be necessary for increase in the dust collection efficiency to use either a multi-cyclone or filter dust collector.

Achievement of complete combustion should be the top priority aim, and application of the dust collectors should be considered when combustion control only has proved not sufficiently compatible.

④ Draft equipment

The principal draft currently used in Santa Fe de Bogota City includes forced draft and natural draft. Problems such as dust generation, etc. occur particularly frequently in facilities which burns coals under natural draft.

Generally, the coal combustion amount is related to the stack size such that the optimum coal combustion amount becomes about 23 kg/h for the stack height of 15m and stack inside diameter of 35cm and about 40 kg/h for the height of 20m and inside diameter of 40cm.

It may be necessary to use these values as the standard and to demand improvement for a facility which deviates excessively from this standard.

When a facility emits dust in extremely high concentration only for short period of time, the concentration on ground in the surrounding area should be calculated using a dispersion equation and improvement demanded if the result proves adverse effect on the health of people.

(3) Fuel Reforming

Factors responsible for production of dust from coal combustion are deficient air during heated decomposition of coal, drop of the furnace internal temperature due to cal feeding, and inadequate grain size.

Most of facilities in Santa Fe de Bogota City are using currently coals in large lumps as they were excavated. This causes remarkable smoke generation particularly from hand firing combustion systems.

The smoke generation amount can be reduced to about minimum 50% of the current level by using coals small and uniform in grain size within the capacity range of the draft equipment. The similar effect can be achieved also by mixing coals with low volatile content to those with high volatile content.

Among kilns, the continuous kilns are firing small-sized coals. But, because of large grain size, it takes long until coals are burnt completely, allowing unburnt coals to accumulate on bricks or kiln bottom and making effective utilization impossible in the present stage. These furnaces can achieve complete combustion by using fine coals, helping reduce the dust generation rate and fuel consumption.

Crude oil among liquid fuels has the sulfur content of about 2.3%, generating large quantity of SOx and its combustibility is poorer than other liquid fuels.

On the other hand, it is advantageous in inexpensive fuel cost. Because of adverse effect on people and the nature by SOx generated in large quantity, the use of low-sulfur fuel is recommended. But this can not be chosen freely in view of various restrictions inflicted.

The basic means of sulfur reduction of the fuel is to carry out desulfurization in a stage of refining, but this is difficult to achieve immediately due to various problems, such as new installation of a desulfurization system, adjustment of the supply amount, etc.

Under situations as above described, adjustment of a mixture of crude oil and light oil is a method which can reduce sulfur of the fuel. Though suffering from increase in the fuel price, this method offers advantages such as planned reduction of the sulfur content and almost no necessity of any additional equipment/

(4) Fuel Conversion

Generation of unburnt carbon (soot) is greatly affected by the nature of fuel and generally tends to occur quite readily with increasing C/H ratio of the fuel.

When fuels are burnt under same conditions, tar produces the largest amount of unburnt carbon, with the generation amount decreasing in the order of bituminous coal with high volatile content, heavy oil, and light quality oil.

Fig. 5.1.3 shows relationship between the NOx emission concentration and fuel for boilers.
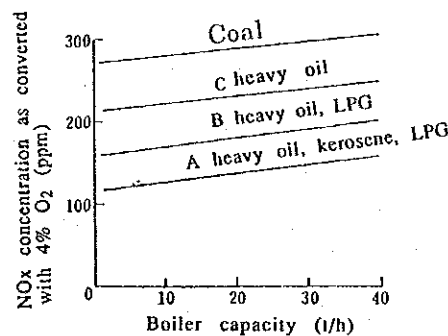

Fig. 5.1.3   NOx Emission Concentration vs Fuel for Boilers.

Conversion to the light quality oil or gas-fuel may prove effective for reduction of dust and NOx, but is difficult to apply practically in the present state except for special cases because of limited supply amount and cost increase of the fuel. This fuel conversion must be attempted for small boilers in small enterprises.

Though it is ideal for kilns to convert fuels to liquid fuel or natural gas. In view of the supply amount of natural gas to the southern zone of the city scheduled for completion in 1991, however, fuel conversion is impossible. It is expected that the supply amount will be increased in future.

(5) Energy Saving

The purpose of energy saving in enterprises is to (1) alleviate the energy supply burden from an aspect of demand and (2) increase in profit through energy saving. This also help reducing the generation of dust.

Another effective method apart from fuel saving through combustion with lean air is to prevent heat radiation from the heat utilizing facilities. The new boiler facility is of a heat insulation construction as a whole, but the old type boilers have the boiler body exposed, promoting radiation.

The radiation amount when the refractory wall is used is about 800 kcal/m^2·h for the furnace wall surface temperature of 100°C. The radiation amount becomes about 200 kcal/m^2·h, about 3/4 reduction, if the surface temperature is 50°C. Such reduction of radiation, however, requires the heat insulation work, and thus the work should be made with the economically feasible thickness.

As is evident from the above description, the bare boiler body need be provided by all means with heat insulation work. When coal firing boilers are operated in daytime only, lived coal or combustion with cokes to keep temperature during the down time up to the next morning will prevent pressure drop of the steam or shorten the restart time period. As a result, dust generation can be reduced along with energy saving.

(6) Coal Preparation Reforming Facility

Demand on coal from users vary widely not only in quantity, but also in quality.

To meet these demands as well as to control dust generation or to save energy, installation of a coal adjusting facility with coal collection, crushing, screening, and storage functions is necessary.

The capacity required for the adjusting equipment will be enough if it is 2 to 2.5 times the coal consumption (i.e., about 15 x 10^3 t/month) of Santa Fe

de Bogota City. The location should be within an area where the demand is high and should be equipped with the dust preventing measures.

(7) Raising the Stack Height

Raising the stack height is effective in reducing the concentration on ground by its diluting SOx, NOx, and dust concentration using the scattering effect of exhaust gas.

Scattering of pollutants by stack varies depending on the stack height, exhaust gas release speed, temperature, and mass and is affected by meteorological and topographical conditions. It is therefore impossible to indicate the concentration decreasing rate by a certain numerical figure. Any accurate numerical figures should be determined by calculation using dispersion equation. In any case, the stack height, gas release rate, and gas temperature are factors most decisive for the scattering effect.

In this respect, raising the stack height has been made as an elementary means to prevent pollution. But, this raising of the stack height is in a sense difficult to execute because of limited site available, difficulty of the work, and stack material.

The stack construction cost is advantageous in respect of inexpensiveness more than the exhaust gas treatment system and less cost of operation.

5.1.3 Outline of Coal Adjusting Facility

1. Raw coal storage amount: 15,000 t/M

2. Product production rate:

(1)	25 ~ 15 mm	19 t/h
(2)	15 ~ 5 mm	19 t/h
(3)	5 ~ 1 mm	19 t/h
(4)	1 mm or less	76 t/h

3. Crushing equipment:

(1)	Hammer mill	1 unit
(2)	Screening unit	4 units
(3)	Dust collector (bag filter)	1 unit
(4)	Transport units	(dump truck x 2, bulldozer x 1, shovel loader x 1, belt conveyor x 1)

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(5) Loader for coal storage yard   1 set

4. Product storage banker   4 units

5. Water storage tank
for treatment of washing water   1 set

6. Fly dust preventive equipment
(sprinkler)   1 set

7. Required land area

(1)	Coal storage yard	1,800 m^2
(2)	Crushing plant	600 "
(3)	Work yard	200 "
(4)	Administration	100 "
(5)	Water storage tank	25 "
(6)	Mechanized warehouse	200 "
	Total	19,125 m^2

5.1.4 Price List for Calculation of Control Costs

1. Measuring instrument for combustion control

(1)	Flow meter		2.66 x 10^6 $
	① Fuel	1,301,000 $	
	② Water supply to boiler	1,360,000 $	
(2)	Thermometer (0 ~ 1,100°C)		0.26 x 10^6 $
(3)	Gas analyzer		0.92 x 10^6 $
	① Orsat	510,000 $	
	② O$_2$ meter	411,000 $	
	Total		3.84 x 10^6 $

2. Stoker
   (1) Hopper and Bin feed stoker
   Made by Will-Burt, the USA
   Feed rate: 200 kg/h   4.00 x 10^6 $
   (2) Blower/coal feeder separated (domestic)
   Feed rate: 1,800 kg/h   2.00 x 10^6 $

3. Fuel conversion burner

(1) For heavy oil/light oil

① Combustion rate

50 l/h (13.2 gal/h)

a. Equipment cost		6.27×10^6 $
1) Burner	383.000 $	
2) Blower	4,498,000 $	
3) Oil pump	90,000 $	
4) Flow meter	1,301,000 $	
b. Construction cost		4.38×10^6 $
Total		10.65×10^6 $

② Combustion rate

270 l/h (71.38 gal/h)

a. Equipment cost		8.92×10^6 $
1) Burner	1,931,000 $	
2) Blower	5,600,000 $	
3) Oil pump	90,000 $	
4) Flow meter	1.301,000 $	
b. Construction cost		6.25×10^6 $
Total		15.17×10^6 $

③ Combustion rate

500 l/h (132 gal/h)

a. Equipment cost		12.03×10^6 $
1) Burner	5,040,000 $	
2) Blower	5,600,000 $	
3) Oil pump	90,000 $	
4) Flow meter	1,301,000 $	
b. Construction cost		8.42×10^6 $
Total		20.45×10^6 $

(2) For gas

5×10^4 Kcal/h

a. Equipment cost		5.05×10^6 $
1) Burner	448,000 $	
2) Blower	448,000 $	
3) Gas meter	126,000 $	

b. Construction cost   3.54 x 10^6 $

   Total   8.59 x 10^6 $

②   Combustion rate
   12 x x 10^4 Kcal/h
  a. Equipment cost   5.39 x 10^6 $
   1) Burner   784,000 $
   2) Blower   4,480,000 $
   3) Oil pump   126,000 $
  b. Construction cost   3.77 x 10^6 $

   Total   9.16 x 10^6 $

③   Combustion rate
   25 x x 10^4 Kcal/h
  a. Equipment cost   6.40 x 10^6 $
   1) Burner   1,792,000 $
   2) Blower   4,480,000 $
   3) Oil pump   126,000 $
  b. Construction cost   4.48 x 10^6 $

   Total   10.88 x 10^6 $

4.   Low NOx burner (for heavy oil)
(1)   Combustion rate
   150 l/h (40 gal/h)
  ①   Main body price   4.22 x 10^6$
  ②   Labor cost   2.11 x 10^6 $
  ③   Various expenses   2.22 x 10^6 $
  ④   Overseas price (1.64)   5.47 x 10^6 $

   Total   14.02 x 10^6 $

(2)   Combustion rate
   250 l/h (66 gal/h)
  ①   Main body price   4.58 x 10^6 $
  ②   Labor cost   2.29 x 10^6 $
  ③   Various expenses   2.40 x 10^6 $
  ④   Overseas price (1.64)   5.93 x 10^6 $

   Total   15.20 x 10^6 $

(3) Combustion rate

540 l/h (143 gal/h)

①	Main body price	7.24×10^6 $
②	Labor cost	3.62×10^6 $
③	Various expenses	3.80×10^6 $
④	Overseas price (1.64)	9.39×10^6 $
	Total	24.05×10^6 $

5. Dust collector

(1) Cyclone

① 900 ~ 1,380 m³/h

1)	Main body price	1,120,000 $
2)	Construction cost	784,000 $
	Total	1.90×10^6 $

② 2,000 ~ 3,000 m³/h

1)	Main body price	1,344,000 $
2)	Construction cost	941,000 $
	Total	2.29×10^6 $

(2) Multi-cyclone

① 3,000 m³/h

1)	Main body price	2,240,000 $
2)	Construction cost	1,568,000 $
	Total	3.81×10^6 $

② 6,000 m³/h

1)	Main body price	5,600,000 $
2)	Construction cost	3,920,000 $
	Total	9.52×10^6 $

(3) Bag filter

① 1,200 m³/h

1)	Main body price	2,464,000 $
2)	Construction cost	1,725,000 $
	Total	4.19×10^6 $

③   3,300 m³/h

    1) Main body price   5,040,000 $

    2) Construction cost   3,528,000 $

      Total 8.57×10^6 $

④   6,000 m³/h

    1) Main body price   10,080,000 $

    2) Construction cost   7,056,000 $

      Total 17.14×10^6 $

6. Stack

(1) Height 30m, made from SS

  ① Main body price   289,000 $

  ② Construction cost   202,000 $

      Total 0.49×10^6 $

7. Coal adjusting facility

  ① Coal adjusting equipment cost

    (1) Mechanical 315.87×10^6 $

        ① Crusher   36,772,000 $

        ② Screening unit   86,669,000 $

        ③ Transporting and

            loading machines   152,660,000 $

        ④ Dust collector   38,080,000 $

        ⑤ Fly dust preventive

            equipment   1,689,000 $

    (2) Product storage bank 59.43×10^6 $

    (3) Attachments 2.84×10^6 $

    A set of water storage tank

    (4) Buildings 52.27×10^6 $

        ① Administration building   600,000 $

        ② Crushing machine yard 31,420,000 $

        ③ Mechanized warehouse 20,250,000 $

    (5) Wiring equipment 6.18×10^6 $

      Total 436.59×10^6 $

Note) The required land area is 38,000 m2 and the land cost not included.

② Product price

1) A set of equipment cost 437×10^6 $

2) Production   daily production

19 t/h x 4 kinds = 608 t/d

608 t/h x 250d = 152,000 t/Y

3) Raw coal

$15,000$ t/M x 12 = 180,000 t/Y

$180,000 \times 170,000$$/t = $3,060 \times 10^6$ $

4) Electricity charges

$1,120$KWh x 250d x 43.73$/KWh

$= 12 \times 10^6$ $

5) City water charges

20m3 x 250d x 153.85%/m3

$= 0.77 \times 10^6$ $

Fixed rate $5,823$$/M x 12 $= 0.07$ $/Y

Total 0.8 $/Y

6) Personnel expenses

Four in office, six for construction work, and two for maintenance, totaling 12

$200,000$$/M x 12 p x 12M = 28.8×10^6 $/Y

7) Depreciation (durable years, 20 years; return of fixed amount)   1) x 1/20 = 21.85×10^6 $

8) Interest (4%)   1) x 0.04 x 17×10^6 $/Y

9) Maintenance equipment and materials (2%)

1) x 0.02 = 7×10^6 $/Y

10) annual expenses

③ $3,060 \times 10^6$ $

④ 12 x x 10^6 $

⑤ 1×10^6 $

⑥ 29×10^6 $

⑦ 22×10^6 $

⑧ 17×10^6 $

⑨ 7×10^6 $

Total $3,148 \times 10^6$ $

11) Product unit price

10) / 2) = 3,148,000,000$/152,000t = 20,700 $/t

12) Coal price rise rate

20,700/17,000 = 1.22   22% increase

(8) ① Coal firing
  1) Boiler capacity   10 t/h (640 HP)
  2) Main body price (FOB)   2,423.56 x 10^6 \$
  3) Transport cost,
     installation cost, insurance   211.11 x 10^6 \$
              Total   2,634.67 x 10^6 \$
  4) Utilities
     i) Coal   1.1 t/h
     ii) Electricity   200 kw/h
     iii) Air   70 m^3/h

② Heavy oil combustion
  1) Boiler capacity 10 t/h (640 HP)
  2) Main body price (FOB)   484.71 x 10^6 \$
  3) Transport cost,   211.11 x 10^6 \$
     installation cost, insurance

              Total   695.82 x 10^6 \$

(9) Heat insulating Work

The work cost for each facility was calculated using the unit price shown below.

For wall surface temperature at 200°C: 14,740 \$/m^2
                          ① Material: glass fiber
                          ② Thickness: 5 cm

For wall surface temperature at 500°C: 25,780 \$/m^2
                          ① Material: Kawool 1600
                          ② Thickness: 5 cm

For wall surface temperature at 700 ~ 1,200°C: 57,150 \$/m^2
                          ① Material: Seramica 2300
                          ② Thickness: Kawool 1600 3 cm,
                                            Seramica 3 cm

Note)   Finishing made with fixed wire and Aluminium plate cover.

① Cornish boiler
   Boiler capacity   2 t/h   Work area: 6.21m^2 Surface temperature
                                            200°C
                                            6.21 x 14,740 = 91,535 \$

② Lancashire boiler

Boiler capacity 3 t/h   Work area: 20m^2 Surface temperature 200°C

20 x 14,740 = 294,800 $

③ Externally-fired fire tube boiler

Boiler capacity 4 t/h   Work area: 10.5m^2 Surface temperature 200°C

10.5 x 14,740 = 154,770 $

④ Kewanee boiler   4 t/h   Work area: 15.4m^2 Surface temperature 200°C

15.4 x 14,740 = 226,996 $

⑤ Vertical boiler

Boiler capacity 1 t/h   Work area: 6.3m^2 Surface temperature 200°C

6.3 x 14,740 = 92,862 $

⑥ Heating furnace

1) 500°C   @ 25,780 $/m^2
2) 700~1,200°C   @ 57,150 $/m^2
                    @ : construction unit price