Chapter 6 EFFECT OF STACK GAS ON AIR QUALITY

6.1 Outline of Impact Assessment from Stack Gas

The Impacts of the stack gas emitted from the power plants to the surroundings were estimated with a dispersion simulation model. The model based on Plume and Puff formulae, simulated annual averages, daily averages and hourly values of SO_2, NO_2, and SPM concentrations. The conversions from NO_x to NO_2 were conducted with the measured ratios of NO_2 to NO_x in each region. The usual NO_2 conversion models was not be applicable because of the lack of O_3 concentrations data and of only one monitoring station in each region.

The pollutant emission intensity, wet gas volume and so on were based on the results of the Stack Gas Monitoring, the specifications of stacks, and annual electricity generation data.

The necessary meteorological inputs to the simulation model are wind direction, wind speeds and atmospheric stability. Wind speed data at the stack height were estimated from the wind speed data with correction factors. The measured stability were shifted to neutral conditions to calculate diffusion parameters, because of the nature of the ambient air at high altitude.

6.2 Distribution of Annual Average Concentration

6.2.1 Annual Average Simulation Model

Details of the annual average simulation model are explained below.

(1) Target Year

One Year from March 1996 to February 1997

(2) Calculation of Annual Average

First, frequencies and averages of the necessary meteorological data by seasons, time zones, wind directions, wind speed classes, and stability classes are calculated. Also, pollutant emission rates and wet gas emission rates are averaged by seasons and time zones. Next, concentration contributions from each source to each calculation point are calculated by the averages for each class. Finally, the annual averages are obtained by the following formula.

$$C_y = \sum_t \left(\sum_s \left(\sum_{rm} F(Q_s, W_{rm}) \cdot f_{rm} \right) \cdot f_t \right)$$

Where,

C_y	:	Annual Average Concentration
t	:	Seasons & Time Zones Categories
s	:	Source Classes
rm	:	Meteorological Classes
$F()$	:	Dispersion Model
Q_s	:	Pollutant Emission Rate of Each Source
W_{rm}	:	Average of Meteorological Factors by Meteorological Classes
f_{rm}	:	Frequency of Meteorological Condition by Season & Time Zone
f_t	:	Frequency of Season & Time Zone

(3) Season and Time Zone

Two seasons and two time zones are defined considering the operation pattern of power plant, time-dependent characteristics of meteorological factors and ambient air concentrations.

Seasons:	Summer(November to April), Winter (May to October)
Time Zones:	Daytime(8:00 to 22:00), Nighttime (22:00 to 8:00)

(4) Meteorological Class

Wind Directions:	16 directions and Calm (Wind Speed <=0.4 m/s)
Wind Speed Classes:	~0.4m/s, ~0.9m/s, ~1.9m/s, ~2.9m/s, ~3.9m/s ~5.9m/s, ~7.9m/s, 8.0m/s~

Stability Classes: A(Strongly Unstable), AB, B, BC, C, CD, dD(Daytime Neutral), nD(Nighttime Neutral), E, F, G(Strongly Stable)

(5) Target Pollutants and Pollutant Sources

Target pollutants are SO_2, NO_x, NO_2, and SPM. All existing units of each power plant were targeted, and the pollutants are compiled by stacks and treated as point sources in the simulation model.

Generally, pollutants emitted from power plants are called SO_x, NO_x, and Dust, and ambient air concentrations caused by the pollutants are SO_2, NO_x & NO_2, and SPM. Here, NO_x means the summation of NO and NO_2, and a part of NO_x is converted to NO_2 in the atmosphere.

(6) Dispersion Formulae

Windy Condition: Simple Plume Formula

$$C(R,z) = \sqrt{\frac{1}{2\pi}} \frac{Q_p}{\frac{\pi}{8} R \sigma_z u} \cdot F$$

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

C:	Pollutant Concentration at Calculation Point (ppb, μ g/m^3 etc.)
R:	Distance from Source to Calculation Point (m)
z:	Height of Calculation Point (m).
Q_p:	Pollutant Emission Rate (m^{3}N/sec, Kg/sec etc.).
u:	Wind Speed (m/sec).
He:	Effective Stack Height
σ_z:	Vertical Diffusion Parameter (m)

Calm Condition: Simple Puff Formula

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

$\alpha = \sigma_x / t = \sigma_y / t$

$\gamma = \sigma_z / t$

t: Duration Time

(7) Effective Stack Estimation Formulae

Windy Condition: CONCAWE Formula

$$H_e = H_0 + 0.175 \cdot Q_H^{\frac{1}{2}} \cdot u^{-\frac{3}{4}}$$

H_e: Effective Stack Height (m)

H_0: Actual Stack Height (m)

Q_H: Heat Emission (cal/s)

u: Wind Speed at Stack Top (m/s)

$$Q_H = \rho \cdot C_p \cdot Q \cdot (T_G - T_A)$$

ρ: Gas Density at 0°C (1.293×10^3 g/m^3)

C_p: Isopiestic Specific Heat (0.24 cal/°K/g)

Q: Emission Gas Volume (m^{3}N/s)

T_G: Emission Gas Temperature (°C)

T_A: Ambient Temperature (°C)

Calm Condition: Briggs Formula (Calm)

$$H_e = H_0 + 1.4 \cdot Q_H^{1/4} \cdot (d\theta / dz)^{-3/8}$$

$d\theta/dz$: Potential Temperature Gradient
(Daytime:0.005 °C/m, Nighttime: 0.010 °C/m)

(8) NO_2 Conversion Model

Usually, simple chemical reaction models (Exponential Approximation Model or Steady State Approximation Model) or statistical relationships of NO_2/NO_x (Statistical Model) are used to estimate NO_2 concentration. However, the usual models can not be used this time because of no O_3 measurement data and NO_x measurement at only one station in each region. Then, NO_2/NO_x ratios at NO_x monitoring stations in each region are used for estimation of NO_2 concentrations (Table 6.2.1).

Table 6.2.1 NO_2/NO_x Ratios in Each Region

Power Plant	Station	NO_2/NO_x
Jorge Lacerda	Capivari	0.54
Charqueadas	DEPREC	0.75
Candiota	Airport	0.64

(9) Wind Speed Estimation at Stack Top

Wind speed at stack top is estimated by the following formula by ground level wind speed.

$$U_z = U_s \cdot \left(\frac{Z}{Z_s} \right)^p$$

U_z : Wind Speed at Stack Top (Height: Z m)
U_s : Wind Speed at Ground (Height: Z_s m)
p : Factors for Wind Speed Correction by Stability Class (Table 6.2.2)

Table 6.2.2 Factors for Wind Speed Correction

Stability	A	AB-B	BC-C	CD-D	E	F & G
p	0.1	0.15	0.2	0.25	0.25	0.3

(10) Relation between Stability Class and Diffusion Parameter

Generally, diffusion field at high altitude shifts to neutral and diffusion parameters should be correct. Diffusion parameters are related to stability classes as in **Table 6.2.3** based on the accumulated experience in Japan **(Appendix 6-3)**.

Table 6.2.3 Settings of Diffusion Parameters by Stability Classes

	Stability Class	A	AB	B	BC	C	CD	dD	nD	E	F	G
Diffusion Parameters	Winter/Day	C	C	C	CD	CD	D	D	D	E	E	E
	Winter/Night	CD	CD	CD	D	D	D	D	D	E	E	E
	Summer/Day	C	C	C	CD	CD	D	D	D	E	E	E
	Summer/Night	C	C	C	CD	CD	D	D	D	E	E	E

(11) Calculation Points

Concentrations were calculated at the automated continuous monitoring stations and center points of each grid with 1 km spans inside 20 km from the power plants. Number of calculation points were more than 1,200 for each region. Calculation heights were defined as the height of the sampling holes at the monitoring stations, and 1.5 m for the points at each grid.

6.2.2 Emission Source Model

Pollutant emission rate (SO_x, NO_x, and Dust), wet gas volume, and gas temperature were based on the results of stack gas monitoring. If one of the parameters among gas volumes, pollutant concentrations, and operation load at measurement is not measured or regarded abnormal, the data set of the measurement at the date are discarded. The averages of the parameters were obtained from the multiple measurements for the same unit **(Appendix 6-1)**.

Hourly values of pollutants emission rates and wet gas volumes were obtained from the conversion of the basic measurement data with the ratios of hourly electricity generation and the electricity generation at the time of the stack gas monitoring.

Pollutant Emission Rate:

$$Q_P = Q_D \times C_S \times MW_h / MW_m$$

Q_P : Pollutant Emission Rate at Each Hour

Q_D : Dry Gas Volume at Stack Gas Monitoring

C_S : Pollutant Concentration in Stack Gas

MW_h : Electricity Generation at Each Hour

MW_m : Electricity Generation at Stack Gas Monitoring

Wet Gas Volume:

$$QW_h = QW_m \times MW_h / MW_m$$

QW_h : Wet Gas Volume at Each Hour

QW_m : Wet Gas Volume at Stack Gas Monitoring

MW_h : Electricity Generation at Each Hour

MW_m : Electricity Generation at Stack Gas Monitoring

Next, the averages by seasons and time zones were calculated for pollutant emission rate and wet gas volume. The averages of wet gas volumes were calculated for operation hours. Finally, the emission parameters were compiled by each stack to which each unit is connected(**Table 6.2.4**).

Table 6.2.4(1) Emission Parameters (Jorge Lacerda)

Stack Code Connected UNIT	Unit	1 1-4	2 5	3 6	4 7
Electricity Generation	(MWh)	232	125	125	320
Stack Height	(m)	150	100	100	200
Gas Temperature	(℃)	170.3	164.0	155.5	192.0
Wet Gas Voulme	(Km^3N/h)	672.7	640.7	742.8	649.7
Dust	(Kg/h)	297.0	336.8	73.0	104.4
SO_x	(m^3N/h)	1137.1	773.1	930.9	239.6
NO_x	(m^3N/h)	163.2	179.2	223.1	55.6

Table 6.2.4(2) Emission Parameters (Charqueadas)

Stack Code Connected UNIT	Unit	1 1-4
Electricity Generation	(MWh)	72
Stack Height	(m)	62
Gas Temperature	(℃)	179.1
Wet Gas Voulme	(Km^3N/h)	294.4
Dust	(Kg/h)	90.8
SO_x	(m^3N/h)	306.8
NO_x	(m^3N/h)	49.6

Table 6.2.4(3) Emission Parameters (Candiota)

Stack Code Connected UNIT	Unit	1 1-4
Electricity Generation	(MWh)	446
Stack Height	(m)	150
Gas Temperature	(℃)	145.2
Wet Gas Voulme	(Km^3N/h)	1683.2
Dust	(Kg/h)	1211.8
SO_x	(m^3N/h)	1818.8
NO_x	(m^3N/h)	357.5

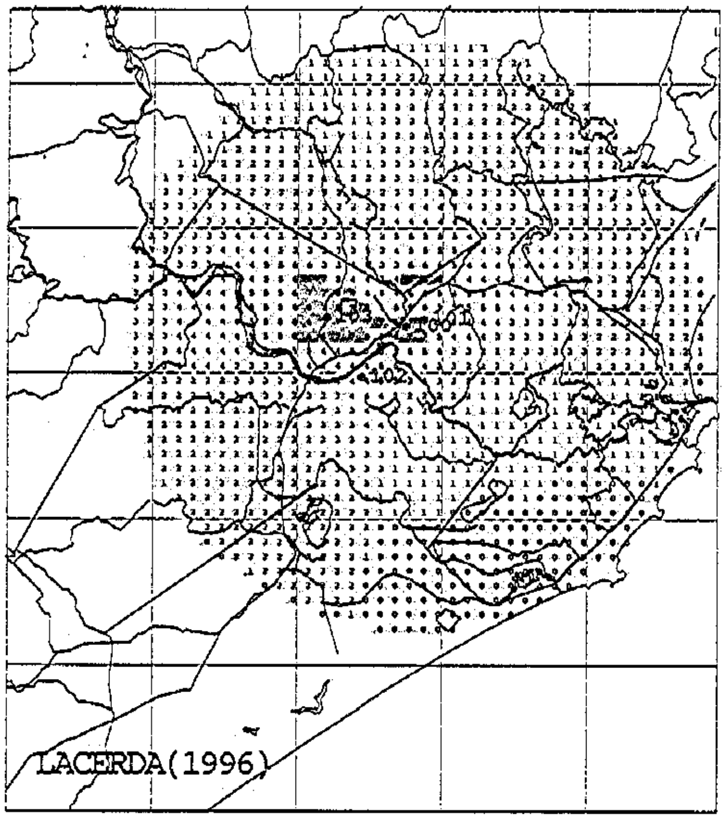
Annual averages of wet gas volumes and pollutant emission rates are shown in **Table 6.2.4**, but the averages by the seasons and the time zones were actually used for simulation. Unit IV (Unit 7 in **Table 6.2.4**) was operated for a few months during target year, and pollutant concentration and dry gas volume were estimated from the data of Unit 5 in **Table 6.2.4**, because no measurement was conducted for the new unit.

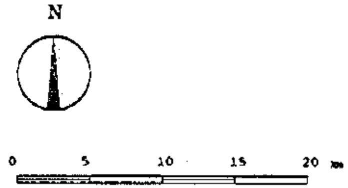
6.2.3 Distribution of Annual Average Concentration

The maximum concentration of the monitoring was 8.0 ppb at Vila Moema in Jorge Lacerda. On the other hand, the maximum concentration of SO_2 annual average was calculated to be 8.5 ppb at WNW with the distance of around 4 km from the stacks in Jorge Lacerda. The concentration is lower than the Primary Criteria (30.56 ppb). The Jorge Lacerda power plant can be said to be the major source of SO_2 in the region (**Figure 6.2.1**). The maximum calculated NO_2 concentration was 1.0 ppb and much lower than the criteria (53.15 ppb). The monitored average of NO_2 at Capivari was 5.7 ppb and the diurnal change of the monitoring data indicated the influence of automobiles. The influence from the power plant is considered to be minor (**Figure 6.2.2**). The maximum SPM concentration calculated was 2.2 ug/m^3 and much lower than the criteria (50 ug/m^3). The power plant is the minor pollutant source for SPM in the Jorge Lacerda region (**Figure 6.2.3**).

The maximum calculated concentration of SO_2 in Charqueadas was 3.1 ppb, and occurred at NNW and with the distances of around 3 km from the stack. The concentration is much lower than the criteria, but about a half of the maximum concentration of the monitoring at Arranca Toco, 6.1 ppb. Charqueadas plant is said to be a major pollutant source for SO_2 in this region (**Figure 6.2.4**). The maximum calculated concentrations of NO_2 and SPM were respectively 0.4 ppb and 0.9 ug/m^3 (**Figure 6.2.5, Figure 6.2.6**).

The maximum calculated concentration of SO_2 was 1.5 ppb in Candiota at WSW and with the distances of around 8 km from the stack. The concentration is low, but the stack may be major pollution source for SO_2 because the measured concentration in the region ranged 3 to 4 ppb (**Figure 6.2.7**). The maximum concentrations of NO_2 and SPM were very low to be respectively 0.2 ppb and 1.0 ug/m^3(**Figure 6.2.8, Figure 6.2.9**).





LEGEND

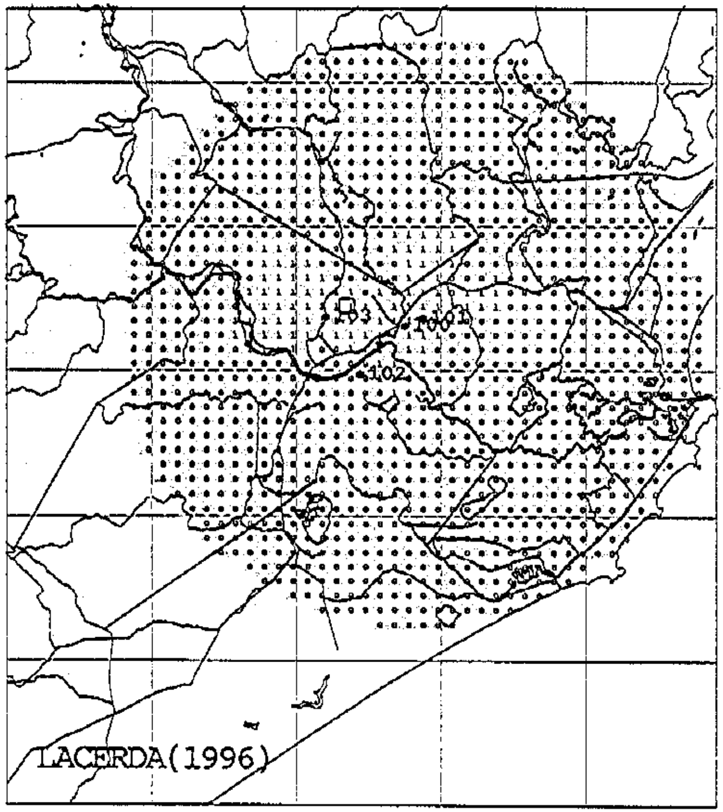
62. < x <=	100.	(ppb)	0 grids
31. < x <=	62.	(ppb)	0 grids
20. < x <=	31.	(ppb)	0 grids
10. < x <=	20.	(ppb)	0 grids
6. < x <=	10.	(ppb)	31 grids
0. < x <=	6.	(ppb)	1265 grids

Monitoring Stations
100 LACERDA
101 CAPIVARI
102 VILA MOEMA
103 SAO BERNARDO

Power Plant
100 LACERDA

SO2 ppb Annual Average □C MAX= 8.5ppb

Figure 6.2.1 Distribution of Annual Average Concentration
(Jorge Lacerda, Current, SO_2)



LEGEND

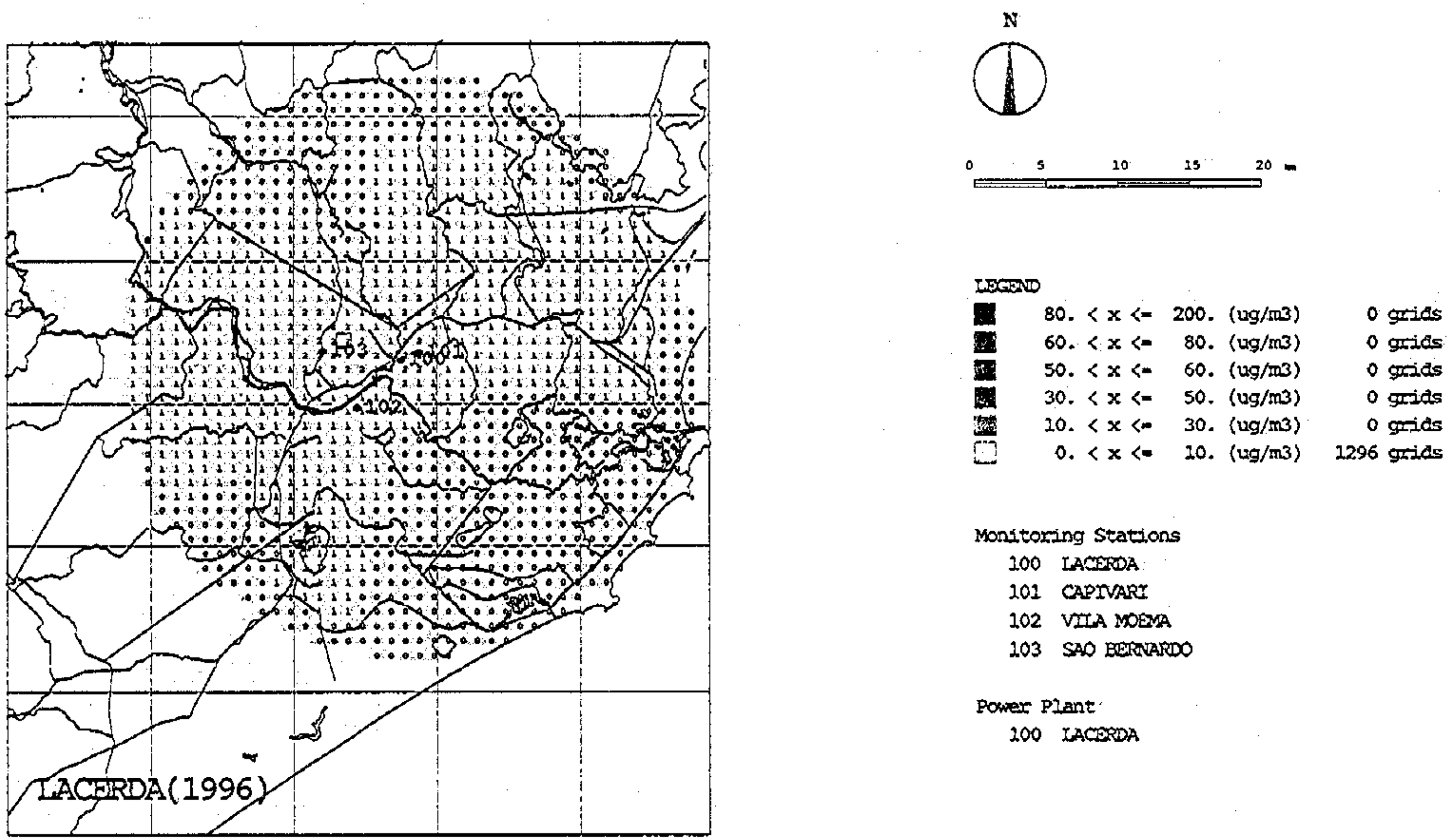
70. < x <= 100.	(ppb)	0 grids
53. < x <= 70.	(ppb)	0 grids
40. < x <= 53.	(ppb)	0 grids
20. < x <= 40.	(ppb)	0 grids
10. < x <= 20.	(ppb)	0 grids
0. < x <= 10.	(ppb)	1296 grids

Monitoring Stations
100 LACERDA
101 CAPIVARI
102 VILA MOEMA
103 SAO BERNARDO

Power Plant
100 LACERDA

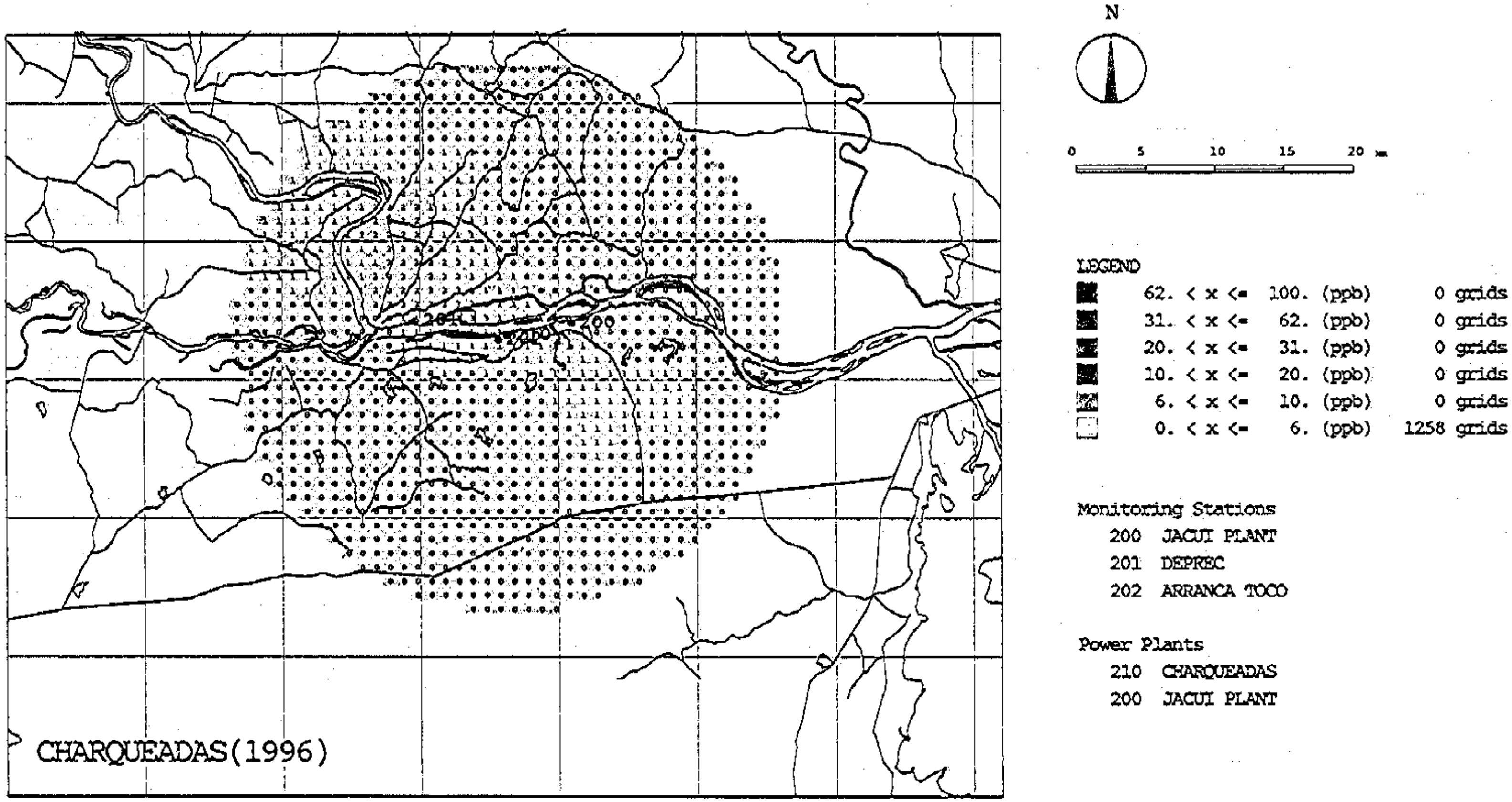
NO2 ppb Annual Average □C MAX= 1.0ppb

Figure 6.2.2 Distribution of Annual Average Concentration
(Jorge Lacerda, Current, NO_2)



SPM ug/m3 Annual Average □C MAX= 2.2ug/m3

Figure 6.2.3 Distribution of Annual Average Concentration (Jorge Lacerda, Current, SPM)



SO2 ppb Annual Average □C MAX= 3.1ppb

Figure 6.2.4 Distribution of Annual Average Concentration (Charqueadas, Current, SO_2)

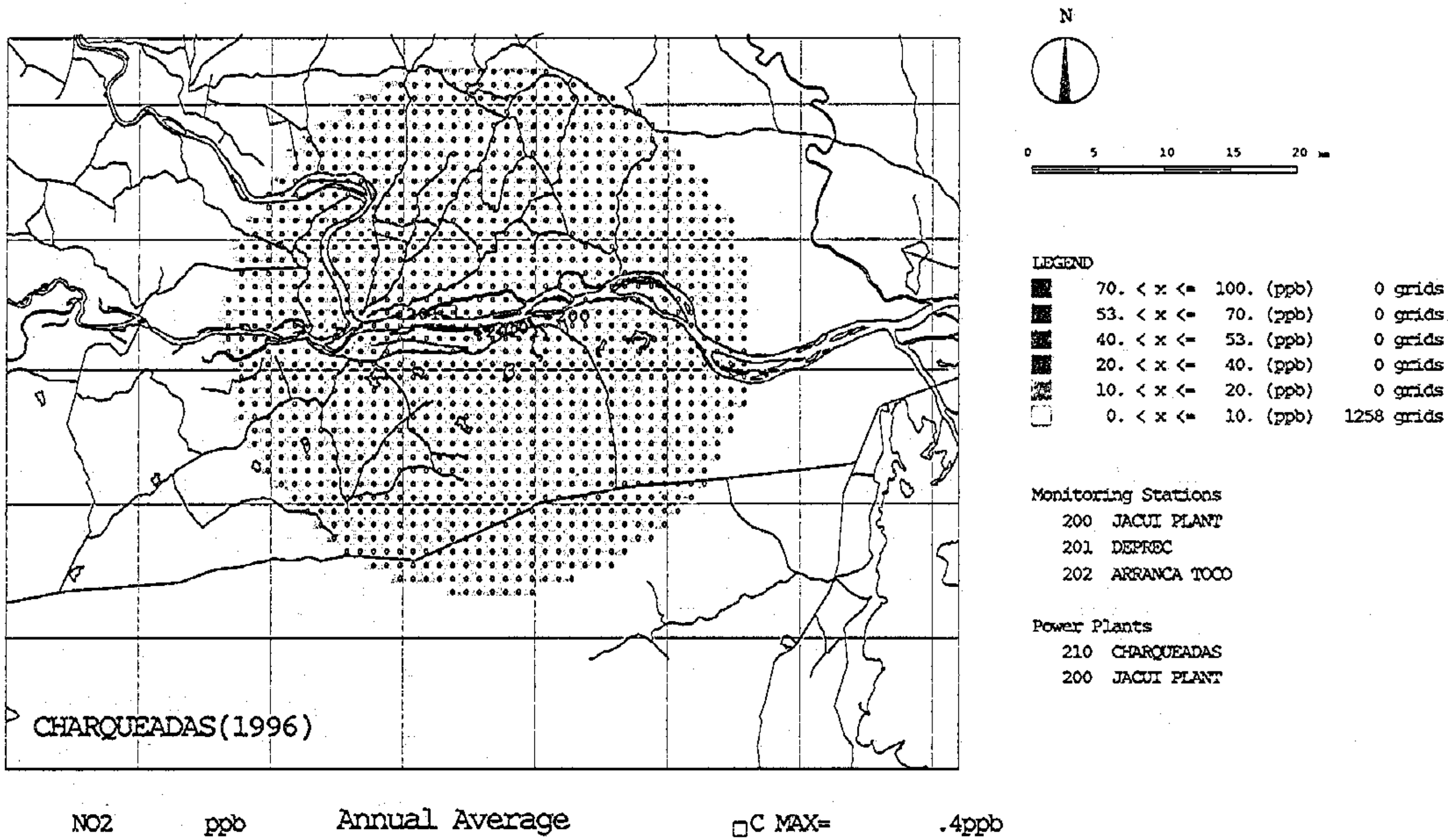


Figure 6.2.5 Distribution of Annual Average Concentration (Charqueadas, Current, NO_2)

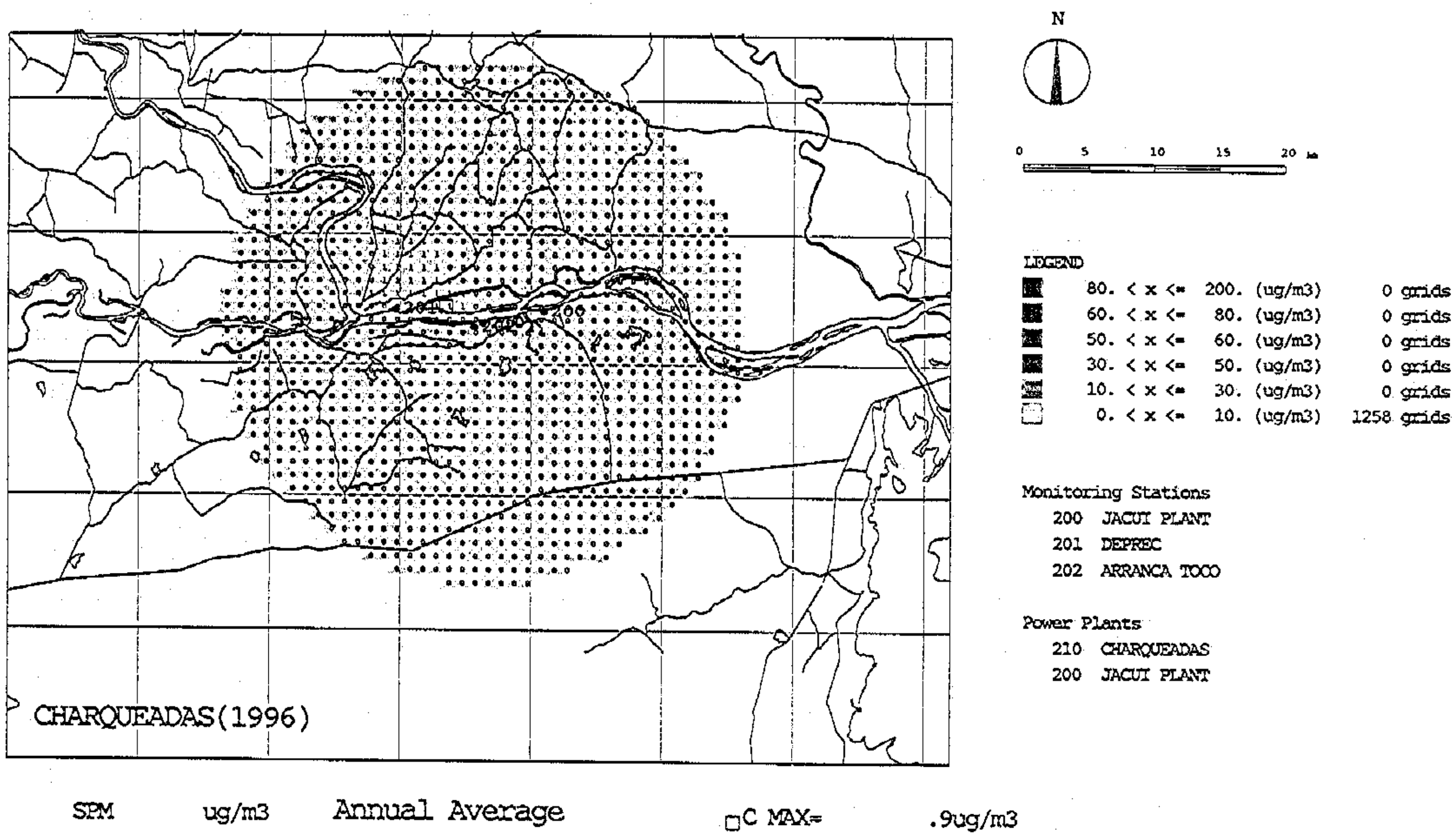


Figure 6.2.6 Distribution of Annual Average Concentration (Charqueadas, Current, SPM)

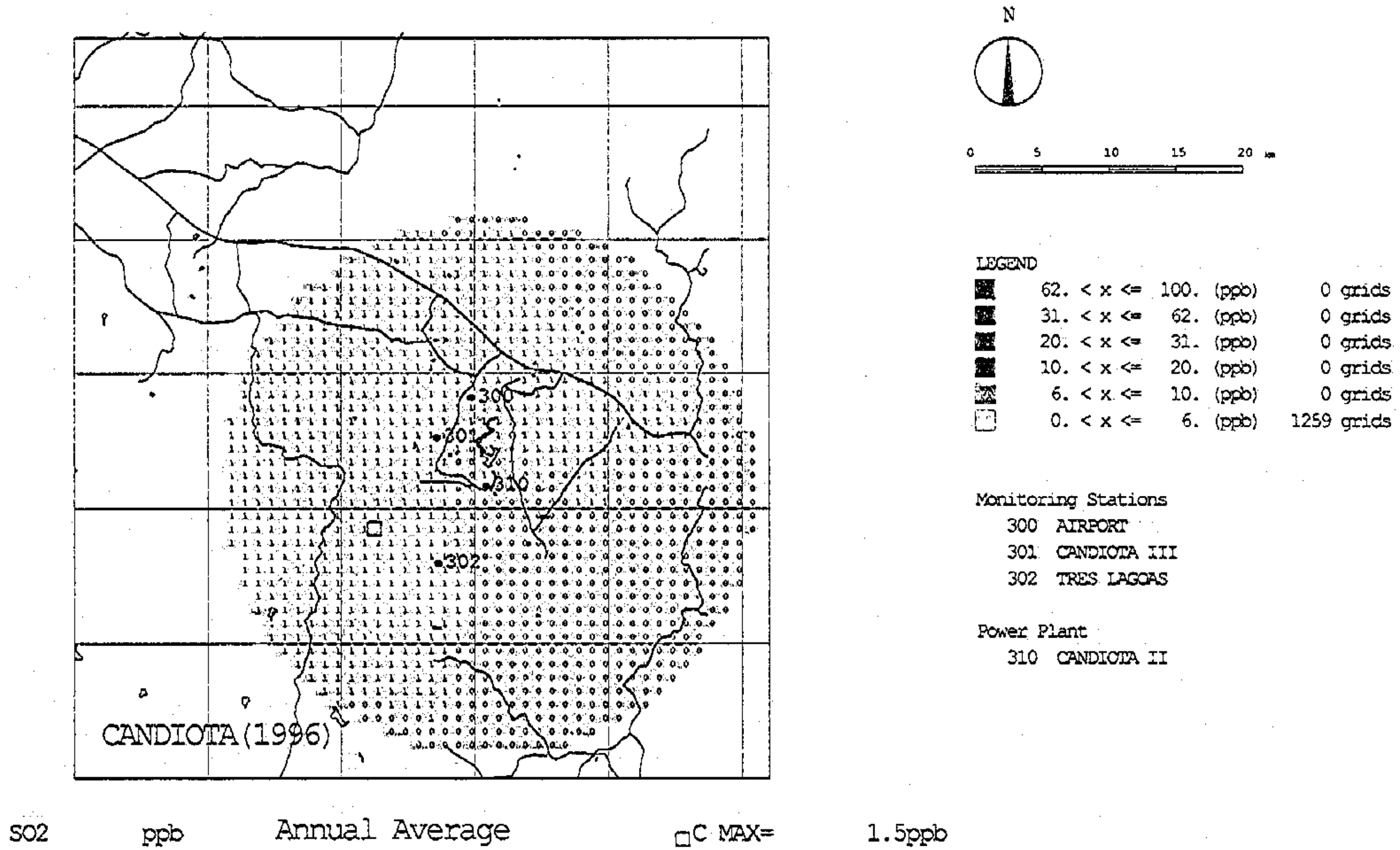


Figure 6.2.7 Distribution of Annual Average Concentration
(Candiota, Current, SO_2)

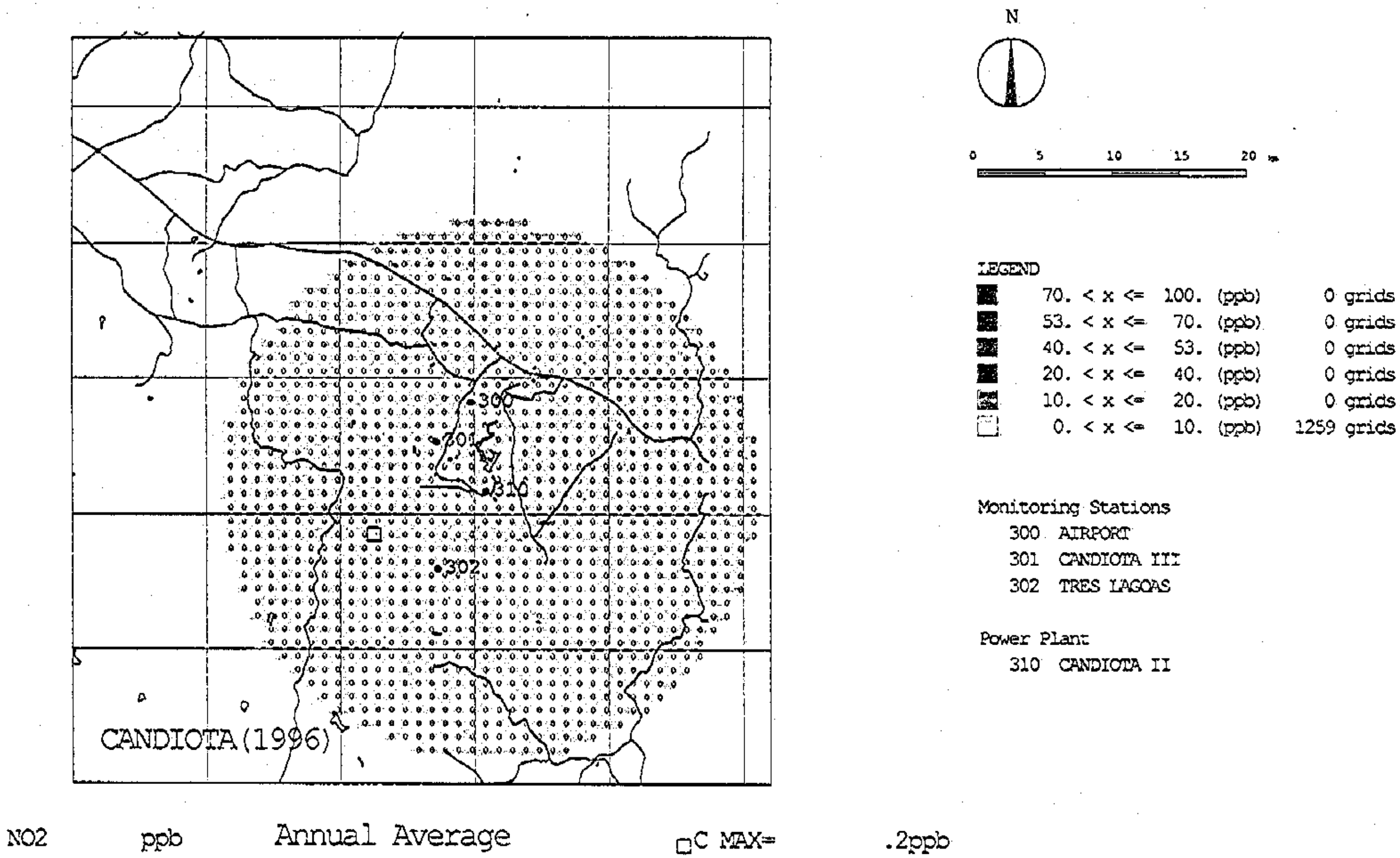


Figure 6.2.8 Distribution of Annual Average Concentration (Candiota, Current, NO_2)

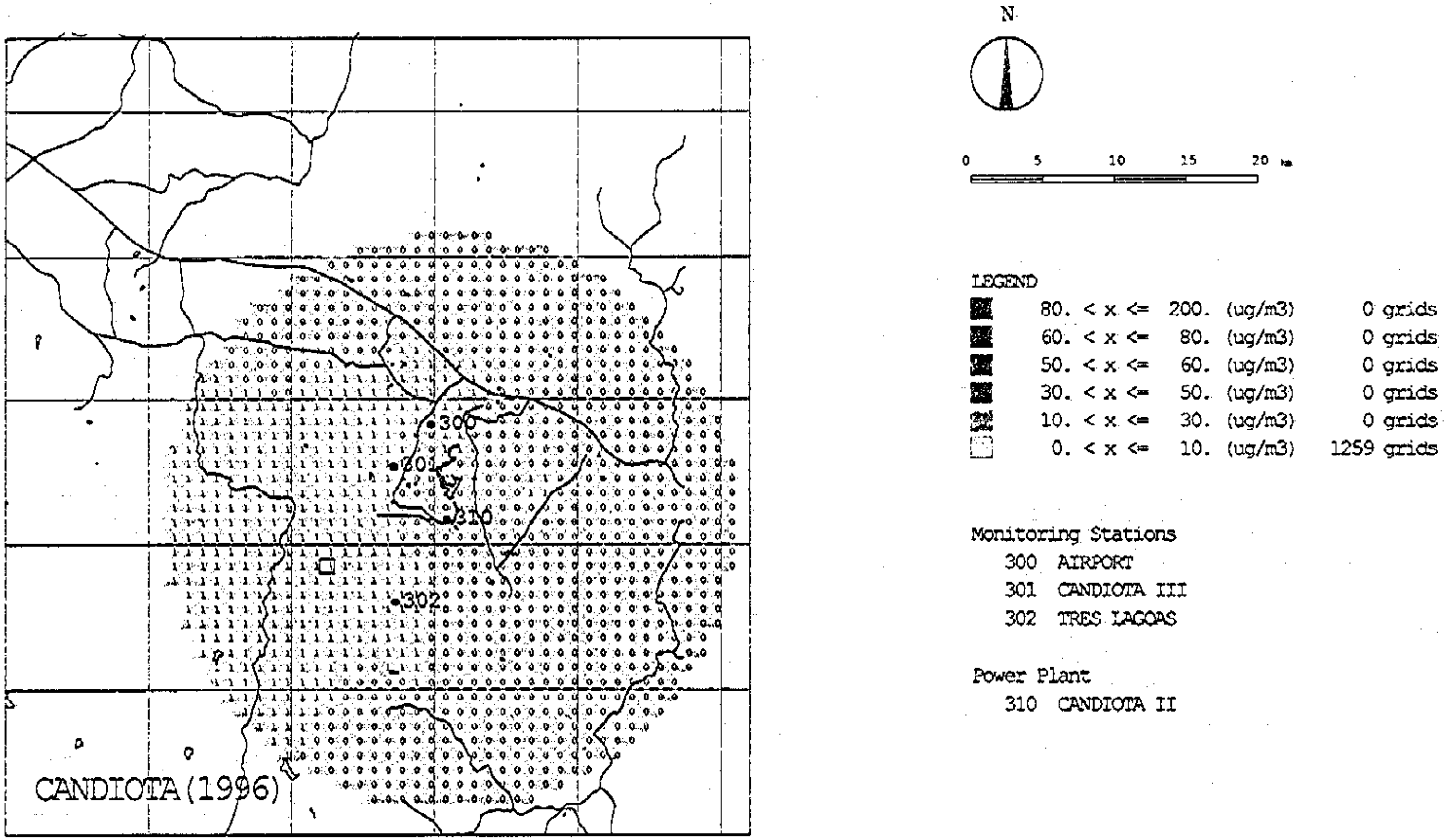


Figure 6.2.9 Distribution of Annual Average Concentration (Candiota, Current, SPM)

6.3 Daily Averages and Hourly Values at Monitoring Station

Daily average concentrations and hourly concentrations were calculated based on the emission conditions and the meteorological conditions at the monitoring stations. The procedures to make emission parameters at each hours and dispersion formula and so on for simulation were the same as for the annual average calculation.

The daily average concentrations and the hourly concentrations were much lower than the criteria as in **Table 6.3.1**.

The maximum value of SO_2 daily averages at Capivari was the highest, 43.3 ppb, and the maximum value of NO_2 hourly values at Vila Moema was the highest, 29 ppb. Both stations locate in Jorge Lacerda region. However, the maximum value of SPM daily averages at Candiota III in Candiota region was the highest, 20.3 μ g/m^3. Short term SPM concentrations at Candiota were higher than the ones in the other regions. All of the pollutant concentrations at Charqueadas were the lowest.

Table 6.3.1 Daily Average and Hourly Value at Monitoring Station

	SO_2 Daily	NO_2 Hourly	SPM Daily
Capivari	43.3	24	10.9
Vila Moema	17.7	29	4.6
Sao Bernardo	42.7	25	11.0
DEPREC	8.2	5	2.4
Jacui	5.4	6	1.6
Arranca Toco	12.0	4	3.5
Airport	14.3	9	14.7
Candiota III	19.0	9	20.3
Tres Lagoas	16.9	9	18.0
Standard	139.4	170.1	150.0
Unit	(ppb)	(ppb)	(ug/m^3)

6.4 Hourly Concentration Profile

6.4.1 Simulation Procedure

(1) Diffusion Formula

Downwind profiles of pollutant concentrations from the power stations were calculated at center line of plume with the following diffusion formula containing lateral diffusion parameter (σ_y), and the height of the calculation points were set as 0 m.

$$C(x,y,z) = \frac{Q_p}{2\pi\sigma_y\sigma_z u} \cdot \exp\left(-\frac{y^2}{2\sigma_y^2}\right) \cdot F$$

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

C:	Pollutant Concentration at Calculation Point (ppb, μ g/m^3 etc.)
x:	Distance from Stack to Calculation Point in Downwind Direction (m)
y:	Lateral Distance from Center Line of Plume (m)
z:	Height of Calculation Point (m)
Q_p:	Pollutant Emission Rate (m^{3}N/sec, Kg/sec etc.)
u:	Wind Speed (m/sec)
He:	Effective Stack Height (m)
σ_y:	Lateral Diffusion Parameter (m)
σ_z:	Vertical Diffusion Parameter (m)

(2) Emission Parameter

Pollutant emission and gas volume were calculated under the conditions of maximum loading (100 %) of all units **(Table 6.4.1)**. Gas temperatures were the same as the ones for annual average calculation. All of the stacks at the power plants were assumed at the same position.

Table 6.4.1(1) Gas Volume and Pollutant Emission under Maximum Loading (Jorge Lacerda)

Stack Code Connected UNIT	Unit	1 1-4	2 5	3 6	4 7
Electricity Generation	(MWh)	232	125	125	320
Wet Gas Voulme	(Km^{3}N/h)	1529.8	785.6	884.8	1126.2
Dust	(Kg/h)	679.9	562.0	108.9	1025.1
SO_x	(m^{3}N/h)	2607.9	1290.1	1388.3	2353.2
NO_x	(m^{3}N/h)	375.5	299.1	332.7	545.6

Table 6.4.1(2) Gas Volume and Pollutant Emission under Maximum Loading (Charqueadas)

Stack Code Connected UNIT	Unit	1 1-4
Electricity Generation	(MWh)	72
Wet Gas Voulme	(Km^{3}N/h)	562.7
Dust	(Kg/h)	173.5
SO_x	(m^{3}N/h)	586.6
NO_x	(m^{3}N/h)	179.2

Table 6.4.1(3) Gas Volume and Pollutant Emission under Maximum Loading (Candiota)

Stack Code Connected UNIT	Unit	1 1-4
Electricity Generation	(MWh)	446
Wet Gas Voulme	(Km^{3}N/h)	4859.5
Dust	(Kg/h)	3838.9
SO_x	(m^{3}N/h)	6147.5
NO_x	(m^{3}N/h)	1135.3

(3) Meteorological Condition

Meteorological conditions at stack top were set considering the settings for annual average simulation (Table 6.4.2)

Table 6.4.2 Meteorological Conditions for Hourly Profiles

Diffusion Parameter	Wind Speed					
	1.0m/s	2.0m/s	3.0m/s	5.0m/s	7.0m/s	9.0m/s
C	O	O	O	–	–	–
CD	O	O	O	O	O	O
D	O	O	O	O	O	O
E	O	O	O	–	–	–

6.4.2 Hourly Concentration Profile

All maximum concentrations were calculated under the conditions of stability C and 3.0 m/s of wind speed. SO_2 maximum concentration was the highest among others at Jorge Lacerda to be 152 ppb. There is no standard for SO_2 hourly concentration in the national air quality regulation and its standard for 24 hours average is 139.4 ppb. The calculated maximum may be not problematic because hourly values is generally higher than the one for 24 hours average. As an example, hourly and daily standards for SO_2 are 100 ppb and 40 ppb, and the hourly standard is 2.5 times higher than the daily one.

The calculated NO_2 and SPM maximum concentrations were also the highest among others at Jorge Lacerda to be respectively 32 ppb and 45 μ g/m^3. The calculated NO_2 concentrations were much lower the national standard for hourly NO_2 of 170.1. The calculated SPM was lower than the national standard for 24 hours average of SPM (Table 6.4.3).

Table 6.4.3 Maximum Concentration on Profile

Power Plant	Item	Maximum	Distance
Jorge Lacerda	SO_2	152ppb	5.9km
	NO_2	32ppb	5.7km
	SPM	45 μ g/m^3	6.1km
Charqueadas	SO_2	41ppb	3.6km
	NO_2	7ppb	3.6km
	SPM	12 μ g/m^3	3.6km
Candiota	SO_2	58ppb	10.1km
	NO_2	11ppb	10.1km
	SPM	36 μ g/m^3	10.1km

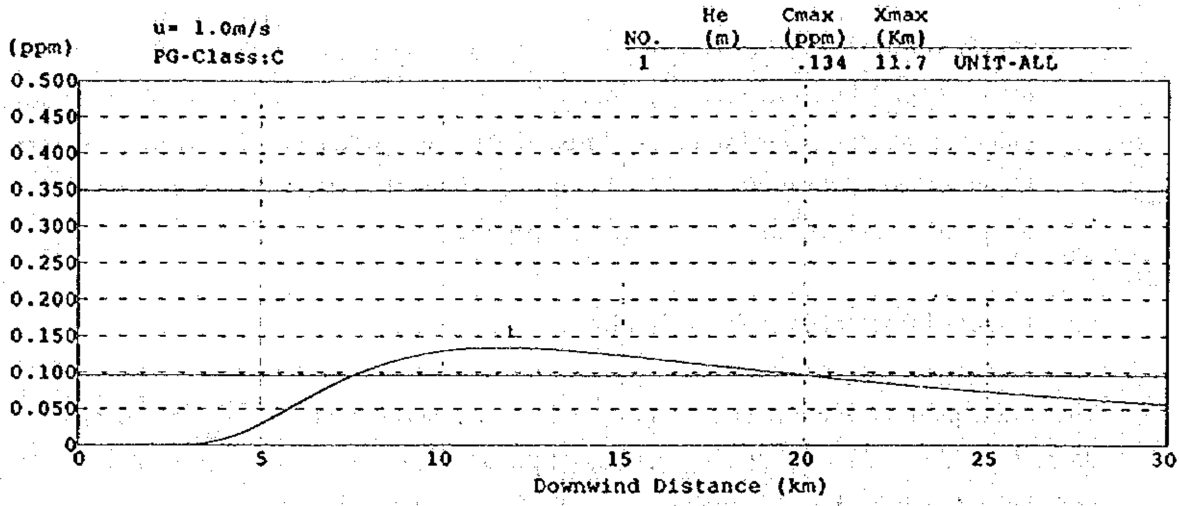
The profiles of the pollutants at the stations with the maximum concentrations are shown in **Figure 6.4.1** to **Figure 6.4.9.** The primary and secondary national criteria for each pollutant are shown together for comparison. In the case of no hourly criteria, reference values were made from daily criteria with correction factors, ratios of hourly standard/daily standard for the same pollutant in Japan. The profiles under the other conditions are included in **Appendix 6-2.**

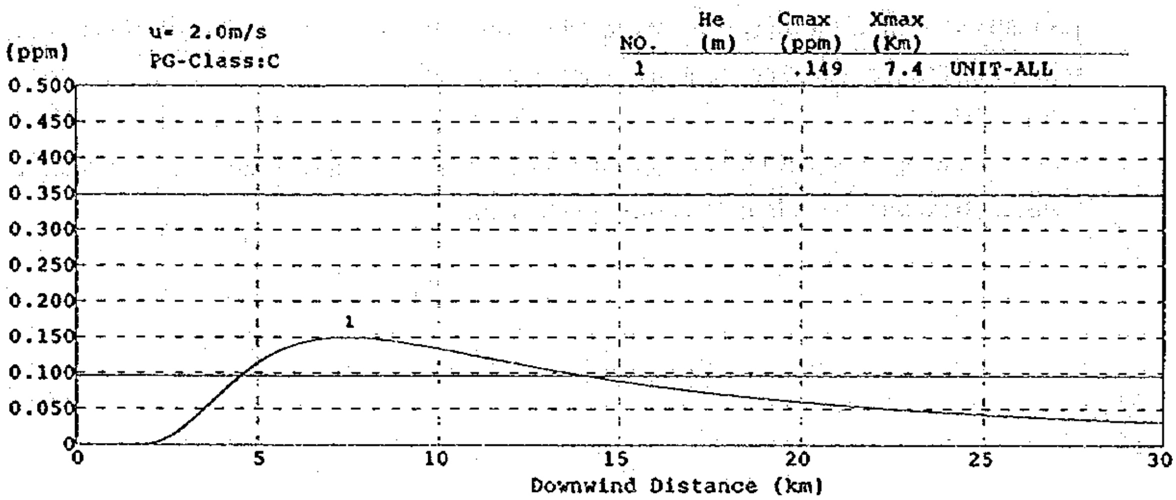
6.5 Effect of Power Plant on Air Quality

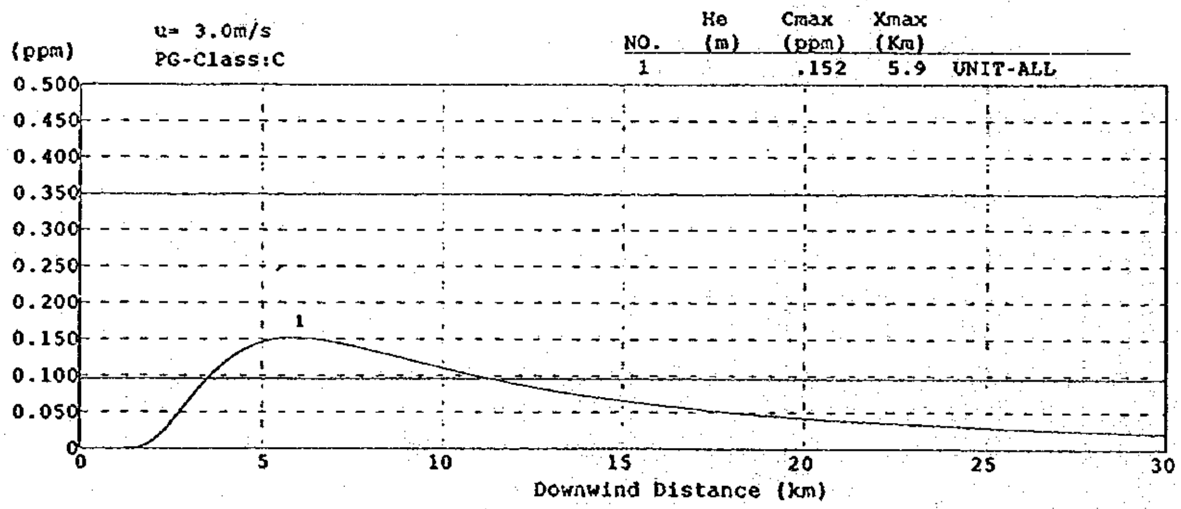
The power plants are the major emission sources for SO_2 in all regions, and especially at Jorge Lacerda. Although nothing serious at present, there is a future possibility of SO_2 pollution in the Jorge Lacerda region, depending on the expansion of the power plant or any other SO_2 sources.

The influences from the power plants to NO_2 and SPM concentrations were small in all regions and the measured concentrations were also low.

24 hours concentrations of TSP at Capivari exceeded the national standard as in Chapter 4. However, the contribution from the power plant is low.

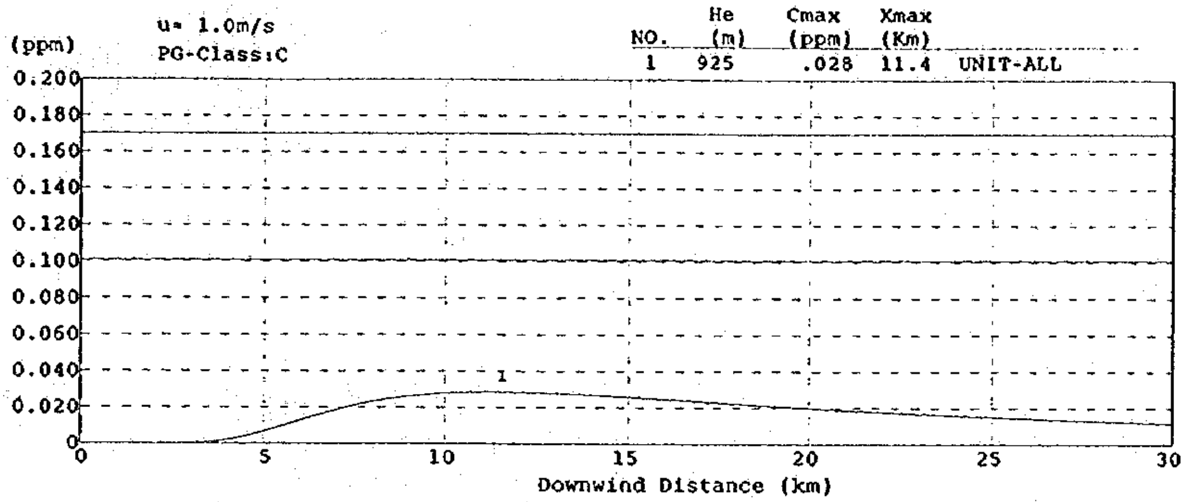


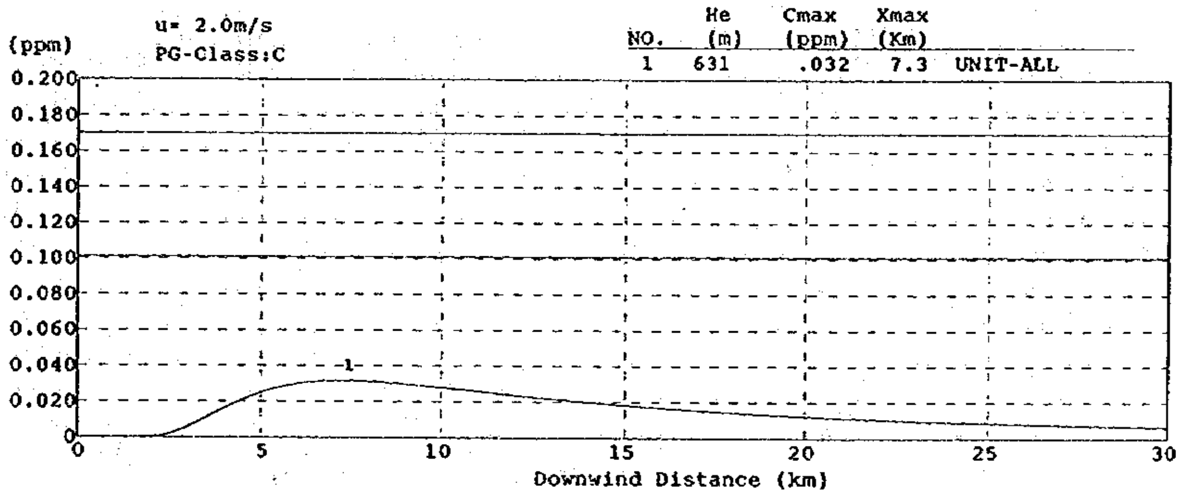


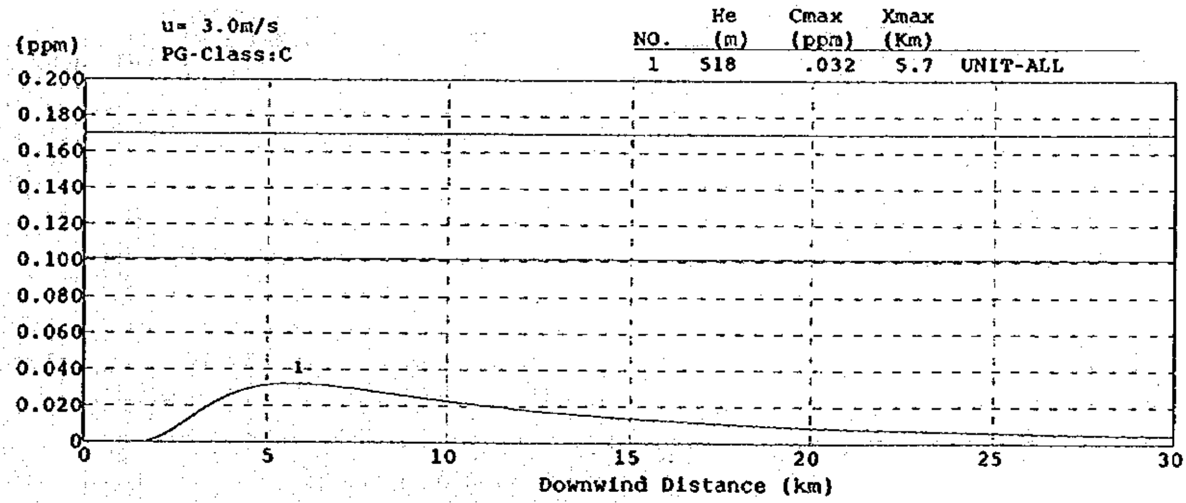


CONCAWE & Plume (SO2)

Figure 6.4.1 Hourly Concentration Profile
(Jorge Lacerda, Current, SO_2)

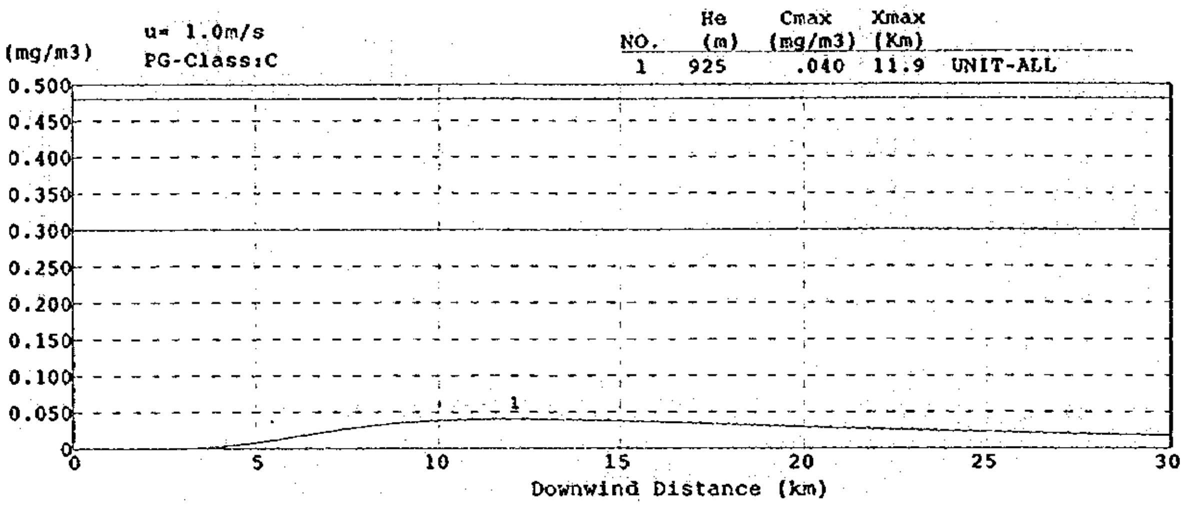


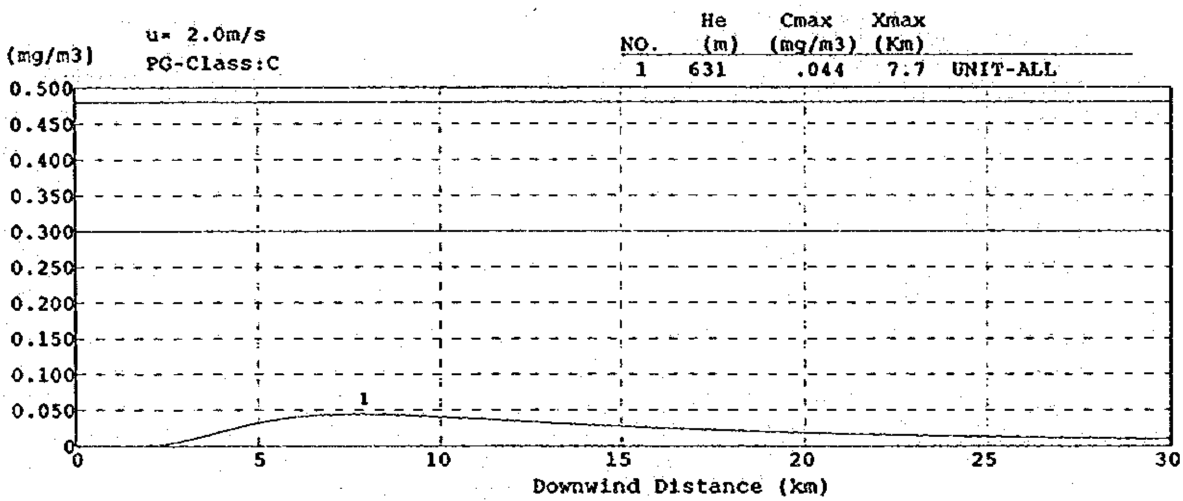


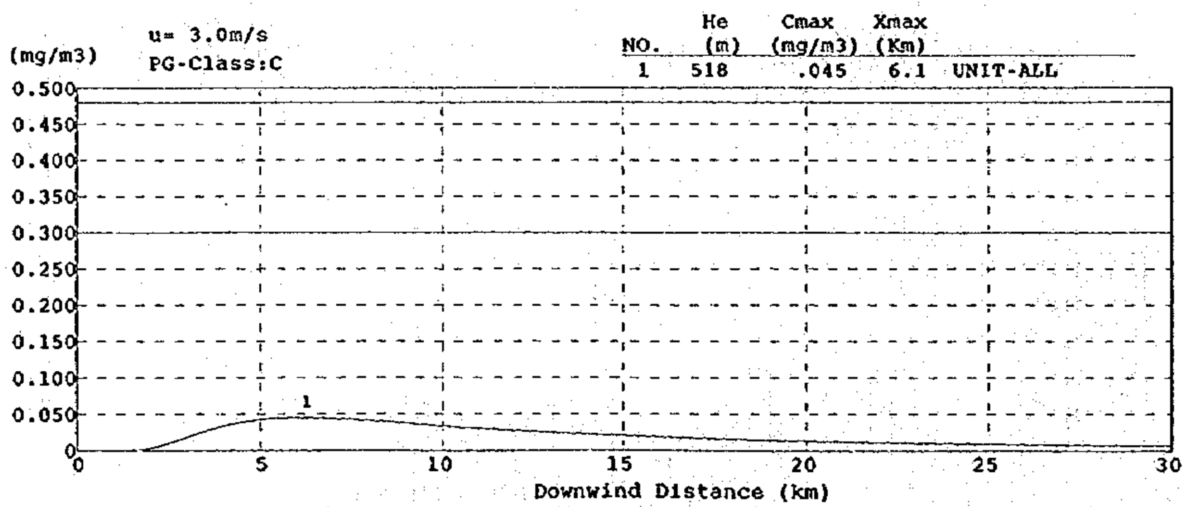


CONCAWE & Plume (NO2)

Figure 6.4.2 Hourly Concentration Profile (Jorge Lacerda, Current, NO_2)

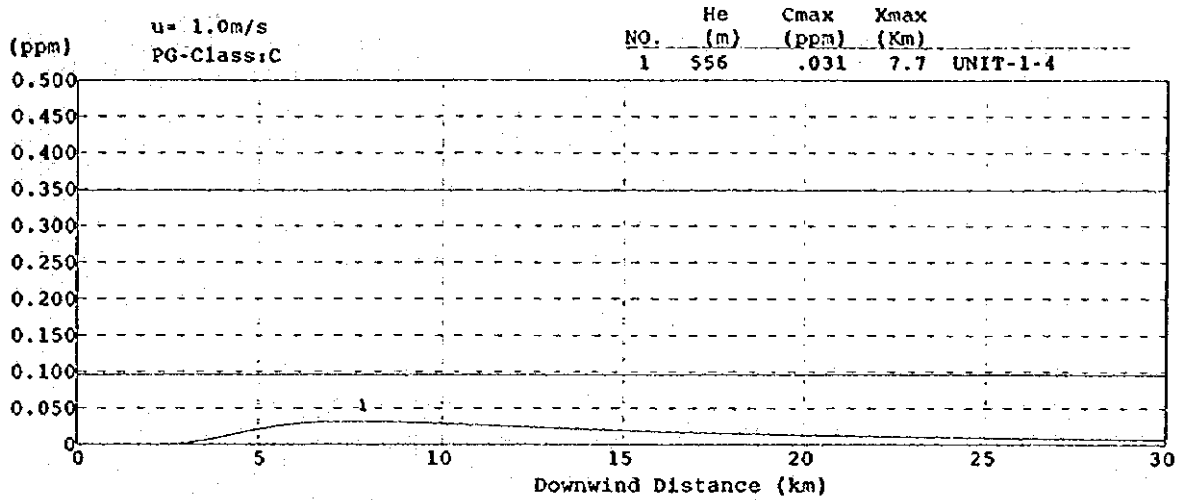


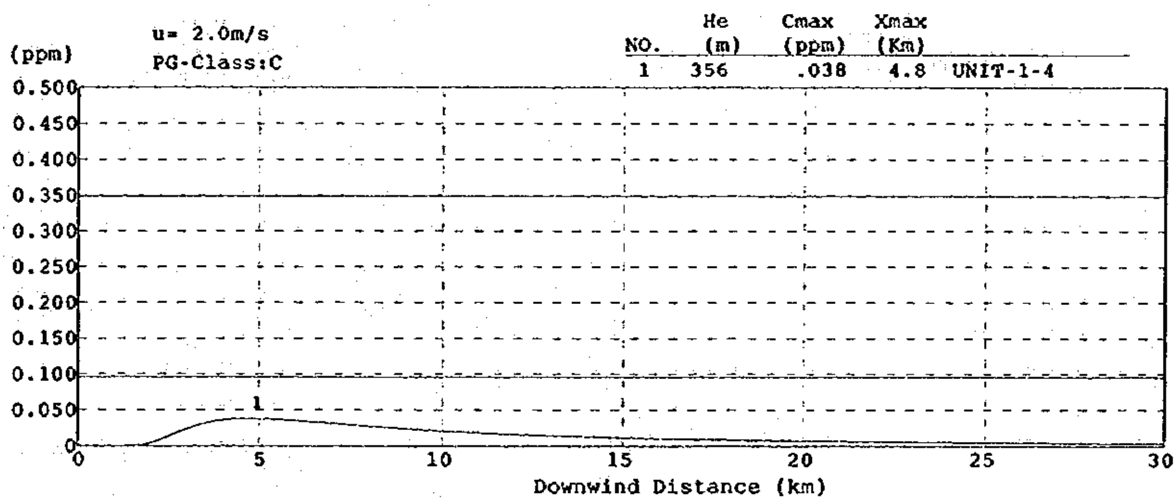


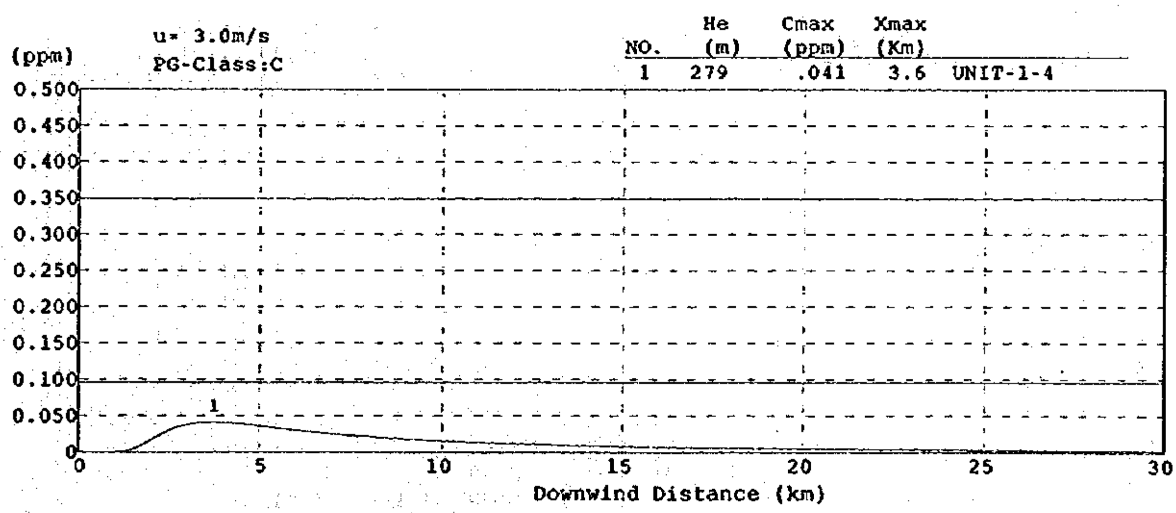


CONCAWE & Plume (Dust)

Figure 6.4.3 Hourly Concentration Profile (Jorge Lacerda, Current, SPM)

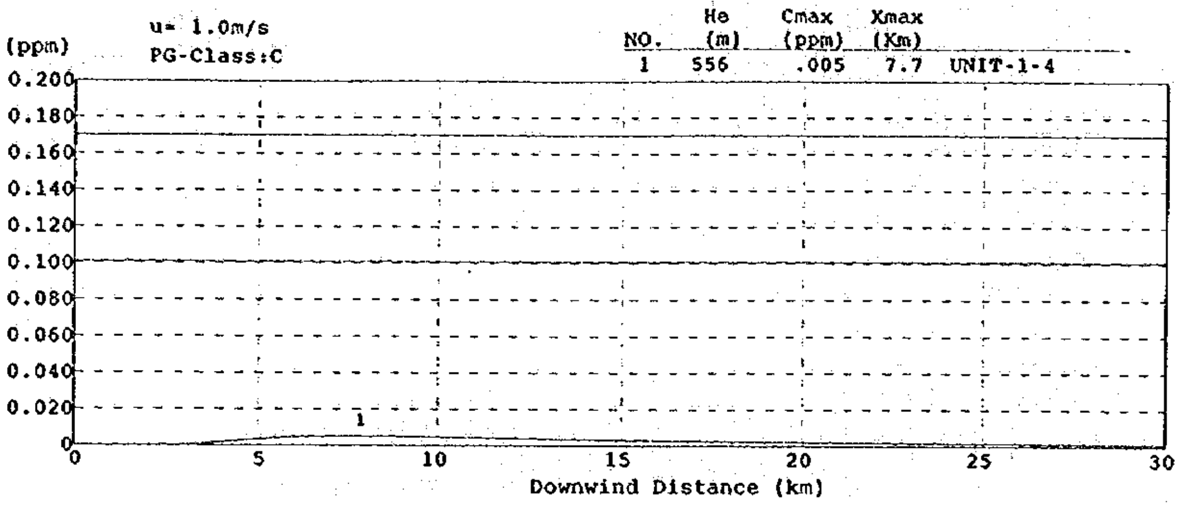


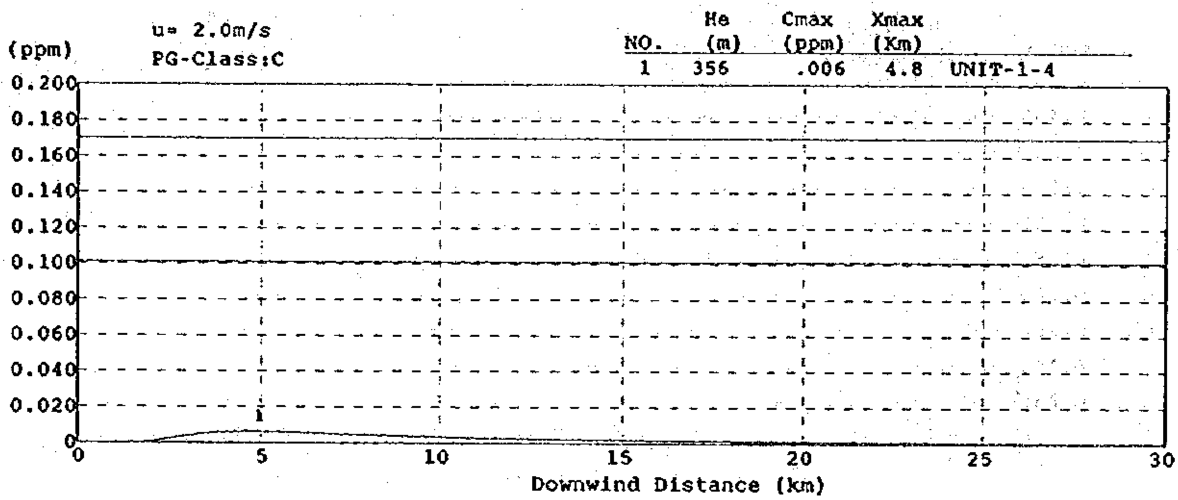


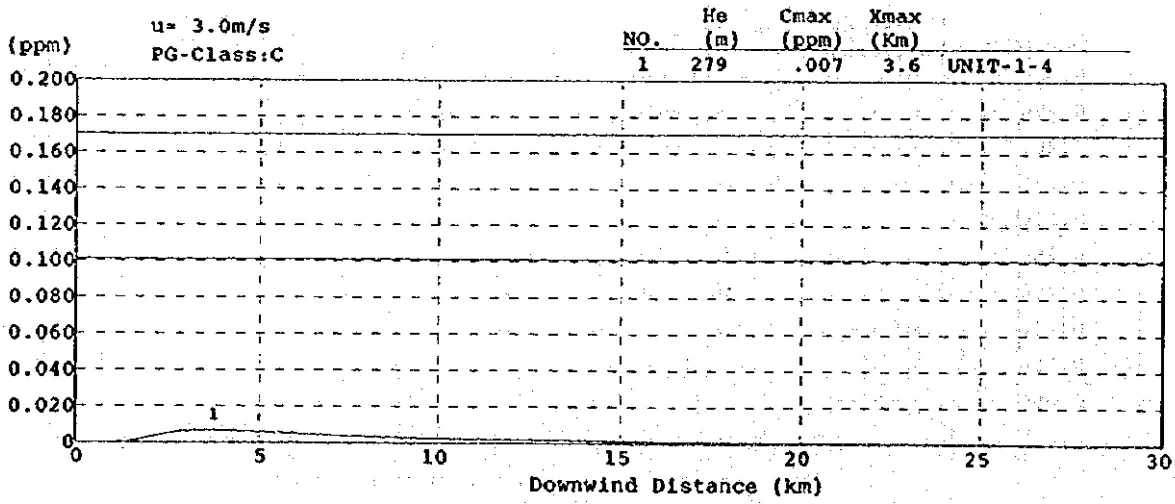


CONCAWE & Plume (SO2)

Figure 6.4.4 Hourly Concentration Profile (Charqueadas, Current, SO_2)

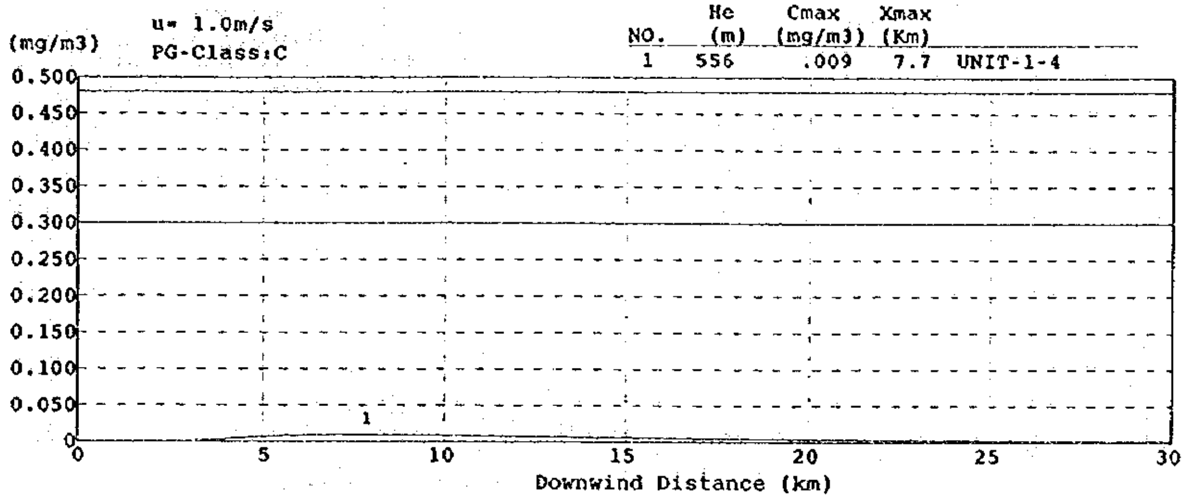


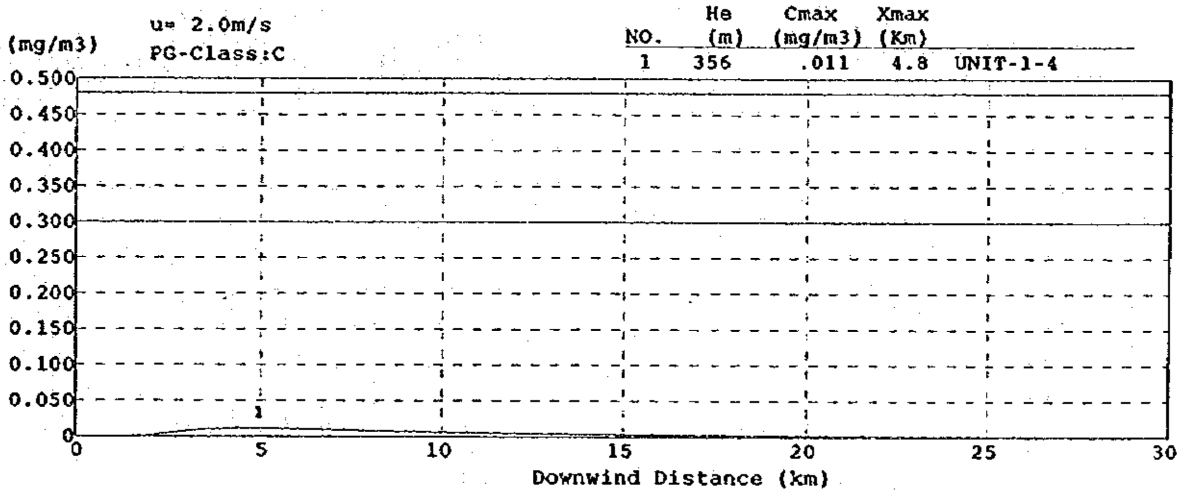


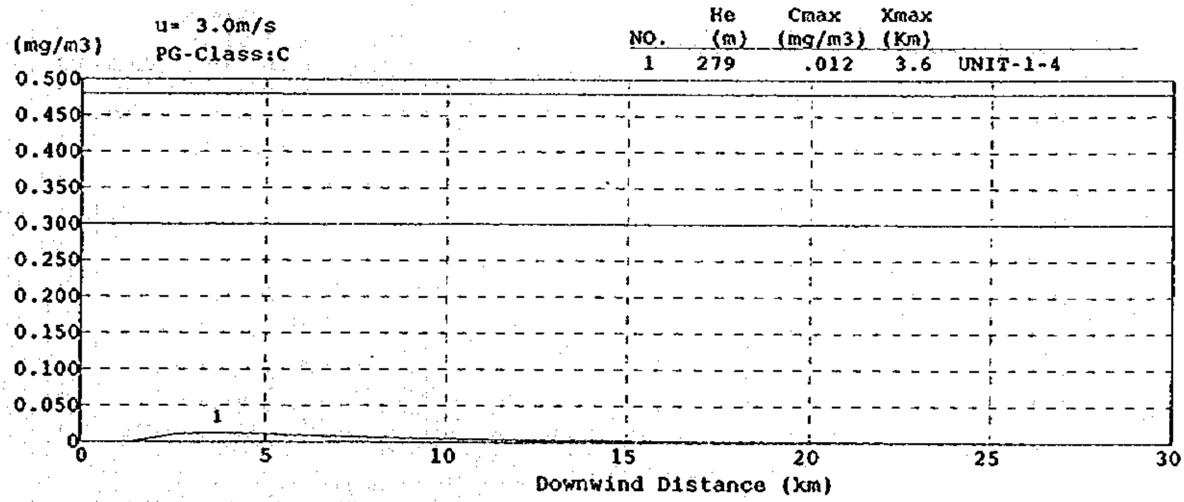


CONCAWE & Plume (NO2)

Figure 6.4.5 Hourly Concentration Profile (Charqueadas, Current, NO_2)

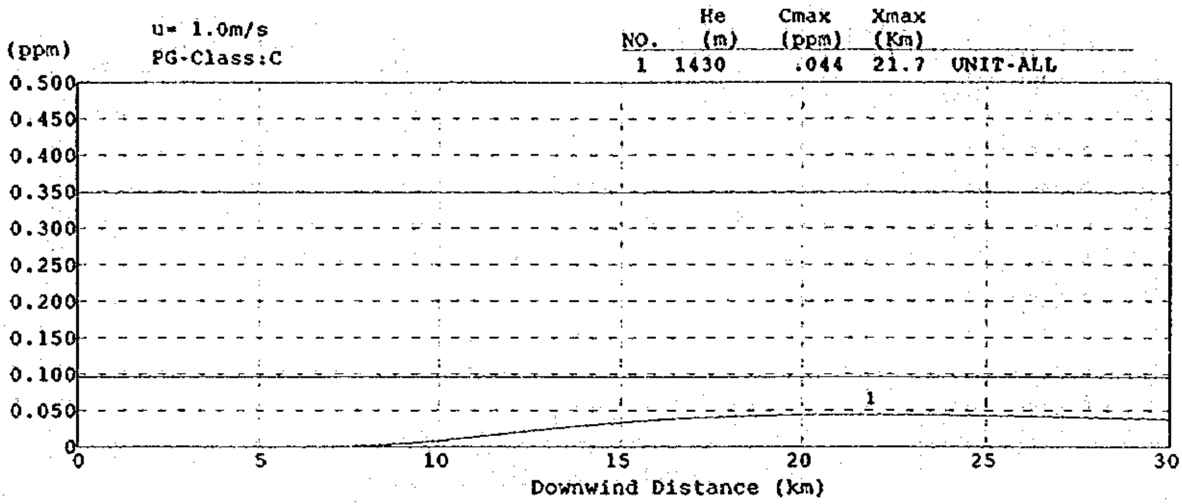


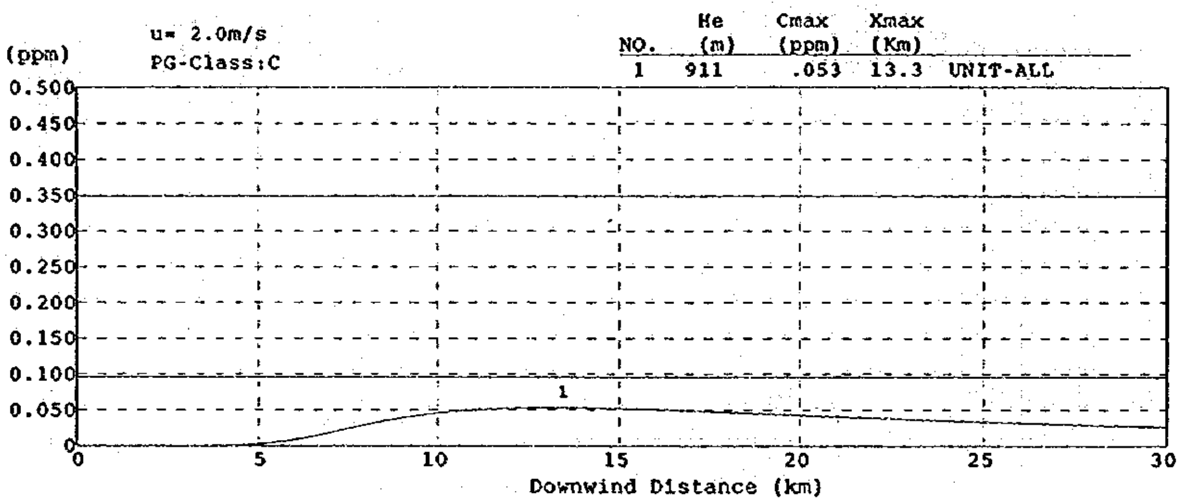


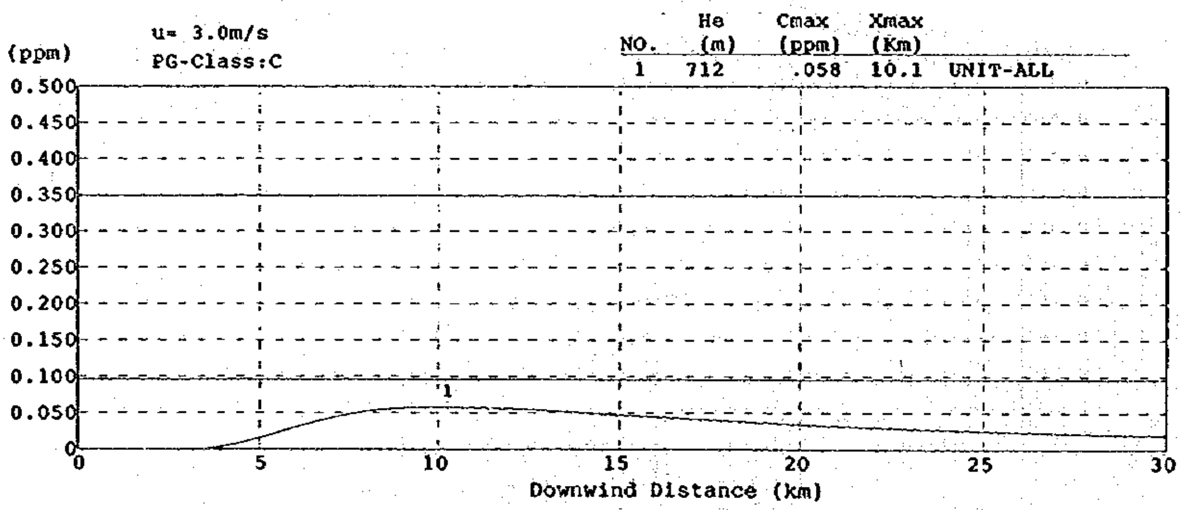


CONCAWE & Plume (Dust)

Figure 6.4.6 Hourly Concentration Profile (Charqueadas, Current, SPM)

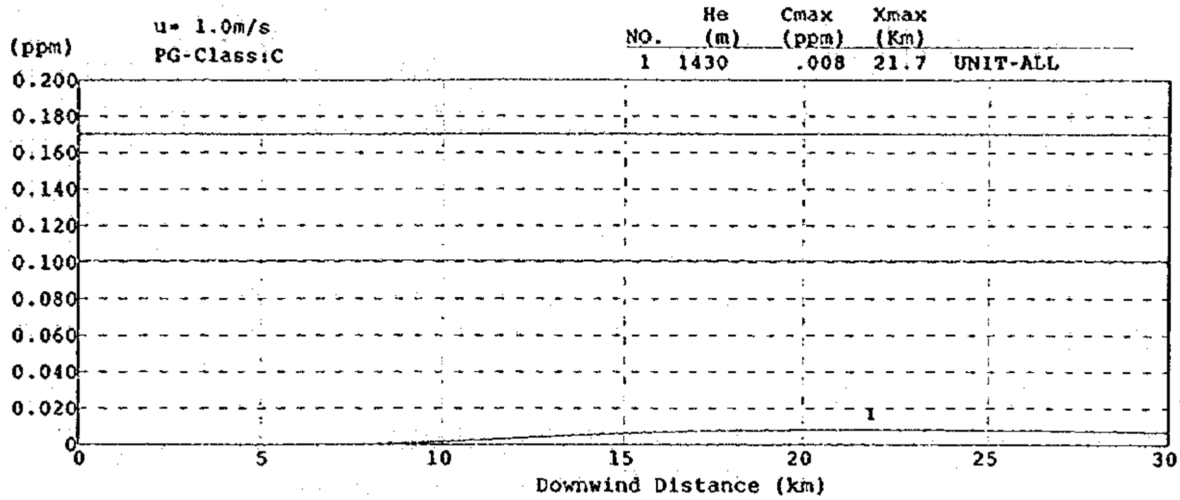


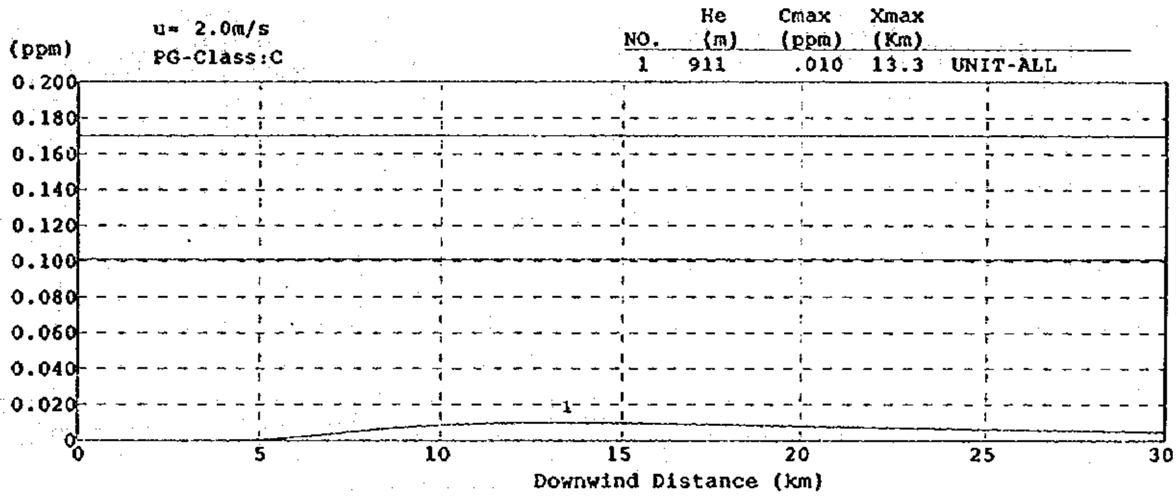


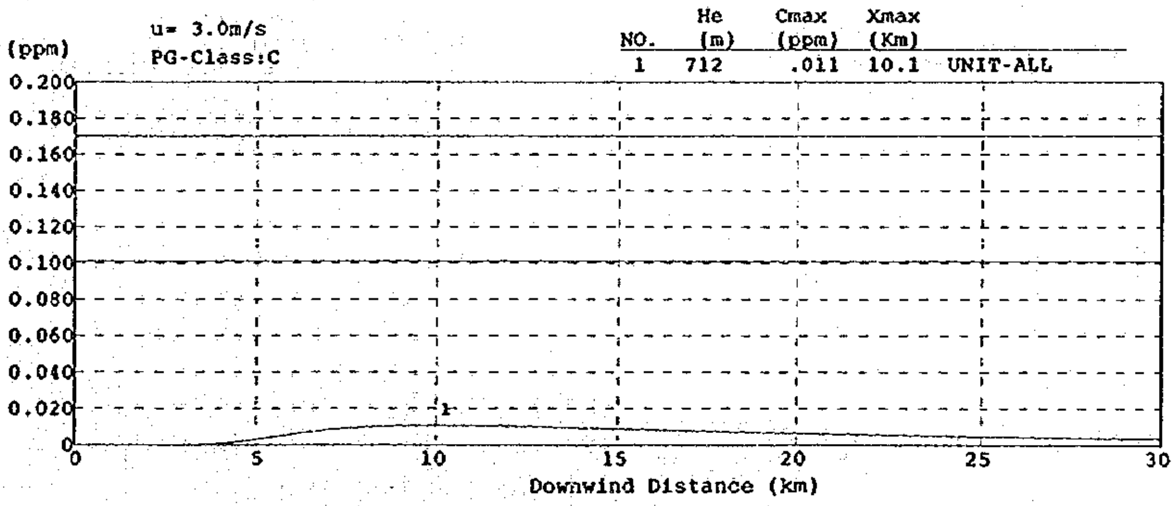


CONCAWE & Plume (SO2)

Figure 6.4.7 Hourly Concentration Profile
(Candiota, Current, SO_2)

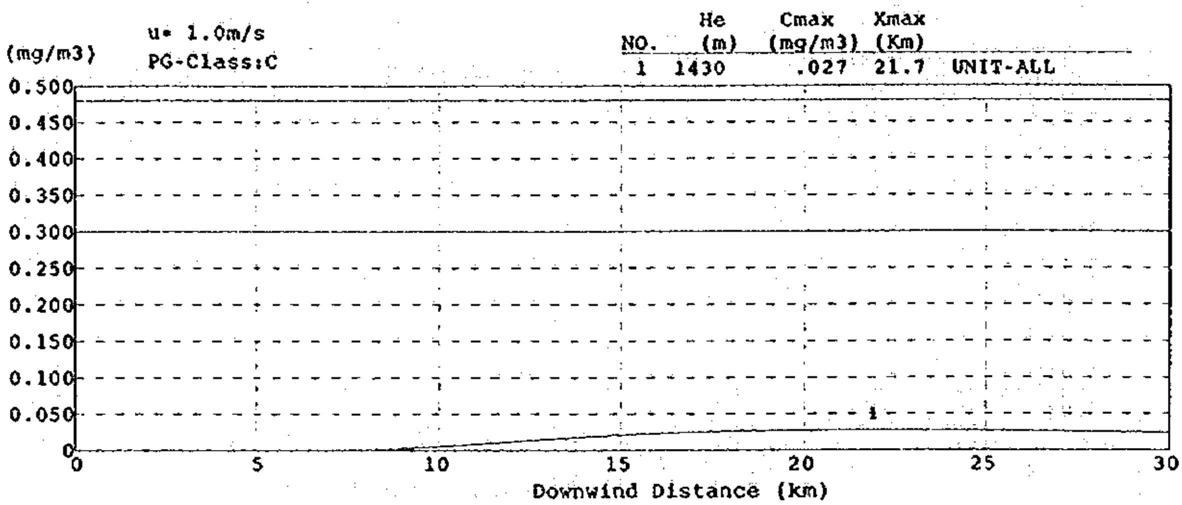


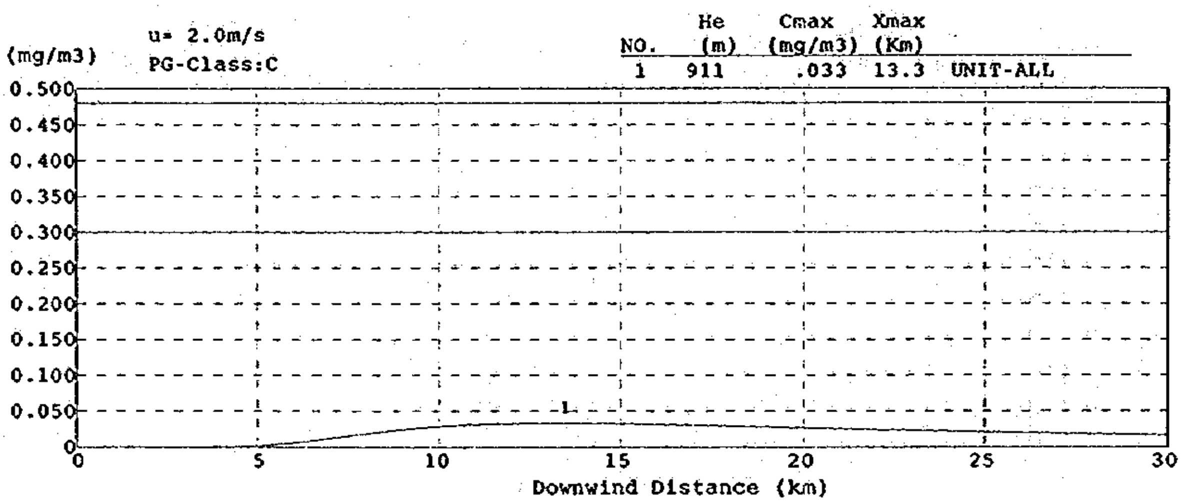


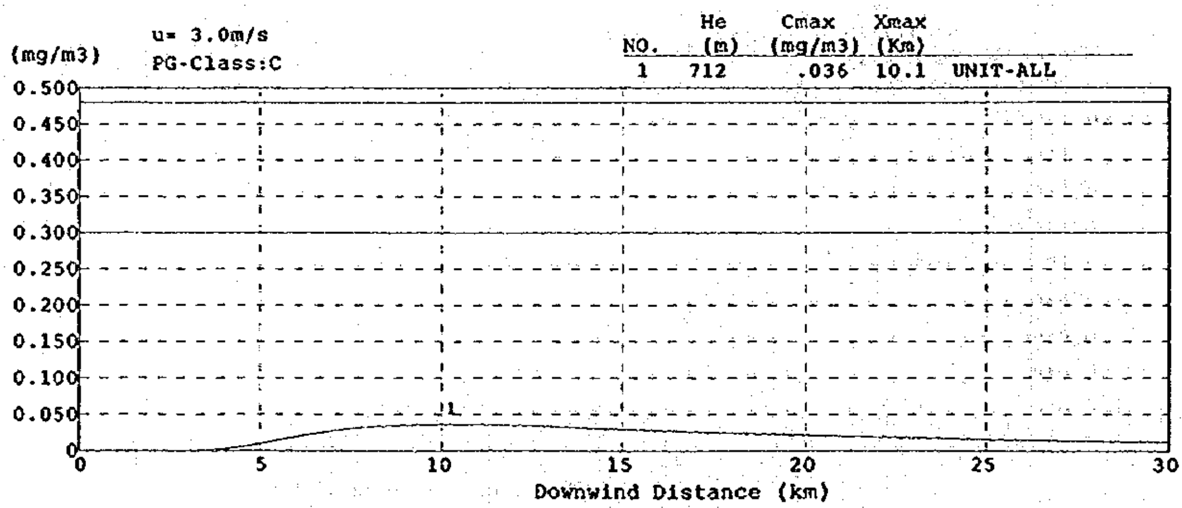


CONCAWE & Plume (NO2)

Figure 6.4.8 Hourly Concentration Profile (Candiota, Current, NO_2)







CONCAWE & Plume (Dust)

Figure 6.4.9 Hourly Concentration Profile (Candiota, Current, SPM)

CHAPTER 7 FUTURE AIR QUALITY ESTIMATION

7.1 Expansion of Coal Power Plants

7.1.1 Planned Location

ELETROSUL and CEEE have their expansion plans of generation capacity by installing new coal power plants.

ELETROSUL has constructed Unit IV of the Jorge Lacerda Plant directly adjacent to the southeast of the existing units, and put it into operation in January, 1997. ELETROSUL is also constructing the Jacui Power Plant at a distance of about 5 km, east of the Charqueadas Plant. However, its construction has been suspended from 1991. A boiler and turbine, etc. have been purchased (made in 1989) and are stored in a warehouse in the premises.

CEEE had purchased required equipment for construction of Unit III of the Candiota Plant and will start its construction targetting to be in operation in the year of 2003. The Candiota III unit will be located directly to the north of the existing Candiota II A and B units. CEEE canceled the expansion plan of five more units of 350 MW in the Candiota plant, although six units of 350MW (total 2,100MW) were originally planned at a distance of about 2km, southeast of the existing plant.

7.1.2 Specification of Expansion Units

The facilities of planned units are described in **Table 7.1.1**. Electrostatic precipitators will be installed at all expansion units for the pollution control measures. Low-NOx burners are employed at the expanded Jorge Lacerda IV and it is uncertain that any other pollution control facilities are employed at the Jacui and Candiota III units.

The construction project of the Jacui and Candiota III is expected to be considerably behind the schedule owing to shortage of funds, negotiations with the State Governments and States' Environment Foundations (FATMA and FEPAM) in respect of pollutant emission control, etc. as well as behind in introduction of private funds.

Table 7.1.1 Specifications of Planned Coal Power Plants

Power Plant	Unit	Rated MW	Amount Coal Burnt (t/h)	Stack Gas (m^3N/h)	Stack Gas Temperature (°C)	Stack Height (m)	Stack Diameter (m)	EP Efficiency (%)	SOx & NOx Removal	Cooling Tower	Startup
Jorge Lacerda	IV	350	185.0	1,126,206	192	200	6.4	99 up	Low NOx Burners	Forced Cooling	1/1997
Jacui	I	350	276.0	1,234,708	159	200	5.6	99 up	Unknown	Forced Cooling	12/1999
Candiota	III	350	393.15	1,360,000	137	230	5.5	99 up	Unknown	Forced Cooling	(9/2003)

7.2 Simulation of Future Air Quality

7.2.1 Condition of Simulation

The emission limits of the agreements with the states were applied to simulating the future air qualities.

The agreement for Jorge Lacerda limit the SO_2 amount from the consumption of the 2.2 % sulfur coal at rated load. However, the utilizing rate of the plant was around 50 % and sulfur contents of the used coal were below 2.2 %. It has been assumed that the agreement with the state has no influence to the current emission conditions and pollutant concentrations from the stack are the same as the current ones. Unit IV started from January, 1997 will be operated for full years in the future.

Pollutant concentration limits are determined for Dust, SO_x, and NO_x from the existing Charqueadas plant and the planned Jacui plant. Pollutant concentrations will be reduced to the limits of the agreement, and the estimation of emission amounts in the future is changed accordingly. Although the pollutant concentrations limits are defined at 6 % O_2, the existing units will be operated at current actual O_2 concentrations. The limited concentrations values are converted to the ones at the actual O_2 concentrations. The new plant will be operated at 6 % O_2. Gas volume and gas temperature are obtained from the design specifications.

The limited concentration for NO_x is defined in mg/m^3 unit, and converted in ppm unit, by assuming NO_x as NO. This assumption is more reasonable and indicates the highest emission within the limit.

For Candiota, pollutant concentrations limits are also set for Dust, SO_x, and NO_x from the existing and the planned units. Dust concentration for the existing units and NO_x concentrations for the planned units are not determined and these concentrations are assumed as same to the current ones. The existing units will be operated at the current actual O_2 concentrations, and the planned units at 6 % O_2.

The flue gas temperature of all the units having FGD installed is assumed to be 100 ℃. The pollutant concentrations and gas volume in the future are shown in **Appendix 7-1**. Meteorological conditions are the same as the current ones.

7.2.2 Distribution of Annual Average Concentration

(1) Emission Parameters

The parameters of the power plants are shown in **Table 7.2.1**

Table 7.2.1(1) Emission Parameter (Future, Jorge Lacerda)

Stack Code Connected UNIT	Unit	4 7
Electricity Generation	(MWh)	320
Stack Height	(m)	200
Gas Temperature	(℃)	192.0
Wet Gas Voulme	(Km^3N/h)	605.5
Dust	(Kg/h)	551.1
SO_x	(m^3N/h)	1265.0
NO_x	(m^3N/h)	293.3

Note: Unit 1-6 will be the same as the ones at current

Table 7.2.1(2) Emission Parameter (Future, Charqueadas+Jacui)

Power Plant Stack Code Connected UNIT	Unit	Charqueadas 1 1-4	Jacui 2 X
Electricity Generation	(MWh)	72	320
Stack Height	(m)	62	200
Gas Temperature	(℃)	100.0	100.0
Wet Gas Voulme	(Km^3N/h)	294.4	647.0
Dust	(Kg/h)	18.0	82.9
SO_x	(m^3N/h)	31.6	310.8
NO_x	(m^3N/h)	49.6	300.6

Table 7.2.1(3) Emission Parameter (Future, Candiota)

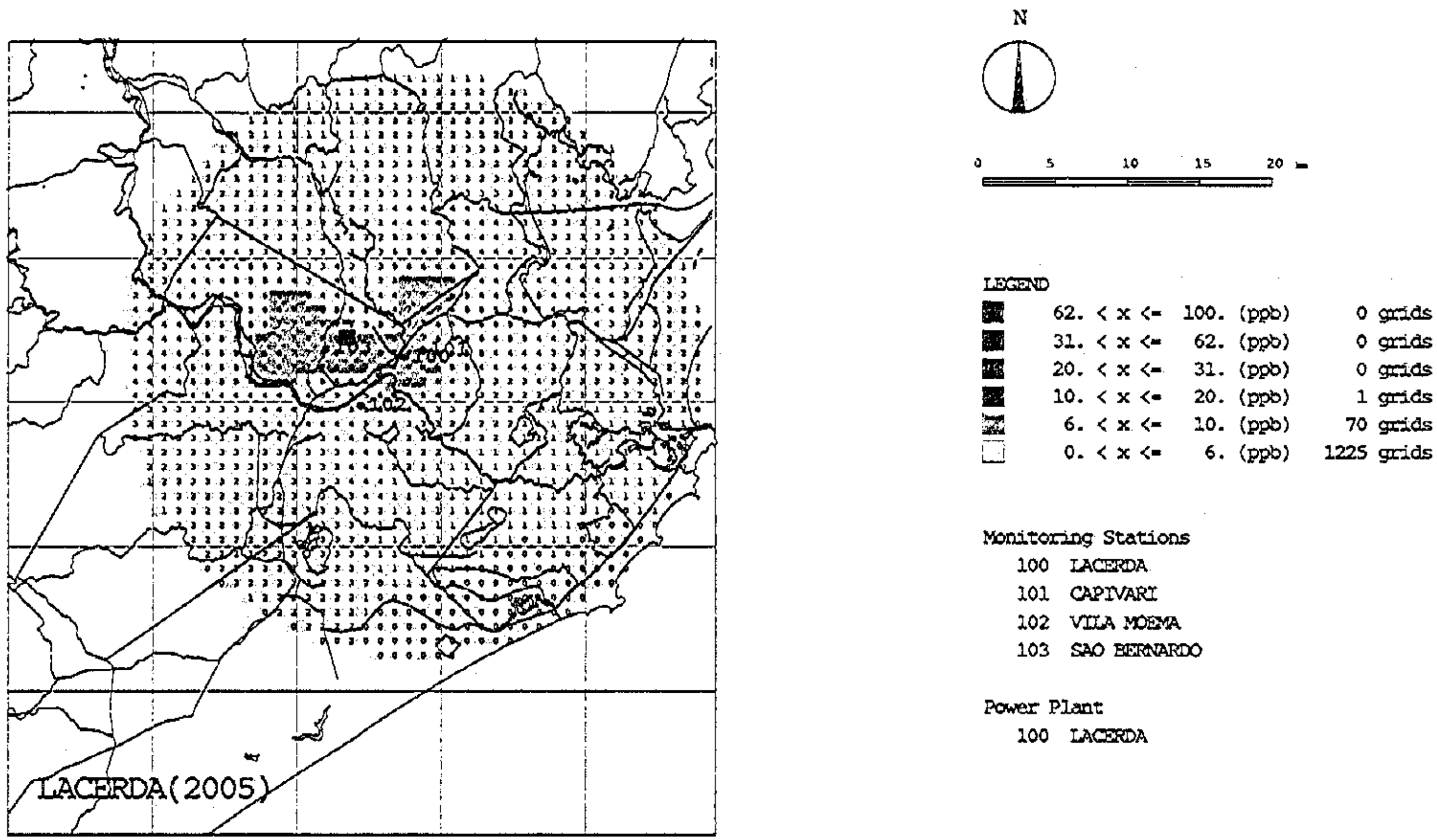
Stack Code Connected UNIT	Unit	1 1-4	2 5
Electricity Generation	(MWh)	446	320
Stack Height	(m)	150	230
Gas Temperature	(℃)	100.0	100.0
Wet Gas Voulme	(Km^3N/h)	1683.2	470.3
Dust	(Kg/h)	1063.0	101.9
SO_x	(m^3N/h)	487.2	269.2
NO_x	(m^3N/h)	330.5	172.0

(2) Estimated Distribution of Annual Average Concentration

In the Jorge Lacerda region, the calculated maximum concentration of SO_2 annual average is increased to 10.0 ppb from 8.5 ppb of the current conditions. The position with the maximum concentration is the same as the current one. SO_2 concentration will be below the criteria even after the expansion and one year operation of Unit IV (**Figure 7.2.1**). The maximum concentration of NO_2 and SPM will increase to 1.2 ppb and 2.9 ug/m^3 respectively, and they will not be the problem as well as not at present (**Figure 7.2.2, Figure 7.2.3**).

The Jacui plant will be constructed in the future in addition to the existing Charqueadas plant. However, the maximum concentration of SO_2 will be reduced to 1.4 ppb from 3.1 ppb under the current conditions because of the agreement for both of the plants (**Figure 7.2.4**). Because the emission limits for NO_x is higher than the current emission concentrations, NO_2 concentrations will increase to 1.2 ppb by construction of the Jacui plant, but it will not violate the national criteria (**Figure 7.2.5**). SPM concentration will be reduced to 0.5 ug/m^3 (**Figure 7.2.6**).

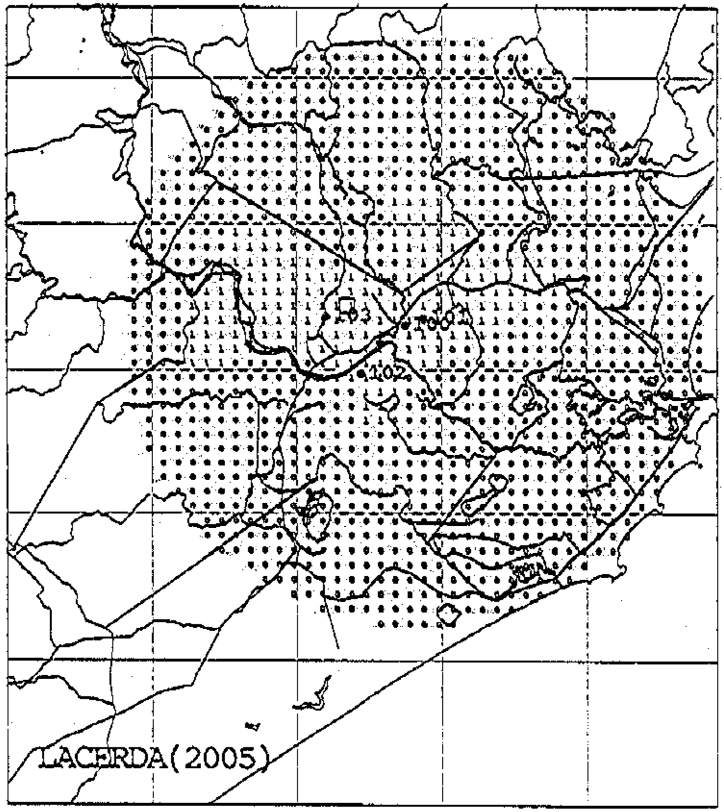
In the Candiota region, the maximum SO_2 concentration will be reduced to 0.8 ppb from 1.5 ppb under the current conditions even after the expansion of Candiota III because the agreement is set for both of the existing and the planned units (**Figure 7.2.7**). NO_2 and SPM concentrations will increase to 0.4 ppb and 1.3 ug/m^3, not exceeding the national criteria (**Figure 7.2.8, Figure 7.2.9**).

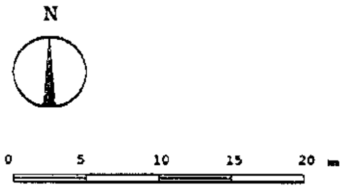


SO2 ppb Annual Average □C MAX= 10.0ppb

Figure 7.2.1 Distribution of Annual Average Concentration

(Jorge Lacerda, Future, SO_2)





LEGEND

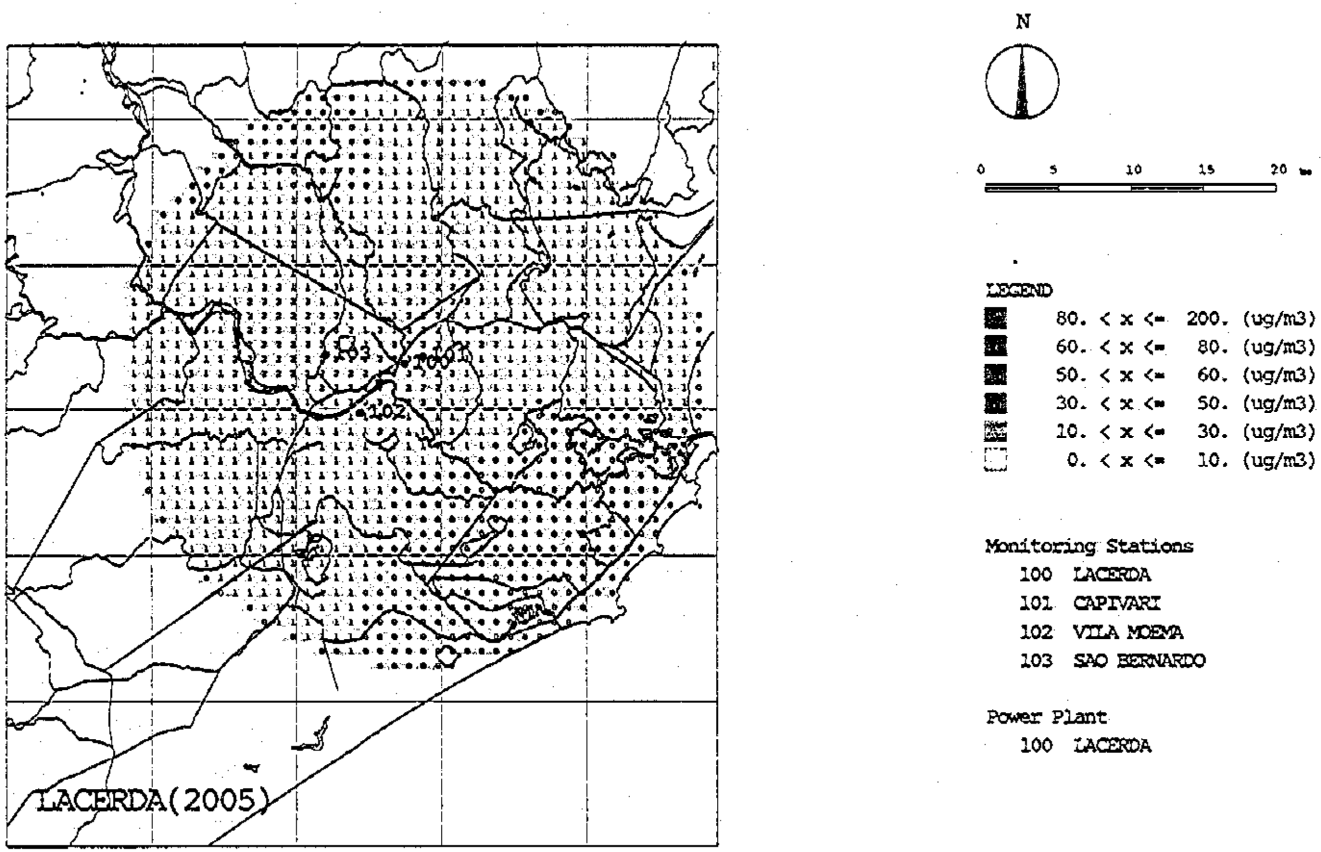
70.	< x <=	100.	(ppb)	0 grids
53.	< x <=	70.	(ppb)	0 grids
40.	< x <=	53.	(ppb)	0 grids
20.	< x <=	40.	(ppb)	0 grids
10.	< x <=	20.	(ppb)	0 grids
0.	< x <=	10.	(ppb)	1296 grids

Monitoring Stations
100 LACERDA
101 CAPIVARI
102 VILA MOEMA
103 SAO BERNARDO

Power Plant
100 LACERDA

NO2 ppb Annual Average □C MAX= 1.2ppb

Figure 7.2.2 Distribution of Annual Average Concentration (Jorge Lacerda, Future, NO_2)



LEGEND

80. < x <=	200.	(ug/m3)	0 grids
60. < x <=	80.	(ug/m3)	0 grids
50. < x <=	60.	(ug/m3)	0 grids
30. < x <=	50.	(ug/m3)	0 grids
10. < x <=	30.	(ug/m3)	0 grids
0. < x <=	10.	(ug/m3)	1296 grids

Monitoring Stations
100 LACERDA
101 CAPIVARI
102 VILA MOEMA
103 SAO BERNARDO

Power Plant
100 LACERDA

SPM ug/m3 Annual Average □C MAX= 2.9ug/m3

Figure 7.2.3 Distribution of Annual Average Concentration
(Jorge Lacerda, Future, SPM)

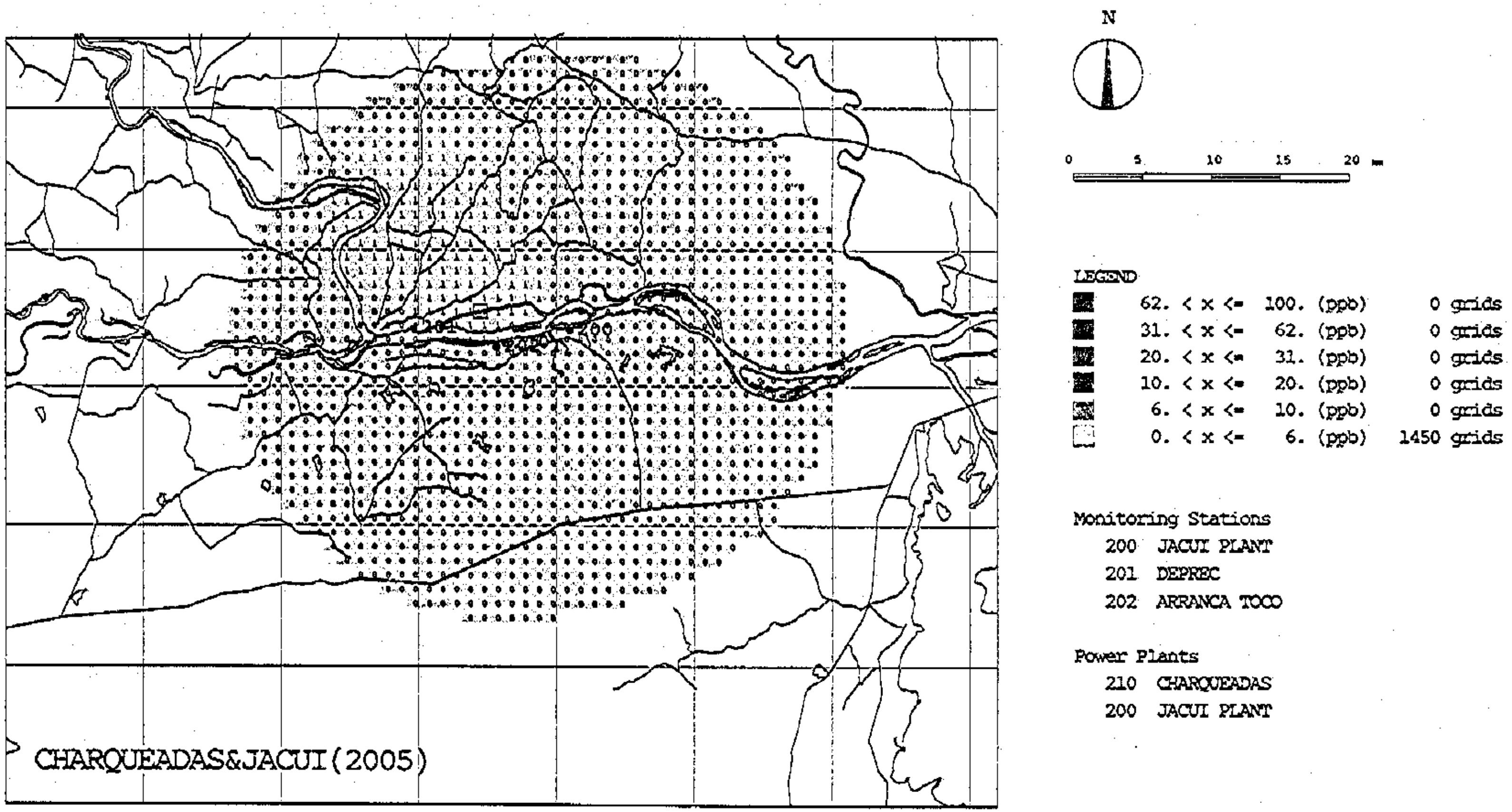


Figure 7.2.4 Distribution of Annual Average Concentration (Charqueadas, Future, SO_2)

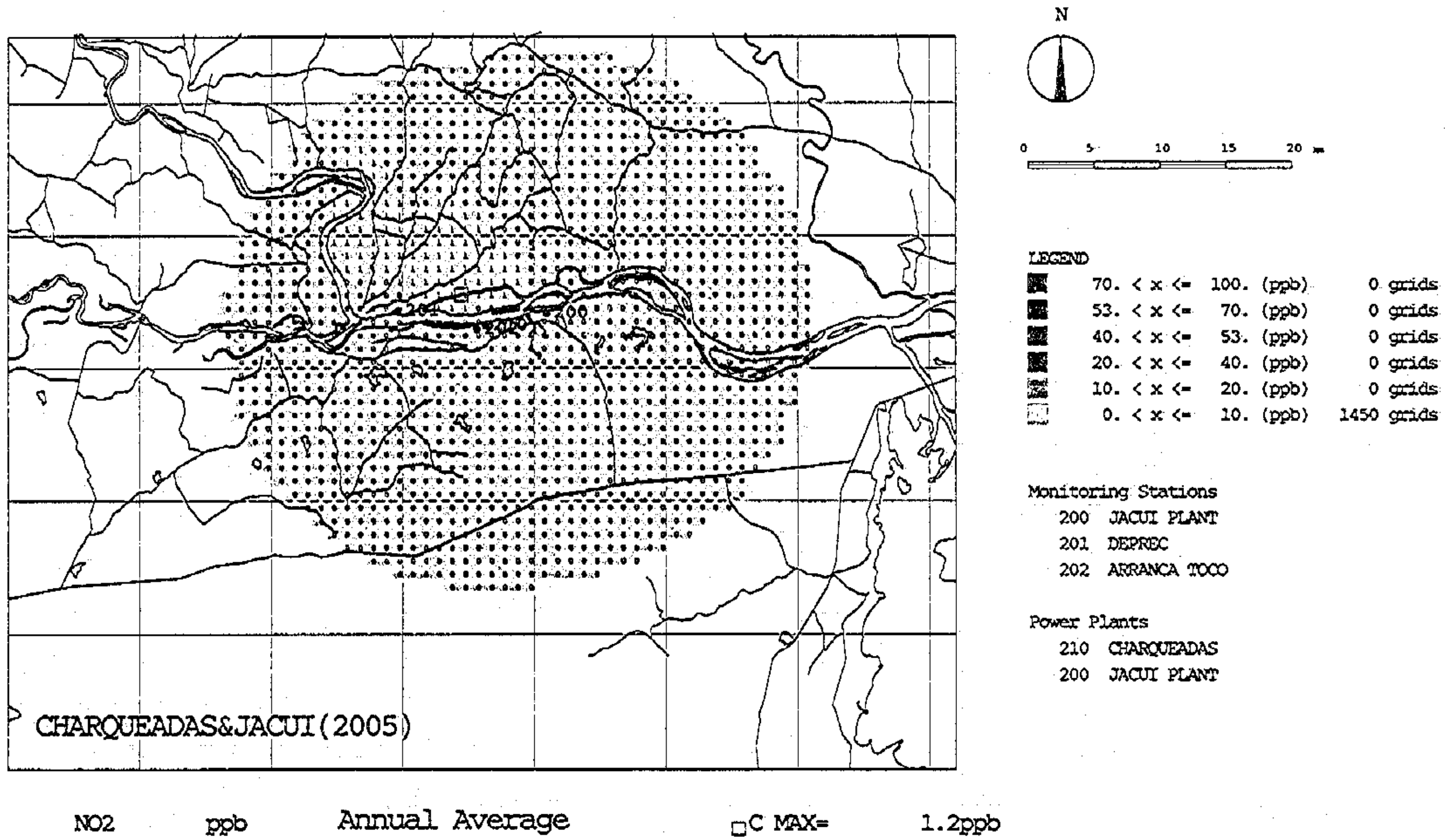


Figure 7.2.5 Distribution of Annual Average Concentration (Charqueadas, Future, NO_2)

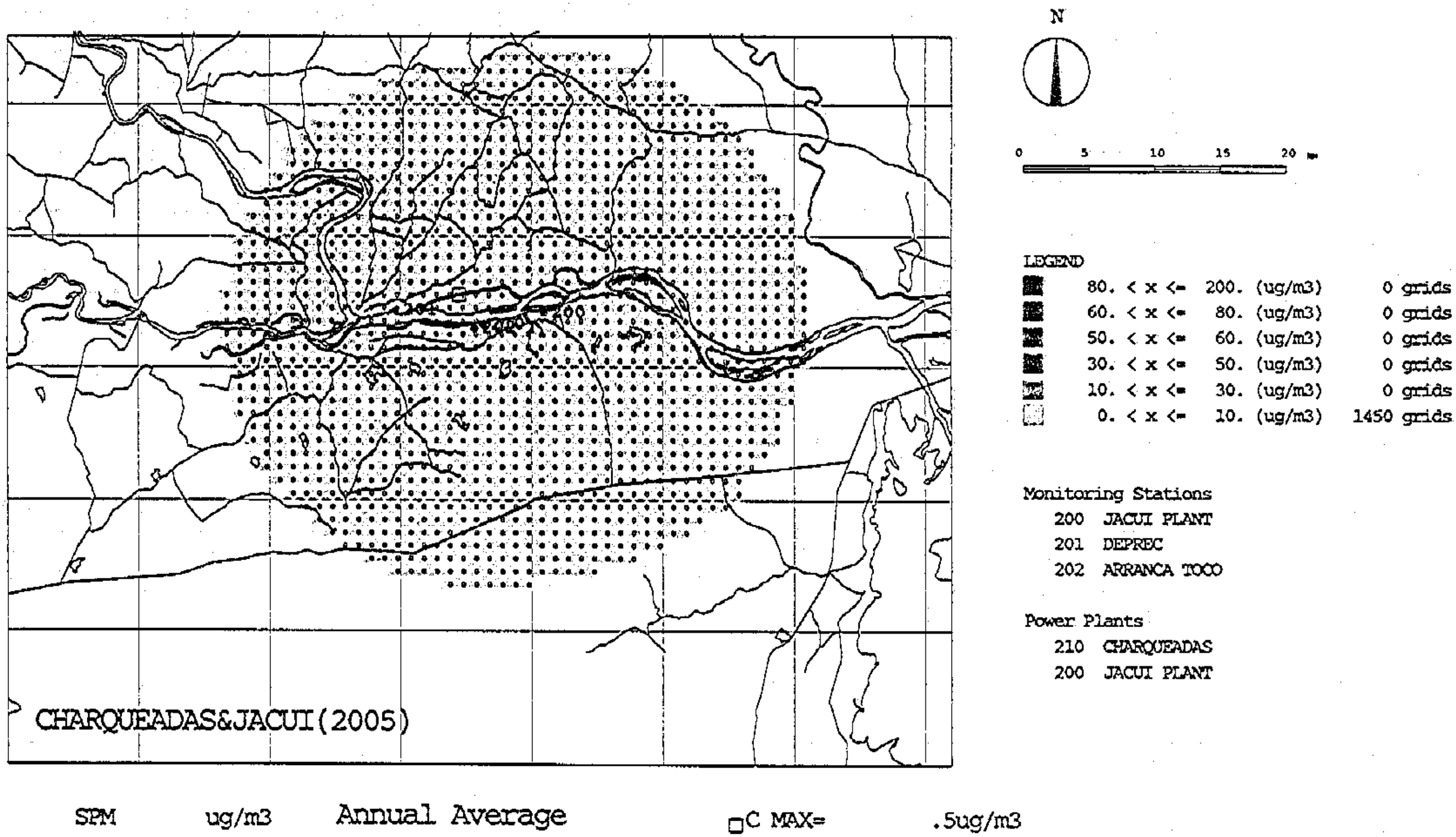


Figure 7.2.6 .Distribution of Annual Average Concentration
(Charqueadas, Future, SPM)

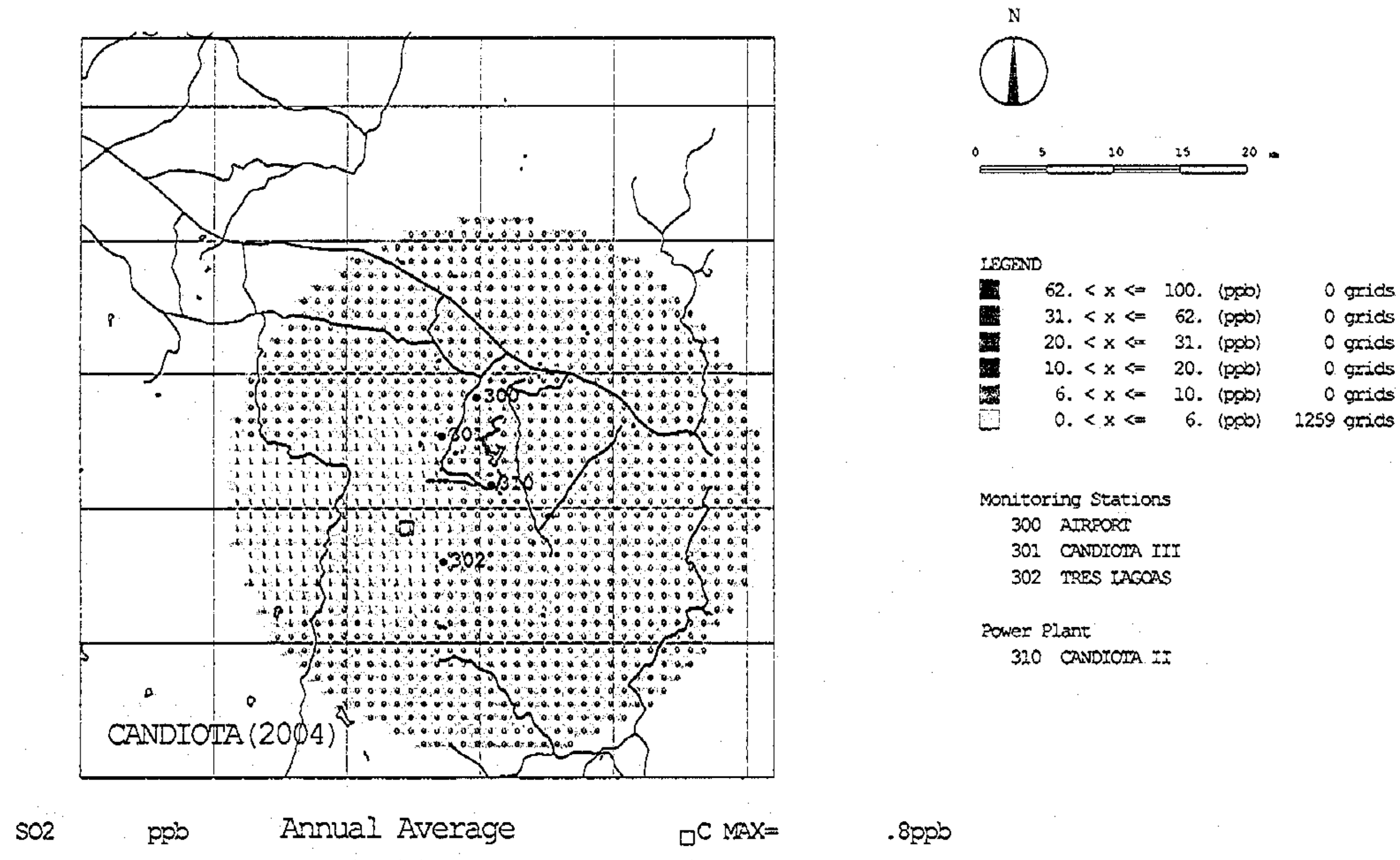


Figure 7.2.7 Distribution of Annual Average Concentration (Candiota, Future, SO_2)

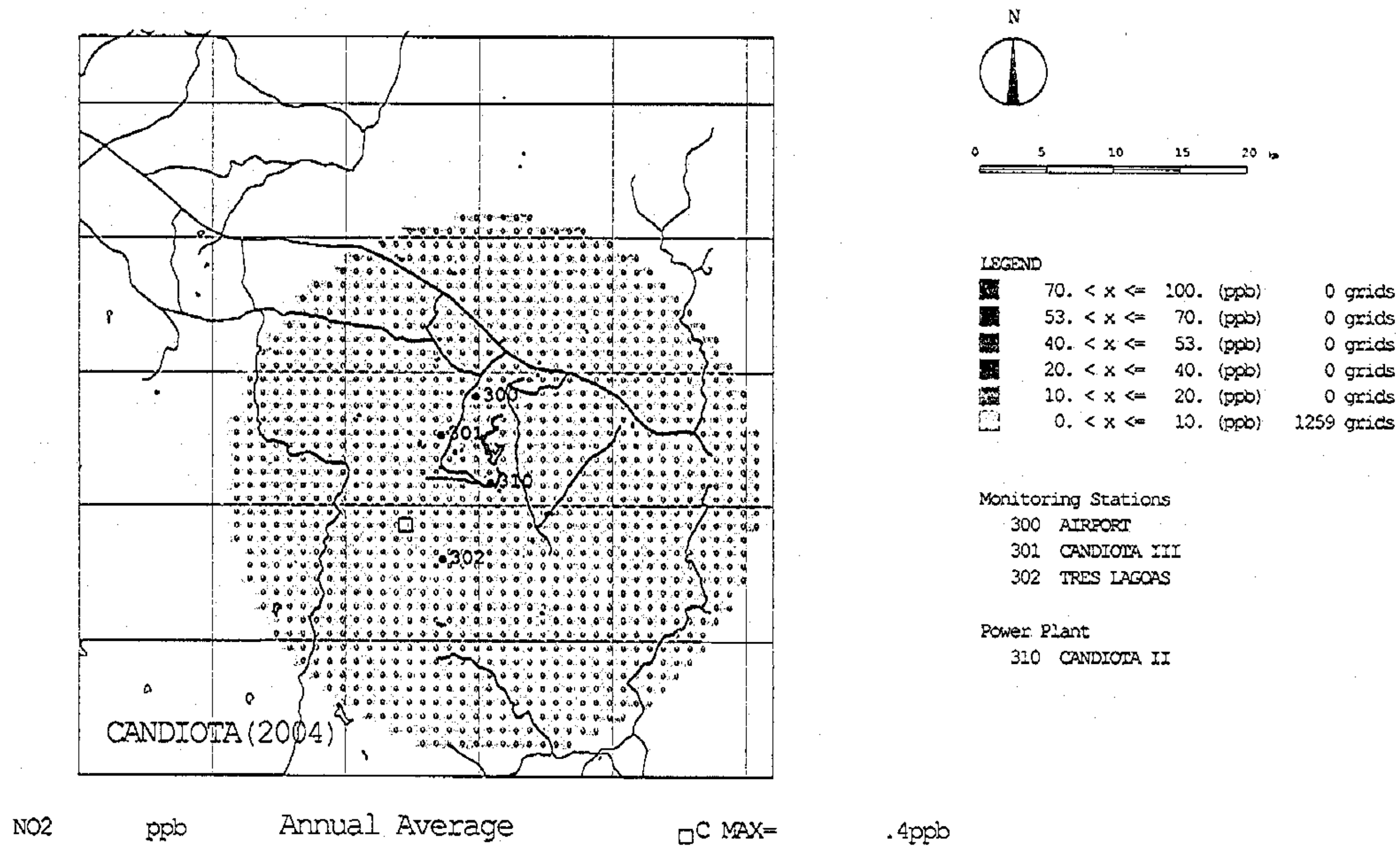


Figure 7.2.8 Distribution of Annual Average Concentration (Candiota, Future, NO_2)

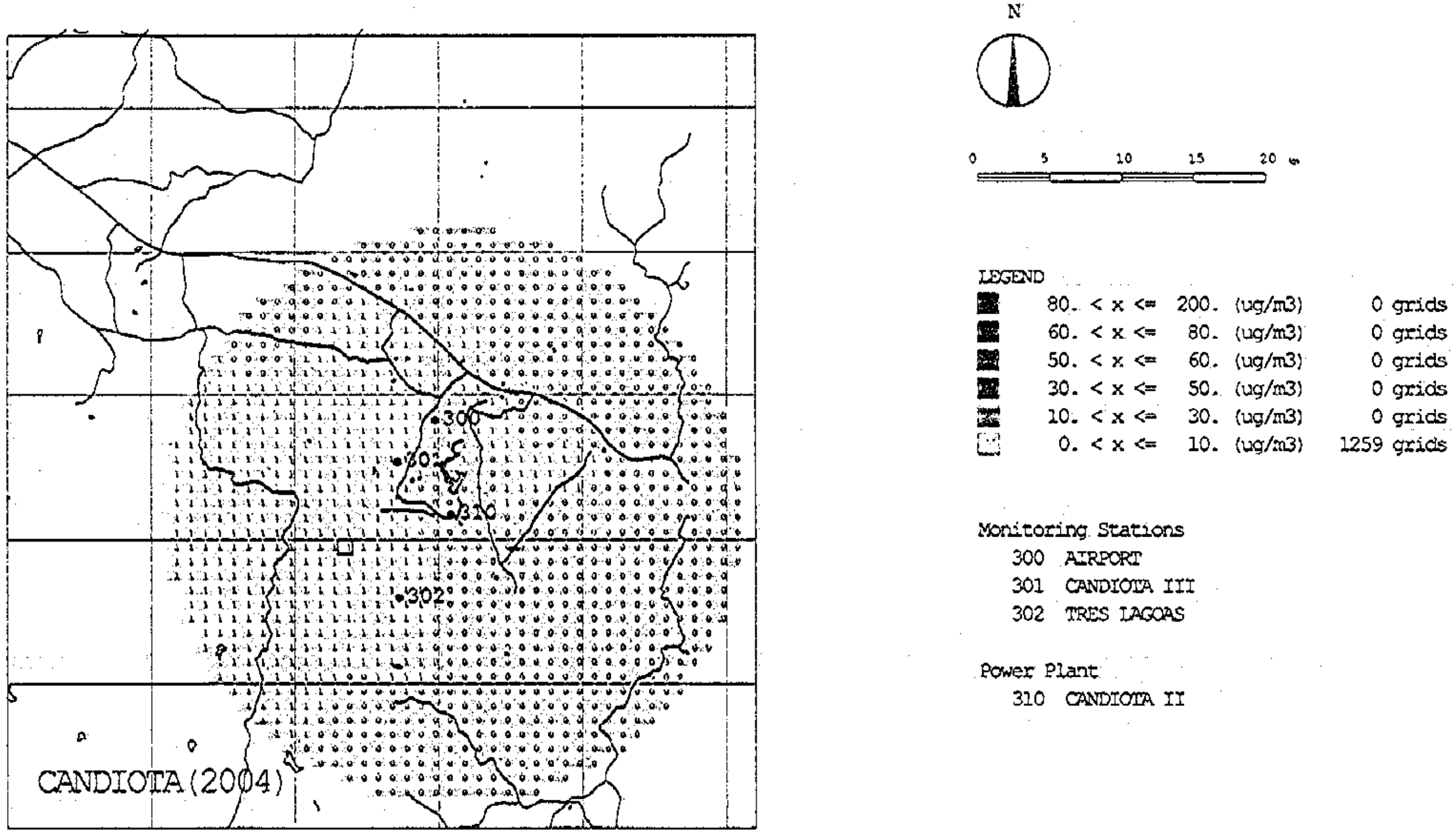


Figure 7.2.9 Distribution of Annual Average Concentration
(Candiota, Future, SPM)

7.2.3 Daily Averages and Hourly Values at Monitoring Stations

Estimation procedure of emission parameters is the same as the one for the annual average simulation. Also simulation procedure is the same as the one under the current conditions.

The maximum value of SO_2 daily averages within the 9 stations in the future is calculated at Capivari as the same under the current condition. The value increases from 43.3 ppb of the current to 64.7 ppb in the future, because of the assumed continuous operations of the new unit.

The maximum value of NO_2 hourly values is 33 ppb at Vila Moema within the 9 stations in the future under the current condition. However, the values at Capivari and Vila Moema, and at Jacui and DEPREC in the Charqueadas area are almost in the same level in the future.

The maximum value of SPM daily averages is calculated at Canidota III within the 9 stations in the future in Candiota area as the same in the current condition, and the value increase from 20.3 μ g/m^3 of the current to 37.5 μ g/m^3 in the future.

Some of the calculated concentrations at certain stations will increase. However, they are lower than the national ambient air standards (**Table 7.2.2**).

Table 7.2.2 Daily Average and Hourly Value at Monitoring Station (Future)

	SO_2 Daily	NO_2 Hourly	SPM Daily
Capivari	64.7	33	19.3
Vila Moema	26.0	28	8.6
Sao Bernardo	43.7	25	11.4
DEPREC	7.1	29	2.2
Jacui	14.8	33	4.0
Arranca Toco	6.2	21	2.0
Airport	6.7	18	24.9
Candiota III	10.5	18	37.5
Tres Lagoas	7.6	18	28.3
Standard	139.4	170.1	150.0
Unit	(ppb)	(ppb)	(ug/m^3)

7.2.4 Hourly Concentration Profile

Most of simulation procedures are the same as the ones under the current conditions, except that the Jacui plant was placed at around 4.7 km far from the Charqueadas plant. Downwind direction is assumed from Jacui to Charqueadas.

Emission conditions of Charqueadas, Jacui, and Candiota at the maximum load in the future are included in **Appendix 7-2**. Because emission conditions at the maximum load never change for the future case at the Jorge Lacerda plant (the emissions from the new plant was included in the last part of the Study), the calculated maximum concentrations are the same. Although all maximum concentrations at all three regions were resulted under the conditions of stability C and 3.0 m/s of wind speed, the maximum calculated concentration for the Charqueadas and Jacui region was resulted under the conditions of stability C and 2.0 m/s of wind speed.

As in **Table 7.2.3**, SO_2 and NO_2 concentrations will be the top of the three at Jorge Lacerda in the future. SPM concentration at Candiota will increase and be the top of the three. However, all the concentrations will be under the national criteria.

Table 7.2.3 Maximum Concentration on Profile (Future)

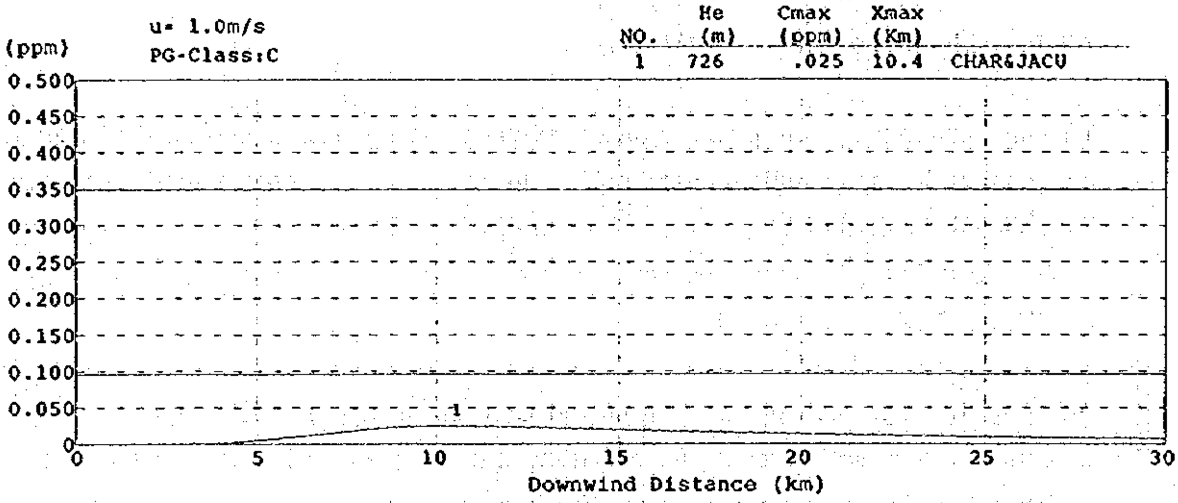
Power Plant	Item	Maximum	Distance
Jorge Lacerda	SO_2	152ppb	5.9km
	NO_2	32ppb	5.7km
	SPM	45 $\mu g/m^3$	6.1km
Charqueadas	SO_2	25ppb	7.9km
	NO_2	28ppb	8.0km
	SPM	9 $\mu g/m^3$	8.1km
Candiota	SO_2	36ppb	7.6km
	NO_2	25ppb	7.7km
	SPM	47 $\mu g/m^3$	8.3km

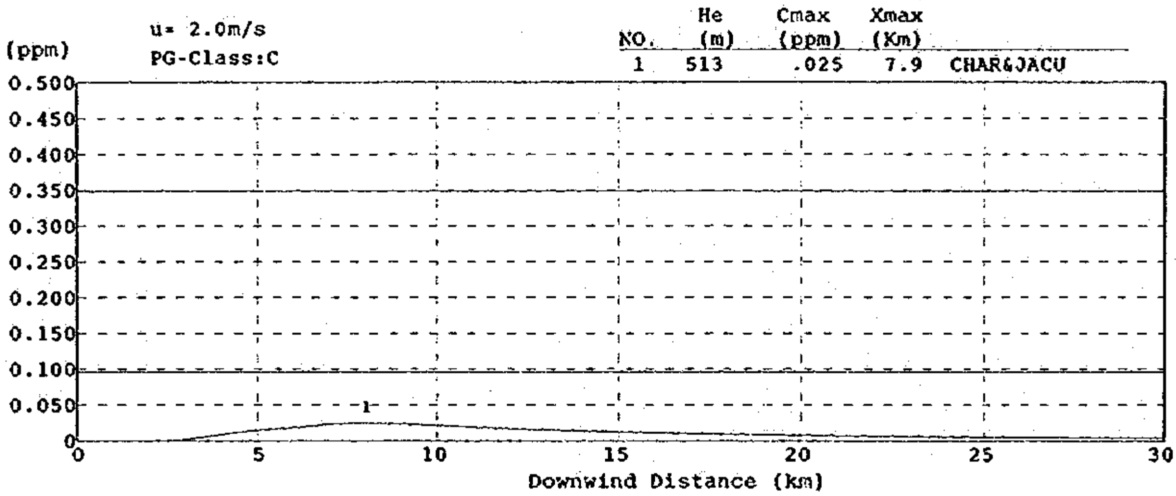
The profiles of the pollutants at the stations with the maximum concentrations are shown in **Figure 7.2.10** to **Figure 7.2.15**. The profiles under the other conditions are included in **Appendix 7-3**.

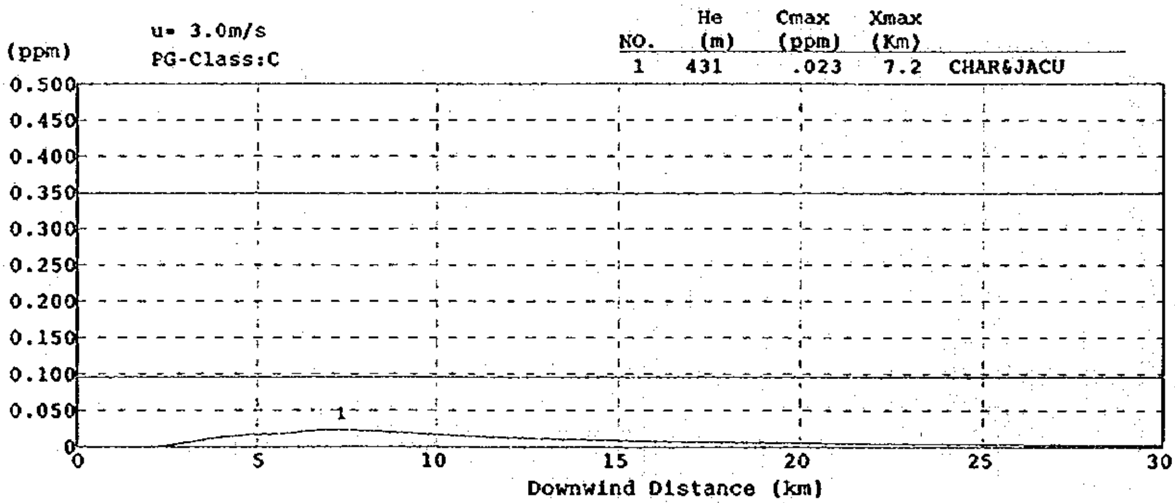
7.2.5 Evaluation of Future Air Quality

The impact from the power plants to annual average concentration is estimated as 10ppb and is lower than the standard (30.56 ppb). However, there is a possibility of exceeding the national standard of SO_2 concentrations in the Jorge Lacerda region, because of the contributions from the other pollutant sources. Therefore, the ambient air quality monitoring should be continued.

Although the expansion plans of Jacui and Candiota III are relatively large ones, the agreements were set for both of the existing and the planned plants. As far as the agreements are observed, no problem would happen even after the expansion, according to the simulation. Implementation of the countermeasure to satisfy the agreement are very important.

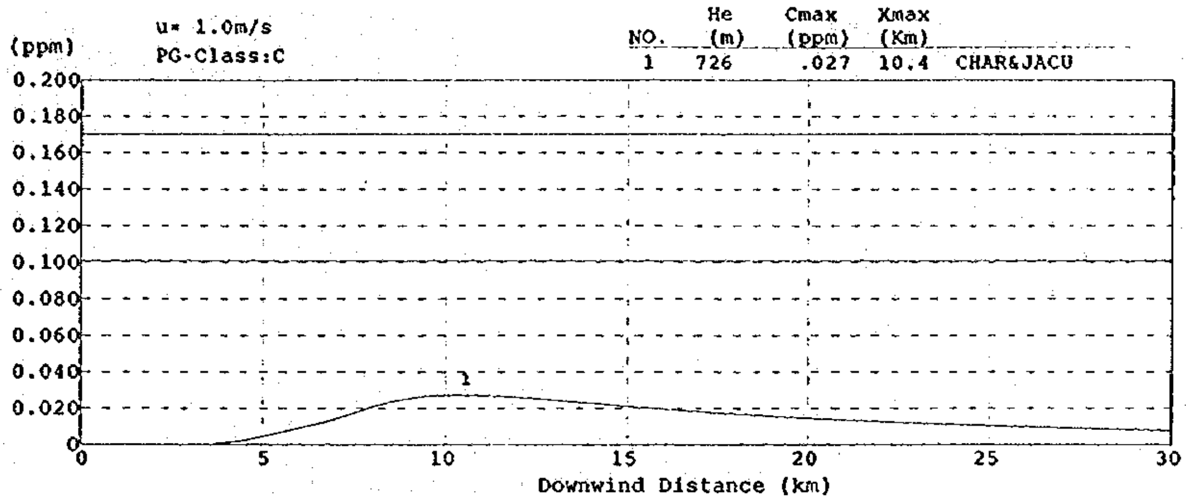


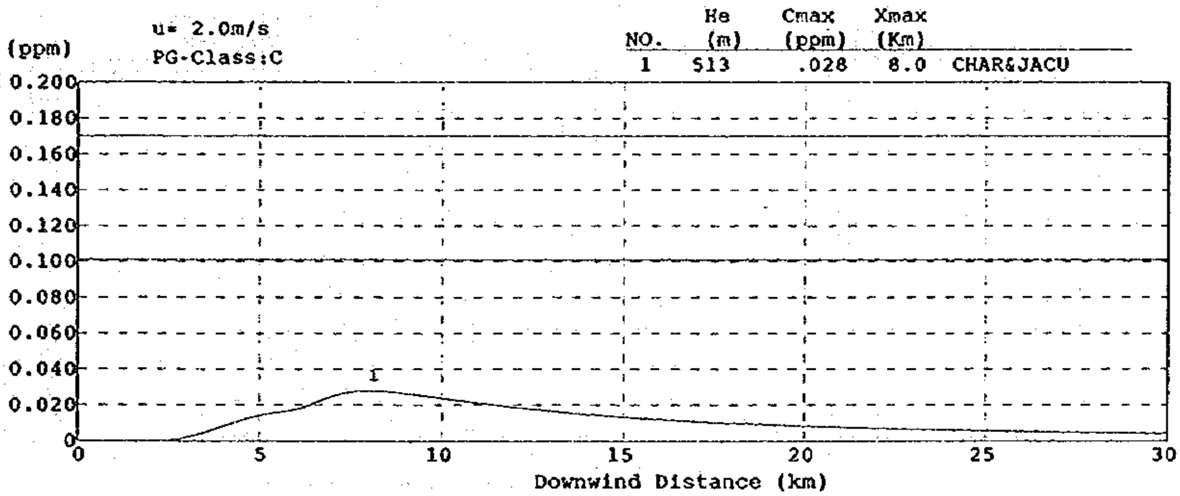


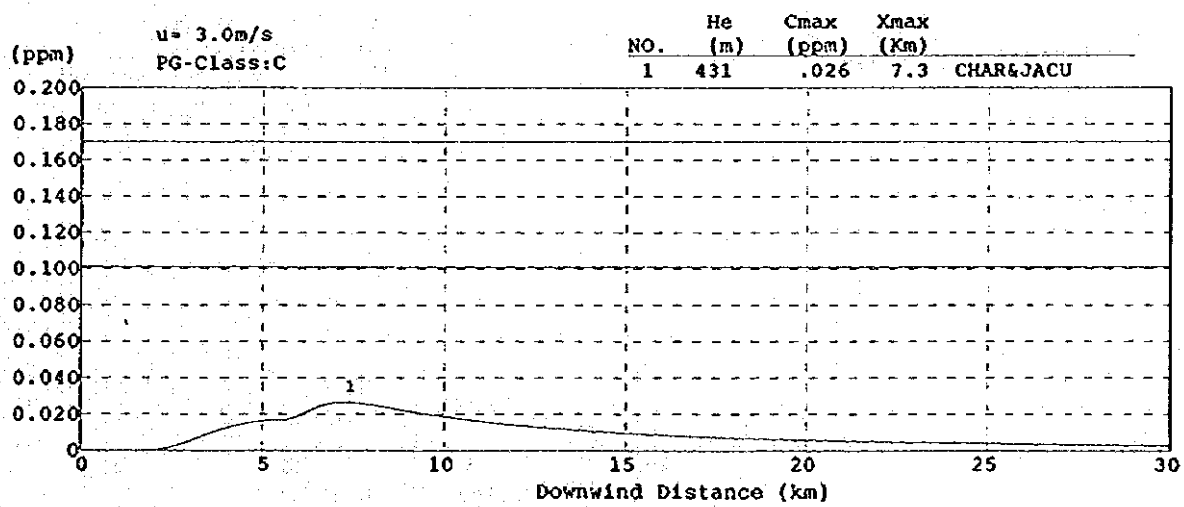


CONCAWE & Plume (SO2)

Figure 7.2.10 Hourly Concentration Profile (Charqueadas, Future, SO_2)

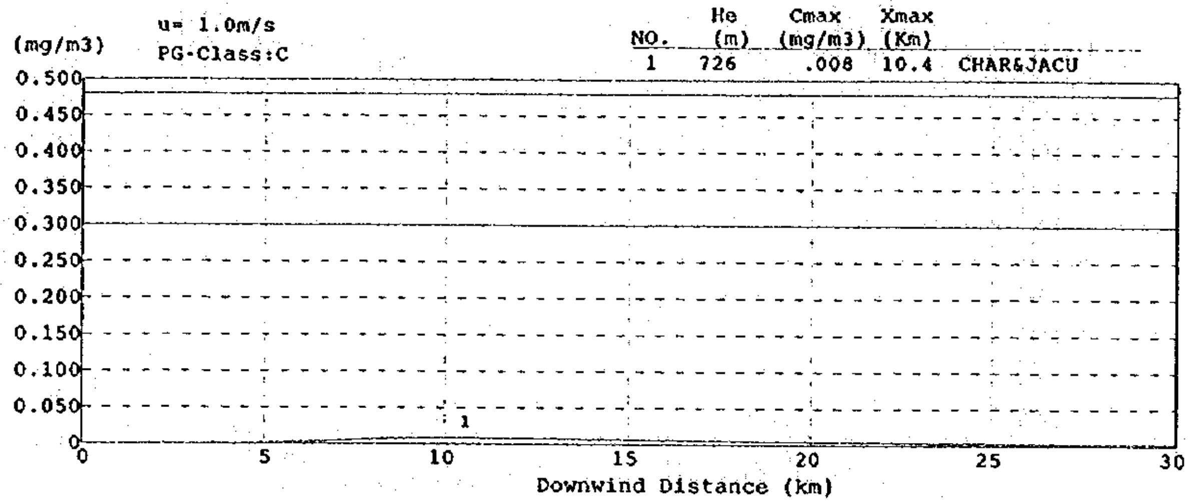


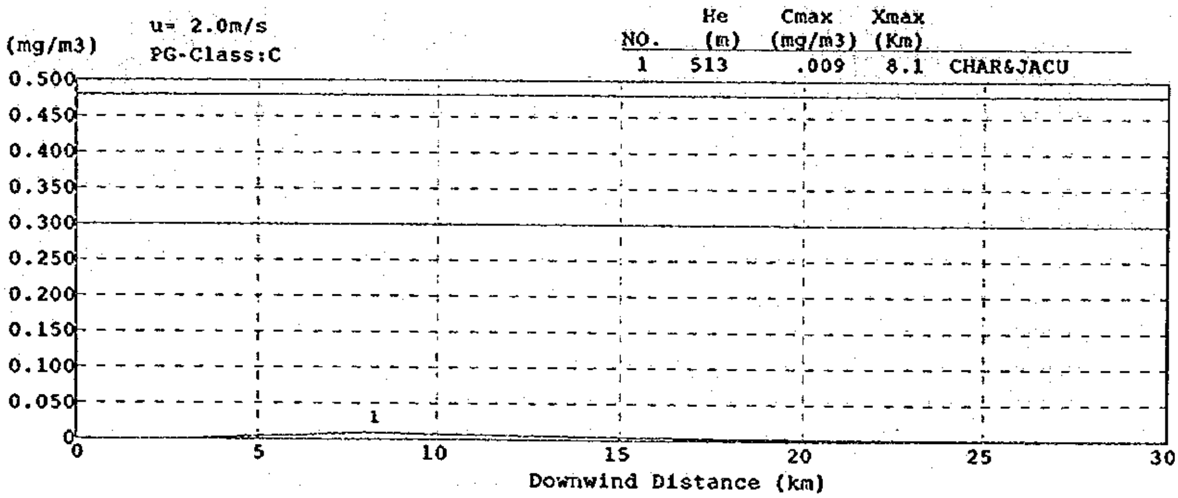


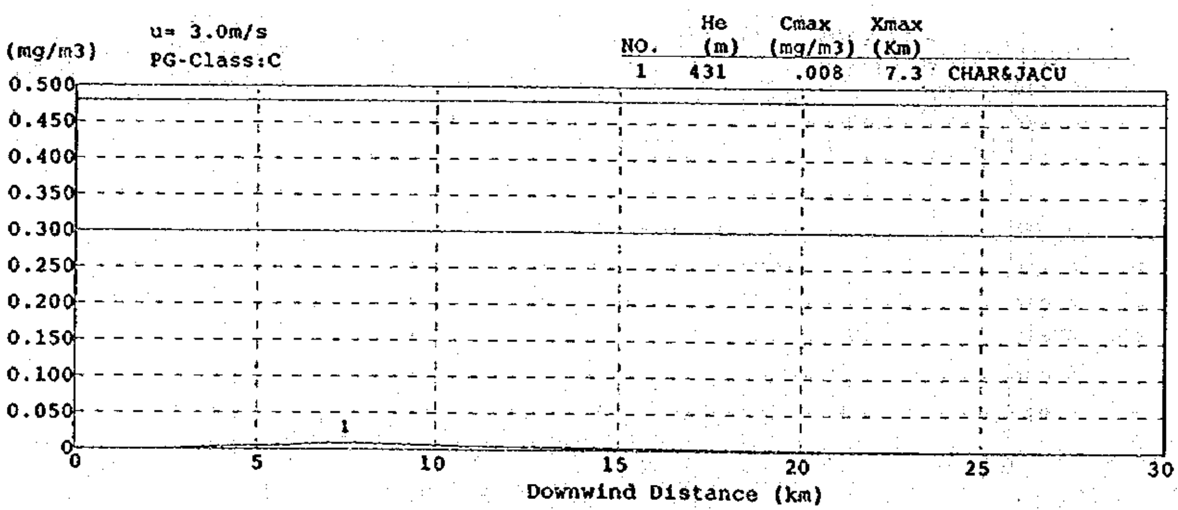


CONCAWE & Plume (NO2)

Figure 7.2.11 Hourly Concentration Profile
(Charqueadas, Future, NO_2)

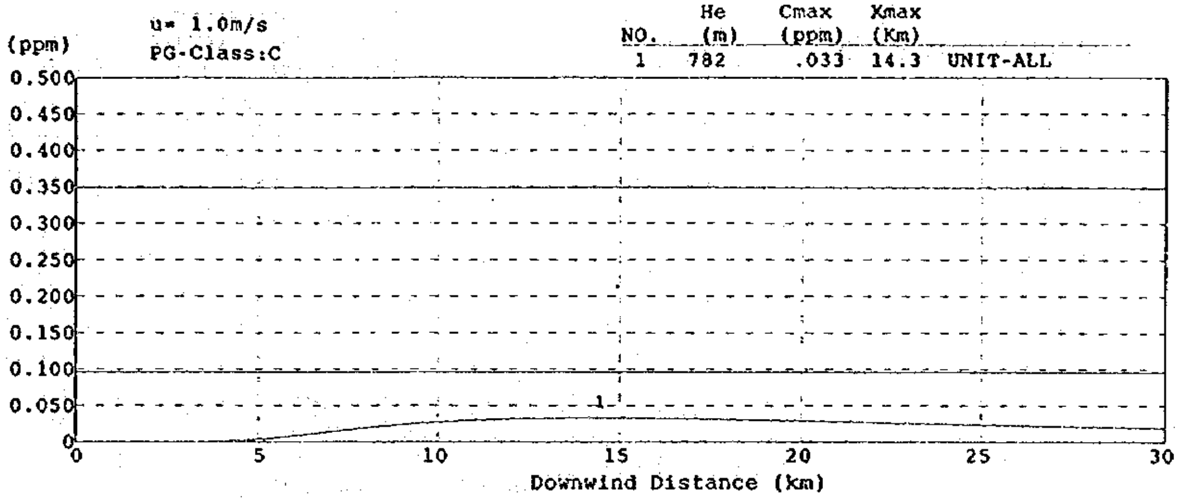


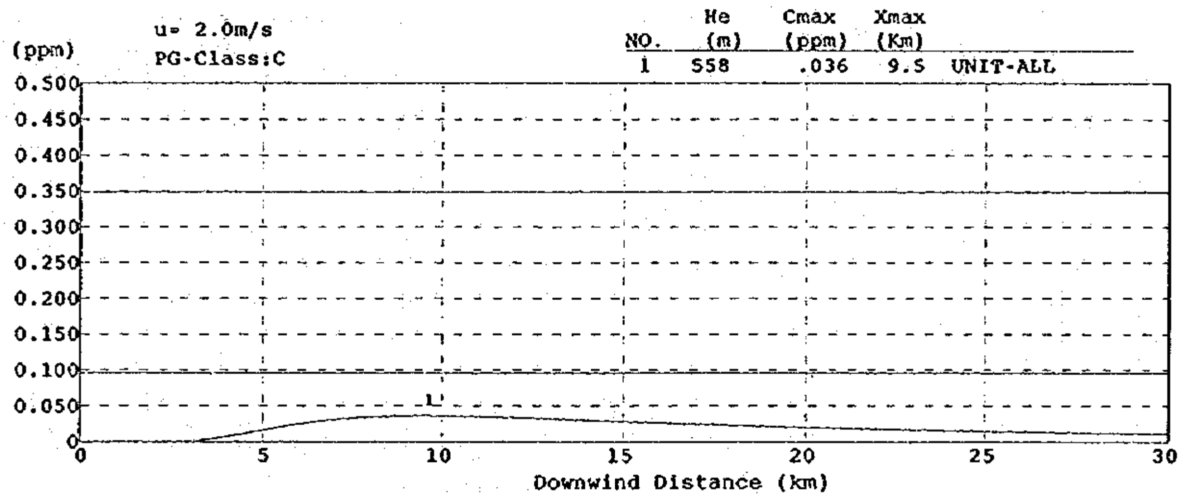


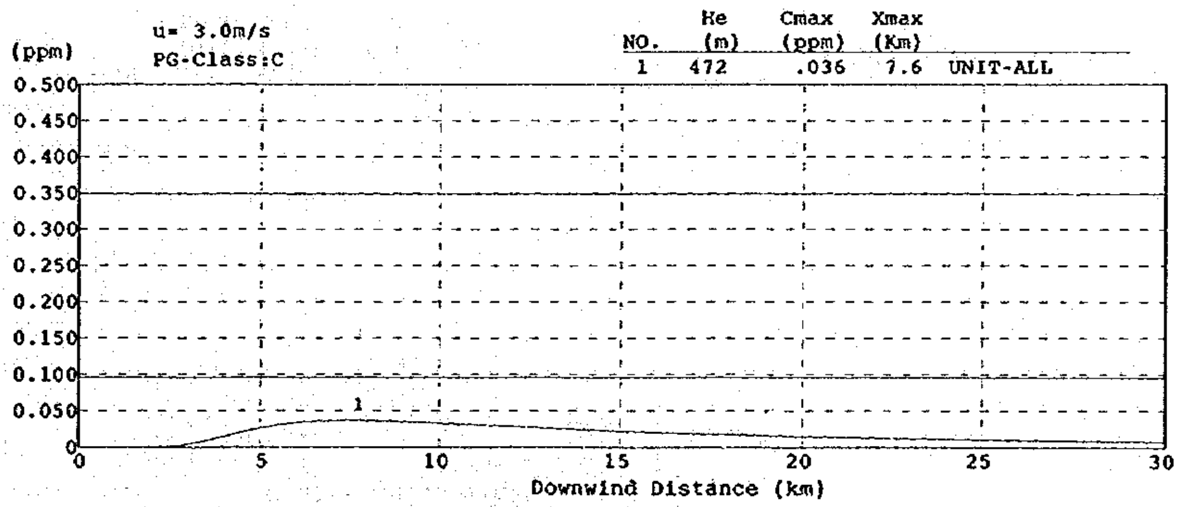


CONCAWE & Plume (Dust)

Figure 7.2.12 Hourly Concentration Profile (Charqueadas, Future, SPM)

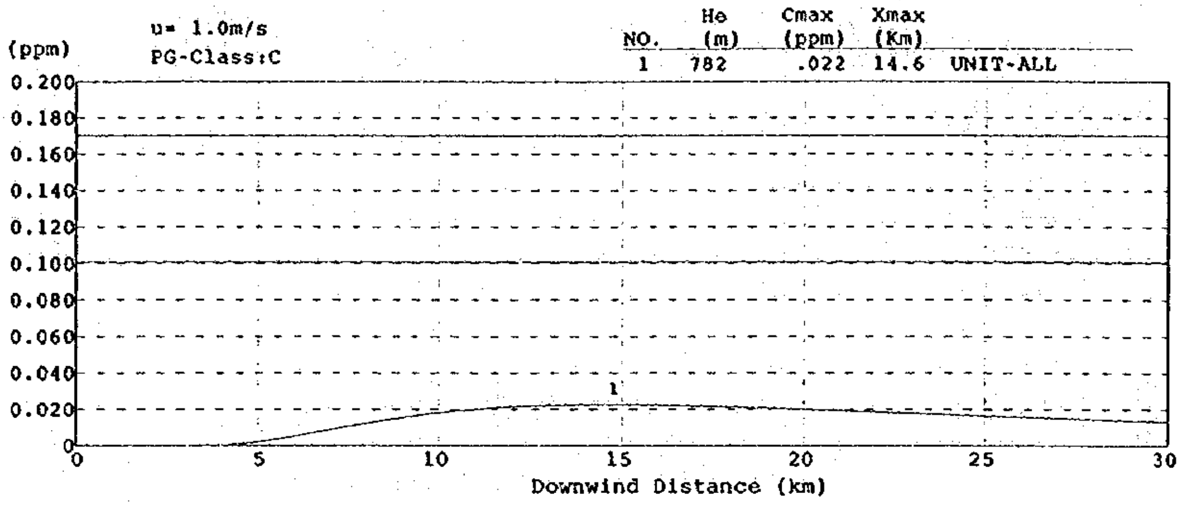


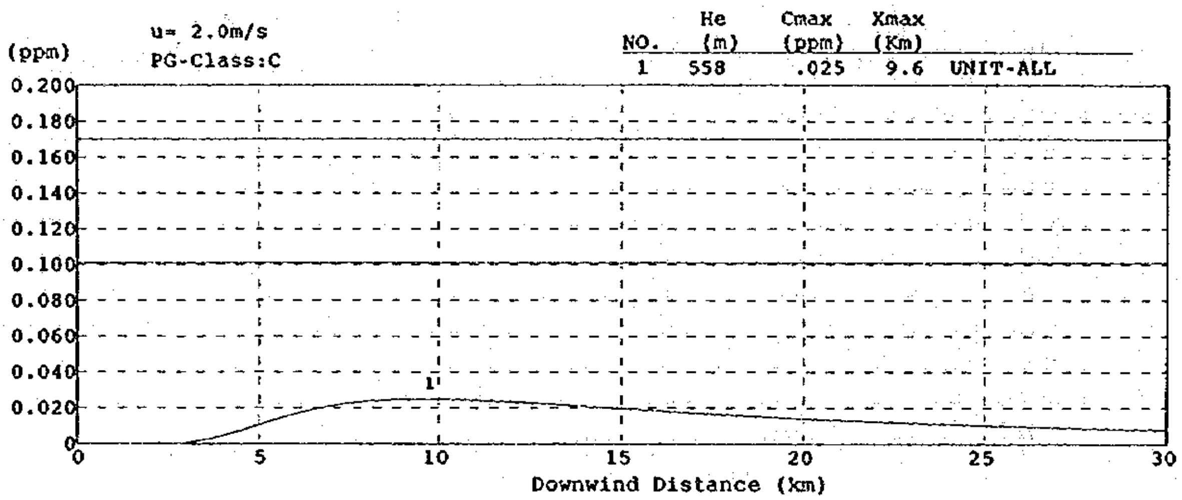


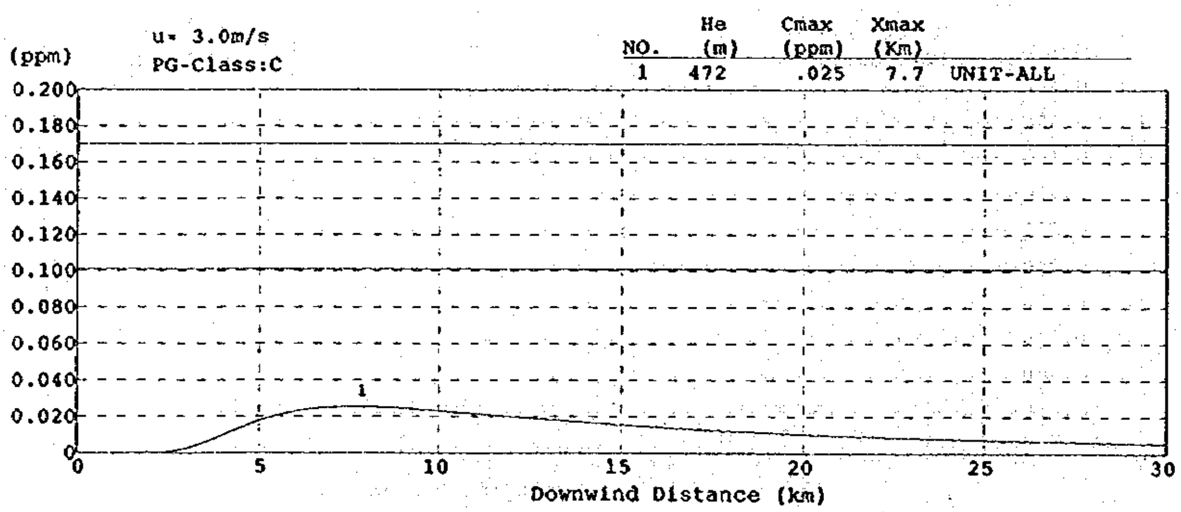


CONCAWE & Plume (SO2)

Figure 7.2.13 Hourly Concentration Profile
(Candlota, Future, SO_2)

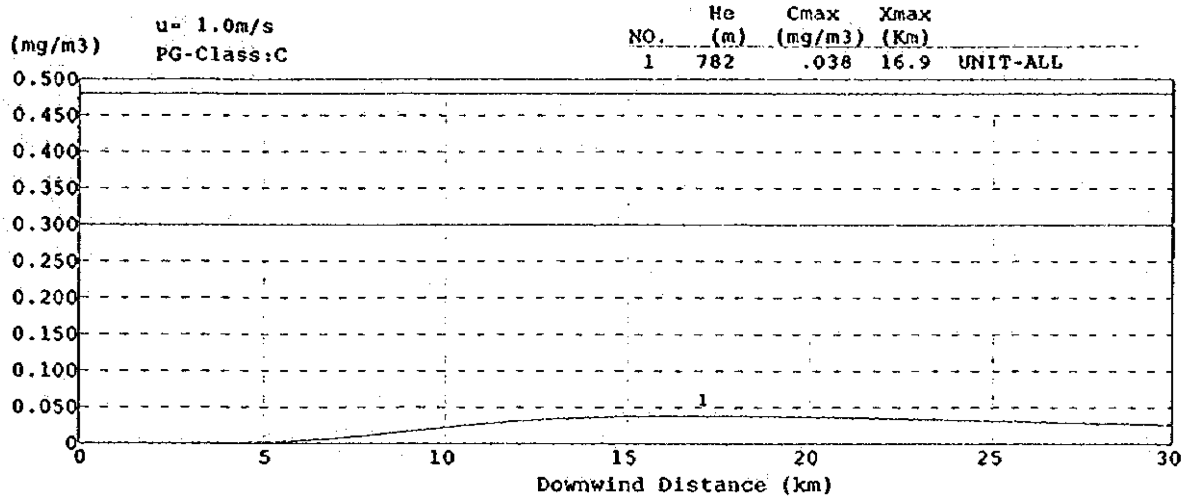


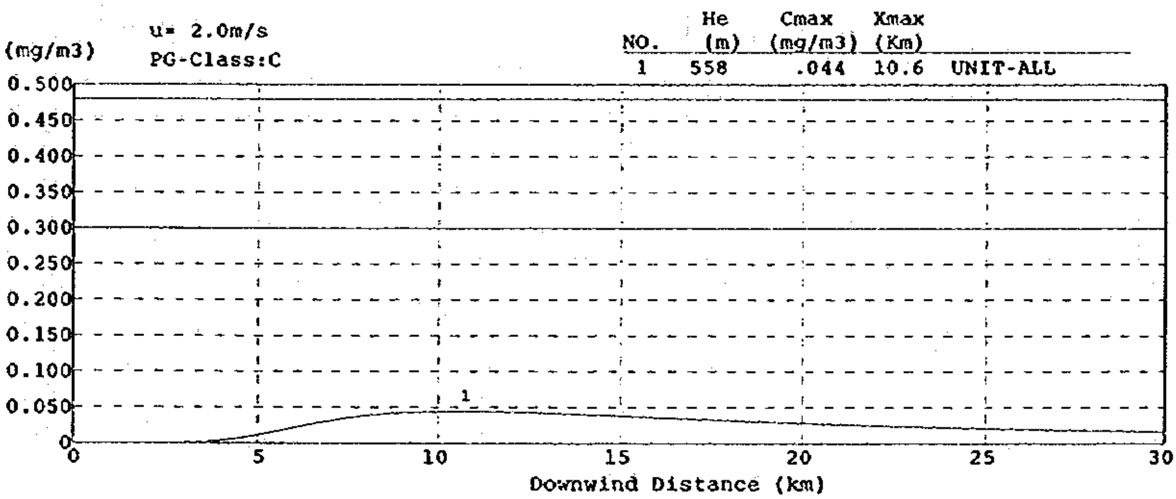


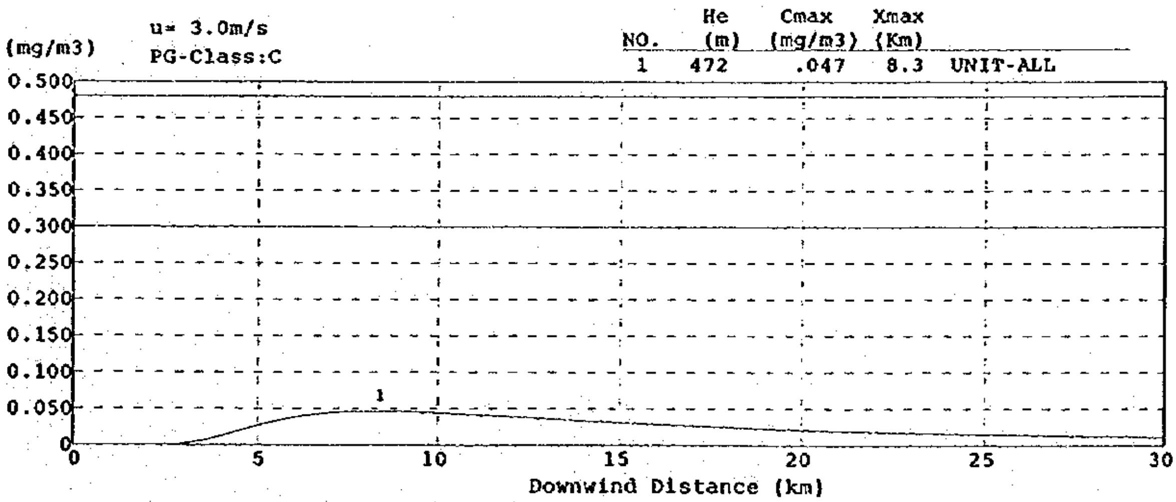


CONCAWE & Plume (NO2)

Figure 7.2.14 Hourly Concentration Profile (Candiota, Future, NO_2)







CONCAWE & Plume (Dust)

Figure 7.2.15 Hourly Concentration Profile (Candiota, Future, SPM)

CHAPTER 8 RECOMMENDATION FOR AIR CONTROL MEASURES

8.1 Preface

Electrostatic precipitators are installed in the three existing power plants as the air pollution control measure. However, any facility other than that, such as flue gas desulfurization or denitrification is not installed. The flue gas to the air contains highly concentrated particulate and SO_2.

Nevertheless, according to the results of the air quality monitoring, daily mean and monthly mean concentrations of SO_2 and NO_x in the surrounding areas of these three power plants were extremely low, never exceeding the national air quality standards for one year monitoring, while sometimes slightly predominant concentration is recorded sometimes in the leeward area. Daily mean concentration of TSP also maintained low. These are because that (a) the emission gas volume from the power plants is a comparatively little, (b) there are very few stationary emission sources near the power plants, excepting the existence of some residences, iron works and cement plants, and (c) their surrounding environment consists of farm and pasture land with lush green. Only, the surrounding areas of the Charqueadas plant were visibly impacted by the particulate dispersion from the nearby iron works.

There are the 350 MW expansion plan in each power plant of the three. In order to obtain operational permissions of these expansion units, ELETROSUL and CEEE concluded agreements with the respective State: FATMA and FEPAM. The Jorge Lacerda plant as a whole has to use coal with sulfur at the same as or smaller than the amount of SO_2 generated when coal with the 2.2% of sulfur content is combusted at the rated capacity. The Charqueadas and Candiota existing units have to reduce SO_2, NOx and particulate emissions from the present rates. Also, ELETROSUL has promised to completely cooperate with the State in the Porto Alegre Metropolitan Area air monitoring project, because the Charqueadas and Jacui plants are in the region. CEEE does the same in relation to the Sao Jeronimo Power Plant in the region.

As mentioned above, FATMA and FEPAM take various kinds of measures to aim at prevention of air environment pollution. It is expected that regulation will be tightened more and more. Furthermore, it is considered that citizens' interest in matters on environmental protection will continue to be increasing.

It is common to all power plants that residual oxygen concentration in flue gas is high and loss of heat is large. Improving thermal efficiency indirectly cuts down consumption of fuel coal and, as a result, enables the reduction of SO_x and particulate emissions. As the amount of NO_x generated varies depending on condition of combustion and nitrogen contents in coal, continuous monitoring of NO_x and implementation of combustion control are required.

Under these background, it is necessary to strengthen environmental control facilities in the power plants and to improve and continue monitoring of flue gas and environmental air quality in the surrounding area of the plants.

8.2 Air Pollution Control at Power Plants in General

Generally, air pollution control measures taken at thermal power plants can roughly be classified into three categories; i.e. fuel, facility and operation measures. These three measures are integrated to work together as the best way. The outline of air pollution control measures is as shown in **Figure 8.2.1**.

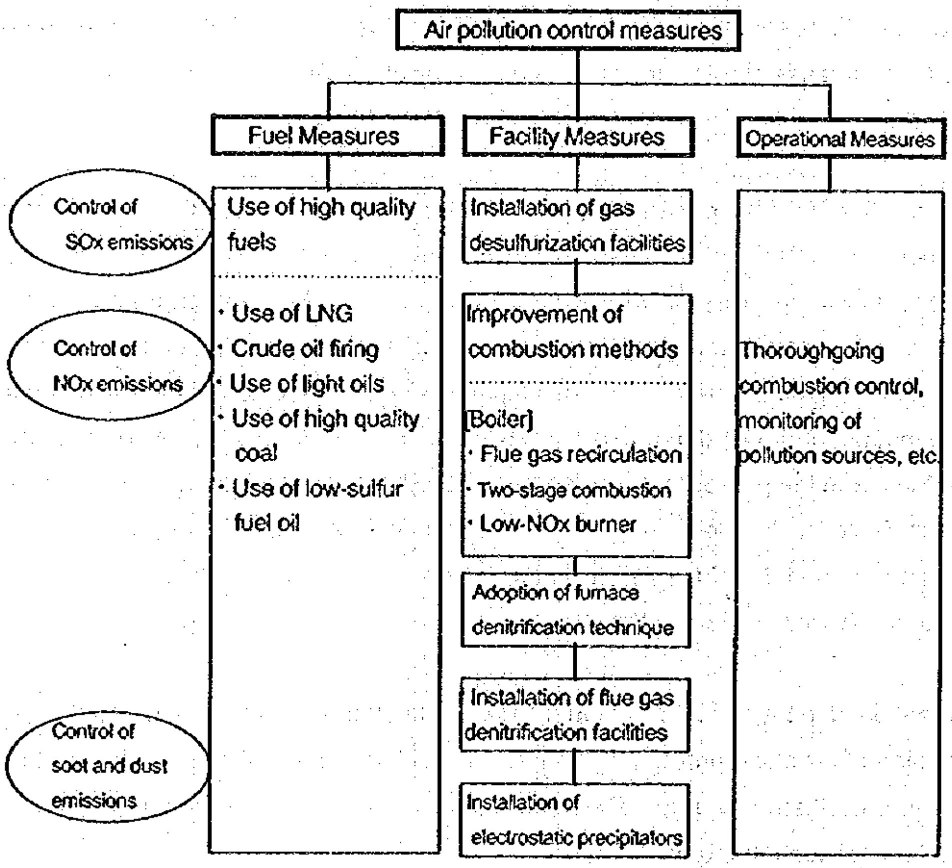


Figure 8.2.1 Outline of Air Pollution Control Measures at Thermal Power Plants

Sometimes, tall, centralized and narrowed-top smokestacks, which can serve diffusing flue gas at the upper air, are employed as a part of the facility measures in order to increase the diffusion effect of flue gas, so that the effects of these pollutants on the surrounding environment can be reduced.

Upon decision and implementation of air pollution control plans for thermal power plants, the important factors to be examined are, particularly in the case of existing facilities, availability of installation space, the number of years of operation, difficulty of modification work, construction process etc. as well as economic burden in the general cases, and naturally emission standards of flue gas and possible influence on surrounding air environment.

For reference, individual measures for control of particulate, NOx, and SO_2 emissions are summarized in **Appendix 8.1**.

8.3 Recommendation for Individual Plants

8.3.1. Basis of Recommendations

The agreements with FATMA and FEPAM will govern emission control of the power plants in Santa Catarina and Rio Grande Do Sul, in addition to the national emission standards (to be applied to facilities newly constructed). FATMA and FEPAM recognize the thermal electric power plants as a pollution source and have an intention of taking measures for preservation of air quality by adopting emission permission rates based on evaluation of EIA (RIMA) of new facilities.

Table 8.3.5 at the last page of this Section 8.3 summarizes recommendations for control of flue gas for existing and new facilities at each power plant.

8.3.2 Measures for Existing Facilities

For the existing facilities, following various conditions were taken into considerations for planning of facility measures for environmental preservation:

① Local coal should be used as fuel.
② The annual use rate is around 32% - 67%.
③ In some installations, rated output is difficult to be maintained.
④ Some installations are under severe deterioration.
⑤ Space between a boiler and a smokestack is not enough to install facilities for

desulfurization and denitrification.

⑥ Installation of such facilities above will accompany large-scaled reconstruction.

⑦ Output capacities are relatively small and influence on the ambient air is little.

⑧ There are only a few large-sized fixed sources other than the power plants.

⑨ The surrounding ambient air quality is below the national standards.

(1) Jorge Lacerda Units (No.1 - No.6)

1) Measures for Dust Emission Control

As the result of measurement of flue gas, the concentrations of dust in flue gas were 265 - 1,261 in the Jorge Lacerda existing units. The TSP quality in the surrounding environment is lower than the national environmental standard except at Capivari which seems not to be caused by the power plant. There will be little influence in the future from the plant, and the facilities are relatively old with 20 - 30 years passing after start of operation. It is desirable to strengthen operational measures such as repair of the present facilities, maintenance management, combustion control (for example by means of an operational maintenance management manual etc.) rather than reconstruction or installation of EP.

Though EP's collection efficiency is 99% or more in the specifications, it is found that its performance seems to be deteriorated. Therefore, it is necessary to conduct performance tests of EP (measuring dust concentration at a inlet and a outlet of EP) so as to grasp its actual performance and combustion conditions, and then to take proper operational measures.

2) Measures for Control of Nitrogen Oxide (NO_x) Emissions

As the result of measurement of flue gas, the concentrations of NOx (NO) in flue gas were 264 - 750 mg/m^{3}N in the units. As any emission standard is not applied and there is little influence on the surrounding environment, measures are not required.

3) Measures for Control of Sulfur Oxide(SO_x) Emissions

FATMA indicated condition for operation permission of the Jorge Lacerda Plant that the total amount of SO_2 generated from the whole plant (at the rated output) should be the same as or smaller than the amount generated when coal with the 2.2% of sulfur content is combusted.

Table 8.3.1 Permissible SO_2 Emission from Jorge Lacerda Plant

Power plant		Amount of coal rated output (t/h))	Water%	Sulfur%	Amount of SO_2 emission(t/h)
Jorge Lacerda	Existing	278.32	average		11.26
	IV	185.00	8		7.5
	Total	463.32	8	2.2	18.76

Table 8.3.1 shows trial calculation of the amount of SO_2 generated under the FATMA agreement. According to the agreement, 18.76 tons/hr of SO_2 emission is the maximum allowable rate at the whole Jorge Lacerda plant. If the new unit IV is in full operation with 2.2% sulfur coal, the remaining existing units are allowed to emit 11.26 tons/hr of SO_2. The maximum of the total measured SO_2 emission rates of the existing units (Appendix 5-2) is 12.2 tons/hr which is equivalent to 2.38% sulfur in coal at the full capacity.

As the ELETROSUL plans to purchase coal with the S content of 1.8 - 2.3% from local coal mines over a long period, it is considered proper to continue careful attention on the sulfur contents and the generating capacity not to exceed the SO_2 emission agreement.

(2) Charqueadas Units (No.1 - No.4)

1) Measures Dust Emission Control

As the result of measurement of flue gas, the concentrations of dust in flue gas were 81 - 1,081 mg/m3N. Though national emission standards are not applied for a while, the emission values agreed with the state, 80 mg/m3N, shall be observed by the Charqueadas Plant from 2005. For the due time, it is necessary to strengthen operational measures similar to the case of the existing facilities at the Jorge Lacerda Plant, and to confirm that EP's collection efficiency is maintained as specifications by conducting performance tests.

For leakage of gas exhausted from flues and suspended fly ash inside the plant, from the viewpoint of health care of operators as well, it is urgently necessary to improve and refine working environment by repairing parts of leakage. In order to operate these existing facilities continuously on and after 2005, it is necessary to further improve performance of EP. For this purpose, it is economical to add a new dust removal facility to the existing EP.

The precipitators at the Charqueadas Plant were retrofitted later. Therefore, there is not enough space to install new EP and to carry out large-scaled reconstruction work. Advisable measures are provided later, together with measures for control of SO_2 emissions.

2) Measures for Control of Nitrogen Oxide (NO_x) Emissions

As the result of measurement of flue gas, the concentrations of NOx (NO) in flue gas were 196 - 368 mg/m3N which satisfy the emission standard value(400 mg/m3N)agreed with the state and to be applied in 2005. As influence on the surrounding environment is also little, it is considered that further measures for control of NOx emissions are not necessary. However, if operational measures such as combustion control are strengthened to improve thermal efficiency etc., as boiler combustion temperature will become higher and the amount of thermal NOx will increase as a result, care should be taken.

3) Measures for Control of Sulfur Oxide (SOx) Emissions

As the result of measurement of flue gas, the concentrations of SO_2 in flue gas were 3,257 - 5,086 mg/m3N. This means that SO_2 in high concentration was emitted from smokestacks. However, as any emission standards are not applied for a while, capacity is small and there is little influence on the surrounding environment, it is considered that facilities measures are not necessary for a moment. The emission rate agreed with the state, 400 mg/m3N, will be applied in 2005 and it will be necessary to reduce the present SO_2 concentration by over 88 - 92%.

As far as local coal is used as fuel, the SO_2 emission standard values can not be conformed with fuel measures. Some facility measures will be required in order to satisfy the agreement. Facility measures include replacement the existing boiler by a circulating fluidized-bed boiler or installation of flue gas desulfurization facilities. As the replacement of the main body of a boiler will require large-scaled reconstruction of the existing facilities in addition to purchase of a new boiler, this measure is not advisable.

Installation of a flue gas desulfurization facilities can be carried out independently by extending the existing flues so as to secure installation space. It is possible technically to treat flue gas together from the two unit (2 x 18 MW). For desulfurization process, the wet type limestone - gypsum method is considered to be effective because high desulfurization rate can be obtained, stable operation is possible, there is reliability and actual results at power plants, limestone as absorbent can be easily obtained, and disposal of by-products (gypsum) is permitted. With the wet type process, dust can be also removed and then the agreed emission standard values will be satisfied. The construction cost of 2 x 36 MW SO_2 removal units is around US$12 million.

It is a large economic burden to install emission control facility measures with high efficiency to the deteriorating small and old (29 - 41, or 37 - 49 years in 2005) power generating units. Cooperation of the local government and consumers will be mandatory.

As a result of comprehensive consideration of measures for control of dust and SO_2 emissions, probably, it would be better to ensure supply of 50 cycles to Charqueadas City by installing a synchronous motor at Jacui or by connecting high-voltage lines from the Jacui Plant to the existing synchronous motor, and meanwhile to consider the fate of the existing plant: to re-construct them by combining into one unit or else.

(3) Candiota Power Generation Facilities (No.A1,A2,B1,B2)

1) Measures for Dust Emission Control

As the result of measurement of flue gas, the concentrations of dust in flue gas were 938 - 1,531 mg/m^{3}N in the A line and 1,207 - 2,052 mg/m^{3}N in the B line. The emission agreement with the state (B line: not determined, A line: 80 mg/m^{3}N) will be applied to the B line in 2002 and to the A line in 2004.

Meanwhile, it is necessary to grasp actual EP performance by conducting performance tests for EP as well as to strengthen operational measures for facilities in both lines. Influence of dust and particulate due to habitual leakage of gas exhausted from flues and suspended fly ash, etc. around the fly ash storage area, from the viewpoint of health care of operators as well, it is urgently necessary to improve and refine working environment by repairing and mending.

Assuming that the allowable emission rate (not determined yet) to be applied to the B line in and after 2002 is similar to that for the A line or the Unit III, it is necessary to greatly increase performance of EP for continuous operation in both of the A and B lines. However, it is advisable to conform to the dust emission agreement together with measures for control of sulfur oxide emissions, without installation of new EP.

2) Measures for Control of Nitrogen Oxides (NO_x) Emissions

As the result of measurement of flue gas, the concentrations of NOx (NO) in flue gas were 370 - 509 mg/ m3N in the A line and 442 - 663 mg/m3N in the B line. It is considered enough that only proper operational measures will be taken because any emission standards are not applied for the present and there is little influence on the surrounding environment. However, the emission standards agreed with the state will be applied to the B line in 2002 and to the A line in 2004. The standard values are 680 mg/m3N and 400 mg/m3N respectively. As values of the A line will not conform to this emission standard, some measures will be required.

It is necessary to determine NO_x concentration in both A and B lines after the implementation of combustion control with the proper excess air rate in order to increase thermal efficiency and to reduce thermal NO_x as well. If the emission standards will not be satisfied even with the above-mentioned combustion control, it is necessary to plan for reduction with Low-NOx burners.

3) Measures for Control of Sulfur Oxides (SO_x) Emissions

As the result of measurement of flue gas, the concentrations of SO_2 in flue gas were 6,057 - 7,457 mg/m^{3}N in the A line and 6,086 - 7,000 mg/m^{3}N in the B line. SO_2 in high concentration was emitted from smokestacks. The emission rates agreed with the state will be applied to the B line in 2002 and to the A line in 2004. The values are 2,100 mg/m3N and 400 mg/m^{3}N respectively. If local coal (with the S content of 0.8 - 1.5%) is used as fuel, the amount of SO_2 generated will be around 7,500 mg/m3N. In order to conform to the agreement, the desulfurization efficiency required will be over 70% and 95% in B and A lines respectively.

The wet type lime - gypsum method is effective as flue gas desulfurization which enable conformity to the agreed sulfur oxide emission rates and also can be expected its dust-removing effect. It is considered proper that flue gas from two units will be treated with one desulfurization facility in the A line and flue gas from each unit in the B1 and B2 units will be treated separately with one desulfurization unit. The agreed dust emission rates will be satisfied with installation of these desulfurization units. The construction cost of flue gas desulfurization facilities is about US$17 million in the A line and US$32 million for one unit in the B line.

The A line is in operations for 23 years (30 years in 2004). The units with small capacity now show deterioration for the operated years. It is a large economic burden to continuously operate such facilities with desulfurization facilities on and after 2004. Therefore, disuse of them upon start of operation of Unit III, additional SO_2 removal at the B line without removal at the A line, or else may be discussed.

8.3.3 Measures for New Facilities

(1) Jorge Lacerda Power Generation Unit IV

1) Measures for Dust Emission Control

Unit IV has been already started operation, and is equipped with EP with collecting efficiency of 98% or more. As any emission standards are not applied and there is little influence on the surrounding environment, it is appropriate to take operational measures such as proper operation and maintenance control according to a operation manual and combustion control. It is desirable to grasp the EP performance by conducting performance tests for the EP at need, coinciding with dust measurement.

2)Measures for Control of Nitrogen Oxides (NOx) Emissions

Low-NOx burners are employed to Unit IV. As any emission standards are not applied and there is little influence on the surrounding environment, it is considered enough to carry out appropriate operation and maintenance control.

3)Measures for Control of Sulfur Oxides (SO_x) Emissions

As mentioned in Section 8.3.2(1), the ELETROSUL will be able to purchase coal with the S content of 2.2% or lower over a long period and it is known from the results of simulation that influence on the surrounding environment is little. Therefore, it is considered that paying attention on sulfur contents in coal is enough.

(2) Jacui Power Generation Facilities

Construction of Jacui Power Plant has been suspended since 1991. A boiler and a turbine have been purchased and are stored in a warehouse in the premises. An EP is still under construction. Therefore, it is a waste of money to purchase a new circulating fluidized bed boiler etc. in order to reduce pollutants. Upon restart of construction, it is better to strengthen environmental control measures with the facilities in hands.

1) Measures for Dust Emission Control

At the time of start of operation of Jacui Power Plant, the agreed emission rates of 140mg/m^{3}N (280MW) and 85mg/m^{3}N (175MW) will be applied. At Jacui Power Plant, an EP with 99% collection efficiency is now under construction. However, the EP will not satisfy the emission agreement with the state. On the assumption of 69.17g/m^{3}N as EP inlet concentration and 99.5% collection efficiency under 280MW (#065), concentration of flue gas is about 350mg/m^{3}N (on the wet base).

Though a possible measure to satisfy the agreed values for dust emissions is to reinforce the EP, measures without reinforcement of the EP is possible here together with measures for control of sulfur oxides emissions.

2) Measures for Control of Nitrogen Oxides (NO_x) Emissions

At the time of start of operation of Jacui Power Plant, the agreement with the state, 680mg/m^{3}N, will be applied. As the actually measured values of NOx emitted from the Charqueadas plant are in the range of 196 - 368 mg/m^{3}N, it is considered that the emission standards will be conformed at the Jacui power plant, by employing Low-NOx burners and full implementation of combustion control with the proper excess air ratio.

3) Measures for Control of Sulfur Oxides (SO_x) Emissions

At the time of start of operation of the Jacui Plant, the agreement with the state for SOx emission, 1,500mg/m^{3}N, will be applied. As the concentration of sulfur oxides in flue gas is estimated to be approximately 3,400mg/m^{3}N, the emission standard will not be satisfied. Therefore, it is required to install a wet type flue gas desulfurization (FGD) unit which will also serve to conform to the agreed emission rate of dust emission. The initial investment cost of the wet FGD is about US$35 million.

Note: The estimation of 3400 is based on 276 tons/hr coal consumption of 0.7% sulfur, and the wet flue gas flow rate of 1,234,708 m^{3}N/hr with 9% of water vapor in it.

(3) Candiota III Power Generation Facilities

CEEE has already purchased a boiler, a turbine etc. for Candiota III unit from France. Therefore, it is advisable to further strengthen implementation of control measures with the purchased facilities as the case of Jacui.

1) Measures for Dust Emission Control

At the start of operation of Candiota III unit, the agreement with the state for dust emission, 265 mg/m^{3}N (under 280MW) and 100 mg/m^{3}N (under 158MW), will be applied. Although it is not confirmed whether or not an EP has purchased, measures with new facilities are assumed here that the EP with a high collection efficiency is already in possession of CEEE. With estimation of EP inlet concentration of dust emission in flue gas of 133.0 g/m^{3}N (on the dry base), the EP requires to have the removal efficiency of around 99.8% in order to satisfy the agreement with the state. The EP will be rather large.

Note: The number of 133.0 g/m^{3}N is based on the calculation assuming coal rate of 393.15 tons/hr, ash contents of 53.5%, and 80% of the ash to the EP inlet, and stack gas of 1,360,000 m^{3}N/hr with 7 % of water vapor in it.

2) Measures for Control of Nitrogen Oxides (NO_x) Emissions

At the time of start of operation of Candiota III unit, the agreement with the state (not determined yet) for NOx emission will be applied. On the assumption that the emission standard agreed with the state is of the same level as the Jacui and the existing Candiota-B line, it is considered that the emission agreement will be satisfied by employing Low-NOx burners and implementation of full combustion control with the proper excess air ratio

3) Measures for Control of Sulfur Oxides (SOx) Emissions

At the time of start of operation of Candiota III unit, the emission agreement for SOx with the state, 2,000 mg/m^{3}N, will be applied. By estimating concentration of sulfur oxides in flue gas of 9,300 mg/m^{3}N, it is necessary that any reliable type flue gas desulfurization can accomplish the desulfurization rate of around 80% in order to conform to the emission standards agreed with the state. Because of the similarity with the ones in the existing units and the security margin for dust emission, the wet type is recommendable. The construction cost is about US$40 million.

Note: The estimation of 9,300 mg/m^{3}N is based on the same numbers given in the above and sulfur contents of 1.5% in coal.

8.3.4 Costs and Summary of Recommendations

(1) Investment Costs and Areas Required

Initial investment costs are estimated as in **Table 8.3.2** for the flue gas desulfurization units having capability to reduce dust emissions recommended in the previous section.

The costs of Low NOx burners are disregarded in the table. Because, a) it is better to install them after accumulation of more monitored data and after application of the operational measures to reduce excess O_2 in the flue gas in the Candiota A units, b) the detailed specifications of the Jacui and Candiota III units are not disclosed yet. To change burners to the Low NOx type, one such burner costs in Japan around US$140,000 and probably the discharge pressure of the air blower has to be increased to compensate higher pressure drop of the new burners.

Table 8.3.2 Investment Costs and Areas Required of Flue Gas Desulfurization Units

Plant	Unit	Flue Gas Rate m^3N/hr	Removal $SO_2\%$	Investment million US$	Area m^2
Charqueadas	1,2	192,000	90	6	1,500
	3,4	192,000	90	6	
Jacui		1,235,000	70	35	3,000
Candiota	A	492,000	95	17	1,500
	B1	910,000	70	32	3,000
	B2	910,000	70	32	
	III	1,360,000	80	40	3,000

(2) Utility Consumptions

Utilities required to operate the flue gas desulfurization (FGD) units are roughly estimated by assuming all units be operated in 50% of the full capacity annually. Another conditions of estimation are given in **Table 8.3.3** in addition to **Table 8.3.2**.

Table 8.3.3 Estimation Condition of FGD Utility Consumption

Item		Charque-adas	Jacui	Candiota		
				A	B	III
Coal	t/hr	41.2 x 2	276.0	138.6	207 x 2	393.2
S in Coal	%	1.0	0.7	1.15	1.15	1.15
Water in Coal	%	13.5	13.5	14	14	14

Table 8.3.4 is the operation costs of the FGD units of the above conditions and taking limestone powder costs to be US$83/ton, electricity to be US$0.067/kwh, and water to be US$0.083/$m^3$. With addition of depreciation, overhead expenses and wages of operators, and with alteration to local unit price of utilities, the FGD operation costs will become more comprehensive and realistic. One additional operator for one FGD unit in a shift is enough if the operations of the boiler and FGD units are under one group. If the operation is separated from the boiler group, two operators in a shift with four shifts are required to operate it.

Table 8.3.4 Operation Costs of FGD Units

	Limestone Powder		Water		Electricity		Total
	t/year	US$$10^6$	m^3/year	US$$10^6$	MWh	US$$10^6$	US$$10^6$
Charqueadas	8,800	0.73	130,000	0.01	4,730	0.32	1.06
Jacui	16,000	1.33	360,000	0.03	23,000	1.54	2.90
Candiota A	17,800	1.48	110,000	0.01	8,278	0.55	2.04
Candiota B	36,400	3.02	560,000	0.05	21,000	1.41	4.48
Candiota III	42,500	3.53	300,000	0.02	23,000	1.54	5.09

Table 8.3.5 is the summary of the recommendation in the Section 8.3.

Table 8.3.5 Outline of Air Pollution Control Measures at Thermal Power Plants

Power Plant	Unit	Rated output (MW)	Flue gas Flow rate m^3N/h	Start of Construction *1) (Year)	Start of Operation (Year)	Measures for Control of flue gas: Item	Measures *2)	Current Concentration mg/m^3N *3)	Agreed Concentration mg/m^3N	Facilities cost (US\$10^6)	Operation cost *4) (US\$10^6/yr)	Space needed (m^2)	Remarks
Jorge Lacerda	All existing	50×2	238,000×2	-	Jan. 1997	Dust	-	83~1,261		-	-	-	
		66×2	260,000×2			NOx		264~750					
		125×2	480,000×2			SOx	Coal with 2.2% or smaller of S content	5,829~8,371	≦3,941m^3N/h				
	Ⅳ	350	1,126,206			Dust	-	Uncertainty					SO_2 emission amount is same as or smaller than 6,566m^3N/h at the whole plant
						NOx		Uncertainty					
						SOx	Coal with 2.2% or smaller of S content	≦2,625m^3N/h					
Charqueadas	All existing	18×4	96,000×4	-	In 1997	Dust	-	81~1,081		-	-	-	
						NOx		196~368					
						SOx		3,257~5,429					
				-	by 2005	Dust	-	81~1,081	≦80	-	-	-	Dust emissions are ≦ the agreed standards by FGD facility
						NOx		196~368	≦400				
			192,000×2	2003		SOx	Flue gas desulfurization	3,257~5,429	≦400	12	1	1,500	2 units treated by 1 FGD facility
Jacui	Ⅰ	350	1,234,708	1997	at the time of operation 2000 (schedule)	Dust	Existing EP	(400)	≦140(at 280MW) ≦85(at175MW)	-	-	-	Dust emissions are ≦ the agreed standards by FGD facility
						NOx	Low-NOx burner	Uncertainty	≦680				
						SOx	Flue gas desulfurization	(3400)	≦1,500	35	3	3,000	
Candiota	A Line	63×2	246,000×2	-	In 1997	Dust	-	929~1,530		-	-	-	
						NOx		370~509					
						SOx		6,057~7,457					
				-	by 2004	Dust	-	929~1,530	≦80	-	-	-	Ditto
						NOx	Low-NOx burner(if neccessary)	370~509	≦400				
			492,000×1	2001		SOx	Flue gas desulfurization	6,057~7,457	≦400	17	2	1,500	2 units treated by 1 FGD facility
	B Line	160×2	910,000×2	-	In 1997	Dust	-	1,207~2,052		-	-	-	
						NOx		442~663					
						SOx		6,086~7,000					
				-	by 2002	Dust	-	1,207~2,052	≦standards	-	-	-	Dust emissions are ≦ the agreed standards by FGD facility Installation of 2 units of FGD
						NOx	Low-NOx burner(if neccessary)	442~663	≦680				
				1999		SOx	Flue gas desulfurization	6,086~7,000	≦2100	64	4.5	3,000	
	Ⅲ	350	1,360,000	2000	at the time of operation 2003 (schedule)	Dust	Planned EP	≦265(at 280MW) ≦100(at 158MW)		-	-	-	
						NOx	Low-NOx burner	Uncertainty	≦standards				
						SOx	Flue gas desulfurization	(9300)	≦2000	40	5	3,000	

Note *1) The time of start of construction includes the period of designing.
*2) "-" is operational measure i.e. repair,mending,maintenance,combustion control,periodical inspection etc. should be carried out without implementing facility measures.
*3) As for the existing plants, the figures are actual values and those in parenthesis ( ) are estimated values.
*4) Estimated amount of materials i.e limestone, water etc. and electricity consumption is based on 50% of annual availability ratio.

8.4 Ambient Air Monitoring System

8.4.1 Continuous Ambient Air Quality Monitoring

Continuous ambient air quality monitoring should be kept in operations in order to accumulate data to know trends of air qualities and to ascertain locations of pollutant sources. It makes possible to realize the air qualities in the surrounding area and to judge if the air quality is adequate in view of the environmental standards. The data can tell the impact strength of emissions from the sources (power plants) in comparison with the data taken at the places apparently without the impact. Accordingly, countermeasures against air pollution, if any, can be planned effectively.

The data are better to be submitted to the government and to the public for their review as a token of a social responsibility of the company possessing the emission sources.

Together with the air qualities, meteorological conditions shall also be monitored in order to analyze the impact from the sources and to make possible to simulate dispersion of pollutants in the atmosphere.

8.4.2 Review of Monitoring and Simulation Results

There are no violation of the national ambient air quality standards (the primary criteria) of SO_2 and NO_2 at present and in the foreseeable future.

TSP concentration was recorded over the national primary standard three times at Capivari in the Jorge Lacerda region. The meteorological data do not point direction to the power plant as the source of the TSP. The simulation study of SPM diffusion also shows no indication of the strong impact from the power plant.

8.4.3 Characteristics of Study Regions

The sketch maps of land use at three areas are shown in **Fig.8.4.1 - Fig 8.4.3.**

(1) Jorge Lacerda - The Jorge Lacerda plant is located west side of the village named Vila Capivari. There are residential areas named Capivari, Tubarao, Laguna, and Imarui around the plant. Marshy area and paddy fields are distributed in the west and beyond there hilly districts are distributed. East goes to the Atlantic Ocean, through marshy area and lagoons named "Mirim", "Imarui" and "Santo Antonio".

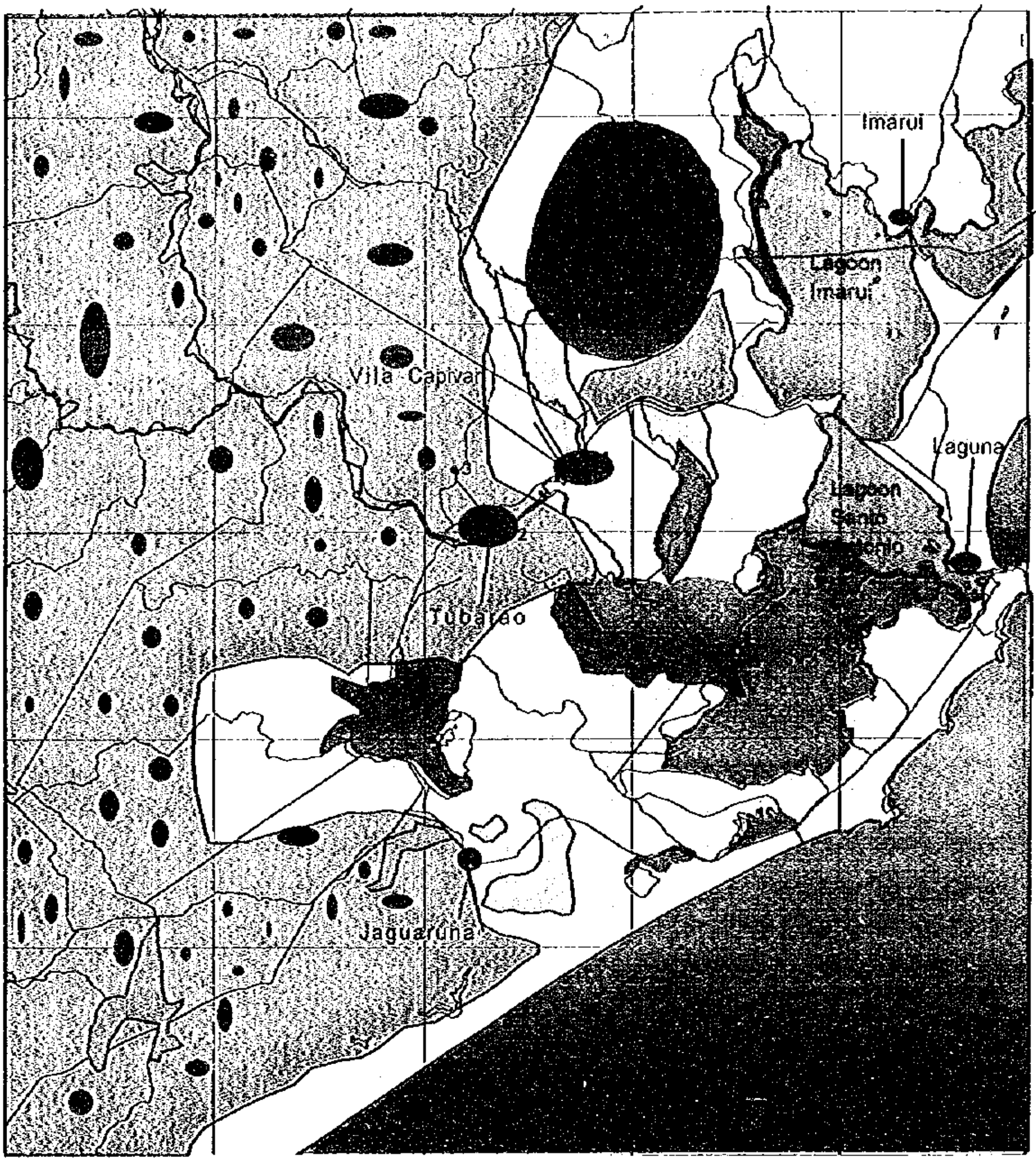
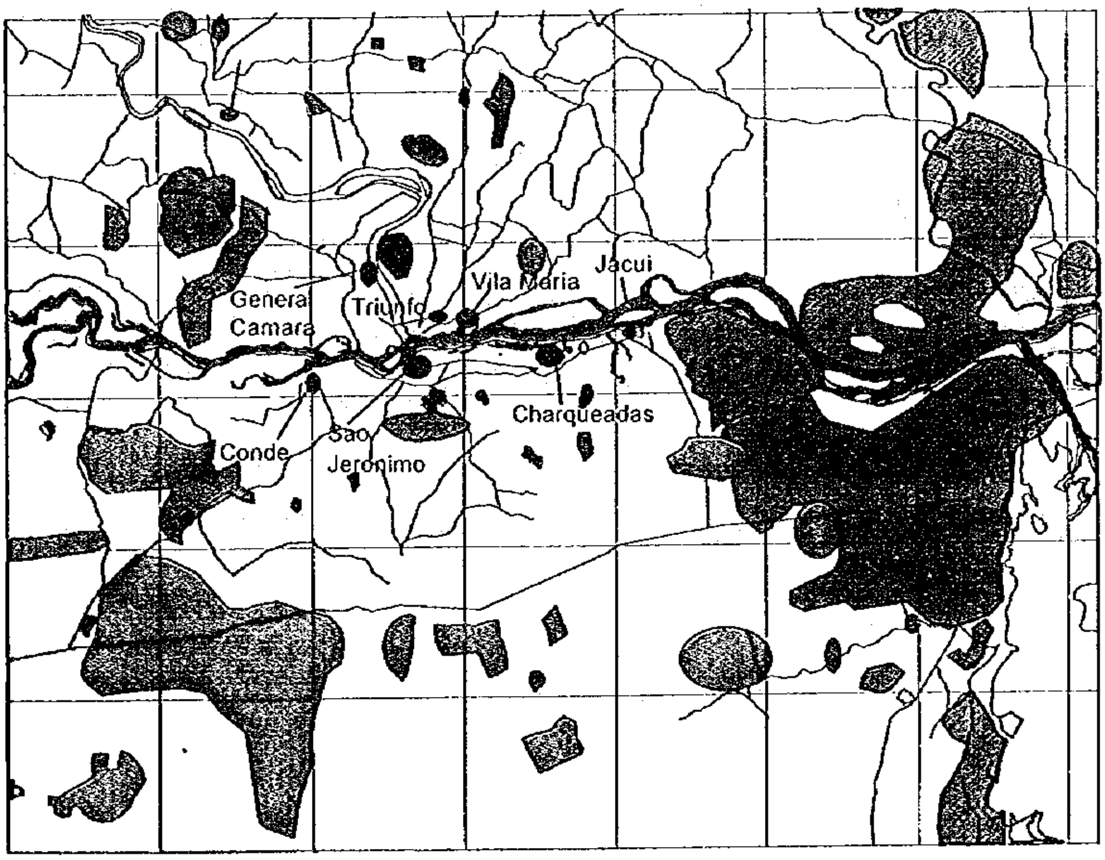


Fig. 8.4.1 Land Characteristics - Jorge Lacerda Region

Monitoring Stations
0 LACERDA
1 CAPIVARI
2 VILA MOEMA
3 SAO VERNARDO

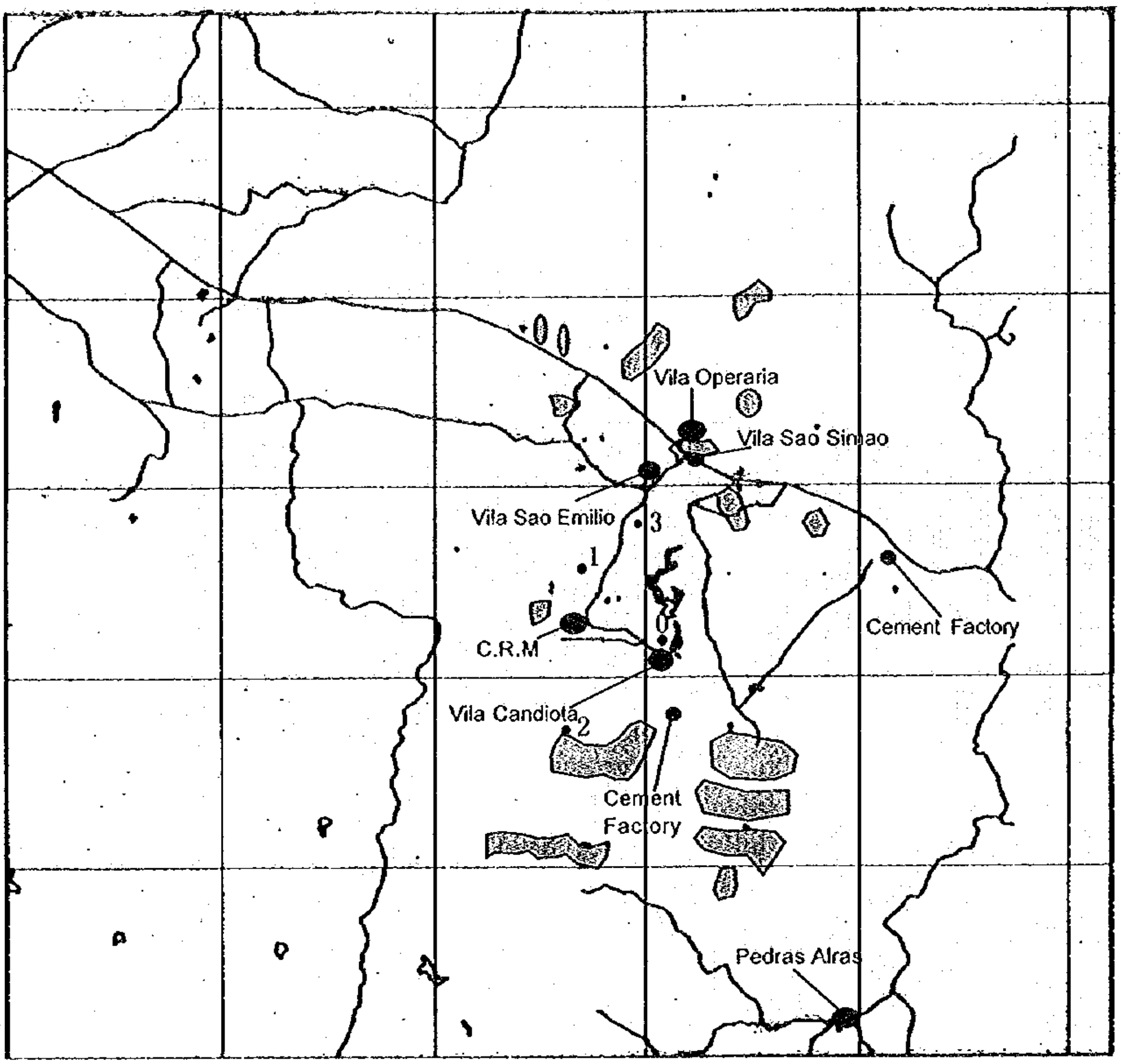
Forest
Agricultural
Paddy field
mangrove
marshy area
Village and Town



Monitoring Stations
0 CHARQUEADAS
1 ARRANCA TOCO
2 DEPREC
3 JACUI PLANT

Fig. 8.4.2 Land Characteristics - Charqueadas Region

- Forest
- Paddy field
- Fruits farm
- Lake
- Rio Jacui
- Marshy area
- Village and Town



Monitoring Stations
0 CANDIOTA II
1 CANDIOTA III
2 TRES LAGOAS
3 AIRPORT

Fig. 8.4.3 Land Characteristics - Candiota Region

Agricultural

Vilage and Town

Cement Factory

(2)Charqueadas - The Charqueadas plant is located east side of the town named Charqueadas and is facing a river named "Rio Jacui" to the north. Next to the plant, there is a steel mill which operates an electric furnace emitting brown smoke occasionally. Main residential areas are Charqueadas, Sao Jeronimo and Vila Maria and Triunfo. Around Charqueadas area small scale village named "Vila Sao Miguel", "Vila Pirayin" and so on are distributed. Fields and ranches are scattered all over the area. North of the plant is hilly and lushly forested regions. Toward the east, it is marshy along "Rio Jacui", and most of the area is used as paddy fields. Paddy fields are distributed along waterways, and large scale of fruit farms are there toward the south-west.

(3) Candiota - The Candiota power plant is located about 50 km in the ESE direction from the City Bage. Two cement factories are located in the south ward and the east ward of the plants. Main residential areas are Vila Candiota I and C.R.M. (coal mining), and small villages such as Vila Pereira. Most part of the area around the Candiota power plant is a grand plain called "panpa" and some agricultural areas are distributed in the north and the south ward from the plant.

8.4.4 General Air Quality Monitoring Improvement

(1) Particulate

a) SPM Analyzer: Suspended particulate monitoring should be improved because of no continuous analyzer to record the particulate concentration and of the TSP overrun at Capivari. It is recommended that two SPM analyzers in the Jorge Lacerda region and one each respectively in the Charqueadas and Candiota regions are to be newly installed to monitor continuously before materialization of the individual expansion plans **(Table 8.4.1)**. Nevertheless, the monthly TSP monitoring using the high-volume samplers should be kept in operations. The type of recommendable SPM Analyzer is beta-ray absorption **(Appendix 8-6)**.

b) CMB Evaluation: The TSP incident in the Jorge Lacerda region seems not to be caused from the power plant. The CMB method is recommended later to evaluate contributions of different sources to air borne particulate.

Table 8.4.1 New Power Plants' Expansion Plan

Power Plant	Generating Capability(MW)			Expansion	Note
	Present	Expan-sion	Total	%	Name of Plant (in operation)
J. Lacerda	482	350	832	72.6	Jorge Lacerda IV (1/1997)
Charqueadas	72	350	422	486.0	Jacui (12/1999)
Candiota	446	350	796	78.5	Candiota III (9/2003)

(2) Wind Observation

Anemoscopes and anemometers possessed by the power plants are better to change to propeller type, in order to observe wind down to lower velocity accurately. This is to simulate pollutants dispersion more accurately with accurate meteorological data.

8.4.5 Discussion on Individual Region

(1) Jorge Lacerda

Jorge Lacerda IV has been in operations from January 1997. The monitoring system should be improved rather quickly. The necessary improvement items are as follows, and tabulated in Table 8.4.2.

a) The Sao Bernard monitoring station shall be relocated about 2 or 3 km toward the North, since the impact concentration from the power plant will be at the highest there within the region according to the simulation.
b) The Vila Moema station shall also be relocated about 1 or 2 km toward the East, if possible. The station monitors ambient air quality of Tubarao, the most populated town in the region and where the impact from the power plant seems to be relatively high. One analyzer should be added to monitor the SPM concentration there.
c) The Capivari station shall be kept for monitoring around Vila Capivari and Jorge Lacerda, because the concentration from the power plant will be the second highest around there above the region. One SPM analyzer should be installed additionally.
d) If possible, a new monitoring station shall be established around Sertao do Santiago which is located about 3 km in NNE direction from the power plant, for surveillance the habitants and the agricultural land around there, because the concentration from the power plant is relatively high. This new addition can be considered after knowing the incremental trends of one pollutant concentration in the existing three monitoring station.

Table 8.4.2 Improvement of Monitoring Stations in Jorge Lacerda Region

Station	Condition		Ground	Improvement
	Present	Future		
Jorge Lacerda	○	○	Observation of Meteorology	Change wind vane
Sao Bernard	○	○	Signified (Cmax) concentration Area Surveillance of the agricultural land	Relocate 2-3 km to North
Vila Moema	○	○	Surveillance of Tubarao	Relocate 1-2 km to East; Add SPM analyzer
Capivari	○	○	Surveillance around Vila Capivari and Jorge Lacerda	Add SPM analyzer
Sertao do Santiago	-	◎	Surveillance of the habitants and the agricultural land	After knowing the trends of pollutant concentration at other stations

Legend: ○;Kept monitoring, ◎;Newly established, if possible.

Table 8.4.3 summarizes parameters to be monitored at the monitoring stations around the Jorge Lacerda plant.

Table 8.4.3 Plan of Monitoring Parameters at Jorge Lacerda

Monitoring Station	Status	Parameters						
		SO_2	**NOx**	**SPM**	TSP	**WD・WS**	**SUN・NETR**	A-P
Jorge Lacerda	Present	—	—	—	—	○	○	○
	Future	—	—	—	—	□	○	○
Sao Bernard	Present	○	—	—	○	—	—	—
	Future	○	—	◎	○	—	—	—
Vila Moema	Present	○	—	—	○	—	—	—
	Future	○	—	—	○	—	—	—
Capivari	Present	○	○	—	○	—	—	—
	Future	○	○	◎	○	—	—	—
Sertao do Santiago	Present	—	—	—	—	—	—	—
	Future	◎	—	—	◎	—	—	—

Note: Parameters Bold are measured by automatically continuous method

WD and WS: wind direction and speed, SUN and NETR: solar radiation and net radiation, and A-P: precipitation.

Legend:○;Kept monitoring, ◎;Newly equipped, □;Exchanged for new equipment

(2) Charqueadas

Because existing facilities at the Charqueadas plant are to be regulated when the Jacui plant is in operations, the impact concentration will be reduced because of the observation of the agreement and the higher chimney at Jacui. Monitoring shall be continued as in **Table 8.4.4**.

Meanwhile, there is a plan to monitor ambient air quality of the greater Porto Alegre region, because the region has many industries such as paper mills, oil refinery, petrochemical factories, steel mills, power plants, etc. Also motorization becomes heavier in the region. The monitoring system of the Charqueardas region should be included in the planned system and be managed by one control center. FEPAM seems the best organization in charge of its planning and operation.

a) Jacui shall be kept for the observation of meteorology and for the surveillance of the concentration around the Jacui plant.
b) DEPREC shall be kept for the surveillance of residence Vila Maria because the impact concentration from the power plant will be of the highest in the region.
c) Arranca Toco shall be kept for the surveillance of residence Charqueadas, the most populated town in the region. One SPM analyzer should be installed additionally.

Table 8.4.4 Improvement of Monitoring Stations in Charqueadas

Station	Condition		Ground	Improvement
	Present	Future		
Jacui	O	O	Observation of Meteorology, Surveillance around Jacui	Change wind vane
DEPREC	O	O	Signified (Cmax) concentration Area Surveillance of Residence Vila Maria	
Arranca Toco	O	O	Surveillance of Residence Charqueadas	Add SPM analyzer

Legend:O;Kept monitoring

Table 8.4.5 summarizes parameters to be monitored at the monitoring stations around the Charqueadas-Jacui plant.

Table 8.4.5 Plan of Monitoring Parameters at Charqueadas and Jacui

Station	Time	Parameters						
		SO2	NOx	SPM	TSP	WD·WS	SUN·NETR	A-P
Jacui	Present	○	–	–	○	○	○(SUN)	–
	Future	○	–	–	○	□	○(SUN)	–
DEPREC	Present	○	○	–	–	–	○(NETR)	○
	Future	○	○	–	–	–	○(NETR)	○
Arranca Toco	Present	○	–	–	○	–	–	–
	Future	○	–	◎	○	–	–	–

Legend:○;Kept monitoring, ◎;Newly equipped, □;Exchanged for new equipment

(3). Candiota

Because Candiota Ⅲ will be in operations sometime in 2003, monitoring system shall be improved until that time. The necessary improvement items are as in **Table 8.4.6.**

Table 8.4.6 Monitoring Stations at Candiota

Station	Condition		Ground	Improvement
	Present	Future		
Airport	○	○	Observation of Meteorology; Surveillance of Residence around	Change wind vane.
Candiota Ⅲ	○	○	Surveillance around	
Tres Lagoas	○	○	Signified (Cmax) concentration Area Surveillance of Agricultural Land	Relocate 3-4 km to West. Add SPM analyzer.
Acegua	○	○	Surveillance of Rain & Dry Precipitation	Add wind vane.

Legend:○;Kept monitoring

a) Airport shall be kept for the observation of meteorology and for the surveillance of the residence Vila Sao Emilio, Vila Sao Simao, Vila Euimaraes and Vila Operaria.

b) Candiota Ⅲ shall be kept for the surveillance around the previous Candiota Ⅲ site.

c) Tres Lagoas shall be kept for surveillance of the agricultural land because the impact concentration from the power plant will be the highest around there in the region. It shall be relocated about 3 or 4 km toward the west

d). Acegua shall be kept for the surveillance of rain and dry precipitation, with an additional wind vane to analyze the relationship between precipitation and wind.

Table 8.4.7 summarizes parameters to be monitored in the Candiota region.

Table 8.4.7 Plan of Monitoring Parameters at Candiota

Station	Time	Parameters						
		SO2	NOx	SPM	TSP	WD·WS	SUN·NETR	A-P
Airport	Present	○	○	–	○	○	○	○
	Future	○	–	–	○	□	○	○
Candiota Ⅲ	Present	○	–	–	○	–	–	–
	Future	○	–	–	○	–	–	–
Tres Lagoas	Present	○	–	–	–	–	–	–
	Future	○	○	◎	–	–	–	–
Acegua	Present	–	–	–	–	–	–	○
	Future	–	–	–	–	◎	–	○

Legend:○;Kept monitoring, ◎;Newly equipped, □;Exchanged for new equipment

8.4.6 Observation of Upper Air Wind

The wind condition varies as the altitude becomes high. Observation of upper air wind is important for analyze the relation between the air quality and the meteorology, especially by the diffusion simulation model in the future. The ideal altitude to observe is the same height with the top of the chimney. However, it will become difficult to maintain the equipment there. It is better to install the wind observation equipment with a tall pole on the power plant roof. The type of equipment shall be as the same as that is used for the surface wind observation.

8.4.7 Measurement by Simple Method

Three monitoring stations are not enough number for monitoring wide area around power plant. Therefore, the simplified measurement shall be continued to realize the transition of air quality in the course of years in the wide area. It shall be enforced once or twice a year and sampling points shall be the same as used by the Study.

8.4.6 Monitoring Staff

In order to maintain the equipment in good condition and to manage the monitoring system, it is necessary to keep permanent staff. The staff member shall be educated and trained periodically to catch up technical advances in the monitoring field.

8.4.9 Cost

Cost of the new equipment are as in **Table 8.4.8.** Costs of spare and consumable parts for one year operation are as follows in Japan (1996, US $1=¥120).

SO_2 Analyzer US $ 3,600

NOx Analyzer US $ 3,600

Table 8.4.8 Costs of New Equipment

Equipment	Catalogue Price in Japan / one
SPM Analyzer (Beta Ray Absorption)	US $ 30,000
SO_2 Analyzer	US$ 36,000
Propeller wind vane and anemometer	US $ 13,000
Data Logger	US $ 12,000

8.4.10 CMB Method

The CMB (Chemical Mass Balance) method is a type of receptor model to estimate the contribution from sources to ambient SPM/TSP concentration. Chemical elemental profiles of assumed sources and ambient SPM/TSP are necessary for the CMB method. One element in ambient air SPM/TSP results from contributions from various sources. This relation have to be established in a set of linear equations for each elements to get the contributions from each source.

Generally, more than 30 heavy metals are analyzed by Neutron Activation, with high accuracy. Adding to the ambient SPM/TSP, the particulate matter emitted from the assumed sources like power plant, cement factory, automobile, soil and so on should be analyzed for the CMB method. During the evaluation by the CMB method, source-specific tracer elements are determined to obtain good answers.

The total cost of the CMB method is roughly estimated as US$ 400,000 assuming the chemical analysis and the CMB evaluation to be carried out in Japan. This investigation should be conducted by FATMA in charge, because many local industries are involved.

Appendix 8-5 explains briefly how the CMB method can evaluate contribution of each sources to the airborne particulate.

8.4.11 Summary of Air Monitoring Recommendation

Table 8.4.9 summarizes the recommendations proposed in this section.

Table 8.4.9 Summary of Air Monitoring Recommendation

	Item	Description	Cost	Year	Remarks
1	SPM Analyzers	Newly install at monitoring stations: Capivari, Vila Moema, Arranca Toco Tres Lagoas.	Investment $120,000	1998	
2	CMB Evaluation	Contributions to airborne particulate of emission sources	Analyses, evaluation $400,000	1999	FATMA in charge
3	Relocation of Monitor. Stations	Sao Bernard - 3 km N, Vila Moema - 2 km E, Tres Lagoas - 4 km W	--	--	for better monitoring
4	Wind Meter	Change the all existing wind meters to a propeller type. Add one at Acegua.	$13,000 for one set	--	before to simulate again
5	Greater Porto Alegre	Transfer the Charqueadas monitor system to the management of the Greater Porto Alegre System.	--	--	when emerged by FEPAM
6	Continuat-ion	Continue monitoring in all three regions and publish the data.	--	--	
7	New Station	Monitor TSP and SO_2 at Sertao do Santiago	SO_2 meter $36,000	--	when air becomes deteriorated

8.5 Stack Gas Monitoring System

8.5.1 Purposes of Stack Gas Monitoring

The most important air pollutants emitted in industrial exhaust gases are SO_2, NO_x, and dust. The amount of pollutants generated depends on the operating conditions of the boiler (such as operation capacity, fuel-air ratio and combustion temperature), properties of fuel, etc. Therefore, it is necessary in compiling data to measure continuously and repeatedly the amount of these pollutants generated and related operating conditions. The purposes of the stack gas monitoring system are as follows.

① To obtain quantitative data which provides reliable basis to examine the impact of exhaust gas on air pollution.
② To determine the main sources for emission controls, in case that there are many sources of exhaust gas.
③ To afford data for selection of appropriate exhaust emission control devices, and to help evaluation of the effects after such measures are conducted.
④ To be used for combustion control and management.

8.5.2 Monitoring Plan

(1) Basis

In accordance with the plan to expand power plants, both ELETROSUL and CEEE agreed with FEPAM on the measures for pollution. Exhaust gases from the Charqueadas plant should be monitored automatically and continuously by 2005. In Jacui and Candiota Ⅲ plants the same methods should be applied for monitoring from the beginning of their operation. In Candiota, the same should be put into place by 2004 for Units A, and by 2002 for Units B.

The batch measurement adopted in the Study is to be conducted during the intermediate period before adoption of the automatic continuous measurement. After that, the batch measurement will also be required for measurement of dust concentration, exhaust gas volume, and water content.

(2) Measured Items, Methods and Frequencies

Measured items are determined as follows:

Measured items are determined as follows:

① Batch measurement (manual analytical method)

- Twice/year. Also every time after changing the kind of coal, and after alteration of boiler and EP operational conditions.
- Items to be measured: Amount of dust, Flow velocity, Gas Temperature, Water Contents, SO_2, NO_x, and O_2

② Automatic continuous measurement (installed type)

- Items to be measured: Dust concentration, SO_2, NO_x, O_2, and Gas Temperature

As for flue gas monitoring, the measuring methods listed in **Table 8.5.1** are appropriate in light of the JICA Equipment used for the Study.

Table 8.5.1 Stack Gas Measuring Methods

Measured Item	Measuring Principle
Amount of dust	Dynamic pressure balance or Photo extinction type
Flow velocity / Temperature	Pitot tube / thermocouple
Water content	$CaCl_2$ absorption method
SO_2	Infrared-absorbing method
NO_x	Chemiluminescence method or Infrared-absorbing method
O_2	Zircon type or Magnetic type

(3) Analyzer Location

① Batch measurement (manual analytical method): the same as ones employed in the Study

② Continuous measurement

As shown in **Figure 8.5.1**, the gas analyzer is generally composed of a gas sampling probe which is inserted directly into the duct, a gas analyzer (including cubicle), and a conduit which connects them.

a. Location, point and tap of gas sampling

It is very important to determine the sampling points of exhaust gas in its flow channel to the stack through the duct. To obtain accurate results, the following points should be selected;

- where distribution of gas concentration is uniform
- where flow velocity of gas is stable
- where flow velocity is the largest

b. Piping

Short gas piping is necessary to avoid drain deposits. The pipe should be heat-traced so as not SO_2 to be absorbed into the drain. Heating of the pipe is not required for analysis of NO_x and O_2.

c. Main body of analyzer

Location is to be determined to isolate radiation heat from direct sunlight and heat sources (ambient temperature 40℃ maximum).

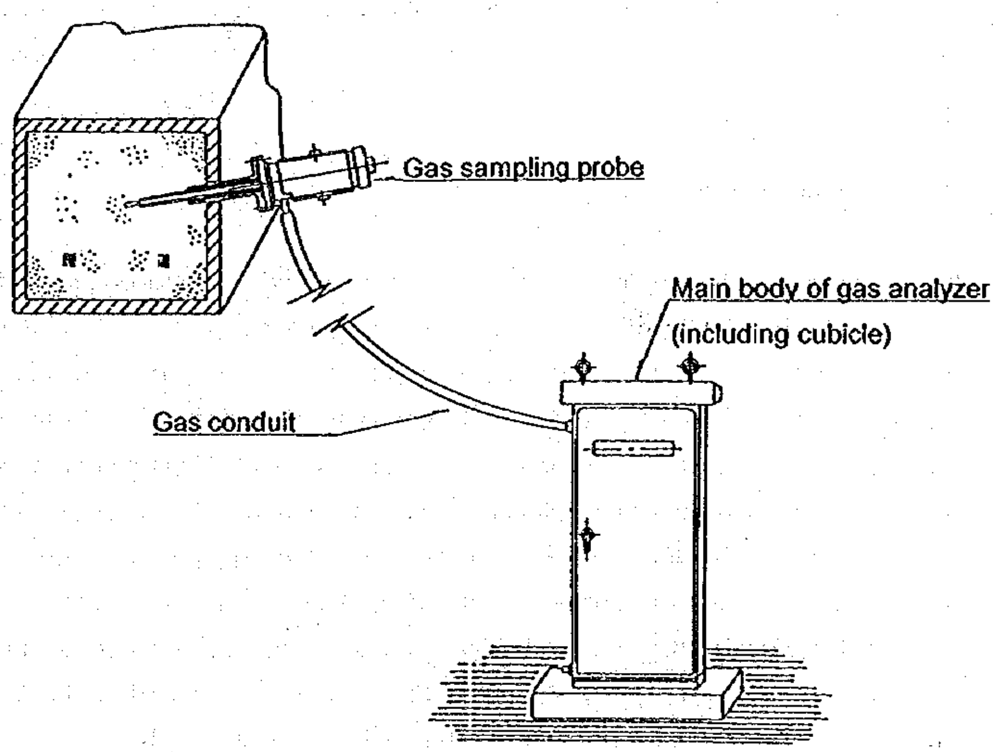


Figure 8.5.1 General Configuration of Continuous Stack Gas Analyzer

(4) Maintenance Automatic Analyzer

Regarding maintenance and checks on the batch measuring device, see the manufacturer's manual. The automatic analyzer, as equipment new to the Brazilian side, is especially referred to here. There are several maintenance routine practices. The purpose of daily checks is to ensure the continuous operation for the automatic analyzer under normal conditions and also to replace and supplement parts if necessary. The purpose of annual checks is to maintain the measuring accuracy of the analyzer, to prevent faulty measurement caused by faults and breakdown, and to replace deteriorated parts. The purpose of emergency checks is to deal with abnormal operations and failures of the analyzer immediately and in emergencies.

The contents of maintenance and checks commonly adopted for analyzers and the checking frequency are indicated in **Appendix 8-4**, while the instruction manual should be referred to for the individual items of each analyzer.

(5) Data Records

It is desirable that the records of measurements by automatic analyzers be kept at least for 3 years, since they are valuable as a future reference to reconfirming the measured values etc.

(6) Operation and Maintenance Organization

It is necessary that the organization should be established for operation and maintenance in order to operate the automatic analyzer in stable conditions for a long time with high accuracy and secure reliable measurement values, as well as to make use of the data promptly. Staff members who are proficient in maintenance and data management of analyzers are essential. Recent improved and advanced high-performance analyzers require more technology and high-level knowledge. Therefore, it is necessary that the proper education and training for the staff members in charge be appropriately carried out and that they learn the latest technology and information. For this purpose, requests to manufacturers for dispatch of technical experts as well as dispatch of staff members concerned in practical operations for training (to a foreign power plant for data management, and to the manufacturer for analyzer maintenance) are most desirable.

(7) Entrusted Jobs

It is possible to entrust a specialized company outside with part of a job concerning the operation and maintenance of analyzers. Unfortunately, as there are few specialized companies in Brazil, staff members of the thermal power plants have to conduct the daily and regular checks on analyzers. However, it is impossible for these staff members to overhaul and repair damaged parts of analyzers in the daily checks, as their technical skills are limited. As overhauling and repairing are very critical for collecting data with high accuracy continuously for a long time, these jobs should be entrusted to a technical expert of the analyzer manufacturer.

(8) Cost of Analyzer

The initial investment costs (Catalogue price in Japan) of analyzers are as follows:

SO_2, NOx, and O_2 Continuous Analyses in one case	US$ 67,000
TSP Continuous Analyzer (Relative Concentration)	US$ 43,000
Total	US$110,000

A shelter and an Air Conditioner are included in the above.

The costs in Japan for consumable and repair parts (excluding repair parts in case of trouble) required for one analyzer per year are shown below. The costs below show those for one analyzer and should be simply multiplied when more than one analyzer is involved.

Regular inspection	= US$ 2,500
Except regular inspection	= US$ 2,000
3 cylinders of standard gas	= US$ 1,300
3 cylinders of zero gas	= US$ 500

(9) Analyzer manufacturers

Analyzers obtainable in Brazil are listed in **Appendix 8-2** based on the research by the Study Team. In the table, some analyzers can be applicable in place of the JICA Equipment for the batch measurement, when the JICA Equipment becomes unable to use. Some of imported automatic continuous analyzers are also available in Brazil.

(10) Special Notation on Dust Analyzer

There are two types of automatic dust monitoring instrument. One is the type that brings sample gas from the suction nozzle in the duct into the detector outside of the duct, through a connecting pipe. The other is the type that a sensor is installed inside of the duct. Also there are two kinds of the instrument, actual mass analyzer and relative analyzer as in **Table 8.5.2**. While the mass concentration analyzer has advantages of rapid and real-time measurement, it has been failed in commercialization in Japan. Even, the relative concentration analyzer requires a lot of attention, because deposition of dust inside of the connecting pipe causes the increase of blank values and choking of the suction system.

Acidic gas causes corrosion of the detector, etc. The dust monitoring instrument (JIS A 1306) is installed in almost every thermal power plant in Japan. However, it is mostly used for combustion control or as a supporting equipment for the dust monitoring. When the relative concentration type is applied, the batch dust sampler system shall be frequently mobilized to measure the actual dust loading in the stack gas in order to calibrate the relative value to the actual one.

Table 8.5.2 Methods and Principles of Various Continuous Dust Analyzers

Methods	Measuring principles	Measured values
Photo extinction type	Measure light attenuation by dust particles passing across the parallel luminous flux.	Relative concentration
Light scattering method	After irradiation of luminous flux to exhaust gas, detect the light scattered by dust particles with the definite scattered angle.	Relative concentration
Contact charging type	Place semiconductor or conductor in flow of exhaust gas and measure the loading travel on the contact surface of semiconductor or conductor sensor and dust particles.	Mass concentration
Diluent associated method	Dilute with the definite quantity of air and measure by instrument as for atmospheric particulate matter.	Mass concentration

US EPA mentions the specifications of photo extinction type relative concentration analyzer in its Code of Federal Registrations - 40CFR60.

8.5.3 Summary of Recommendations on Stack Gas Monitoring

Table 8.5.3 summaries the recommendations mentioned in this section.

Table 8.5.3 Summary of Stack Gas Monitoring Recommendations

Plant or Unit	Description	Year	Cost
All Existing Units	Continue the batch monitoring twice a year or occasionally when operating conditions changed, until continuous monitoring systems have installed.	--	--
Charqueadas	Install 4 continuous monitoring system	2005	$440,000
Jacui	Install one continuous monitoring system before the startup of operations	(1998)	$110,000
Candiota A	Install the continuous monitoring system, total 2 units	2004	$220,000
Candiota B	ditto, total 2 units	2002	$220,000
Candiota III	Install one continuous monitoring system before the startup of operations	(2003)	$110,000

CHAPTER 9 CONCLUSION

The Brazilian power industry entered the transitional period of privatization during the Study period. The 2100 MW expansion plan at Candiota was reduced to 350 MW. This unit is in the process of privatization, as is the Jacui plant where construction has suspended for a long time. Although hydraulic power supplies about 93% of Brazil's electricity, coal power industries are important in the two southern states where almost all Brazilian coal is deposited. Coal supplies electricity in the dry season, and supports local people in mining, washing, and transporting. ELETROSUL generates about 10% of its power by burning coal and CEEE does about 40%. The key operational issue for the privatized coal power plants would be to endure severe competition with the hydraulic power plants without jeopardizing ambient air quality.

One year of continuous monitoring in the Study found that the ambient air qualities of SO_2 and NO_2 in the Study regions did not exceed the National Standards of the primary criteria in annual or shorter (24 hours or one hour) average times. Also dispersion simulation projected that SO_2, NO_2 and SPM concentrations in the future after the planned expansion of 350 MW on each power plant would still be under the National Standards, if there were no more expansion or introduction of other industries. TSP concentrations measured at the three power plants were also under the National Standards, except at Capivari. The reason of the Capivari phenomenon seems not to be caused by the power plant. The acidity values of precipitation measured at the three power plants and at Acegua, a border city with Uruguay, were in the normal range, although there was a question remained unanswered about the accuracy of the measurements.

Table 9.1 summarizes proposed recommendations, as the results of the Study, to be carried out by the Brazilian side. There are agreements on items related to stack emissions between the power companies and each local state agency (FATMA and FEPAM) for the operations. FATMA and ELETROSUL have agreed on keeping SO_2 emission from Jorge Lacerda plant below an amount equivalent to the emission when burning coal of 2.2% sulfur contents at full-rated load of the total unit generation capacity. As all the units in the plant are burning 1.8 to 2.3 % sulfur coal, SO_2 emission agreement can easily be met by controlling the sulfur contents or generation capacities. All the units of Charqueadas and Candiota in the state of Rio Grande do Sul have to meet the agreements with FEPAM when each individual expansion unit (Jacui and Candiota III) comes into operations. Stack gas treatment processes are recommended.

The monitoring of stack gas emissions shall be carried out in meeting the agreement. Although there is no agreement with FATMA, it is recommended that the units in the Jorge Lacerda plant monitor TSP, SO_2, and NOx using the JICA Equipment at least twice a year. Units in Charqueadas, Jacui, and Candiota are requested in the agreement with FEPAM to monitor TSP, SO_2, and NOx continuously and automatically.

It is recommended that the CMB method be employed to evaluate the source contribution and an automated continuous SPM monitoring instrument be installed in the Jorge Lacerda region, in order to clarify the TSP incident at Capivari. Also each one of the SPM instrument should be installed in the remaining two regions to record the trends of SPM concentration changes.

The ambient air quality shall be continuously monitored by the automated three stations around each power plant with focus on any changes in the quality. The monitoring stations around Charqueadas Power Plant shall be combined with the Greater Porto Alegre Monitoring Plan when the Plan is materialized, and the collected data shall be managed, for example, through a telemeter system by its monitoring center.

In Brazil, local states have authorities in making environmental policies. The before-mentioned agreements were concluded after long discussion between FATMA or FEPAM and ELETROSUL and CEEE. The principles of the agreements were not readily available to the JICA Team, because there may have been delicate political and technical issues involved. Both power companies reported to the state agencies occasionally on the progress of the Study or invited their representatives to the sites of the Study. The JICA Team felt that the purpose of the Study would be more effectively satisfied if they were invited as Study Team members from the beginning.

The Brazilian counterparts were all eager to learn technologies from the JICA Team. In addition, they were also eager to cooperate with the JICA Team. Especially during the Second Field Work period, they sacrificed part of their Carnival summer vacations for the custom clearance, installation, start-up of the JICA Equipment, etc. Without their sacrifice and cooperation, the JICA Team would not have been able to implement its tasks so smoothly and to achieve its planned objectives so firmly. The JICA Team very much appreciated their efforts for the Study. It hopes that the clean air would be kept forever in the regions as it is.

Table 9.1 Summary of Recommendations[1)]

No.	Items	Description	Background	Investment[2)]	Substitute Plan	Plan	Startup	Remarks
1	Power Plant	One train of wet FGD unit in Jacui	Agreement	$35 x 10^6$	Separate SO_2 and Dust Removal	see Remarks	(E/1999)	Immediately to start design, depending on the start-up date
2	Power Plant	Decision of the fate of Charqueadas Plant	Small and Old Agreement	—	2 Wet FGDs	—	2005	Investment of the substitute plan: $ $12 x 10^6$
3	Power Plant	One train of wet FGD in Candiota A	Agreement	$17 x 10^6$	—	2001	2004	
4	Power Plant	Low NOx Burners in Candiota A	Agreement		Stack Gas Recycle	2003	2004	
5	Power Plant	Two trains of wet FGDs in Candiota B	Agreement	$64 x 10^6$	—	1999	2002	
6	Power Plant	One train of wet FGD in Candiota III	Agreement	$40 x 10^6$	Dry FGD	2000	(9/2003)	
7	Plant Management	Strict operation and maintenance management of boiler, ESP, etc. at all power units	Save Energy, Remove Dust	—	—	Always	—	
8	Stack Gas	Batch monitoring at all units until another monitoring system installed	Social Responsibility	—	—	Occasion -ally	—	
9	Stack Gas	Continuous monitoring of SO_2, dust, and NOx at Jacui	Agreement	$110,000	—	(1998)	(E/1999)	
10	Stack Gas	Charqueadas - see Item 2	—	—	Auto. Continuous Monitoring	—	2005	Investment of the substitute plan: $440,000
11	Stack Gas	Continuous monitoring of SO_2, dust, and NOx at Candiota A	Agreement	$220,000	—	—	2004	
12	Stack Gas	Continuous monitoring of SO_2, dust, and NOx at Candiota B	Agreement	$220,000	—	—	2002	
13	Stack Gas	Continuous monitoring of SO_2, dust, and NOx at Candiota III	Agreement	$110,000	—	—	(9/2003)	
14	Air Monitoring	SPM analyzers 2 in Jorge Lacerda Area, each one in other areas, total 4 units	Violation of TSP Air Quality	$120,000	—	1998	—	
15	Air Monitoring	CMB evaluation of SPM sources in Jorge Lacerda Area	ditto	see Remarks	—	1999	2001	FATMA's Project; Estimated total cost=$400,000 including analyses in Japan
16	Air Monitoring	Move monitoring stations slightly in J. Lacerada and Candiota; Change or add wind meters	Better Monitoring	—	—	—	—	4 sets of Wind meters $52,000
17	Air Monitoring	Transfer the monitoring system in Charqueads Area to the Greater Porto Alegre System	Cooperate with the State	—	—	—	Not Dis-closed	FEPAM's Project
18	Air Monitoring	Continue monitoring in all three regions and report the results to the public and authorities	Social Responsibility	—	—	Always	—	

Note: 1) Eliminated those items to be carried out in unknown future or ones related to undisclosed details of new or expanded units, such as ESP and low NOx Burners.

2) Japanese catalogue prices for hardware only; Conversion rate: $1.00=¥120