

5.2.3 Air Pollutant Emission Factors

(1) Classification of Roads

In calculating air pollutant concentrations due to motor vehicles by dispersion simulation, main roads, namely roads with heavy traffics, hence emits much pollutants, are treated as unique sources (line sources) and narrower roads with less heavy traffics, hence do not emit so much pollutants are grouped into area sources. The main roads are shown in Fig.5.2.4.

(2) Classification of Motor Vehicles

Motor vehicles were classified into 3 groups, namely, automobiles, buses and camiones shown in Table 5.2.2. As to fuels used, automobiles and small buses use gasoline, buses and trucks use both gasoline and light oil (diesel oil).

Table 5.2.2 Classification of Motor Vehicles

Vehicle Type			Fuel
Automobiles	Passenger car	4-cylinder	Gasoline
		6- and 8-cylinder	
	Jeep	- 3,000 cc	
		3,001 cc -	
	Light truck	- 3,000 cc	
		3,001 cc -	
Microbus	- 3,000 cc		
	3,001 cc -		
Buses	Small bus	Gasoline	
	Bus	Gasoline	
		Diesel	
Trucks	Truck	- 8,000 cc	Gasoline
	Dump truck	- - - - -	
	Trailer	8,001 cc -	Diesel

Source: #5051,5052

(3) Classification of Roads by Average Driving Speed

In general, pollutant emission rates from motor vehicles are closely related to their average driving speed. This time the study area was divided into 2 zones: central zone with heavy traffics and surrounding zone with rather less traffics. In Fig. 5.2.4 the central zone is the area inside of the thick-line roads.

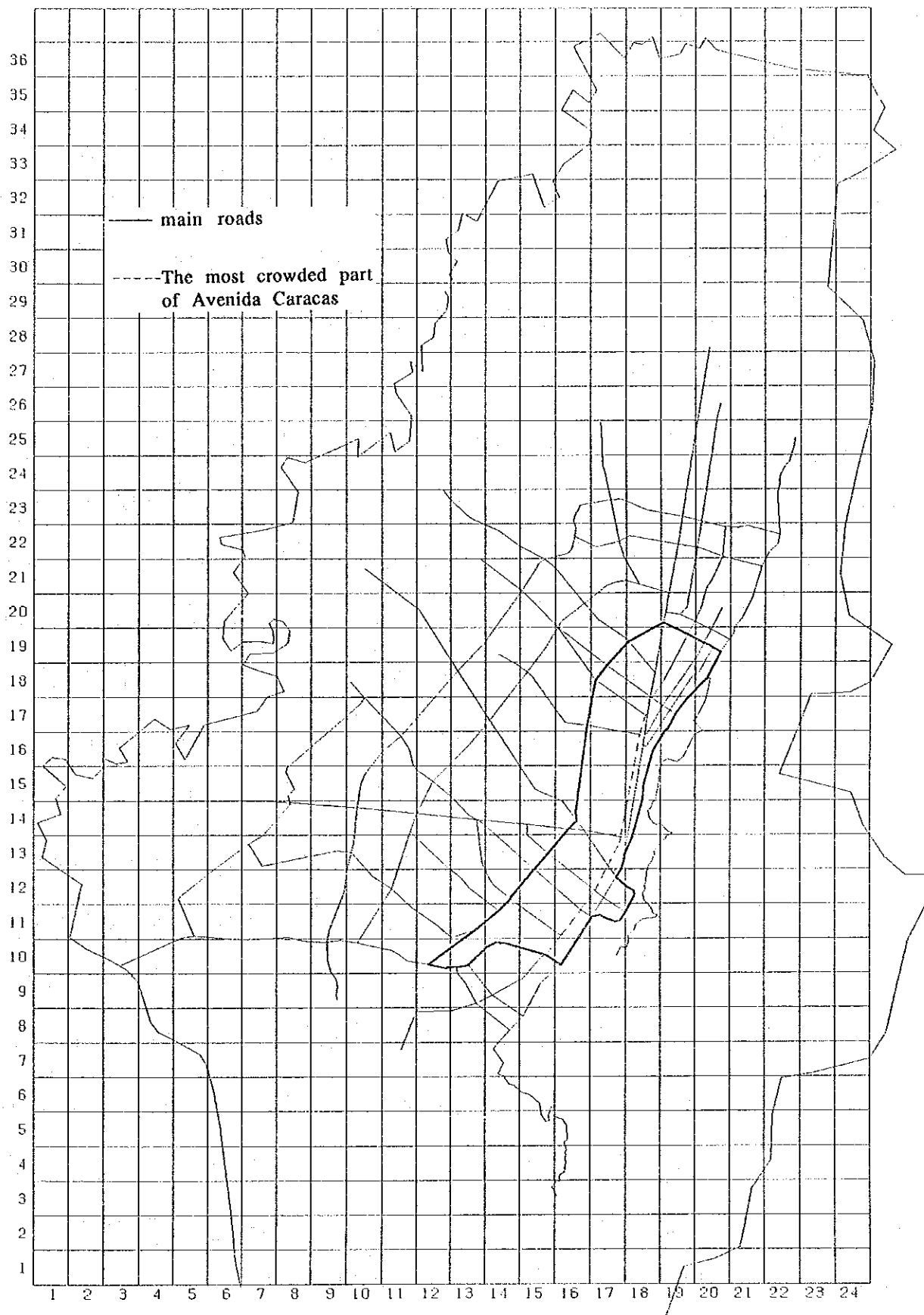


Fig. 5.2.4 Main Roads in the Study Area

Weekly and hourly average driving speed patterns of main roads and narrower roads in the 2 zones were set for automobiles, buses and trucks based on the driving conditions survey. Weekly patterns include weekday, Saturday and Sunday patterns. The driving speed patterns are shown in Table 5.2.3 and Table 5.2.4.

Table 5.2.3 Driving Mode of the Main Roads (Average Speed)

(1) Weekday

(Unit: km/h)

Zone	Vehicle Type	Time Zone				
		07-09	09-16	16-18	18-20	20-07
Central Zone	Automobiles	20(15)	30(25)	20(15)	30(25)	30(25)
	Buses	10	15	10	20	30
	Trucks	20(15)	30(25)	20(15)	30(25)	30(25)
Surrounding Zone	Automobiles	25	30	30	25	30
	Buses	20	25	20	25	30
	Trucks	25	30	30	25	30

Note The values in the parenthesis are those applied to Avenida Caracas (the dotted road in Fig.5.2.4).

(2) Saturday and Sunday (Holiday)

(Unit: km/h)

Zone	Vehicle Type	Time Zone			
		07-09	09-16	16-18	18-07
Central Zone	Automobiles	30	40(45)	30	40(45)
	Buses	20	30(40)	20	40(45)
	Trucks	30	40(45)	30	40(45)
Surrounding Zone	Automobiles	45(50)			
	Buses				
	Trucks				

Note The values in the parenthesis are the values for Sunday. In cases where the values on Saturday and Sunday are same they were omitted.

Table 5.2.4 Driving Mode of the Narrower Roads (Average Speed)

(1) Weekday

(Unit:km/h)

Zone	Vehicle Type	Time Zone				
		07-09	09-16	16-18	18-20	20-07
Central Zone	Automobiles	20	30	20	30	30
	Buses	10	15	10	20	30
	Trucks	20	30	20	30	30
Surrounding Zone	Automobiles	25	30	30	25	30
	Buses	20	25	20	25	30
	Trucks	25	30	30	25	30

(2) Saturday and Sunday (Holiday)

(Unit:km/h)

Zone	Vehicle Type	Time Zone			
		07-09	09-16	16-18	18-07
Central Zone	Automobiles	20(25)	25(30)	20(25)	30(35)
	Buses	10(15)	15(20)	10(15)	30(35)
	Trucks	20(25)	25(30)	20(25)	30(35)
Surrounding Zone	Automobiles	30(35)			
	Buses				
	Trucks				

Note The values in the parenthesis are the values for Sunday.

(4) Emission Factors

Emission factors for HC, CO, SO_x and NO_x (as NO₂) were set based on existing data in the U.S., Mexico and Japan. The emission factors for motor vehicles by vehicle type are shown in Table 5.2.5. Using the fraction of automobiles and buses (Table 5.2.6) average emission rates for automobiles, buses and trucks (Table 5.2.7) were calculated.

Table 5.2.5 Emission Rates for Motor Vehicles

(Unit: g/km)

Vehicle	Item	Average Speed(km/h)								
		10	15	20	25	30	35	40	45	50
Passenger car	HC	6.13	4.30	3.40	2.90	2.58	2.35	2.18	2.03	1.88
	CO	63.59	49.36	40.18	35.44	32.27	30.06	28.16	25.94	24.36
	NOx	1.21	1.07	1.01	1.02	1.08	1.15	1.25	1.34	1.42
	SOx	0.12	0.12	0.12	0.11	0.11	0.10	0.09	0.09	0.08
Jeep	HC	7.88	5.53	4.38	3.73	3.31	3.02	2.80	2.61	2.41
	CO	76.59	55.46	45.15	39.81	36.26	33.77	31.64	29.15	27.37
	NOx	1.25	1.10	1.05	1.06	1.11	1.19	1.29	1.38	1.46
	SOx	0.14	0.13	0.13	0.12	0.12	0.11	0.10	0.09	0.08
Light truck	HC	8.65	6.06	4.79	4.08	3.61	3.29	3.04	2.82	2.61
	CO	102.61	73.70	59.85	52.68	47.99	44.58	41.64	38.25	35.88
	NOx	1.52	1.34	1.28	1.30	1.37	1.47	1.60	1.71	1.81
	SOx	0.21	0.20	0.19	0.18	0.17	0.16	0.15	0.14	0.13
Microbus	HC	7.73	5.43	4.29	3.66	3.25	2.97	2.74	2.56	2.37
	CO	71.08	51.34	41.79	36.86	33.57	31.26	29.29	26.98	25.34
	NOx	1.22	1.08	1.02	1.03	1.09	1.17	1.27	1.35	1.43
	SOx	0.12	0.12	0.12	0.11	0.11	0.10	0.09	0.09	0.08
Small bus	HC	14.66	10.22	8.06	6.83	6.02	5.49	5.02	4.61	4.26
	CO	168.32	119.17	96.08	84.16	76.71	70.76	65.54	60.33	55.86
	NOx	2.09	1.87	1.81	1.87	1.99	2.15	2.33	2.50	2.66
	SOx	0.37	0.31	0.28	0.26	0.25	0.24	0.23	0.23	0.22
Buse	HC	19.60	15.26	12.08	9.71	7.93	6.62	5.57	4.74	4.17
	CO	379.14	294.68	233.48	189.74	157.64	132.87	115.35	102.19	91.97
	NOx	6.29	5.90	5.57	5.35	5.19	5.08	4.98	4.99	5.00
	SOx	1.40	1.18	1.07	1.01	0.96	0.93	0.91	0.89	0.88
Trucks	HC	18.98	14.83	11.79	9.51	7.79	6.53	5.52	4.70	4.16
	CO	356.21	276.90	219.42	*178.32	148.16	124.90	108.43	96.05	86.44
	NOx	7.44	6.91	6.47	6.16	5.92	5.76	5.62	5.61	5.59
	SOx	1.62	1.38	1.25	1.18	1.13	1.09	1.07	1.05	1.03

Table 5.2.6 Fraction of Automobiles and Buses

Vehicle Type		Ratio
Automobiles	Passenger car	0.717
	Jeep	0.119
	Light truck	0.159
	Microbus	0.005
Buses	Bus	0.626
	Small bus	0.374

Source: #6022

Table 5.2.7 Average Emission Rates for Motor Vehicles

(Unit: g/km)

Vehicle	Item	Average Speed(km/h)								
		10	15	20	25	30	35	40	45	50
Automobiles	HC	6.75	4.73	3.74	3.19	2.83	2.58	2.39	2.23	2.06
	CO	71.38	53.97	43.91	38.71	35.25	32.82	30.72	28.28	26.55
	NO _x	1.26	1.12	1.06	1.07	1.13	1.21	1.31	1.40	1.49
	SO _x	0.14	0.13	0.13	0.12	0.12	0.11	0.10	0.10	0.09
Buses	HC	17.75	13.38	10.58	8.63	7.22	6.20	5.36	4.69	4.20
	CO	300.29	229.04	182.09	150.25	127.37	109.64	96.72	86.53	78.46
	NO _x	4.72	4.39	4.16	4.05	3.99	3.98	3.99	4.06	4.12
	SO _x	0.68	0.59	0.53	0.50	0.48	0.47	0.46	0.45	0.45
Trucks	HC	18.98	14.83	11.79	9.51	7.79	6.53	5.52	4.70	4.16
	CO	356.20	276.90	219.42	178.32	148.16	124.90	108.43	96.05	86.44
	NO _x	7.44	6.91	6.47	6.16	5.92	5.76	5.62	5.61	5.59
	SO _x	1.12	0.97	0.89	0.84	0.81	0.79	0.78	0.76	0.75

5.2.4 Quantity of Air Pollutant Emission

Based on the traffic volume and emission factors, driving kilos and quantity of air pollutant emissions were estimated.

(1) Driving Kilos by Vehicle Type

The annual driving kilos by vehicle type and zone type are shown in Table 5.2.8. The total annual volume of driving is $5,191 \times 10^6$ km and that of automobiles accounted for $4,285 \times 10^6$ km (82.5%). The annual driving kilos by road type is shown in Table 5.2.9. In this table line source means main roads and area source means narrower roads.

Table 5.2.8 Annual air Pollutant Emission from Motor Vehicles by Vehicle and Zone Type

Vehicle type	Zone	Vehicle Kilos Traveled	HC	CO	SOx	NOx
Automobiles	Central zone	1,153	3,423	42,947	138	1,335
	Surrounding zone	3,121	8,616	107,199	358	3,704
	Small total	4,285	12,039	149,237	496	5,039
Buses	Central zone	183	2,184	37,170	150	785
	Surrounding zone	458	3,617	63,373	325	1,859
	Small total	641	5,781	100,543	475	2,644
Trucks	Central zone	38	319	6,055	44	228
	Surrounding zone	227	1,706	32,536	254	1,339
	Small total	265	2,025	38,651	298	1,567
Grand total		5,191	19,845	288,433	1,269	9,250

Unit V.K.T: 10^6 unit·km/year

HC, CO, NOx, SOx: ton/year

Table 5.2.9 Annual Air Pollutant Emission from Motor Vehicles by Road and Zone Type

Source	Zone	Vehicle Kilos Traveled	HC	CO	SOx	NOx
Line	Central zone	1,280	3,448	78,566	308	2,175
	Surrounding zone	3,132	11,181	161,945	743	5,587
	Small total	4,412	16,629	240,511	1,049	7,762
Area	Central zone	99	458	6,706	28	173
	Surrounding zone	680	2,758	41,216	194	1,315
	Small total	779	3,216	47,922	220	1,488
Grand total		5,191	19,845	288,433	1,269	9,250

Unit V.K.T: 10^6 unit·km/year

HC, CO, SOx, NOx: ton/year

(2) Fuel Consumption by Vehicle Type

The annual fuel consumption by vehicle type and zone type is shown in Table 5.2.10. The total annual consumptions of gasoline and light oil were 634.5×10^3 k/ and 55.6×10^3 k/ respectively.

Table 5.2.10 Annual Fuel Consumption by Motor Vehicle type

(Unit: 10^3 k/year)

Type	Zone	Gasoline	ACPM
Automobiles	Central zone	124.6	
	Surrounding zone	288.0	
	Small total	412.6	
Buses	Central zone	58.0	10.9
	Surrounding zone	103.1	20.4
	Small total	161.1	31.3
Trucks	Central zone	10.4	4.1
	Surrounding zone	50.4	20.2
	Small total	60.8	24.3
Total		634.5	55.6

(3) Quantity of Air Pollutant Emission

The annual pollutant emissions by vehicle type and by zone type are shown in Table 5.2.8. The total annual emissions of HC, CO, SOx and NOx were 19,845 tons, 288,433 tons, 1,269 tons and 9,250 tons respectively. The annual pollutant emissions by road type are shown in Table 5.2.9. Air pollutant emission ratios by vehicle type are shown in Table 5.2.11. As can be seen from this table, with HC, CO and NOx, automobiles accounted for the greater part of their total emissions.

Table 5.2.11 Air Pollutant Emission Ratio by Vehicle Type

(Unit: %)

Vehicle Type	HC	CO	SOx	NOx
Automobiles	60.7	51.7	39.1	54.5
Buses	29.1	34.9	37.4	28.6
Trucks	10.2	13.4	23.5	16.9
Total	100.0	100.0	100.0	100.0

5.3 Aircraft

5.3.1 Number of Takeoff and Landing

El Dorado airport (El Dorado Relaciones Aeropuerto) is located in the west of Bogota City and receives both domestic and international flights. Table 5.3.1 shows annual number of takeoff and landing by jet airplanes, calculated out of the airport schedule.

Table 5.3.1 Annual Number of Takeoff and Landing by Aircraft Type

Aircraft Type	Small-sized			Medium-sized			Large-sized			Total
	DC8	B707	B757	DC9	B727	B767	DC10	B747	AB3	
Number of engines	4	4	2	2	3	2	3	4	2	-
International	104	886	-	-	1,747	156	287	939	365	4,484
Domestic	1,251	1,095	574	3,780	22,500	-	-	-	-	29,200
Total	1,355	1,981	574	3,780	24,247	156	287	939	365	33,684

5.3.2 Exhaust Emission Factor

SO_x and NO_x are major air pollutants contained in exhaust fume from aircrafts. Both exhaust emission factor and amount of fuel consumption were calculated from data in No.8005 and were determined by type of aircraft and navigation mode. Results are shown in Table 5.3.2. In calculating amount of SO_x emitted by aircrafts, amount of sulphur contained in jet fuel was defined as 0.05% (wt%), according to reference No.8005.

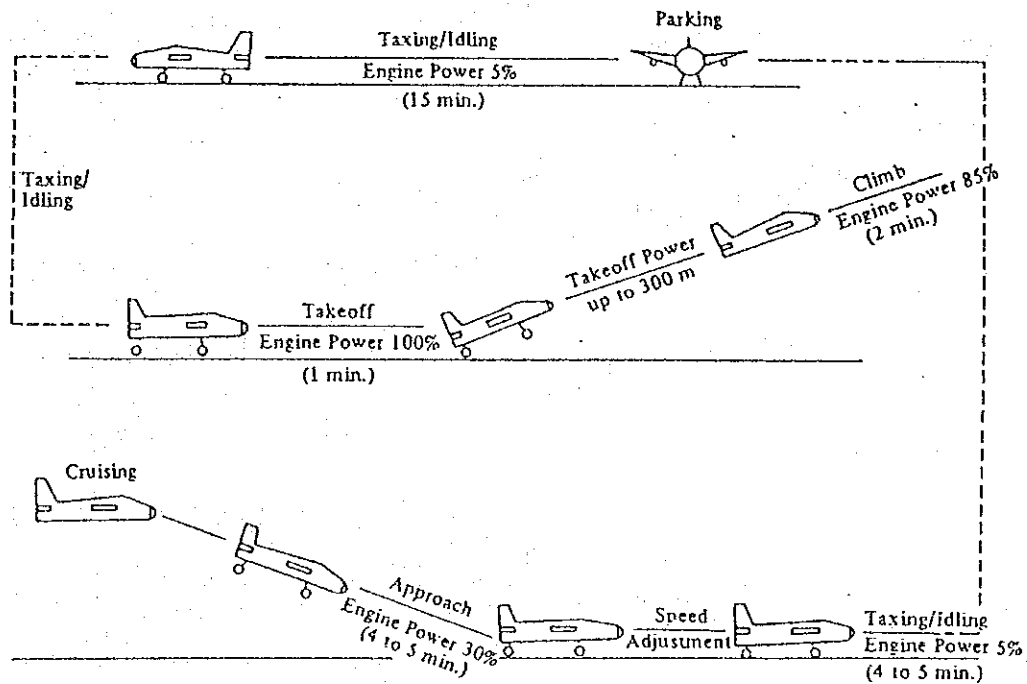
A simulation of navigation mode is shown in Fig. 5.3.1.

The amount of air pollutants emitted both modes of approach and climb was calculated up to 500 m above ground.

Table 5.3.2 Nox Emission Factor and Fuel Consumption Classified by Plane Type

Unit : g/s number of engines

Items	Model of Flight				Aircraft Type
	Idling	Take-off	Ascent	Approach /Landing	
NOx	0.21	14.4	9.40	2.44	DC8, B707, B757
Fuel consumption	153	1,200	975	450	
NOx	0.085	3.50	3.50	0.81	DC9, B727,B767
Fuel consumption	115	755	755	465	
NOx	0.83	94.1	52.6	6.51	DC10, B747,,AB3
Fuel consumption	220	2,650	1,730	640	
Cycle time (min)	20	2	0.4	2.5	-



Note: For DC-8 and B727, engine power for approach is 40%.

Fig. 5.3.1 Airplane Navigation Mode

5.3.3 Amount of Air Pollutant Emitted

The calculation results on amount of air pollutants emitted from aircraft are shown in Table 5.3.3. Annual amount of total SO_x emission was 29.0 tonnes, while the equivalent of NO_x emission was 114.0 tonnes.

Table 5.3.3 Quantity of Pollutant Emission from Aircraft

Unit: ton/year

Items	Model of Flight				Total
	Idling	Take-off	Ascent	Approach /Landing	
SO _x	15.1	5.6	2.0	6.4	29.0
NO _x	17.2	59.6	16.8	20.3	114.0

5.4 Domestic Source

In Santa Fe de Bogota City, the main energy sources for cooking and hot water supply are electricity, kerosene and propane gas. But there is little information on the energy consumption by the households there. So in this study the pollutant emissions from domestic sources were estimated tentatively based on Japanese data.

(1) Fuel Consumption

In 1990 the population of Santa Fe de Bogota City was approximately 4.90 million (#1021 and #1004). If an average family consists of 5 persons, there are 980,000 households there. If 50%, 20% and 30% of the total households use electricity, kerosene and propane gas respectively (#7009), 190,000 households use kerosene and 294,000 households use propane gas. In Japan a household consumes 3.65 million kcal of town gas for cooking and hot water supply in a year.

The characteristics of kerosene and propane gas are shown in Table 5.4.1.

Table 5.4.1 Characteristics of Kerosene and Propane Gas

Fuel	Density (g/ml)	Calorific Value (kcal/kg)	Sulfur Content (%)
Kerosene	0.92	11,900	0.07
Propane gas	0.54	16,560	-

The energy of 3.65 million kcal corresponds to 306.7 kg of kerosene and 220.4 kg of propane gas. Based on the Japanese data, the households use 60,113 tons (65,340 kl) of kerosene and 64,798 tons (119,996 kl) of propane gas in a year in Santa Fe de Bogota City.

(2) Emission Factors

The emission factors for kerosene and propane gas were set as shown in Table 5.4.2 (EPA #4016).

Table 5.4.2 Emission Factor for Kerosene and Propane Gas

(Unit: kg/10³l)

Fuel	Emission Factor	
	Dust	NOx
Kerosene	1.2	1.5
Propane gas	0.223	1.3

(3) Quantity of Air Pollutant Emission

With the fuel consumptions, sulfur contents and emission factors above, the annual quantities of dust, SOx and Nox emissions from domestic sources were 105 tons, 84 tons and 254 tons respectively (Table 5.4.3).

Table 5.4.3 Air Pollutant Emission from Domestic Sources

(Unit: ton/year)

Fuel	Dust	SOx	NOx
Kerosene	78.4	84.2	98.0
Propane gas	26.4	-	156.0
Total	104.8	84.2	254.0

5.5 Summary for Quantity of Air Pollutant Emission

(1) Pollutant Emission Quantity by Source

The pollutant emission quantity by source is shown in Table 5.5.1. Although the quantity of pollutant emissions shown in this table is used in the air quality simulation, it does not represent the total emission in the study area as stated at the beginning of this chapter. Dust emission quantity was calculated solely for stationary sources and the emission from factories amounts to 2,198 tons/year. CO emission was calculated solely for motor vehicles and amounts to 288,433 tons/year. The SO_x emission was primarily from factories at 6,504 tons/year (83.4%) of the total 7,802 tons/year. The NO_x emission was primarily from motor vehicles at 9,250 tons/year (83.7%) of the total 11,052 tons/year.

Table 5.5.1 Air Pollutant Emission by Source

(Unit: ton/year)

Classification	Source	Dust	SO _x	NO _x	CO	HC
Stationary Sources	Factories and Establishments	2,198	6,504	1,688	-	-
Mobile Sources	Motor Vehicles	-	1,269	9,250	288,433	19,845
	Aircraft	-	29	114		
Total		2,198	7,802	11,052	288,433	19,845

(2) Regional Distribution of Pollutant Emission

Regional distributions of the total emissions of SO_x, CO, NO_x and Dust are shown in Fig. 5.5.1 - 5.5.4 respectively.

Because the factories are mainly located at the central part of the study area and the traffic volumes are also highly concentrated there, the central part accounts for the greater part of the total emission of each pollutant.

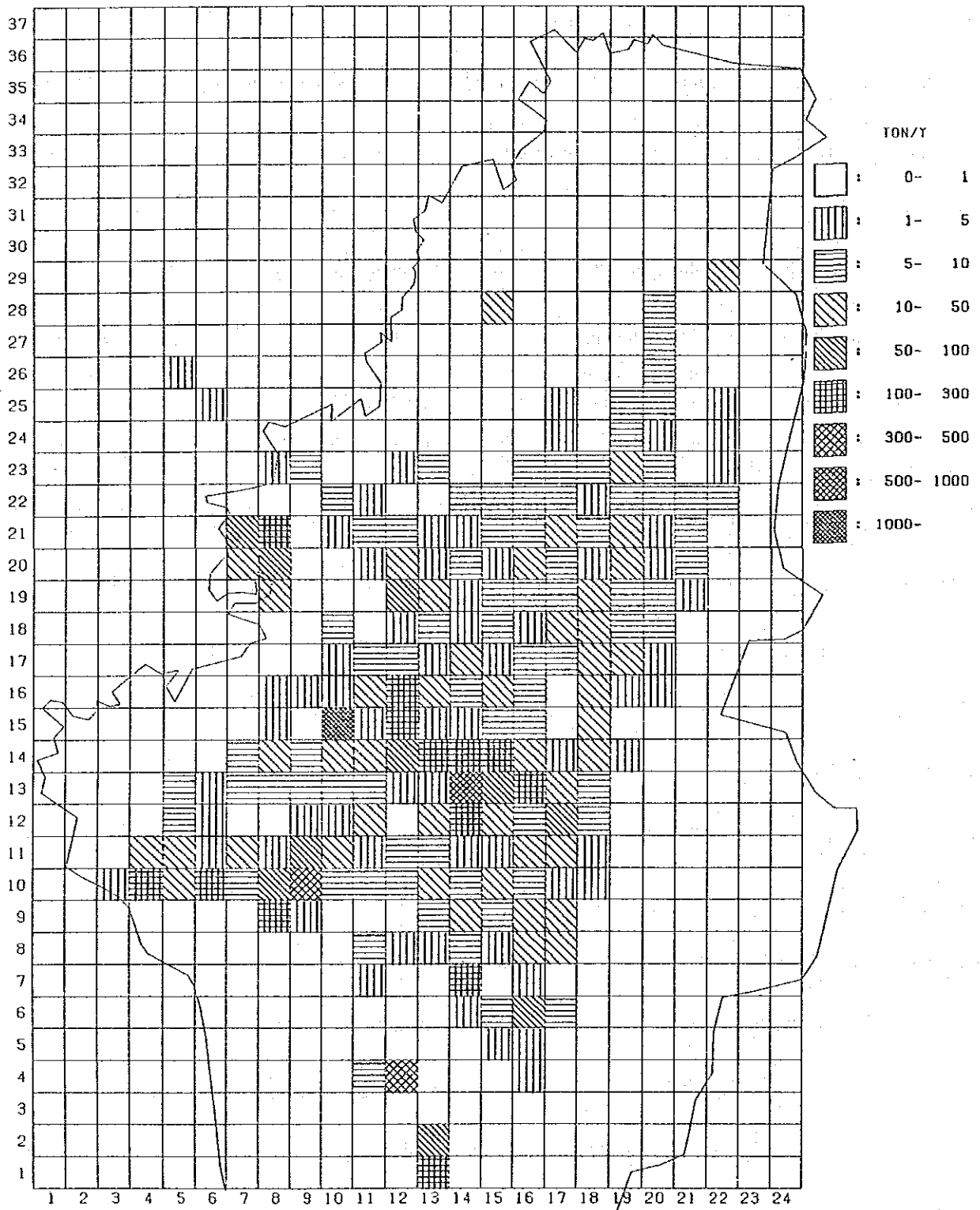


Fig. 5.5.1 Distribution of SOx Emission from All Sources

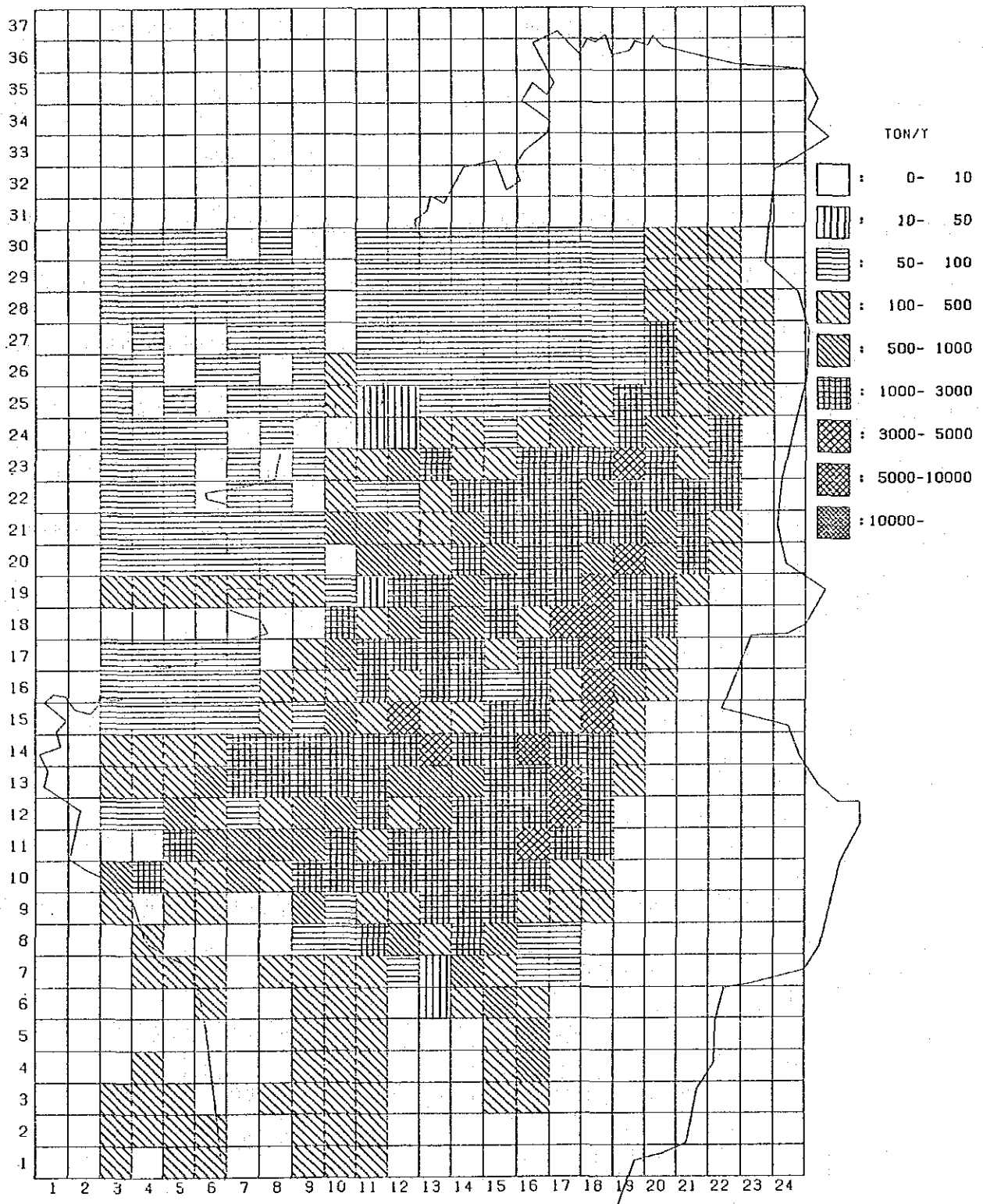


Fig. 5.5.2 Distribution of CO Emission from All Sources (Motor Vehicles)

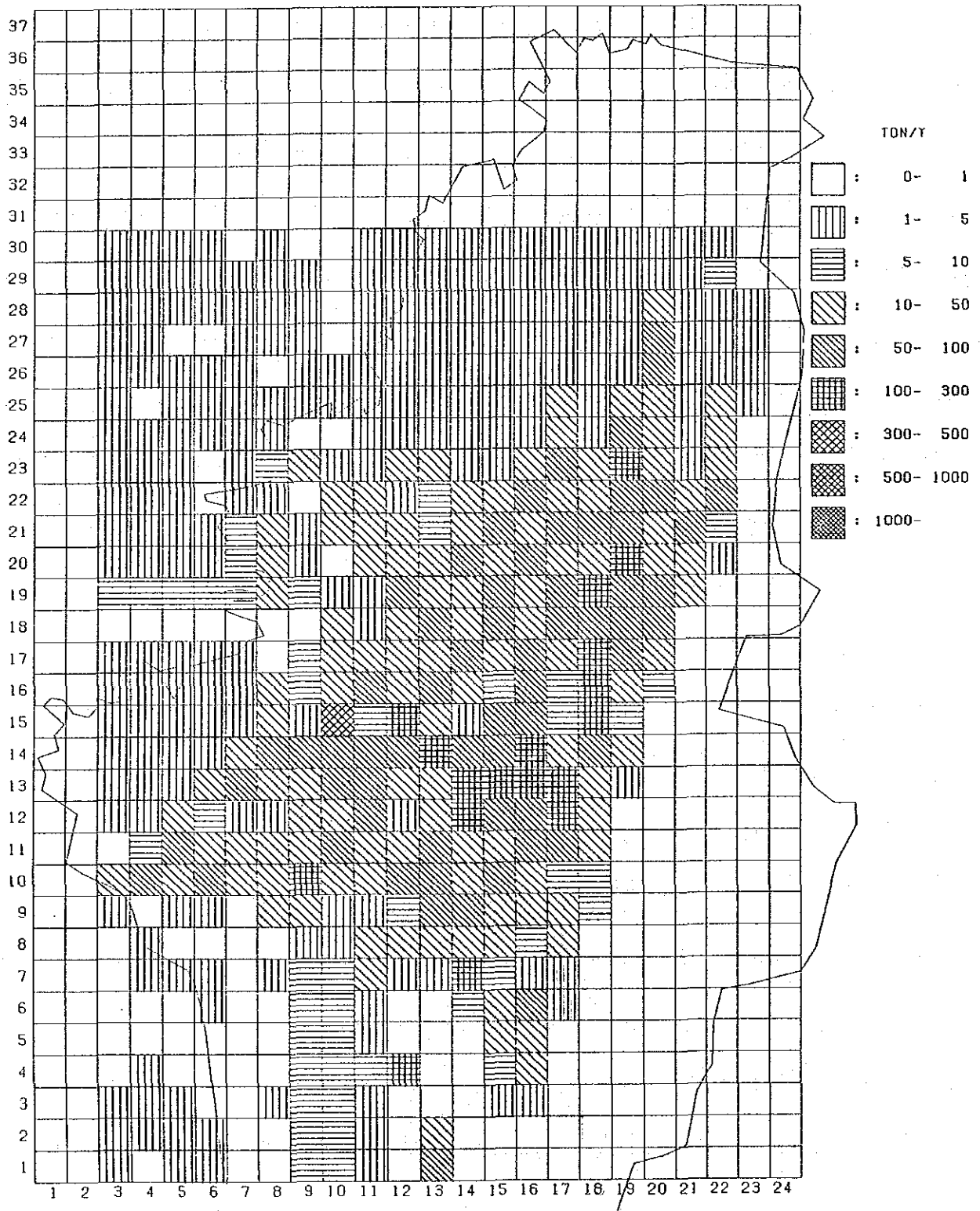


Fig. 5.5.3 Distribution of NOx Emission from All Sources

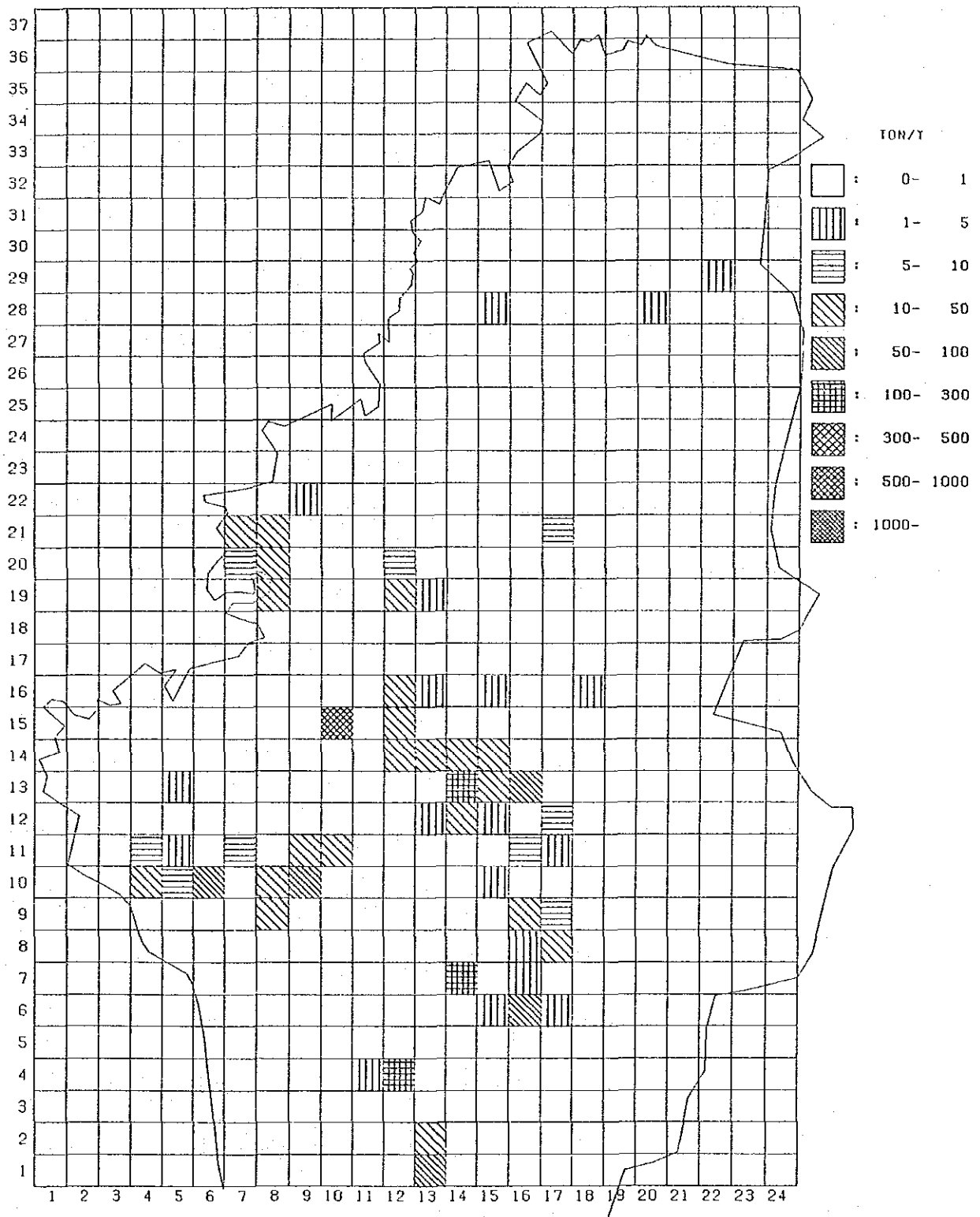


Fig. 5.5.4 Distribution of Dust Emission from All Sources (Factories)

**CHAPTER 6 ANALYSIS OF AIR POLLUTION STRUCTURE
BY AIR DISPERSION SIMULATION MODEL**

CHAPTER 6. ANALYSIS OF AIR POLLUTION STRUCTURE BY AIR DISPERSION SIMULATION MODEL

6.1 Outline of Air Dispersion Simulation Model

6.1.1 Air Dispersion Simulation Model Preparation Procedure

Modeling was made with information pertinent to emitting condition obtained from analysis of airpollutant sources, and the air dispersion field obtained from analysis of meteorological condition and environment concentration. The dispersion simulation model (hereinafter called the "dispersion model") representing the current air pollution state was prepared according to the procedure shown in Fig. 6.1.1.

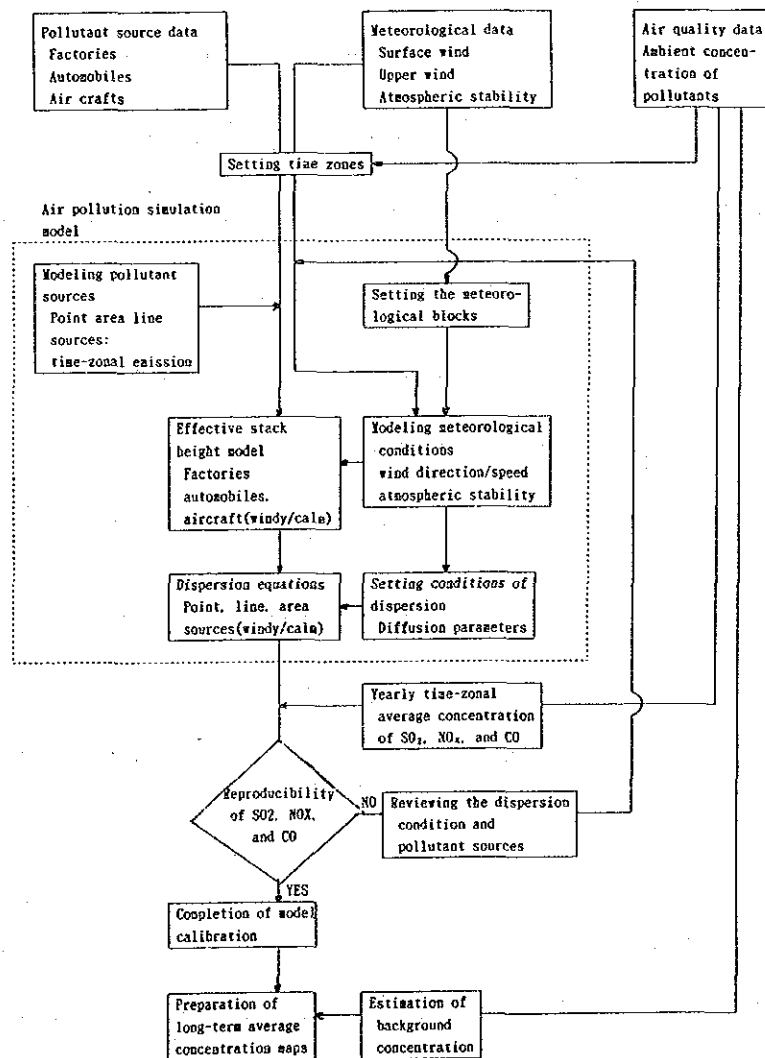


Fig. 6.1.1 General Process of Air Quality Simulation

6.1.2 Scope of the Dispersion Model

This dispersion model covers the following matters:

- a. Air pollutants concerned
Sulfur dioxide (SO₂), Nitrogen oxide (NO_x),
Nitrogen dioxide (NO₂), Carbon monoxide (CO)
- b. Averaging time of concentration
Taking into consideration the accuracy of the data on the air pollutant sources and meteorology, the predictable ambient air quality should be a long-term average concentration. So the 6-month average concentration was estimated to evaluate the ambient air quality.
- c. Source concerned
Factories, motor vehicles, aircraft
- d. Model evaluation points
Air quality monitoring stations (5)
- e. Period
November 23, 1990 - June 10, 1991
- f. Area covered by prediction
Area around Santafe de Bogota City as shown in Fig. 6.1.2

6.1.3 Setting the Period and Time Zone

Though there are dry and rainy seasons, the metrological conditions of the Santafe de Bogota area has less fluctuation in the air temperature throughout the year. Factors to cause fluctuation of the source activity by heating are also considered limited.

Since the actual measurement data of meteorology and environmental concentration available currently are only for less than one year, the period shown below was chosen for this survey.

Table 6.1.1 Classification of Time Zone

Morning	6~ 10	0'Clock	(5 hours)
Afternoon	11~ 16	0'Clock	(6 hours)
Evening	17~ 23	0'Clock	(7 hours)
Midnight	24~ 5	0'Clock	(6 hours)

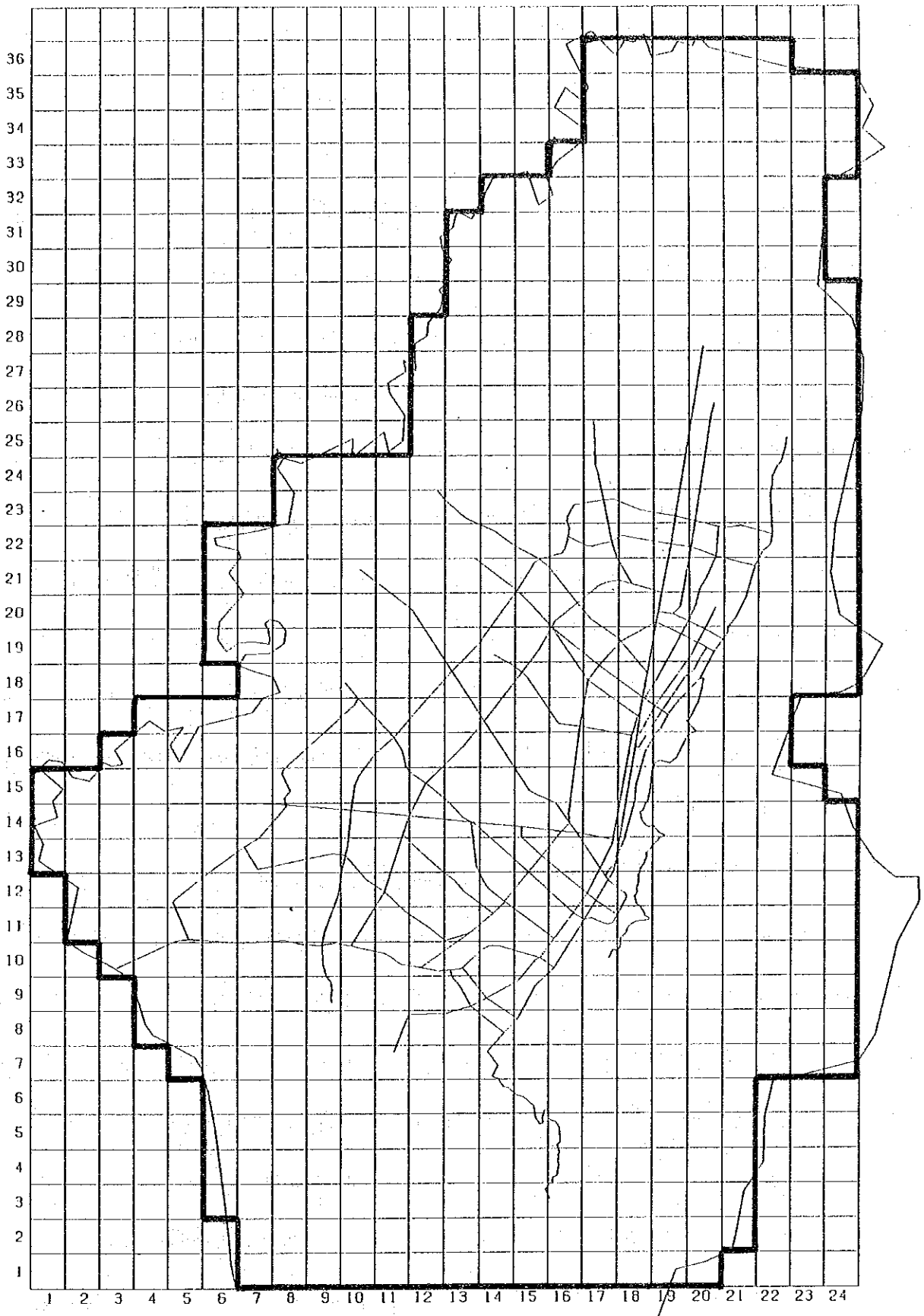


Fig. 6.1.2 Area for Computation of Air Pollutant concentration

Period concerned: November 23, 1990 - June 10, 1991

The time zone was set as shown in Table 6.1.1, with reference made to hourly changes in the NO_x environmental concentration (which is said to be affected to a relatively large extent by fluctuation of the meteorology and sources) and the hourly change in the automobile traffic volume.

6.1.4 Modeling of Pollutant Sources

To handle the sources on the dispersion model, source modeling was made while taking their configuration and scale into account. Basically, the sources (stack, road, etc.) with large air pollutant emission amount were modeled individually. Sources which are large in quantity, but individually less in the emission amount were collectively modeled.

Sources concerned include factories, automobiles (trunk road, alleys) and airplanes leaving and arriving at El Dorado Airport.

Table 6.1.2 Form of Pollutant Sources

Type of Pollutant sources \ Item			Form of Source	Number of Sources
Stationary Source	Factories		Point Source	361
Mobile Source	Motor vehicles	Major Roads	Line Source	422
		Narrower Roads	Area Source	425
	Aircraft	Idling/Takeoff	Area Source	6
		Climb, Approach/Landing	Point Source	474

6.1.5 Meteorological Modeling

(1) Setting A Meteorological Block in the Horizontal Direction

Since Santafe de Bogota City is wide (about 25 km from east to west and about 35 km from north to south), the meteorological appearance condition is considered to vary from one region to another. Accordingly, the area was divided into 5 blocks as shown in Fig. 6.1.3 in view of topographical state and source distribution state. Meteorological observation data of each observation point were applied as representative meteorological data to each block.

— Ratio of Wind Direction (%)
 - - - Average of Wind Speed (m/s)

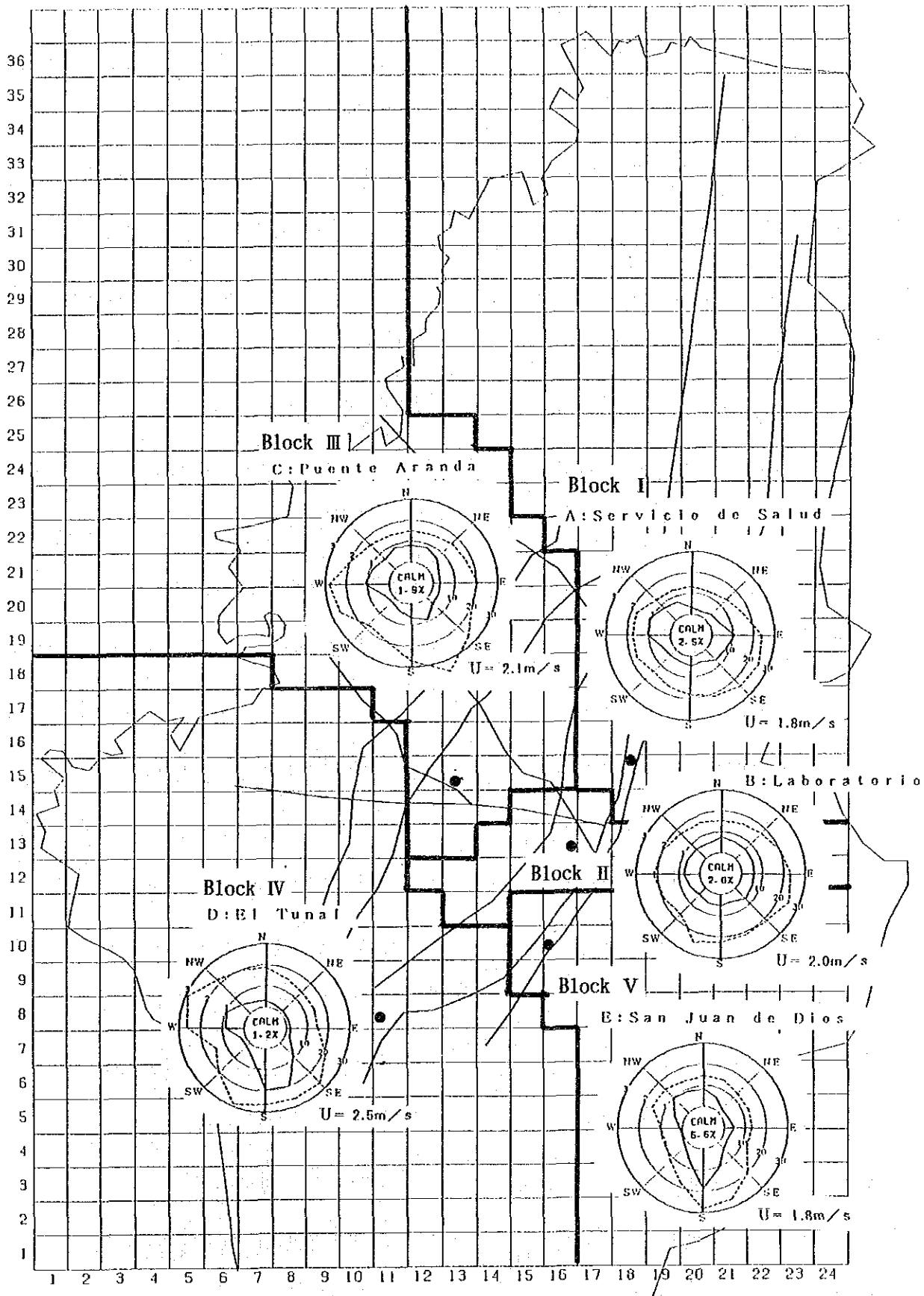


Figure 6.1.3 Meteorological Blocks and Typical Wind Conditions

(2) Meteorological Classification in the Vertical Direction

Generally, the wind speed tends to increase as the height from the ground surface rises. To reflect this trend, the source emission height on the dispersion model was divided into three in a vertical direction as shown in Table 6.1.3 and the representative meteorological data were applied to each field.

The observation data of wind speed were used as they are for the lower field while the wind speed was compensated by using the power index P shown in Table 6.1.4 according to the emission height of sources and applied to surface and upper fields respectively.

Table 6.1.3 Vertical Division of Dispersion Field and Corresponding Pollutant Sources

Category of Dispersion Field	Pollutant Sources
Surface Field	Motor Vehicles
Lower Fields	Factories (Stack Height $h_o \leq 30m$) Aircraft (Idling/Takeoff)
Upper Field	Factories (Stack Height $h_o > 30m$) Aircraft (Climb, Approach/Landing)

Table 6.1.4 Number of P by Atmospheric Stability

Pasquill's Atmospheric Stability	A	B	C	D	E	F, G
P	0.10	0.15	0.20	0.25	0.25	0.30

Wind speed estimation formula : $U_z = U_s (Z/Z_s)^P$

U_z : Estimated wind speed (m/s)

U_s : Wind speed on the ground (m/s)

Z : Height of wind speed to be estimated (m)

Z_s : Surface wind observation height (m)

(3) Modeling of Meteorological Data

Meteorological observation data are modeled through classification as follows:

- Wind direction : 16 direction and calm ($U \leq 0.4$ m/s)
- Wind speed : 8 classes of wind speed as shown in Table 6.1.5
- Air stability : 11 classes of stability categories [A (unstalbe) ~ D (neutral) ~ G (stable)]

Table 6.1.5 Wind Speed Classification

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

6.1.6 Effective Stack Height Calculation Equation

As there was no particularly large scale facility in the area, the CONCAWE equation (when it was windy) and the Briggs equation (when it was calm) was used to predict the rising height of the exhaust gas from a plant stack.

For pollutant sources other than plants, the setting as shown in Table 6.1.6 was used in view of individual emission characteristics.

For climbing, approaching/landing of airplanes, point sources were arranged along the route and their height was used as the emission height.

- CONCAWE Equation

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

- Briggs Equation

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

ΔH : The rise of the plume above the stack (m)

Q_H : Heat emission due to efflux of stack gases (cal/s)

$$= \rho \cdot Q \cdot C_p \cdot \Delta T$$

ρ : Density of emitted gases at 0°C (= 1.293 x 10³ g/m³)

Q : Emission rate of gaseous effluent (Nm³/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 (15°C) (°C)

u : Wind speed at the top of stack (m/s)

$d\theta/dz$: Vertical potential temperature gradient of atmosphere (°C/m)

(to be set at 0.003 for daytime and 0.010 for nighttime)

Table 6.1.6 Effective Stack Height Model

Pollutant Source	Windy	Calm
Automobiles	5 m	7 m
Airplanes	10 m	15 m

6.1.7 Air Dispersion Equation

When it was windy, the equation obtained by improving the plume equation so that the concentration distribution in the Y direction became uniform within one orientation ($2\pi/16$)(Holland, 1953) was used to predict the long-term average concentration. A method of integration within the size (1 km x 1 km) was used for the area source and a method of integration within the range of the length (finite length) for the line source.

When it was calm, an equation based on a simplified puff equation was used.

The plume equation and the Holland equation deduced from the former are shown below.

Table 6.1.7 Application of Dispersion Equation

Wind Condition	Windy	Calm
Form of Source		
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

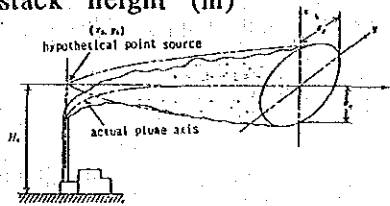
Plume equation (original)

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

c : concentration of a pollutant (m^3/m^3)

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 dispersion parameter evaluated in terms of downwind distance x (m)
 σ_z : vertical dispersion parameter evaluated in terms of downwind distance x (m)
 U : wind speed (m/s)
 H_e : 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.

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

6.1.8 Setting the Dispersion Parameters

The condition of atmospheric dispersion field is said to vary depending on the time zone (daytime, night time). In view of such characteristic of the dispersion field, dispersion parameters were adjusted so that the measured value of environmental concentration agreed better with the calculated value. As a result, the dispersion parameters were set as shown in Table 6.1.8 in correspondence to the atmospheric stability that was classified using meteorological observation data. For calculation, the Pasquill-Gifford chart shown in Fig. 6.1.4 was used as dispersion parameter.

Note that according to the observation results of the upper layer meteorology, the appearance frequency of upper-layer inversion at a height of 100m is so low at about 5% that the "Lid effect" (existence of an inversion layer disturbs dispersion of air pollutants to the upper layer)

was neglected. But the appearance frequency of inversion near ground is at 6%, which was taken into consideration in dispersion model by setting the diffusion parameter for the morning and midnight more stable.

Table 6.1.8 Atmospheric Stability Class to Obtain Diffusion Parameter

Classified Atmospheric Stability		A	AB	B	BC	C	CD	D	D	E	F	G
Dispersion Time Zone Field								(Day-time)	(Night-time)			
Morning	Surface	A	AB	B	BC	C	CD	CD	D	D	E	F
	Lower	A	AB	B	BC	C	CD	CD	D	D	E	E
	Upper	BC	BC	C	CD	CD	CD	CD	D	D	E	E
Afternoon	Surface	A	A	B	BC	C	CD	CD	CD	D	D	D
	Lower	A	A	B	BC	C	CD	CD	CD	D	D	D
	Upper	B	BC	C	CD	CD	CD	CD	CD	D	D	D
Evening	Surface	A	AB	B	BC	C	CD	CD	CD	D	D	D
	Lower	B	B	BC	C	CD	CD	CD	CD	D	D	D
	Upper	BC	BC	C	CD	CD	CD	CD	D	D	D	D
Midnight	Surface	B	B	BC	C	CD	CD	D	D	E	F	G
	Lower	B	B	BC	C	CD	CD	D	D	E	F	F
	Upper	BC	BC	C	CD	CD	CD	CD	D	D	E	E

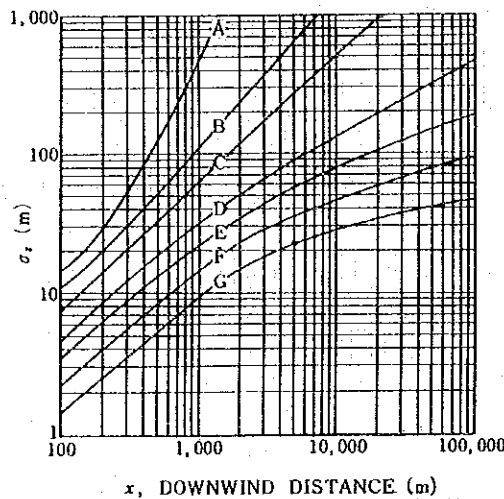


Fig. 6.1.4 Pasquill-Gifford Chart

6.1.9 Equation to Convert from NO_x to NO₂

Conversion from the NO_x to NO₂ concentration was made with a statistic model based on a relationship between individual measured values.

The regression analysis to the exponential function was made for NO_x and NO₂ averages at each station for a period from November, 1990 to June, 1991 as shown in Table 6.1.9, leading to the regressive equation as shown below. This equation was used for conversion.

Fig. 6.1.5 shows the scatter diagram of NO₂ and NO_x of actual values and the regression equation obtained from analysis.

$$(NO_2) = 3.41 \cdot (NO_x)^{0.527}$$

Table 6.1.9 Actual value of NO_x and NO₂

(Period : Nov., '90 ~ Jun., '91)

Item	A : Servicio de Salud	B : Laboratorio	C : Puente Aranda	D : El Tunal	E : San Juan de Dios
NO _x (ppb)	64.0	30.0	41.3	28.6	111.1
NO ₂ (ppb)	30.5	22.2	25.3	18.0	40.4

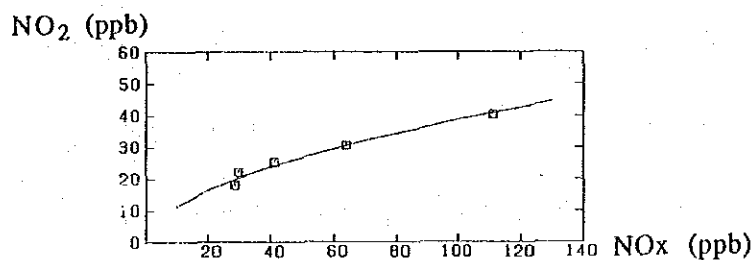


Fig. 6.1.5 Scatter Diagram of Actual Value of NO_x and NO₂

6.2 Calculation Result of Dispersion Model

Table 6.2.1 shows the average for the period for which calculation with the dispersion was made as well as the contribution concentration by source.

Appropriateness of measured and calculated values is shown in Table 6.2.2 and summarized in two cases as described below:

Case 1: Evaluation made at five measuring points

Case 2: Evaluation made at four points excluding E. San Juan de Dios which was situated along the road and the plume equation was difficult to reproduce the concentration when affected by local meteorology due to topography or building.

Reproducibility of the concentration by means of the dispersion model of each pollutant was 0.8 or more in the correlation coefficient and 0.45 or less in the coefficient of variation for Case 1. This was 0.8 or more in the correlation coefficient and 0.4 or less in the coefficient of variation for Case 2.

Namely, the dispersion model was decided to be used for estimation of long term averaged concentration, because reproducibility was roughly satisfactory.

However, attention shall be paid when the CO concentration along the road is estimated, because the CO estimated concentration of E. San Juan de Dios which is located along the road, had a tendency to underestimating the actual concentration.

The method of computing for correlation and coefficient of variation, and term of decision for reproducibility of dispersion model are shown in Supporting Report.

Fig. 6.2.1 - 6.2.4 show the scatter diagram of measured and calculated values.

Table 6.2.1 Computed Concentration by Pollutant Source

(Nov. '90 ~ Jun. '91)

Item	Pollutant Source Receptor	Total	Factory	Motor vehicles		Aircraft
				Major Road	Narrower Road	
SO ₂ (ppb)	A. Servicio de Salud	10.9	4.8	6.2	0.4	0.0
	B. Laboratorio	12.4	8.1	3.9	0.4	0.0
	C. Puente Aranda	18.5	14.2	3.8	0.5	0.0
	D. El Tunal	6.7	5.6	0.9	0.3	0.0
	E. San Juan de Dios	15.8	5.9	9.5	0.5	0.0
NO _x (ppb)	A. Servicio de Salud	65.3	1.2	60.1	4.0	0.0
	B. Laboratorio	45.7	2.3	39.4	4.0	0.1
	C. Puente Aranda	46.0	3.6	38.1	4.1	0.1
	D. El Tunal	13.7	2.4	8.7	2.6	0.0
	E. San Juan de Dios	95.3	1.9	89.1	4.3	0.0
NO ₂ (ppb)	A. Servicio de Salud	32.2	-	-	-	-
	B. Laboratorio	27.2	-	-	-	-
	C. Puente Aranda	27.2	-	-	-	-
	D. El Tunal	14.0	-	-	-	-
	E. San Juan de Dios	38.1	-	-	-	-
C O (ppm)	A. Servicio de Salud	3.89	-	3.38	0.20	-
	B. Laboratorio	2.49	-	2.05	0.21	-
	C. Puente Aranda	2.09	-	1.72	0.19	-
	D. El Tunal	0.57	-	0.40	0.12	-
	E. San Juan de Dios	4.99	-	4.41	0.22	-

Table 6.2.2 Reproducibility of Simulation Model

(Nov. '90~ Jun. '91)

Item	Case	Regression Line	Number of Stations for Evaluation	Correlation Coefficient	Coefficient of Variation	Back-ground
SO ₂	1	Y=1.451X-3.42 (ppb)	5	0.826	0.373	2.39 (ppb)
	2	Y=1.130X-1.06 (ppb)	4	0.883	0.289	0.51 (ppb)
NO _x	1	Y=1.060X-1.38 (ppb)	5	0.921	0.284	1.84 (ppb)
	2	Y=0.617X+14.6 (ppb)	4	0.806	0.379	-1.71 (ppb)
NO ₂	1	Y=0.988X-0.68 (ppb)	5	0.946	0.119	-1.02 (ppb)
	2	Y=0.722X+5.46 (ppb)	4	0.925	0.140	-1.69 (ppb)
CO	1	Y=1.721X-0.73 (ppm)	5	0.947	0.445	1.29 (ppm)
	2	Y=1.184X+0.21 (ppm)	4	0.949	0.252	0.63 (ppm)

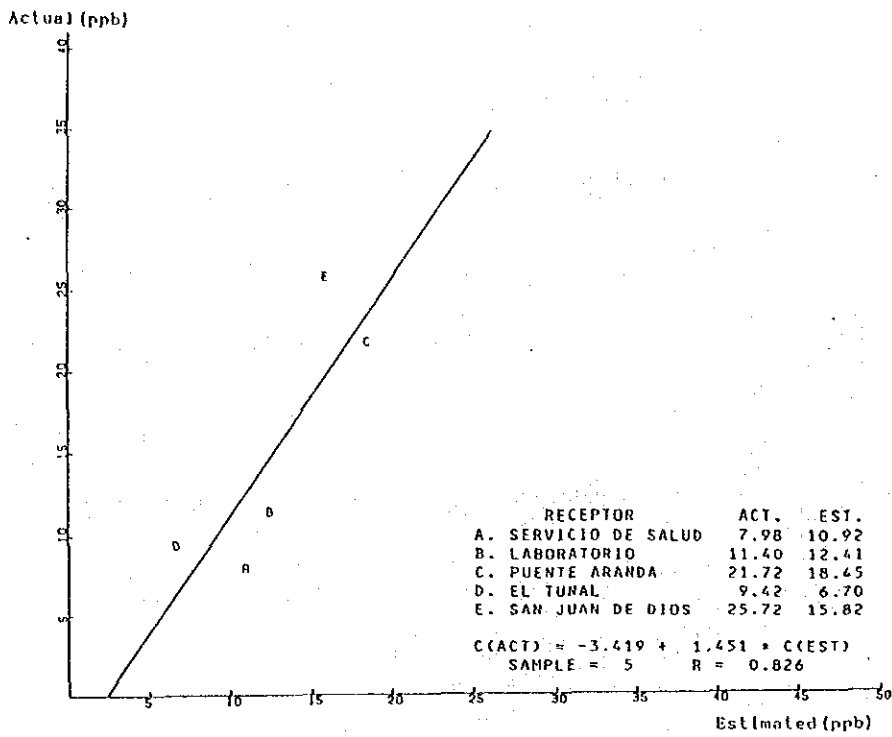


Fig. 6.2.1 Scatter Diagram of Actual and Estimated Values of SO₂

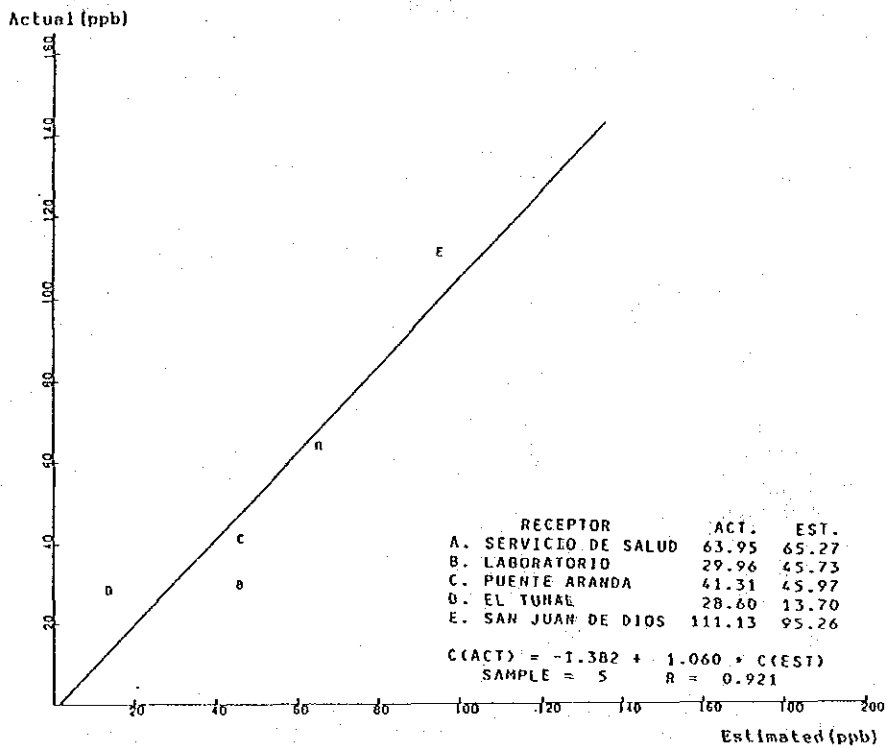


Fig. 6.2.2 Scatter Diagram of Actual and Estimated Values of NO_x

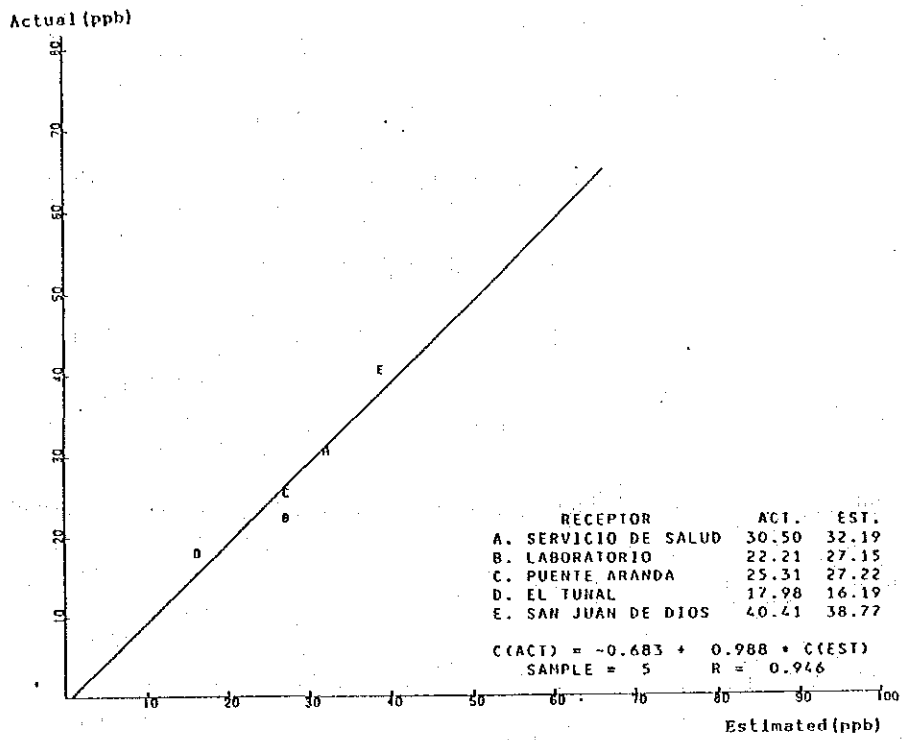


Fig. 6.2.3 Scatter Diagram of Actual and Estimated Values of NO₂

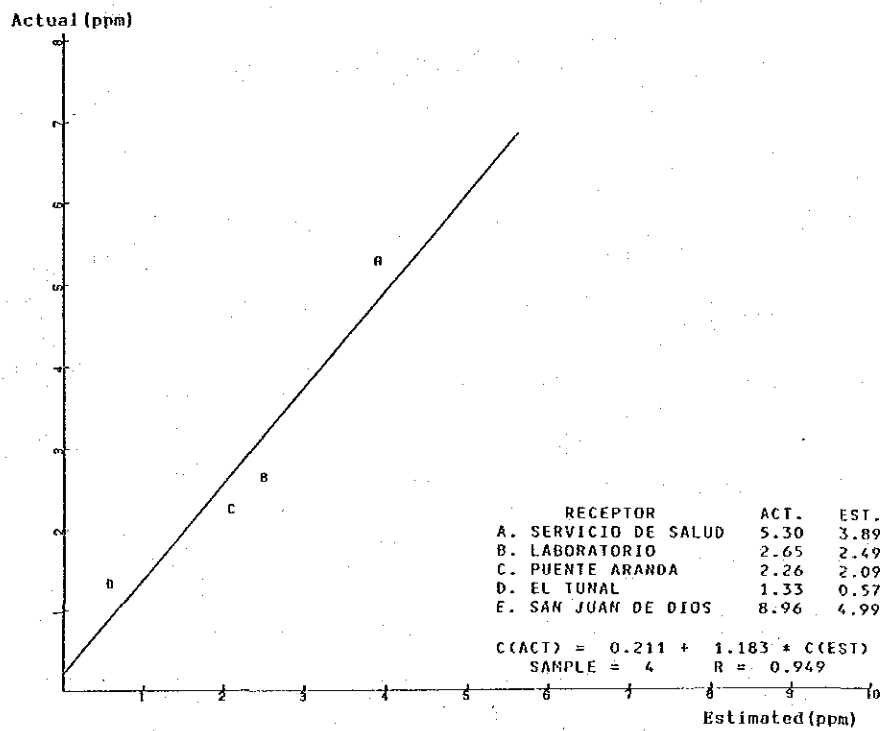


Fig. 6.2.4 Scatter Diagram of Actual and Estimated Values of CO

Note: E. San Juan de Dios is excluded

6.3 Analysis of Air Pollution Structure

6.3.1 Analysis of Pollutant Source Contribution by Air Simulation Model

(1) Contribution Concentration by Air Pollution Sources

Using the dispersion model described in the previous item, estimated result of each air pollutant concentration at each monitoring stations and maximum concentration point in the area is shown in Table 6.3.1.

Note that background concentration is added to the contribution concentration of each pollutant sources, and summing up of them is the estimated concentration.

Concentration of pollutant source which is not grasped yet, concentration by blowing back phenomenon of pollutants, error of measurement and concentration in nature are included in the background concentration.

In this investigation difference between measured value and computed value (shown in Table 6.2.2 as background) is set as background concentration.

Though estimated concentration is averaged values of 6 months from November, '90 to June, '91, comparing results of these concentrations to the target concentrations are follows.

SO₂ concentration at any computed points is less than the target concentration (38.2ppb).

NO₂ concentration at any computed points is also less than the target concentration (53.2 ppb).

CO concentration at computed points excluding C. Puente Aranda and D. El Tunal is more than the target concentration (3.6 ppm).

Table 6.3.1 Computed Concentration (Nov., '90 ~ Jun, '91)

Items	SO ₂ (ppb)	NO _x (ppb)	NO ₂ (ppb)	CO (ppm)
A. Servicio de Salud	13.8	67.1	32.2	5.18
B. Laboratorio	14.8	47.6	27.2	3.78
C. Puente Aranda	20.8	47.8	27.2	3.38
D. El Tunal	9.1	15.5	16.2	1.86
E. San Juan de Dios	18.2	97.1	38.8	6.28
Cmax Point	32.3	108.8	40.4	6.96
Mesh Index	(12, 15)	(16, 14)	(16, 14)	(16, 14)

Contribution concentration by sources at each monitoring stations and maximum concentration point in the area is shown in Fi. 6.3.1. - Fig. 6.3.3.

Because of too small concentration, contribution concentration of aircraft is not included in the figure.

① SO₂

The contribution ratio of factories to the estimated value is 22% - 64%, and the contribution of motor vehicles to the estimated value is 5% - 50%.

The contribution of factories takes greater part than the other sources at estimated points excluding E. San Juan de Dios.

② NO_x

The contribution ratio of motor vehicles to the estimated value is very high at 71% - 96%.

Note that contribution of NO₂ concentration by sources is not calculated, because estimated concentration of NO₂ was calculated by method of converting the total value of NO_x.

③ CO

As the concerned source for estimating CO concentration is only motor vehicles, they occupies all of contribution excluding background concentration in all stations and the point with maximum concentration.

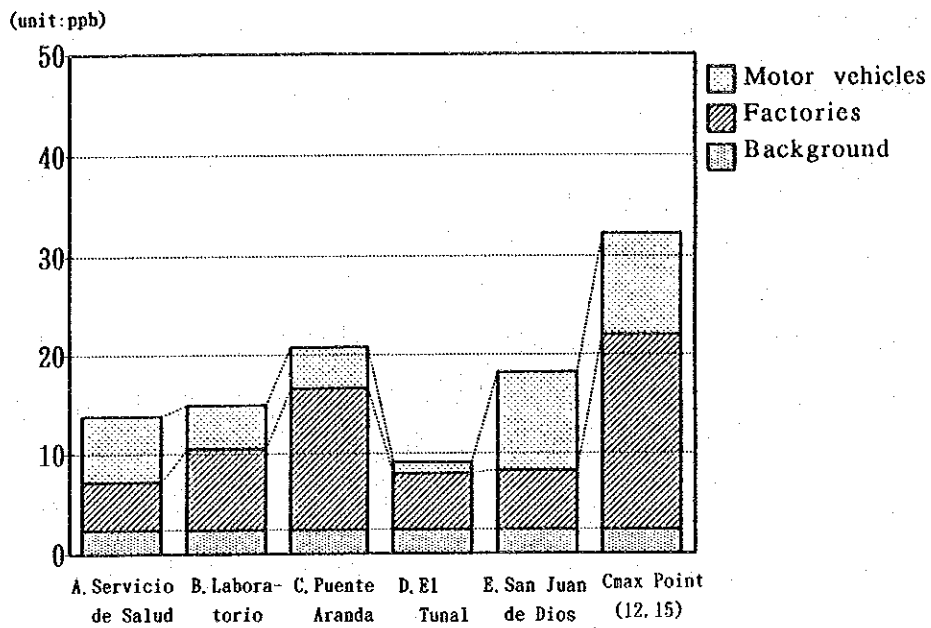


Fig. 6.3.1 Contribution of Sources to SO₂ Concentration

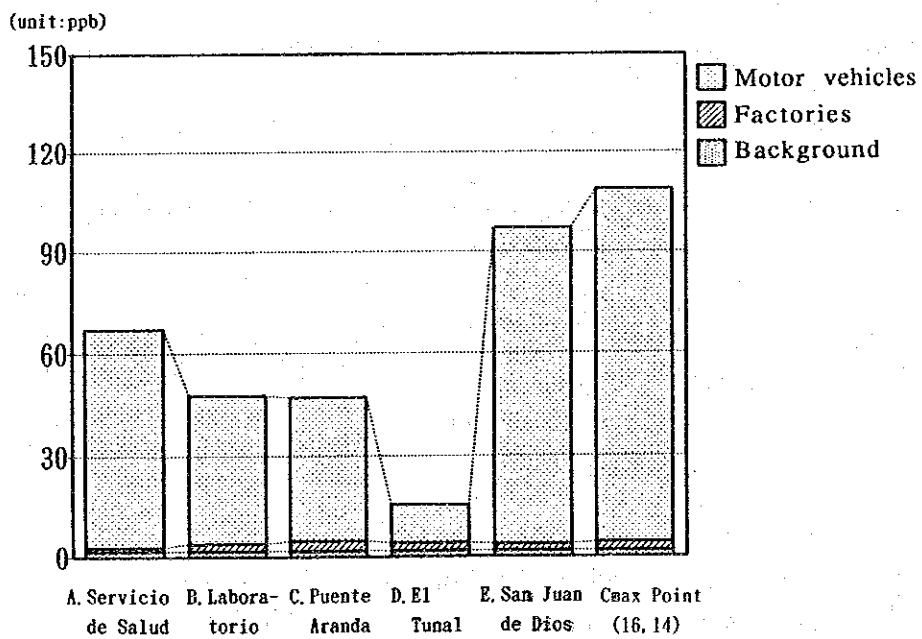


Fig. 6.3.2 Contribution of Sources to NO_x Concentration

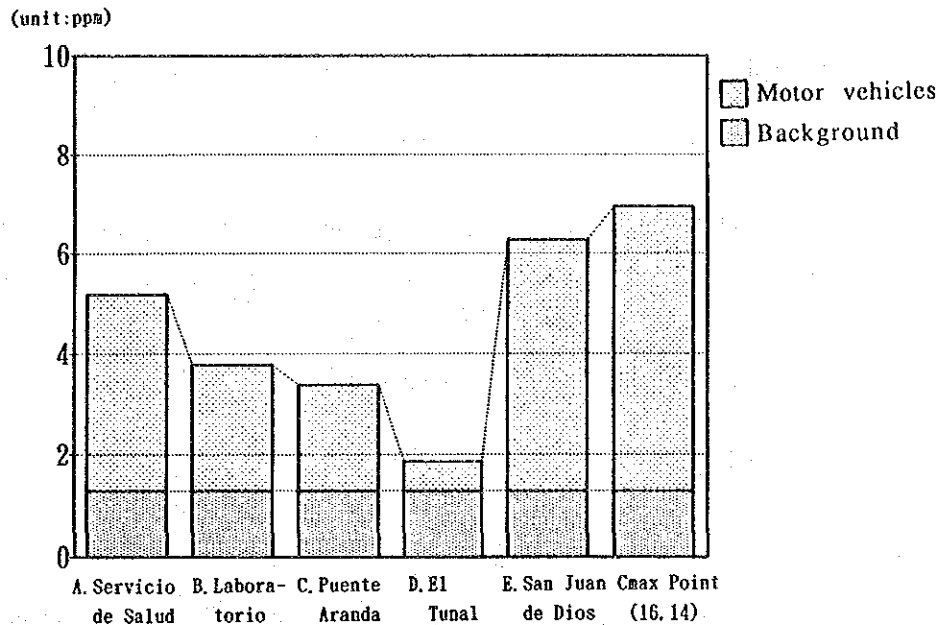


Fig 6.3.3 Contribution of Sources to CO Concentration

- (2) Estimation of plane concentration distribution using the dispersion model described in the previous item, the plane concentration distribution of each air pollutant was estimated as follows.

Note that the estimated concentration is the average of about 6 months from November, 1990 to June, 1991. The distribution of contribution concentration by pollutant source is shown in Appendices.

① SO₂

The result of estimation of plane concentration distribution of SO₂ is shown in Fig. 6.3.4. The concentration of 10 ppb or more was distributed in an area near to the city center, with the maximum concentration being 32.3 ppb in the mesh index (12, 15).

② NO_x, NO₂

The result of estimation of plane concentration distribution of NO_x is shown in Fig. 6.3.5, with the concentration of 60 ppb or more distributed same and more to the east of an area with high SO₂ concentration. The maximum concentration was 108.8 ppb in the mesh index (16, 14).

The result of estimation of plane concentration distribution of NO₂ is shown in Fig. 6.3.6, with the concentration distribution showing the

trend similar to that of NOx. The maximum concentration was 40.4 ppb in the mesh index (16,14).

③ CO

The result of estimation of plane concentration distribution of CO is shown in Fig. 6.3.7, with the concentration distribution showing the trend similar to that of NOx. The maximum concentration was 7.0 ppm in the mesh index (16, 14).

x : Cmax Point

unit:ppb



Fig. 6.3.4 Average Concentration Isopleths for SO₂ (All Sources)

× :Cmax Point

unit:ppb

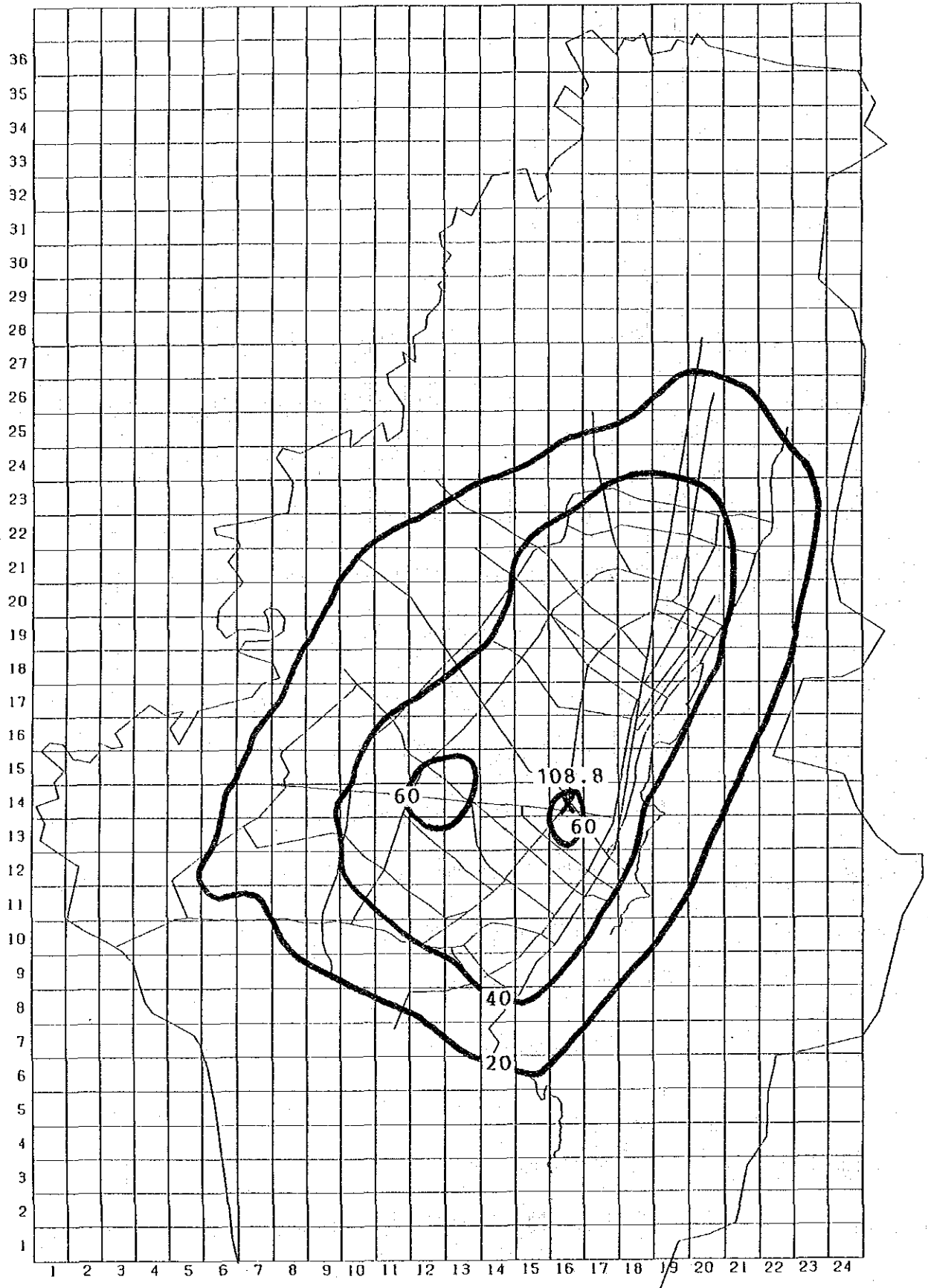


Fig. 6.3.5 Average Concentration Isopleths for NOx (All Sources)

x : Cmax Point

unit:ppb

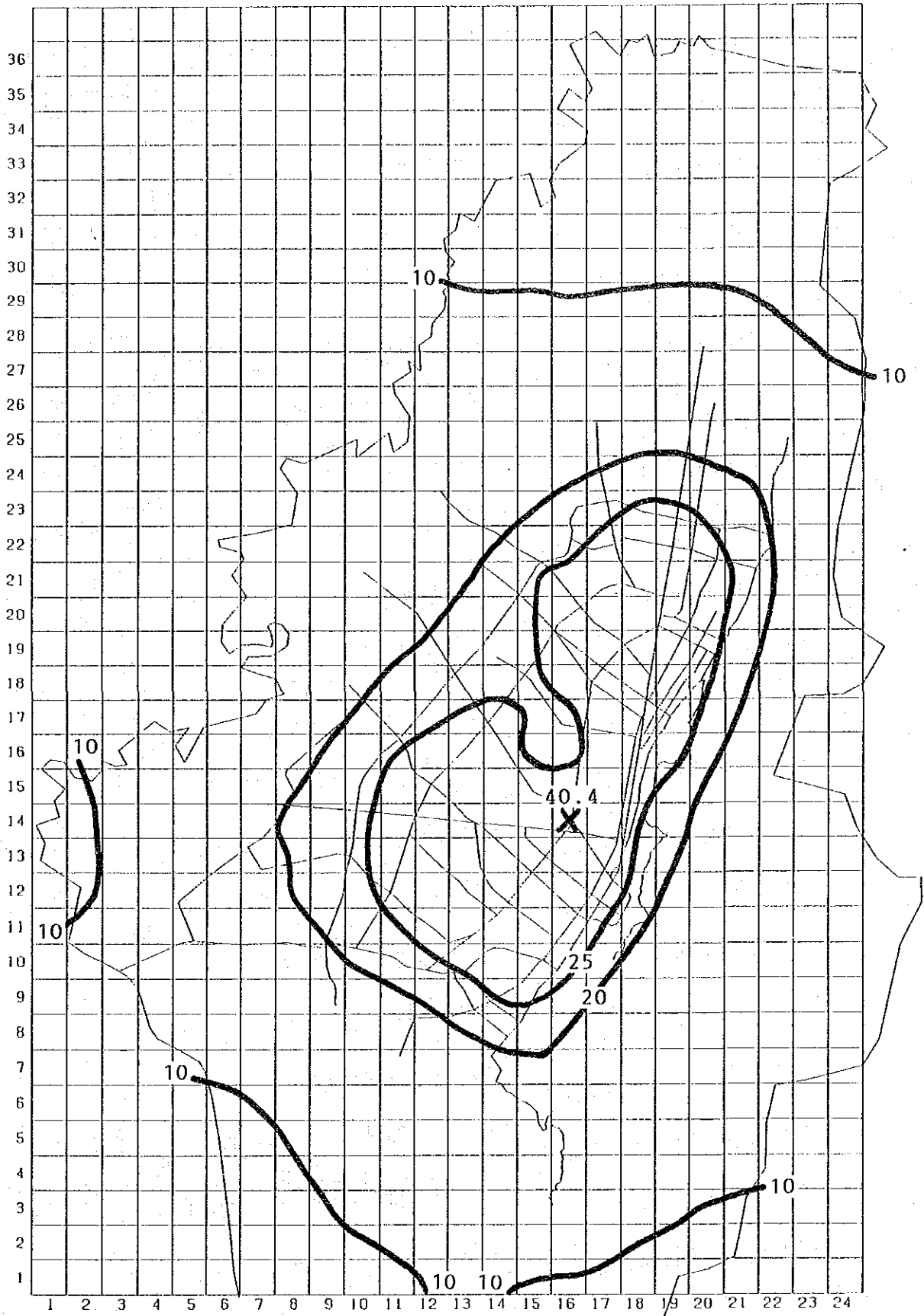


Fig. 6.3.6 Average Concentration Isopleths for NO₂ (All Sources)

× :Cmax Point

unit:ppm

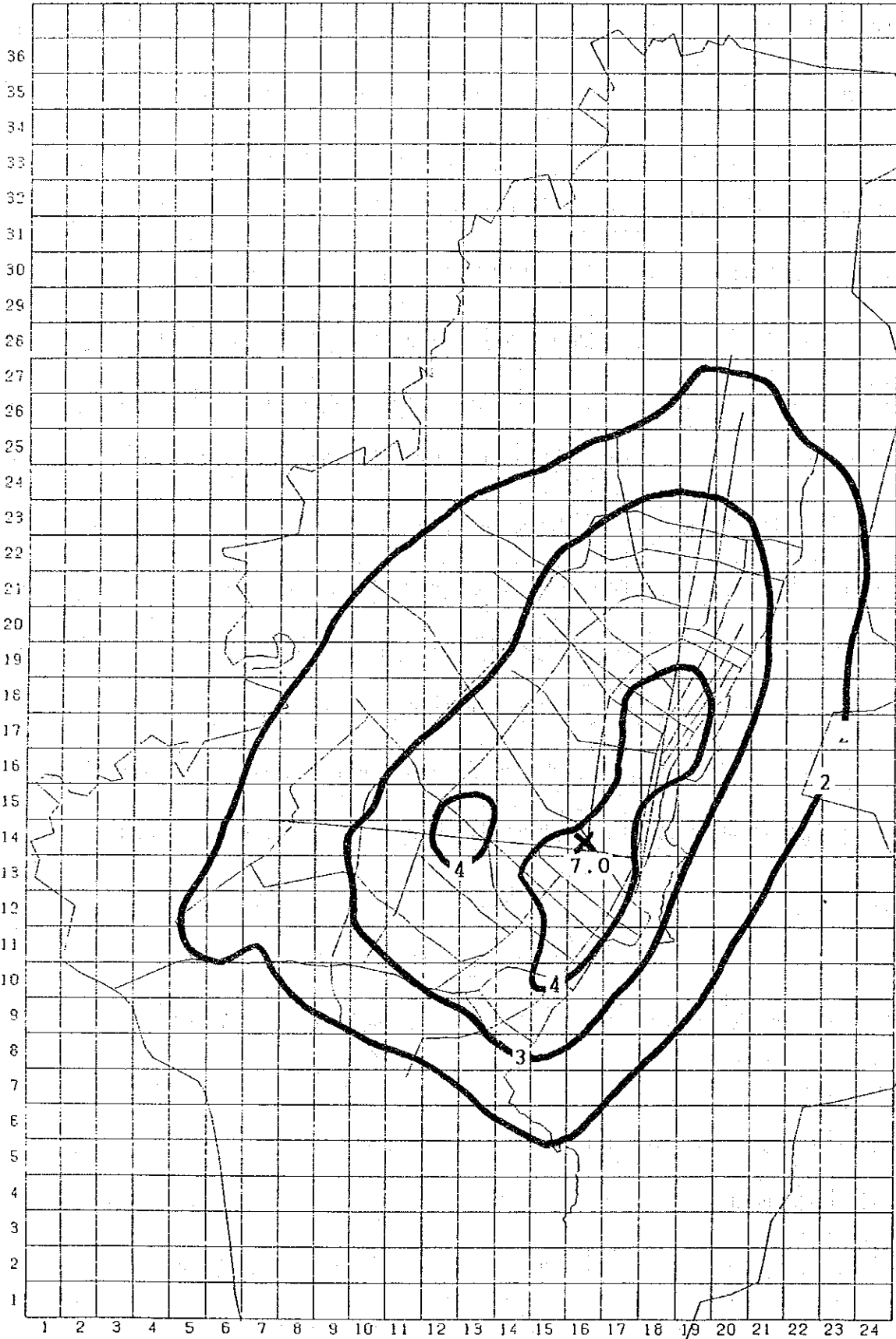


Fig. 6.3.7 Average Concentration Isopleths for CO (All Sources)

6.4 SPM Source Analysis according to the CMB Method

(1) Outline of the CMB Method

Generation of suspended particulate matter (SPM) can be traced back to artificial sources (factories, motor vehicles) and natural sources (soil, etc.). As the numerical simulation method using a dispersion model is not yet established, the SPM contribution ratio by source is mostly estimated in accordance with the CMB method. This survey has also used this method. For details of the CMB method, refer to Supporting Report.

(2) Data Used

Data used for analysis according to the CMB method necessary for this approach include the percent component of heavy metal elements in dust emitted from various sources and that of heavy metal elements in suspended particulate matters in the atmospheric environment. In this analysis, data on the percent component of heavy metal elements of sources and atmospheric environment, which were collected in the city of Santafe de Bogota, were used.

The percent component of heavy metal elements in SPM of the atmospheric environment was analyzed for 11 heavy metal elements using data sampled by means of the low volume air sampler at each station every month during a period from November, 1990 to May, 1991. The average value of this period was used as basic data.

The stations and heavy metal elements analyzed are shown below:

Stations: A. Servicio de Salud, B. Laboratorio, C. Puente Aranda,
D. El Tunal, E. San Juan de Dios

Heavy metal elements concerned: Cd, Cr, Mn, Fe, Zn, Cu, V, Ni, Co, Pb, Al

The metallic component concentration of SPM at each station during a period (used in the CMB method) is shown in Table 6.4.1.

Table 6.4.2 shows the metallic element concentration of dust emitted from the sources, which were used in the CMB method.

Table 6.4.1 Concentration of Metallic Element in the Ambient Air

(Unit: ng/m³)

Station Items	A	B	C	D	E
Cd	1.0	1.0	2.6	0.9	0.6
Cr	16.1	12.0	12.1	14.7	14.6
Mn	7.9	8.4	19.7	32.7	16.6
Fe	530.0	412.9	568.6	848.6	549.4
Zn	222.7	254.1	535.7	398.6	345.7
Cu	34.0	52.7	68.0	37.6	34.9
V	13.1	22.4	27.9	226.6	44.6
Ni	53.1	34.6	88.4	59.3	85.9
Co	12.7	12.4	10.7	5.3	135.6
Pb	219.9	207.3	241.3	400.1	401.4
Al	304.4	409.1	350.6	1046.9	597.9

Table 6.4.2 Concentration of Metallic Element from Sources (Unit: %)

Sources Items	Soil ⁽¹⁾	Coal ⁽¹⁾ Boiler	Oil ⁽¹⁾ Boiler	Auto- ⁽²⁾ mobile	Incine- ⁽³⁾ rater	Steel ⁽³⁾
Cd	0.000033	0.0001	0.00007	0.0	0.0500	0.0252
Cr	0.00527	0.00452	0.003	0.0	0.0850	0.316
Mn	0.0116	0.000832	0.031	0.0	0.0330	2.20
Fe	1.95	1.04	11.6	2.0	0.610	15.7
Zn	0.00706	0.00198	0.197	0.06	2.60	5.15
Cu	0.00184	0.00177	0.033	0.	0.360	0.370
V	0.00845	0.0241	1.136	0.	0.00270	0.0125
Ni	0.00112	0.00551	0.319	0.	0.	0.290
Co	0.000285	0.00218	0.007	0.	0.00210	0.00440
Pb	0.00466	0.00114	0.008	4.0	0.	0.
Al	4.88	12.2	0.0007	0.	0.420	0.999

Notice : (1) Measured Numbers in Bogota City

(2) Quoted Numbers from " Atmospheric Environment, Vol.12 P1143 "

(3) Quoted Numbers from " Analysis and Simulation of Air Pollution by SPM (supervised by Air Pollution Control Division of Japan Environmental Agency) "

(3) Analytical Result

Estimation of the contribution of sources to SPM concentration according to the CMB method may not necessarily prove reasonable in certain cases because numerical calculation is made according to the minimum square method under various prerequisites.

In this survey, combination of elements and the kind of sources was reviewed through trial and error and the actual regional state into account. Table 6.4.3 shows cases for which approximately reasonable results were obtained.

Table 6.4.3 Contribution of Sources to SPM Concentration Computed by the CMB Method

Unit : $\mu\text{g}/\text{m}^3$: Concentration
: (%)

Sources Stations	Total	Soil	Coal Boiler	Oil Boiler	Motor Vehicles	Incinerator	Steel	Unknown
A. Servicio de Salud	44.1 (100.)	2.0 (4.5)	1.2 (2.7)	5.3 (12.0)	5.4 (12.2)	12.6 (28.6)	-	17.6 (39.9)
B. Laboratorio	56.9 (100.)	5.2 (9.1)	0.9 (1.6)	1.9 (3.3)	5.2 (9.1)	12.5 (22.0)	-	31.3 (55.0)
C. Puente Aranda	59.3 (100.)	4.0 (6.7)	0.7 (1.2)	2.4 (4.0)	6.0 (10.1)	16.3 (27.5)	0.6 (1.0)	29.4 (49.6)
E. San Juan de Dios	52.5 (100.)	2.8 (5.3)	3.5 (6.7)	3.6 (6.9)	10.1 (19.2)	9.3 (17.7)	-	23.2 (44.2)

According to the result, the percentage of "Unknown" was highest at 40 - 55% in each point, followed by contribution of incineration of wastes at 18 - 29%, and contribution of motor vehicles 9 - 19%

Contribution of soil and boiler were slightly smaller in percentage at 5 - 9% and 1 - 12% respectively when compared with former sources. As is estimated from the above result, incineration of wastes and motor vehicles contributed greatly to generation of SPM in Santafe de Bogota. Because of high percentage of "Unknown", the accuracy of estimation may be considered not so high.

A probable reason is the limited data availability on heavy metal elements in SPM in the atmospheric environment (i.e., data were collected only 7 months for a period from November, 1990 to May 1991). Another reason may be that data on heavy metal elements in dust from pollutant sources may not necessarily agree with the actual state because reference to the survey cases of other countries (Japan, USA) using literatures was made depending on sources though these data were attempted to set on the basis of information materials available in Santafe de Bogota as much as possible.

It will be necessary for analytical result with much higher accuracy to collect and accumulate data on heavy metal elements in SPM in the atmospheric environment and on heavy metal elements in dust from various pollutant sources.

**CHAPTER 7 FUTURE CONCENTRATION
AND REQUIRED EMISSION REDUCTION**

CHAPTER 7 FUTURE CONCENTRATION AND REQUIRED EMISSION REDUCTION

For the future year of 2001, the air pollutant emission from each source and the air pollutant concentration were predicted, and the required emission reduction was calculated.

7.1 Prediction of Future Air Pollutant Sources

7.1.1 Factories and Establishments

(1) Prediction Method

Table 7.1.1 (#1004, #1005, and #1065) shows the economical growth rate and the industrial growth rate for the 1977 - 1988 period in Colombia and Bogota. The growth rate by industrial type was set on the basis of this table and the fuel consumption and air pollutant emission were predicted for the year 2001. The growth rate by industrial type is shown in Table 7.1.2.

Table 7.1.1 Growth of Gross Domestic Product in Colombia and Bogota City

	Growth Rate (1975=100)											Mean Annual Growth Rate	
	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	78-88(\$)	83-88(\$)
National industrial growth	116.4	123.6	125.1	121.8	120.0	121.4	128.6	132.4	140.3	149.0	152.3	2.77	4.65
1 Elaborate coffee	110.7	134.1	137.1	118.6	117.4	122.2	133.5	132.5	149.6	140.9	123.0	1.58	0.58
2 Meats and preparations	108.5	115.2	120.6	126.4	130.0	124.9	128.5	134.5	131.7	131.3	141.8	2.78	2.63
3 Cereal transformations	116.2	119.3	116.2	121.6	127.0	130.3	126.2	136.4	139.7	141.7	144.3	2.24	2.12
4 Milky products	119.1	122.2	114.2	116.4	128.4	134.0	130.7	136.6	147.4	151.0	158.8	3.02	3.51
5 Sugar and by-products	98.3	109.1	122.9	115.9	135.3	137.6	135.9	156.1	151.6	154.9	163.9	6.11	3.75
6 Beverages	114.1	126.0	134.7	134.0	131.3	134.8	136.7	145.6	148.3	152.6	148.2	2.73	1.96
7 Elaborate tobacco	93.9	94.3	99.9	101.7	92.5	98.1	116.5	125.4	116.1	109.3	102.5	1.21	1.38
8 Other elaborate foods	121.3	134.0	134.7	137.4	133.8	134.1	137.1	150.8	150.3	153.9	156.8	2.64	3.24
9 Textiles, confections and leathers	123.6	120.3	113.4	111.0	103.8	97.8	104.3	105.5	112.0	117.2	122.3	-0.02	4.59
10 Food and wood furnitures	112.4	107.5	110.9	99.2	99.9	103.0	107.8	113.4	126.9	140.5	158.0	3.10	8.99
11 Paper and printing	124.0	131.5	136.2	137.5	136.5	135.8	148.1	155.1	162.9	180.5	194.1	4.65	7.43
12 Chemicals and rubber	122.5	133.6	132.9	132.6	129.5	134.0	140.3	153.2	156.0	176.7	186.5	4.40	6.91
13 Petroleum refined products	94.1	86.7	92.9	102.3	101.8	108.8	115.0	122.6	145.3	171.8	164.6	6.07	8.97
14 Non-metallic minerals	123.7	126.3	130.9	127.3	129.0	133.9	137.6	142.2	161.8	176.4	189.5	4.45	7.27
15 Basic metals and metal products	126.8	130.4	130.2	125.1	115.0	118.3	123.2	117.4	128.5	150.0	182.0	2.72	6.72
16 Machinery and equipment	133.1	143.0	145.5	134.7	129.6	126.9	143.3	135.9	142.9	167.0	189.6	3.38	7.58
17 Transport material	121.7	136.1	132.0	124.6	117.3	114.8	149.5	113.2	122.5	140.7	166.0	4.22	9.40
18 Diverse industry	102.1	96.1	103.7	101.0	114.5	111.3	120.3	127.1	124.7	129.9	135.1	3.00	4.00
GDP growth of Nation (Annual %)	8.47	5.38	4.09	2.28	0.95	1.57	3.35	3.11	5.82	5.37	3.71	3.56	4.27
GDP growth of Bogota (Annual %)							3.50	3.50	4.97	5.36	4.58		4.38

Source : #1056, #1004, #1051

Table 7.1.2 Industrial Growth Rate

No.	Industry	Annual Growth Rate (%)	Growth Rate 2001/1990	Source Growth Rate in Table 7.1.1
1	Food and kindered products	2.67	1.34	Average of 2, 3, 5 and 8
2	Drink food	2.73	1.34	6
3	Tobacco	1.21	1.14	7
4	Textile	1.56	1.19	9
5	Leather, leather products	1.56	1.19	11 (annual growth rate
6	Footgear products	4.40	1.61	12
7	Lumber and wood products	3.70	1.49	10
8	Furniture and fixture	3.70	1.49	10
9	Pulp, paper and allied products	4.65	1.65	11
10	Industrial chemical products	4.40	1.61	12
11	Other chemical products	4.40	1.61	12
12	Petroleum, coal and products	4.40	1.61	12
13	Rubber products	4.40	1.61	12
14	Plastic products	3.00	1.38	18
15	Ceramic, stone and clay products	4.45	1.61	14
16	Glass products	4.45	1.61	14
17	Mineral and nonmetal products	4.45	1.61	14
18	Iron and steel	2.72	1.34	15
19	Non-ferrous metals and products	2.72	1.34	15
20	Transportation equipment	4.22	1.58	17
21	Auto industry	4.22	1.58	17
22	Other manufacturing industries	3.00	1.38	18
23	Hospitals	3.56	1.47	National GDP growth
24	Hotels	3.56	1.47	National GDP growth
25	Other establishments	3.56	1.47	National GDP growth

(2) Fuel Consumption

The fuel consumption was predicted using the industrial growth rate. The fuel consumption by facility type is shown in Table 7.1.3.

(3) Air Pollutant Emission

The current emission factor (Table 5.1.4) was used to predict the air pollutant emission in future. The air pollutant emission by industrial type is shown in Table 7.1.4, and that by facility type is shown in Table 7.1.5

The total annual emissions in 2001 of Dust, SO_x and NO_x, are 3,155 tons, 9,076 tons and 2,475 tons respectively.

Table 7.1.3 Predicted Annual Fuel Consumption in 2001 by Facility Type

No.	Facility Type	Liquid				Solid			Gas
		Crude oil	Light oil	Fuel oil	Others	Coal	Coke	Wood	Propane gas
1	Boiler	130944.3	25124.0	2818.4	47.3	83678.0		4061.0	
2	Gas furnace								835.7
3	Melting furnace for casting iron and steel						7332.0		
4	Melting furnace for aluminium			125.4	426.0				
5	Metal heat treating furnace	473.9	26895.2						
6	Petroleum refinery heater								489.1
7	Brick kiln (tunnel kiln)	3603.3				65095.0			
8	Brick kiln (downdraft round kiln)	720.7				25424.0			
9	Other kiln for bricks and clay pipes		467.9			38204.0			
10	Glass melting furnace	1468.5							
11	Direct heating furnace for inorganic chemical products		1005.5						
12	Direct heating furnace for foodstuff	164.3	973.5						344.5
13	Drying oven		11755.3					146.0	858.7
14	Incinerator for domestic waste		133.5						
15	Incinerator for industrial waste	6.1	85.5						
16	Burning kiln		90.1						
17	Other furnaces		304.3						
	Total	137381.1	66834.8	2943.8	473.3	212401.0	7332.0	4207.0	2528.1

Unit Liquid and gas : k_l/year

Solid : ton/year

Table 7.1.4 Predicted Pollutant Emissions in 2001 by Industrial Type

(Unit: ton/year)

No.	Industry	Dust	SOx	NOx
1	Food and kindred products	415.5	2022.3	287.5
2	Drink feed	1028.9	2484.6	550.0
3	Tobacco	6.0	29.1	3.4
4	Textile	171.5	949.3	123.7
5	Leather, leather products	2.5	34.8	4.3
6	Footgear products	14.9	73.7	8.7
7	Lumber and wood products	4.6	22.5	18.0
8	Furniture and fixtures	40.2	138.4	116.9
9	Pulp, paper and allied products	89.2	286.8	48.0
10	Industrial chemical products	20.0	96.1	12.4
11	Other chemical products	14.0	62.3	19.5
12	Petroleum, coal and products	32.6	72.5	9.2
13	Rubber products	15.8	88.5	16.4
14	Plastic products	0.2	0.0	1.1
15	Ceramic, stone and clay products	1088.3	1671.4	1105.6
16	Glass products	7.2	66.2	8.4
17	Mineral and nonmetal products	0.0	7.0	3.0
18	Iron and steel	14.1	90.8	9.2
19	Non-ferrous metals and products	18.8	2.9	3.6
20	Transportation equipment	28.7	166.5	23.9
21	Auto industry	0.8	9.9	4.5
22	Other manufacturing industries	96.3	459.0	60.7
23	Hospitals	26.6	153.0	21.2
24	Hotels	15.7	86.8	15.7
25	Other establishments	2.7	1.5	0.4
Total		3155.1	9075.9	2475.1

Table 7.1.5 Predicted Pollutant Emissions in 2001 by Facility Type

(Unit: ton/year)

No.	Facility Type	Dust	SOx	NOx
1	Boiler	1934.9	6951.9	1187.2
2	Gas furnace	0.2	0.0	1.1
3	Melting furnace for casting iron and steel	19.8	60.2	8.8
4	Melting furnace for aluminium	20.0	6.7	1.1
5	Metal heat treating furnace	32.8	208.6	27.4
6	Petroleum refinery heater	17.7	0.0	0.7
7	Brick kiln (tunnel kiln)	562.0	909.1	570.9
8	Brick kiln (downdraft round kiln)	213.9	324.1	217.3
9	Other kiln for bricks and clay pipes	316.3	441.5	321.4
10	Glass melting furnace	7.2	66.2	8.4
11	Direct heating furnace for inorganic chemical products	1.8	7.0	9.7
12	Direct heating furnace for foodstuff	2.1	14.2	2.8
13	Drying oven	21.5	81.8	114.2
14	Incinerator for domestic waste	2.7	0.9	0.2
15	Incinerator for industrial waste	1.8	0.9	0.2
16	Burning kiln	0.1	0.6	0.9
17	Other furnaces	0.5	2.1	2.9
	Total	3155.3	9075.8	2475.2

7.1.2 Motor Vehicles

(1) Number of Motor Vehicles Registered

For automobiles, the number of registered units was predicted from the distribution of the number of registered units by vehicle type and model year, (Table 7.1.6). The predicted number of buseta was assumed to be the same as the current number, judging from the present distribution of the number of registered units by model year.

For buses, prediction was made on the basis of the distribution of the number of registered units by model year and the predicted population of Bogota City (4,899,180 for 1990 and 6,590,979 for 2001) (#1004 and #1021). For trucks prediction was made while considering the distribution of the

number of registered units by model year, the national economical growth rate (annual 3.56%) from 1977 to 1988, and their recent size increase due to employment of diesel engine. The number of registered units by vehicle type for the year 2001 is shown in Table 7.1.7. To calculate the ratio of diesel vehicles in buses and trucks for the year 2001, it was assumed that the vehicles before 1960 were scrapped and the proportion of gasoline and diesel vehicles newly registered is 1:1. The ratio of diesel vehicles for the year 2001 is shown in Table 7.1.8.

Table 7.1.6 Motor Vehicle Registration in Santafe de Bogota City as Date of April 30, 1991

Model Year's	Passenger car	Jeep	Light truck	Microbus	Small bus	Bus	Truck	Dump truck	Trailer
-50	7,094	190	1,965	3	4	123	1,579	13	166
51-60	16,548	1,098	10,157	182	44	931	4,489	43	628
61-65	8,818	2,041	2,338	469	38	1,550	996	18	137
66-69	8,646	3,745	2,091	482	459	1,501	993	22	129
70-71	6,055	2,321	992	73	504	1,008	783	25	81
72-73	12,222	1,274	764	22	780	419	728	9	44
74-75	14,474	1,483	2,332	44	678	843	839	49	68
76	6,107	1,124	1,258	21	508	764	436	18	17
77	7,142	1,316	1,672	15	277	555	471	11	20
78	8,081	2,544	1,910	39	306	321	682	18	60
79	6,425	2,181	1,861	37	461	509	512	53	28
80	8,699	2,310	2,042	41	550	348	398	61	49
81	7,208	2,744	1,383	19	670	302	349	18	38
82	6,767	3,560	1,840	27	643	276	144	12	15
83	7,861	1,836	2,071	5	373	171	270	12	21
84	10,966	754	2,498	6	480	245	361	11	25
85	11,829	501	2,074	1	168	124	194	6	33
86	11,421	366	2,028	0	4	268	342	13	21
87	14,120	465	1,494	8	1	164	510	15	25
88	15,912	744	2,069	2	1	228	335	19	52
89	11,547	1,457	1,571	5	1	497	327	5	12
90	8,810	1,383	1,652	9	5	510	280	7	4
91	4,187	765	618	15	0	228	62	0	0
Other	23	4	3	0	0	1	2	0	1
TOTAL	220,962	36,806	48,683	1,525	6,335	11,889	16,082	458	1674

Source: 7 6022

Table 7.1.7 Predicted Number of Motor Vehicles Registered in Santa Fe de Bogota City in 2001

Vehicle Type	Growth of Vehicles Registered		Number of Vehicles Registered	
	(2001/1990)		1990	2001
	Passenger car	1.60		216,752
Jeep	1.45	1.52	36,037	52,254
Light truck	1.20		48,062	57,674
Microbus	1.00		1,510	1,510
Small bus	1.00	1.13	6,955	6,955
Bus	1.20		11,660	13,993
Trucks	1.20		18,149	21,779
Total	1.48		339,125	500,968

Table 7.1.8 Ratio of Diesel Engine Vehicle in Buses and Trucks

	Ratio of diesel vehicle (%)	
	1990	2001
Bus	18.1	25.8
Trucks	23.5	36.3

(2) Traffic Volume

The traffic volume of automobiles (gasoline-engine vehicles) was assumed to grow at an annual of rate 3.9% (#5028) of gasoline sales from 1980 to 1989 in Bogota City and its vicinity. Though the annual national economic growth rate was 3.78% (approximately same as the growth rate of Bogota City), the traffic volume of trucks was considered not so high as the economic growth in view of their increase in size due to employment of the diesel engine. This traffic volume was therefore predicted using the growth rate of the population. The growth rate of automobiles, buses and trucks is shown in Table 7.1.9.

Table 7.1.9 Growth Rate of Traffic Volume by Vehicle Type

Vehicle Type	Growth of Traffics (2001/1990)
Automobiles	1.52
Buses	1.35
Trucks	1.35

(3) Emission Factor

The future emission factor was calculated in a manner same as for the current one. The emission rate by vehicle type for the year 2001 is shown in Table 7.1.10, while the average emission rate in Table 7.1.11.

Table 7.1.10 Predicted Emission rates for Motor Vehicles in 2001

(Unit: g/km)

Vehicle	Item	Average Speed(km/h)									
		10	15	20	25	30	35	40	45	50	
Passenger car	HC	6.30	4.42	3.49	2.98	2.65	2.42	2.24	2.08	1.93	
	CO	59.98	46.55	37.90	33.42	30.44	28.35	26.56	24.17	22.98	
	NOx	1.19	1.05	0.99	1.00	1.26	1.13	1.23	1.31	1.39	
	SOx	0.12	0.11	0.11	0.11	0.10	0.10	0.09	0.08	0.07	
Jeep	HC	7.38	5.53	4.38	3.73	3.31	3.02	2.80	2.61	2.41	
	CO	76.59	55.46	45.15	39.81	36.26	33.77	31.64	29.15	27.37	
	NOx	1.25	1.10	1.05	1.06	1.11	1.19	1.29	1.38	1.46	
	SOx	0.14	0.13	0.13	0.12	0.12	0.11	0.10	0.09	0.08	
Light truck	HC	3.65	6.06	4.79	4.08	3.61	3.29	3.04	2.82	2.61	
	CO	102.61	73.70	59.85	52.68	47.99	44.38	41.64	38.25	35.88	
	NOx	1.52	1.34	1.23	1.30	1.37	1.47	1.60	1.71	1.81	
	SOx	0.21	0.20	0.19	0.18	0.17	0.16	0.15	0.14	0.13	
Microbus	HC	7.73	5.43	4.29	3.68	3.25	2.97	2.74	2.56	2.37	
	CO	71.08	51.34	41.79	36.86	33.57	31.29	29.29	26.98	25.34	
	NOx	1.22	1.08	1.02	1.03	1.09	1.17	1.27	1.35	1.43	
	SOx	0.12	0.12	0.12	0.11	0.11	0.10	0.09	0.09	0.08	
Small bus	HC	14.66	10.22	8.06	6.83	6.02	5.43	5.02	4.61	4.26	
	CO	168.32	119.17	96.08	84.16	76.71	70.76	65.34	60.38	55.86	
	NOx	2.09	1.87	1.81	1.87	1.99	2.15	2.33	2.50	2.66	
	SOx	0.37	0.31	0.28	0.26	0.25	0.24	0.23	0.23	0.22	
Buses	HC	18.72	14.65	11.66	9.42	7.73	6.19	5.49	4.69	4.15	
	CO	346.44	269.32	213.43	173.45	144.12	121.50	105.48	93.43	84.09	
	NOx	7.93	7.34	6.85	6.50	6.23	6.03	5.89	5.87	5.85	
	SOx	1.72	1.46	1.33	1.25	1.19	1.16	1.13	1.11	1.10	
Trucks	HC	17.51	13.82	11.09	9.03	7.47	6.32	5.38	4.63	4.11	
	CO	301.85	234.75	186.09	151.25	125.69	105.99	92.02	81.49	73.35	
	NOx	10.18	9.31	8.60	8.07	7.66	7.37	7.12	7.06	6.99	
	SOx	2.15	1.84	1.57	1.58	1.52	1.47	1.44	1.41	1.40	

Table 7.1.11 Predicted Average Emission rate for Motor Vehicles in 2001
(Unit: g/km)

Vehicle	Item	Average Speed(km/h)								
		10	15	20	25	30	35	40	45	50
Automobiles	HC	6.78	4.76	3.76	3.21	2.85	2.60	2.41	2.24	2.07
	CO	67.28	51.00	41.50	36.59	33.32	31.02	29.05	26.75	25.11
	NOx	1.24	1.09	1.03	1.04	1.10	1.18	1.28	1.37	1.45
	SOx	0.13	0.12	0.12	0.12	0.11	0.11	0.10	0.09	0.08
Buses	HC	17.96	13.59	10.75	8.75	7.30	6.24	5.39	4.70	4.20
	CO	309.15	236.41	187.86	154.69	130.77	112.25	98.81	88.29	79.98
	NOx	4.90	4.56	4.32	4.19	4.13	4.11	4.10	4.16	4.22
	SOx	1.27	1.08	0.98	0.92	0.88	0.85	0.83	0.82	0.81
Trucks	HC	17.51	13.82	11.09	9.03	7.47	6.32	5.38	4.63	4.11
	CO	301.85	234.75	186.09	151.25	125.69	105.99	92.02	81.49	73.35
	NOx	10.18	9.31	8.60	8.07	7.66	7.37	7.12	7.06	6.99
	SOx	2.15	1.84	1.67	1.58	1.52	1.47	1.44	1.41	1.40

(4) Quantity of Air Pollutant Emission

Table 7.1.12 shows the air pollutant emission for the year 2001 which was predicted using the predicted traffic volume and emission factor. The total annual emissions of HC, CO, SO_x and NO_x, are 28,947 tons, 898,375 tons, 2,057 tons and 13,886 tons respectively.

Table 7.1.12 Predicted Annual Pollutant Emissions from Motor Vehicles in 2001 by Vehicle and Zone Type

Vehicle type	Zone	Vehicle Kilos Traveled	HC	CO	SOx	NOx
Automobiles	Central zone	1,759	5,237	60,414	194	1,976
	Surrounding zone	4,753	13,182	154,021	507	5,482
	Small total	6,512	18,419	214,435	701	7,458
Buses	Central zone	246	2,961	51,686	256	1,100
	Surrounding zone	617	4,944	87,989	558	2,595
	Small total	863	7,905	139,675	814	3,695
Trucks	Central zone	51	412	6,934	79	400
	Surrounding zone	306	2,211	37,331	463	2,333
	Small total	357	2,623	44,265	542	2,733
Grand total		7,732	28,947	398,375	2,057	13,886

Unit V.K.T: 10⁶unit·km/year

HC, CO, NO_x and SO_x: ton/year

7.1.3 Aircraft

As for aircraft, since El Dorado Airport has no expansion plan, the number of take off and landing and therefore the air pollutant emission in future were assumed to be same in present.

7.1.4 Summary for Quantity of Air Pollutant Emission

The pollutant emissions quantity by source is shown in Table 7.1.13. The total annual emissions of Dust, CO, SO_x and NO_x in 2001 are 3,155 tons, 398,375 tons, 11,162 tons and 16,475 tons respectively. The growth rates of Dust, CO, SO_x and NO_x between 1990 and 2001 are 1.44, 1.38, 1.43, and 1.49 respectively.

Table 7.1.13 Predicted Air Pollutant Emission by Source in 2001

(Unit: ton/year)

Classification	Source	Dust	SO _x	NO _x	CO	HC
Stationary Sources	Factories and Establishments	3,155	9,076	2,475	-	-
Mobile Sources	Motor Vehicles	-	2,057	13,886	398,375	28,947
	Aircraft	-	29	114		
Total		3,155	11,162	16,475	398,375	28,947

7.2 Prediction of Concentration Distribution in Future

7.2.1 Prediction of Concentration at Monitoring Stations and Maximum Concentration Point.

Using future sources described in the previous item, predicted results of future concentration of each pollutants at monitoring stations and maximum concentration point are shown in Table 7.2.1.

Note that predicted value contains background concentration same as the present.

Though predicted concentrations are averaged value of 6 months, compared results of these concentration to the target concentrations are follows.

SO₂ concentration at monitoring stations is less than the target concentration (38.2 ppb) but concentration at maximum point is more than the target concentration.

NO₂ concentration at any predicted points is less than the target concentration (53.2 ppb).

CO concentration at predicted points excluding D. El Tunal is more than the target concentration (3.6 ppm).

Table 7.2.1 Computed Concentration in Future

Stationns	Items	SO2 (ppb)	NOx (ppb)	NO2 (ppb)	CO (ppm)
A.	Servicio de Salud	18.8	98.4	38.3	7.08
B.	Laboratorio	19.8	69.3	31.8	5.13
C.	Puente Aranda	27.3	70.6	32.1	4.52
D.	El Tunal	12.1	22.0	17.4	2.45
E.	San Juan de Dios	26.7	142.7	46.6	8.55
Cmax Point		43.7	163.3	50.0	9.58
Mesh Index		(12, 15)	(12, 15)	(12, 15)	(16, 14)

The contribution concentration by sources at monitoring stations and maximum concentration point is shown in Fig. 7.2.1 to 7.2.3.

As in the case of the present state, the contribution concentration of airplanes is not included.

(1) SO₂

The contribution ratio of factories to the predicted value is 29% - 65% while that of motor vehicles 16 - 62%, which is approximately equivalent to the present trend.

(2) NO_x

The contribution ratio of motor vehicles to the predicted value is 77 - 97%. As in the case of the present state, motor vehicles occupy more than half of the contribution in all stations and maximum concentration point.

(3) CO

As in the case of the present state, the predicted CO value covers automobiles only as a source. Therefore, the concentration excluding the background concentration is totally contributed by motor vehicles.

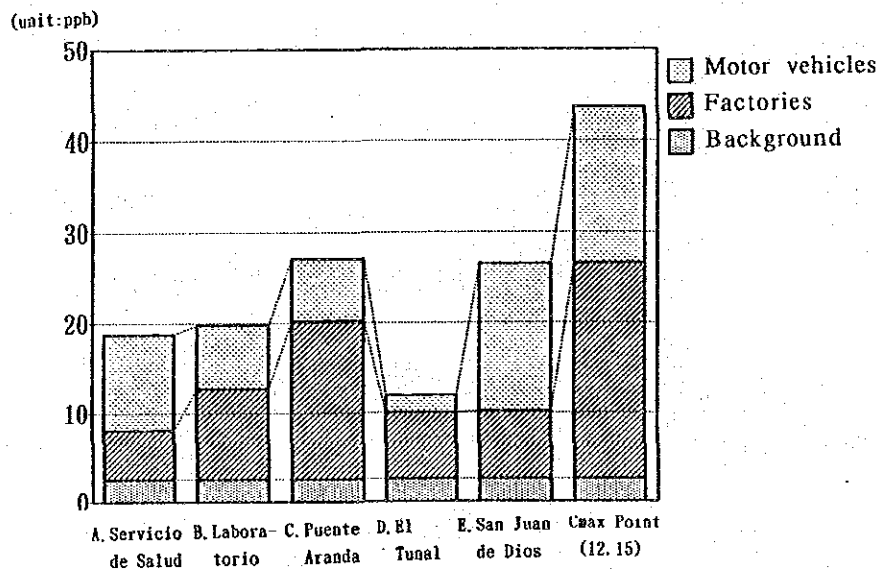


Fig. 7.2.1 Source Contribution to SO₂ Concentration

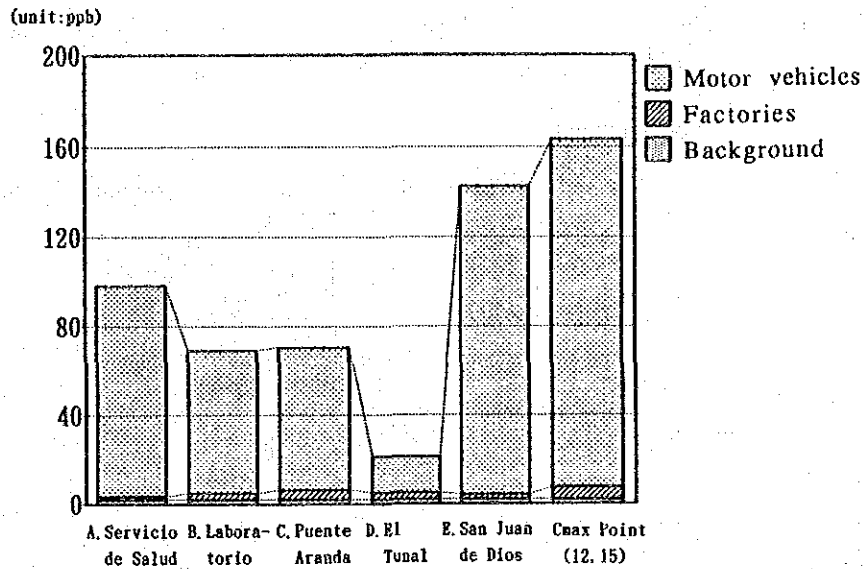


Fig. 7.2.2 Contribution of Sources to NO_x Concentration

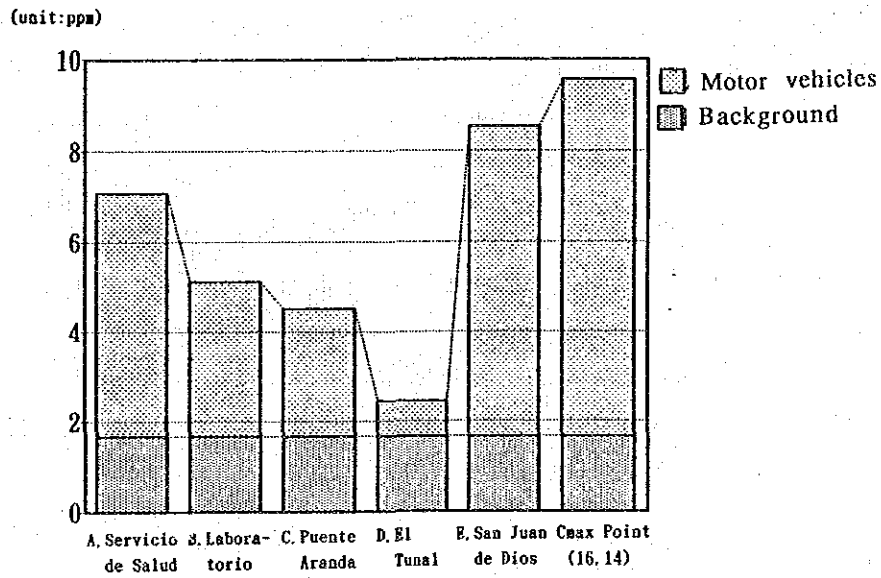


Fig. 7.2.3 Contribution of Sources to CO Concentration

7.2.2 Prediction of Plane Concentration Distribution

The plane distribution of concentration of air pollutants in future was predicted using future sources described in the previous item. The result is described below.

The contribution concentration distribution by source is described in Appendices.

(1) SO₂

The result of prediction on the SO₂ plane concentration distribution in future is shown in Fig. 7.2.4. The concentration of 15 ppb or more is distributed over the area similar to the present state and the maximum concentration of 43.7 ppb which is more than target concentration, appears in the mesh index (12, 15) same as the present state.

(2) NO_x, NO₂

The result of prediction on the NO_x plane concentration distribution in future is shown in Fig. 7.2.5. The concentration of 80 ppb or more is distributed in the area similar to the present state and in the area on its north side. The maximum concentration of 163.3 ppb appear in the mesh index (12, 15) different from the present state.

The result of prediction of the NO₂ plane concentration distribution in future is shown in Fig. 7.2.6. The trend of concentration distribution is similar to the case with NO_x, with the maximum concentration at 50.0 ppb which is more than target concentration, in the mesh index (12, 15).

(3) CO

The result of prediction of the CO plane concentration distribution in future is shown in Fig. 4.2.7. Though the trend of concentration distribution is similar to the case with NO_x, concentration more than target (3.6 ppm) is distributed in the city center and outskirts.

The maximum concentration of 9.6 ppm appears in the mesh index (16, 14) same as the present state.

x : Cmax Point

unit:ppb



Fig. 7.2.4 Average Concentration Isoleths for SO₂ (All Sources)

× :Cmax Point

unit:ppb

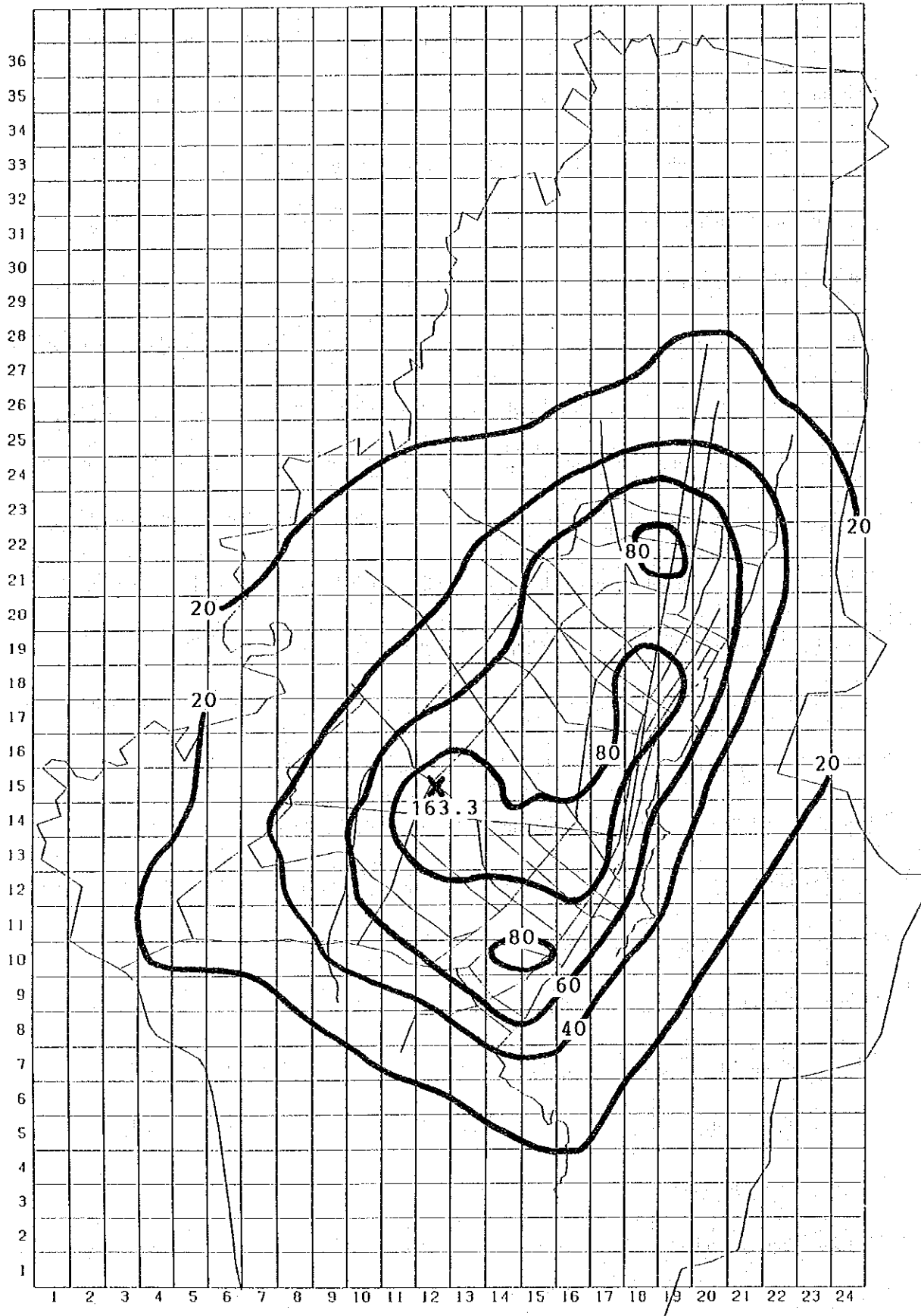


Fig. 7.2.5 Average Concentration Isopleths for NO_x (All Sources)

× :Cmax Point

unit:ppb

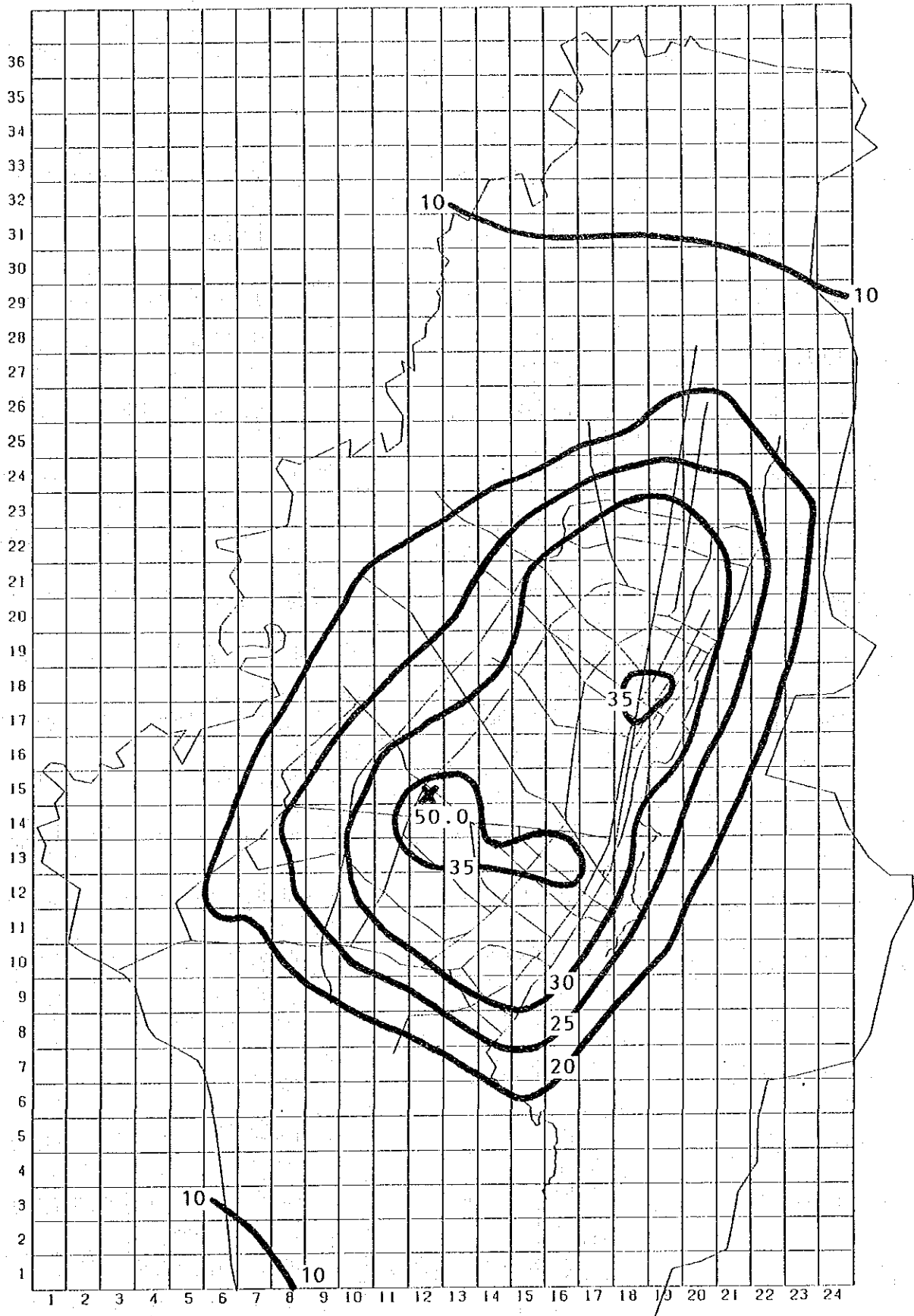


Fig. 7.2.6 Average Concentration Isopleths for NO₂ (All Sources)

× :Cmax Point

unit:ppm

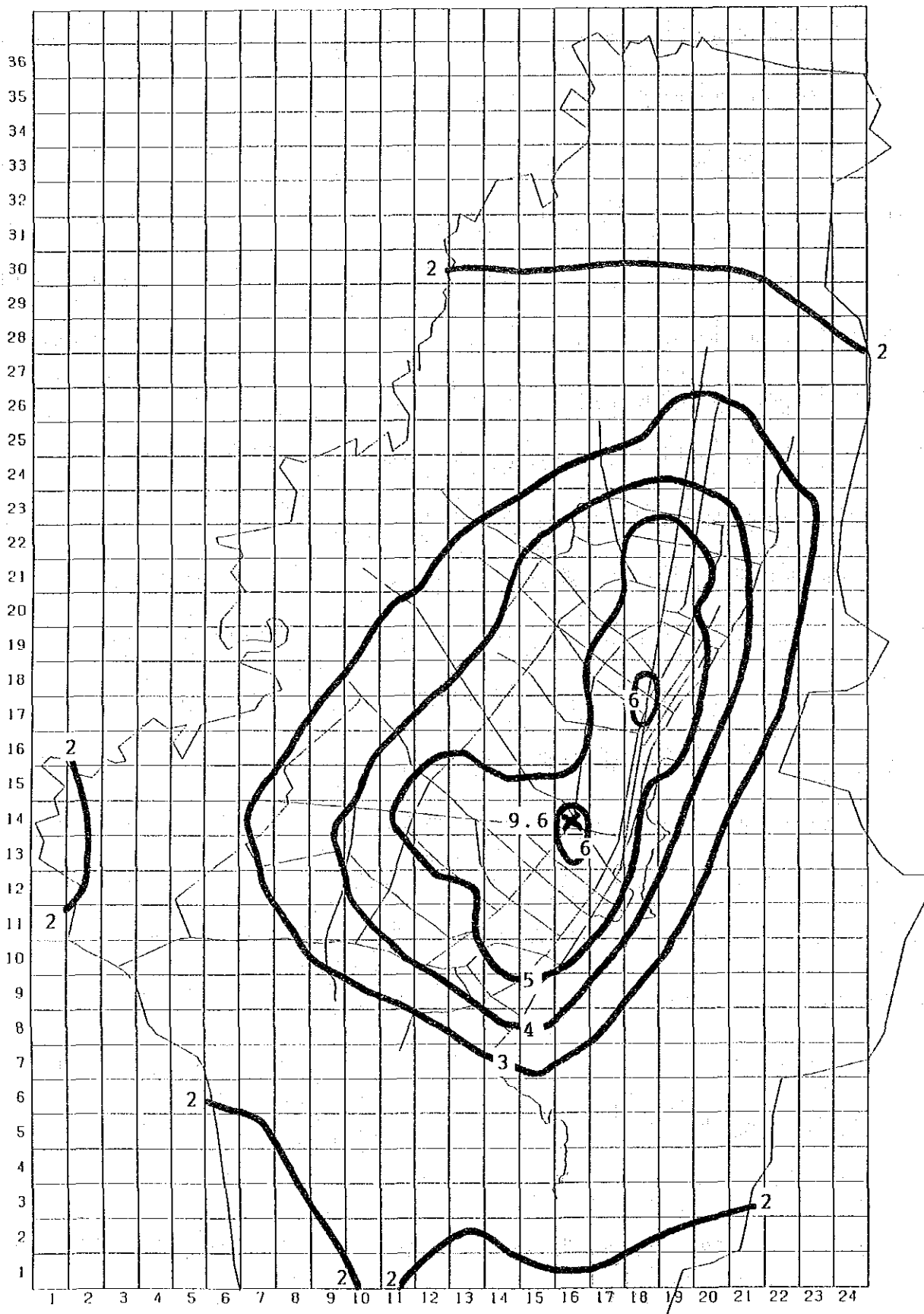


Fig. 7.2.7 Average Concentration Isopleths for CO (All Sources)

7.3 Target in Air Quality

(1) Target Concentration

Against air pollution, the ambient air quality standard has been set, therefore the targets in air quality is expected to satisfy the standards even in future.

In this study the air quality predicted by the dispersion simulation is given as annual average concentration. So, the target concentration values are also set in terms of annual average concentration.

(2) Determination of Target Concentration of SO₂, NO₂, SP and CO

For SO₂, NO₂, SP and CO the target concentration in the annual average corresponding to the ambient air quality standard was set using the regression line. With the pollutants like SO₂ which also have the annual average criterion, the lowest value among the target concentrations and the annual average concentration was chosen as the final target concentration.

Generally speaking, relationship between actual annual average and a short-term average concentration varies somewhat from year to year. This is particularly remarkable when the measured concentration is below the corresponding standard value. Accordingly, the target concentrations in annual average should be checked once in several years using the newly accumulated data.

On the other hand, what is to be emphasized is that target concentrations should be determined using the one-year data. But in this study, only 8-month data were available to estimate the target concentrations. The estimated target concentrations of SO₂, SP and CO are shown in Table 7.3.1. As can be seen from this table, with SO₂ and SP, the target concentrations corresponding to the short-term criteria are higher than the standard values of annual average, so the former values were not adopted. But, for CO, the target value corresponding to the 8-hour criterion was lower than the standard value for annual average, so the former value was adopted as the final target concentration.

Table 7.3.1 Target Concentration in Annual Average by Air Pollutant

Item	Air Quality Criteria	Ambient Air Quality Standard	Target Concentration in annual average	Regression Equation (*2)
SO ₂	Annual average	38.2 ppb	-	-
	Daily average (*1)	152.8 ppb	69.8 ppb	y=0.46x-0.5 r=0.89
	3-hour average	573.1 ppb	252.8 ppb	y=0.477x-20.6 r=0.88
NO ₂	Annual average	53.2 ppb	-	-
SP	Annual average	100 µg/m ³	-	-
	Daily average (*1)	400 µg/m ³	107 µg/m ³	y=0.19x +30.7 r=0.44
CO	Annual average	-	-	-
	8-hour average	13.1 ppm	3.6 ppm	y=0.38x-1.34 r=0.96
	1-hour value	43.7 ppm	12.2 ppm	y=0.35x-3.13 r=0.90

*1 The second highest value of all measured values

*2 y : Annual average

x : Value corresponding to the averaging time

r : Correlation coefficient

(3) Determination of Target Concentrations of HC and O₃

The ambient air quality standard for O₃ is one-hour value of 86.6 ppb. Since O₃ is produced from NO_x and NMHC through complicated photochemical reaction, it is meaningless to set the O₃ target concentration like SO₂ and CO. This study showed that the O₃ concentration exceeded the standard value as shown in Table 7.3.2, and NMHC marked high concentration as well. Therefore, in order to satisfy the ambient air quality standard for O₃, it is necessary to reduce the concentration of NMHC and NO_x which are source pollutants of O₃.

Table 7.3.2 Concentration of O₃, NMHC and NO_x

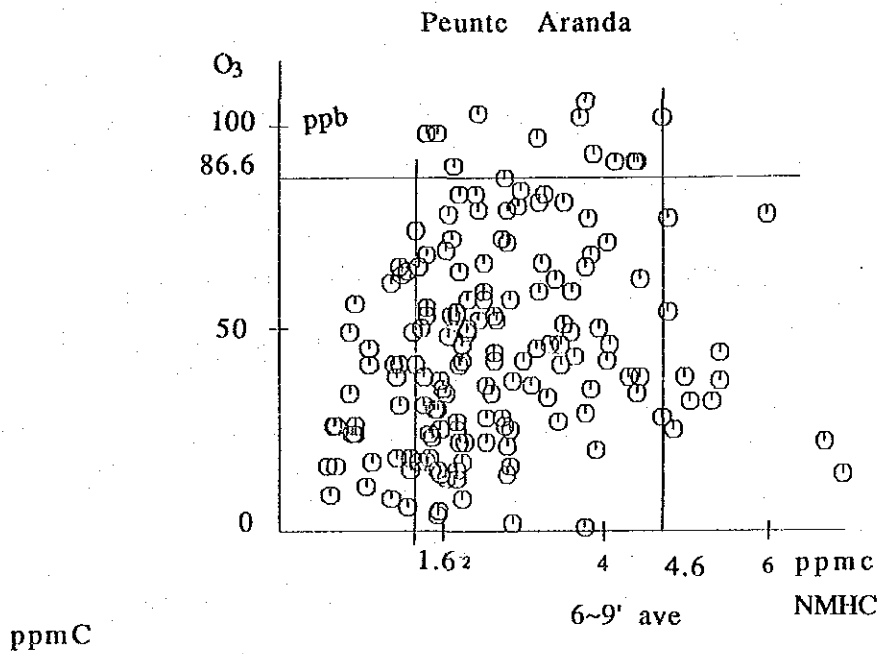
STATION NAME	O ₃ (86.6 ppb)		NMHC		NO _x
	1 hr-Max	Over times*	Ave	1 hr-Max	Ave
Puente Aranda	123 ppb	0.4%	1.86ppmC	13 ppmC	39.2 ppb
San Juan de Dios	114	0.2	2.70	11	101.2

* Frequency exceeding the standard value

To determine the NMHC and NO_x concentration levels necessary to satisfy the O₃ standard in Santafe de Bogota City, is difficult for the time being because of the extreme complexity of the photochemical reaction and lack of data available at the present.

In this study, taking into consideration that in Japan the target average concentration of NMHC from 6:00 to 9:00 has been set at 0.2 - 0.3 ppmC, and the relationship between the 3-hour average of NMHC from 6:00 to 9:00 and daily maximum 1-hour value of O₃ at Puente Aranda (Fig.7.3.1), 0.5 ppmC (about 1/3 of the current concentration level) was set for the temporary target concentration from NMHC. However, it should be recommended that appearance state of the O₃ concentration and its relation to NMHC should be reexamined when the NMHC concentration reduces to a certain level.

Fig. 7.3.1 Standard Value of O₃ : 86.6 ppb



(4) Summary for Target Concentration

The target concentrations are summarized in Table 7.3.3.

Table 7.3.3 Target Concentration

Item	Target Value
SO ₂	38.2 ppb
NO ₂	53.2 ppb
SP	100 µg/m ³
CO	3.6 ppm
NMHC	0.5 ppmC

7.4 Required Reduction Rate

Table 7.4.1 is comparison between the predicted air pollutant concentration in 2001 and the required reduction rate.

With CO, the predicted concentration exceeds the target concentration in the four monitoring stations other than the Station D (El Tunal). And this is also true in the greater part of the Santafe de Bogota City area predicted.

As regards SO₂, the concentration of the monitoring stations is lower than the target concentration while exceeding the target value in certain areas including the points where the value is maximum.

Table 7.4.1 Predicted concentration (2001) and Reduction Rate

Monitoring station	Air pollutant	CO (ppm)		NO ₂ (ppb)		SO ₂ (ppb)	
		3.6		53.2		38.2	
		Predicted concentration	Reduction rate (%)	Predicted concentration	Reduction rate (%)	Predicted concentration	Reduction rate (%)
(A) Servicio de Salud		7.1	49	38.3	-	18.8	-
(B) Laboratorio		5.1	29	31.8	-	19.8	-
(C) Puente Aranda		4.5	20	32.1	-	27.2	-
(D) El Tunal		2.5	-	17.4	-	12.0	-
(E) San Juan de Dios		8.6	58	46.6	-	26.6	-
Max. concentration		9.6	63	50.0	-	43.7	13%

(1) CO

The required CO reduction rate is 63% at the mesh point with maximum concentration, 58% at the Station E (San Juan de Dios) which is located around the road, followed by 49% at Station A (Servicio de Salud). As is evident from the result, the reduction rate around the road under very heavy influence of CO emission from motor vehicles is so high that as the tentative required reduction rate, was chosen the reduction rate of 49% at Station A which is regarded as a general ambient air quality monitoring station. When the tentative rate is achieved, the reduction rate will be set to 63% in order to achieve the target value around the road.

(2) SO₂

The SO₂ reduction rate is 13% at the mesh point where the concentration is maximum. The reduction rate is 0% for the monitoring stations, but their concentration level is high nearly equivalent to the target value. So, the reduction rate will be set to 26% in order to reduce their concentration to the current concentration level.

(3) NO₂

The NO₂ reduction rate is 0% because the predicted value is lower than the target value at all monitoring stations and points predicted. But the future concentration predicted is not always low enough and the current concentration level should be maintained. Accordingly, the reduction rate was set to 33%.

(4) NMHC

For NMHC which is one of source materials of O₃, the reduction rate will be set to reduce the concentration to 1/3 of the current concentration, as shown in 7.3, in view of the current concentration appearance state. The required reduction rate however will be extremely strict at 80% (i.e., reduction to about 1/5 of the current concentration when considering that the traffic volume will increase by about 1.5 times in 2001 and the unknown sources at present will increase by the same rate.

Though in this study were not included other sources than motor vehicles for hydrocarbon, the emission amount from factories may be negligibly smaller than those from motor vehicles because there is no large chemical factories in Santafe de Bogota City.

The reduction rate for each pollutant may be summarized as follows: 49 - 63% (around road) for CO, 13 - 26% for SO₂, 0 - 33% for NO_x, and 80% for NMHC.

**CHAPTER 8 CONTROL MEASURES AGAINST
AIR POLLUTANT SOURCES**

CHAPTER 8 CONTROL MEASURES AGAINST AIR POLLUTANT SOURCES

8.1 Control Measures against Factories and Establishments

8.1.1 Necessity of Control Measures and Actual State of Air Pollutant Sources

The flue gas measurement results with 51 factories show that few factories exceeded the current dust emission standard of the Colombia Air Pollution Control Act (#2001). The factory investigation by questionnaire for the smoke and soot emitting facilities shows that the total 381 units include 177 boilers using liquid fuel, 27 coal firing boilers, and 83 brick/clay pipe kilns and that these three kinds of facilities account for about 76%. Moreover, the boilers are mostly small in size and old.

Combustion control is not good and there were some liquid fuel combustion boilers emitting black smoke. In particular, coal firing boilers emit much black smoke: black smoke from low stack give bad effect on houses nearby.

Dust collectors are the only exhaust gas treatment facilities and only 26 units are in operation. To make the matter worse, their efficiency is as low as 50 ~ 60%.

The sulfur content of the fuel is 2.3% for crude oil (Crudo de Castilla), 0.4% for light oil (ACPM), and 0.6 ~ 0.7% for coal, showing very high sulfur content in crude oil. Assuming that crude oil is burnt with a excess air of 1.24, the SO_x concentration in the flue gas is about 1,300 ppm. The stacks are low in general. As a result, low stacks emit considerably high concentration of SO_x.

8 case studies were made based on the flue gas measurement results using the plume model. The calculated concentrations on the ground are shown in Table 8.1.1.

Each calculation facilities is a rather serious problem; If there are several coal firing facilities, the concentration on the ground will be high.

So, not only control against facilities violating the emission standard but also control of high concentration in a short period are necessary.

Table 8.1.1 Maximum Concentration on the Ground by Source Conditions

Calculation conditions: Plume model (σ_y equation), Dilution Coefficient 1.82
 Effective stack height: CONCAWE equation

Smoke source		Meteorological conditions		Effective stack height	X max (m)	C max		
		Wind speed	Atmospheric stability	He (m)		SO ₂ (ppb)	NO _x (ppb)	Dust ($\mu\text{g}/\text{m}^3$)
1	Boiler (Crude 300 HP)	1.0	A	50.8	268	31.73	1.44	19.46
2	Boiler (Crude 300HP)	1.0	A	66.7	321	12.53	1.32	10.05
3	Boiler (Carbon 120HP)	1.0	A	55.4	284	1.55	1.55	14.02
4	Boiler (Carbon 300HP)	1.0	A	75.9	350	39.69	12.69	52.92
5	Boiler (Carbon 75HP)	1.0	A	45.3	221	2.16	1.30	11.34
6	ditto, (during coal feeding)	1.0	A	47.0	228	2.74	1.12	46.58
7	Clay pipe kiln	1.0	A	42.9	210	2.02	0.83	22.34
8	ditto, (during coal feeding)	1.0	A	44.4	217	2.91	0.56	55.29

X max: Appearance distance of maximum concentration on the ground

C max: Maximum concentration on the ground

As regards the present air quality, though the measurement results show that SO_x, NO_x, and SPM (Suspended Particulate Matter) satisfy the ambient air quality standards, they are very high. In particular, SP (SPM is particles with diameter less than 10 μ) may possibly exceed the standard.

Moreover, business activities and fuel consumption are expected to grow at an annual rate of 4%, so the dust emission will increase by about 40% in 2001.

Under such circumstances, some measures must be taken to maintain the emission at the present level.

8.1.2 Present State of Emission Control

Santafe de Bogota City has regulated the air pollution in compliance with the act (#2001) based on the Sanitation Law of 1979. Since the act is intended to cover the country as a whole, the regulation objects and standard values are not appropriate to present Santafe de Bogota City due to the reasons below.

- ① The regulation objects of dust emission are divided into coal firing boilers, asphalt plants, incinerators and other facilities. Crude oil combustion boilers and brick/clay pipe kilns, which are major

pollutant sources in Santafe de Bogota City, are included in the category of "Other factories" whose standard value is not so strict.

- ② As regards SO_x, the standard value is set only for sulfuric acid plants. Against the other facilities only emission height is regulated.
- ③ As regards NO_x, only nitric acid plants are regulated.

The standard value is extremely low compared with that of Japan, so NO_x emission of considerably high concentration will not violate the emission standard.

Activities to control air pollution are executed by the government in conjunction with local governments. The government, particularly the Ministerio de Salud, sets up the national standards, while the local governments can establish their own standards. In the case of Sanfate de Bogota City, the Secretaria Distrital de Salud of the City is in charge of the specific functions, such as supervisory and guidance for air pollutant sources.

As the new constitution has been promulgated, the agency of environment is planned to promote environmental protection.

Appropriate institutes, organizations, and control technologies are necessary to execute air pollutant control effectively. However, in the case of Santafe de Bogota City, the following problems must be solved:

- ① Insufficient budget and organization in the national and municipal environmental administration
- ② Insufficient production technology of air pollution control equipment and engineers for air pollution control
- ③ No preferential treatment in financing and taxes to promote air pollution control

8.1.3 Control Measures against Air Pollutant Sources

Following will be the control measures against air pollutant sources; revision of the emission standard, dust emission reduction through combustion control, and SO_x reduction through reduction of sulfur content in the fuel, followed by introduction of dust collectors and NO_x control measures.

(1) Emission Regulation (See Supporting Report 5.1.1)

In the present law the emission standards for crude oil combustion boilers and brick kilns are so low that they will be not able to meet the emission increase in the future.

In this context, the standard value for this short term is to be set approximately equal to the current level, and in the medium and long term the standard value is to be set to cope with the emission increase. Facilities with fuel consumption at 50 l/h or more (as converted to crude oil will be regulated). For smaller boilers, their dust emission will be monitored and they will receive guidance and advice concerning combustion control technology.

For areas where facilities are so densely located that there will be high air pollutant concentrations, following measures will be taken; special emission standard, restriction of fuel kinds, introduction of new emission standard for new/added facilities and their obligation to install air pollution control equipment.

① Dust emission standard

Flue gas measurements show that except for two or three facilities, the dust emission rates from the facilities are generally under the emission standard. But there are several liquid fuel combustion boilers whose emission rates are higher than those of coal firing boilers. Because the contribution of brick/clay pipe kilns to the total dust emission is high, the standard value equivalent to the one for coal firing boilers will be necessary for brick and clay pipe kilns and asphalt plants.

The emission standard for the short term is intended to achieve 10 ~ 20% dust reduction, and the emission standard for the long term is intended to achieve about 40% reduction of dust emission due to expansion of industrial activities.

As regards coal firing which produces black smoke in a short period, the black smoke concentration must be regulated to No.2 or below of the Ringelmann Chart in addition to the emission standard.

② Nitrogen oxides emission standard

With the present NO_x emission control, only nitric acid plants are regulated. Nitrogen oxides are the source materials to cause photochemical smog and their emission must be controlled.

The emission rate of nitrogen oxides varies considerably depending on combustion control, kinds of combustion units and kinds of fuels. So, the emission standard must be set for each smoke and soot emitting facility.

The standard value for medium to long terms is intended to achieve reduction of about 50% for crude oil combustion boilers and about 17% for coal firing boilers. The similar standard value will be set for other facilities.

③ Sulfur oxides emission standard

The emission rate of sulfur oxides varies depending on the sulfur content of the fuel. Sulfur in the liquid fuel is considered to be emitted entirely. However, with solid fuel (particularly coal), the sulfur in the fuel is not completely emitted; only about 80% of the sulfur is emitted from combustion units. The sulfur content of the crude oil which is popularly used in the smoke and soot emitting facilities is about 2.3%, and the exhaust gas is emitted from low stacks. Since SO₂ concentration and symptoms of bronchial asthma are said to be closely related, the emission rate must be regulated for other combustion facilities as well.

Plants other than sulfuric acid plants must be also under regulation, based on emission standards with definite oxygen concentrations in the flue gas by facility type. The short-term standard is intended to achieve reduction of 7% of the SO_x emission and the medium- long-term standard is intended to reduce about 20% of SO_x emission.

In the future, control of the total SO_x emission must be considered to meet the increase of the facilities and air pollution due to business expansion.

④ Relationship between emission standard and concentration on ground

Air pollutant emitted from a stack is diluted in the atmosphere and reaches to the ground. Emission standard to control air pollutant emission rate from smoke and soot emitting facilities is an allowable emission rate; if a facility observes it, the air pollutant emitted from the stack does not give a concentration on ground higher than a certain level (e.g. ambient air quality standard).

In it is also taken into consideration easiness of control measures against facilities.

Relation between air pollutant emission rate (emission standard) and concentration on ground varies depending on meteorological conditions, such as wind, atmospheric stability and source conditions such as stack height and temperature of flue gas. In Japan in the "Sulfur Oxides Emission Standard - K-value Control" of the Japanese Air Pollution Control Act are used Bosanquet equation and Sutton equation.

The maximum concentration on ground can be calculated by the following Sutton model:

$$C_{\max} = \frac{2q}{2.72 \cdot \pi \cdot U \cdot H_e^2} \cdot \frac{C_z}{C_y} \cdot \frac{T_1}{273} \cdot \frac{1}{3600}$$
$$= 0.234 \frac{q}{U \cdot H_e^2} \cdot \frac{C_z}{C_y} \cdot \frac{T_1}{273} \cdot \frac{1}{3600}$$

C_{\max} : Maximum concentration on ground (ppm)

q : Air pollutant emission rate (m^3N/hr)

C_y, C_z : Dispersion parameter

U : Wind speed (m/sec)

H_e : Effective stack height (m)

T_1 : Air temperature

Assuming representative meteorological values of $U = 6$ m/s for the wind speed, $C_y = 0.47$ and $C_z = 0.07$ for dispersion parameters (with the atmospheric stability assumed as neutral), and $15^\circ C$ for the air temperature, the maximum concentration on ground per hour is calculated as follows:

$$C_{\max} = 0.234 \frac{q}{6 \cdot \pi \cdot H_e^2} \cdot \frac{0.07}{0.47} \cdot \frac{273 + 15}{273} \cdot \frac{1}{3600}$$

$$= 1.7 \frac{q}{H_e^2} \text{ (ppm)}$$

Note that this value is calculated as follows when the air pollutant emission rate is expressed in kg/hr:

$$C_{\max} = 9.6 \cdot \frac{1}{U \cdot H_e^2} \text{ (mg/m}^3\text{)}$$

The distance between the source and the maximum concentration on ground is expressed as follows:

$$X_{\max} = \frac{H_e^{2/(2-n)}}{C_z} \text{ (m)}$$

* n = 0.25 when neutral

Relationship between maximum concentration on ground "C_{max}" and the effective stack height "H_e" when q is assumed 100 m³N/h is shown in the following table.

(q: 100m³N/h, U: 6 m/s)

He (m)	30m	50m	100m	200m	300m	400m	500m
C _{max} (ppm)	0.189	0.068	0.017	0.004	0.002	0.001	0.0007

Note that the maximum concentration on ground of 0.189 ppm for H_e at 30m exceeds the Japanese ambient air quality standard for SO₂. of 0.1 ppm (one-hour value).

When there are more than one stacks in an area, the concentration on ground becomes much higher due to superimposition of each concentration. So, in setting the emission standard (which determines the allowable emission rate per stack), the source conditions must be taken into consideration: Each area will have its own emission standard.

Taking the case of the sulfur oxides emission standard of Japan, the emission rate for a stack is determined as follows:

- Emission rate for the concentration on ground not to exceed 0.030 ppm in areas where the regulation is most loose
- Emission rate for the concentration on ground not to exceed 0.002 ppm in area where the regulation is most strict (wards of Tokyo, etc.)

Assuming H_e is 100m, the emission rate for these concentrations on ground is calculated at 177 m^3N/hr for 0.03 ppm and 12 m^3N/hr for 0.002 ppm under the previous meteorological conditions.

Relation between the 24-hour average (daily average) and one-hour value varies depending on the meteorology of the area concerned, mainly on the appearance frequency of each wind direction. The relation proposed by Meade et al shows that the 24-hour value is about one half (0.59) of the one-hour value.

(2) Control Technologies (See Supporting Report 5.1.2)

In order to reduce air pollutant emissions, methods which are economical and the most efficient must be taken.

Since the facilities in Santafe de Bogota City are mostly small in size and obsolete, the following methods centering on combustion control and reformation of fuels are recommended to reduce pollutant emissions mainly.

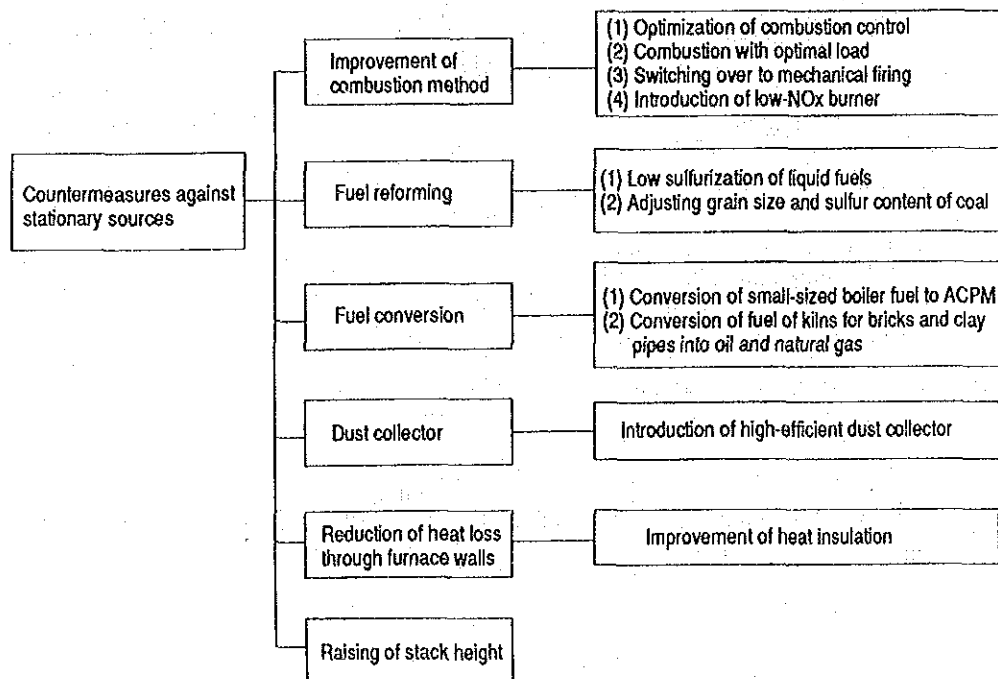


Table 8.1.2 shows the countermeasure by facility type.

Table 8.1.2 Countermeasures against Smoke and Soot Emitting Facilities (Draft)

Facilities	Short-term Countermeasures	Medium- and Long-term Countermeasures
BOILER (CRUDO)	<ol style="list-style-type: none"> 1. Combustion method <ol style="list-style-type: none"> (1) Low excess air combustion (2) Optimizing of combustion load 2. Combustion equipment <ol style="list-style-type: none"> (1) Preparation of instruments for combustion control 3. Fuel reforming <ol style="list-style-type: none"> (1) Use of crude oil with 2% Sulfur content (Mixed oil) 4. Fuel conversion <ol style="list-style-type: none"> (1) Small-sized boiler: Use light oil 5. Other <ol style="list-style-type: none"> (1) Improvement of heat insulation 	<p>Steam injection method</p> <ol style="list-style-type: none"> 1) Low NOx burner 2) High efficient dust collector <p>Reduction of the sulfur content to 1.8% (Mixed oil)</p>
BOILER (CARBON)	<ol style="list-style-type: none"> 1. Combustion method <ol style="list-style-type: none"> (1) Low excess air combustion (2) Change of coal input method (small-sized coal) (3) Constant load operation 2. Combustion equipment <ol style="list-style-type: none"> (1) Preparation of instruments for combustion control (2) Preparation of draft equipment 3. Fuel adjusting <ol style="list-style-type: none"> (1) Combustion of small-sized coal (low sulfur reformed coal) 4. Fuel conversion <ol style="list-style-type: none"> (1) Use of the small-sized boiler and light oil 5. Others <ol style="list-style-type: none"> (1) Improvement of heat insulation 	<p>Stoker method</p> <ol style="list-style-type: none"> 1) Adoption of fluidized bed combustion 2) High efficient dust collector
BRICK KILN	<ol style="list-style-type: none"> 1. Combustion method [Batch furnace] <ol style="list-style-type: none"> (1) Change of coal input method (2) Change to the stoker method 2. Combustion system <ol style="list-style-type: none"> (1) [Batch furnace] (2) [Continuous furnace] (3) Dust collector 3. Fuel reforming <ol style="list-style-type: none"> (1) [Batch furnace] (2) Combustion of small-sized mixed coal (low sulfur reformed coal) (3) [Continuous furnace] (4) Combustion of fine coal (low sulfur reformed coal) 4. Fuel conversion <ol style="list-style-type: none"> (1) [Batch furnace] (2) [Continuous furnace] 5. Others <ol style="list-style-type: none"> (1) Improvement of heat insulation 	<p>[Batch furnace]</p> <ol style="list-style-type: none"> (1) Burner for fuel conversion (2) Draft equipment <p>[Continuous furnace]</p> <ol style="list-style-type: none"> (1) ditto (2) ditto (3) High efficient dust collector <p>[Batch furnace] Natural gas [Continuous furnace] Crude oil</p>
OTHERS	<ol style="list-style-type: none"> 1. Improvement of combustion control 2. Combustion equipment <ol style="list-style-type: none"> (1) Combustion into high efficient bag filter (2) Water washing (cupola) 3. Fuel conversion <ol style="list-style-type: none"> (1) Conversion to fuel with low sulfur content 4. Energy saving 5. Others 	<p>Waste heat recovery (combustion of CO)</p> <p>Factory movement</p>

① Improvement of combustion method

Reduction of dust emission and saving of fuel are to be achieved through complete combustion by installing combustion control instruments and by optimal combustion control.

For coal firing facilities, mechanical stokers will be introduced to prevent generation of black smoke during coal feeding. NO_x emission will be reduced by introducing steam injector and low-NO_x burner.

② Fuel reforming

Since SO_x emission depends on the sulfur content of the fuel, the boilers which burn crude oil will use the fuel mixed with light oil to reduce the sulfur content.

As regards the coal, mixing will be made to keep the sulfur content at the current 0.6 ~ 0.7% level. Coal will also be adjusted to the optimal grains to achieve optimal combustion.

③ Fuel conversion

It is necessary for small-sized crude oil and coal firing boilers in the urban district to convert the fuel to the light quality fuel.

Fuel conversion must be made for kilns for bricks and clay pipes, because they generate a lot of black smoke. But conversion to liquid fuel will need complicated equipment and therefore, large sum of cost. This method does not seem much advantageous. So fuel conversion to natural gas should be planned in future. For the time being, it may be recommended to employ stoker burning with adjusted coal.

It may be necessary for the tunnel kilns for high-quality products to introduce oil combustion.

④ Dust collector

The dust collector is installed to collect dust that will remain after improving the combustion method. The dust collector to be used must be able to collect fine particles at high efficiency. Available types include multicyclone and bag filter.

⑥ Reduction of heat loss through furnace walls

For boilers, the outside of the boiler is to be covered with heat insulating material to keep the surface temperature at around 50°C.

This method is relatively inexpensive and can be employed immediately. This method will prove particularly effective for boilers.

⑥ Coal adjusting facility (See Supporting Report 5.1.3)

This facility will be a coal adjusting plant, which will be constructed at an appropriate place in Bogota City, adjusting the grain size and sulfur content by mixing various coals for factories. The capacity of this plant will be about twice as large as the consumption in Bogota City.

Supply of coal of the grain size appropriate to combustion facilities will improve the combustion, contributing to reduction of dust and saving of the fuel. But this in turn causes rising of the coal price.

⑦ Raising of stack height

Raising of stack height is not to reduce the amount of air pollutants, but may prove effective in reducing the concentration on ground through more dispersion of the exhaust gas.

Before employment of this method, it is necessary to study the dispersion, taking meteorological and topographical conditions into account, as well as to check the surrounding situation, site restrictions, and difficulty of the work.

⑥ Factory movement

Though movement of factories requires considerable cost, plants causing high degree of air pollution should be dispersed to areas where dispersion conditions are better, based on city planning.

⑥ Countermeasures against soil dust

Main sources of soil dust in soil mining sites and asphalt plants are stone storage yard, crusher, and screening plant, and basic countermeasures against dust are installation of water spray, provision of dust collector, and enclosure with building.

1) Countermeasures in the storage yard

Water spray over stones, prevention of leak from a loader, pavement of the road, and water spray to clean mud will be made to prevent particulate generation.

2) Countermeasures in crushing and screening facilities

These facilities are to be constructed as a closed type. Dust will be collected by dust collector.

3) Countermeasures for conveyor

Water spray to prevent dust generation at the joint and chute and installation of a dust collector with dust collecting hood will be made.

4) Forestation of the site

(3) Settlement of Countermeasures

Concerning countermeasures against stationary sources described above, short-term measures to be executed within the coming five years and medium and long-term measures to be executed by the year 2001 are summarized in Table 8.1.6.

Table 8.1.6 Summary of Countermeasures against Stationary Sources

Countermeasures	Short-term measures	Medium- to long-term measures
1. Emission regulation	Revision of emission standard	Phased revision
2. Boiler	a. Improvement of combustion method b. Fuel reforming c. Fuel conversion d. Improvement of combustion facilities e. Dust collection of flue gas f. Energy saving	a. High efficiency dust collection b. Suppression of NOx c. Fluidized bed combustion
3. Ceramic kiln	a. Improvement of combustion method b. Furnace reforming c. Dust collection of flue gas	a. Fuel conversion (natural gas) b. High efficiency dust collection
4. Asphalt plant	a. High efficiency dust collection b. Control of dust	Fuel conversion (natural gas)
5. Other facilities	a. Improvement of combustion method b. Fuel reforming c. Control of dust	a. High efficiency dust collection b. Energy saving
6. Raising of stack height	Medium-sized facilities	Large-sized facilities

Above countermeasures cover the facilities with fuel consumption of 50 l/h or more as converted to the liquid fuel. Facilities smaller in scale are to be covered by the administrative guidance concerning the pollution control measures. Special regulation and increase of the natural gas supply will be necessary to prevent worsening of the air pollution in the polluted area in the center of Santafe de Bogota City.

(4) Outline of Countermeasure Cost (See Supporting Report 5.1.4)

To evaluate the Countermeasures of 8.1.3 (2) from a viewpoint of costs, the equipment cost in the initial investment was roughly estimated.

It was assumed that various equipment necessary for the countermeasures are to be Colombian products unless they are not produced in Colombia:

Prices of the equipment are determined based on the price survey in Bogota City from August to September in 1991.

The unit prices include the sales tax of 12% and, for all units requiring installation work, 70% of the unit price was calculated as installation and other expenses.

For import products, the cost includes the price in the export country and the supply cost in Colombia. The latter was calculated by multiplying the price in Japan by 1.64 (the World Bank Technical Paper No.59). With exchange rate, the value as of September, 1991 was used.

① Facilities for improving combustion method

The cost is about 3.43×10^6 \$ for a set of the measuring instruments combustion control (flow meter, thermometer, and gas analyzer), about 4.50×10^6 \$/unit for draft equipment, and 4.00×10^6 \$/unit for coal firing stoker (US make).

The cost required will be only 3.43×10^6 \$ if only the instruments are to be installed, but about 8.00×10^6 \$ if the draft system is to be installed as well.

There are three types of stoker available. The stoker chosen in this section is a type for boilers, offering satisfactory combustion, but expensive. Since the brick kiln has multiple fuel holes, stokers to be used have six supply ports per unit. The price is nearly equivalent to that of the stokers for boiler.

② Price of mixed oil

When crude oil and light oil are mixed to reduce the sulfur content from 2.3 to 1.8% to reduce SOx emission, the price increase can be calculated as follows from the present price (crude oil 30 \$/kg, light oil 68 \$/kg):

Sulfur content	Price rise (%)
2.17	12.3
2.06	18.5
1.82	37.0

The crude oil price, which is currently 30 \$/kg, will rise to 41 \$/kg when the sulfur content is reduced to 1.8%. This price is equivalent to about 60% of 68 \$/kg of light oil, and further sulfur reduction by mixing is considered unreasonable.

③ Equipment with fuel conversion (all burners are to be imported.)

1) The total cost of a set of burners, oil pump, blower, flow meter, and construction cost will be as follows when coal firing is to be converted to oil combustion:

Fuel consumption	Cost (\$)
50 l/h	10.60×10^6 \$
270 l/h	15.10×10^6 \$
500 l/h	20.50×10^6 \$

2) The equipment cost for conversion from coal or liquid fuel to natural gas is as shown below. Since the equipment becomes simpler than that for oil, the cost will lower by the corresponding amount, but the fuel cost rises.

Fuel consumption	Cost (\$)
5×10^4 kcal/h:	8.60×10^6 \$
12×10^4 kcal/h:	9.16×10^6 \$
25×10^4 kcal/h:	10.88×10^6 \$

Note that the above price does not include the gas supply piping work from the outside.

④ Low-NOx burner (Import)

The low-NOx burners are to be used for crude oil combustion facilities large in quantity and in NOx emission. The cost includes the repair cost:

Fuel consumption	Cost (\$)
150 l/h:	14.02×10^6 \$
250 l/h:	15.20×10^6 \$
540 l/h:	24.05×10^6 \$

⑤ Dust collector

The compensation value for dust collecting efficiency was set at 70% for multicyclone and 95% for bag filter, and the price calculated includes the work cost:

1) Multicyclone

Flue gas treatment capacity

3,000 m³/h: 3.81 x 10⁶ \$

2) Bag filter

The filter cloth needs to be replaced once in 8,000 to 10,000 hours, but the price of replacement cloth is not included:

Treatment capacity	Cost (\$)
1,200 m ³ /h:	4.19 x 10 ⁶ \$
3,300 m ³ /h:	8.57 x 10 ⁶ \$

In selecting the dust collector, not only the price, but also the dust concentration and grain size in flue gas should be taken into consideration.

⑥ Stack

The price of stack is estimated for the steel plate made stack with the height of 30m and diameter of 1m. As no corrosion-resistant material is assumed to be used, the life is expected to be 5 years in average.

The facility cost is relatively inexpensive at about 0.50 x 10⁶ \$, which is about 17,000 \$ per 1m. But this is not applied to stacks whose height exceeds 30m.

⑦ Coal reforming facility (See Supporting Report 5.1.3)

It is desirable that this facility is founded and operated under cooperation of both coal supplier and consumer. The facility must be provided with perfect anti-dust measures.

1) Machine equipment	315.87 x 10 ⁶ \$
2) Product storage	59.43 x 10 ⁶ \$
3) Attached equipment	2.84 x 10 ⁶ \$
4) Building	52.27 x 10 ⁶ \$
5) Power distribution	6.18 x 10 ⁶ \$

Total 436.59 x 10⁶ \$

Note that this cost does not include the cost of 38,000 m² land and the operation expenses.

According to the result of rough estimation of the cost of reformed coal, the product price will be 20.700 \$/ton, which is about 20% increase from 17,000 \$/ton of raw coal, when the equipment cost is assumed to be 437 x 10⁶ \$ and the annual running cost to be 3.148 x 10⁶ \$.

⑧ Fluidized bed combustion boiler
(Estimation based on Japan-made boiler)

The calculation here was made for the boiler evaporation rate at 10 t/h (640 HP).

- 1) Coal firing 263.47 x 10⁶ \$
(main body, transport cost, installation, and insurance included)
- 2) Crude oil combustion 69.58 x 10⁶ \$
(main body, transport cost, installation, and insurance included)

In this cost are included SO_x and NO_x reduction equipment. So the effect of SO_x and NO_x reduction must be taken into consideration.

⑨ Cost to reduce heat loss through walls

This method proves considerably effective with relatively low cost. The work cost to decrease the boiler surface temperature from 200°C before work to 50°C after work is shown below for three kinds of boilers:

- 1) Cornish boiler 0.09 x 10⁶ \$
(evaporation rate 128 HP) (work area 6.2 m²)
- 2) Lancashire boiler 0.29 x 10⁶ \$
(evaporation rate 190 HP) (work area 20 m²)
- 3) Kewanee boiler 0.23 x 10⁶ \$
(evaporation rate 250 HP) (work area 15 m²)

Note that in the case of industrial heating furnaces, the work cost per 1 m^2 is about 0.025×10^6 \$ for the surface temperature of about 500°C .

8.1.4 Training of Engineers

(1) Training of Combustion Engineers

Generation of dust in Bogota City are mainly attributed to lack of proper combustion control.

To solve this problem training of combustion engineers is indispensable. Among lots of knowledge and technologies necessary for combustion control, they must master at least technologies concerning the fuel, combustion, device, measurement, and exhaust gas treatment.

They will master above knowledge and technology through lectures and practical training.

(2) Training of Boiler Inspection Engineers

Since boilers are worn out physically and decrease in strength during use, it is important to check the wear state periodically, carry out necessary repair, and to correct the maximum operating pressure.

Duties of boiler inspection engineers include the structural inspection of newly manufactured boiler, operation and performance inspection on used or imported boilers. They also check whether the structure standards are kept in order as well as the wear state, and take necessary measures.

They will master the technology beyond a certain level through lectures and practical training.

(3) Training of Smoke Inspectors

The smoke inspectors will check the smoke sources if the color of the smoke is under the grade 2 in the Ringelmann chart and advise the violating factory to observe the standard. They will also give technical guidance to reduce black smoke. They will have a certain level of knowledge and technology and will be qualified by the municipal authority and function as a civil servant. They will be trained through lectures on combustion and measurement technologies by personnel rich with knowledge and experience.

8.1.5 Enhancement and Dissemination of Technologies

Combustion and gas treatment technologies are the technologies needed most urgently at present. These technologies are highly sophisticated in countries advanced in air pollution control, and their mastering is the best way to enhance the technology.

There are various training systems in the U.S. and Japan. It would be wise to make good use of them.

These systems include both dispatching researchers and engineers to foreign countries and inviting engineers from these countries. It is advised to fully utilize these systems.

It is also important to introduce overseas information to businesses and citizens and hold course or seminar to promote recognition of pollution.

8.1.6 Various Systems

(1) Flue Gas Measuring System

Those who are responsible for smoke and soot emitting facilities must be obliged to measure the pollutant emission or concentration and keep the measurement result and fuel consumption on file. The facilities to be measured will be as those under emission regulation and the measurement must be made every six months by the following methods.

① Sulfur oxides

The measurement must be made by one of the following methods:

- 1) Determination of SO_x concentration according to the method equivalent to JIS K 0103 of Japan
- 2) Determination by calculation from the sulfur content of the fuel and the fuel consumption

② Sulfur content of the fuel

The sulfur content must be determined using a LECO analyzer (SC-132) or other methods that can check the sulfur content.

③ Dust emission rate

The method equivalent to JIS Z 8808 of Japan must be used.

④ Nitrogen oxides

The method equivalent to JIS K 0104 of Japan must be used. Note that the residual oxygen concentration of the flue gas must be measured as well.

(2) Combustion Controller System

Those who have obtained a certain level of knowledge and technology through the lecture are qualified as combustion controllers. They are allowed to execute the practical affairs on combustion control.

The combustion controller will execute combustion control of combustion facilities exceeding a certain scale (50 l/h) according to the control criteria established by the municipal authority.

The criteria include the excess air, measurement and recording of combustion, maintenance and inspection of equipment, heat loss reduction, and dust prevention. They must be prescribed in detail.

(3) Boiler Inspection System

To maintain the safety and efficiency of boilers, will be set up an official agency which will perform the structure, reuse, and performance inspections during production process or operation.

Maintenance of boilers will improve the boiler efficiency and save energy.

① The structure inspection will involve check of material and appearance, pressure test, and inspection of accessories (safety valve, etc.)

② The objects of the reuse inspection will be used boilers or imported boilers. The inspection items are same as those of the structure inspection.

③ The performance inspection will be made on the boiler wear state or efficiency.

If any improvement is judged necessary, the chief of the inspection agency can request the improvement.

(4) Smoke Inspection System

This system is to regulate emission of black smoke within a short period from low smoke sources in order to prevent environmental degradation around them. Inspectors will patrol and watch black smoke.

To measure smoke concentration the Ringelmann smoke chart will be used, because it enables immediate judgement of the smoke concentration. The criteria will be grade 2. If the smoke concentration is over grade 2 in the Ringelmann smoke chart, the smoke source will be judged to be faulty. Recommendation of reduction, technical guidance, or advice will be provided by the inspector when the smoke source is judged to be faulty.

This system will be independent from the regulation by the emission standard.

(5) Preferential Treatments

Originally, enterprises which emit air pollutants are responsible for taking necessary measures to prevent air pollution. But, for the enterprises whose basis of management are so weak that they cannot afford to take necessary measures, preferential treatments must be instituted. This system will help them to take anti-pollution measures. The preferential treatments include reduction of taxes, financing the fund and grant of interest.

① Reduction of tax

For medium and small enterprises to install pollution control equipment, must be establish a system which can exempt or reduce them from commercial/industrial and fixed property taxes after examination of the plan and management state.

② Financing fund for pollution control equipment

In order that enterprises may install or improve pollution control equipment or move their factories, a system must be installed to finance them the expenses at long-term low interest.

The financing limit and interest rate will be determined based on the socio-economic conditions.

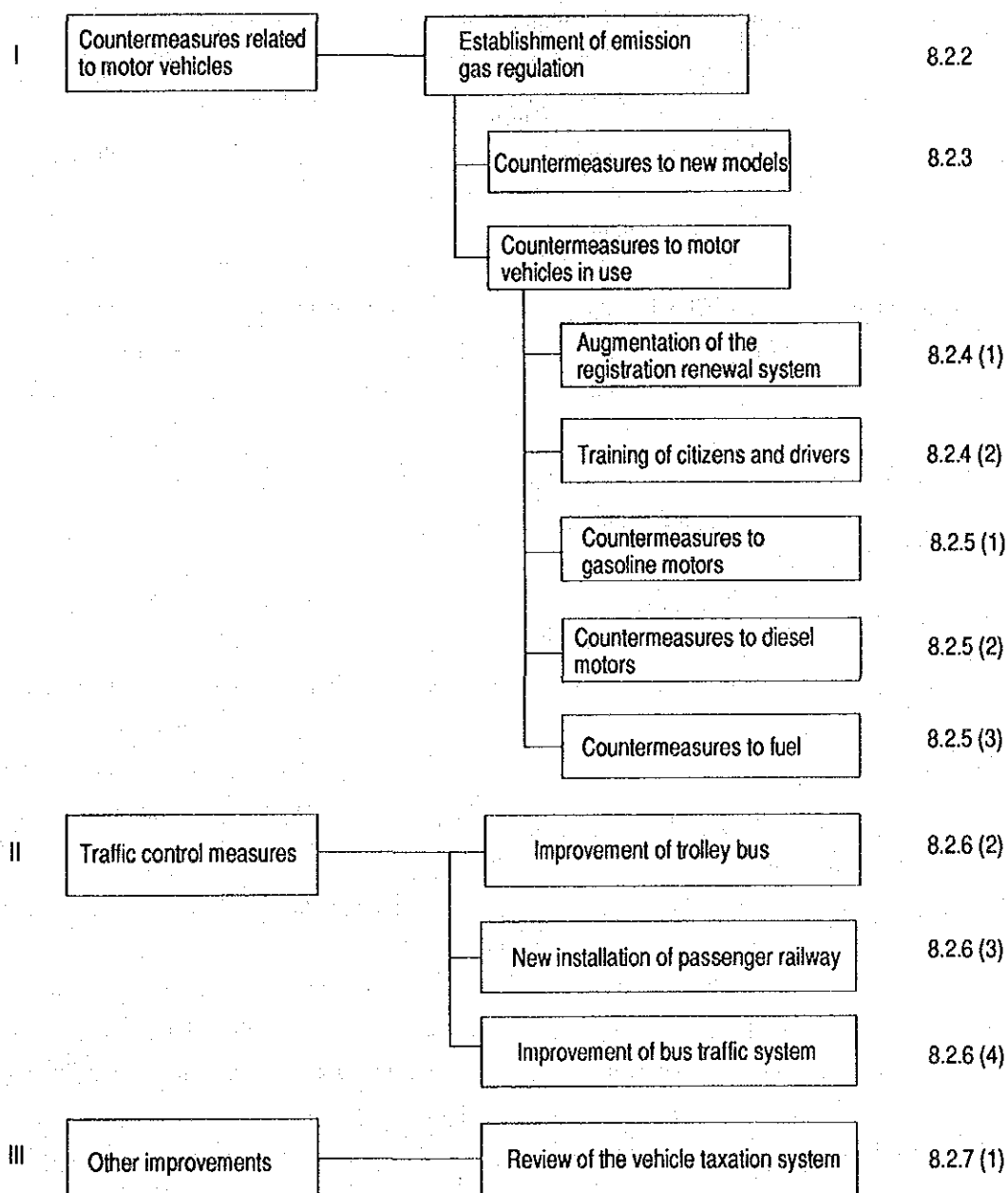
③ Grant for loan interest

To those receiving loan for pollution control equipment, the government or municipal authority will grant a part of the interest to alleviate their interest burden.

This system will cover only small enterprises and joint venture business.

8.2 Control Measures against Emission Gas from Motor Vehicles

Motor Vehicle emission gas control measures in Santafe de Bogota, Special District, of Colombia were examined while dividing these measures roughly into three categories described below. Subdivisions under each item describe the content of principal countermeasures and the related numbers in this report.



Note that the final summary is described under a title of "Selection of Countermeasure plans and Estimate of Cost" in the final item of 8.2.8. Moreover, for the sake of reference, "Automobiles and Pollutants", "History of Exhaust Emission Standards in Various Countries", and "Emission Countermeasures on Gasoline Automobiles" are summarized in Appendices.

8.2.1 Necessity of Countermeasures and Present State of Countermeasures against Pollutant Sources

According to the result of measurement of the environmental atmospheric quality in Santa Fe de Bogota by this team, carbon monoxide (CO) and ozone (O₃) around the trunk road exceeded the standard value of the environmental quality as specified in the Colombian National Air Pollution Control Act (#2001) while the suspended particulate material (SPM) and sulfur oxides (SO_x) remained below the standard level.

As Colombia specifies the standard for the nitrogen dioxide (NO₂) instead of nitrogen oxides (NO_x), it was found not exceeding the standard in our survey. Moreover, though not included in the environmental quality, hydrocarbons (NMHC) excluding methane showed the high concentration. NMHC is harmful in itself and, when coexistent with nitrogen oxides, produces peroxides, causing ozone and photochemical smog. CO and NMHC are considered to be generated mostly from automobiles.

In Colombia, the Ministerio de Salud is taking a leadership to draft ordinances and guidance procedure in order to regulate pollutant emission from motor vehicles, but the fuel regulation has not yet been made public. Since publication of the draft (#5023) in 1989, such draft has been reviewed repeatedly and a part of the regulation has been issued recently to Santafe de Bogota only. The issue (#5057) specifies only the allowable emission rates of carbon monoxide and hydrocarbons during idling, and installation of fuel vapor trap from 1994 models and of blow-by gas return system from 1992 models, for gasoline motor vehicles.

Because of lack of emission control, motor vehicles that have been assembled and produced in Colombia or imported as finished ones up to now are not equipped enough with pollutant emission control means. Motor vehicles partially equipped with a blow-by gas return unit, a gasoline supply shutdown unit during speed reduction, an electronic control ignition unit, or an electronic control fuel injection unit, among a few unit