社会開発調査部報告書

THE REPUBLIC OF COLOMBIA

THE STUDY ON AIR POLLUTION CONTROL PLAN IN SANTAFE DE BOGOTA CITY AREA

FINAL REPORT

VOL.1
SUMMARY

23502

FEBRUARY 1992

JAPAN INTERNATIONAL COOPERATION AGENCY

PREFACE

In response to a request from the Government of the Republic of Colombia, the Government of Japan decided to conduct a study on Air Pollution Control Plan in Santafe de Bogota City Area and entrusted the study to the Japan International Cooperation Agency (JICA).

JICA sent to Colombia a study team headed by Mr. Yoshikazu Sugita, SUURI-KEIKAKU CO., LTD. and composed of members from SUURI-KEIKAKU CO., LTD. and Pacific Consultants International, five times between August 1990 and December 1991.

The team held discussions with the officials concerned of the Government of Colombia, and conducted field surveys at the study area. After the team returned to Japan, further studies were made and the present report was prepared.

I hope that this report will contribute to the promotion of the project and to the enhancement of friendly relations between our two countries.

I wish to express my sincere appreciation to the officials concerned of the Government of the Republic of Colombia for their close cooperation extended to the team.

February 1992

Kensuke Yanagiya

Kensuke Yanagiya
President
Japan International Cooperation Agency

CONTENTS

CHAPTER 1 INTRODUCTION

1.1 Background and Objective of the Study

(1) Background of the Study

In Santafe de Bogota City, the capital of the Republic of Colombia, air pollution is getting heavier by pollutants emitted from motor vehicles and factories increasing year by year. The air pollution there is worsened by the meteorological factors due to the topographical condition that it is located in a highland basin at 2,600m above sea level. In this situation, the Health and Welfare Bureau of Santafe de Bogota D.C. began measuring the ambient air quality with a semi-automatic monitoring system in 1984, taking air pollution control measures. In the present state, however, collection of basic data and an organization, which is indispensable to put air pollution control measures into effect, have not yet been established. The Republic of Colombia decided to establish the air pollution control plan comprising understanding of the actual state of air pollution and air pollutant sources, countermeasures against pollutant sources, improvement of the monitoring system, and environmental information system. In February, 1988, the Government of Colombian requested the Government of Japan for technical cooperation concerning the air pollution control measures there. In response to this request, the preliminary survey team was dispatched to Colombia in January, 1989 and determined the scope of the work through negotiation with Colombia authorities concerned. This study was made from July, 1990 to February, 1992. This report summarizes the contents of the study.

(2) Objective of the Study

The objective of the study was to investigate and analyze air pollution, meteorology, air pollutant sources, socio-economic conditions and air pollution control measures in Santafe de Bogota City, on the basis of which to propose a guideline for the air pollution control measures there. And through this study was aimed technology transfer from the study team to Colombian counterpart on various surveys, analysis and air pollution control measures.

1.2 Outline of the Study

(1) Scope of the Study

As shown in Fig. 1.2.1, the study area is the area under the jurisdiction of the Health and Welfare Bureau of Santafe de Bogotá D.C., approximately 35 km from south to north and 24 km from east to west, which includes the urban area of Santafe de Bogota City.

This study was executed in Santafe de Bogota City and Japan. As shown in Fig. 1.2.2, the study includes the basic study and the analytical study. Detailed description is given below.

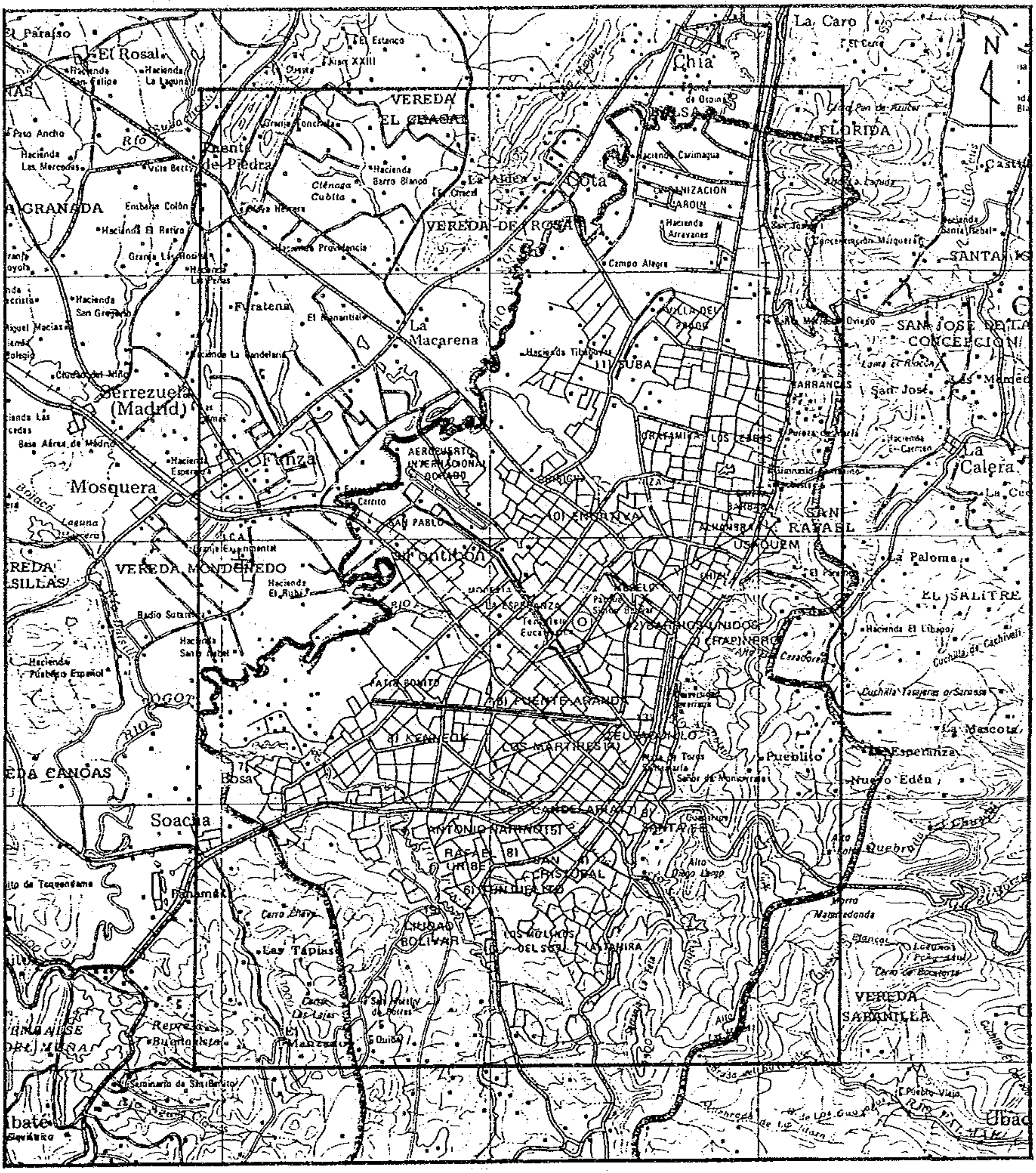


Fig. 1.2.1 Study Area

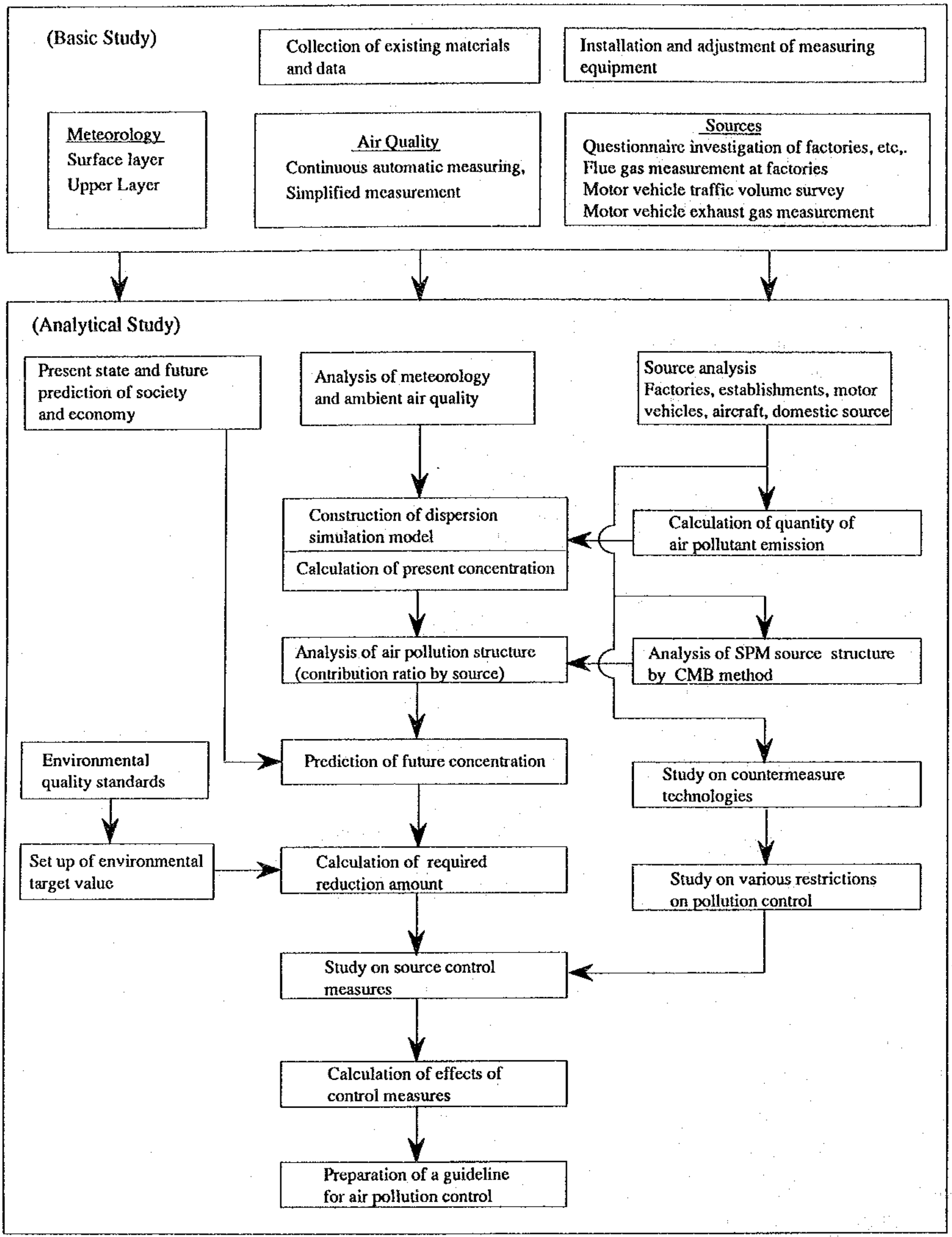


Fig. 1.2.2 Outline of the Study

1) Basic Study

a) Collection of existing materials and data

- Meteorology, climate
- Ambient air quality
- Mobile sources: motor vehicles, aircraft
- Stationary sources: factories, establishments and domestic source
- Socio-economic conditions
- Source control measures
- Laws, regulations, standards, etc.

b) Installation and adjustment of measuring equipment

- Monitoring station
  - air quality monitoring equipment, wind vane and anemometer, pyranometer and balance meter
- Upper layer meteorology
  - tethered sonde, radio sonde, wind vane and anemometer
- Factory flue gas measuring vehicle
- Motor vehicle exhaust gas measuring vehicle

c) Field Investigation

- Meteorology
  - observation of surface meteorology: wind direction and speed, solar radiation, net radiation
  - observation of upper layer meteorology: vertical distribution of wind direction, wind speed and temperature
- Ambient air quality
  - monitoring at 5 stations
    SO_2, NO, NO_2, NOx, SPM, CO, NMHC, CH_4, THC,
    particle size distribution and heavy metal components of SP
  - measurement of SO_2, NO_2, NOx, CO by simplified method
- Pollutant sources
  - investigation of factories by questionnaire
    type of facility, type of fuel and its consumption, stack height and its position, etc.
  - measurement of factory flue gas
    SO_2, NOx, PM (Particulate matters), O_2, temperature and quantity of flue gas

  - survey of traffic volume and vehicle driving speed
  - measurement of motor vehicle exhaust gas
    CO, HC, NOx
  - analysis of sulfur content in fuels
  - analysis of heavy metal components of surface soils

2) Analytical Study

- o Analysis of social and economic conditions
  - society, economy, land use, traffic and transportation, energy
  - laws, regulations, standards, administrative organization
- o Analysis of meteorological data
  - surface meteorology
  - upper layer meteorology
- o Analysis of ambient air quality
  - monitoring station
  - simplified method
- o Analysis of pollutant source
  - factories, establishments, motor vehicles, aircraft, domestic source
- o Development of air dispersion simulation model and analysis of air pollution structure
  - air dispersion simulation for SO_2, NOx, NO_2 and CO
    meteorological model, source model, dispersion model
  - contribution of pollutant sources
  - contribution of SPM sources by Chemical Mass Balance Method
- o Prediction of air quality and required reduction amount
  - prediction of air pollutant emission from sources
    factories, establishments, motor vehicles
  - prediction of ambient air quality
  - target value of ambient air quality
  - Air pollutant reduction amount
- o Study of air pollutant source control measures and their effects
  - control measures against factory exhaust gas
    technology, restriction, cost
  - control measures against motor vehicle emission gas
    technology, restriction, cost
  - prediction of effect of control measures
    factories, motor vehicles

- o Presentation of guideline for air pollution control
  - targets
    basic concept
  - implementation of pollutant reduction measures
    summary of control measures, schedule
  - execution organization
    organization, institution, legal regulation, monitoring system

(2) Study Time Schedule

The study was made from July, 1990 to February, 1992.
The study time schedule is shown in Figure 1.2.3.

(3) Technology Transfer

The study team achieved technology transfer to the counterpart of Santafe de Bogota D.C. concerning fundamental knowledge of measurement, measurement method, and equipment maintenance technique on meteorology, ambient air quality, and pollutant sources.

Technology transfer was also made on the measured data analysis by explaining the analytical results.

The contents of technology transfer is described below:

- o Meteorological Observation
  - surface meteorology
  - upper meteorology

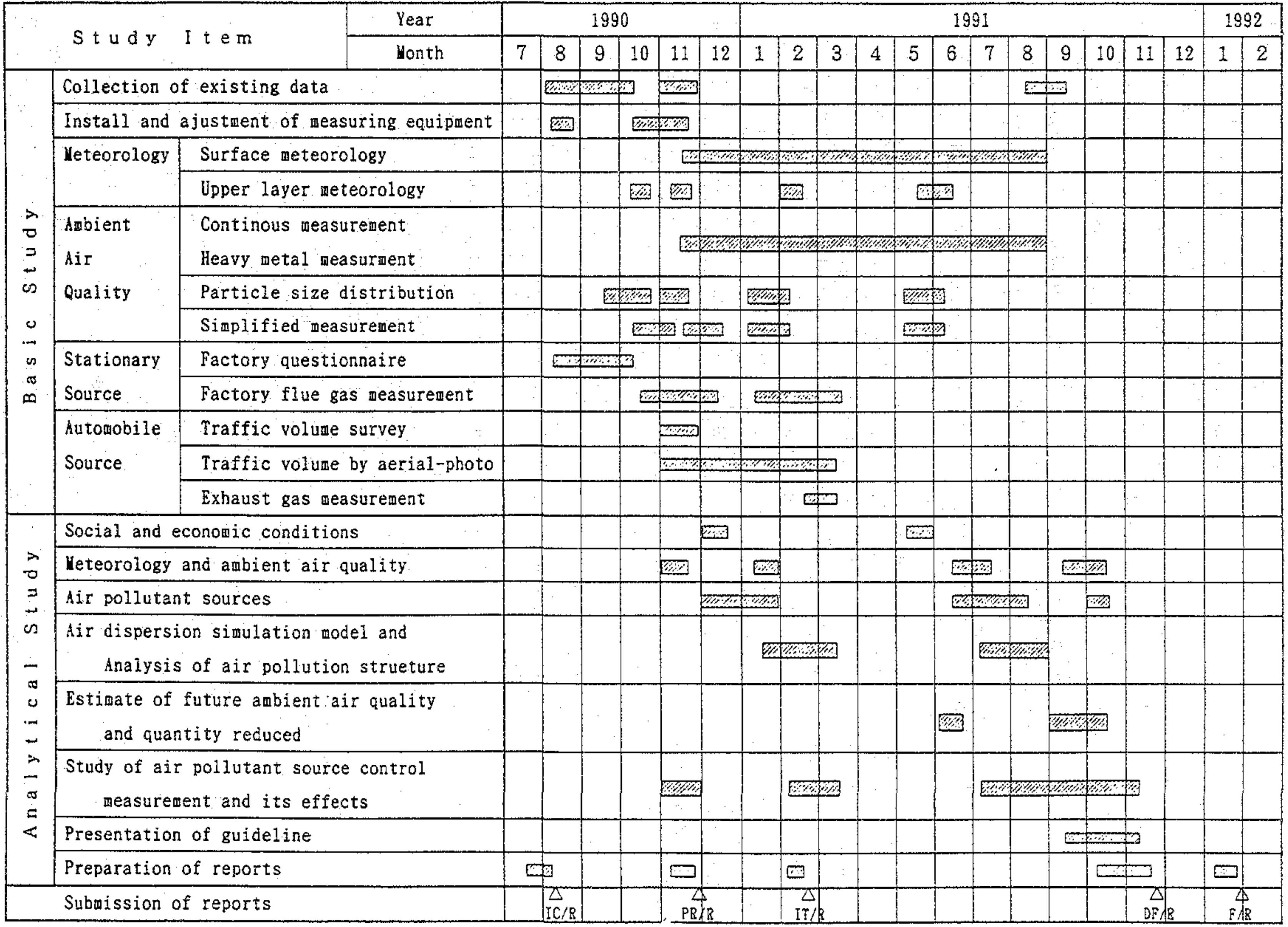
- o Measurement of Ambient Air Quality
  - continuous measurement at the monitoring station (SO_2, NO, NO_2, NO_x, SPM, CO, NMHC, CH_4, THC, O_3)
  - measurement and analysis by simplified method in the wide area and around the road (SO_2, NO, NO_2, CO)
  - measurement by high-volume air sampler and analysis of Suspended Particulates by particle size
  - measurement by low-volume air sampler and analysis of metalic component by atomic absorption spectrophotometry

- o Measurement of Pollutant Sources
  - measurement of factory flue gas

- measurement of motor vehicle exhaust gas
- survey of traffic volume and driving speed

o Analytical Study

- meteorology, ambient air quality, air pollutant sources
- air dispersion simulation model
- control measures for air pollution
- *guideline for air pollution control*



Study Item		Year	1990						1991												1992	
		Month	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2
Basic Study	Collection of existing data			▨	▨	▨	▨									▨	▨					
	Install and ajustment of measuring equipment			▨		▨	▨															
	Meteorology	Surface meteorology					▨	▨	▨	▨	▨	▨	▨	▨	▨	▨						
		Upper layer meteorology				▨	▨			▨			▨	▨								
	Ambient Air Quality	Continous measurement Heavy metal measurment					▨	▨	▨	▨	▨	▨	▨	▨	▨	▨						
		Particle size distribution			▨	▨	▨		▨	▨			▨	▨								
		Simplified measurement				▨	▨	▨	▨	▨			▨	▨								
	Stationary Source	Factory questionnaire		▨	▨	▨																
		Factory flue gas measurement				▨	▨	▨	▨	▨	▨											
	Automobile Source	Traffic volume survey					▨															
		Traffic volume by aerial-photo					▨	▨	▨	▨	▨											
		Exhaust gas measurement								▨	▨											
Analytical Study	Social and economic conditions							▨					▨									
	Meteorology and ambient air quality						▨		▨					▨	▨		▨	▨				
	Air pollutant sources							▨	▨					▨	▨	▨		▨				
	Air dispersion simulation model and Analysis of air pollution strueture								▨	▨	▨				▨	▨						
	Estimate of future ambient air quality and quantity reduced													▨			▨	▨				
	Study of air pollutant source control measurement and its effects						▨			▨	▨				▨	▨	▨	▨	▨			
	Presentation of guideline																▨	▨	▨			
	Preparation of reports		▨	▨			▨			▨								▨	▨		▨	
Submission of reports				△ IC/R			△ PR/R			△ IT/R									△ DF/R		△ F/R	

Fig. 1.2.3 Time Schedule for the Study

1.3 Organization for the Study

(1) Organization of the Health and Welfare Bureau of Santafe de Bogotá D. C.

For conducting the Study, the Health and Welfare Bureau of Santafe de Bogotá D.C. established a counterpart team headed by Dr. Edgar Camilo Luengas Pinzon, the Head of Environmental Protection Division of Health and Welfare Bureau, Santafe de Bogotá D. C. The members of the team are as shown in Table 1.3.1.

Table 1.3.1 Members of the Counterpart Team

Field	Items in Charge	Name
Supervision	Entire study	ING. EDGAR CAMILO LUENGAS PINZON
Socio-economic Analysis	Present state of society and economy and urban plan	TEC. JAIME MERCHAN PULIDO
Meteorological Observation	Upper layer and surface meteorological observation	TEC. JOSE ARDILA MORENO TEC. JAIME MERCHAN PULIDO
Air Quality Measurement	Measurement at stationary measuring points and simplified measurement	ING. CESAR A. GARCIA UBAQUE TEC. MIGUEL ANTONIO CARO TEC. JAIRO TELLEZ BALLEN
Air Quality Chemical Analysis	Chemical analysis	ING. MAURICIO DIAZ ZAPATA ING. EDGAR BELTRAN
Stationary Source	Stationary source measurement and analysis	TEC. HERNAN G. PATINO GARZON TEC. DIEGO RAYO ANTURY TEC. RICARDO CEBALLOS QUINTERO
Mobile Source	Mobile source measurement and analysis	ING. RAFAEL OSPINA LOPEZ TEC. ANGELA GOMEZ FORERO TEC. ERNESTO HERRAN PRIETO TEC. JAIME MERCHAN PULIDO
Modeling and Simulation	Simulation analysis	ING. RAFAEL OSPINA LOPEZ
Pollutant Source Control	Stationary and mobile source control	ING. RAFAEL OSPINA LOPEZ TEC. HERNAN G. PATINO GARZON
Guideline Preparing	Organization and regulation for air pollution control	ING. EDGAR CAMILO LUENGAS PINZON

(2) Japanese Organization

The Japanese organization for the Study consisted of the Advisory Committee and the Study Team which had been organized by Japan International Cooperation Agency. The members of the Advisory Committee and the Study Team are shown in Tables 1.3.2 and 1.3.3 respectively.

Table 1.3.2 Members of the Advisory Committee

Name	Field in Charge	Present Post	Remark
Tomokazu Okumura	Chairman/Overall Supervision	Head of Planning Division Planning and Coordination Bureau, Environment Agency	July, 1990 ~
Kenzi Kazuno	Pollutant Source Measurement	Staff of Air Pollution Control Section, Environmental Protection Bureau, Yokohama City	July, 1990 ~
Gen Inoue	Air Pollution Analysis	Chief of Section of Atmospheric Measurement, Division of Atmospheric Environment, The National Institute for Environmental Studies	July, 1990 ~
Satoru Mizuno	Stationary Source Control	Chief of Total Pollution Control Section, Air Pollution Control Division, Air Quality Bureau, Environment Agency	July, 1990 ~ Aug., 1991
Takashi Shimodaira	Stationary Source Control	Head of Automotive Pollution Control Division, Air Quality Bureau, Environment Agency	Sept. 1991 ~
Shinsuke Unisuga	Mobile Source Control	Chief of Section, Automotive Pollution Control Division, Air Quality Bureau, Environment Agency	July, 1990 ~ July, 1991
Motoharu Yamazaki	Mobile Source Control	Chief of Section, Automotive Pollution Control Division, Air Quality Bureau, Environment Agency	Aug., 1991 ~

Table 1.3.3 Members of the Study Team

Name	Field in Charge
Yoshikazu Sugita	Overall Supervision
Nobuo Araki	Meteorological and Air Quality Analysis
Makoto Miyakawa	Pollutant Source Analysis
Haruo Kikuchi	Modeling and Simulation Analysis
Kihachiro Urushibata	Air Pollution Control Planning
Shinzo Hirasawa	Stationary Source Control
Masaaki Noguchi	Mobile Source Control
Yutaka Nozaki	Socio-economic Analysis
Masanori Fuzikawa	Meteorological Observation
Yoichiro Okayama	Air Quality Monitoring
Kazuo Watanabe	Stationary Source Investigation
Tsutomu Kurihara	Mobile Source Investigation
Nobumasa Morita	Equipment Maintenance

CHAPTER 2 OVERVIEW OF THE STUDY AREA

2.1 Geography and Climate

Santafe de Bogota City is located in the southeast part of the basin on the plateau 2,600 m high above sea level, and in the eastern part of the area there are mountains about 3,000 m high, that is, higher by 500 m than the plateau.

As the study area is located in the highland basin at 2,600 m above sea level, it belongs meteorologically to Cw (clima humedo de tierras templadas y frias) with the low annual mean air temperature at 14°C, which in turn belongs to the clima de montana tropical though its position is in the low altitude near the equator.

Other characteristics iclude small fluctuation of temperature along with seasonal change, rainy seasons twice a year, and low annual mean wind speed of 1.9 m/s.

2.2 Society and Economy

The population of Santafe de Bogotá D.C. (total area is 1,587 km^2) in 1985 was 4,236,000, accounting for 14.1% of the national population. The population of Santafe de Bogota City (311 km^2) was 3,950,000, indicating the growth at a rate of 4.7% during these four years. Most of such growth could be observed in southern and northern areas, with the population decreasing in the central area (the so-called doughnut phenomenon).

The industrial structure of Bogota shows that the tertiary industry accounts for 71% of GDP, with development observed in commercial, transportation, and telecommunication fields. The secondary industry accounted for 29%. When viewed by sector, the percentage of around 22% went for the manufacturing industry. In this industry, foods, chemistry, rubber, textiles, machinery and equipment, and transportation equipment were ranked high. The actual growth rate was about 5%.

2.3 Land Use

In the city of Santafe de Bogota, residential lands are located in the northern and southern parts, and the area between them are metropolitan facility lands. The agriculture lands are found in the western part while the industrial lands are located in western and southern parts nearer to the central area.

The central area is highly urbanized, with urbanization spreading to the suburban agriculture lands.

2.4 Traffic and Transportation

The principal road network of the city consists of the roads running parallel and right-angled with the mountains in the east and three ringed roads. Among these roads, the AVENIDA CARACAS is the most important road.

In Santafe de Bogota City, the main traffic means of the citizens are motor vehicles. The buses and small buses (buseta), which are mass traffic means in the city, occupy 75% of the total traffic. Trolley buses are the only means available except them.

The registered number of vehicles in Santafe de Bogota City in 1991 was around 350,000, of which passenger cars accounted for 63%, followed by light trucks (14%), jeeps (11%), and buses (5%). The number of vehicles per 100 people was 6.8. The rate of increase in the registered vehicles was very high at an annual rate of 7.9% during these five years, which was beyond that of the population.

The number of vehicles used for public transportation (bus and buseta) was about 14,000. They are operated by the city authority and 39 private enterprises. The number of routes was 450, which include 268 routes running through the city center. The number of passengers was 2.5 million persons, with an annual growth rate of about 3%.

Old vehicles occupy a high percentage; vehicles over 20 years of age are 23% while those from 10 to 20 years are 70%. There is El Dorado Airport in the western part of Santafe de Bogota City, offering international and domestic flight services. The takeoff and landing frequency was about 170 times/day, of which about 90 times/day were for large passenger jets.

2.5 Energy

The main industrial fuels are crude oil (Crudo de Castilla) and coal. The majority of household energy consumption is for cooking and hot water supply.

2.6 Laws and Organization

The main national organization of Colombia responsible for air pollution control is the Ministry of Health and Welfare, under which, La Servicio Seccional de Salud of Sistema Nacional de Salud is active in each state. In Santafe de Bogota City, Secretaria de Salud de Bogotá (Bogota Health and Welfare Bureau) is responsible for the same task.

The statutes on air pollution are Decree No. 2 of 1982 and No. 2206 of 1983, enacted pursuant to the Sanitation Law (Law No. 9) of 1979. The former provides the ambient air quality standards (SP, SO_2, NO_2, CO, O_3) and the factory emission standards and related regulations.

To know the state of compliance with the air quality standards, the Environmental Protection Division of Health and Welfare Bureau, Santafe de Bogotá City, has been monitoring the air quality at 13 stations since 1984. And also has been made measurement of dust concentration in factory flue gas.

CHAPTER 3 PRESENT STATE OF ATMOSPHERIC ENVIRONMENT

Meteorological observation and air quality measurement were conducted in Santafe de Bogota City area from the fall of 1990 to the summer of 1991. The results are summarized as below.

3.1 Meteorology

(1) Surface Meteorology

According to the observation results of wind direction and wind speed at five points shown in Fig. 3.1.1, the mean wind speed was rather low at 1.9 - 2.5 m/s and it tended to be lower particularly in the urban area in the eastern part of the study area (Fig. 3.1.2).

As to the hourly change of wind speed (Fig. 3.1.3), it was extremely low from 20:00 at night to 8:00 in the morning. Then it became gradually high reaching its peak at 14:00 and lowering after that. The monthly change of wind speed (Fig. 3.1.4), on the other hand, showed the high speed in February and August and low speed in March in the whole area. The wind rose within the city area showed that there was no prevailing wind in the central area, but the southern wind was prevailing in El Tunal and San Juan de Dios located in the southern part.

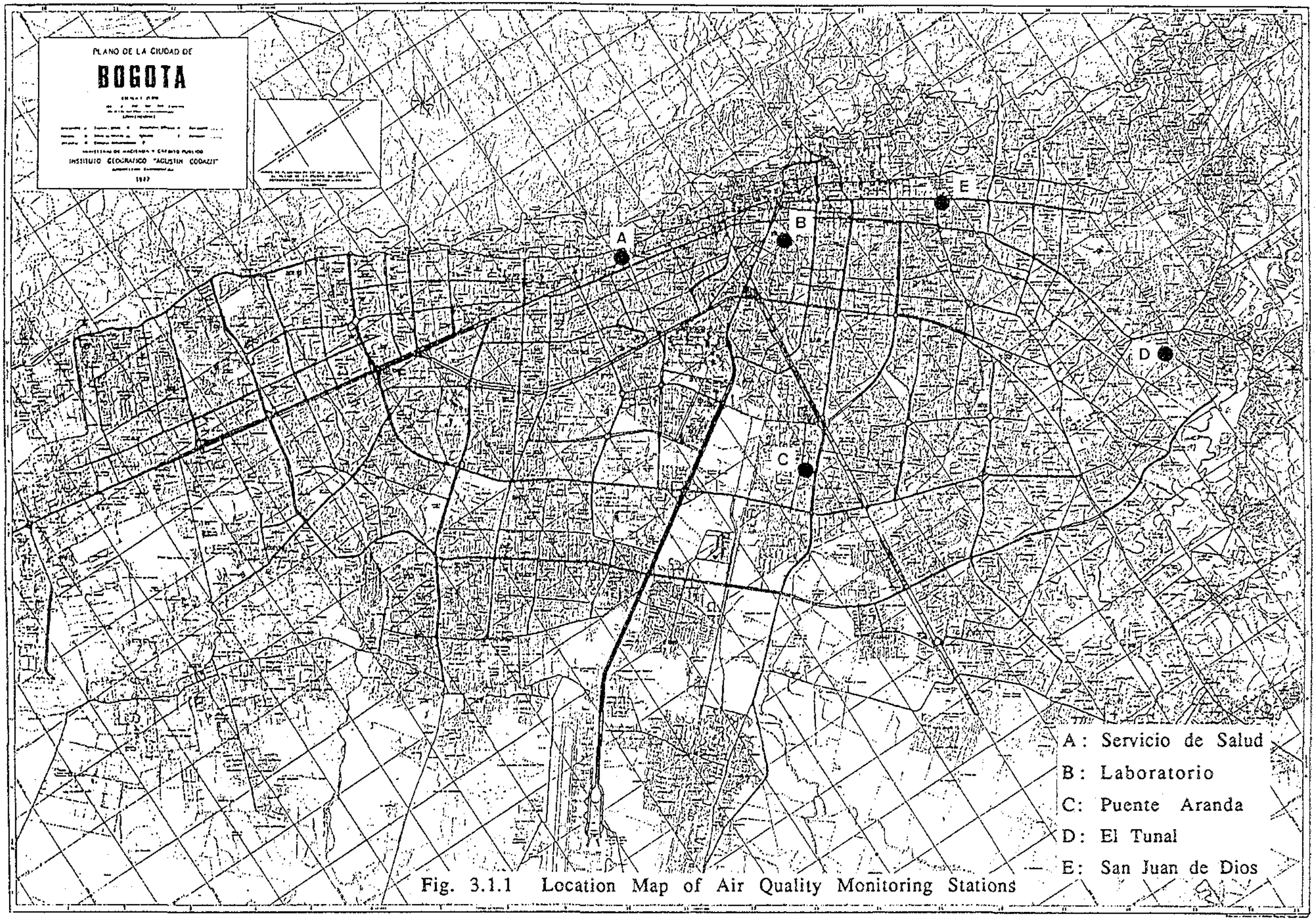


Fig. 3.1.1 Location Map of Air Quality Monitoring Stations

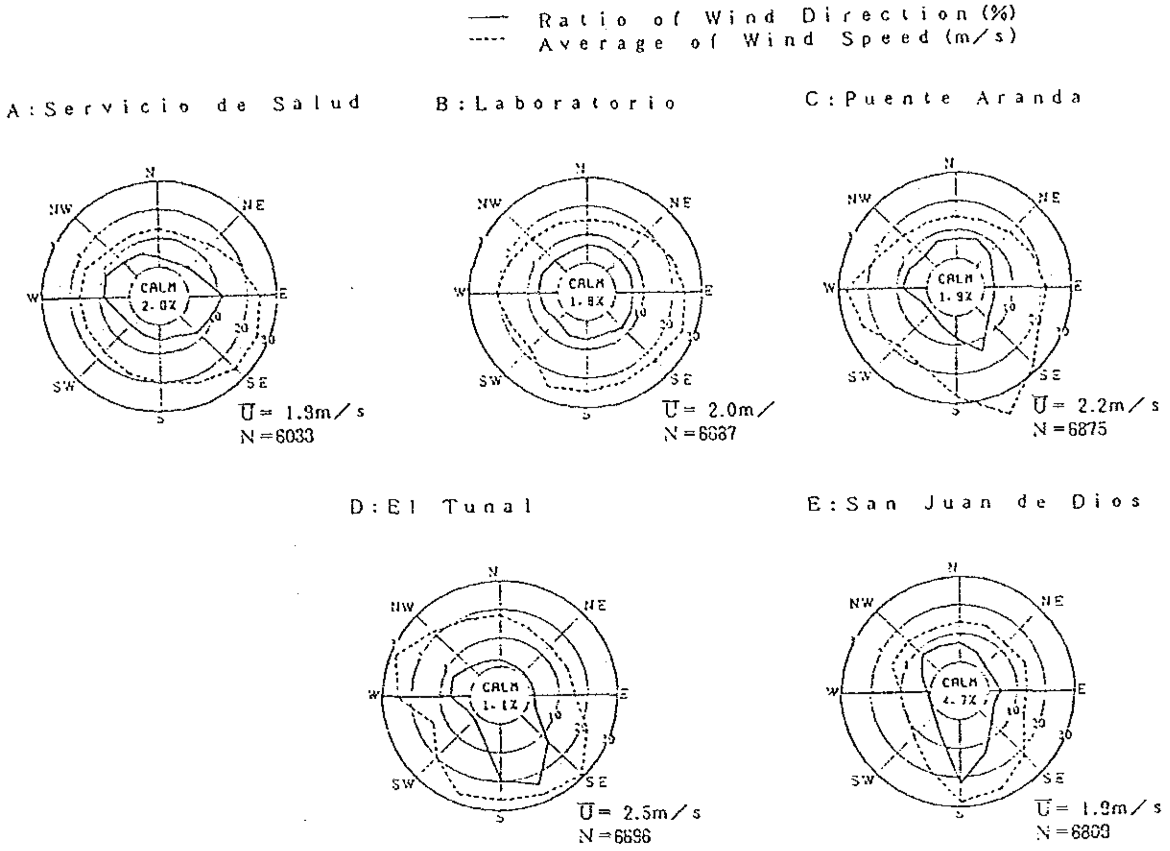


Fig. 3.1.2 Wind Rose

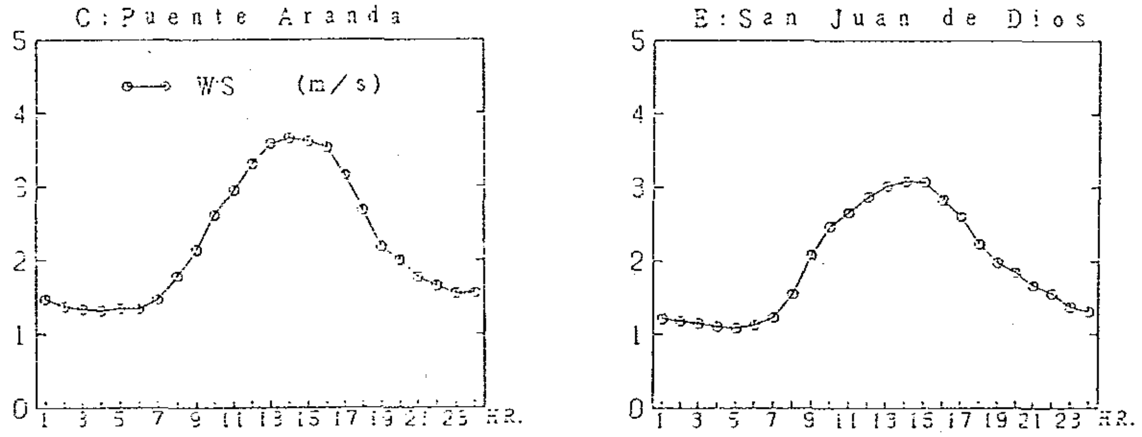


Fig. 3.1.3 Hourly Change of Wind Speed

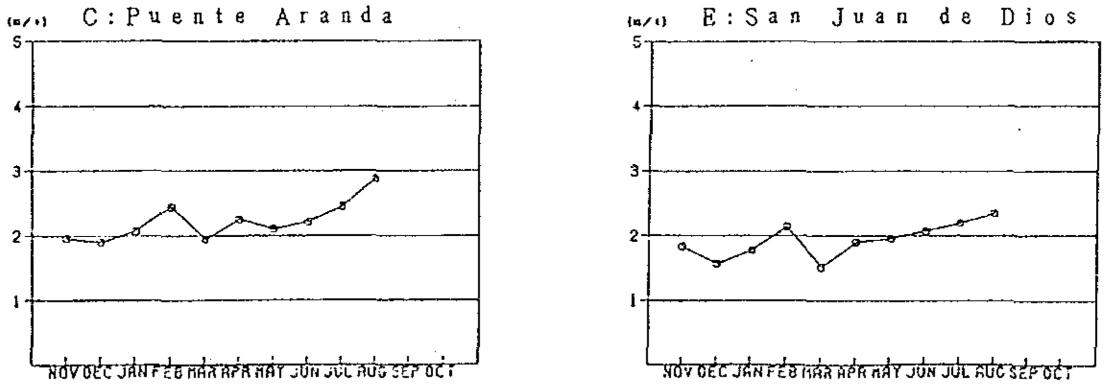


Fig. 3.1.4 Monthly Change of Wind Speed

(2) Upper Layer Meteorology

Upper layer meteorology observation was conducted four times, each time for seven days, at Hospital Simon Bolivar. According to the observation results (Fig. 3.1.5), the vertical profile of the wind speed showed increase of wind speed up to an altitude of 150 - 300 m, above which it remained almost constant. The mean wind speed at an altitude of 500 m was 3.5 m/s, which is not so high when compared with the speed of 2.2 m/s on the ground.

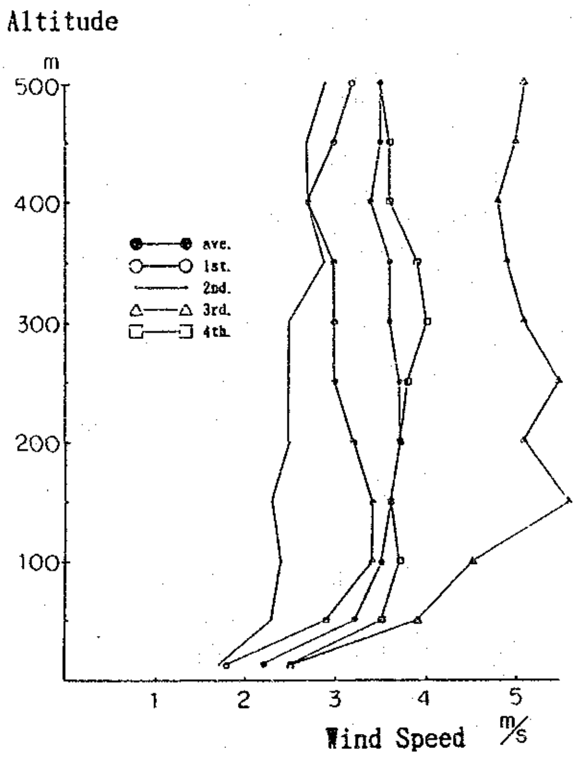


Fig. 3.1.5 Vertical Profile of Wind Speed

As regards the wind direction in the upper layer (Fig. 3.1.6), the pattern of wind roses by altitude were similar up to 500 m from the ground, showing the east wind was prevailing.

Fig. 3.1.7 is examples of appearance of inversion layer, showing existence of inversion up to a height of 200 m. The appearance frequency of surface inversion was 10 times at 7% of the total 146 observations. The maximum appearance frequencies of inversion layer at a height of 100 m and below, and at a height over 100 m were 5 times and 10 times respectively. The appearance frequencies of inversion layer were comparatively low.

at Simon Bolivar

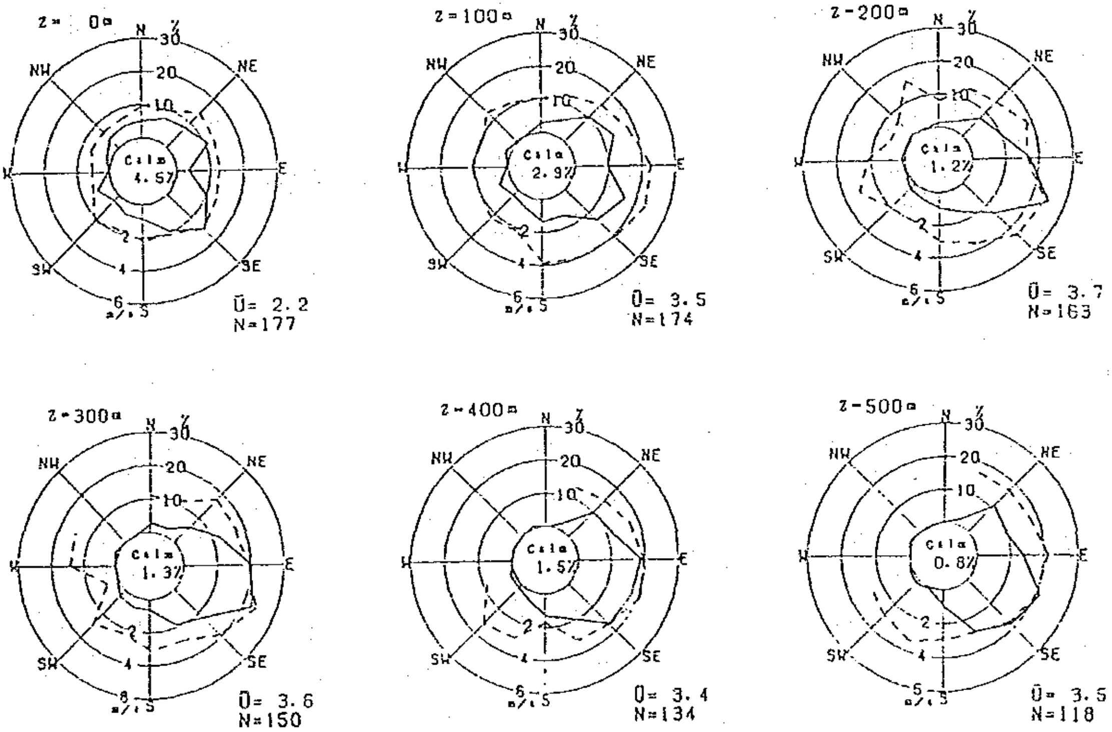


Fig. 3.1.6 Vertical Profile of Wind Direction at Simon Bolivar

Meteorology of U. L.

Observed Point : Simon Bolivar (U. L.) Observed Date : 1990-12- 1

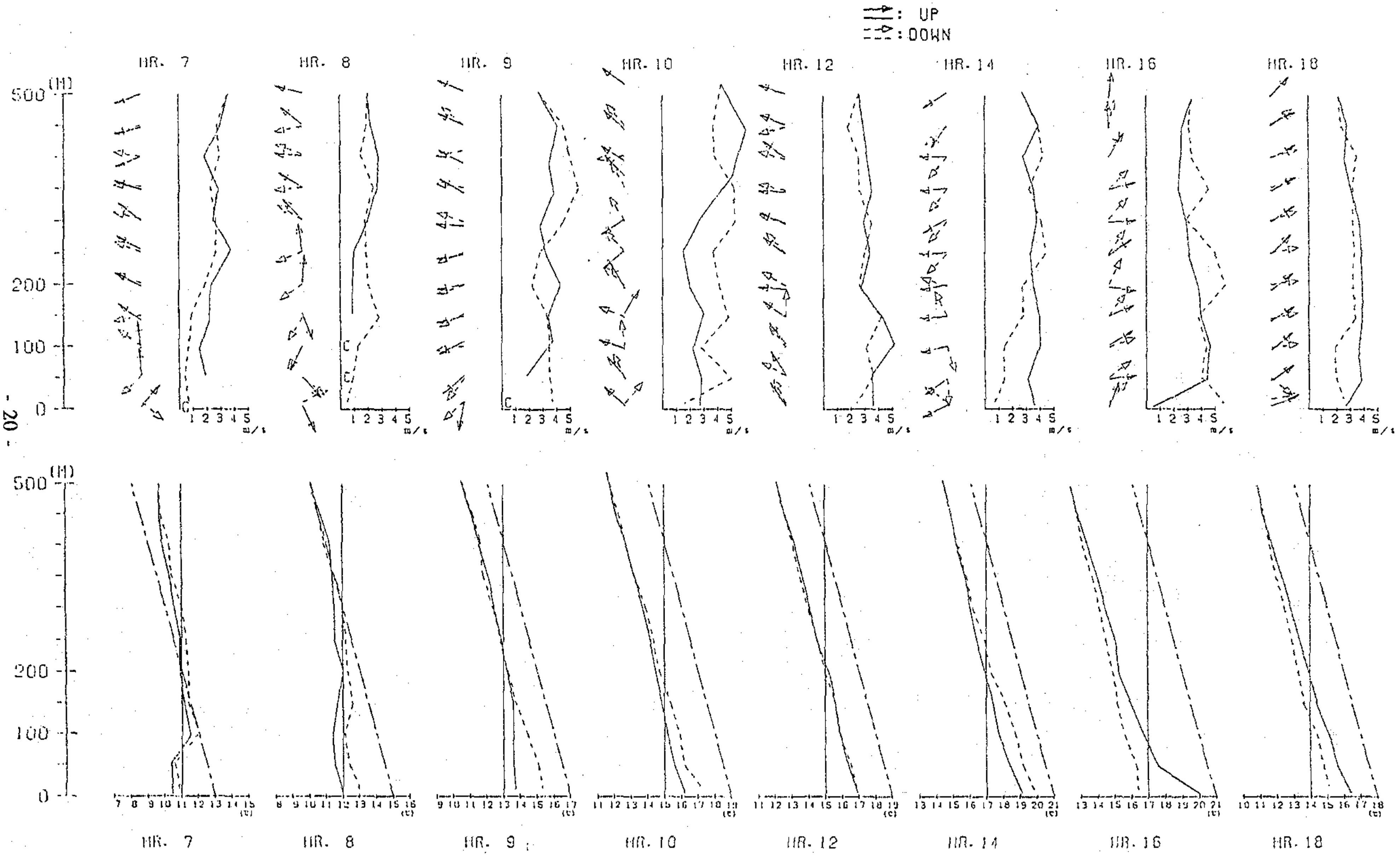


Fig. 3.1.7 Examples of Appearance of Inversion Layer

3.2 Ambient Air Quality

(1) Present State of Ambient Air Quality

The concentrations of SO_2, NO_2, NO_x, SPM, CO, NMHC, and O_3 as measured at five monitoring stations from November, 1990 to August, 1991 are shown in Table 3.2.1.

Sulfur Dioxide (SO_2): Ranged from 7.0 - 25.2 ppb in average: highest at station E positioned on the roadside, followed by 22.9 ppb at station C. The SO_2 value was relatively low at station A, B, and D.

Nitrogen Dioxide (NO_2): Ranged from 16.5 to 33.3 ppb in average: highest at station E and lowest at station D, showing considerable regional difference.

Nitrogen Oxides (NO_x): Ranged from 27.1 to 101.2 ppb in average: highest at station E, followed by 60.4 ppb at station A. It was low at stations B and D.

Suspended Particulate Matter (SPM): Ranged from 43.3 to 70.2 $\mu g/m^3$ in average. Though the SPM value was highest at station C positioned in the industrial area, there was not much regional difference. They were relatively high

Carbon Monoxide (C O): Ranged 1.5 to 8.5 ppm in average: high at stations E and A on the roadside. The CO value at other stations ranges 1.5 to 2.3 ppm, which is about two times as high as the concentration level in Tokyo.

Non-Methane Hydrocarbon (NMHC): Ranged 1.9 to 2.7 ppm in average: high at 2.7 ppmC at station E positioned on the roadside and at 1.9 ppmC (about four times as high as the concentration level in Tokyo) at station C positioned in the industrial area.

Ozone (O_3): The maximum one-hour value was 114 ppb at station E and 123 ppb at station C.

(2) State of Compliance with Air Quality Standards

Compared with the air quality standards of Colombia (shown in the parentheses in Table 3.2.1), CO and O_3 did not satisfy the standards.

SO_2: Proved satisfactory in terms of three-hour average, daily average, and annual average criteria.

NO_2: Satisfactory in all stations: the station E marked the highest value at 33.3 ppb.

SPM: Comparison of the measured value (SPM) with the standard value (SP) proved satisfactory both in terms of daily and annual averages criteria. But the concentration level at each station was not low.

CO: Both stations A and E proved unsatisfactory in terms of eight-hour average criterion, but satisfactory in terms of one-hour criterion. Other three stations proved satisfactory, both with respect to eight-hour and one-hour average criteria.

O_3: O_3 was measured at stations C and E, but both proved unsatisfactory. The appearance frequencies of values over the standard value (86.6 ppb) were 0.4% and 0.2% respectively.

(3) Hourly Change of Concentration

Fig. 3.2.1 shows hourly change of each air pollutant concentration. They show that each air pollutant concentration reached its peak in the morning. In particular, the hourly change patterns of CO and NOx were extremely similar, which means that their main pollutant source was same. The appearance time of the O_3 peak concentration was 10:00: two hours behind those of CO and NOx. The decreasing of the concentrations in the afternoon may be due to increase in the wind speed as shown in Fig. 3.1.3.

(4) Monthly Change of Concentration

Fig. 3.2.2 is monthly change of the concentration, which shows that the concentrations of the pollutants excluding O_3 were roughly low in February and high in March. This corresponds to the monthly change of the wind speed, that is, high in February and low in March, as shown in

Table 3.2.1 Measurement Result for Ambient Air Quality (1990.11 ~ 1991.8)

SO_2

unit: ppb

Measuring Point	Measuring Period(hour)	Annual Average (38.2)	Max Daily Average (152.8)	Max 3-hours Average (573.1)	Max Hourly Value
(A)Servicio de Salud	5513	7.0	20.7	57.3	71
(B)Laboratorio	6248	9.9	29.7	77.7	90
(C)Puente Aramda	6419	22.9	57.9	81.3	89
(D)El Tunal	6008	8.6	20.7	59.0	73
(E)San Juan de Dios	6502	25.2	42.7	95.0	147

note : ( ) is ambient air quality standard value

NO_2, NO_x

unit:ppb

Measuring Point	Measuring Period(hour)	NO_2		NO_x	
		Annual Average (53.2)	Max Hourly Value	Annual Average	Max Hourly Value
(A)Servicio de Salud	6478	27.2	215	60.4	331
(B)Laboratorio	6212	20.2	144	27.4	212
(C)Puente Aramda	6488	23.2	132	39.2	245
(D)El Tunal	6153	16.5	139	27.1	258
(E)San Juan de Dios	6102	33.3	282	101.2	344

SPM

unit: $\mu g/m^3$

Measuring Point	Measuring Period(hour)	Annual Average (100)	Max Daily Average (400)	Max Hourly Value
(A)Servicio de Salud	6502	53.1	175.2	387
(B)Laboratorio	5612	43.3	110.8	397
(C)Puente Aramda	5415	70.2	147.4	322
(D)El Tunal	6669	59.1	160.0	567
(E)San Juan de Dios	5845	62.2	172.5	575

CO

unit:ppm

Measuring Point	Measuring Period(hour)	Annual Average	Max 8-hour Average (13.1)	Maximum Hourly Value (43.7)
(A)Servicio de Salud	4973	4.7	17.8 (1.4%)	23.9
(B)Laboratorio	5292	2.3	10.8	16.3
(C)Puente Aranda	5755	2.0	10.2	19.3
(D)El Tunal	5647	1.5	5.0	9.9
(E)San Juan de Dios	6422	8.5	23.6 (13.0%)	29.5

note : ( ) is percentage exceeded standard value

NMHC, THC

unit:ppmC

Measuring Point	Measuring Period(hour)	non-CH_4		Total HC	
		Annual Average	Maximum 6~9 o'clock Average	Annual Average	Maximum Hourly value
(C)Puente Aranda	4164	1.9	2.6	3.9	15.3
(E)San Juan de Dios	4451	2.7	4.3	4.7	13.3

O_3

unit:ppb

Measuring Point	Measuring Period(hour)	Annual Average	Maximum Hourly Value (86.6)
(C)Puente Aranda	6153	10.7	123 (0.4%)
(E)San Juan de Dios	3716	6.7	114 (0.2%)

note : ( ) is percentage exceeded standard value

Fig. 3.1.4. The O_3 concentration tended to be high during a period from January to April.

(5) Regional Concentration Distribution

Fig. 3.2.3 shows the result of simplified measurement of SOx and NOx at 50 points in the city area. SOx was measured by PbO_2 method for a month, and NO_2 and NOx were measured by NO_2 plate method for a month as well.

The regional concentration distribution of SO_2 showed the appearance of higher concentration from the central to southwestern parts of the city area, which may be due to the factories located in there.

The NOx value tended to be high in the central part of the city while the NO value was high around the major roads. And, the NO_2/NOx ratio was small at about 0.3, indicating the influence of the exhaust gas from motor vehicles.

(6) Concentration Distribution around Road

The CO and NOx concentration along the road was measured by the simplified method, that is, the detector tube method. Both CO and NOx showed high concentration at the roadside, which also shows that the influence of the exhaust gas from motor vehicles reached places as far as about 40 m from roads.

(7) Size Distribution of Suspended Particle (SP)

Fig. 3.2.4 shows the size distribution of SP as measured at the Puente Adranda monitoring station positioned in the industrial area. The result shows that the percentage of SP with the size of less than 7 μm, which is said to give adverse effect on the human health, was 50 - 60% in the months other than November, 1990. The percentage of SP for the size of 1.0 μm or less whose main sources are considered to be artificial ones was about 30%.

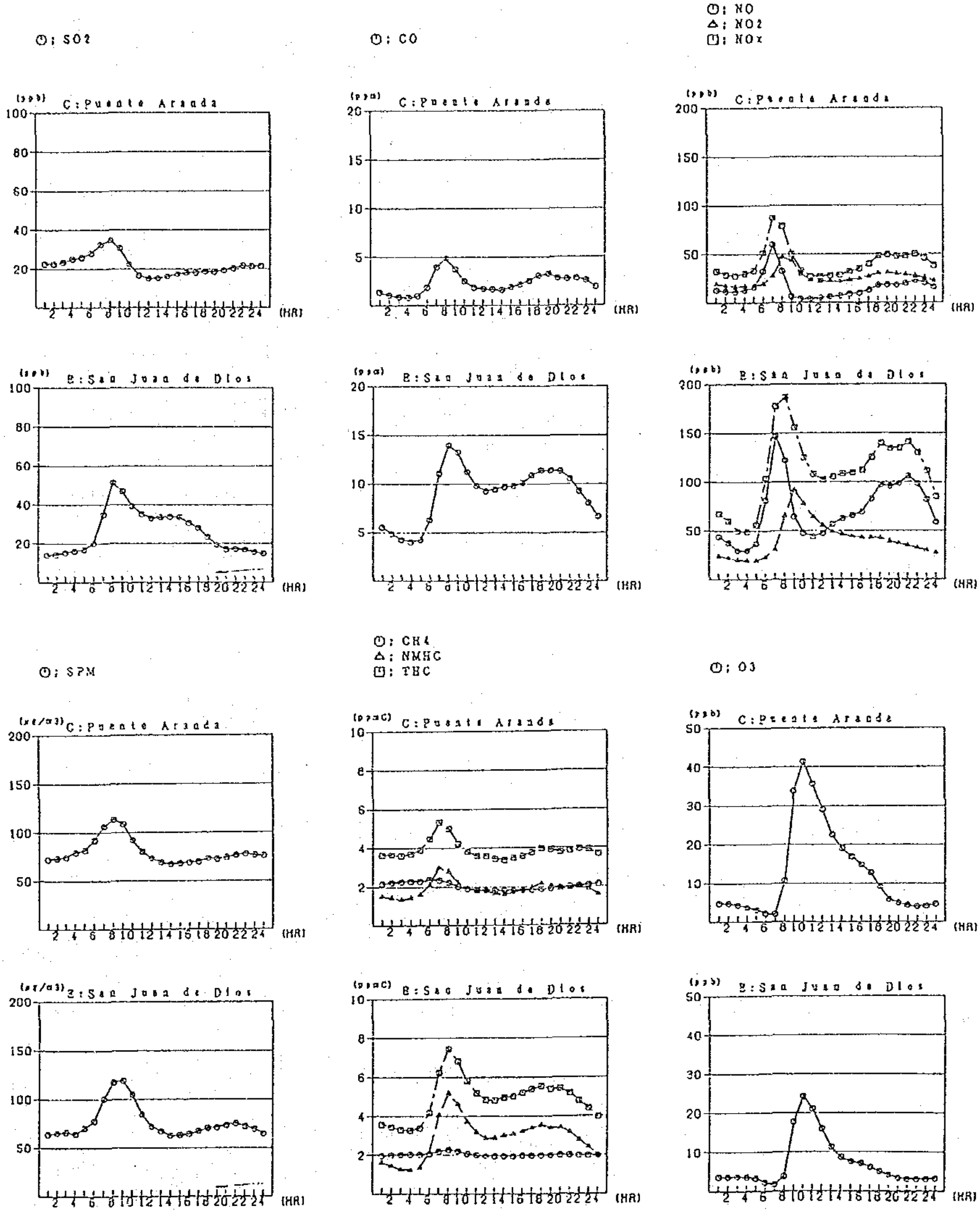


Fig. 3.2.1 Hourly Concentration Change

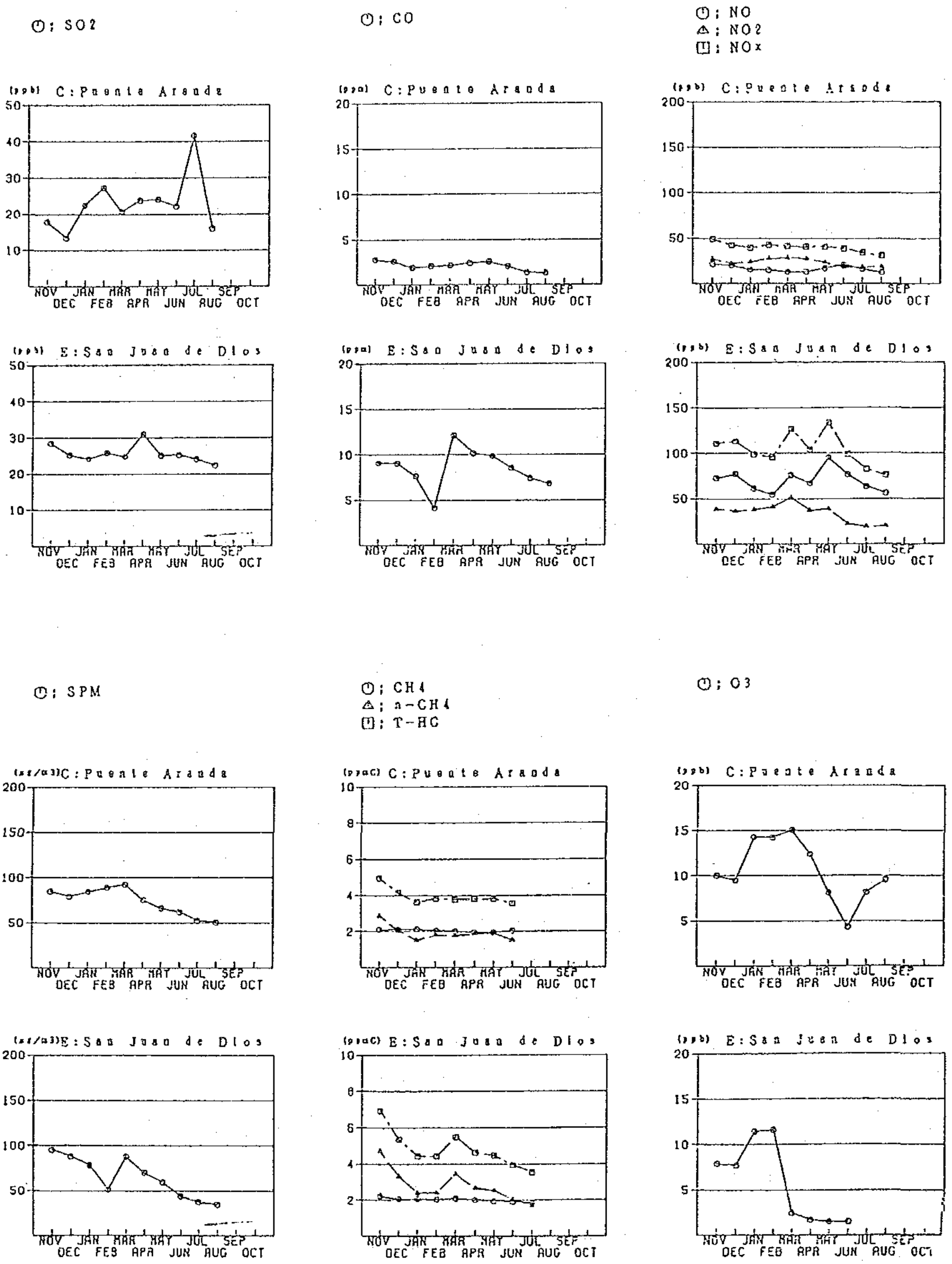


Fig. 3.2.2 Monthly Concentration Change

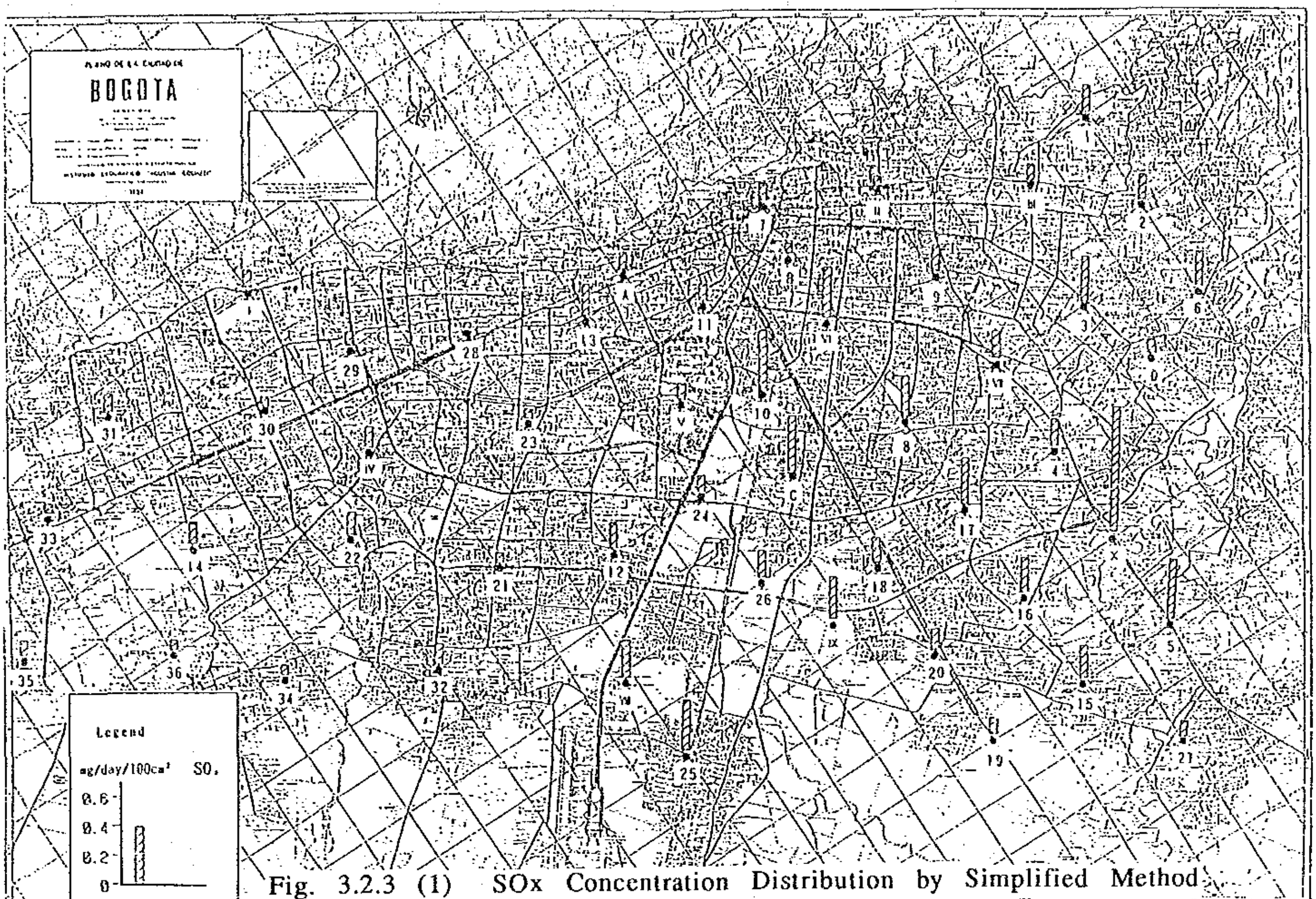


Fig. 3.2.3 (1) SOx Concentration Distribution by Simplified Method

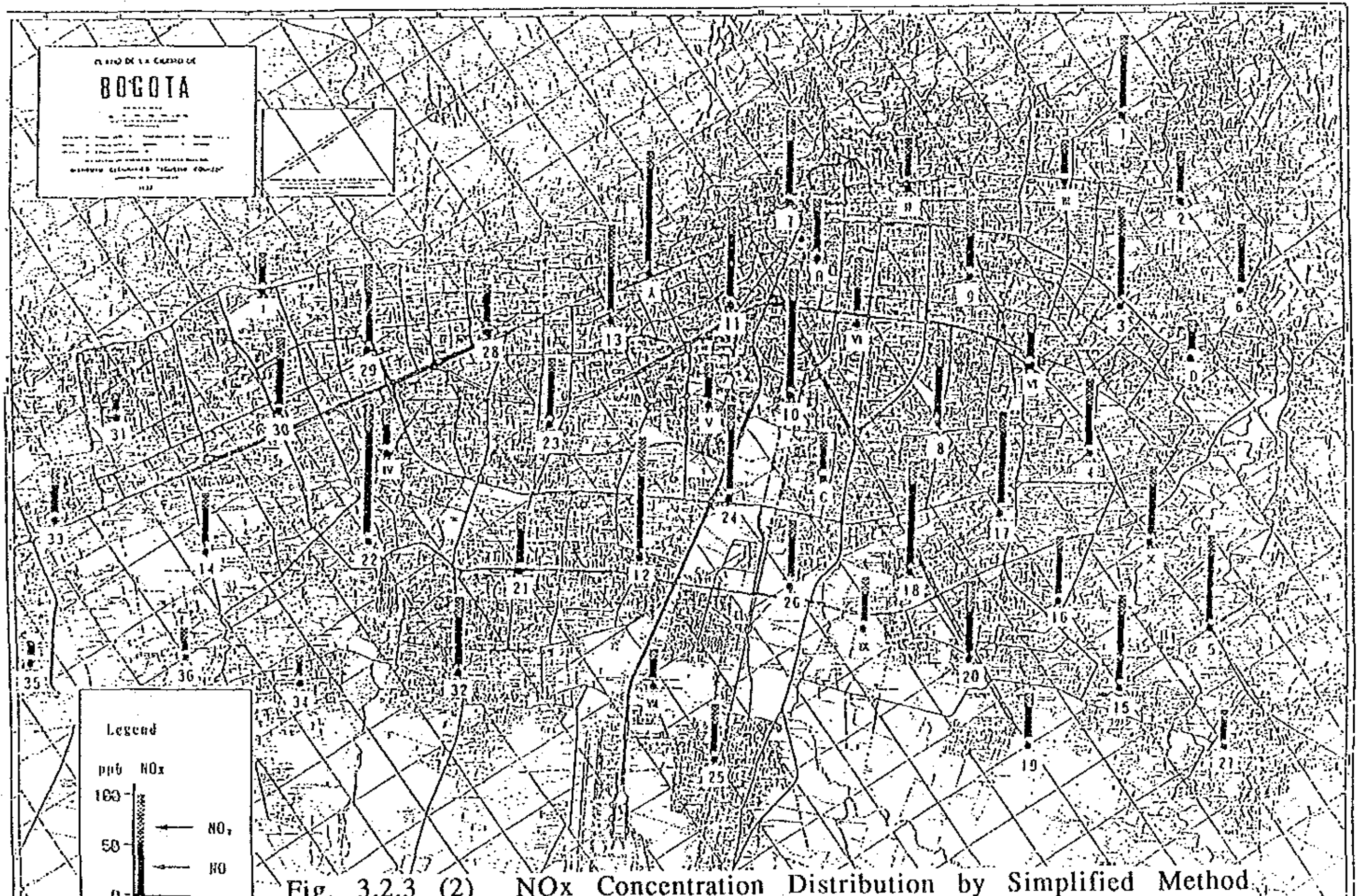


Fig. 3.2.3 (2) NOx Concentration Distribution by Simplified Method

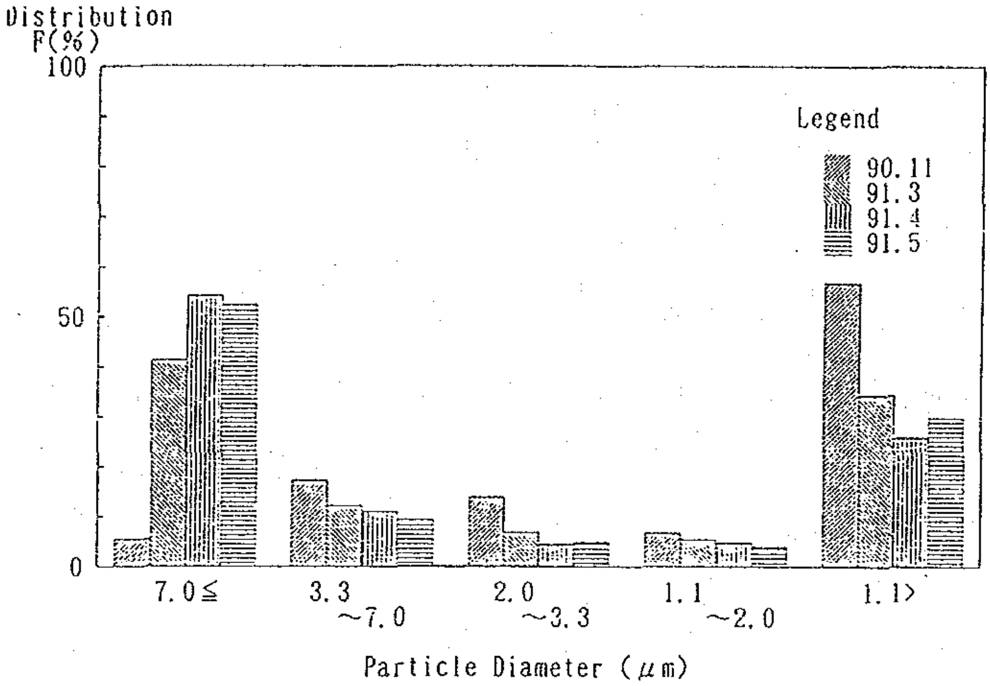


Fig. 3.2.4 Particle size Distribution of SP (Station C: Puente Aranda)

CHAPTER 4 ANALYSIS OF PRESENT STATE OF AIR POLLUTANT SOURCES

Pollutant sources covered by this study were factories, establishments, motor vehicles, aircraft, and domestic source.

4.1 Factories and Establishments

154 factories in the city area were surveyed with questionnaire. The major survey items included fuel type and its consumption, type of smoke and soot emitting facilities, etc. Flue gas measurement was also made at 51 factories, along with analysis of the sulfur content of the fuels used at these factories. Based on these results were estimated emissions of SOx, NOx and dust from factories and establishments.

(1) Factory Questionnaire Survey

According to the result of the questionnaire survey, the number of factories by industry types was largest at 31.2% for the food and drink industries, followed by 13.0% for ceramic, stone and clay products industry.

The number of facilities by facility types was 205 (53.8%) for boilers and 83 (21.8%) for kilns for bricks and clay pipes of the total 381 facilities. Both occupied the percentage of 75.6% of the whole.

As regards the fuel consumption by types, the crude oil (Crudo de Castilla) was consumed most at 102,000 kl/year among liquid fuels, and the crude oil was used mostly for boilers (Caldera). The second most consumed fuel was light oil (ACPM) with its consumption estimated at 45,000 kl/year. For solid fuel, consumption of coal was 142,000 ton/year, most of which was for boilers and brick kilns. The gas fuel used was propane gas, whose consumption, however, was small at 1,800 kl/year. The consumption of woods was 2,800 ton/year.

Table 4.1.1 shows the number of stacks by height, which indicates that the percentage of low stacks of 11 - 20 m was 75% while that of 31 m or more 3% (11 stacks).

As regards exhaust gas treatment facilities, dust collectors were the only ones, and only 26 units were in operation. Among them the cyclones were 13 units.

Table 4.1.1 Number of Stacks by Height

Height (m)	No. of Stacks
~ 10	37
11 ~ 20	275
21 ~ 30	43
31 - 50	8
51 - 70	3
Total	366

(2) Factory Flue Gas Measurement

Flue gas measurement from factories was made with 51 factories. Facilities covered by this measurement included 30 boilers, 6 brick kilns, 3 clay pipe kilns, and 12 other facilities. The measurement result is summarized in Table 4.1.2.

Table. 4.1.2 Factory Flue Gas Measurement Results

No.	Facility	Fuel	Dust g/m^3N	SOx ppm	NOx ppm	O2 %	Temperature ℃
1	Boiler	Crude oil	0.15-1.8	270-1370	15-681	3-16	112-288
		Fuel oil	0.15-0.25	420-460	199-210	5-14	199-200
		Coal	0.02-2.7	5-220	31-510	10-17	28-244
2	Brick kiln	Coal	0.08-0.39	66-180	12-118	18-20	72-230
3	Clay pipe kiln	Coal	0.02-1.9	11-99	11-27	15-20	28-430
4	Drying oven	Light oil	0.11-0.53	5-11	29-33	19-20	67-75
		Oil or Gas	0.01-0.02	0	3-4	19-20	74-97
5	Incinerator	Light oil	0.07-0.75	0-53	0-30	13-20	91-144
6	Burning kiln	Light oil	0.01-0.07	20-48	53-61	15-18	188-516

(3) Fuel Analysis

The analytical result of the sulfur content (percent by weight) of the fuel showed the average value of 2.3 wt% for crude oil, 0.4 wt% for light oil, and 0.57 - 0.74 wt% for coal. The sulfur content of fuel oil was 2.4 wt%. Actually, however, mixing of oil of poor quality was often seen.

(4) Air Pollutant Emission Factors

The air pollutant emission factors for smoke and soot emitting facilities were established on the basis of the result of the factory flue gas measurement and existing data of the USA and Japan. The result is shown in Table 4.1.3.

(5) Quantity of Air Pollutant Emission

Table 4.1.4 shows the estimated result of the annual emission quantity of dust, SOx, and NOx on the basis of the above data.

When viewed by the industry type, the emission quantity of these three pollutants was high in food and kindred products industry, drink feed industry, and ceramic, and stone and clay products industry.

Table 4.1.3 Emission Factores for Factories and Establishments

No.	Facility Type	Fuel Used	SOx	Dust	NOx (as NO_2)
1	Boiler	Crude oil Fuel oil Machine oil	45.08 kg/kℓ 46.56 kg/kℓ 46.56 kg/kℓ	9.27 kg/kℓ	5.28 kg/kℓ
		Light oil	6.96 kg/kℓ	0.58 kg/kℓ	2.98 kg/kℓ
		Coal	8.84 kg/ton	12.00 kg/ton	4.78 kg/ton
		Wood	-	2.26 kg/ton	1.44 kg/ton
2	Gas furnace	Propane gas	-	0.20 kg/kℓ	1.35 kg/kℓ
3	Melting furnace for casting iron and steel	Coke	8.84 kg/ton	2.70 kg/ton	1.20 kg/ton
4	Melting furnace for alminium	Fuel oil	46.56 kg/kℓ	14.39 kg/kℓ	3.61 kg/kℓ
		Kerosen	1.92 kg/kℓ	42.79 kg/kℓ	1.58 kg/kℓ
5	Metal heat treating furnace	Crude oil Light oil	45.08 kg/kℓ 6.96 kg/kℓ	1.20 kg/kℓ	1.00 kg/kℓ
6	Petroleum refinery heater	Propane gas	-	36.18 kg/kℓ	1.49 kg/kℓ
7	Brick and clay pipe kiln	Coal	11.47 kg/ton	8.18 kg/ton	8.31 kg/ton
8	Glass melting furnace	Crude oil	45.08 kg/kℓ	4.91 kg/kℓ	5.71 kg/kℓ
9	Direct heating furnace for inorganic chemical products	Light oil	6.96 kg/kℓ	1.80 kg/kℓ	9.60 kg/kℓ
10	Direct heating furnace for foodstuff	Crude oil Light oil	45.08 kg/kℓ 6.96 kg/kℓ	1.20 kg/kℓ	1.50 kg/kℓ
		Propane gas	-	0.22 kg/kℓ	1.30 kg/kℓ
11	Drying oven	Light oil	6.96 kg/kℓ	1.80 kg/kℓ	9.60 kg/kℓ
		Wood	-	2.26 kg/ton	1.44 kg/ton
		Propane gas	-	0.20 kg/kℓ	1.35 kg/kℓ
12	Incinerator	Light oil	6.96 kg/kℓ	20.10 kg/kℓ	1.65 kg/kℓ
13	Burning kiln	Light oil	6.96 kg/kℓ	1.80 kg/kℓ	9.60 kg/kℓ
14	Other furnaces	Light oil	6.96 kg/kℓ	1.80 kg/kℓ	9.60 kg/kℓ

Table 4.1.4 Air Pollutant Emission by Industrial Type

(Unit: ton/year)

No.	Industry	Dust	SOx	NOx
1	Food and kindered products	310.1	1509.1	214.4
2	Drink feed	767.8	1854.2	410.4
3	Tobacco	5.2	25.5	3.0
4	Textile	144.1	797.7	104.0
5	Leather, leather products	2.1	29.2	3.6
6	Footgear products	9.3	45.8	5.4
7	Lumber and wood products	3.1	15.1	12.1
8	Furniture and fixtures	27.0	92.9	78.4
9	Pulp, paper and allied products	54.1	173.8	29.1
10	Industrial chemical products	12.4	59.7	7.7
11	Other chemical products	8.7	38.7	12.1
12	Petroleum, coal and products	20.3	45.0	5.7
13	Rubber products	9.8	55.0	10.2
14	Plastic products	0.1	0.0	0.8
15	Ceramic, stone and clay products	676.0	1038.2	686.8
16	Glass products	4.5	41.1	5.2
17	Mineral and nonmetal products	0.0	4.3	1.9
18	Iron and steel	10.6	67.8	6.9
19	Non-ferrous metals and products	14.0	2.2	2.7
20	Transportation equipment	18.2	105.4	15.1
21	Auto industry	0.5	6.2	2.8
22	Other manufacturing industries	69.7	332.6	44.0
23	Hospitals	18.1	104.1	14.4
24	Hotels	10.7	59.1	10.7
25	Other establishments	1.9	1.0	0.3
	Total	2198.3	6503.7	1687.7

4.2 Motor Vehicles

(1) Traffic Volume Survey

Measurement of the traffic volume was made by using counters at a total of 46 points for principal roads in Santafe de Bogota City. The result shows that the daily traffic volume was large within the city area, with the maximum volume achieved by AUTOPISTA NORTE at 132,000 units/day. Traffic volume of 30,000 units/day or more was also observed in other arterial roads. Percentage of buses was at 20 - 30% in southern and western parts of the city higher than that in the northern parts, and more higher in the central part and particularly high at about 70% at Carrera 10. Truck share was low within the city, but high at about 15% on the arterial roads connecting Santafe de Bogota with other cities.

Hourly change of the traffic volume was remarkable along the south-north roads. Namely, the peak traffic volume appeared from north to south in the morning and to the north in the evening as shown in Fig. 4.2.1.

(2) Survey on Percentage of Motor Vehicles Registered in Santafe de Bogotá City

The ratio of motor vehicles registered in and outside Santafe de Bogota City was measured by reading the number plate of vehicles at four points along arterial roads in the city area. The result shows that motor vehicles registered in Santafe de Bogota was about 50%.

(3) Driving Speed Survey

The mean driving speed of motor vehicles in the city area was measured by actual vehicle driving. The speed was found to be 20 - 30 km/h on the arterial roads in the normal traffic state and 15 - 20 km/h when the road was crowded.

In Particular, bus speed on Ave. CARACAS and Ave. 10 was often 10 km/h or less and the bus stop frequency per 1 km was as high as 5 to 10 times.

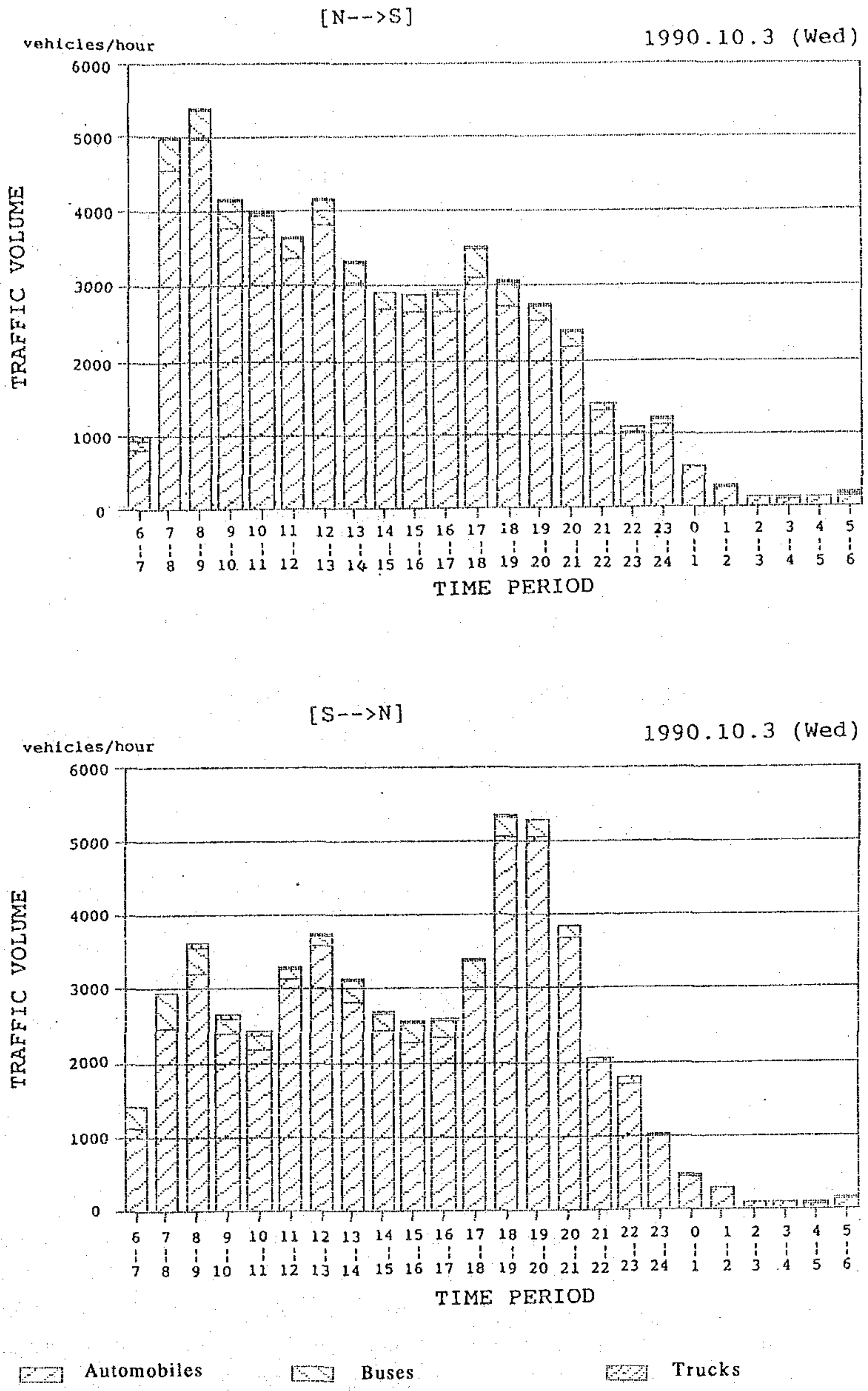


Fig. 4.2.1 Typical Hourly Traffic Fluctuation of Radial Road (Carrera 30)

(4) Measurement of Exhaust Gas from Motor Vehicles

Measurement of exhaust gas during idling from tail pipes was conducted for CO, NOx, and HC with 160 units running in the city. The result showed CO at 6.1%, NOx at 55 ppm and HC at 1,505 ppm in average for gasoline passenger cars, with maximum being 11.6%, 369 ppm, and 5,470 ppm respectively. For gasoline-engined buses and trucks, the HC concentration was high at around 3,000 ppm.

(5) Volume of Driving

The volume of driving was calculated by using the traffic volume obtained from the on-site measurement for arterial roads and by that from the aerial photos for narrower roads.

Table 4.2.1 shows the volume of driving (unit: unit•km) by vehicle type within the city area.

This table shows that the traffic volume of automobiles accounted for extremely high percentage at about 83% of the whole. The percentage of buses including small buses was about 12%.

Table 4.2.1 Volume of Driving by Vehicle Type

unit: 10^6 km/year

Type	Volume of Driving
Automobiles	4,285 (82.5)
Buses	641 (12.3)
Trucks	265 (5.1)
Total	5,191 (100.0)

( ) : %

(6) Air Pollutant Emission Factors

The quantity of air pollutant emission when a motor vehicle has run for 1 km (the so-called emission factor) was assumed as shown in Table 4.2.2, with reference to Mexican, American and Japanese data because no direct measurement data in the Santafe de Bogota City area was available. Note that the emission factor varies depending on vehicle driving speed, and was thus calculated by a function with average driving speed as explanatory variable.

Table 4.2.2 Motor Vehicle Emission Factor

(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
	NOx	1.26	1.12	1.06	1.07	1.13	1.21	1.31	1.40	1.49
	SOx	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
	NOx	4.72	4.39	4.16	4.05	3.99	3.98	3.99	4.06	4.12
	SOx	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
	NOx	7.44	6.91	6.47	6.16	5.92	5.76	5.62	5.61	5.59
	SOx	1.12	0.97	0.89	0.84	0.81	0.79	0.78	0.76	0.75

(7) Quantity of Air Pollutant Emission

Table 4.2.3 shows the quantity of air pollutant emission calculated using the volume of driving and emission factor. This table shows that the percentage of each air pollutant was about 40 - 60% for automobiles, about 30% for buses, and 10 - 20% for trucks. The percentage of buses and trucks was higher for their volume of driving.

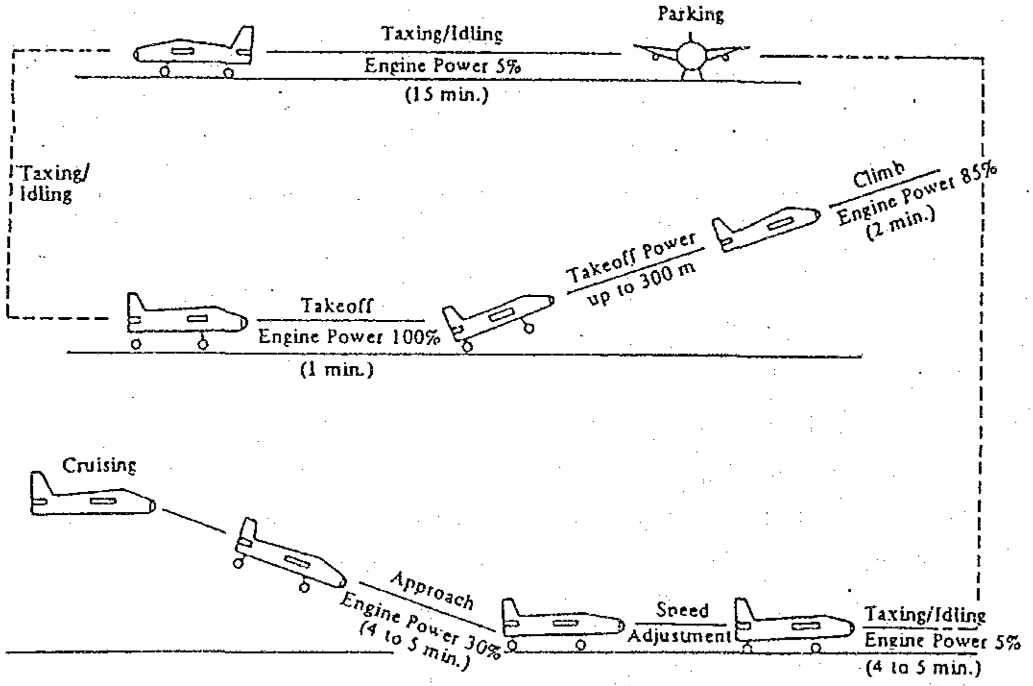
Table 4.2.3 Annual Quantity of Air Pollutant Emission from Motor Vehicles

unit: ton/year (%)

Vehicle Type	SOx (as SO2)	NOx (as NO2)	CO	HC
Automobiles	496 (39.1)	5,039 (54.5)	149,237 (51.7)	12,039 (60.7)
Buses	475 (37.4)	2,644 (28.6)	100,545 (34.9)	5,781 (29.1)
Trucks	298 (23.5)	1,567 (16.9)	38,651 (13.4)	2,025 (10.2)
Total	1,269 (100)	9,250 (100)	288,433 (100)	19,845 (100)

4.3 Aircraft

El Dorado Airport located in the west of Santafe de Bogota City receives both domestic and international flights; 29,200 flights and 4,484 flights for large airplanes in a year respectively. The mode of flight on ground and at low altitude includes four modes; idling, take-off, ascend, and approach-landing as shown in Fig. 4.3.1. Principal air pollutants, NOx and SOx, of the exhaust gas from aircraft were calculated at 114 ton/year for NOx and 29 ton/year for SOx by using the emission factor by mode.



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

Fig. 4.3.1 Airplane Navigation Mode

4.4 Domestic Source

Among fuels used in households of about 4 million (1990) population in Santafe de Bogota City, cocinol and propane gas were estimated in all to emit air pollutants at a rate of 84 ton/year for SOx, 254 ton/year for NOx and 105 ton/year for dust.

4.5 Summary for Quantity of Air Pollution Emission

The pollutant emission quantity by source is shown in Table 4.5.1. For SOx, factories and establishments occupied 85% of the whole. For NOx, motor vehicles occupied 82% of the whole. The emission quantity from aircraft and domestic source was small in percentage at 1 - 3%.

The regional distribution of SOx emission quantity from factories and establishments is shown in Fig. 4.5.1.

Table 4.5.1 Air Pollutant Emission Quantity

Unit: ton/year (%)

Source	SOx	NOx	Dust	CO	HC
Factories and Establishments	6,504 (82)	1,688 (15)	2,198(95)	-	-
Motor vehicles	1,269 (16)	9,250 (82)	-	288,433	19,845
Aircraft	29 (0.4)	114 (1)	-	-	-
Domestic source	84 (1)	254 (3)	105 (5)	-	-
Total	7,886(100)	11,306(100)	2,303(100)	288,433	19,845

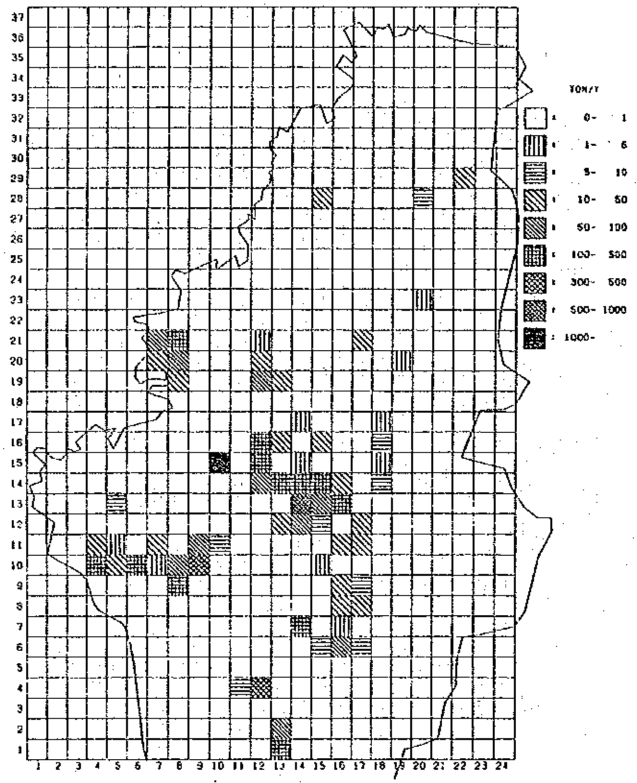


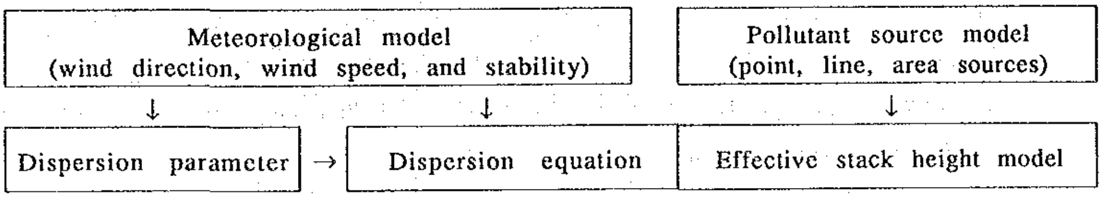
Fig. 4.5.1 Regional Distribution of SOx Emission Quantity from Factories and Establishments

CHAPTER 5 AIR DISPERSION SIMULATION MODEL

The dispersion simulation model was prepared in order to determine contributions of factories and motor vehicles to the air quality.

5.1 Outline of Air Dispersion Simulation Model

The model consists of sub-models shown below.



(1) Scope of the Dispersion Simulation Model

① Calculated concentration

Long-term average (annual average) of SO_2, NO_x, NO_2, and CO

② Sources concerned

Factories, establishments, motor vehicles, and aircraft

③ Calculation point

Monitoring station (5 points), and 1 km mesh points (at the center) in the city area

(2) Meteorological Model

Meteorological data used for dispersion simulation are wind direction, wind speed, and atmospheric stability. Since these meteorological elements differ from one region to another, the calculated area are divided into several blocks by meteorology. In this study, the city area was divided into five blocks, and the data obtained at monitoring stations in each block were used as the representative meteorology for that block concerned. The atmospheric stability for the daytime, was determined by using the data of the wind speed and solar radiation, and for the nighttime the wind speed and net radiation. The wind speed was corrected according to the height of the source concerned.

The meteorological classification of each element is shown below.

Wind direction: 16 directions and calm ($\leqq 0.4$ m/s)
Wind speed: 8 classes
Atmospheric stability: 11 classes

(3) Pollutant Source Model

Stacks of factories and establishments were all treated as point source. Roads on which motor vehicles travel were handled as line source for arterial roads and as area source for narrower roads. As regards aircraft, its staying on ground was handled as area source and its flying up to a height of 500 m above ground as point source.

(4) Effective Stack Height Model

Exhaust gas rises up to a certain height (effective stack height) under the effect of temperature-induced buoyancy and discharge speed. In this study, this height was calculated using the CONCAVE equation when there was wind and the Brigges equation when there was no wind.

(5) Air Dispersion Equation

For the dispersion equation, the plume equation was used when there is wind and the puff equation when there is no wind.

(6) Dispersion Parameter

The dispersion parameters were set by using the Pasquill-Gifford chart for the plume equation and the Turner chart for the puff equation.

(7) Equation to convert from NOx to NO_2

To calculate the NO_2 concentration from the NOx concentration determined from dispersion simulation, the statistical method described below was used:

$NO2 = 3.41 \cdot NOx^{0.527}$ (unit:ppb)

NO2, NOx: Long-term average (annual average)

Factor: Determined by applying logarithmic linear regression method to data measured at five stations (Fig. 5.1.1).

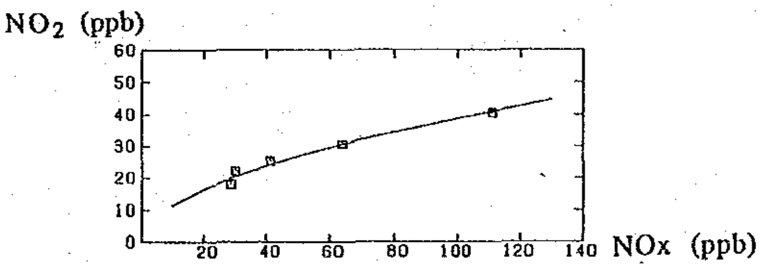


Fig. 5.1.1 Logarithmic Linear Regression between NO2 and NOx

5.2 Reproducibility of the Dispersion Simulation Model

The reproducibility for each pollutant was evaluated by means of correlation coefficient. The result shows that four substances had good correlation of more than 0.8 as shown in Table 5.2.1. Note that, CO concentration at stations whose actual CO concentration was high was a bit under-estimated. Fig. 5.1.2 is scatter diagram of actual and estimated values for each pollutant.

Table 5.2.1 Measured vs Calculated Values

Item	Correlation coefficient r	Regression line $Y = aX + b$	Scattering of relative error S/Y	$\bar{Y} - \bar{X}$
SO_2 (ppb)	0.83	$Y = 1.5X - 3.4$	0.37	2.4
NOx (ppb)	0.92	$Y = 1.1X - 1.4$	0.28	1.8
NO_2 (ppb)	0.95	$Y + 1.0X - 0.7$	0.12	-1.0
C O (ppm)	0.95	$Y = 1.7X - 0.7$	0.45	1.3

Y: Measured concentration X: Calculated concentration

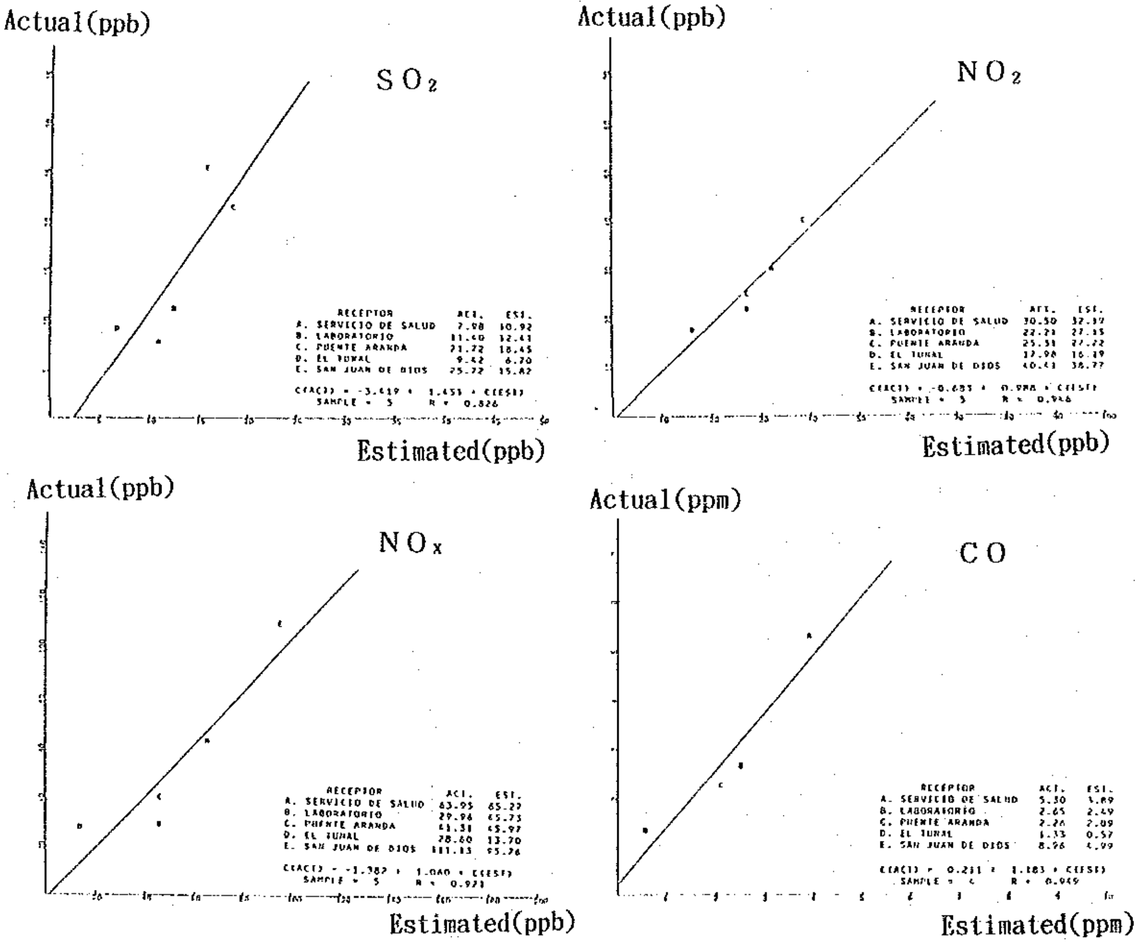


Fig. 5.1.2 Scatter Diagram of Actual and Estimated Values

CHAPTER 6 AIR POLLUTION STRUCTURE

6.1 Principal Features of Air Pollution

Principal features of air pollution in the Santafe de Bogota city area are summarized from analytical results up to now. Meteorological features responsible for air pollution are:

- Low wind speed, particularly low until 8:00 in the morning and thus greatly responsible for appearance of the high concentration of CO from 7:00 to 9:00. Generally speaking, the wind speed in the upper layer is also low.
- Appearance of the surface inversion layer and isothermal layer near the ground surface, often bringing about high concentration of CO, etc.

Sources of air pollutants may be characterized as follows:

- SO_2 is emitted mostly from fuel combustion in factories and establishments, with the high concentration area located to the southwest of the city. Most of factories have stacks low in height.
- NO_x and NO_2 are emitted mostly from motor vehicles, with the effect particularly remarkable on the roadside.
- As to dust, smoke with high dust content is emitted because few stacks are equipped with dust collectors.
- Large quantity of CO is emitted from motor vehicles because the Santafe de Bogota City is located in a basin where the atmospheric pressure is low, extremely old vehicles are running in the city, and there is no emission regulation for motor vehicles.
- Large quantity of HC is emitted from motor vehicles because of the same reasons as CO. HC is considered mostly non-methane hydrocarbon.

The present state of the ambient air quality under the meteorological and pollutant source conditions described above is summarized as following:

- High concentration of CO on the roadside, proving not satisfactory to the air quality standard. The concentration at places away from roadside is also nearly as high as the standard value.

- O_3 concentration exceeding the standard value appears 20 times (hours) or more in a year. Also high is the concentration of NMHC responsible for O_3.

- SPM satisfies the standard at all monitoring stations, but relatively high concentration appears in the industrial areas and around roads.

- SO_2 satisfies the air quality standard at all monitoring stations, but relatively high concentration appears in industrial areas and around roads.

- NO_2 satisfies the environmental standard at all monitoring stations, but relatively high concentration appears at roadsides.

The dispersion simulation as described below was also made to grasp the source contribution quantitatively.

6.2 Pollutant Source Contribution and Regional Distribution by Air Dispersion Simulation

(1) Contribution Concentration and Ratio

The contribution concentration and contribution ratio by source at each monitoring station and maximum concentration mesh are described below:

SO_2: Among five monitoring stations, the Puente Aranda station (C) showed the highest concentration (20.8 ppb), of which 68% was contribution by factories and establishments. Their contribution concentration was 14.2 ppb. The maximum concentration point was found at a roadside of the western industrial area, with the concentration at 32.3 ppb approximately equal to the environmental standard value. The contribution ratio of factories and motor vehicles there was 61% and 32% respectively. (See Fig. 6.2.1.)

NO_x: The environmental standard for nitrogen oxides is specified by NO_2. However, NO emitted from pollutant sources is converted into NO_2 through complicated reaction, the contribution ratio with NO_x was calculated in this study.

The calculation result shows high concentration at San Juan de Dios (E) and Servicio de Salud (A) stations, and at the maximum concentration mesh, principally due to motor vehicles. The *contribution concentration of motor vehicles* was 42.3 - 104.4 ppb and its ratio 89 - 97%, excluding the El Tunal station where the concentration was low. Though the NO_x emission quantity from factories amounted to 15% of the total emission, their contribution was lower because emitted pollutant from stacks are dispersed widely in the atmosphere. (See Fig. 6.2.2.)

CO: There is almost no emission of CO from factories. Apart from CO of natural origin, motor vehicles may be considered as the sole source.

The calculation result shows high concentration at monitoring stations (A and E) on the roadside and the maximum concentration mesh with a value of 5.2 - 7.0 ppm, in which is included the background value (difference in average between the measured and calculated averages). (See Fig. 6.2.3.)

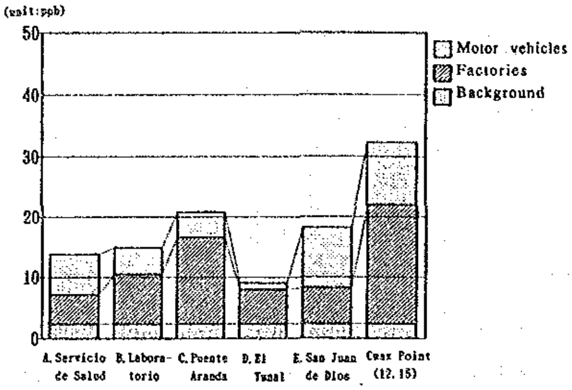


Fig. 6.2.1 Source Contribution to SO_2 Concentration

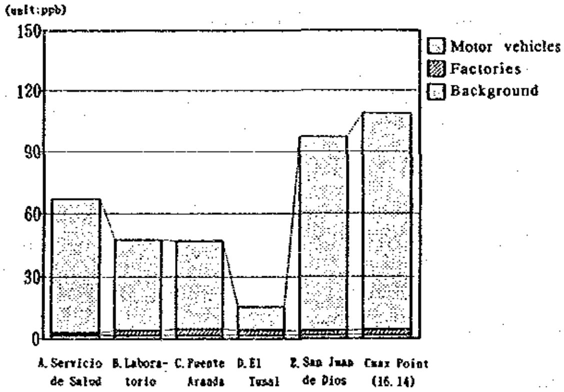


Fig. 6.2.2 Source Contribution to NOx Concentration

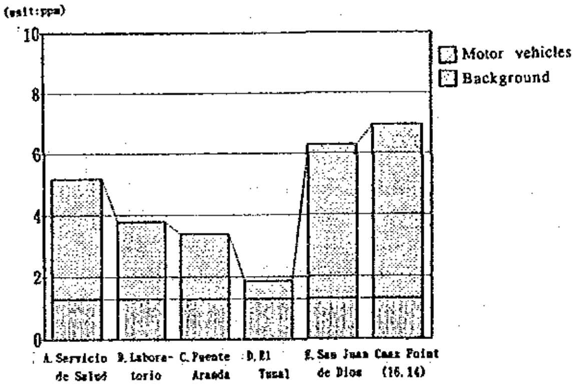


Fig. 6.2.3 Source Contribution to CO Concentration

(2) Regional Concentration Distribution

The regional distribution of concentration of SO_2, NO_2, and CO obtained through the dispersion simulation are as follows (Figs. 6.2.4 - 6.2.6):

SO_2:	Concentration is high in the industrial area located to the west and southwest of the city center.
NO_2:	NO_2 concentration of 25 ppb and over appears widely due to the wide and dense road network
CO:	High concentration appears along the arterial roads running from south to north through the city center.

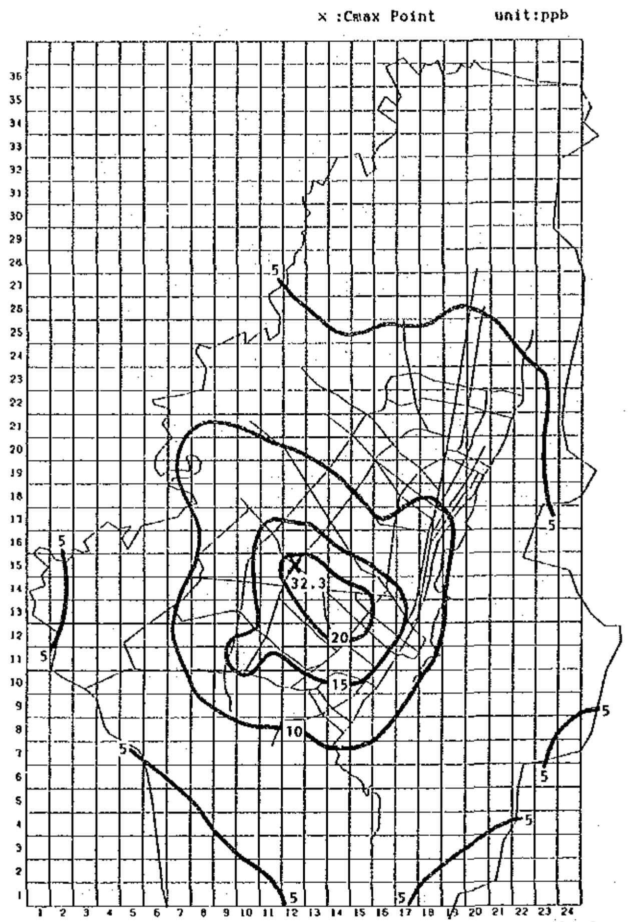


Fig. 6.2.4 Average Concentration Isopleths for SO2

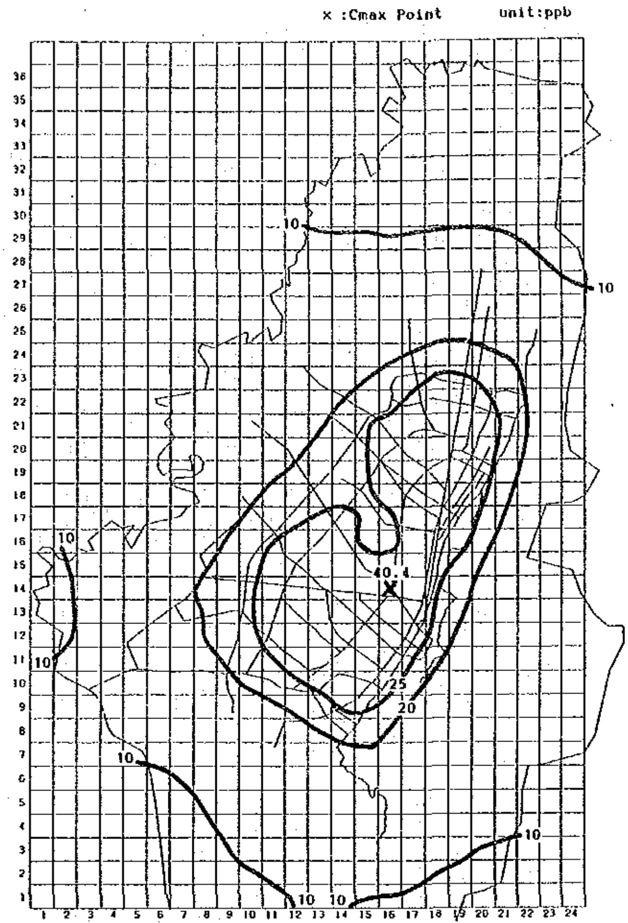


Fig. 6.2.5 Average Concentration Isopleths for NO2

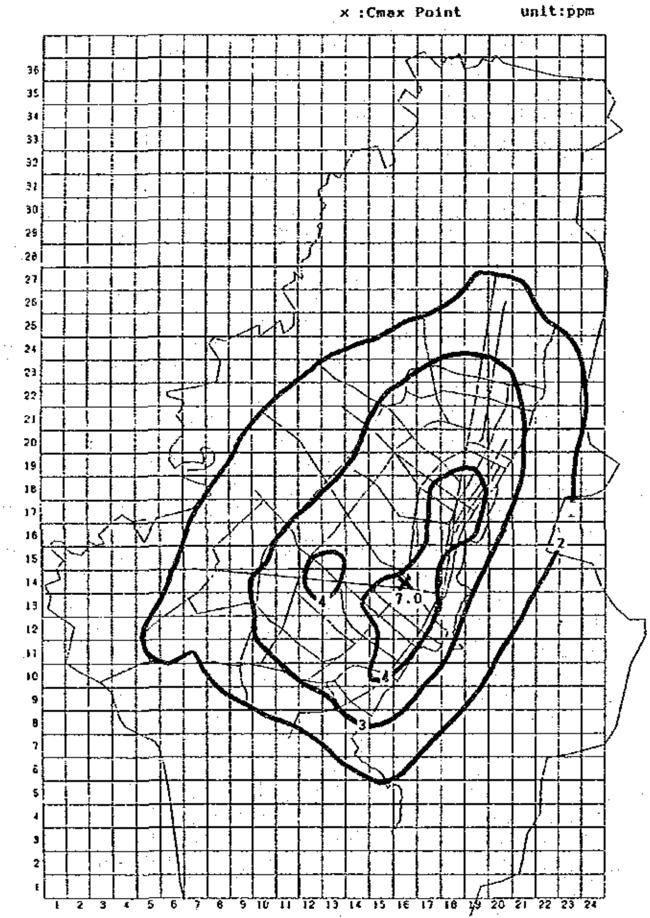


Fig. 6.2.6 Average Concentration Isopleths for C O

6.3 SPM Contribution Ratio by Source according to CMB Method

The SPM contribution ratio by source was determined by CMB (Chemical Mass Balance) method (a statistical method) while using SPM (Suspended Particulate Matter) concentration and heavy metal emission quantity by source as basic data. The analytical result shows about 50% of SPM concentration was from the unknown smoke source, but data available were not enough to identify the contribution ratio by source. This may be possibly due to unsatisfactory data on the heavy metal composition of the sources. So, further accumulation of data and information will be required in future.

CHAPTER 7 FUTURE CONCENTRATION AND REQUIRED EMISSION REDUCTION

7.1 Prediction of Future Pollutant Source

For the year 2001, 10 years from now, the air pollutant emission from each source was predicted as following.

Factories and establishments:

The fuel consumption was predicted using each industrial growth rate during the recent ten years of Santafe de Bogota City (the annual average growth rate: 4.4%).

Motor vehicles:

The growth rate of the automobile traffic volume was assumed to be an annual rate of 3.9% from the past record of the gasoline consumption. The predicted population growth rate (2.8%/year) was used as the growth rate of buses and trucks. As regards buses and trucks, 50% of new vehicles were assumed to diesel vehicles, taking into consideration the recent trend toward increase in diesel vehicles.

For aircraft, the present state was assumed to continue in future because there is no future airport expansion plan.

As a result, the total quantity of pollutant emission in the year 2001 was predicted as shown in Table 7.1.1. The pollutant emissions were predicted to increase by about 40%.

Table 7.1.1 Predicted Air Pollutant Emission by Source in 2001

Source		Dust	SOx	NOx	CO	HC
Stationary Sources	Factories and Establishments	3,155	9,076	2,475	-	-
Mobil 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
Growth Rate (2001/1990)		+44%	+43%	+49%	+38%	+46%

7.2 Prediction of Concentration in Future

The concentration predicted as shown in Table 7.2.1 and Fig. 7.2.1 is 40 to 50% higher than the present level.

With SO_2, the maximum concentration is 43.7 ppb, exceeding the environmental standard.

As for NO_2, all monitoring stations and meshes satisfy the standard value. But the concentration of 50 ppb appears at the maximum concentration mesh, which is almost equal to the standard value of 53.2 ppb.

As to CO, all monitoring stations excluding one station do not satisfy the standard value.

Besides, CO concentration is high at above 4.0 ppm in the greater part of Santafe de Bogota city area.

Table 7.2.1 Predicted Concentration in 2001

Items *Stationns*	SO_2 (ppb	NOx (ppb)	NO_2 (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* Mesh Index	43.7 (12, 15)	163.3 (12, 15)	50.0 (12, 15)	9.58 (16, 14)

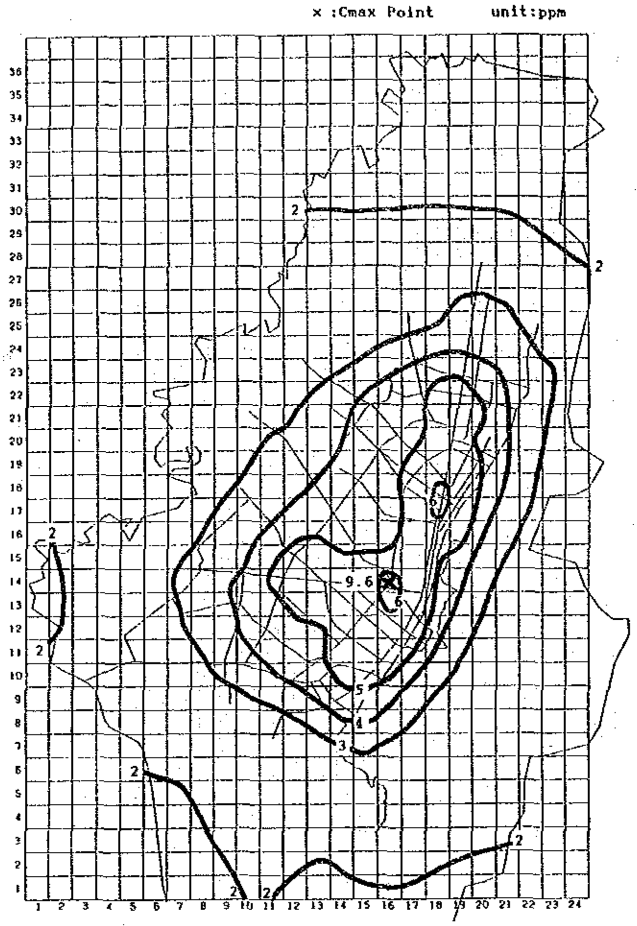


Fig. 7.2.1 Predicted Average Concentration Isopleths for CO

7.3 Target in Air Quality

The objective of air pollution control is to achieve and maintain the national air quality standard. Pollution control measures for this purpose are often evaluated and determined based on their effects on annual pollutant emission reduction and annual average concentration reduction predicted by air dispersion simulation. Therefore, target in air quality (environmental target value) to observe the standard is set in terms of annual average concentration.

In this study the air quality predicted by dispersion simulation was annual average concentration. So, the target concentration was also set in terms of annual average concentration.

Apart from the annual average criterion, the air quality standard specifies the daily average or hourly value criteria for certain pollutants. These criteria must also be satisfied. Accordingly, the measurement data were used to estimate the annual averages corresponding to the standard values for the daily average and hourly criteria. For each pollutant, the lowest value among the several annual averages was used as the environmental target value.

For all pollutants, annual averages corresponding to short-term criteria were higher than the specified annual average criterion as shown in Table 7.3.1 below.

Table 7.3.1 Annual Average Concedntration Corresponding to Short-Term Criteria

(__ : Adopted value)

Item	Air Quality Criteria	Air Quality Standard	Corresponding annual Average
SO_2	Annual average	38.2 ppb	-
	Daily average (*1)	152.8 ppb	69.8 ppb
	3-hour average	573.1 ppb	252.8 ppb
NO_2	Annual average	53.2 ppb	
SP	Annual average	100 $\mu g/m^3$	-
	Daily average (*1)	400 $\mu g/m^3$	107 $\mu g/m^3$
CO	Annual average	-	-
	8-hour average	13.1 ppm	3.6 ppm
	1-hour value	43.7 ppm	12.2 ppm

*1 The second highest value among all measured values

(Note) Conversion of the environmental standard values from by weight to by volume was made according to the specifications of the measuring instruments used in this study.

As for O_3, it is produced from non-methane hydrocarbon or nitrogen oxides through complicated photochemical reaction, so achievement of the O_3 standard requires reduction of the concentration of source pollutants such as non-methane hydrocarbon and NOx. But, O_3 production mechanism is very complicated and the data available now is insufficient. So, in this study, based on the relationship between the maximum O_3 concentration and the corresponding NMHC concentration which marks very high values, for the O_3 target concentration, the tentative environmental target value of NMHC was set at 0.5 ppmC, corresponding to 1/3 of the current concentration level. The environmental target values are shown in Table 7.3.2.

Table 7.3.2 Environmental Target Concentration

Pollutant	Target Concentration (Annual Average)
SO_2	38.2 ppb
NO_2	53.2 ppb
S P	100 µg/m³
C O	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 environmental target value. As is known from this table, the predicted CO concentration exceeds the target value at all stations other than Station D (El Tunal) and in the greater part of the Bogota city area. The SO_2 concentration at the monitoring stations is lower than the target value, but the concentration exceeds the target level in a certain area.

Necessary reduction ratio as shown in Table 7.4.1, a convinient measure to estimate air pollutant emission reduction, was set by comparing predicted concentration with environmental target concentration.

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

The SO_2 reduction rate is 13% at the mesh point where the concentration was predicted 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 was set at 26% in order to reduce their concentration back to the current concentration level.

The NO_2 reduction rate is 0% because the predicted level is lower than the target value at all monitoring stations and mesh points. But the future concentration predicted is not low enough, so the current concentration level should be maintained. Accordingly, the reduction rate was set at 33%.

For non-methane hydrocarbon (NMHC) which is one of the source substances for O_3, the reduction rate was set to reduce the future concentration to 1/3 of its current concentration, as described in 7.3, in view of the current appearance state of the NMHC and Ox concentration. The required reduction rate, however, will be extremely strict at 80% (i.e., reduction to about 1/5 of the future concentration) when considering that the traffic volume will increase by about 1.5 times in future and the unknown sources will increase as well.

The reduction rate for each pollutant may be summarized as follows: 49 - 63 % for CO, 13 - 26% for SO_2, 0 - 33% for NOx, and 80% for NMHC.

Table 7.4.1 Predicted concentration (2001) and reduction rate

Monitoring station	Air pollutant	CO (ppm)		NO_2 (ppb)		SO_2 (ppb)	
	Target concentration	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%

CHAPTER 8 CONTROL MEASURES AGAINST AIR POLLUTANT SOURCES

The sources examined for pollution control in this study are factories, establishments, and motor vehicles.

8.1 Control Measures against Factories and Establishments

8.1 1 Present State and Necessity of Control

According to the factory survey for the smoke and soot emitting facilities, the total 381 units include 177 boilers using liquid fuel, 27 coal firing boilers, and 83 brick/clay pipe kilns, and these three kinds of facilities account for about 76% of the total units.

Santafe de Bogotá D.C. has regulated the air pollution in compliance with the Sanitation Law of 1979. However, in this emission standard, no appropriate standard values are being set for boilers and brick/clay pipe kilns which are major air pollutant facilities in Santafe de Bogota City, and most of these facilities proved satisfactory to these standard values. So, the regulation effect cannot be expected.

Boilers are mostly small in size and obsolete, with no proper combustion control, resulting in emission of black smoke due to incomplete combustion. Dust collectors are the only exhaust gas treatment facilities with the efficiency as low as around 50 - 60%. Besides, there are only 26 units of dust collectors installed at present, and most of smoke and soot emitting facilities are discharging smoke and soot without treatment from low stacks, giving bad effect on houses nearby.

The sulfur content of the fuel is 2.3% for crude oil, 0.4% for light oil, and 0.6 - 0.7% for coal, showing very high sulfur content in crude oil. When the concentration on ground is calculated for the case of crude oil burning while referring to the factory flue gas measurement data, the maximum hourly concentration value of SO_2 was calculated at 30 - 40 ppb. This is the calculation result for one stack, and the concentration will be further multiplied and increase, possibly exceeding the environmental value, if there are multiple stacks nearby.

As regards the present air quality, though the measurement results showed that SO_2, NOx, and SPM satisfied the ambient air quality standards, they were very high. In particular, control of the quantity of SO_2 emission is necessary because it may exceed the environmental target value in 2001 due to business activities and fuel consumption are expected to increase in future.

NO_2 was predicted to satisfy the environmental target value in future, but the concentration was predicted to be as high as a level nearly equal to the environmental target value. Though the contributing source is mostly motor vehicles, the long-term NOx emission standard needs be proposed for factories.

For SPM, the present concentration is below the environmental target value, but not low enough. Though the contributing source could not be identified clearly, the appearance state of SPM concentration shows that human activities such as factories, motor vehicles will be major contributors.

As the concentration of SPM is expected to rise further along with further urbanization and industrialization in Santafe de Bogota city area in future. So, reinforcement of the current institution and control, including review of the present emission standard for factories, will be necessary.

8.1.2 Content of the Control Measures

The control measures against stationary sources to achieve and maintain the environmental target value were proposed as shown in Fig. 8.1.1, examining the present state of the combustion facilities and fuels used at factories in Santafe de Bogota city area. They include revision of the current emission standard, reduction of dust emission by good combustion control, and reduction of SOx emission by using low-sulfur fuels. These measures will be given the priority, and introduction of dust collectors and NOx control measures will follow.

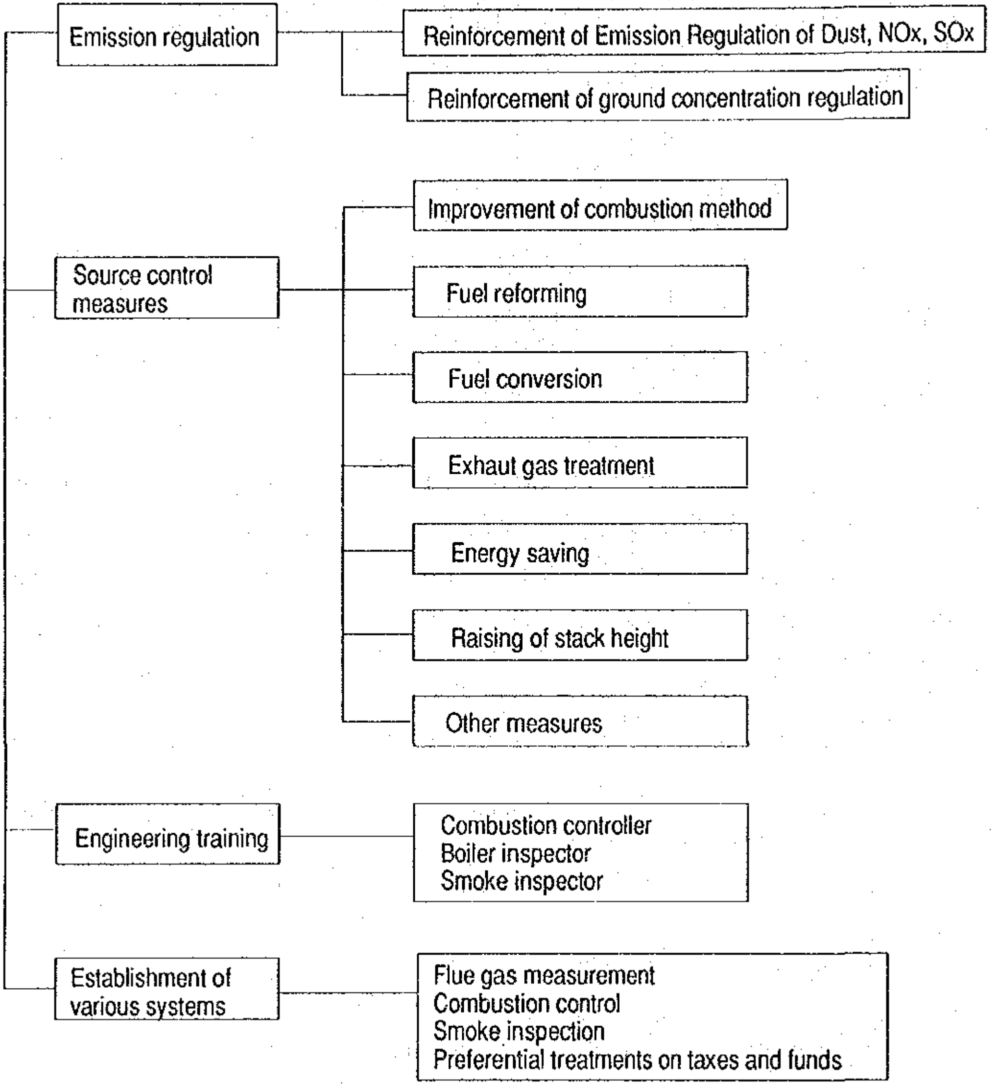


Fig. 8.1.1 Control Measures for Factories and Establishments

(1) Emission Regulation

The current law has the emission standard not strict enough for crude oil combustion boilers and brick kilns emitting large quantity of smoke and soot, and cannot cope with increase in the emission quantity in future effectively.

So, the standard value for short term needs be set at a level nearly equal to the current level while for medium to long term, will aim at keeping the emission quantity at present level.

The scope of regulation will cover those with fuel consumption at a rate of 50 l/h (as converted to crude oil) or more. For other small boilers monitoring of the smoke and soot emission state will be conducted and guidance and advice concerning the combustion control technology will be provided.

For areas where facilities are concentrated so much that there is a possibility of high concentration pollution, will be proposed special emission standard, restriction of the kind of fuels used, specification of new standard value for new or additional facilities, and obligation of installing the preventive equipment.

1) Dust emission standard

The target reduction rate of the dust emission quantity is 10 - 20% for short term and about 40% for long term. For small facilities which emit a large quantity of black smoke for a short period of time, color of black smoke will be regulated under the grade 2 in the Ringelmann Chart.

Brick/clay pipe kilns and asphalt plants whose emission contribution is large, the standard value for coal-firing boilers, which are to be set up newly, will be applied to.

2) Emission standard for sulfur oxides

Facilities to be controlled by this standard will be those using coals as fuel. The target reduction rate of the emission quantity will be 7% for short term and 20% for medium to long term.

3) Emission standard for nitrogen oxides

All smoke and soot emitting facilities (50 l/h or more) will be controlled.

The emission quantity will be reduced to the current level. The medium- to long-term reduction rate will be 50% for boilers using crude oil and 17% for coal-firing boilers. The same will be applied to other facilities.

4) Relationship between emission standard and concentration on ground

Emission standard to control air pollutant emission quantity from stacks of factories, etc. is an allowable emission quantity which will guarantee satisfaction of a certain value (e.g., the environmental standard value) when the emission gas is dispersed and reaches the ground.

The relationship between the mass of air pollutants emitted and the concentration on the ground varies depending on meteorological conditions (wind speed, atmospheric stability, etc.) and smoke source conditions (stack height, etc.). So, allowable emission quantity is set in representative meteorological conditions. One example is the "Sulfur Oxides Emission Standard - K value Control" of the Japanese Air Pollution Control Act.

(2) Source Control Technology

Source control technologies to be employed must be economical and practical appropriate to its actual state. Since the smoke and soot emitting facilities in Santafe de Bogota City are mostly small in size and obsolete and the combustion control is not good, the following control measures must be put into practice:

1) Improvement of combustion method

Control method

- Optimizing of combustion control
- Optimum load combustion
- Change to mechanical firing
- Introduction of low-NOx burner

Reduction of dust emission and saving of fuel are to be achieved by installing combustion control instruments for optimal combustion control. A whole set of measuring instruments may cost about 3.4 million pesos, but use of a gas analyzer only may bring a certain level of combustion control.

For coal firing facilities, mechanical stokers (about 4 million pesos) will be introduced for mechanical firing. In future, steam injection method, low-NOx burner will be installed to reduce NOx. Though the steam injection method is inexpensive and easy to install, the low-NOx burner requires the cost of 14 million pesos including reconstruction cost for a facility consuming fuel at a rate of 150 l/h.

In order to reduce emission of SOx and NOx from large boilers, introduction of fluidized combustion boiler is recommended in the long run. This type of boiler is relatively expensive, with price being about 260 million pesos for a coal firing boiler (evaporation rate at 10 t/h).

2) Fuel reforming

Control method

- Reduction of the sulfur content in fuel
- Adjustment of the grain size and sulfur content of coal

Mixing of crude oil with light oil is recommended as a method to reduce the sulfur content from 2.3% to 1.8%. This is expected to raise the oil price by about 37%.

As regards the coal, coal mixing at a coal reforming facility will keep the sulfur content at around 0.6 - 0.7%. At the same time, the grain size and its composition (volatile matter, etc.) are to be adjusted to achieve complete combustion. The coal reforming facility will require the equipment cost of about 440 million pesos for a facility with a capacity of 1,500 t/month. The price of reformed coal will be about 20,000 pesos, about 20% increase from 17,000 peso/t of raw coal.

3) Fuel conversion

Control method

- Conversion of small-sized boiler fuel to light oil

- Conversion of fuel of kilns for bricks and clay pipes to oil and natural gas

It is necessary for small-sized crude oil and coal firing boilers in the urban area to convert the fuel to light quality oil (light oil, etc.). The cost necessary for fuel conversion is about 10.6 million pesos for conversion from coal to light oil (a facility with fuel consumption of 50 l/h) and about 10.9 million pesos for conversion from liquid fuel to natural gas (fuel consumption of 25 l/h). In either case, the fuel cost will increase.

For brick/clay pipe kilns, stoker firing of reformed coal will be implemented for the time being, and conversion to natural gas will be planned in future. In this case, additional construction of natural gas supply facility will be necessary.

4) Exhaust gas treatment

Exhaust gas treatment will mainly be dust removal by dust collectors. Multicyclones and bag filters with high efficiency will be used as dust collectors.

A multicyclone will cost about 3.8 million pesos for treatment of 3,000 m^3/h while a bag filter of the same capacity about 8.6 million pesos.

5) Energy saving

In line with fuel saving through combustion control, reduction of radiation heat from boiler and other furnace wall will be made by installing heat insulating material to reduce heat radiation.

The cost will be about 10,000 - 25,000 pesos per 1 m^2.

6) Raising of stack height

At present, the stacks are mostly low in height though their air pollutant emission quantity is relatively large. Because of low stack height, high-concentration pollution appears due to down-draft phenomenon caused by factory building. Raising of stack height must be attempted by reinforcing the regulation of the concentration on ground.

7) Factory movement

Factories located in areas with high pollution concentration need be moved and scattered according to plan, to districts where dispersion and surrounding conditions are favorable.

8) Countermeasures against soil dust

For soil dust sources (soil mining sites and asphalt plants), water spray, dust-proof transport equipment, pavement of road, use of dust collector, and tree planting at soil mining sites and ruins will be made.

(3) Various Systems

1) Training of combustion controllers

Engineers to conduct proper combustion control are to be fostered through lecture and practical training on combustion and measurement technology by experts in this field.

2) Training of boiler inspectors

In order to save energy and operate boilers safely, will be fostered the engineers who can inspect the boiler structure and wear state, judge proper boiler pressure, boiler age and necessary reform, and provide guidance and service on them.

3) Training of smoke inspectors

Training will be provided to foster the engineers who can check facilities emitting black smoke, with reference to the Ringelmann Chart, to see if the standard is complied with, providing necessary guidance and advice on black smoke reduction technology for faulty facilities.

4) Flue gas measuring system

Smoke source enterprisers are obliged to measure flue gas volume, pollutant concentration, fuel consumption, and fuel composition and to keep these records on file.

5) Establishment of qualification system of combustion controllers, etc.

The combustion controllers, boiler inspectors, and smoke inspectors will be qualified. The national qualification will be established to guarantee them to do their duty with fare wage.

6) Preferential treatments for promotion of pollution control

Enterprises are responsible for taking necessary measures to prevent air pollution. For enterprises with weak management foundation which cannot take the necessary measures, tax reduction, financing fund, grant for paying interest, etc. should be established to promote introduction of pollution control measures.

8.2 Control Measures against Motor Vehicles

8.2.1 Present State and Necessity of Control

According to the result of measurement of the air quality, the CO concentration closely related to motor vehicles exceeded the air quality standard on the roadside. Non-methane hydrocarbon, a source material of O_3 which is another pollutant exceeding the standard, was extremely high in concentration though its air quality standard has not been set up. It is also a pollutant attributable mostly to motor vehicles.

Since the emission standard for motor vehicles has not yet established in Colombia, it may be said that no emission control measures have been taken yet, though blow-by gas return units and high altitude compensators have been installed partially.

The principal features of the motor vehicles running in the Santafe de Bogota City area are that most of large motor vehicles are gasoline vehicles and old vehicles are large in quantity. These features coupled with low atmospheric pressure there cause emission of CO and HC in large quantity due to incomplete combustion.

Examining the measures compatible with the above situation in Santafe de Bogota City, the control measures as shown in Fig. 8.2.1 are proposed.

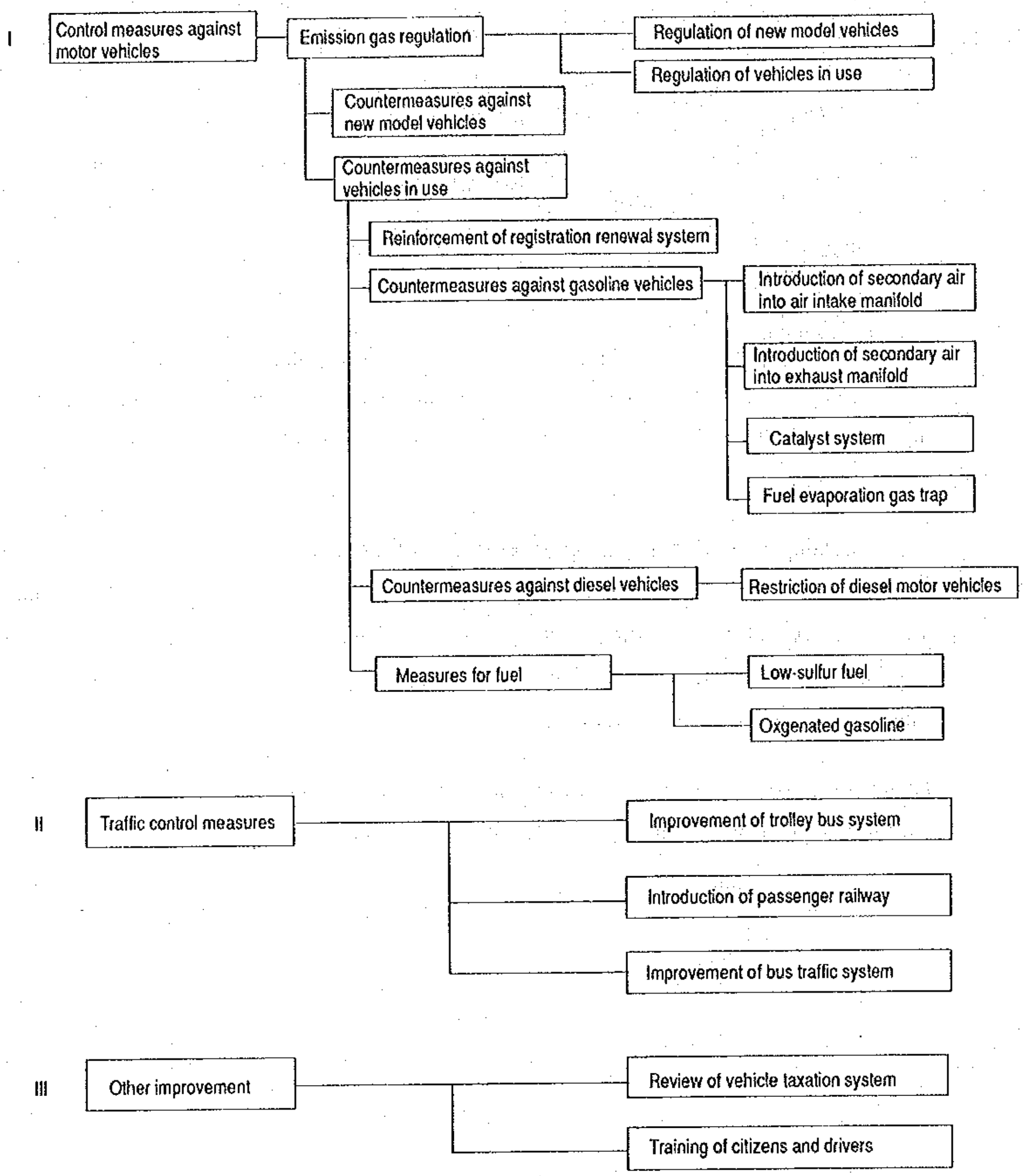


Fig. 8.2.1 Control Measures against Motor Vehicles

8.2.2 Content of the Control Measures

(1) Regulation of Emission Gas

It is recommended to establish motor vehicle emission regulation as early as possible concerning CO and O_3 whose air quality standards are not complied with.

As regards O_3, emission regulation of HC, which is a source material of O_3 and is currently high in concentration as described above, should be made. Regulation of NO_x will also become necessary in future since the traffic volume is expected to increase.

The regulation values must be set forth by vehicle type and engine type for used and new vehicles respectively. And such regulation values must be determined step by step for each vehicle model year, taking into account the parts supply, modification of assembly system, preparation of the maintenance system and the increase in the traffic volume as well.

In December, 1991, the Santafe de Bogota municipal authority announced that CO and HC concentration regulation during idling would be executed for gasoline vehicles from the year 1992, while referring to the result of this study. The regulation value will become more stringent gradually according to model year for used and new vehicles respectively.

This measure will prove particularly effective during traffic congestion. But emission regulation suitable for actual driving state must be established as early as possible. For this purpose, the emission testing system using a chassis dynamometer will be necessary to check the regulation effect, and the related institutions such as type approval system need be reexamined.

(2) Emission Gas Control Technology

Technology to reduce air pollutants in the emission gas from motor vehicles are described below.

1) Gasoline Motor Vehicles

① Countermeasures against carbon monoxide and hydrocarbon

Both of them are emitted into exhaust gas in large quantity when the air and gasoline mixing is not satisfactory for combustion or during deceleration, and measures as described below are taken generally.

a) Performance improvement of carburetor
   - Enhancement of part accuracy, use of electronic control

b) *Employment of electronic fuel injector* (EFI) *to* replace carburetor

c) Air preheating

d) Improvement of configuration of air intake manifold to improve gas distribution to each cylinder

e) Turbulence of mixed gas to improve combustion

f) Prevention of sudden closing of throttle valve during deceleration (TP, DP)

g) Introduction of air into air intake manifold during deceleration

h) Stop of gasoline supply during deceleration

i) Structural improvement of combustion chamber

j) Optimizing of valve timing to avoid leakage of non-combusted gas due to overlap

k) Increase in ignition energy

l) Helping re-combustion of non-combusted gas by raising the exhaust gas temperature through delaying of the ignition timing (SC)

m) Helping re-combustion of non-combusted gas by improving the shape of exhaust manifold

n) Helping re-combustion of non-combusted gas by introducing secondary air into the exhaust manifold (AI, AS)

o) Installation of catalyst in the exhaust system to oxidize non-combusted gas (OC, TWC)

p) Against blow-by gas, installation of reduction unit which returns the leakage gas to the air intake system through forced ventilation of a crankcase (PCV).

q) For fuel vapor gases, installation of a vapor entrap system (EVAP), such as adsorption by activated carbon.

② Countermeasures against nitrogen oxides

Emission of nitrogen oxides can be reduced if driving with theoretical air ratio is avoided and the combustion temperature is lowered. The measures as described below are taken generally.

a) Maintaining the air-fuel mixture gas in a state where the fuel is thinner than the theoretical ratio

b) Maintaining the air-fuel mixture gas in a state where the fuel is thicker than the theoretical ratio

c) Employment of an exhaust gas re-circulation method to lower the combustion temperature (EGR)

d) Optimization of the valve timing to lower the combustion temperature

e) Acceleration of the flame propagation speed and shortening period on high-temperature by activating the swirl of mixture gas

f) Improvement of a shape of combustion chamber to increase the flame shape speed

g) Installation of decomposition catalyst (TWC) in the exhaust system to eliminate nitrogen oxides.

PCV: Positive Crankcase Ventilation System
TP: Throttle Positioner System

DP: Dash Pot System
SC: Ignition Timing Control System
EGR: Exhaust Gas Recirculation System
AI: Secondary Air Injection System
AS: Secondary Air Suction System
EVAP: Fuel Evaporation Emission Control system
OC: Oxidizing Catalyst System
TWC: Three-Way Catalyst System
EFI: Electronic Fuel Injection System

③ Countermeasures against new motor vehicles

Motor vehicle makers in the USA, Japan, etc. where emission gas regulations have been put into practice have adopted the above countermeasures, and their technology has reached to a practical level. So, even if new emission regulation against new motor vehicles is put into practice in Colombia, the Colombian motor vehicle makers will be able to satisfy the regulation if there is a certain time in advance.

2) Diesel motor vehicles

The pollutants concerned with diesel vehicles are mainly black smoke, and nitrogen oxides and sulfur in diesel oil.

Control measures against black smoke include improvement of an air intake system to secure sufficient amount of air, optimization of air swirl flow in cylinder to improve mixture with fuel, and improvement of injection timing and fuel atomization to ensure satisfactory combustion. But these measures are not yet sufficiently effective, and a black smoke collector and catalyst unit are under research for practical application.

3) Low pollution motor vehicles

As low-pollution motor vehicles, various kinds of vehicles have been developed up to now. Among them, LPG motor vehicles and methanol-driven motor vehicles are representative ones using low-pollution fuels. They are less in emission of CO and HC (less than 50%) than gasoline vehicles. Vehicles using pollution-free energy include trolley bus and electric motor vehicle.

(3) Countermeasures against Motor Vehicles in Use

This kind of vehicles are out of auto factories, and they are more restricted than new ones in countermeasure installation from socio-economical and technical standpoint of view.

① Reinforcement of the registration renewal system

The reinforcement of the current registration system as described below must be made.

a. Expansion of the registration area

It is meaningless to restrict the motor vehicles subject to emission regulation to those registered in Santafe de Bogota City only.

This study showed that about 40% of passenger cars running in the city were those registered outside Santafe de Bogota City.

It is therefore recommended that the registration area includes the administrative departments around Santafe de Bogota D.C. (e.g., Department Cundinamarca in which is included Santafe de Bogota D.C.).

b. Obligation of periodic inspection/maintenance

During use, vehicles develop clogging of air cleaner, change in the air-fuel ratio due to contamination of carburetor, deviation in the ignition timing, deviation of the idling speed, resulting in increase in emission of pollutants.

Obligation of periodic inspection/maintenane of the engine system in a service shop technically qualified is expected to achieve substantial decrease in the air pollutant emission as shown in Fig. 8.2.2.

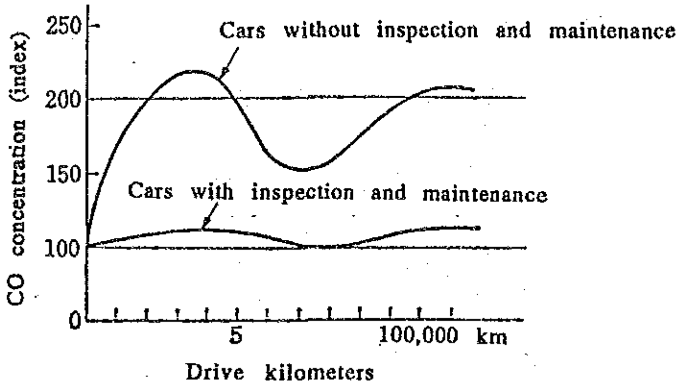


Fig. 8.2.2 Effect of Inspection and Maintenance (1970 White Paper on Pollution)

c. Measurement of exhaust gas during idling

Though the exhaust gas volume is small during idling, the concentration of CO and HC is high. It is therefore necessary to measure the CO and HC concentration during the periodic inspection, thereby confirming appropriateness of the adjustment of the engine, etc. in terms of air pollution control.

These values must be checked and regulated. The Santafe de Bogota municipal authority will put this regulation into practice in 1992 as above described.

② Emission gas control

In view of the actual state of motor vehicles running in Santafe de Bogota, the following emission gas control measures are proposed:

a. Gasoline motor vehicles

- Introduction of secondary air into air intake manifold

Provision of secondary air valve between the throttle and engine will prove effective in reducing the CO and HC emission during idling or deceleration.

- Introduction of secondary air into exhaust manifold

When the exhaust temperature is 600°C or more at the engine exhaust valve outlet, a unit to introduce secondary air from the air cleaner allows combustion of CO and HC, reducing their emission.

- Catalyst system

When substantial improvement is necessary in the motor vehicle exhaust gas control, a catalyst unit installed in exhaust pipe will prove effective. Oxidation catalyst method may be used for reduction of CO and HC while three-way catalyst is for reduction of NOx in addition to above pollutants. The elimination rate is 90%.

Since CO and HC are the pollutants subject to control for the time being, the oxidation catalyst may be used.

But the use of the three-way catalyst system will become mandatory for new vehicles in the future.

Note that the oxidation catalyst requires O_2 in sufficient quantity for combustion of CO and HC, and introduction of secondary air is employed in general. But reduction of the sulfur content in gasoline must be achieved because of its adverse effect on the catalyst system and possible occurrence of new pollution by emission of sulfuric acid mist from the catalyst. The use of lead-free gasoline is also essential in view of adverse effect of lead on the catalyst, but Colombia has already adopted lead-free gasoline in 1991.

- Prevention of HC evaporation

Currently, the fuel tank of motor vehicles in Colombia is open to the atmosphere and the atmospheric pressure is low there. Accordingly, the evaporation pressure becomes low, allowing large quantity of gasoline (HC) to evaporate. As a control measure, tight sealing of a tank plug and introduction of evaporated gasoline through adsorptive material of activated carbon into air intake manifold may be recommended.

- Restriction on implementation of countermeasures to motor vehicles in use

  There are various problems associated with the measures against motor vehicles in use. Among them are difficulty of implementation because they must be taken against vehicles which have been marketed as finished products, large quantity of extremely old vehicles running in Santafe de Bogota City, and many motor vehicle makers and engine types, and assignment of cost for control measures.

b. Diesel motor vehicles

As described in the passage of control technology for diesel vehicles, their exhaust gas problems include nitrogen oxides and black smoke (suspended particulates). The control measure technology regarding these problems are not yet established sufficiently in spite of gradual improvement. Besides, the diesel oil has high sulfur content, by the use of which will be emitted much sulfur oxides, and sulfur trioxide associating sulfur dioxide causes increase in aerosol and SPM. What should be done at present is to reduce diesel motor vehicles running inside the city of Santafe de Bogota City within the current level.

③ Countermeasures for fuels

- Supply of low-sulfur gasoline

  San Juan de Dios facing an arterial road was the highest at 25 ppb in average SO_2 concentration among five monitoring stations. This is principally due to extremely high sulfur content at 0.06% (by weight) of gasoline (far beyond 0.008% in Japan).

  If oxidation catalyst unit is installed in a vehicle using gasoline with such high sulfur content, the sulfur content oxidized will produce aerosol (sulfate) of SO_3, in addition to its adverse effect on the catalyst unit itself. Accordingly, the sulfur content in gasoline must be reduced to 0.01% or less.

- Supply of oxygenated gasoline

  If the gasoline contains oxygen, generation of HC as well as CO can be suppressed. Compounds containing oxygen to be added to gasoline include methanol, MTBE (methyl tributyl ether), ethanol, and ETBE (ethyl tributyl ether). There is a preceedent in the USA that their mixing ratio has been regulated at 2.7%.

(4) Traffic Control Measures

As effective countermeasures against motor vehicles, there is a method of reducing traffic volume, apart from those of reducing air pollutant emission from individual vehicles. The only traffic means currently available in Santafe de Bogota City is motor vehicles when excluding the trains for sightseeing. Though buses and trolley buses are available as mass transit means, the passenger rate of trolley buses is extremely low because of frequent troubles and inadequate routes. The trolley bus service is therefore suspended down now. On the other hand, about 14,000 units of buses are operated at present. Because of their large number for the urban scale of Santafe de Bogota City, its radial city structure, and improper bus stop facilities, they cause a substantial congestion of the arterial roads in the city.

The traffic control measures in such a traffic situation will be to introduce and improve mass traffic means to replace passenger cars and buses. Specifically;

① Increase in the number of trolley bus users through improvement of the existing trolley bus system

② Introduction of passenger railway

③ Renovation of the bus traffic system through installation of new bus stops

These measures are now in the planning stage in the respective divisions concerned.

(5) Other Improvements

- Review of vehicle tax system

The present vehicle taxation system is based on the evaluated vehicle value. According to this system, the tax amount decreases as the motor vehicles get older. From the viewpoint of air pollution, however, older vehicles emit larger quantity of air pollutants while making installation of control measures more difficult.

In this context, the tax system must be modified in such a manner that users are encouraged to abolish old vehicles with larger air pollutant emission and use new vehicles equipped with control measures.

- Training of citizens and drivers

The municipal Traffic/Transport Bureau is providing training on vehicle driving to drivers. It is necessary to add a curriculum on enhancement of the recognition of air pollution. In particular, citizens, for whom the traffic means is mostly motor vehicles, must be demanded to recognize that they are not only sufferers but also responsible for air pollution and called upon to cooperate with various air pollution control measures such as vehicle maintenance.

8.3 Effect of Source Control Measures

(1) Menu of Control Measures

The control measures as described below were set up for factories and motor vehicles in order to ensure the required reduction rate examined in 7.4

Control measures against factories are shown in Table 8.3.1, and emission reduction rate by facility type is shown in Table 8.3.2

Table 8.3.1 Countermeasures against Factories

	Countermeasure		Dust	SOx	NOx
Crude oil combustion boiler	Improvement of combustion method	• Low excess air combustion	o	-	o
		• Fuel saving	o	-	o
		• Steam injection	-	-	o
	Fuel reforming	• Sulfur content 1.8%	-	o	-
	Fuel conversion	• Light oil	o	o	o
Coal firing boiler	Improvement of combustion method	• Low excess air combustion	o	-	-
		• Fuel saving	o	-	-
		• Steam injection	-	-	o
	Fuel reforming	• Sulfur content 0.5%	-	o	-
	Fuel conversion	• Crude oil	o	-	-
		• Light oil	o	o	o
	Gas treatment	• Multicyclone	o	-	-
Brick and clay pie kiln	Improvement of combustion method	• Stoker	o	-	o
		• Fuel saving	o	-	o
	Fuel reforming	• Sulfur content 0.57%	-	o	-
	Fuel conversion	• Natural gas	o	o	o
Raising of stack height			o	o	o

Fig. 8.3.2 Air Pollutant Emission Reduction Ratio by Facility Type

(Unit: %)

Facility Type	Fuel Type	Dust	SOx	NOx
Boiler	Light oil	-	-	25
	Other oils	58	22	50
	Coal	42	22	17
Kiln for bricks and clay pipes	Coal	42	24	22
Incinerator	Light oil	-	-	29
Other furnaces	Light oil	-	-	29

Control measures against motor vehicles are shown in Table 8.3.3. The emission rate of HC and CO per unit vehicle for all automobiles registered after the year 1975 will be reduced to one tenth of the current level. On the other hand, the traffic volume of buses will be reduced by 20% by improvement of the trolley bus system and introduction of the passenger railway.

Table 8.3.3 Summary for countermeasures for Motor Vehicles

Item	Target	Contents	Target Air Pollutant			
			CO	HC	SOx	NOx
Exhaust gas regulation	New automobiles of 1995 year and after	Introduction of Oxidation catalyst	0	0		
	Used automobiles of 1975 year and after	Introduction of Oxidation catalyst and secondary air into the exhaust manifold (start year: 1995 end year: 2001)	0	0		
		Periodic inspection at idling	0	0		
Control of traffic volume	Buses	Improvement of trolly bus system	0	0	0	0
		Introduction of passenger railway	0	0	0	0
Control of traffic flow	Buses	Speed-up by improving bus stop system	0	0	0	0

(2) Reduction of Air Pollutant Emission Quantity

The air pollutant emission quantity after execution of control measures is summarized together with the present and future quantity in Table 8.3.4. Table 8.3.5 shows comparison of the result with the required reduction rate as set up in 7.4.

The reduction rate as planned can be achieved, except for CO at roadside and HC.

Tble 8.3.4 Summary for Air Pollutant Emission

(Unit: ton/year)

Item	Source	Present	Future (2001)	with Countermeasures
SOx	Factories and Establishments	6,504	9,076	7,333 (19%)
	Motor vehicles	1,269	2,057	1,309 (36%)
	Aircraft	29	29	29 (0%)
	Total	7,802	11,162	8,671 (22%)
NOx	Factories and Establishments	1,688	2,475	1,791 (28%)
	Motor vehicles	9,250	13,886	13,142 (5%)
	Aircraft	114	114	114 (0%)
	Total	11,052	16,475	15,047 (9%)
CO	Motor vehicles	288,433	398,375	193,183 (52%)
Dust	Factories and Establishments	2,198	3,155	1,816 (42%)
HC	Motor vehicles	19,845	28,947	12,230 (58%)

Note ( ) : Reduction percent

Table 8.3.5 Summary for Reduction Ratio

Pollutant	Necessary Reduction Ratio	Maximum Target Reduction Ratio	Reduction Ratio with Control Measures
SOx	13%	25%	22%
NOx	0%	33%	9%
CO	49%	63%	52%
HC	80% (NMHC)	-	58% (T-HC)

Note NHMC: Non methane hydrocarbon
T-HC: Total Hydrocarbon

(3) Prediction of Concentration after Execution of Control Measures

The predicted result with the dispersion simulation model of the concentration after execution of control measures is shown in Table 8.3.6 and Figs. 8.3.1 to 8.3.4. The result shows that the predicted concentration at all stations and mesh points were all below the environmental target values (other than CO at Station E (San Juan de Dios) and the maximum concentration mesh). So, much more strict measures are necessary with regard to CO because the predicted concentration is still high extremely near the arterial roads and is not in compliance with the environmental standard. But, most of the control measures assumed in predicting the future concentration require considerable efforts for their execution by the governmental and local authorities, enterprises, and citizens.

Table 8.3.6 Predicted Concentration When Control Measures Are Executed

Monitoring Station	Pollutant	SO_2 (ppb)	NO_2 (ppb)	CO (ppm)
	Environmental Target Concentration	38.2	53.2	3.6
(A) Servicio de Salud		13.4	36.7	3.5
(B) Lavoratorio		15.1	30.6	2.6
(C) Puente Aranda		21.7	31.0	2.4
(D) El Tunal		9.8	16.6	1.4
(E) San Juan de Dios		20.1	44.4	4.9
Maximum Concentration Mesh Point		34.6	48.5	4.4

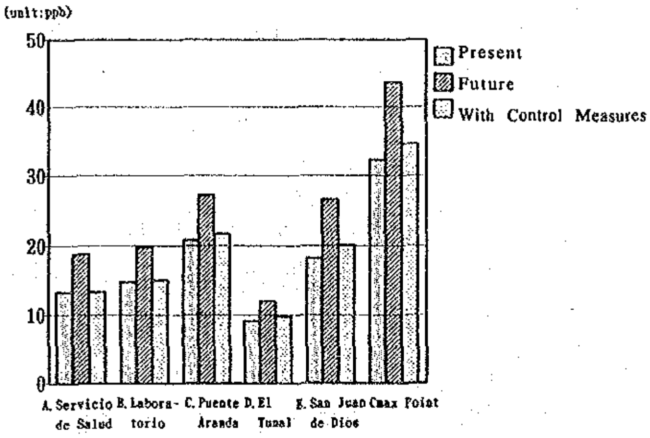


Fig. 8.3.1 Summary for Computed SO2 Concentration

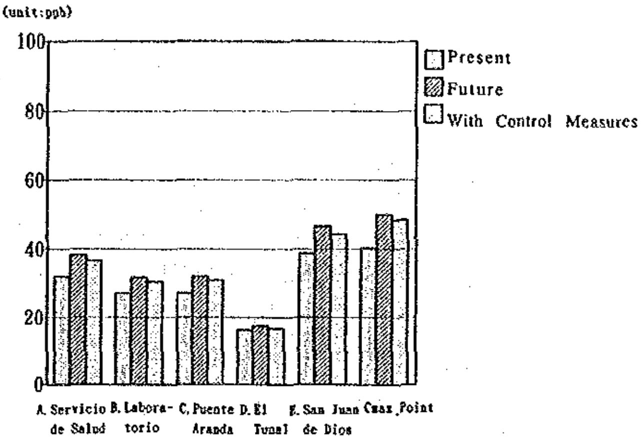


Fig. 8.3.2 Summary for Computed NO2 Concentration

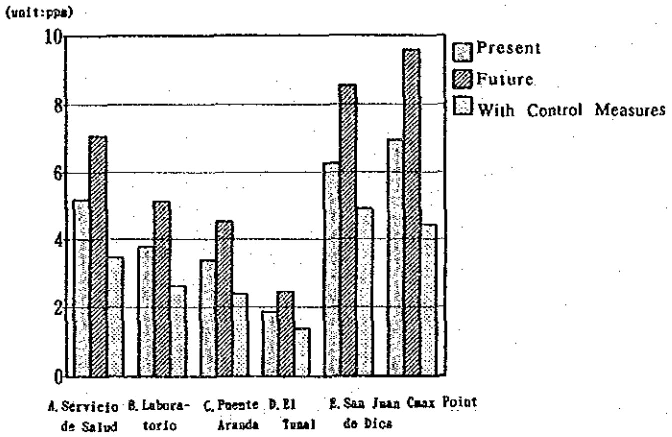


Fig. 8.3.3 Summary for Computed CO Concentration

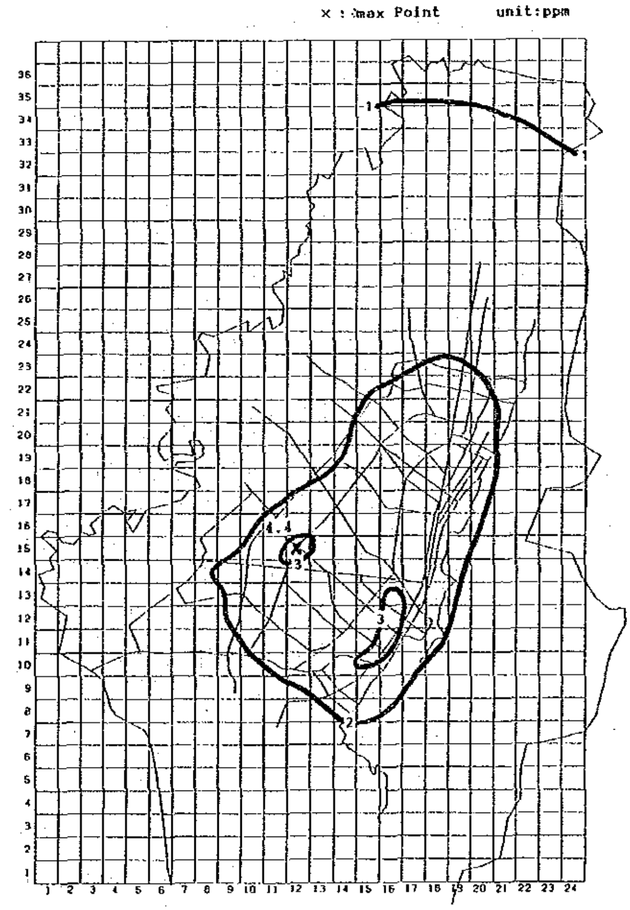


Fig. 8.3.4 Average Concentration Isopleths for CO with Control Measures

CHAPTER 9 PROPOSITION OF GUIDELINE FOR CONTROL MEASURES

9.1 Target

9.1.1 Basic Concept

The City of Santafe de Bogota, which is the capital of Colombia, is the center of government and economy. The population of Santafe de Bogotá D.C. was about 4.2 million in 1985 and is growing now. The economy and industry are also growing further. As a result of lively urban activities along with the growth of the population and industry, the air pollution phenomenon has become apparent, giving adverse effect on the health of citizens. For example, the result of the sampling inspection on diseases in Santafe de Bogota City shows that respiratory diseases have been always at the top in disease incidence ever since 1985.

The government of Colombia and the municipal authority of Santafe de Bogota have made efforts to prevent air pollution. However, according to this joint study by Santafe de Bogota City and Japan International Cooperation Agency, the concentration of carbon monoxide (CO) and ozone (O_3) exceeded the environmental standard and the concentration of non-methane hydrocarbons (NMHC), which is one of source substances to produce ozone, was high. In addition, the concentration of sulfur dioxide (SO_2) and nitrogen dioxide (NO_2) was high in certain areas though it satisfied the environmental standard. It was also confirmed that the SPM concentration was high in the wide area. The concentrations of these air pollutants are expected to increase further along with economical and industrial development in the Santafe de Bogota City area. It is therefore necessary to establish and put into practice the air pollution control plan as early as possible.

The purpose of this guideline is to propose the foundation, on which the air quality is to be improved, in order to establish healthy and comfortable living environment for citizens, by understanding the present state of the air pollution and pollutant sources and by clarifying the countermeasures and their problems to set and achieve the targets for the control plan.

The areas to be covered by the plan will be the area under the jurisdiction of La Secretaria Distrital de Salud de Santafe de Bogotá.

9.1.2 Target of the Plan

The target of the plan is to achieve and maintain the ambiental air quality standard as set forth in Decrees No. 2 of 1982 and No. 2206 of 1983 promulgated pursuant to the Sanitation Law (Law No. 9) of 1979.

There are pollutants whose standard includes short-term average such as daily average and one-hour value other than annual average. In determining the environmental target value, they were converted corresponding annual average values. Besides, Santafe de Bogota City is located at a high altitude, which was also taken into consideration in setting the target value. The target values thus obtained are shown in Table 9.1.1.

The target value for O_3 was set in terms of that of non-methane hydrcarbon (NMHC) which is one of the source pollutants of O_3. The target value for NMHC was determined tentatively based on the relationship between the NMHC and O_3 concentrations.

Table 9.1.1 Target Level of Air Quality

Item	Environmental Target Value (annual average)
SO_2	38.2 ppb
NO_2	53.2 ppb
SP	100 μg/m^3
CO	3.6 ppm
NMHC	0.5 ppmC

9.1.3 Target Reduction of Air Pollutants

The target reduction must be established while taking into account the increase in the pollutant emission quantity by around 40% in 2001 from the present level along with the economical development. The reduction of each pollutant was calculated based on the following reduction rate.

a) Dust

Dust emission quantity from stationary sources will be reduced by 20% for short term and by 40% for medium to long term.

b) Nitrogen oxides (NOx)

The NOx emission quantity from crude oil combustion boilers will be reduced by 50% while that from coal firing boilers by 17%.

c) Sulfur oxides (SOx)

The SOx emission quantity from stationary sources will be reduced by 7% for short term and by 20% for medium to long term.

d) Carbon monoxide (CO)

The carbon monoxide emission quantity will be reduced by 50% as a whole, but reduction by 60% will be achieved in the high-concentration area near roads.

e) Non-methane hydrocarbon (NMHC)

The present emission quantity from motor vehicles will be reduced by 2/3.

If these regulations will prove effective, the pollutant emission quantity in the year 2001 will be as shown in Table 9.1.2.

Table 9.1.2 Estimated Pollutant Emission Quantity of Santafe de Bogota

Unit: 1000 ton/year

Pollutant	Present	Future (2001)	After Execution of Control Measures
CO	288	398	193
HC	20	29	12
SOx	7.8	11.2	8.7
NOx	11	16	15
Dust	2.2	3.2	1.8