PART V SIMULATION OF SO_2 CONCENTRATION

Using the source emission, meteorology and concentration data already discussed in Part III and IV, present (1981) and future (1990) status of sulfur dioxide pollution are simulated by the model stated in this part. The flow of the simulation procedure is shown in Fig. I-2-2 of Part I.

CHAPTER 1 SIMULATION METHODS GENERALLY USED

V-1-1 Physical and Numerical Simulation Models

Up to present, many methods of atmospheric diffusion simulation have been proposed. These are roughly classified into two groups. The first is the physical laboratory model like wind tunnel, water channel etc., and the other is the mathematical models. The classification of those models are given in Fig. V-1-1.

- * Air tracer experiment
- * Fluid models
  - Wind tunnel experiment
  - Water channel experiment
- * Mathematical simulation model
  - Numerical model
    - Finite element method
    - Finite difference method
    - etc.
  - Analytical model
    - Plume model
    - Puff model
    - etc.
  - Empirical Model

Fig. V-1-1 Classification of simulation models of air pollution

Here we explain these models, first.

(1) Air tracer experiment and laboratory model simulation

Air tracer experiment is a direct method of diffusion study, i.e., by releasing air tracer substances from objective stacks or site, sampling the mixture gas and analyzing it, we obtain diffusion characteristics just at the objective area.

As the air tracer, SF_6 (Sulfur Hexa Fluoride) or fine luminescent particles which are harmless for human being and also for plants, are usually used. The air tracer substances also should be detectable by chemical or physical method, even trace amount of it.

By analyzing diffusion results together with the meteorological data obtained at the same time, characteristics of atmospheric diffusion at the site are clarified.

For the diffusion over complex terrain or abnormal diffusion problems near stacks like down wash or down draft, fluid model simulation such as wind tunnel or water channel are sometimes adopted, since the mathematical model is not yet adequate. In fluid model simulation, tracer substances are emitted from model stacks and the diffusion is examined visually or by quantitiative measurements.

(2) Mathematical models

Fluid model simulation requires special facilities like wind tunnel or water channel and it is not adequate for variety of meteorological or source conditions. Therefore, it is suitable for regulated diffusion problems.

On the other hand, meteorological model is the one in which the diffusion is expressed by mathematical formula and diffusion conditions are easily controlled only by input parameters.

However, presently available mathematical models have still difficulties to apply special diffusion problems like diffusion over complex terrain, diffusion around buildings etc.

Therefore, we have to select models depending on the problems, as such, mathematical models for long term diffusion problem and fluid models for terrain affected diffusion.

The pollutants released into atmosphere are transported and dispersed by wind. If we can assume that the diffusion of pollutant is proportional to the gradient of concentration, then the diffusion is expressed by the following equation:

$$\frac{\partial C}{\partial t} + u\frac{\partial C}{\partial x} + v\frac{\partial C}{\partial y} + w\frac{\partial C}{\partial z} = \frac{\partial}{\partial x}(Kx\frac{\partial C}{\partial x}) + \frac{\partial}{\partial y}(Ky\frac{\partial C}{\partial y}) + \frac{\partial}{\partial z}(Kz\frac{\partial C}{\partial z}) + Q$$

Equation V-1-1

where;

Kx : eddy-diffusion coefficient in the x-direction (m^2/sec)
Ky : eddy-diffusion coefficient in the y-direction (m^2/sec)
Kz : eddy-diffusion coefficient in the z-direction (m^2/sec)
Q : Source strength (unit/sec)

Almost all of mathematical models adopt this equation of diffusion.

(i) Numerical model

Numerical models solve diffusion equation by finite difference method or finite element method using digital computer. They are quite effective because of their applicability to non-steady conditions and also to complicated flow field conditions.

However, they require long computer time and expenses, therefore, it is not adequate to apply a numerical model to a simulation of long term average concentration, in which calculation should be done for many meteorological conditions.

Numerical methods are now adopted for regulated problems which are difficult to apply by analytical models, such as diffusion of chemically active pollutants like hydrocarbon, oxidant, etc.

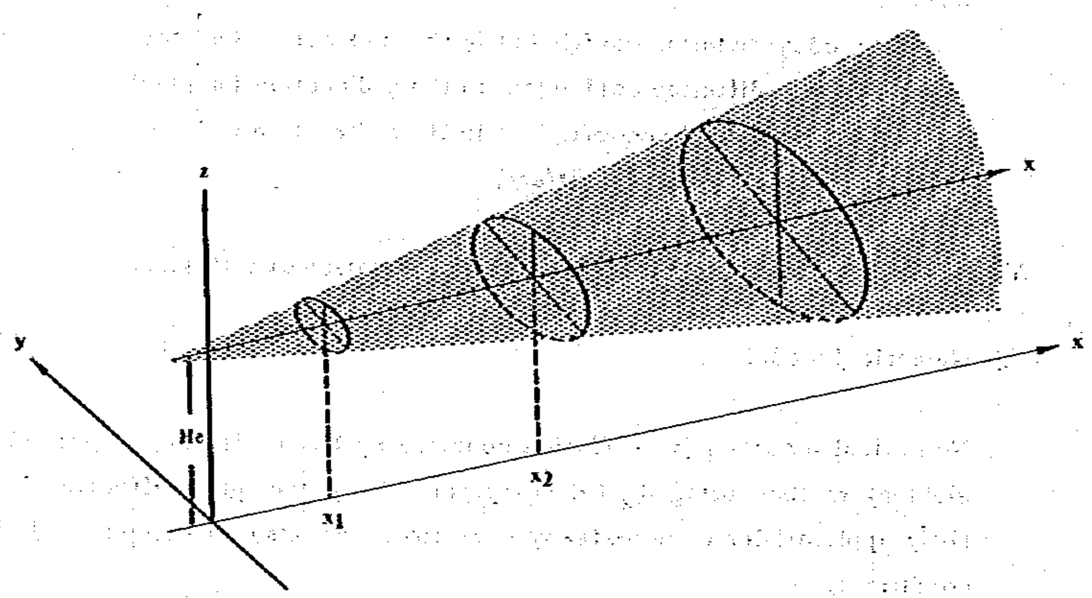
(ii) Analytical models

Analytical model is the model in which analytical solution of diffusion is used to estimate concentration of pollutants. Many solutions have been proposed for different boundary and flow conditions. And now, Gaussian plume and Gaussian puff models are most commonly used.

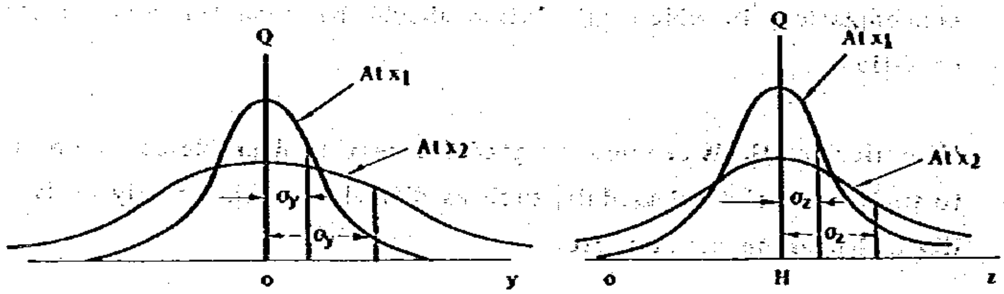
(a) Gaussian plume model

Gaussian plume model is the solution of Fickian type diffusion equation in which flow velocity and diffusivities are assumed constant every where and source emission is also continuous.

Then the pollutant disperses like a plume and the concentration profiles in lateral and vertical are expressed by Gaussian distributions.



A. Three dimensional plume of material



B. Component distribution of material at (x_1, o, He) and (X_2, o, He)

Fig. V-1-2 Schematic representation of the Gaussian plume model

By the plume equation, concentration of a pollutant at a point (x, y, z) is given by

$$C(x,y,z) = \frac{Q}{2\pi\sigma_y\sigma_z u} \exp\left(-\frac{y^2}{2\sigma_y^2}\right) \left\{\exp\left(-\frac{(z-He)^2}{2\sigma_z^2}\right) + \exp\left(-\frac{(z+He)^2}{2\sigma_z^2}\right)\right\} \quad \text{Equation V-1-2}$$

where the notations are as follows :

- C (x,y,z) : Concentration of a pollutant at a point (x,y,z)
- x,y,z : Longitudinal, lateral and vertical coordinate of the point. x and y are measured from source point and lateral distance from the axis which passes through source point, respectively. z is the vertical height of the point above the ground.
- Q : Emission rate of the pollutant (m^3/s)
- U : Wind velocity (m/s)
- He : Effective height of the plume axis (m)
- σy : Plume width in lateral direction (m)
- σz : Vertical plume width (m)

In the equation, the ground point where source stack stands is the origine (0,0,0), x axis is down wind and y axis is taken normal to the x axis. The z axis is taken vertically upwards. Therefore, the coordinate of the source point is (0,0,He), where He is the effective plume height, i.e., sum of stack height and plume rise.

The Equation V-1-2 gives Gaussian distribution of concentration in y direction with highest concentration just below the plume axis (y=0). The ground surface is assumed to be perfect reflective, so the imaginary source is introduced by the second term in the square brackets.

The plume Equation V-1-2 requires following conditions to apply in strict sense.

i) The pollutant should be gases or small particles which should be small enough to neglect falling velocity.
ii) The pollutants should be inert gases or substances which are inactive, so that any production or dissipation can be neglective.
iii) The pollutants may not be absorbed or released from the ground surface.
iv) Wind velocity and direction should be constant in space and time.
v) The diffusivity is homogeneous.

vi) Emission rate of pollutant is constant and does not change with time.

vii) The diffusion in x direction can be negligible since the gradient of concentration is more than one order smaller than y or z direction.

The plume Equation V-1-2 is derived from the governing equation of diffusion (Equation V-1-1), together with the above assumptions. Then the diffusion coefficients and plume widths are related by

$$\sigma y^2 = 2Ky\ t$$
$$\sigma z^2 = 2Kz\ t \qquad \text{Equation V-1-3}$$

where, t is the travelling time.

The plume width σy and σz, especially σz is strongly influenced by the stability of atmosphere. In unstable atmosphere, where fluctuation of wind direction in vertical is large, plume disperses quickly and σz becomes large. On the other hand, in stable case, turbulence is suppressed and σz becomes small.

The plume width depends strongly on the turbulence intensity and several formulae of plume width in terms of turbulence intensity have been proposed. But in practical point of view, turbulence data for long terms are not easily obtained. Therefore, Pasquill's method which gives vertical and lateral plume widths for each stability category in the graph form is commonly used. The Pasquill's stability classification is already given in Table IV-1-12.

Pasquill's chart for σy and σz are given in Figs. V-1-3. The plume widths are read off from the figures at any down wind distance between 0.1 to 100 km and each stability class.

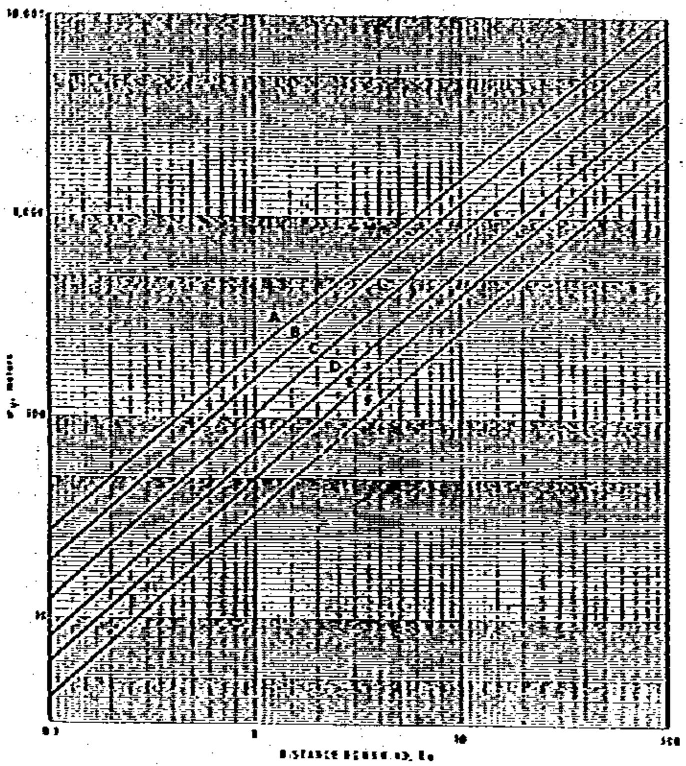


Fig. V-1-3-(a) Lateral plume width with respect to down wind distance for Pasquill's stability category A to F

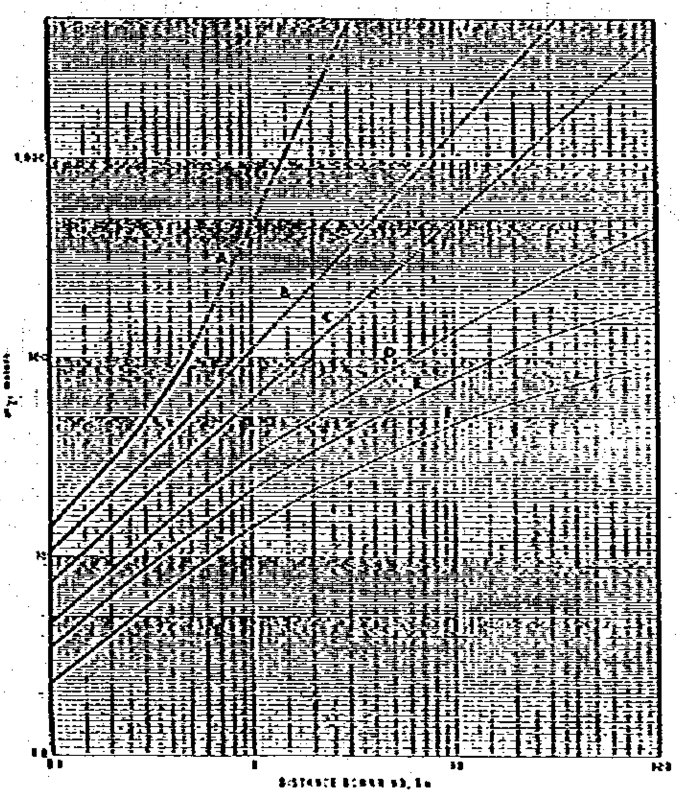
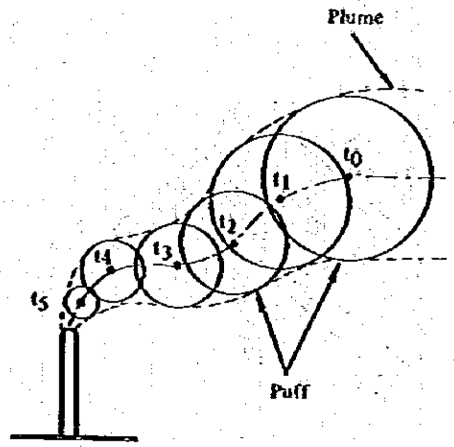


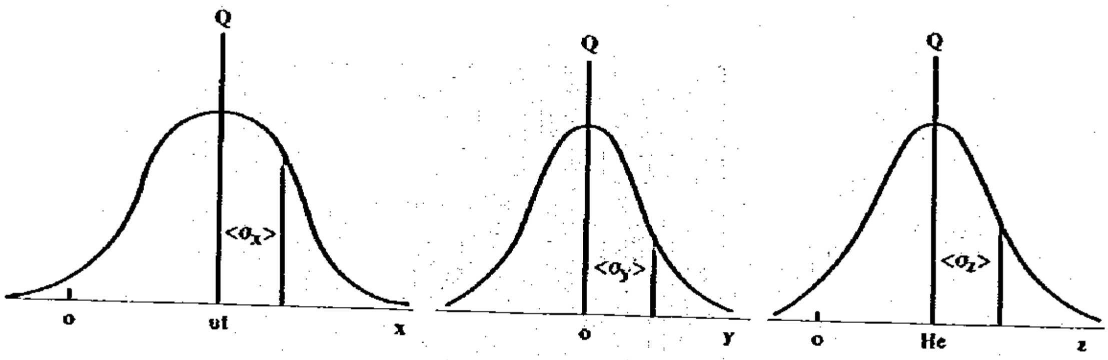
Fig. V-1-3-(b) Lateral plume width with respect to down wind distance for Pasquill's stability category A to F

(b) Gaussian puff model

The basic idea of the puff model is to express continuous plume by a series of discrete puffs as illustrated in Fig. V-1-4(A). In Gaussian puff model, the concentration profiles take Gaussian form for x, y and z axes (Fig. V-1-4(B)).



A. Expression of a plume by series of puffs



B. Component distributions of material about axes through (ut,o,H)

Fig. V-1-4 Schematic representation of the Gaussian puff model

The concentration at a point (x,y,z) by a puff element is expressed by the following equation:

$$C(x, y, z, t) = \frac{Q}{(2\pi)^{3/2} \sigma_x \sigma_y \sigma_z} \exp - \left[\frac{(x - \bar{u}t)^2}{2\sigma_x^2} + \frac{y^2}{2\sigma_y^2} \right]$$

Equation V-1-4

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

where, the symbols are

Q : Amount of pollutant emitted per unit time

x,y,z : Cartesian coordinates with the origin at the ground level point bellow the source. x axis is down wind direction, y is normal to x and z in vertical upwards.

U : Wind velocity

σx,σy,σz : Standard deviations of the material concentration distribution

t : Floating time of the puff after emitted from the source

Equation V-1-4 expresses the concentration by a puff and actual concentration by continuous source is given by summing up concentrations of all puffs. Then the equation is

$$C = \int_{T_1}^{T_2} \frac{Q}{(2\pi)^{3/2} \sigma_x \sigma_y \sigma_z} \exp \left\{ - \frac{(x - ut)^2}{2\sigma_x^2} - \frac{y^2}{2\sigma_y^2} \right\}$$

Equation V-1-5

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

For puff models, the regulation condition (iv), (vi) and (vii) are relaxed. Puff model is suitable for diffusion of nonsteady source and flow field conditions and also in light wind condition when pollutants disperse even up wind side. Puff models are usually used to calculate diffusion in calm condition. Then, the puff diffusion parameters σx, σy and σz are given as the function of travelling time and also stability conditions. Turner's charts in Figs. V-1-5 are most common as the puff diffusion parameters which are derived from the plume diffusion parameters by Pasquill and Gifford.

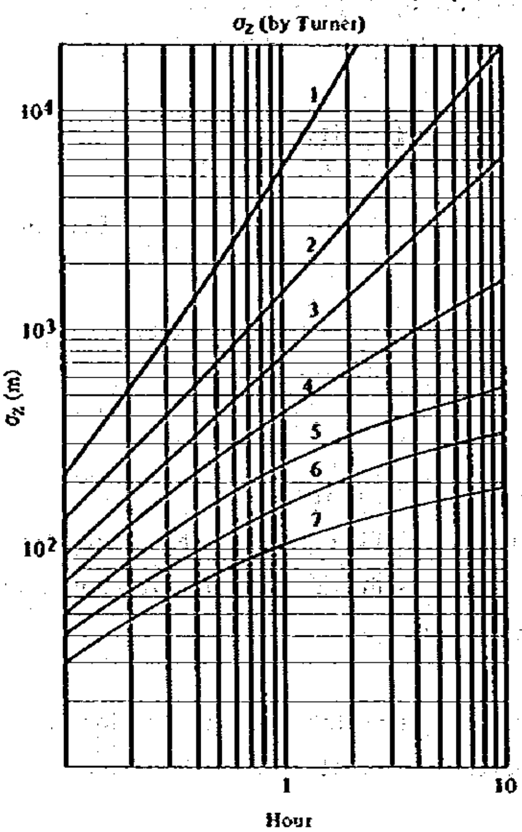


Fig. V-1-5-(a) Vertical puff width with respect to travelling time

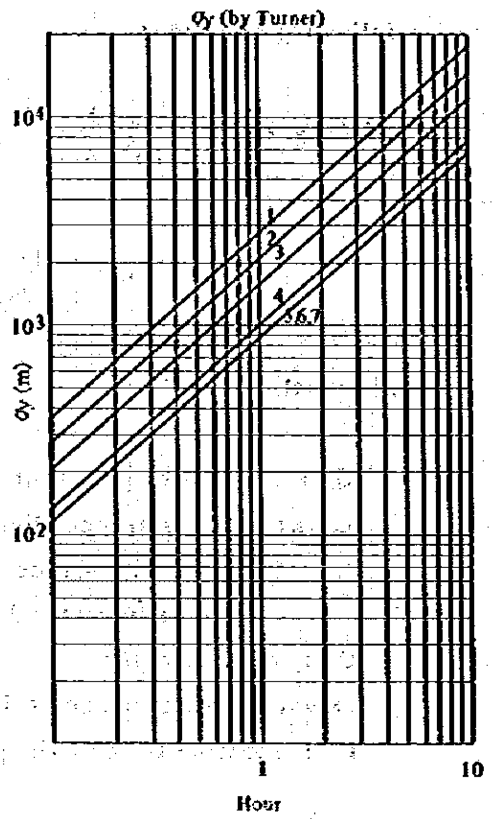


Fig. V-1-5-(b) Lateral puff width with respect to travelling time

(c) Calculation of plume rise

Stack gas emitted into the atmosphere rises itself by its momentum and buoyance and reaches to a height. The height is called as the effective stack height and denoted by He. He is the sum of stack height Ho and plume rise ΔH.

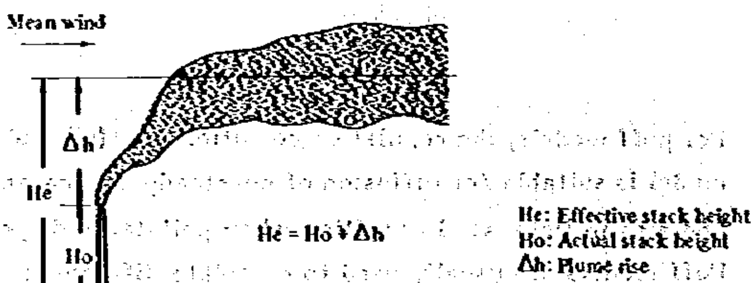


Fig. V-1-6 The relation between plume rise ΔH and effective plume height

In the calculation of plume and puff equations, pollutant is conventionally assumed to be emitted at the effective stack height. For the plume rise, many formulae, theoretical, empirical or semi emipirical have been proposed. Table V-1-1 shows the representative plume rise equations together with the application conditions of them.

In Japan, Moses-Carson and CONCAWE models are common in windy condition, and in calm condition Brigg's model is usually used. Moses-Carson formula takes into account the effect of stability but not in CONCAWE. And in Brigg's model, thermal stability is involved as the potential temperature gradient.

Table V-1-1 Plume rise equation and its application range

	Year	Plume rise equation Q_H (kcal/sec), U (m/sec), H_S (m), ΔT (°K) T_a (°K), V (m/sec), Q_V (m³/sec), $\Delta\theta/\Delta z$ (°K/m)	Theoretical or empirical	Stability condition	Basic conditions of used data			
					Q_H (kcal/sec)	Hs (m)	U (m/sec)	V (m/sec)
1 Bosanquet 1st formula	1950	$\Delta h = \Delta h_m + \Delta h_b$ $\Delta h_m = [4.77/(1+0.43U/V)] \cdot \sqrt{Q_v \cdot V}/U$ $\Delta h_b = 6.37g \frac{Q_v \cdot \Delta T}{U^3 \cdot T_s}(\ln J^2 + \frac{2}{J} - 2)$ $J = \frac{U^2}{\sqrt{Q_v \cdot V}}(0.43\sqrt{\frac{T_s}{g\Delta\theta/\Delta z}} - 0.28\frac{V}{g}\frac{T_s}{\Delta T}) + 1$	Theoretical (Bosanquet)	Unstable to neutral $\Delta\theta/\Delta z = 0.003$	70~1500	-	3.1~8.1	8~10.8
2 Bosanquet 2nd formula	1957	$\Delta h = \Lambda U\left[f_I(a) + f_{II}(a_o) - \{0.615\, a_o^{1/2}/(\langle V/U\rangle^2 + 0.57)^{1/2}\}\right]$ $\Lambda = g \cdot Q_v \cdot \Delta T/2\pi C^2 Ta^* U^*$ $a = (t + t_o)/\Lambda = (t/\Lambda_s) + a_o$ $a_o = t_o/\Lambda \quad t = x/U \quad t_o = 4 \cdot V \cdot Ta/3g\Delta T$ $t + t_o = 20$ sec, $C = 0.13$ $f_I(a), f_{II}(a_o)$	Theoretical (Bosanquet)	Unstable to neutral $t + to = 200$sec at stable $t + to = 1.572 \times (2To/g\Delta\theta/\Delta z)^{1/2}$	70~1500	-	3.1~8.1	8~10.8
3 Bosanquet II modified at CRIEPI	1965	Diffusion coefficient $C = 0.13$ of Bosanquet 2nd formula replaced by $C = 0.26U^{-1/2}$	Theoretical (Bosanquet)	Same as above	1500~17000	80~200	1~15	13.2~35
4. CERL formula (Lucas 2nd formula)	1967	$\Delta h = (104 + 0.17\,Hs)\,Q_H^{1/4}/U$	Theoretical (Priestley)	Consideration not given	7000~25000	76~183	1.5~11.3	14~24.5
5 Moses & Carson formula	1968	$\Delta h = (C_1\, VD + C_2\, Q_H^{1/2})/U$ $C_1 = 0.35,\ C_2 = 5.41$ (at neutral)	Regression equation	C_1, C_2 different at unstable or stable	2~2500	34~183	1~11.7	2.2~24.5
6 CONCAWE formula	1968	$\Delta h = 5.53\, Q_H^{1/2} U^{-3/4}$	Regression equation	Consideration not given	70~4000	-	4~10	3.3~17
7 Briggs formula	1969	$\Delta h = 1.6F^{1/3}U^{-1}(3.5x^K)^{2/3} \quad x^K = 34F^{2/3}$ ($F > 55$ m⁴/sec³) $\Delta h = 5.35\, Q_H^{0.6}/U$ ($Q_H > 1500$ kcal/sec)	Dimensional analysis (Briggs)	Applied at unstable to neutral, another formula for stable	1000~21000	61~183	1.8~16.5	5.5~28.9
8 TVA formula	1971	$\Delta h = 114\, CF^{1/3}/U,\ C = 1.58 - 41.4\,\Delta\theta/\Delta z$ $\Delta\theta/\Delta z = 0 \quad \Delta h = 60Q_H^{1/3}/U$	Dimensional analysis	$\Delta\theta/\Delta z > 0.003$	7000~25000	76~183	1.5~11.3	14~24.5
9 Okamoto, Okanishi and Shiozawa formula	1979	$\Delta h = 5.5\, Q_H^{1/2}/U^{3/4}$	Regression equation	Consideration not given	100~47000	20~366	1~17	2~40

V-1-2 Composition of the Diffusion Model

As stated in the previous section, many models or equations have been proposed as the diffusion prediction model, and each of them possesses own speciality. The optimal prediction models should be selected by considering the pollutant species, source conditions, width of the objective area, topographical conditions, time scale of averaging of concentration.

The objective of this research is to predict the environmental concentration of SO_2 in Singapore at the future stage (1990), when electric power plants and steel plant are planned to work. The time scale of averaging is one year or a season and the regional scale is whole of Singapore, and Singapore is flat and topographical effect is negligible. Therefore, in this research, Gaussian plume and puff models which are most commonly used and well established technically are adopted as the diffusion model.

The present model consists of four sub-models of flow field, source emission, diffusion and averaging models. The construction of prediction model and outline of sub-models are given in Fig. V-1-7 and Table V-1-2.

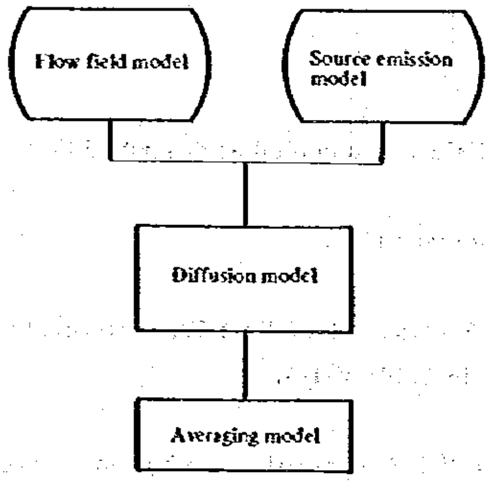


Fig. V-1-7 Construction of prediction model

Table V-1-2 Items in construction of prediction model

	Items	Description
Flow field model	Occurrence frequency	Joint probability frequency of wind direction, velocity and stability
	Wind velocity of upper layer	Power law exponent
Source emission model	Source data	Source location, height, emission data etc.
	Plume rise calculation	Moses & Carson and Brigg's equation
Diffusion model	Diffusion equation	Gaussian plume and puff equation
	Plume and puff widths	Pasquill-Gifford, Turner's chart
Averaging model	Calculation of annual average	Weighed average by joint frequency occurrence of meteorological conditions

The source emission and flow field submodels have been produced on the basis of the analyzed results of meteorology and source emission data.

V-1-3 Description of Submodels

V-1-3-1 Flow field model

Meteorological flow field was modeled as described below by season, time and region.

(1) Classification by season and time

As already stated in Section 1-1 of Part IV, meteorological flow field was classified by season and time as in Table V-1-3.

Table V-1-3 Classification by season and time

Season / Time	SW Monsoon	NE Monsoon
	April to October	November to March
Day	7:00 - 17:59	7:00 - 17:59
Night	18:00 - 6:59	18:00 - 6:59

(2) Classification of meteorological condition

Meteorological condition was classified by wind direction, wind velocity and stability. The classification of each term is as follows:

Wind direction: 16 different wind vectors
Wind velocity : 7 ranks as shown in Table V-1-4.

Table V-1-4 Wind velocity classes and representative wind velocity

Velocity interval		Representative velocity
Calm	0 - 0.4 m/s	0.0
Windy	0.5 - 0.9	0.7 m/s
	1.0 - 1.9	1.5
	2.0 - 2.9	2.5
	3.0 - 3.9	3.5
	4.0 - 5.9	5.0
	6.0 -	7.0

Atmospheric stability: The atmospheric stability was categorized by MITI method which is modified Pasquill's and uses net radiation flux instead of cloud coverage (Table IV-1-13). The stability is categorized into 6 classes for windy and 4 classes for calm.

(3) Regional separation

a. Vertical composition

As explained in Section 1-6 of Part IV, wind velocity and turbulence are influenced by ground surface and change with height. The transport and dispersion of pollutant are also influenced and change with height. To reproduce the difference of diffusion by height, the flow field was separated into two layers as in Table V-1-5.

Table V-1-5 Two layers and meteorological conditions

Classification	Source application	Meteorological condition
Upper layer	Sources with a stack of more than 50 meters high	Wind direction at the representative station. Wind velocity at stack height was calculated by power law and applied.
Lower layer	Factory stacks less than 50 meters high and emission by vessels	Wind velocity at the representative station was applied.

The wind velocity in upper layer was calculated by applying power law. The exponent P should be derived from the data obtained at objective area. But in this research, suitable data were not available. Therefore, the exponent P which are adopted by EPA of U.S.A. in their CDM manual were used. The power law formula is cited again.

$$U(Z_2) = U(Z_1)(Z_2/Z_1)^P \qquad \text{Equation V-1-6}$$

Table V-1-6 Values of P by DDM manual of EPA

Pasquill's stability category	A	B	C	D	E	F
P	0.1	0.15	0.20	0.25	0.25	0.30

Remarks: These values have been proposed by Demarrais (1959) based on the wind velocity data at 145 m and ground level of Brook Haven Tower. The tower is sited near coast and surrounded by gently rolling hills with pine trees.

b. Regional block separation

As stated in Chapter 1 of Part IV, the cluster analysis and principal component analysis suggested that the monitoring stations are divided into two groups, i.e., western group MP-1 to MP-5 and eastern group MP-6 and MP-7. The local wind system is different in two groups.

When these exists clear differences in local wind characteristics, we separate the objective area into several regional blocks and do the diffusion calculation of pollutants sources inside by the local wind of the block.

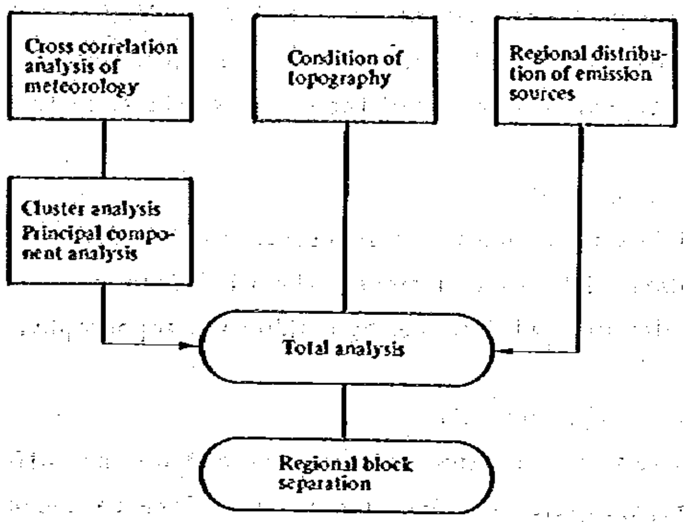


Fig. V-1-8 Procedure of regional block separation

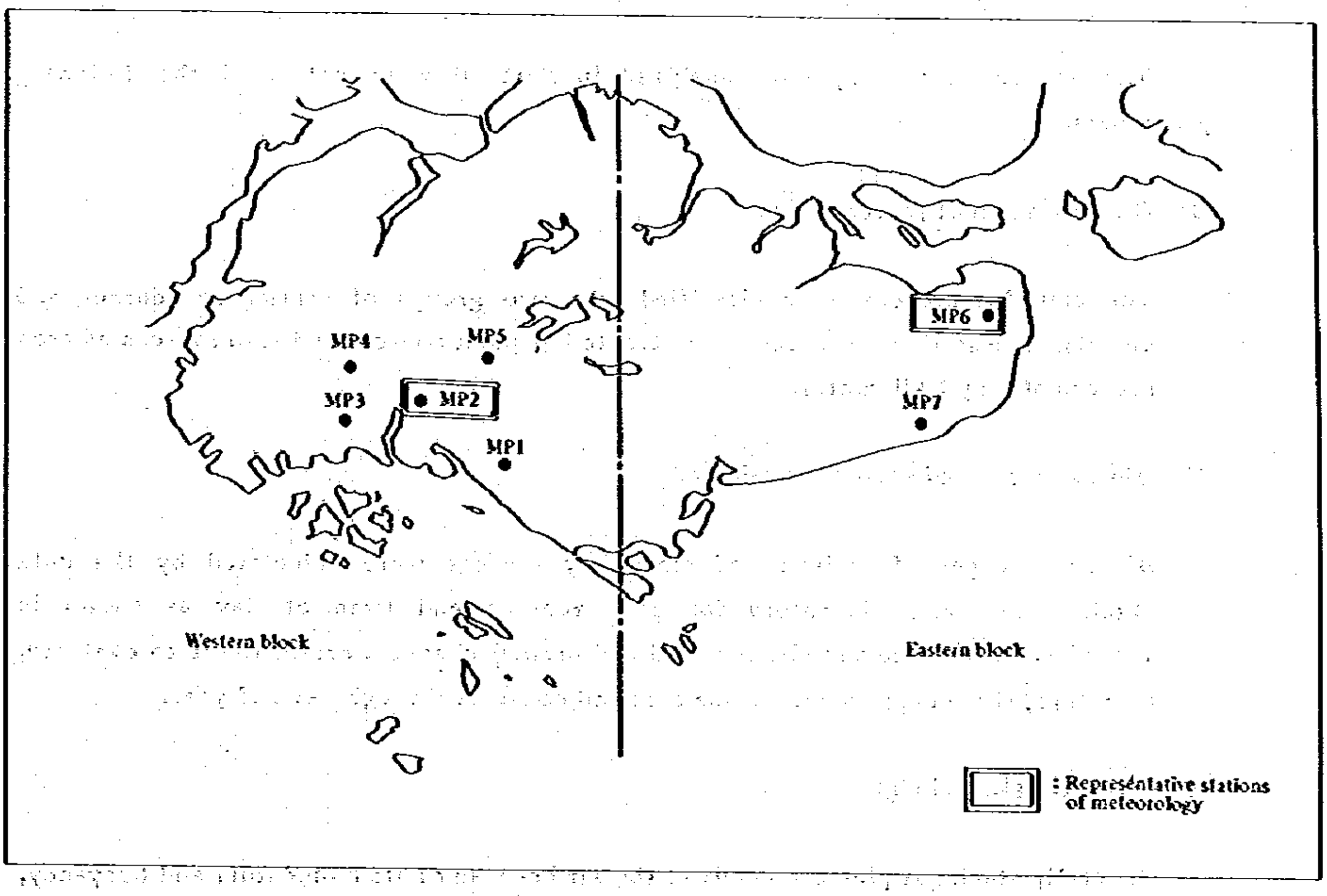


Fig. V-1-9 Regional block and the representative stations

In this research project, the whole area was divided into two regional blocks, e.e., western part and eastern part, and JTC Hall and Changi Airport Monitoring Stations were selected as the representative meteorological stations, respectively. The reason of the choice of the two-stations are as follows:

MP-2 (JTC Hall):

Close to the main emission sources and showed high cross correlation of wind data with other stations. The wind data were obtained at suitable height without any influences by buildings or topography.

MP-6 (Changi Airport):

The station located at open area and was not affected by any buildings and topography. The location is also close to Tekong where steel plant and power plant are planned to locate.

V-1-3-2 Modeling of emission sources

The emission inventory data analyzed in Part III were patterned the following procedures.

(1) Classification of sources

The emission sources were classified into two groups of stationary sources and vessels. The stationary sources were treated as point sources and skip sources as area sources of 1 by 1 kilometer.

(2) Diurnal change of source emission

Diurnal changes of emission of stationary sources were calculated by the data obtained at source inventory for each reasons and time of day as shown in Table V-1-3. For the vessels, seasonal and diurnal change were difficult to evaluate, therefore, the source condition was assumed constant through day and year.

(3) Effective plume height

Generally stack gas plume ascends in the air because of its momentum and buoyancy, and reaches some level (Fig. V-1-10).

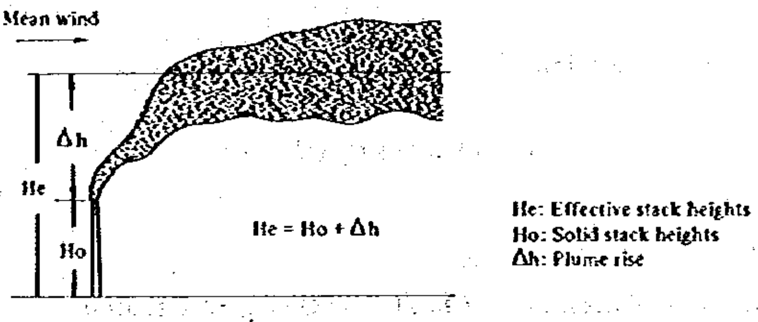


Fig. V-1-10 Effective stack height

The final height is called effective stack height (He) and diffusion calculation is done as if the plume gas is emitted at He. He is the sum of stack height Ho and plume rise ΔH.

In this diffusion model, the plume rise ΔH was calculated by Moses-Carson or CONCAWE equation for windy condition and by Brigg's equation in calm condition. The formulae used for different sources and wind conditions are summarized in Table V-1-7.

Table V-1-7 Plume rise equations applied for sources and wind conditions

Sources		Windy ($U > 0.4$ m/s)	Calm ($U \leq 0.4$ m/s)
Stationary sources	Stack height more than 50 m	Moses & Carson equation	Brigg's equation
	Stack height less than 50 m	CONCAWE equation	
Vessel		CONCAWE equation by average emission of a ship	Brigg's equation *

* The calculated effective stack heights (He) of vessel effluent gas for each wind conditions are as follows:

Velocity (m/s)	CALM (0 - 0.4)	0.5 - 1.9	2.0 - 3.9	4.0 -
Effective height	170 m	54 m	38 m	32 m

The plume rise formulae are given as follows:

a. Moses-Carson equation

$$\Delta h = (C_1 \cdot Vs \cdot D + C_2\ Q_H^{1/2}) \cdot U^{-1} \qquad \text{Equation V-1-7}$$

where;

Q_H : Emission rate of heat = $\rho \cdot Q \cdot C_p \cdot \Delta T$ (cal/s)

C_p : Specific heat of effluent gas at constant pressure usually the gas is assumed to be the air = 0.24 (cal/g.k)

ρ : Density of effluent gas if it is assumed to be the air = 1293 (g/m^3)

Q : Rate of the mass effluent gas (Nm^3/s)

ΔT : Temperature difference between the effluent gas and ambient air, usually assumed to be equal to (T_G - 15) (k)

T_G : Temperature of the effluent gas (°C)

U : Wind velocity at the stack height (m/s)

V_s : Speed of effluent gas at the exit of stack (m/s)

D : Diameter of exit of the stack (m)

For the constants C_1 and C_2, proposed values by Moses and Carson are used.

	$d\theta/dz$	C_1	C_2
Unstable	$d\theta/dz < 0$	3.47	0.33
Neutral	$d\theta/dz = 0$	0.35	0.171
Stable	$d\theta/dz > 0$	-1.04	0.145

Here $d\theta/dz$ is the potential temperature gradient and given by

$$\frac{d\theta}{dz} = \frac{dT}{dz} + \Gamma d \quad (°C/m)$$

where, Γd is the dry adiabatic lapse rate and equal to 0.0098 (°C/m).

b. CONCAWE equations

By CONCAWE equation, plume rise Δh is given by

$$\Delta h = 0.175\, Q_H^{1/2}\, U^{-3/4}$$ Equation V-1-8

c. Brigg's equation for calm condition

Brigg's equation for calm condition is written by

$$\Delta h = 1.4 \cdot Q_H^{1/4} \cdot (d\theta/dz)^{-3/8}$$ Equation V-1-9

where, following value is used for $d\theta/dz$:

$$\frac{d\theta}{dz} = 0.005\ (°C/m)$$

For calculation of plume rises in low wind condition (0.4 - 0.9 m/s), wind velocity of 1 m/s is assumed, since less than that, both equations cannot give reasonable value of plume rise.

V-1-3-3 Diffusion calculation

In this research project, Gaussian plume and puff equations are adopted for diffusion calculation of different category of sources and meteorological conditions. The application of plume and puff equations for sources and wind conditions are shown in Table V-1-8.

Table V-1-8 Diffusion models for different category of sources and wind conditions

Sources	Type of source	Diffusion model	
		Windy (U > 0.4 m/s)	Calm (U ≤ 0.4 m/s)
Stationary source	Point source	Plume equation (Equation V-1-11)	Puff equation Equation V-1-13)
Vessels	Area source	Plume equation for area source (Equation V-1-14)	Puff equation for area source (Equation V-1-15)

(1) Diffusion equation

a. Plume equation for point source

The concentration at a point (x,y,z) by original plume equation for point source is given by

$$C(x, y, z) = \frac{Q_p}{2\pi\sigma_y\sigma_z u} \cdot \exp\left(-\frac{y^2}{2\sigma_y^2}\right) \left[\exp\left\{-\frac{(z-He)^2}{2\sigma_z^2}\right\} + \exp\left\{-\frac{(z+He)^2}{2\sigma_z^2}\right\}\right] \quad \text{Equation V-1-10}$$

where, coordinate system is x axis down wind. y axis horizontal but normal to x, and z axis vertically upwards. The origin is on the grouns surface just below the stack.

x,y,z: Coordinate of the point where the concentration is given (m)
Qp : Rate of pollutant emission (m^3/s at 27°C)
U : Wind velocity (m/s)
He : Effective stack height (m)
C (x,y,z): Pollutant concentration at a point (x,y,z)
σy, σz: Lateral and vertical widths of the plume at a down wind distance x (m).

Plume widths σy, σz will be discussed later.

In the estimation of pollutant concentration, diffusion calculation is done for each wind direction of 16 sectors. The frequency distribution of wind direction inside of each sector is assumed to be equally flat, and the lateral distribution of concentration inside of each sector is also assumed constant. Then a modified plume equation (Holland (1953)) which gives the laterally averaged concentration in one sector is more suitable for long term average concentration. In this research the modified Equation V-1-11 is used.

$$C(R, z) = \sqrt{\frac{1}{2\pi}} \frac{Q_p}{\frac{\pi}{8} R\sigma_z u} \cdot \left[\exp\left\{-\frac{(z-He)^2}{2\sigma_z^2}\right\} + \exp\left\{-\frac{(z+He)^2}{2\sigma_z^2}\right\}\right] \quad \text{Equation V-1-11}$$

where, R is the horizontal distance between source and the calculation point.

b. Puff equation for calm condition

The pollutant concentration at a point (x,y,z) in calm condition by original puff equation is given by

$$C(x,y,z)=\frac{Q_P}{(2\pi)^{3/2}\,\sigma_x\sigma_y\sigma_z}\cdot\exp\left(-\frac{x^2}{2\sigma_x^2}-\frac{y^2}{2\sigma_y^2}\right)\cdot\left[\exp\left\{-\frac{(z-He)^2}{2\sigma_z^2}\right\}+\exp\left\{-\frac{(z+He)^2}{2\sigma_z^2}\right\}\right]$$

Equation V-1-12

The Equation V-1-12 gives the concentration by one puff and should be summed up for all floating puffs to obtain total concentration. The diffusion parameters σx, σy, σz are functions of travelling time t, and if they are assumed to be proportional to t as follows:

$\sigma_x=\sigma_y=\alpha t$

$\sigma_z=\gamma t$,

Then, Equation V-1-12 is integrated with respect to t and steady state concentration by continuous puffs is given by

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

Equation V-1-13

where, R is the horizontal distance between source and calculation point.

c. Plume equation for area source

Since the emission by vessels are difficult to decide strictly the location of them, emission is assumed to spread in an area of a square of 1 kilometers.

The diffusion calculation for area source is done by assuming area source as a set of sub-area sources as shown in Fig. V-1-11. The sub-area source is treated as a point source, and total concentration is given by integrating concentration for whole area, i.e.,

$$C(x,y,z)=\int_{x-a}^{x+a}\int_{y-a}^{y+a}\frac{Q_A}{2\pi\sigma_y\sigma_z u}\cdot\exp\left(-\frac{\eta^2}{2\sigma_y^2}\right)\left[\exp\left\{-\frac{(z-He)^2}{2\sigma_z^2}\right\}+\exp\left\{-\frac{(z+He)^2}{2\sigma_z^2}\right\}\right]d\eta\,d\xi$$

Equation V-1-14

where, symbols are as follows:

Q_A : Source strength of area source for unit area and time ($m^3/s/m^2$ at 27°C)

a : Half length of the side of area source

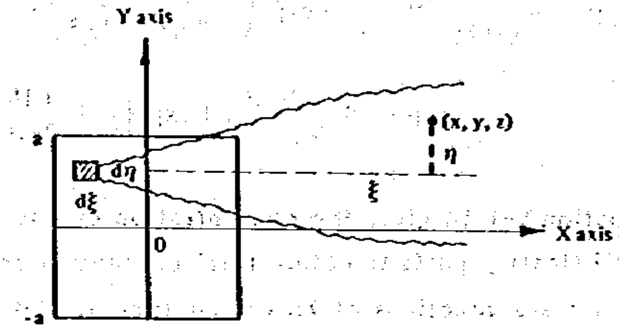


Fig. V-1-11 Area source and sub-area source

In Equation V-1-14, if the calculation point is inside of the source ($|x| < a$), then, integration with respect to ξ is done with respect to x-a to x.

d. Puff equation for area source

In calm condition, puff integration of area source is done in conventional way. The square area source is replaced conventionally to a circular area with equal cross section as shown in Fig. V-1-12.

Then the radias of source circle is equal to $a' = 1.132^a$, and integration with respect to arc element $d\theta.dr$ is done assuming it as a point source. The equation is written as follows:

$$C(R,z)\int_0^{a'}\int_0^{2\pi}\frac{Q_A}{(2\pi)^{3/2}\gamma}\left\{\frac{1}{R'^2+\frac{\alpha^2}{\gamma^2}(He-z)^2}+\frac{1}{R'^2+\frac{\alpha^2}{\gamma^2}(He+z)^2}\right\}d\theta\, d\gamma \quad \text{Equation V-1-15}$$

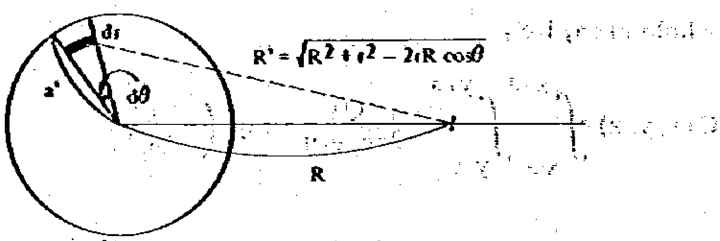


Fig. V-1-12 Concept of puff diffusion model for area source

(2) Diffusion parameters for puff and plume

The diffusion parameters (plume widths) for plume equation are decided as in Table V-1-9 for each stability category and also for higher and lower sources. The parameters are equal to Pasquill's charts but the stability is changed as to reproduce the actual concentration as well as possible.

Table V-1-9 Diffusion parameter for plume equation

Source	Stability	A	B	C	D	E	F
Higher source	Stationary source of stack height over 50 m	C			D	D-E	E
Lower source	Stationary source of stack height less 50 m & vessels	B		C	D	E	F

Note: Symbols are equal to Pasquill's chart.

For diffusion parameters of puff model, MITI charts which are modification of Turner's charts are examined and used. The Pasquill-Gifford charts and MITI charts are shown in Figs. V-1-13 and V-1-14.

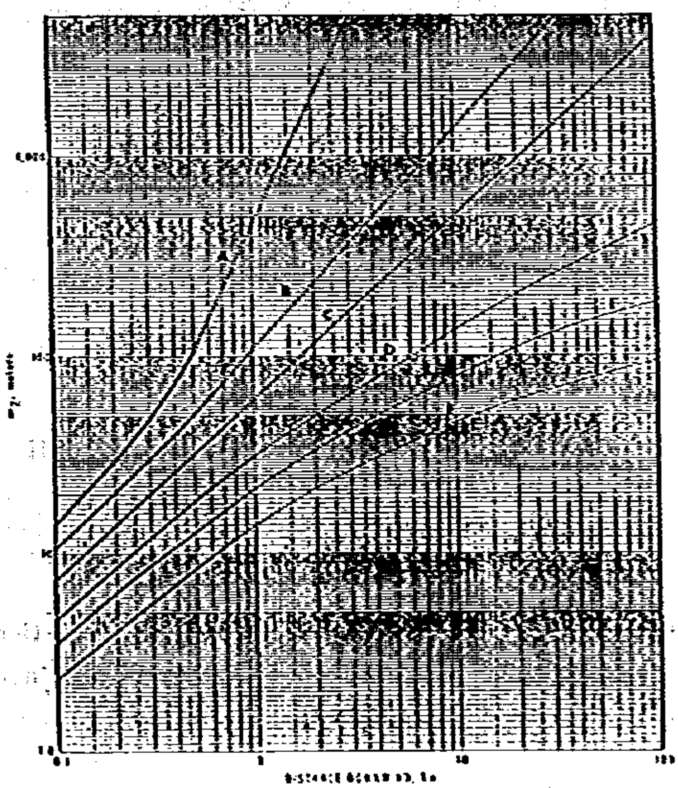


Fig. V-1-13-(1) Pasquill-Gifford charts

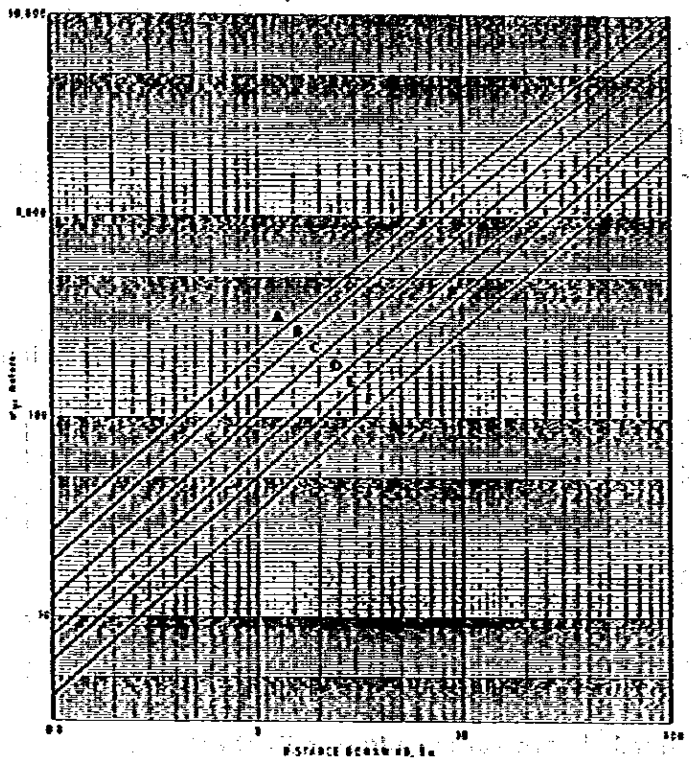


Fig. V-1-13-(2) Pasquill-Gifford charts

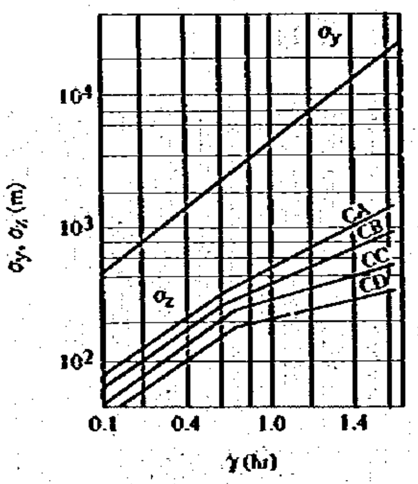


Fig. V-1-14 Puff diffusion parameters by MITI

V-1-3-4 Calculation of long term average concentration

Diffusion calculations are done for each class of wind direction, wind velocity and stability category, and long term average concentration is obtained by taking weighed average by joint frequency of each meteorological class.

The weighed average concentration for windy condition is given by

$$\bar{C} = \sum_i \sum_j \sum_k C(D_i,V_j,st_k) \cdot f(D_i,V_j,st_k)$$

where, $C(D_i,V_j,st_k)$ is the hourly concentration under the meteorological category of wind direction D_i, wind velocity rank V_j and stability category st_k, $f(D_i,V_j,st_k)$ is the joint frequency of D_i, V_j, st_k.

The weighed average concentration for calm condition is similarly given by

$$\bar{C} = \sum_k C(st_k) \cdot f(st_k)$$

where, $C(st_k)$ is the hourly concentration under stability category st_k. $f(st_k)$ is the frequency of stability category st_k.

The weighed average concentrations for windy and calm conditions are calculated for each season and time of day.

V-1-3-5 Evaluation of the simulated concentration

The simulated long term average concentrations of the diffusion model are examined and evaluated by the following criteria.

(1) Evaluation criteria

For the evaluation of simulated results, criteria by Environmental Agency, Japan has been applied. The method is to evaluate annual, seasonal, daytime and nighttime averages into three ranks A, B and C by regression coefficient, correlation coefficient and variance. The desirable rank for each average values are shown in Table V-1-10, and the criteria of the ranks are given in Table V-1-11.

Table V-1-10 Evaluation criteria by Environmental Agency, Japan

	Seasonal average	Annual average
Daytime or nighttime average	C	B
Total average	B	A

Table V-1-11 Criteria of ranks

Rank	Criteria of ranks
A	$a_0 \leq \frac{1}{3}(\bar{y} - B_G) + B_G$, $a = 0.8 \sim 1.2$, $r \geq 0.71$, $s'/\bar{y} \leq \frac{1}{4}$ or $a_0 \leq \frac{1}{3}(\bar{y} - B_G) + B_G$, $s'/\bar{y} \leq \frac{1}{5}$
B	$a_0 \leq \frac{2}{5}(\bar{y} - B_G) + B_G$, $s'/\bar{y} \leq \frac{1}{4}$
C	$a_0 \leq \frac{2}{5}(\bar{y} - B_G) + B_G$, $s'/\bar{y} \leq \frac{1}{3}$

Remarks: $\bar{y}$ is the average value of observations. $\bar{x}$ is the average of simulated values. a and r are the regression coefficient and correlation coefficient, respectively. $s'/\bar{y}$ is the variance. B_G is the unsimulated background value and assumed as 0.003 ppm.

(2) Evaluation of simulated results

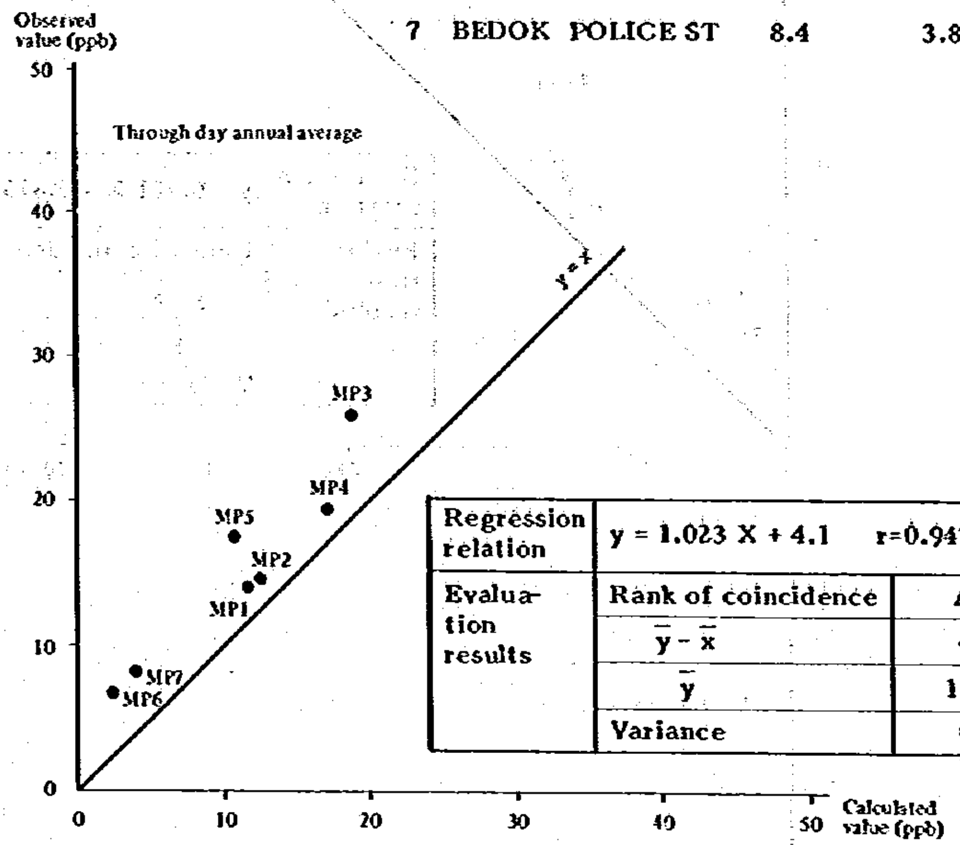
The ranks of simulated results for seasonal, daytime nighttime and annual averages are shown in Table V-1-12. Except nighttime average of NE Monsoon season, ranks of coincidence of observed and simulated concentration were better than B.

Table V-1-12 Evaluated ranks of average concentrations

Season	SW Monsoon (April to Oct.)	NE Monsoon (Nov. to March)	Annual average
Daytime (7:00 - 18:00)	B	B	A
Nighttime (18:00 - 7:00)	A	C	A
Whole day average	B	B	A

A scatter diagram of simulated and observed SO_2 concentration of annual averages is given in Fig. V-1-15.

Site No.	Station	Observed	Calculated
1	N.U.S.	14.2	11.6
2	J.T.C. HALL	14.6	12.4
3	S.I.U.	26.2	18.9
4	BOON LAY APART	19.4	17.1
5	BUKIT TIMAH FS	17.6	10.6
6	CHANGI AIRPORT	6.7	2.4
7	BEDOK POLICE ST	8.4	3.8



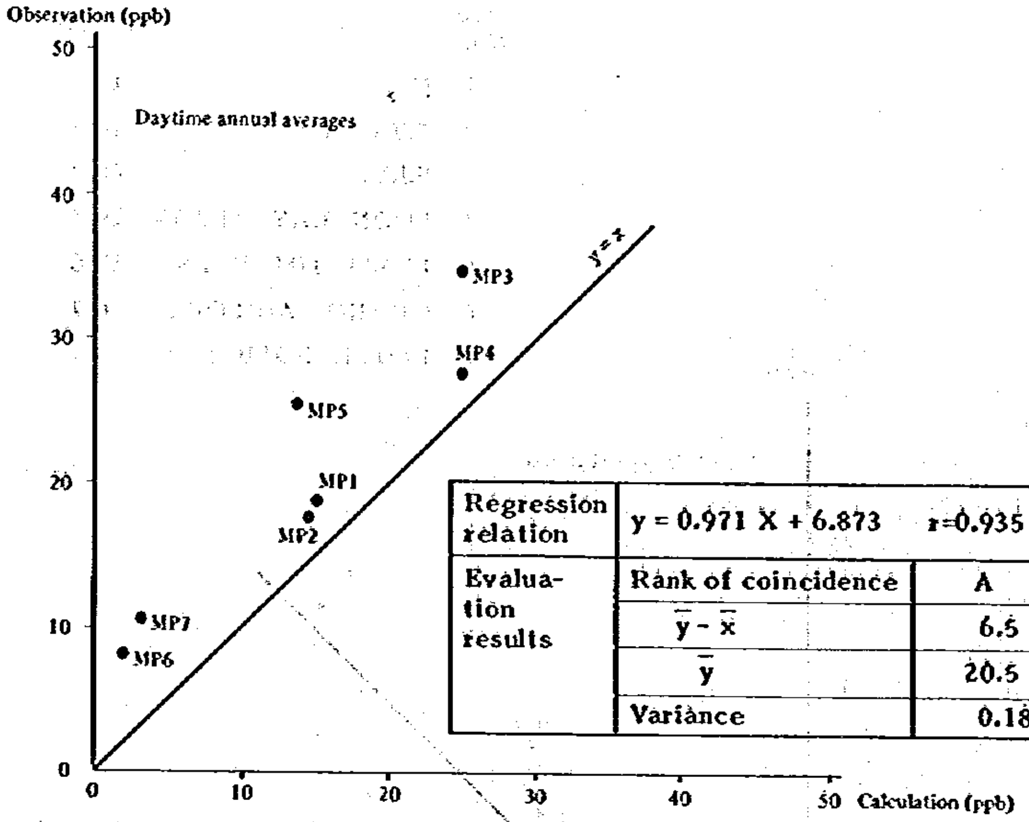
Regression relation	y = 1.023 X + 4.1 r=0.947	
Evaluation results	Rank of coincidence	A
	$\bar{y} - \bar{x}$	4.3
	$\bar{y}$	15.3
	Variance	0.15

Fig. V-1-15 Scatter diagram of simulated and observed SO_2 concentration

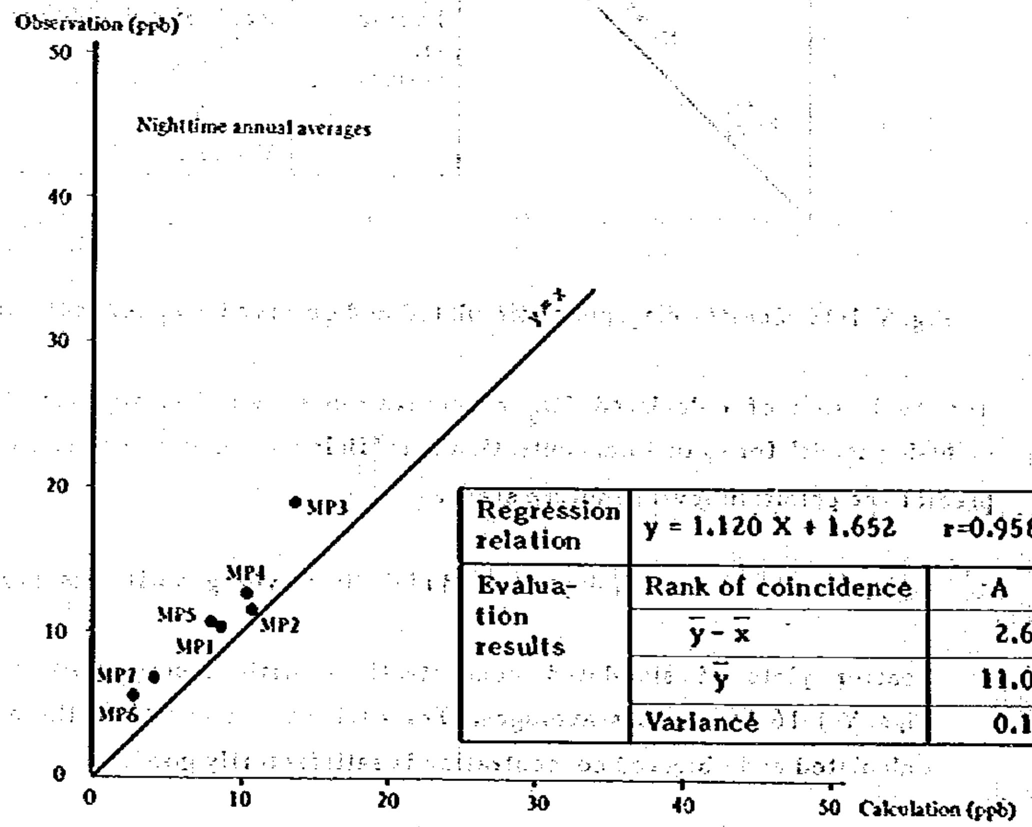
The evaluation of calculated SO_2 concentration shows that reproducibility of the diffusion model for actual concentration is sufficiently good and it can be applied to predict the pollution level in future stage.

a. Comparison of seasonal, daytime and nighttime averages with observation.

Scatter plots of simulated concentrations with observations are given in Figs. V-1-16 for various averages. For each season and time the agreement of calculated and observed concentration is satisfactorily good.

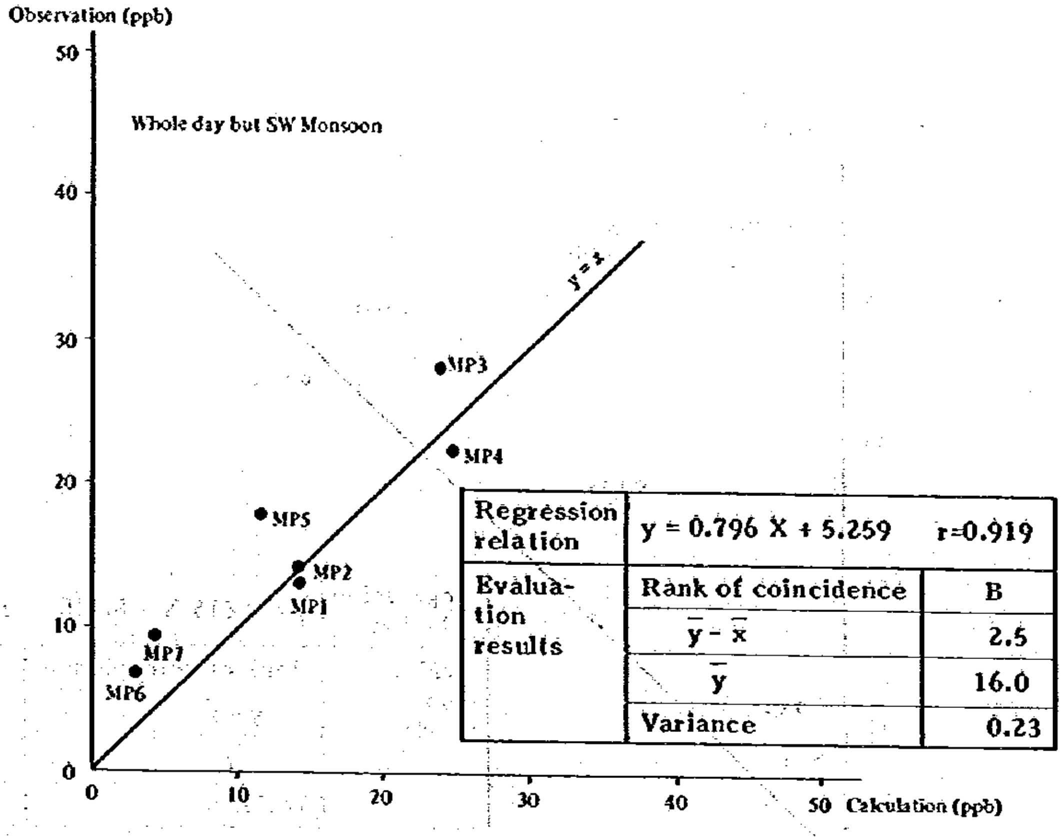


Regression relation	y = 0.971 X + 6.873 r=0.935	
Evaluation results	Rank of coincidence	A
	$\overline{y} - \overline{x}$	6.5
	$\overline{y}$	20.5
	Variance	0.18

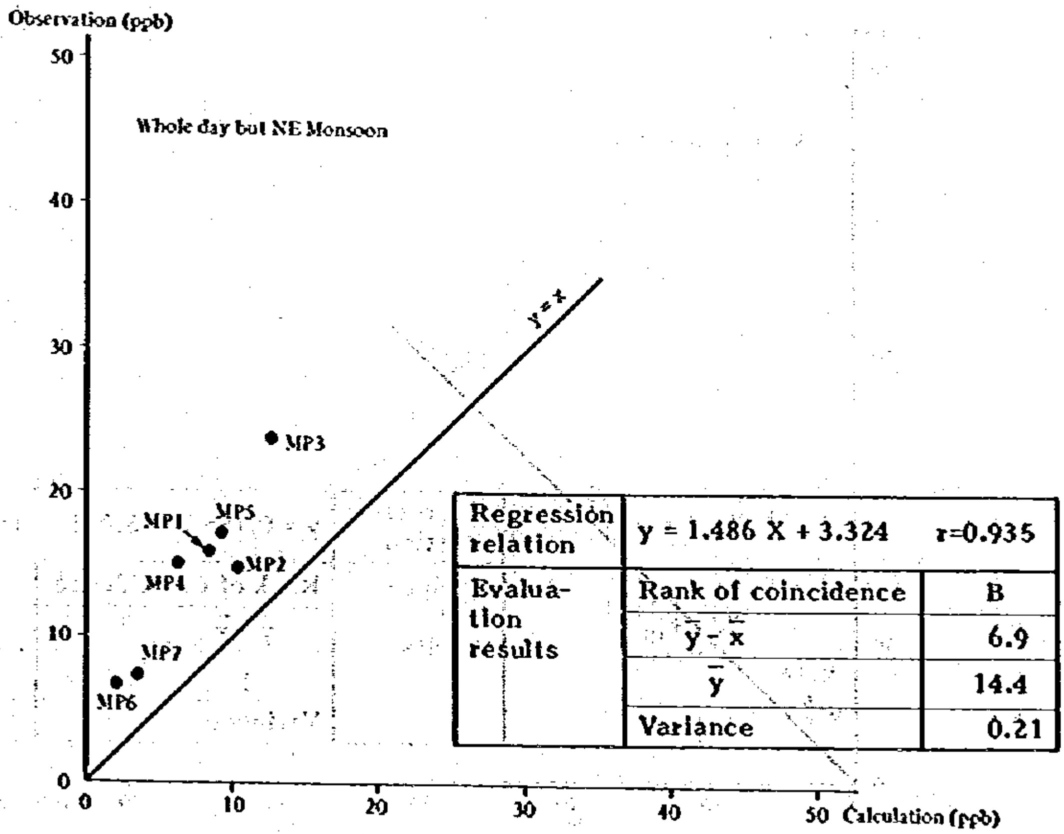


Regression relation	y = 1.120 X + 1.652 r=0.958	
Evaluation results	Rank of coincidence	A
	$\overline{y} - \overline{x}$	2.6
	$\overline{y}$	11.0
	Variance	0.13

Fig. V-1-16 Scatter diagram of simulated and observed SO_2 concentration (a)

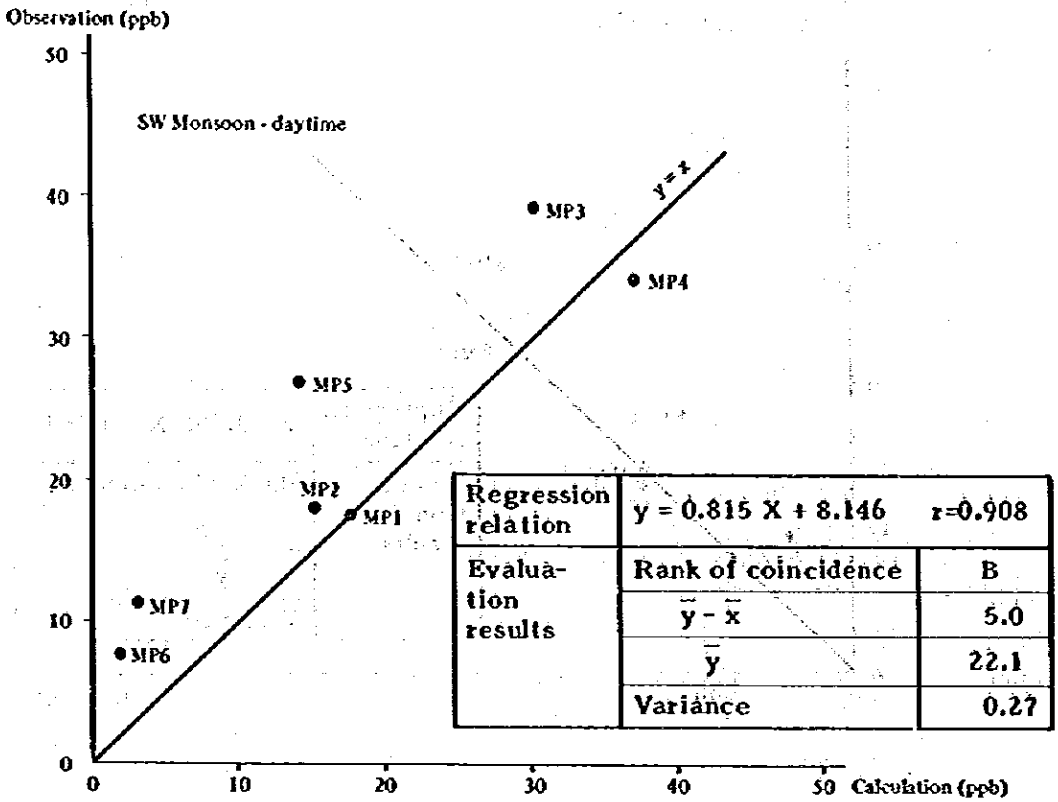


Regression relation	y = 0.796 X + 5.259 r=0.919	
Evaluation results	Rank of coincidence	B
	$\bar{y} - \bar{x}$	2.5
	$\bar{y}$	16.0
	Variance	0.23

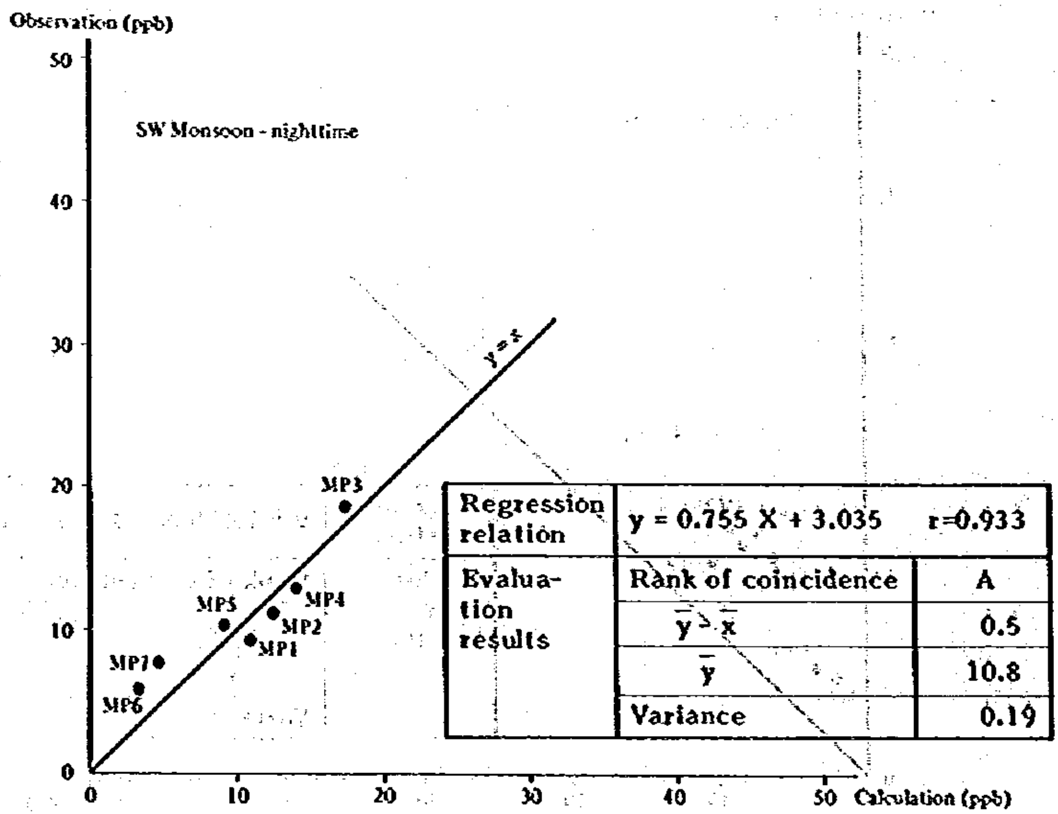


Regression relation	y = 1.486 X + 3.324 r=0.935	
Evaluation results	Rank of coincidence	B
	$\bar{y} - \bar{x}$	6.9
	$\bar{y}$	14.4
	Variance	0.21

Fig. V-1-16 Scatter diagram of simulated and observed SO_2 concentration (b)

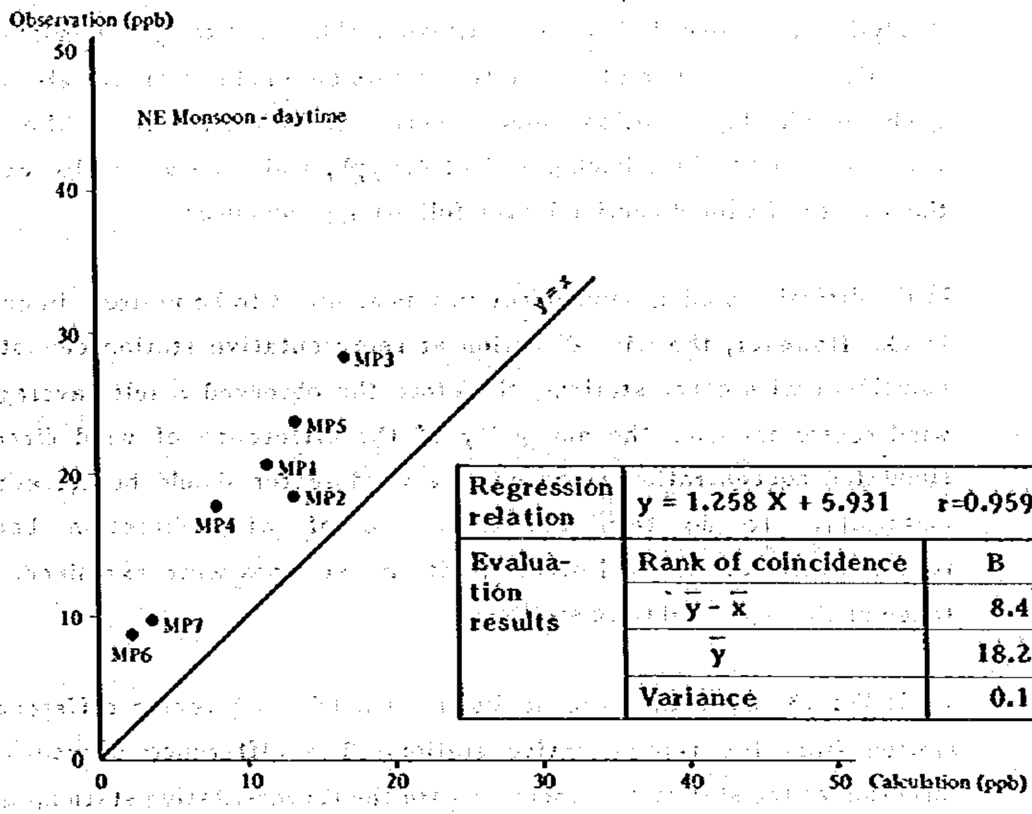


Regression relation	y = 0.815 X + 8.146	r=0.908
Evaluation results	Rank of coincidence	B
	$\bar{y} - \bar{x}$	5.0
	$\bar{y}$	22.1
	Variance	0.27

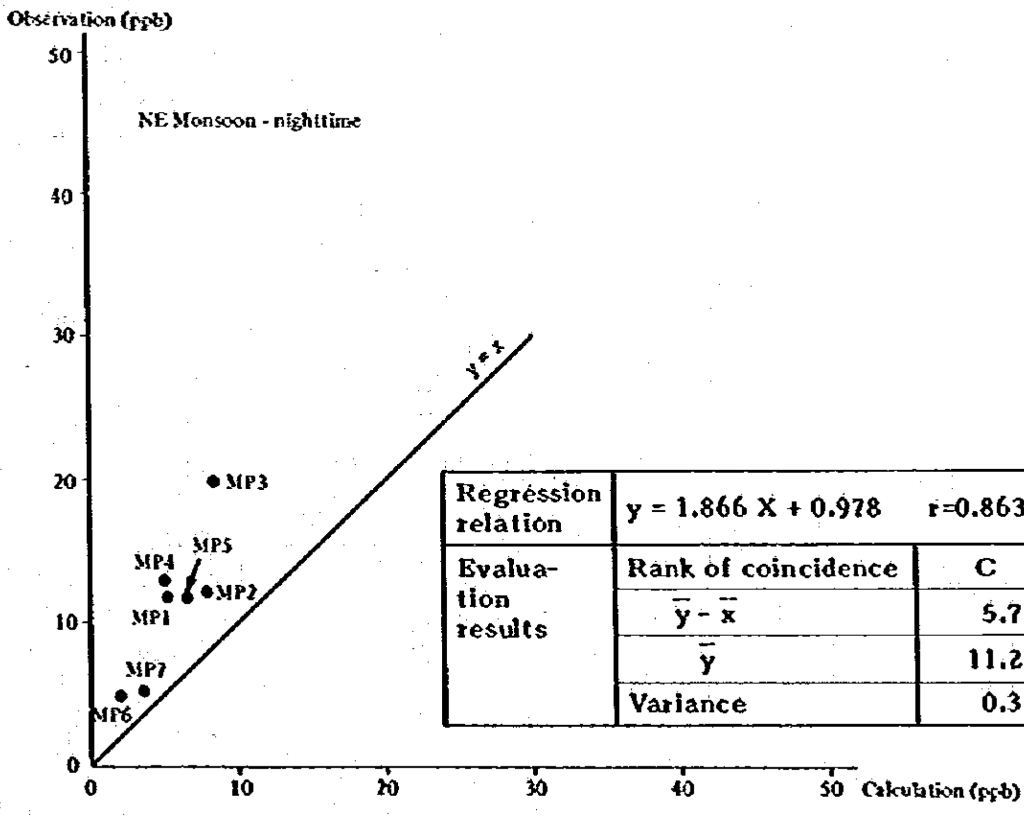


Regression relation	y = 0.755 X + 3.035	r=0.933
Evaluation results	Rank of coincidence	A
	$\bar{y} - \bar{x}$	0.5
	$\bar{y}$	10.8
	Variance	0.19

Fig. V-1-16 Scatter diagram of simulated and observed SO_2 concentration (c)



Regression relation	y = 1.258 X + 5.931	r=0.959
Evaluation results	Rank of coincidence	B
	$\bar{y} - \bar{x}$	8.4
	$\bar{y}$	18.2
	Variance	0.15



Regression relation	y = 1.866 X + 0.978	r=0.863
Evaluation results	Rank of coincidence	C
	$\bar{y} - \bar{x}$	5.7
	$\bar{y}$	11.2
	Variance	0.32

Fig. V-1-16 Scatter diagram of simulated and observed SO_2 concentration (d)

b. Comparison of calculated and observed concentration in each wind sector

Analysis of observed SO_2 concentration showed strong dependence on wind direction. Dependence of calculated results on wind sector was also checked for each monitoring station and shown in Figs. V-1-18. The calculated concentrations include background of 4.3 ppb, and they were also corrected for the scatter of wind direction by the following procedure:

In the diffusion model, wind direction was assumed to be uniform in each regional block. However, the wind direction at representative station cannot always be coincident with other stations, therefore the observed results averaged in each wind sector includes the ambiguity of the difference of wind direction. The simulated concentration averaged in a wind sector should be corrected for the ambiguity. To do this, the difference of wind direction between the representative station and other monitoring stations were examined. MP-2 was taken as the representative station.

Table V-1-13 shows the percent distribution of wind vector difference at each station from the representative station. The difference 0 means the wind direction at the station is coincident with the representative station, and + means the difference is clockwise.

Table V-1-13 Frequency distribution of wind vector difference between each station and representative station (MP-2)

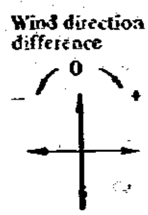
Wind direction difference / Site No.	-7	-6	-5	-4	-3	-2	-1	0	+1	+2	+3	+4	+5	+6	+7	+8
1	0.09	0.06	0.18	0.30	1.95	11.51	33.24	34.14	14.13	3.49	0.51	0.09	0.12	0.06	0.03	0.09
3	0.0	0.0	0.0	0.0	0.0	0.67	11.47	62.28	23.55	1.48	0.34	0.07	0.0	0.0	0.13	0.0
4	0.06	0.10	0.15	0.19	0.48	1.55	9.88	44.39	38.36	3.97	0.52	0.22	0.06	0.04	0.03	0.0
5	0.05	0.30	0.30	0.35	2.13	7.71	21.70	31.24	30.17	5.22	0.15	0.25	0.15	0.05	0.0	0.20
6	0.22	0.31	0.53	1.35	3.64	9.77	15.14	21.41	25.82	12.63	4.11	1.57	1.01	0.90	0.97	0.61
7	0.06	0.06	0.30	0.63	1.46	6.72	18.52	30.85	28.53	7.58	2.21	1.02	0.57	0.37	0.65	0.47

The averages of wind vector difference for stations MP-1, MP-3, MP-4 and MP-5 are shown in Table V-1-14. The difference 0 was 43.01 percents and 89 percents of total data were between -1 and +1 sector. Therefore, for stations MP-1 to MP-4 reliable results may be obtained by considering the wind sectors of neighbouring two.

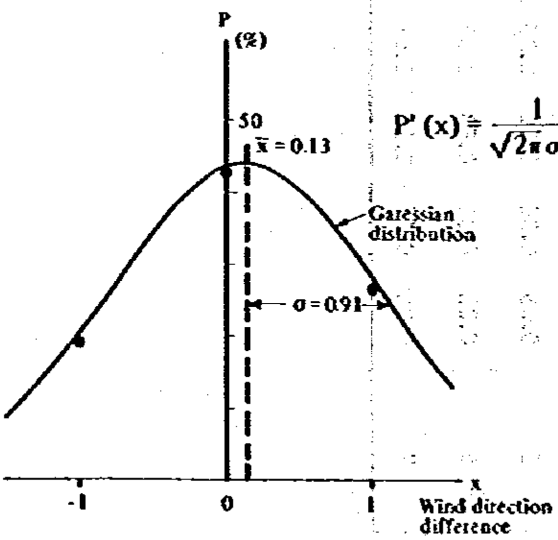
The correction of simulated concentration for the difference of wind sector was done by taking weighed average of the main wind and neighbouring two wind sectors. The weight of the three sectors were derived by fitting Gaussian distribution to the averaged wind sector difference shown in Table V-1-14, and calculating median x and standard deviation σ by least square method.

Table V-1-14 Averaged wind sector difference at MP-1, MP-3, MP-4 and MP-5

Wind direction difference	-1	0	+1
MP-1	33.24	34.14	14.13
MP-3	11.47	62.28	23.55
MP-4	9.88	44.39	38.36
MP-5	21.70	31.24	30.17
Average	19.07	43.01	26.55



The results are shown in Fig. V-1-17. The median x was 0.13 sector and standard deviation was 0.91 sector.



$$P'(x) \doteqdot \frac{1}{\sqrt{2\pi}\sigma} \exp\left\{-\frac{(x-\bar{x})^2}{2\sigma^2}\right\} \quad \text{Equation V-1-16}$$

$\bar{x} = 0.13$ wind direction

$\sigma = 0.91$ wind direction

Fig. V-1-17 The distribution of wind sector difference averaged for MP-1, MP-3, MP-4 and MP-5

Then the estimated frequency of 0 wind sector difference and ±1 sector difference were 43.8 and 24.0 percents, respectively. The concentration variation by wind sector for MP-1 in Figs. V-1-18 were derived by following equation:

$$C'_i = W_{i-1}C_{i-1} + W_iC_i + W_{i+1}C_{i+1} + C_{BG} \qquad \text{Equation V-1-17}$$

where;

C'_i : Concentration at wind sector i corrected for wind direction difference

C_i, C_{i-1}, C_{i+1} : Calculated concentration before correction for wind sector i, i-1 and i+1

W_i, W_{i-1}, W_{i+1} : Weight of objective wind i and neighbouring sectors i-1 and i+1.

$$W_i = 43.8/(43.8 + 2 \times 24.0)$$

$$W_{i-1} = W_{i+1} = 24.0/(43.8 + 2 \times 24.0)$$

C_{BG} : Background concentration (4.3 ppb)

The differences of wind vector of eastern part stations MP-6 and MP-7 to the representative station MP-2 were bigger than the stations in western part. The frequency of wind difference between -1 to +1 sector was 70.14 percents. It is attributable to the difference of wind field system. Therefore, the correction for MP-6 and MP-7 were done by considering ±2 wind sectors. The weight values were derived by the same method with MP-1 to MP-5. The original frequency distribution of wind sector is shown in Table V-1-15.

Table V-1-15 Averaged wind sector difference at MP-6 and MP-7

Wind direction difference	-2	-1	0	+1	+2
MP-6	9.77	15.14	21.41	25.82	12.63
MP-7	6.72	18.52	30.85	28.53	7.58
Average	8.25	16.83	26.13	27.18	10.11

The calculated frequency in percent for x, $x \pm 1$ and $x \pm 2$ were

$$P'(x) = \frac{1}{\sqrt{2\pi}\,\sigma} \exp\left\{-\frac{(x-\bar{x})^2}{2\sigma^2}\right\} \qquad \text{Equation V-1-18}$$

$\bar{x} = 0.29$ average difference of wind direction

$\sigma = 1.4$ standard deviation of wind direction

$P'(x) = 28.5\ \%$

$P'(x \pm 1) = 22.1\ \%$

$P'(x \pm 2) = 10.3\ \%$

The corrected concentration for each wind sector is given by

$$C'_i = W_{i-2}C_{i-2} + W_{i-1}C_{i-1} + W_iC_i + W_{i+1}C_{i+1} + W_{i+2}C_{i+2} + C_{BG} \qquad \text{Equation V-1-19}$$

and weights are

$W_i = 28.5 / (28.5 + 2 \times 22.1 + 2 \times 10.3)$

$W_{i\pm1} = 22.1 / (28.5 + 2 \times 22.1 + 2 \times 10.3)$

$W_{i\pm2} = 10.3 / (28.5 + 2 \times 22.1 + 2 \times 10.3)$

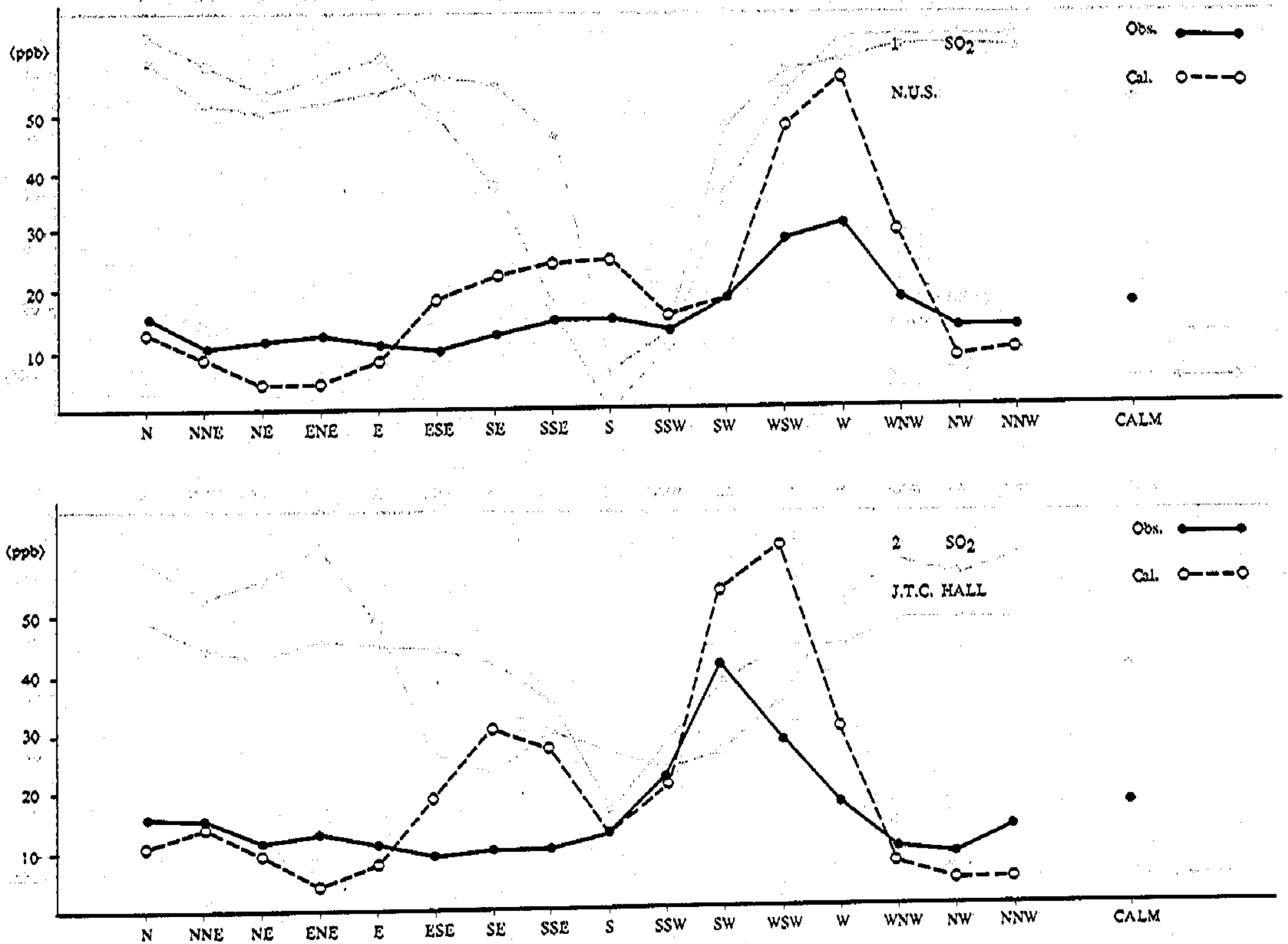


Fig. V-1-18 Observed and calculated variation of SO_2 concentration by wind direction (a)

Note: Simulated values were corrected for fluctuation of wind vector.
Simulated values include back ground concentration.

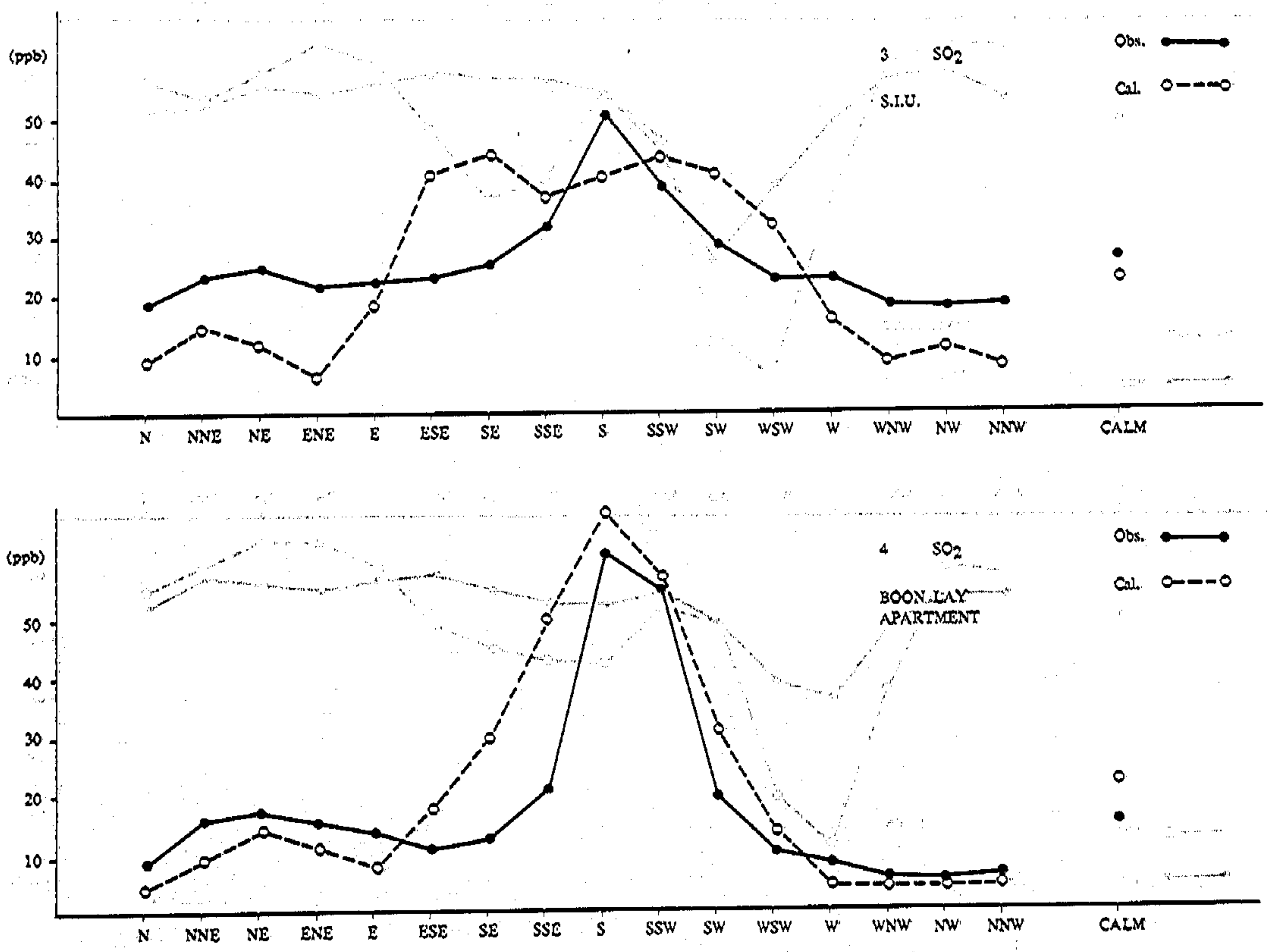


Fig. V-1-18 Observed and calculated variation of SO_2 concentration by wind direction (b)

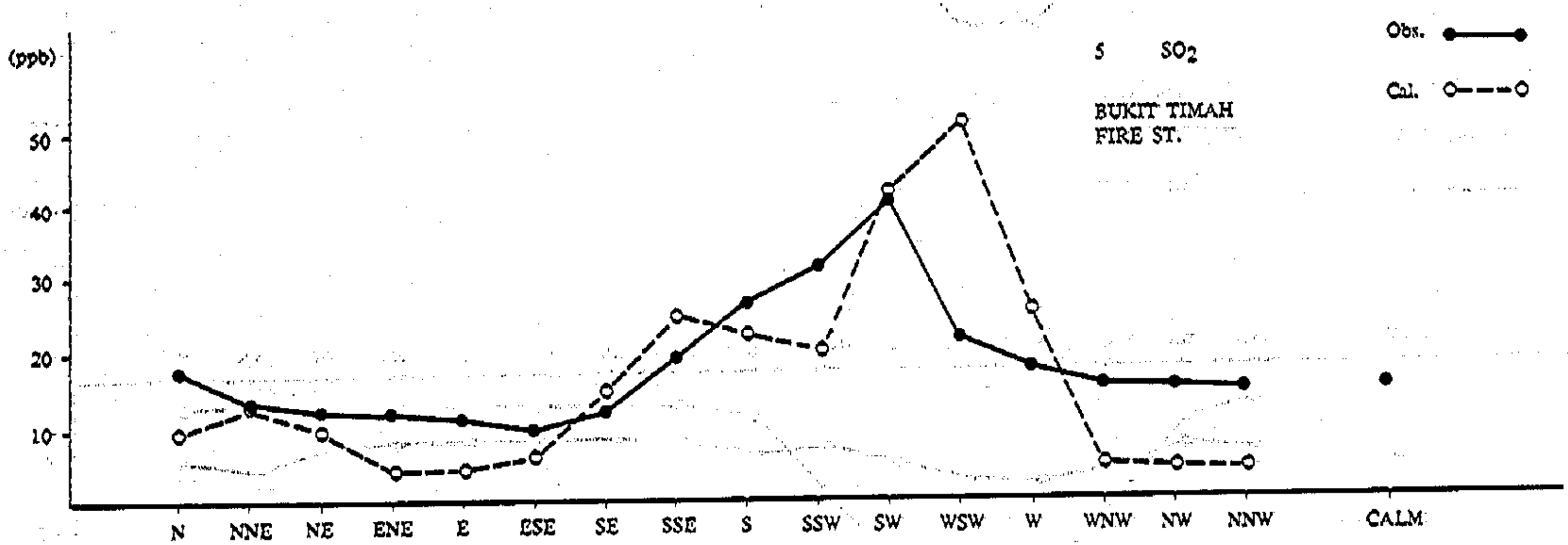


Fig. V-1-18 Observed and calculated variation of SO_2 concentration by wind direction (c)

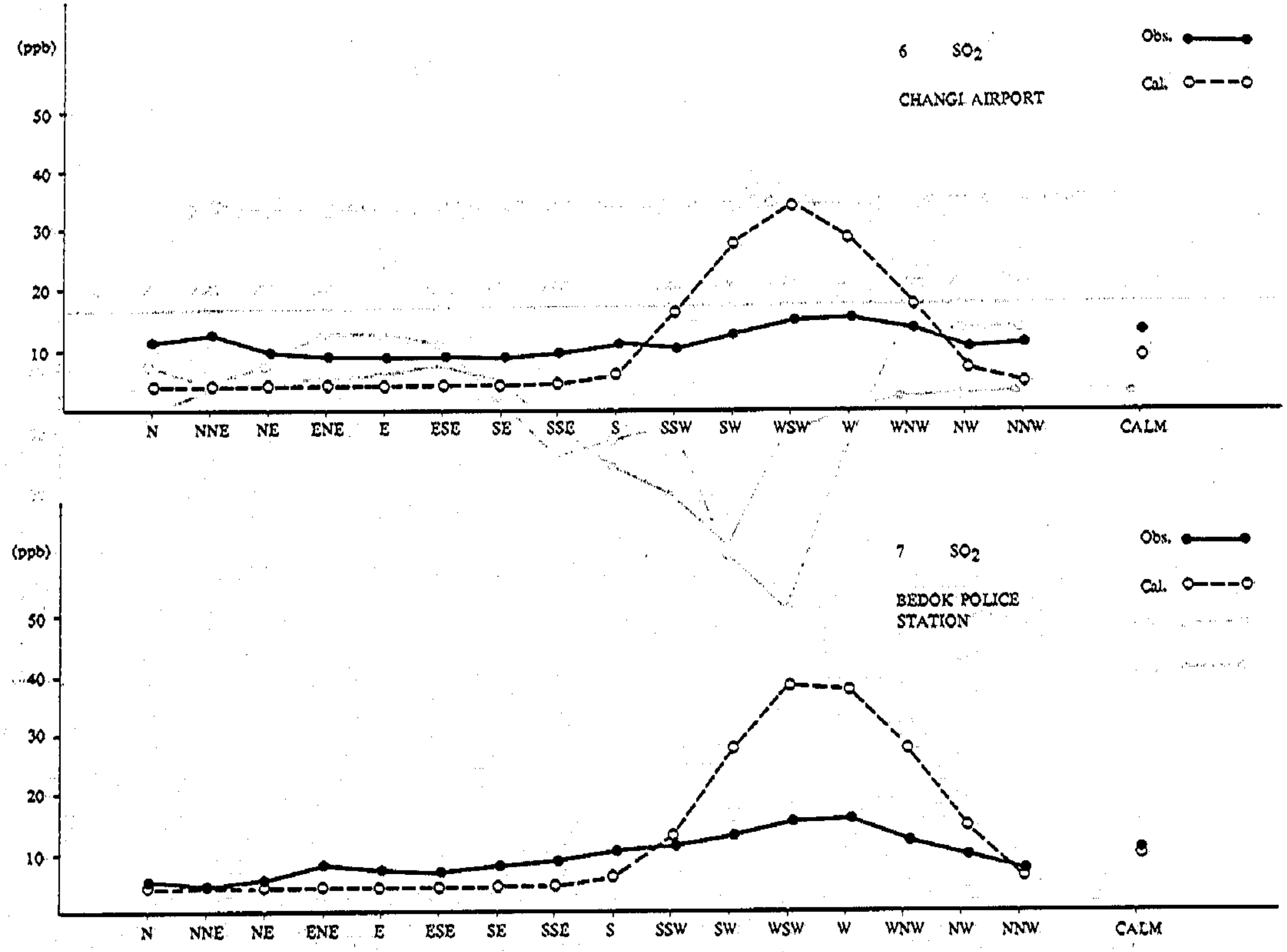


Fig. V-1-18 Observed and calculated variation of SO_2 concentration by wind direction (d)

V-1-3-6 Estimation of background concentration

The average difference of annual concentrations of calculation and observation for all stations was 4.3 ppb. The difference is attributable to the following reasons:

(i) Concentration by the returning pollutants which trapped in a circulation system like sea and land breeze
(ii) Concentration by small scale sources which are not covered by source inventory
(iii) Concentration by pollutant floating long hours which cannot be reproduced in steady plume or puff model
(iv) Measurement error
(v) Absorption or deposition by ground or water surface
(vi) Transfer to another chemical compound by chemical reaction in the atmosphere
(vii) Natural background concentration

In the simulation of present state of SO_2 concentration, background value was decided to be equal to the difference of observed and simulated values ($y - x = 4.3$ ppb). The background level in future stage was derived by following procedure:

The background concentration consists of two components, one is the natural background and does not change with source condition. This component was assumed 3 ppb. The other is the background which is somehow related to artificial sources, and it was assumed to be proportional to the total amount of SO_2 emission. This component in present stage is 1.3 ppb. Then future level of the SO_2 background is given by

$$\text{Future background} = 3.0 + 1.3 \times \frac{\text{Total amount of } SO_2 \text{ emission in future}}{\text{Total amount of } SO_2 \text{ emission in present}}$$
$$= 5.7 \text{ (ppb)}$$

Predicted SO_2 concentration in future stage is given by the sum of calculated value and the background 5.7 ppb estimated as above.

CHAPTER 2 PREDICTED CONCENTRATION OF SO_2 IN FUTURE

SO_2 concentration distribution in future stage (1990) was estimated by the diffusion model stated in Chapter 1 and for predicted source condition in Part III. The concentration estimation was done at all mesh-points of square mesh of 1 kilometer. The calculation area and mesh points are shown in Fig. V-2-1.

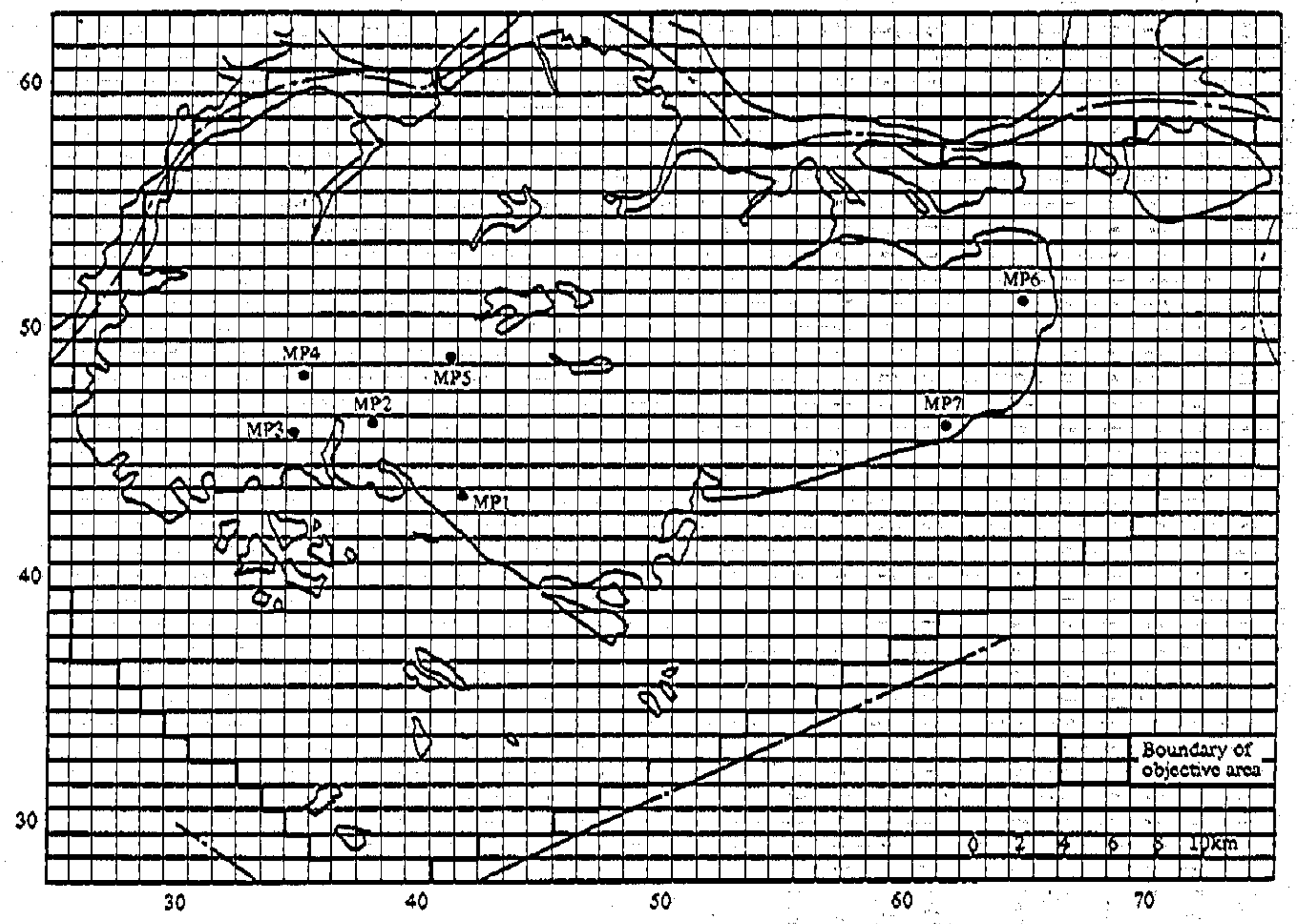


Fig. V-2-1 Objective area and mesh-points

V-2-1 Predicted Concentration at the Monitoring Stations

Predicted SO_2 concentration for annual average at the monitoring stations are shown in Table V-2-1. The predicted concentration for the year 1990 are between 9.5 to 39.9 ppb and indicate the increases of 6.7 to 23.2 ppb from the year 1981, when SO_2 concentrations were between 6.7 to 23.2 ppb.

The contributions of sources on SO_2 concentration of the year 1981 were 29 to 74 percents by stationary sources (Factories), 6 to 11 percents by vessels and background of 19 to 64 percents. Except MP-6 and MP-7 where SO_2 level was low, the source contributions in 1981 were estimated as 64 to 74 percents due to stationary sources, 6 to 9 by vessels and background was 19 to 29 percents. The ratio of these source contributions are predicted to change not significantly even in 1990.

At MP-3, where the highest concentration is predicted to occur, the SO_2 concentration of 23.2 ppb in 1981 is estimated to increase up to 39.9 ppb. The contribution of stationary sources was 74 percents in 1981 but it is predicted to increase to 80 percents in 1990.

Table V-2-1 Simulated and predicted results of annual average SO_2 concentration

Monitoring stations	Year	Measured value (ppb)	Estimated value (ppb)	Stationary sources (ppb)	Contribution rate (%)	Vessel (ppb)	Contribution rate (%)	Background (ppb)	Contribution rate (%)
MP-1) N.U.S	1981	14.2	15.9	10.10	64	1.46	9	4.3	27
	1990	-	21.6	13.66	63	2.23	10	5.7	26
MP-2) J.T.C. HALL	1981	14.6	16.7	11.21	67	1.14	7	4.3	26
	1990	-	24.7	17.30	70	1.74	7	5.7	23
MP-3) S.I.U	1981	26.2	23.2	17.26	74	1.61	7	4.3	19
	1990	-	39.9	31.85	80	2.38	6	5.7	14
MP-4) BOON LAY APARTMENT	1981	19.4	21.4	15.88	74	1.18	6	4.3	20
	1990	-	33.9	26.50	78	1.73	5	5.7	17
MP-5) BUKIT TIMAH FIRE STATION	1981	17.6	14.9	9.70	65	0.94	6	4.3	29
	1990	-	20.7	13.61	66	1.42	7	5.7	27
MP-6) CHANGI AIRPORT	1981	6.7	6.7	1.97	29	0.43	6	4.3	64
	1990	-	9.5	3.18	33	0.66	7	5.7	60
MP-7) BEDOK POLICE STATION	1981	8.4	8.1	2.99	37	0.79	10	4.3	53
	1990	-	11.5	4.58	40	1.26	11	5.7	49

The predicted concentration of seasonal averages are also shown in Tables V-2-2 and V-2-3. For the averages of Southerly Monsoon, concentration of 7.0 to 28.9 ppb in 1981 are predicted to go up to the range of 10 to 48.2 in the year 1990. The concentration ratio of sources are similar to the annual average.

The averages of Northerly Monsoon were in the range of 6.3 to 16.5 ppb in 1981, but it was estimated to increase more than several ppb and reach to 8.8 to 28.2 ppb.

The contributions of sources of factories and vessels are far smaller than in Southerly Monsoon season. This difference of source contribution by seasons is mainly due to the change of prevailing wind. It is NE in Northerly Monsoon, but it changes to SW in Southerly Monsoon.

Table V-2-2 Simulated and predicted SO_2 concentrations at monitoring stations (averages of Southerly Monsoon)

Monitoring stations	Year	Measured value (ppb)	Estimated value (ppb)	Stationary sources (ppb)	Contribution rate (%)	Vessel (ppb)	Contribution rate (%)	Background (ppb)	Contribution rate (%)
MP-1) N.U.S	1981	13.1	18.3	11.78	64	2.23	12	4.3	24
	1990	-	24.2	15.05	62	3.43	14	5.2	24
MP-2) J.T.C. HALL	1981	14.1	18.1	11.98	66	1.79	10	4.3	24
	1990	-	26.6	18.18	68	2.74	10	5.7	21
MP-3) S.I.U	1981	28.0	27.9	21.00	75	2.55	9	4.3	15
	1990	-	48.2	38.68	80	3.80	8	5.7	12
MP-4) BOON LAY APARTMENT	1981	22.3	28.9	22.76	79	1.89	7	4.3	15
	1990	-	45.5	37.01	81	2.79	6	5.7	13
MP-5) BUKIT TIMAH FIRE STATION	1981	17.9	15.7	9.88	63	1.50	10	4.3	27
	1990	-	22.4	14.43	64	2.27	10	5.7	26
MP-6) CHANGI AIRPORT	1981	6.8	7.0	2.11	30	0.61	9	4.3	61
	1990	-	10.0	3.42	34	0.93	9	5.7	57
MP-7) BEDOK POLICE STATION	1981	9.3	8.3	2.94	36	1.04	13	4.3	52
	1990	-	11.8	4.45	38	1.65	14	5.7	48

Table V-2-3 Simulated and predicted SO_2 concentrations at monitoring stations (averages of Northerly Monsoon)

Monitoring stations	Year	Measured value (ppb)	Estimated value (ppb)	Stationary sources (ppb)	Contribution rate (%)	Vessel (ppb)	Contribution rate (%)	Background (ppb)	Contribution rate (%)
MP-1) N.U.S	1981	15.8	12.4	7.72	62	0.36	3	4.3	35
	1990	-	17.9	11.71	65	0.53	3	5.7	32
MP-2) J.T.C. HALL	1981	15.0	14.7	10.12	69	0.23	2	4.3	29
	1990	-	22.1	16.07	73	0.33	1	5.7	26
MP-3) S.I.U	1981	23.7	16.5	11.94	72	0.27	2	4.3	26
	1990	-	28.2	22.16	79	0.37	1	5.7	20
MP-4) BOON LAY APARTMENT	1981	15.0	10.6	6.12	58	0.17	2	4.3	41
	1990	-	17.5	11.59	66	0.24	1	5.7	33
MP-5) BUKIT TIMAH FIRE STATION	1981	17.2	13.9	9.44	68	0.15	1	4.3	31
	1990	-	18.4	12.46	68	0.21	1	5.7	31
MP-6) CHANGI AIRPORT	1981	6.6	6.3	1.78	28	0.18	3	4.3	69
	1990	-	8.8	2.84	32	0.28	3	5.7	65
MP-7) BEDOK POLICE STATION	1981	7.2	7.8	3.07	39	0.43	6	4.3	55
	1990	-	11.2	4.77	43	0.72	6	5.7	51

V-2-2 Concentrations at Mesh Points

SO_2 concentrations were also calculated at mesh-points covering whole Singapore. Isopleths of simulated (1981) and predicted SO_2 concentration (1990) of annual average are shown in Figs. V-2-2 and V-2-3.

The background levels of 4.3 ppb and 5.7 ppb are added to the calculated values of 1981 and 1990, respectively. The concentration distributions of the two different years are very resemble, and high concentration regions are seen in Jurong, Southern Islands and Bukum Island. In the area where present SO_2 concentration was more than 20 ppb, it was predicted to go up to about 30 ppb in the year 1990.

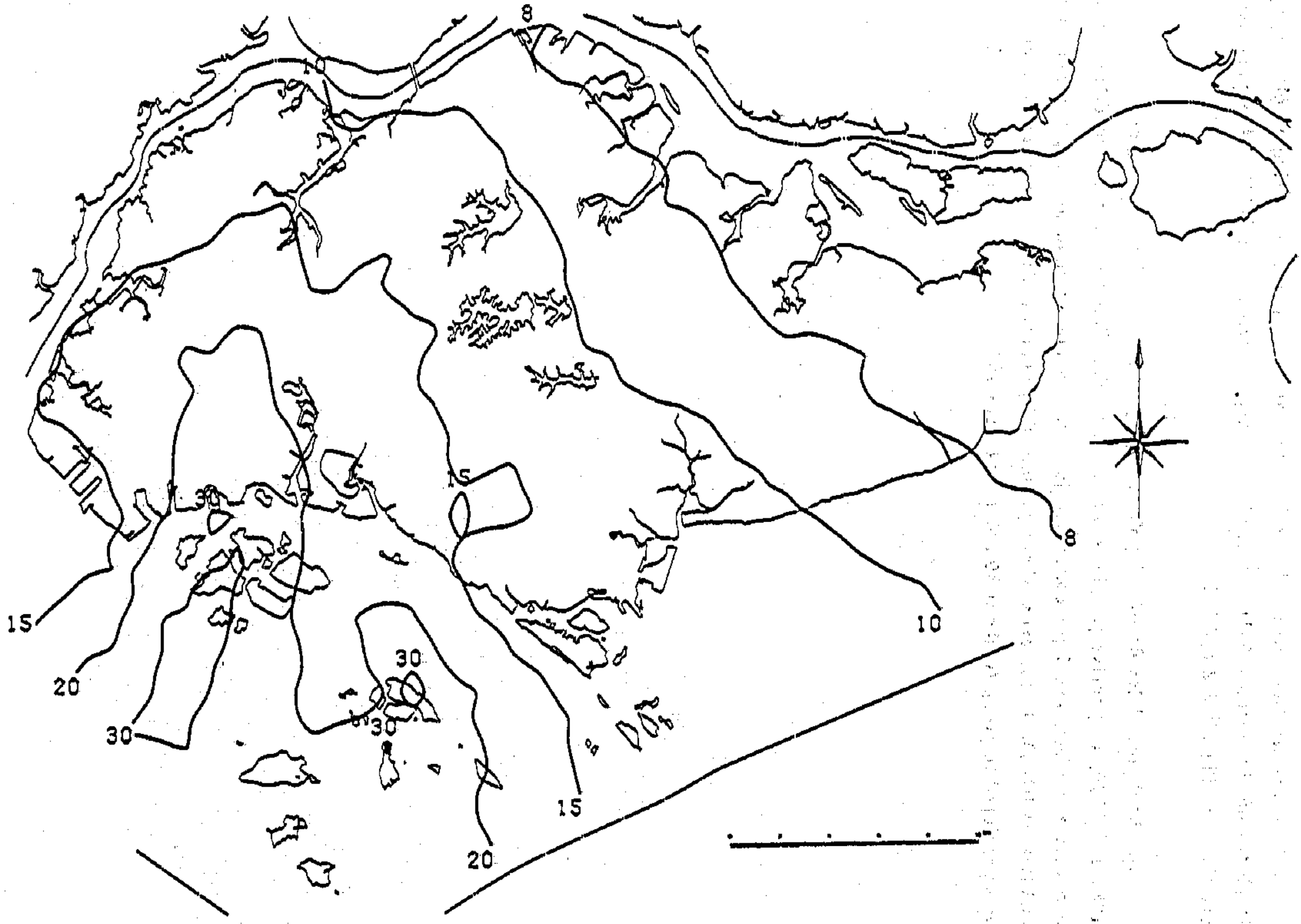


Fig. V-2-2 Isopleths of SO_2 concentration (ppb) in 1981 (annual average)

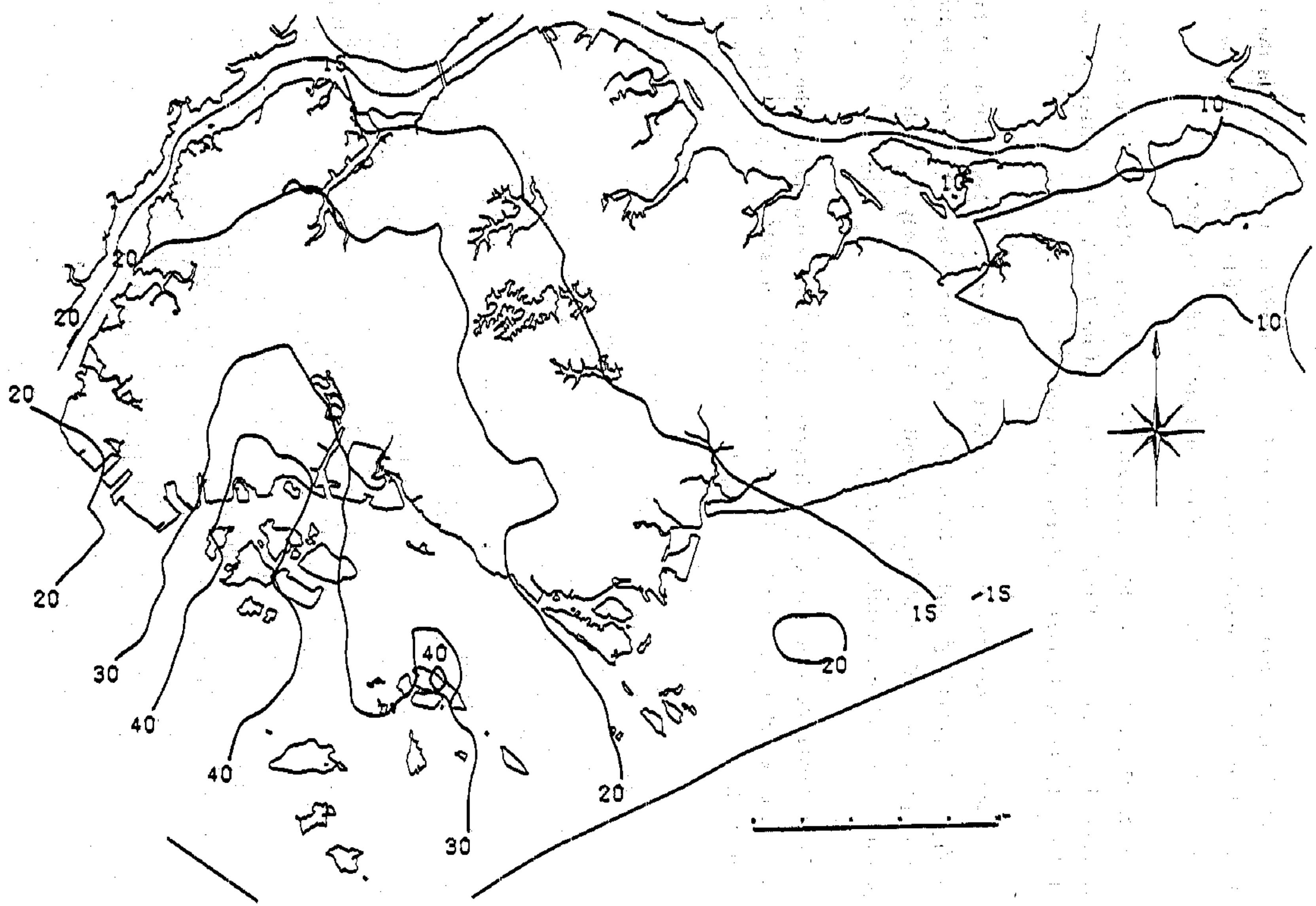


Fig. V-2-3 Predicted isopleths of SO_2 concentration (ppb) in 1990 (annual average)

SO_2 concentration distributions of seasonal average are also given in Figs. V-2-4 to V-2-7 for the year of 1981 and 1990.

In Southerly Monsoon, high concentration is observed in Jurong area. In the region where present SO_2 concentration was more than 30 ppb, it is estimated to increase more than 40 ppb in 1990 and the high level region is predicted to expand.

In Northerly Monsoon, high concentration area was different from in Southerly Monsoon, it appeared in Suthem Island and Bukum Island. The difference is also attributed to the wind direction of prevailing wind.

The main emission sources are concentrated to Jurong, Suthem Island and Bukum Island, and the prevailing wind of NE in Northerly Monsoon brings high concentration in southern part. In Southerly Monsoon, prevailing wind is southerly and high concentration appears in the north of the main sources.

In Southerly Monsoon, pretty high increase of SO_2 concentration on the sea to the southeast of Bedok is predicted due to the expected sources of steel plant and electric power plant.

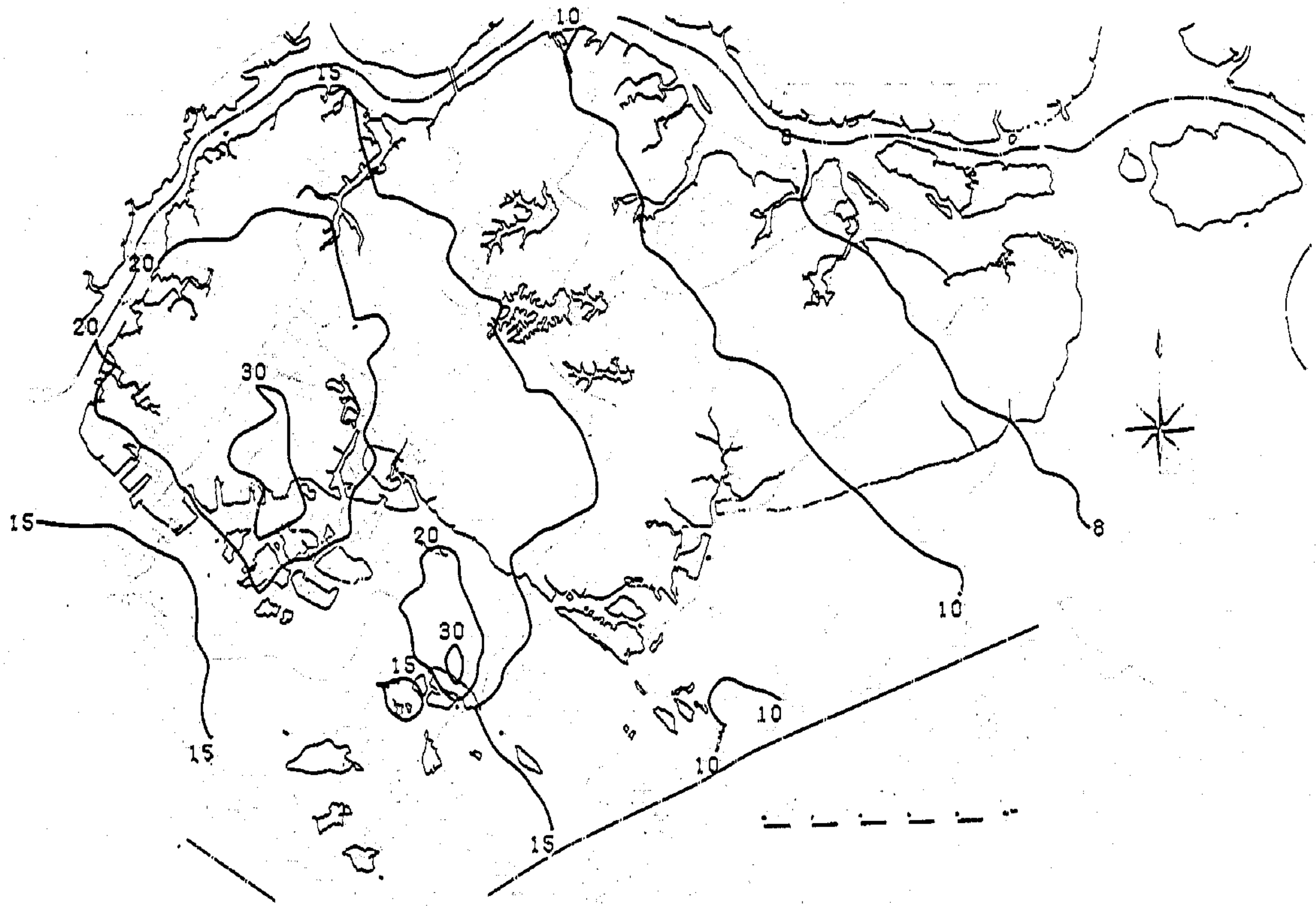


Fig. V-2-4 Calculated isopleths of present SO_2 concentration in Southerly Monsoon (ppb)

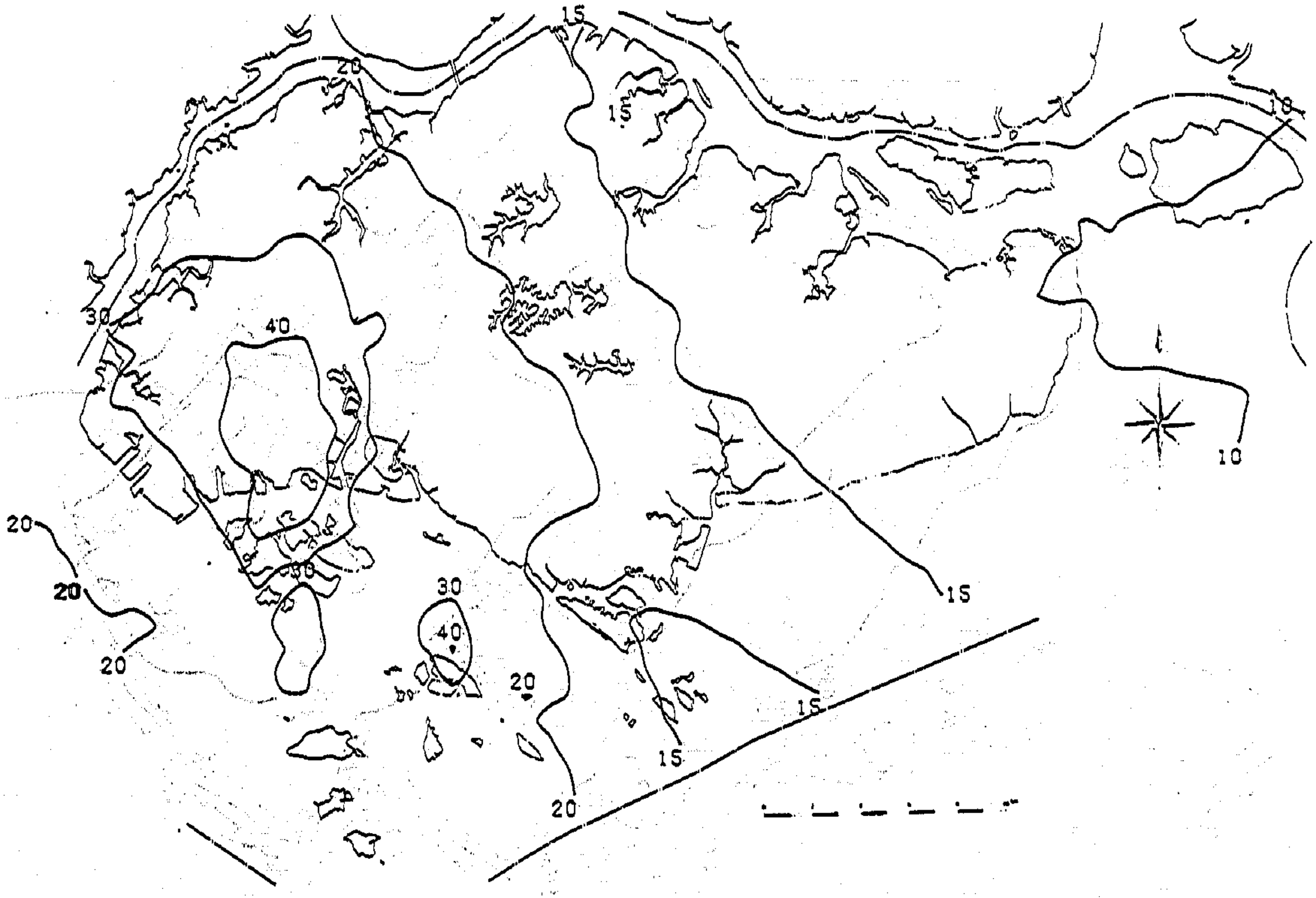


Fig. V-2-5 Predicted isopleths of future SO_2 concentration in Southerly Monsoon (ppb)

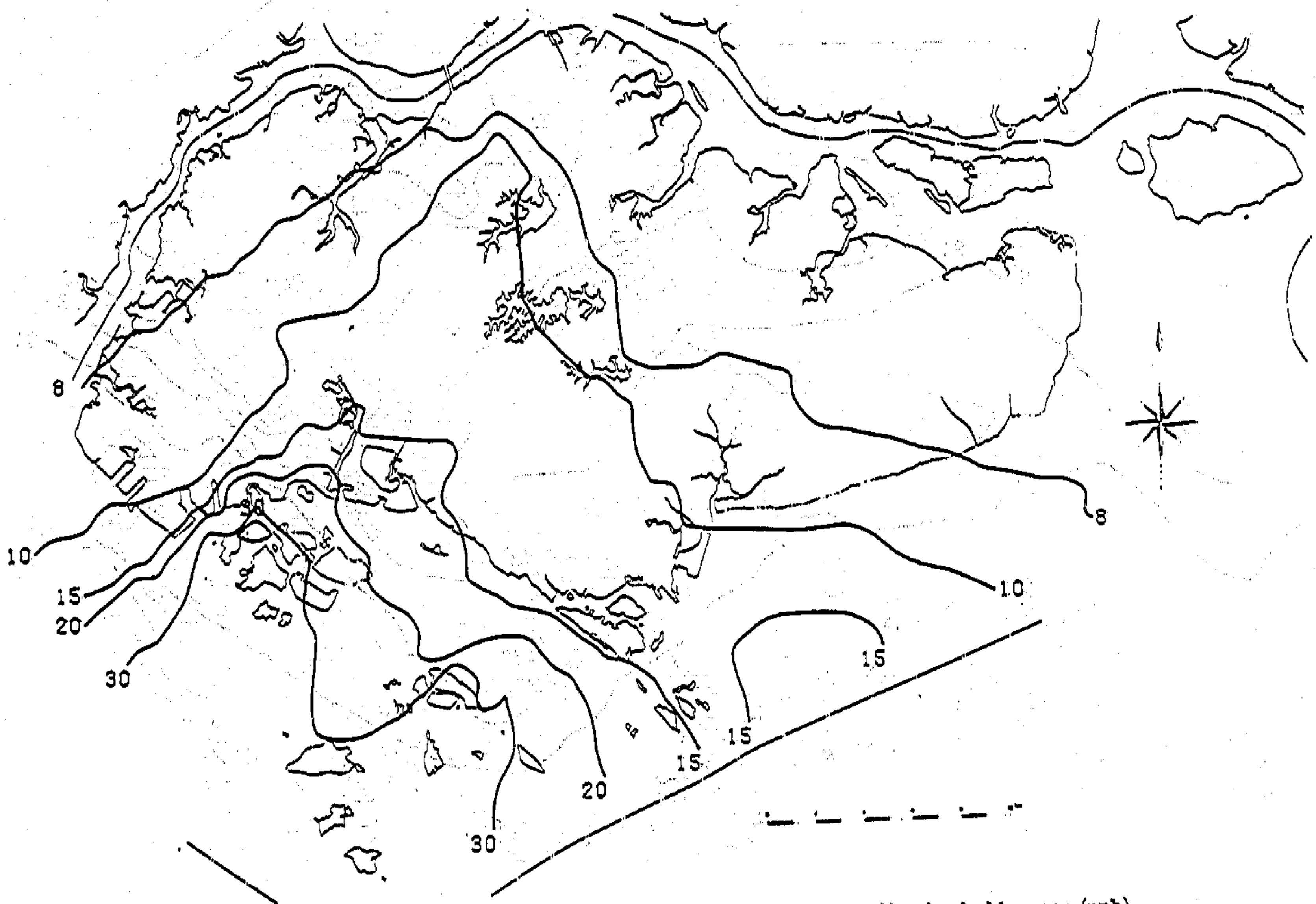


Fig. V-2-6 Calculated isopleths of present SO_2 concentration in Northerly Monsoon (ppb)

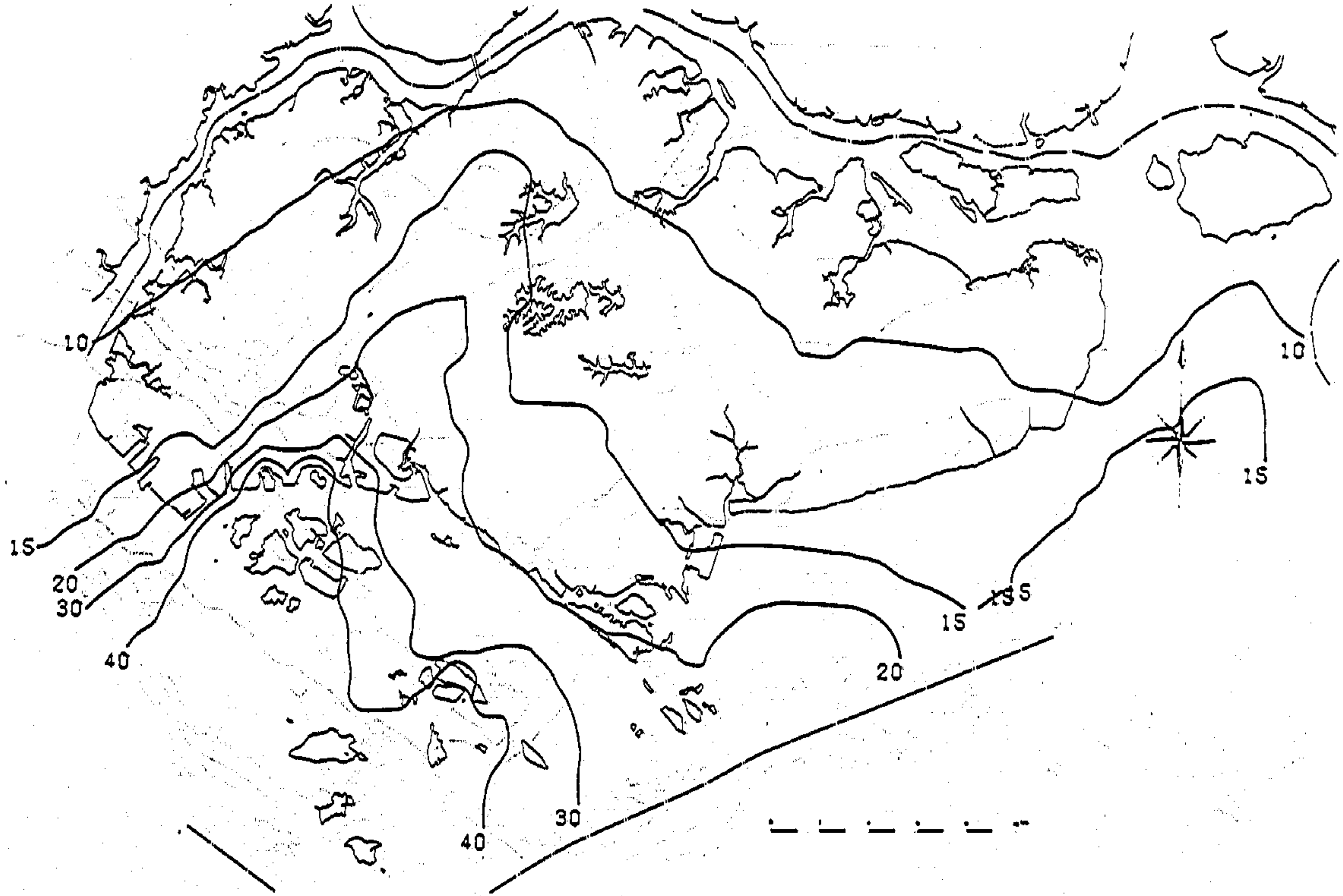


Fig. V-2-7 Predicted isopleths of future SO_2 concentration in Northerly Monsoon (ppb)

To clarify the overall change of SO_2 concentration from the year of 1981 to 1990, concentrations at all mesh-points (total 1210) were classified into five ranks and numbers of mesh-point belong to each rank were counted and shown in Table V-2-4.

Table V-2-4 Numbers of mesh-point belongs to each rank of concentration

Rank of concentration (ppb)	Annual mean		Southerly Monsoon		Northerly Monsoon	
	1981	1990	1981	1990	1981	1990
10	467	103	409	84	694	330
10 - 14.9	368	397	368	368	229	355
15 - 19.9	196	280	304	262	89	183
20 - 29.9	161	262	116	386	84	143
30	18	168	13	110	114	199
Total	1,210	1,210	1,210	1,210	1,210	1,210

The number of the mesh-point where annual average SO_2 is higher than 30 ppb is predicted to increase from 18 in 1981 to 168 in 1990.

V-2-3 Contribution of Individual Sources on the Concentration at Monitoring Stations and High Concentration Points

To clarify the pollution mechanism, share of the concentration by main sources at monitoring stations and at representative mesh-points was analyzed and shown in Tables V-2-12. The sources of 62 factories and companies, 64 area sources (vessels and others) and background were considered. The concentrations were calculated in following two ways:

(a) Each concentration of highest 10 factories and companies and total contribution by other companies and by vessels and share of the background and shares by vessels and background

(b) Each contribution of 10 major companies, together with total by other companies, by vessels and also share of the background

By the list of the first method, major sources affecting high concentration points are evaluated. The second method is convenient to see the contribution by particular sources.

(1) Contribution rate at monitoring stations

Table V-2-5 shows the concentration rate of 10 highest emission sources at each monitoring station. Taking an example from MP-3, where the concentration in 1990 is highest, the contribution from Seneko Power Station is 4.544 ppb, the Chemical Corporation of Singapore Pte Ltd. is 3.933 ppb, and total 10 factories is 23.108 ppb which corresponds 58% of the total concentration.

Table V-2-6-(1) to -(4) and Table V-2-7-(1) to -(4) show the contribution rate of 10 highest emission sources at each monitoring station, classified by seasons.

Table V-2-8 show the yearly average concentration and contribution rate of 10 highest emission sources at each monitoring station. From tables, the contribution of Seneko Power station is found largest at each station. The additional concentration by Tekong Integrated Steel Mill is estimated about 0.2 to 0.3 ppb and its contribution rate is found large at MP-6 and MP-7 which are located near to the proposed site of the steel mill. The contribution concentration of Tekong and Seraya power stations are about 0.05-0.1 ppb and 0.3-2.3 ppb respectively. And these two power stations contribute highest to MP-4 which corresponds about 6.7% of the contribution rate.

The contribution rate in southerly monsoon and northerly monsoon seasons are shown in Table V-2-9 and Table V-2-10.

MP1 N.U.S.					
1981			1990		
Name of factory	Contributing concentration (ppb)	Contribution rate (%)	Name of factory	Contributing concentration (ppb)	Contribution rate (%)
SHELL COMPANIES IN SINGAPORE	2.799	17.65	SHELL COMPANIES IN SINGAPORE	2.799	12.96
SENOKO POWER STATION	1.826	11.52	SENOKO POWER STATION	2.778	12.86
PASIR PANJANG POWER STATION	1.580	9.96	PASIR PANJANG POWER STATION	1.580	7.31
JURONG POWER STATION	1.508	9.51	JURONG POWER STATION	1.508	6.98
ESSO SINGAPORE PTE LTD	0.680	4.29	ESSO SINGAPORE PTE LTD	0.680	3.15
SINGAPORE REFINING CO PTE LTD	0.380	2.40	NATIONAL IRON & STEEL MILLS LTD	0.531	2.46
MOBIL OIL SINGAPORE PTE LTD	0.300	1.89	SUMITOMO KAGAKU PTE LTD	0.405	1.87
NATIONAL IRON & STEEL MILLS LTD	0.213	1.35	SINGAPORE REFINING CO PTE LTD	0.380	1.76
SUGAR INDUSTRY OF SINGAPORE LTD	0.150	0.95	SUGAR INDUSTRY OF SINGAPORE LTD	0.374	1.73
RCD BRICKWORKS TILE WORKS	0.150	0.94	SERAYA POWER STATION	0.341	1.58
- REMAINING FACTORIES -	0.511	3.21	- REMAINING FACTORIES -	2.289	10.62
------- VESSELS -------	1.460	9.21	------- VESSELS -------	2.232	10.33
----- BACK GROUND -----	4.300	27.12	----- BACK GROUND -----	5.700	26.39
-------- TOTAL --------	15.857	100.00	-------- TOTAL --------	21.597	100.00

MP2 J.T.C. HALL					
1981			1990		
Name of factory	Contributing concentration (ppb)	Contribution rate (%)	Name of factory	Contributing concentration (ppb)	Contribution rate (%)
SENOKO POWER STATION	3.093	18.57	SENOKO POWER STATION	4.679	18.91
PASIR PANJANG POWER STATION	1.795	10.78	PASIR PANJANG POWER STATION	1.795	7.25
SHELL COMPANIES IN SINGAPORE	1.714	10.29	SHELL COMPANIES IN SINGAPORE	1.714	6.93
ESSO SINGAPORE PTE LTD	1.156	6.94	SERAYA POWER STATION	1.217	4.92
JURONG POWER STATION	0.884	5.30	ESSO SINGAPORE PTE LTD	1.156	4.67
SINGAPORE REFINING CO PTE LTD	0.744	4.47	JURONG POWER STATION	0.884	3.57
RCD BRICKWORKS TILE WORKS	0.333	2.00	SINGAPORE REFINING CO PTE LTD	0.744	3.01
MOBIL OIL SINGAPORE PTE LTD	0.277	1.67	SIME DARBY OLEOCHEMICALS LTD	0.658	2.66
NATIONAL IRON & STEEL MILLS LTD	0.210	1.26	RCD BRICKWORKS TILE WORKS	0.652	2.63
SIME DARBY OLEOCHEMICALS LTD	0.193	1.16	SUMITOMO KAGAKU PTE LTD	0.649	2.62
- REMAINING FACTORIES -	0.812	4.87	- REMAINING FACTORIES -	3.159	12.76
------- VESSELS -------	1.144	6.87	------- VESSELS -------	1.742	7.04
----- BACK GROUND -----	4.300	25.82	----- BACK GROUND -----	5.700	23.03
-------- TOTAL --------	16.655	100.00	-------- TOTAL --------	24.749	100.00

Table V-2-5-(a) Contribution of highest emission 10 factories at monitoring station (yearly average)

MP3 S.I.U.

1981 Name of factory	Contributing concentration (ppb)	Contribution rate (%)	1990 Name of factory	Contributing concentration (ppb)	Contribution rate (%)
SENOKO POWER STATION	3.002	12.96	SENOKO POWER STATION	4.544	11.38
ESSO SINGAPORE PTE LTD	2.601	11.23	THE CHEMICAL CORPN OF SINGAPORE PTE LTD	3.933	9.85
SINGAPORE REFINING CO PTE LTD	2.381	10.28	ESSO SINGAPORE PTE LTD	2.601	6.51
SHELL COMPANIES IN SINGAPORE	1.621	7.00	NATIONAL IRON & STEEL MILLS LTD	2.513	6.30
PASIR PANJANG POWER STATION	1.252	5.41	SINGAPORE REFINING CO PTE LTD	2.381	5.96
THE CHEMICAL CORPN OF SINGAPORE PTE LTD	1.156	4.99	SHELL COMPANIES IN SINGAPORE	1.621	4.06
NATIONAL IRON & STEEL MILLS LTD	1.011	4.36	SUGAR INDUSTRY OF SINGAPORE LTD	1.556	3.90
SUGAR INDUSTRY OF SINGAPORE LTD	0.625	2.70	DRAGON POLY-FOAM INDS (S) PTE LTD	1.377	3.45
MOBIL OIL SINGAPORE PTE LTD	0.535	2.31	SUMITOMO KAGAKU PTE LTD	1.324	3.31
HUME INDS (S) LTD	0.426	1.84	PASIR PANJANG POWER STATION	1.252	3.14
- REMAINING FACTORIES -	2.642	11.41	- REMAINING FACTORIES -	8.739	21.89
------- VESSELS -------	1.610	6.95	------- VESSELS -------	2.382	5.97
----- BACK GROUND -----	4.300	18.56	----- BACK GROUND -----	5.700	14.28
-------- TOTAL --------	23.162	100.00	-------- TOTAL --------	39.923	100.00

MP4 BOON LAY APARTMENT

1981 Name of factory	Contributing concentration (ppb)	Contribution rate (%)	1990 Name of factory	Contributing concentration (ppb)	Contribution rate (%)
JURONG POWER STATION	4.463	20.89	JURONG POWER STATION	4.463	13.15
SENOKO POWER STATION	1.725	8.08	SENOKO POWER STATION	3.347	9.86
ESSO SINGAPORE PTE LTD	1.692	7.92	SERAYA POWER STATION	2.273	6.70
PASIR PANJANG POWER STATION	1.621	7.59	DRAGON POLY-FOAM INDS (S) PTE LTD	1.709	5.04
SINGAPORE REFINING CO PTE LTD	1.432	6.71	ESSO SINGAPORE PTE LTD	1.692	4.99
SHELL COMPANIES IN SINGAPORE	1.394	6.53	PASIR PANJANG POWER STATION	1.621	4.78
SUGAR INDUSTRY OF SINGAPORE LTD	0.615	2.88	SUGAR INDUSTRY OF SINGAPORE LTD	1.532	4.51
MOBIL OIL SINGAPORE PTE LTD	0.589	2.76	SINGAPORE REFINING CO PTE LTD	1.432	4.22
NATIONAL IRON & STEEL MILLS LTD	0.490	2.29	SHELL COMPANIES IN SINGAPORE	1.394	4.11
THE CHEMICAL CORPN OF SINGAPORE PTE LTD	0.190	0.89	NATIONAL IRON & STEEL MILLS LTD	1.221	3.60
- REMAINING FACTORIES -	1.665	7.80	- REMAINING FACTORIES -	5.812	17.13
------- VESSELS -------	1.182	5.53	------- VESSELS -------	1.734	5.11
----- BACK GROUND -----	4.300	20.13	----- BACK GROUND -----	5.700	16.80
-------- TOTAL --------	21.358	100.00	-------- TOTAL --------	33.930	100.00

Table V-2-5-(b) Contribution of highest emission 10 factories at monitoring station (yearly average)

MP5 BUKIT TIMAH FIRE ST.					
1981			1990		
Name of factory	Contributing concentration (ppb)	Contribution rate (%)	Name of factory	Contributing concentration (ppb)	Contribution rate (%)
SENOKO POWER STATION	3.165	21.19	SENOKO POWER STATION	4.091	19.73
PASIR PANJANG POWER STATION	1.872	12.54	PASIR PANJANG POWER STATION	1.872	9.03
SHELL COMPANIES IN SINGAPORE	1.532	10.26	SHELL COMPANIES IN SINGAPORE	1.532	7.39
JURONG POWER STATION	1.185	7.93	SERAYA POWER STATION	1.426	6.88
ESSO SINGAPORE PTE LTD	0.719	4.82	JURONG POWER STATION	1.185	5.71
SINGAPORE REFINING CO PTE LTD	0.444	2.97	ESSO SINGAPORE PTE LTD	0.719	3.47
MOBIL OIL SINGAPORE PTE LTD	0.188	1.26	SINGAPORE REFINING CO PTE LTD	0.444	2.14
SUGAR INDUSTRY OF SINGAPORE LTD	0.122	0.82	SUMITOMO KAGAKU PTE LTD	0.311	1.50
NATIONAL IRON & STEEL MILLS LTD	0.118	0.79	SUGAR INDUSTRY OF SINGAPORE LTD	0.303	1.46
RCD BRICKWORKS TILE WORKS	0.085	0.57	NATIONAL IRON & STEEL MILLS LTD	0.294	1.42
- REMAINING FACTORIES -	0.266	1.78	- REMAINING FACTORIES -	1.440	6.95
------- VESSELS -------	0.938	6.28	------- VESSELS -------	1.417	6.83
----- BACK GROUND -----	4.300	28.79	----- BACK GROUND -----	5.700	27.49
-------- TOTAL --------	14.934	100.00	-------- TOTAL --------	20.734	100.00

MP6 CHANGI AIRPORT					
1981			1990		
Name of factory	Contributing concentration (ppb)	Contribution rate (%)	Name of factory	Contributing concentration (ppb)	Contribution rate (%)
SENOKO POWER STATION	0.508	7.58	SENOKO POWER STATION	0.769	8.06
JURONG POWER STATION	0.471	7.02	JURONG POWER STATION	0.471	4.94
PASIR PANJANG POWER STATION	0.303	4.52	TEKONG INTEGRATED STEEL MILL	0.309	3.24
SHELL COMPANIES IN SINGAPORE	0.229	3.42	PASIR PANJANG POWER STATION	0.303	3.18
ESSO SINGAPORE PTE LTD	0.160	2.38	SERAYA POWER STATION	0.277	2.90
SINGAPORE REFINING CO PTE LTD	0.091	1.35	SHELL COMPANIES IN SINGAPORE	0.229	2.40
MOBIL OIL SINGAPORE PTE LTD	0.086	1.28	ESSO SINGAPORE PTE LTD	0.160	1.67
NATIONAL IRON & STEEL MILLS LTD	0.029	0.44	TEKONG POWER STATION	0.108	1.14
SUGAR INDUSTRY OF SINGAPORE LTD	0.018	0.27	SINGAPORE REFINING CO PTE LTD	0.091	0.95
HORIZON PAPER INDS PTE LTD	0.012	0.18	MOBIL OIL SINGAPORE PTE LTD	0.081	0.85
- REMAINING FACTORIES -	0.068	1.00	- REMAINING FACTORIES -	0.383	4.02
------- VESSELS -------	0.435	6.48	------- VESSELS -------	0.659	6.90
----- BACK GROUND -----	4.300	64.08	----- BACK GROUND -----	5.700	59.75
-------- TOTAL --------	6.710	100.00	-------- TOTAL --------	9.540	100.00

Table V-2-5-(c) Contribution of highest emission 10 factories at monitoring station (yearly average)

MP7 BEDOK POLICE STATION					
1981			1990		
Name of factory	Contributing concentration (ppb)	Contribution rate (%)	Name of factory	Contributing concentration (ppb)	Contribution rate (%)
JURONG POWER STATION	0.852	10.54	SENOKO POWER STATION	1.047	9.07
SENOKO POWER STATION	0.689	8.52	JURONG POWER STATION	0.852	7.38
PASIR PANJANG POWER STATION	0.386	4.77	SERAYA POWER STATION	0.436	3.77
ESSO SINGAPORE PTE LTD	0.308	3.81	PASIR PANJANG POWER STATION	0.386	3.34
SHELL COMPANIES IN SINGAPORE	0.286	3.54	TEKONG INTEGRATED STEEL MILL	0.328	2.84
SINGAPORE REFINING CO PTE LTD	0.178	2.21	ESSO SINGAPORE PTE LTD	0.308	2.67
MOBIL OIL SINGAPORE PTE LTD	0.104	1.29	SHELL COMPANIES IN SINGAPORE	0.286	2.47
NATIONAL IRON & STEEL MILLS LTD	0.056	0.69	SINGAPORE REFINING CO PTE LTD	0.178	1.54
SUGAR INDUSTRY OF SINGAPORE LTD	0.036	0.44	NATIONAL IRON & STEEL MILLS LTD	0.139	1.20
HORIZON PAPER INDS PTE LTD	0.014	0.17	TEKONG POWER STATION	0.104	0.90
- REMAINING FACTORIES -	0.081	1.03	- REMAINING FACTORIES -	0.516	4.49
------- VESSELS -------	0.789	9.77	------- VESSELS -------	1.264	10.95
----- BACK GROUND -----	4.300	53.22	----- BACK GROUND -----	5.700	49.38
-------- TOTAL --------	8.079	100.00	-------- TOTAL --------	11.544	100.00

Table V-2-5-(d) Contribution of highest emission 10 factories at monitoring station (yearly average)

MP1 N.U.S.

1981 Name of factory	Contributing concentration (ppb)	Contribution rate (%)	1990 Name of factory	Contributing concentration (ppb)	Contribution rate (%)
SHELL COMPANIES IN SINGAPORE	4.409	24.08	SHELL COMPANIES IN SINGAPORE	4.409	18.24
PASIR PANJANG POWER STATION	2.607	14.24	PASIR PANJANG POWER STATION	2.607	10.78
JURONG POWER STATION	1.274	6.96	SENOKO POWER STATION	1.429	5.91
SENOKO POWER STATION	0.932	5.09	JURONG POWER STATION	1.274	5.27
ESSO SINGAPORE PTE LTD	0.820	4.48	ESSO SINGAPORE PTE LTD	0.820	3.39
SINGAPORE REFINING CO PTE LTD	0.448	2.45	NATIONAL IRON & STEEL MILLS LTD	0.538	2.23
MOBIL OIL SINGAPORE PTE LTD	0.281	1.53	SUMITOMO KAGAKU PTE LTD	0.475	1.97
NATIONAL IRON & STEEL MILLS LTD	0.216	1.18	SINGAPORE REFINING CO PTE LTD	0.448	1.85
SUGAR INDUSTRY OF SINGAPORE LTD	0.151	0.83	SERAYA POWER STATION	0.409	1.69
RCD-BRICKWORKS TILE WORKS	0.148	0.81	SUGAR INDUSTRY OF SINGAPORE LTD	0.377	1.56
- REMAINING FACTORIES -	0.487	2.66	- REMAINING FACTORIES -	2.261	9.34
------- VESSELS -------	2.233	12.20	------- VESSELS -------	3.431	14.19
------ BACK GROUND ------	4.300	23.49	------ BACK GROUND ------	5.700	23.58
-------- TOTAL --------	18.306	100.00	-------- TOTAL --------	24.178	100.00

MP2 J.T.C. HALL

1981 Name of factory	Contributing concentration (ppb)	Contribution rate (%)	1990 Name of factory	Contributing concentration (ppb)	Contribution rate (%)
PASIR PANJANG POWER STATION	2.965	16.41	PASIR PANJANG POWER STATION	2.965	11.14
SHELL COMPANIES IN SINGAPORE	2.802	15.51	SHELL COMPANIES IN SINGAPORE	2.802	10.53
ESSO SINGAPORE PTE LTD	1.545	8.55	SERAYA POWER STATION	1.860	6.99
JURONG POWER STATION	1.055	5.84	ESSO SINGAPORE PTE LTD	1.545	5.80
SINGAPORE REFINING CO PTE LTD	0.997	5.52	JURONG POWER STATION	1.055	3.96
SENOKO POWER STATION	0.586	3.24	SINGAPORE REFINING CO PTE LTD	0.997	3.74
MOBIL OIL SINGAPORE PTE LTD	0.319	1.77	SIME DARBY OLEOCHEMICALS LTD	0.990	3.72
SIME DARBY OLEOCHEMICALS LTD	0.291	1.61	SUMITOMO KAGAKU PTE LTD	0.943	3.54
NATIONAL IRON & STEEL MILLS LTD	0.249	1.38	SENOKO POWER STATION	0.890	3.34
RCD-BRICKWORKS TILE WORKS	0.241	1.33	NATIONAL IRON & STEEL MILLS LTD	0.619	2.33
- REMAINING FACTORIES -	0.930	5.14	- REMAINING FACTORIES -	3.515	13.21
------- VESSELS -------	1.788	9.90	------- VESSELS -------	2.738	10.29
------ BACK GROUND ------	4.300	23.80	------ BACK GROUND ------	5.700	21.41
-------- TOTAL --------	18.068	100.00	-------- TOTAL --------	26.619	100.00

Table V-2-6-(a) Contribution of highest emission 10 factories at monitoring station (southerly monsoon)

MP3 S.I.U.					
1981			1990		
Name of factory	Contributing concentration (ppb)	Contribution rate (%)	Name of factory	Contributing concentration (ppb)	Contribution rate (%)
ESSO SINGAPORE PTE LTD	3.968	14.24	THE CHEMICAL CORPN OF SINGAPORE PTE LTD	6.518	13.53
SINGAPORE REFINING CO PTE LTD	3.744	13.44	ESSO SINGAPORE PTE LTD	3.968	8.23
SHELL COMPANIES IN SINGAPORE	2.649	9.51	SINGAPORE REFINING CO PTE LTD	3.744	7.77
PASIR PANJANG POWER STATION	2.051	7.36	NATIONAL IRON & STEEL MILLS LTD	3.411	7.08
THE CHEMICAL CORPN OF SINGAPORE PTE LTD	1.915	6.88	SHELL COMPANIES IN SINGAPORE	2.649	5.50
NATIONAL IRON & STEEL MILLS LTD	1.369	4.92	SUGAR INDUSTRY OF SINGAPORE LTD	2.509	5.21
SUGAR INDUSTRY OF SINGAPORE LTD	1.007	3.62	SUMITOMO KAGAKU PTE LTD	2.061	4.28
HUME INDS (S) LTD	0.693	2.49	PASIR PANJANG POWER STATION	2.051	4.26
SENOKO POWER STATION	0.631	2.27	SERAYA POWER STATION	2.046	4.25
MOBIL OIL SINGAPORE PTE LTD	0.619	2.22	HUME INDS (S) LTD	1.727	3.58
- REMAINING FACTORIES -	2.358	8.44	- REMAINING FACTORIES -	7.997	16.59
------- VESSELS -------	2.555	9.17	------- VESSELS -------	3.803	7.89
----- BACK GROUND -----	4.300	15.44	----- BACK GROUND -----	5.700	11.83
-------- TOTAL --------	27.859	100.00	-------- TOTAL --------	48.184	100.00

MP4 BOON LAY APARTMENT					
1981			1990		
Name of factory	Contributing concentration (ppb)	Contribution rate (%)	Name of factory	Contributing concentration (ppb)	Contribution rate (%)
JURONG POWER STATION	7.181	24.81	JURONG POWER STATION	7.181	15.78
PASIR PANJANG POWER STATION	2.679	9.25	SERAYA POWER STATION	3.604	7.92
ESSO SINGAPORE PTE LTD	2.571	8.88	DRAGON POLY-FOAM INDS (S) PTE LTD	2.692	5.92
SHELL COMPANIES IN SINGAPORE	2.274	7.86	PASIR PANJANG POWER STATION	2.679	5.89
SINGAPORE REFINING CO PTE LTD	2.252	7.78	ESSO SINGAPORE PTE LTD	2.571	5.65
SUGAR INDUSTRY OF SINGAPORE LTD	0.968	3.34	SUGAR INDUSTRY OF SINGAPORE LTD	2.410	5.30
MOBIL OIL SINGAPORE PTE LTD	0.780	2.70	SHELL COMPANIES IN SINGAPORE	2.274	5.00
NATIONAL IRON & STEEL MILLS LTD	0.731	2.52	SINGAPORE REFINING CO PTE LTD	2.252	4.95
SENOKO POWER STATION	0.544	1.88	NATIONAL IRON & STEEL MILLS LTD	1.820	4.00
THE CHEMICAL CORPN OF SINGAPORE PTE LTD	0.311	1.07	SUMITOMO KAGAKU PTE LTD	1.405	3.09
- REMAINING FACTORIES -	2.465	8.52	- REMAINING FACTORIES -	8.126	17.85
------- VESSELS -------	1.892	6.54	------- VESSELS -------	2.786	6.12
----- BACK GROUND -----	4.300	14.85	----- BACK GROUND -----	5.700	12.53
-------- TOTAL --------	28.943	100.00	-------- TOTAL --------	45.500	100.00

Table V-2-6-(b) Contribution of highest emission 10 factories at monitoring station (southerly monsoon)

MP5 BUKIT TIMAH FIRE ST.

1981 Name of factory	Contributing concentration (ppb)	Contribution rate (%)	1990 Name of factory	Contributing concentration (ppb)	Contribution rate (%)
PASIR PANJANG POWER STATION	3.071	19.58	PASIR PANJANG POWER STATION	3.071	13.71
SHELL COMPANIES IN SINGAPORE	2.420	15.43	SHELL COMPANIES IN SINGAPORE	2.420	10.80
JURONG POWER STATION	1.408	8.98	SERAYA POWER STATION	2.168	9.68
ESSO SINGAPORE PTE LTD	0.953	6.08	JURONG POWER STATION	1.408	6.28
SINGAPORE REFINING CO PTE LTD	0.587	3.74	ESSO SINGAPORE PTE LTD	0.953	4.25
SENOKO POWER STATION	0.499	3.18	SENOKO POWER STATION	0.867	3.87
MOBIL OIL SINGAPORE PTE LTD	0.219	1.40	SINGAPORE REFINING CO PTE LTD	0.587	2.62
SUGAR INDUSTRY OF SINGAPORE LTD	0.160	1.02	SUMITOMO KAGAKU PTE LTD	0.405	1.81
NATIONAL IRON & STEEL MILLS LTD	0.142	0.90	SUGAR INDUSTRY OF SINGAPORE LTD	0.399	1.78
RCD BRICKWORKS TILE WORKS	0.085	0.54	TEKONG INTEGRATED STEEL MILL	0.369	1.65
- REMAINING FACTORIES -	0.338	2.17	- REMAINING FACTORIES -	1.786	7.97
VESSELS	1.497	9.55	VESSELS	2.272	10.14
BACK GROUND	4.300	27.43	BACK GROUND	5.700	25.44
TOTAL	15.679	100.00	TOTAL	22.405	100.00

MP6 CHANGI AIRPORT

1981 Name of factory	Contributing concentration (ppb)	Contribution rate (%)	1990 Name of factory	Contributing concentration (ppb)	Contribution rate (%)
JURONG POWER STATION	0.576	8.19	JURONG POWER STATION	0.576	5.73
PASIR PANJANG POWER STATION	0.372	5.29	SENOKO POWER STATION	0.527	5.24
SENOKO POWER STATION	0.346	4.93	TEKONG INTEGRATED STEEL MILL	0.374	3.72
SHELL COMPANIES IN SINGAPORE	0.282	4.01	PASIR PANJANG POWER STATION	0.372	3.70
ESSO SINGAPORE PTE LTD	0.199	2.83	SERAYA POWER STATION	0.329	3.27
SINGAPORE REFINING CO PTE LTD	0.110	1.57	SHELL COMPANIES IN SINGAPORE	0.282	2.80
MOBIL OIL SINGAPORE PTE LTD	0.086	1.23	ESSO SINGAPORE PTE LTD.	0.199	1.98
NATIONAL IRON & STEEL MILLS LTD	0.036	0.52	TEKONG POWER STATION	0.130	1.29
SUGAR INDUSTRY OF SINGAPORE LTD	0.022	0.32	SINGAPORE REFINING CO PTE LTD	0.110	1.10
HORIZON PAPER INDS PTE LTD	0.012	0.17	NATIONAL IRON & STEEL MILLS LTD	0.091	0.90
- REMAINING FACTORIES -	0.073	1.03	- REMAINING FACTORIES -	0.433	4.34
VESSELS	0.612	8.71	VESSELS	0.926	9.21
BACK GROUND	4.300	61.20	BACK GROUND	5.700	56.72
TOTAL	7.028	100.00	TOTAL	10.049	100.00

Table V-2-6-(c) Contribution of highest emission 10 factories at monitoring station (southerly monsoon)

MP7 BEDOK POLICE STATION					
1981			1990		
Name of factory	Contributing concentration (ppb)	Contribution rate (%)	Name of factory	Contributing concentration (ppb)	Contribution rate (%)
JURONG POWER STATION	0.842	10.16	JURONG POWER STATION	0.842	7.13
SENOKO POWER STATION	0.491	5.93	SENOKO POWER STATION	0.753	6.38
PASIR PANJANG POWER STATION	0.470	5.68	PASIR PANJANG POWER STATION	0.470	3.99
SHELL COMPANIES IN SINGAPORE	0.349	4.22	SERAYA POWER STATION	0.417	3.53
ESSO SINGAPORE PTE LTD	0.310	3.74	SHELL COMPANIES IN SINGAPORE	0.349	2.96
SINGAPORE REFINING CO PTE LTD	0.180	2.18	TEKONG INTEGRATED STEEL MILL	0.329	2.79
MOBIL OIL SINGAPORE PTE LTD	0.101	1.22	ESSO SINGAPORE PTE LTD	0.310	2.62
NATIONAL IRON & STEEL MILLS LTD	0.057	0.69	SINGAPORE REFINING CO PTE LTD	0.180	1.53
SUGAR INDUSTRY OF SINGAPORE LTD	0.036	0.44	NATIONAL IRON & STEEL MILLS LTD	0.142	1.20
HORIZON PAPER INDS PTE LTD	0.014	0.17	TEKONG POWER STATION	0.103	0.88
- REMAINING FACTORIES -	0.088	1.05	- REMAINING FACTORIES -	2.034	4.69
------- VESSELS -------	1.044	12.60	------- VESSELS -------	1.650	13.99
----- BACK GROUND -----	4.300	51.92	----- BACK GROUND -----	5.700	45.33
-------- TOTAL --------	8.282	100.00	-------- TOTAL --------	11.794	100.00

Table V-2-6-(d) Contribution of highest emission 10 factories at monitoring station (southerly monsoon)

MP1 N.U.S.					
1981			1990		
Name of factory	Contributing concentration (ppb)	Contribution rate (%)	Name of factory	Contributing concentration (ppb)	Contribution rate (%)
SENOKO POWER STATION	3.093	24.97	SENOKO POWER STATION	4.689	26.14
JURONG POWER STATION	1.838	14.84	JURONG POWER STATION	1.838	10.25
SHELL COMPANIES IN SINGAPORE	0.517	4.17	NATIONAL IRON & STEEL MILLS LTD	0.522	2.91
ESSO SINGAPORE PTE LTD	0.481	3.88	SHELL COMPANIES IN SINGAPORE	0.517	2.88
MOBIL OIL SINGAPORE PTE LTD	0.328	2.65	ESSO SINGAPORE PTE LTD	0.481	2.68
SINGAPORE REFINING CO PTE LTD	0.285	2.30	SUGAR INDUSTRY OF SINGAPORE LTD	0.370	2.06
NATIONAL IRON & STEEL MILLS LTD	0.210	1.69	SUMITOMO KAGAKU PTE LTD	0.304	1.70
RCD BRICKWORKS TILE WORKS	0.151	1.22	MOBIL OIL SINGAPORE PTE LTD	0.297	1.66
SUGAR INDUSTRY OF SINGAPORE LTD	0.148	1.20	RCD BRICKWORKS TILE WORKS	0.296	1.65
PASIR PANJANG POWER STATION	0.123	0.99	SIME DARBY OLEOCHEMICALS LTD	0.295	1.65
— REMAINING FACTORIES —	0.549	4.44	— REMAINING FACTORIES —	2.099	11.68
------- VESSELS -------	0.364	2.94	------- VESSELS -------	0.532	2.97
----- BACK GROUND -----	4.300	34.71	----- BACK GROUND -----	5.700	31.77
-------- TOTAL --------	12.387	100.00	-------- TOTAL --------	17.940	100.00

MP2 J.T.C. HALL					
1981			1990		
Name of factory	Contributing concentration (ppb)	Contribution rate (%)	Name of factory	Contributing concentration (ppb)	Contribution rate (%)
SENOKO POWER STATION	6.646	45.35	SENOKO POWER STATION	10.048	45.47
JURONG POWER STATION	0.641	4.37	RCD BRICKWORKS TILE WORKS	0.908	4.11
ESSO SINGAPORE PTE LTD	0.605	4.13	JURONG POWER STATION	0.641	2.90
RCD BRICKWORKS TILE WORKS	0.464	3.17	ESSO SINGAPORE PTE LTD	0.605	2.74
SINGAPORE REFINING CO PTE LTD	0.386	2.64	SINGAPORE REFINING CO PTE LTD	0.386	1.75
MOBIL OIL SINGAPORE PTE LTD	0.218	1.49	NATIONAL IRON & STEEL MILLS LTD	0.385	1.74
SHELL COMPANIES IN SINGAPORE	0.173	1.18	SUGAR INDUSTRY OF SINGAPORE LTD	0.361	1.63
NATIONAL IRON & STEEL MILLS LTD	0.155	1.05	SERAYA POWER STATION	0.305	1.38
SUGAR INDUSTRY OF SINGAPORE LTD	0.145	0.99	DRAGON POLY-FOAM INDS (S) PTE LTD	0.242	1.09
PASIR PANJANG POWER STATION	0.137	0.94	SUMITOMO KAGAKU PTE LTD	0.232	1.05
— REMAINING FACTORIES —	0.551	3.77	— REMAINING FACTORIES —	1.958	8.86
------- VESSELS -------	0.232	1.58	------- VESSELS -------	0.329	1.49
----- BACK GROUND -----	4.300	29.34	----- BACK GROUND -----	5.700	25.79
-------- TOTAL --------	14.653	100.00	-------- TOTAL --------	22.100	100.00

Table V-2-7-(a) Contribution of highest emission 10 factories at monitoring station (northerly monsoon)

MP3 N.U.S.

1981 Name of factory	Contributing concentration (ppb)	Contribution rate (%)	1990 Name of factory	Contributing concentration (ppb)	Contribution rate (%)
SENOKO POWER STATION	6.361	38.54	SENOKO POWER STATION	9.622	34.09
ESSO SINGAPORE PTE LTD	0.665	4.03	DRAGON POLY-FOAM INDS (S) PTE LTD	2.720	9.64
NATIONAL IRON & STEEL MILLS LTD	0.502	3.04	NATIONAL IRON & STEEL MILLS LTD	1.251	4.43
HERCULES RUBBER & CHAMICAL INDS PTE LTD	0.463	2.80	BEECHAN (MFG) SINGAPORE PTE LTD	0.762	2.70
MAXIM DYEING & FINISHING FTY PTE LTD	0.454	2.75	HERCULES RUBBER & CHAMICAL INDS PTE LTD	0.714	2.53
SINGAPORE REFINING CO PTE LTD	0.450	2.72	BROADWAY ENTERPRISES PTE LTD	0.705	2.50
MOBIL OIL SINGAPORE PTE LTD	0.415	2.51	MAXIM DYEING & FINISHING FTY PTE LTD	0.695	2.46
BROADWAY ENTERPRISES PTE LTD	0.311	1.88	ESSO SINGAPORE PTE LTD	0.665	2.36
DRAGON POLY-FOAM INDS (S) PTE LTD	0.296	1.79	RCD BRICKWORKS TILE WORKS	0.486	1.72
HONGKONG DYEING & WEAVING (S) LTD	0.252	1.53	SINGAPORE REFINING CO PTE LTD	0.450	1.59
- REMAINING FACTORIES -	1.768	10.72	- REMAINING FACTORIES -	4.090	14.48
------- VESSELS -------	0.270	1.64	------- VESSELS -------	0.368	1.31
----- BACK GROUND -----	4.300	26.05	----- BACK GROUND -----	5.700	20.19
-------- TOTAL --------	16.507	100.00	-------- TOTAL --------	28.228	100.00

MP4 BOON LAY APARTMENT

1981 Name of factory	Contributing concentration (ppb)	Contribution rate (%)	1990 Name of factory	Contributing concentration (ppb)	Contribution rate (%)
SENOKO POWER STATION	3.399	32.06	SENOKO POWER STATION	6.872	39.19
JURONG POWER STATION	0.610	5.76	JURONG POWER STATION	0.610	3.48
ESSO SINGAPORE PTE LTD	0.446	4.20	ESSO SINGAPORE PTE LTD	0.446	2.54
MOBIL OIL SINGAPORE PTE LTD	0.318	2.99	SERAYA POWER STATION	0.386	2.20
SINGAPORE REFINING CO PTE LTD	0.270	2.55	NATIONAL IRON & STEEL MILLS LTD	0.371	2.11
NATIONAL IRON & STEEL MILLS LTD	0.149	1.40	DRAGON POLY-FOAM INDS (S) PTE LTD	0.316	1.80
SHELL COMPANIES IN SINGAPORE	0.146	1.38	SUGAR INDUSTRY OF SINGAPORE LTD	0.287	1.63
PASIR PANJANG POWER STATION	0.123	1.16	MOBIL OIL SINGAPORE PTE LTD	0.283	1.61
SUGAR INDUSTRY OF SINGAPORE LTD	0.115	1.08	SINGAPORE REFINING CO PTE LTD	0.270	1.54
RCD BRICKWORKS TILE WORKS	0.069	0.65	BROADWAY ENTERPRISES PTE LTD	0.189	1.08
- REMAINING FACTORIES -	0.482	4.56	- REMAINING FACTORIES -	1.561	8.92
------- VESSELS -------	0.175	1.65	------- VESSELS -------	0.243	1.39
----- BACK GROUND -----	4.300	40.56	----- BACK GROUND -----	5.700	32.51
-------- TOTAL --------	10.602	100.00	-------- TOTAL --------	17.534	100.00

Table V-2-7-(b) Contribution of highest emission 10 factories at monitoring station (northerly monsoon)

MP5 BUKIT TIMAH FIRE ST.					
1981			1990		
Name of factory	Contributing concentration (ppb)	Contribution rate (%)	Name of factory	Contributing concentration (ppb)	Contribution rate (%)
SENOKO POWER STATION	6.944	50.03	SENOKO POWER STATION	8.659	47.14
JURONG POWER STATION	0.868	6.25	JURONG POWER STATION	0.868	4.72
ESSO SINGAPORE PTE LTD	0.388	2.79	ESSO SINGAPORE PTE LTD	0.388	2.11
SHELL COMPANIES IN SINGAPORE	0.273	1.97	SERAYA POWER STATION	0.375	2.04
SINGAPORE REFINING CO PTE LTD	0.242	1.74	SHELL COMPANIES IN SINGAPORE	0.273	1.48
PASIR PANJANG POWER STATION	0.174	1.26	SINGAPORE REFINING CO PTE LTD	0.242	1.32
MOBIL OIL SINGAPORE PTE LTD	0.144	1.04	NATIONAL IRON & STEEL MILLS LTD	0.209	1.14
NATIONAL IRON & STEEL MILLS LTD	0.084	0.61	SUMITOMO KAGAKU PTE LTD	0.177	0.96
RCD BRICKWORKS TILE WORKS	0.084	0.60	PASIR PANJANG POWER STATION	0.174	0.95
SUGAR INDUSTRY OF SINGAPORE LTD	0.067	0.48	SUGAR INDUSTRY OF SINGAPORE LTD	0.167	0.91
- REMAINING FACTORIES -	0.164	1.19	- REMAINING FACTORIES -	0.928	5.07
------- VESSELS -------	0.147	1.06	------- VESSELS -------	0.206	1.12
----- BACK GROUND -----	4.300	30.98	----- BACK GROUND -----	5.700	31.04
-------- TOTAL --------	13.879	100.00	-------- TOTAL --------	18.366	100.00

MP6 CHANGI AIRPORT					
1981			1990		
Name of factory	Contributing concentration (ppb)	Contribution rate (%)	Name of factory	Contributing concentration (ppb)	Contribution rate (%)
SENOKO POWER STATION	0.738	11.79	SENOKO POWER STATION	1.112	12.61
JURONG POWER STATION	0.323	5.15	JURONG POWER STATION	0.323	3.66
PASIR PANJANG POWER STATION	0.206	3.28	TEKONG INTEGRATED STEEL MILL	0.218	2.47
SHELL COMPANIES IN SINGAPORE	0.155	2.47	PASIR PANJANG POWER STATION	0.206	2.33
ESSO SINGAPORE PTE LTD	0.105	1.67	SERAYA POWER STATION	0.203	2.30
MOBIL OIL SINGAPORE PTE LTD	0.086	1.37	SHELL COMPANIES IN SINGAPORE	0.155	1.76
SINGAPORE REFINING CO PTE LTD	0.063	1.00	ESSO SINGAPORE PTE LTD	0.105	1.19
NATIONAL IRON & STEEL MILLS LTD	0.019	0.31	MOBIL OIL SINGAPORE PTE LTD	0.078	0.88
SUGAR INDUSTRY OF SINGAPORE LTD	0.013	0.20	TEKONG POWER STATION	0.078	0.88
HORIZON PAPER INDS PTE LTD	0.011	0.18	SINGAPORE REFINING CO PTE LTD	0.063	0.71
- REMAINING FACTORIES -	0.060	0.98	- REMAINING FACTORIES -	0.297	3.40
------- VESSELS -------	0.184	2.94	------- VESSELS -------	0.280	3.17
----- BACK GROUND -----	4.300	68.66	----- BACK GROUND -----	5.700	64.64
-------- TOTAL --------	6.263	100.00	-------- TOTAL --------	8.818	100.00

Table V-2-7-(c) Contribution of highest emission 10 factories at monitoring station (northerly monsoon)

MP7 BEDOK POLICE STATION					
1981			1990		
Name of factory	Contributing concentration (ppb)	Contribution rate (%)	Name of factory	Contributing concentration (ppb)	Contribution rate (%)
SENOKO POWER STATION	0.969	12.43	SENOKO POWER STATION	1.464	13.08
JURONG POWER STATION	0.866	11.11	JURONG POWER STATION	0.866	7.74
ESSO SINGAPORE PTE LTD	0.306	3.92	SERAYA POWER STATION	0.462	4.13
PASIR PANJANG POWER STATION	0.266	3.41	TEKONG INTEGRATED STEEL MILL	0.327	2.92
SHELL COMPANIES IN SINGAPORE	0.196	2.51	ESSO SINGAPORE PTE LTD	0.306	2.73
SINGAPORE REFINING CO PTE LTD	0.175	2.25	PASIR PANJANG POWER STATION	0.266	2.37
MOBIL OIL SINGAPORE PTE LTD	0.109	1.40	SHELL COMPANIES IN SINGAPORE	0.196	1.75
NATIONAL IRON & STEEL MILLS LTD	0.054	0.70	SINGAPORE REFINING CO PTE LTD	0.175	1.57
SUGAR INDUSTRY OF SINGAPORE LTD	0.035	0.45	NATIONAL IRON & STEEL MILLS LTD	0.135	1.21
HORIZON PAPER INDS PTE LTD	0.013	0.17	TEKONG POWER STATION	0.105	0.94
- REMAINING FACTORIES -	0.076	0.98	- REMAINING FACTORIES -	0.470	4.21
------- VESSELS -------	0.428	5.49	------- VESSELS -------	0.717	6.41
------- BACK GROUND -------	4.300	55.18	------- BACK GROUND -------	5.700	50.94
------- TOTAL -------	7.793	100.00	------- TOTAL -------	11.189	100.00

Table V-2-7-(d) Contribution of highest emission 10 factories at monitoring station (northerly monsoon)

Table V-2-8 Contribution of major emission sources at monitoring stations (yearly average)

Name of factory	(1) N.U.S.				(2) J.T.C. HALL			
	1981		1990		1981		1990	
	Contributing concentration (ppb)	Contribution rate (%)	Contributing concentration (ppb)	Contribution rate (%)	Contributing concentration (ppb)	Contribution rate (%)	Contributing concentration (ppb)	Contribution rate (%)
TEKONG INTEGRATED STEEL MILL	—	—	0.204	0.95	—	—	0.192	0.78
SENOKO POWER STATION	1.826	11.52	2.778	12.86	3.093	18.57	4.679	18.91
JURONG POWER STATION	1.508	9.51	1.508	6.98	0.853	5.30	0.884	3.57
PASIR PANJANG POWER STATION	1.530	9.96	1.580	7.31	1.795	10.78	1.795	7.25
SERAYA POWER STATION	—	—	0.341	1.58	—	—	1.217	4.92
TEKONG POWER STATION	—	—	0.063	0.29	—	—	0.059	0.24
SHELL COMPANIES IN SINGAPORE	2.799	17.65	2.799	12.96	1.714	10.29	1.714	6.93
ESSO SINGAPORE PTE LTD	0.680	4.29	0.680	3.15	1.156	6.94	1.156	4.67
SINGAPORE REFINING CO PTE LTD	0.380	2.40	0.380	1.76	0.744	4.47	0.744	3.01
MOBIL OIL SINGAPORE PTE LTD.	0.300	1.89	0.284	1.31	0.277	1.67	0.263	1.06
-- REMAINING FACTORIES --	1.024	6.45	3.048	14.13	1.548	9.29	4.604	18.59
------- VESSELS -------	1.460	9.21	2.232	10.33	1.144	6.87	1.742	7.04
----- BACK GROUND -----	4.300	27.12	5.700	26.39	4.300	25.82	5.700	23.03
-------- TOTAL --------	15.857	100.00	21.597	100.00	16.655	100.00	24.749	100.00

Name of factory	(3) S.I.U.				(4) BOON LAY APARTMENT			
	1981		1990		1981		1990	
	Contributing concentration (ppb)	Contribution rate (%)	Contributing concentration (ppb)	Contribution rate (%)	Contributing concentration (ppb)	Contribution rate (%)	Contributing concentration (ppb)	Contribution rate (%)
TEKONG INTEGRATED STEEL MILL	—	—	0.177	0.44	—	—	0.233	0.69
SENOKO POWER STATION	3.002	12.96	4.544	11.38	1.725	8.08	3.347	9.85
JURONG POWER STATION	0.104	0.45	0.104	0.26	4.453	20.37	4.463	13.15
PASIR PANJANG POWER STATION	1.252	5.41	1.252	3.14	1.621	7.59	1.621	4.78
SERAYA POWER STATION	—	—	1.243	3.11	—	—	2.273	6.70
TEKONG POWER STATION	—	—	0.054	0.14	—	—	0.071	0.21
SHELL COMPANIES IN SINGAPORE	1.621	7.00	1.621	4.06	1.394	6.53	1.394	4.11
ESSO SINGAPORE PTE LTD	2.601	11.23	2.601	6.51	1.692	7.92	1.693	4.99
SINGAPORE REFINING CO PTE LTD	2.381	10.28	2.381	5.96	1.432	6.71	1.432	4.22
MOBIL OIL SINGAPORE PTE LTD	0.535	2.31	0.505	1.27	0.557	2.76	0.555	1.64
-- REMAINING FACTORIES --	5.756	24.85	17.364	43.48	2.960	13.86	9.412	27.74
------- VESSELS -------	1.610	6.95	2.382	5.97	1.182	5.53	1.734	5.11
----- BACK GROUND -----	4.300	18.56	5.700	14.28	4.300	20.13	5.700	16.80
-------- TOTAL --------	23.162	100.00	37.928	100.00	21.358	100.00	33.930	100.00

Name of factory	(5) BUKIT TIMAH FIRE ST.				(6) CHANGI AIRPORT			
	1981		1990		1981		1990	
	Contributing concentration (ppb)	Contribution rate (%)	Contributing concentration (ppb)	Contribution rate (%)	Contributing concentration (ppb)	Contribution rate (%)	Contributing concentration (ppb)	Contribution rate (%)
TEKONG INTEGRATED STEEL MILL	—	—	0.275	1.33	—	—	0.309	3.24
SENOKO POWER STATION	3.165	21.19	4.091	19.73	0.508	7.58	0.767	8.04
JURONG POWER STATION	1.185	7.93	1.185	5.71	0.471	7.02	0.471	4.94
PASIR PANJANG POWER STATION	1.872	12.54	1.872	9.03	0.303	4.52	0.303	3.18
SERAYA POWER STATION	—	—	1.426	6.88	—	—	0.277	2.90
TEKONG POWER STATION	—	—	0.084	0.41	—	—	0.108	1.14
SHELL COMPANIES IN SINGAPORE	1.532	10.26	1.532	7.39	0.227	3.42	0.229	2.40
ESSO SINGAPORE PTE LTD	0.719	4.82	0.719	3.47	0.160	2.39	0.160	1.67
SINGAPORE REFINING CO PTE LTD	0.444	2.97	0.444	2.14	0.091	1.35	0.091	0.95
MOBIL OIL SINGAPORE PTE LTD	0.189	1.26	0.181	0.87	0.065	1.25	0.061	0.65
-- REMAINING FACTORIES --	0.591	3.96	1.605	8.72	0.127	1.67	0.383	4.02
------- VESSELS -------	0.933	6.28	1.417	6.83	0.455	6.45	0.655	6.50
----- BACK GROUND -----	4.300	28.79	5.700	27.49	4.300	64.08	5.700	59.75
-------- TOTAL --------	14.934	100.00	20.734	100.00	6.710	100.00	9.540	100.00

Name of factory	(7) BEDOK POLICE STATION							
	1981		1990		1981		1990	
	Contributing concentration (ppb)	Contribution rate (%)	Contributing concentration (ppb)	Contribution rate (%)	Contributing concentration (ppb)	Contribution rate (%)	Contributing concentration (ppb)	Contribution rate (%)
TEKONG INTEGRATED STEEL MILL	—	—	0.328	2.84				
SENOKO POWER STATION	0.689	8.52	1.047	9.07				
JURONG POWER STATION	0.852	10.54	0.852	7.38				
PASIR PANJANG POWER STATION	0.386	4.77	0.386	3.34				
SERAYA POWER STATION	—	—	0.435	3.77				
TEKONG POWER STATION	—	—	0.104	0.90				
SHELL COMPANIES IN SINGAPORE	0.286	3.54	0.285	2.47				
ESSO SINGAPORE PTE LTD	0.308	3.81	0.308	2.67				
SINGAPORE REFINING CO PTE LTD	0.176	2.21	0.176	1.54				
MOBIL OIL SINGAPORE PTE LTD	0.104	1.29	0.100	0.87				
-- REMAINING FACTORIES --	0.187	2.35	0.555	4.82				
------- VESSELS -------	0.789	9.77	1.264	10.95				
----- BACK GROUND -----	4.300	53.22	5.700	49.39				
-------- TOTAL --------	8.079	100.00	11.541	100.00				

Table V-2-9 Contribution of major emission sources at monitoring stations (southerly monsoon)

Name of factory	(1) N.U.S.				(2) J.T.C. HALL			
	1981		1990		1981		1990	
	Contributing concentration (ppb)	Contribution rate (%)	Contributing concentration (ppb)	Contribution rate (%)	Contributing concentration (ppb)	Contribution rate (%)	Contributing concentration (ppb)	Contribution rate (%)
TEKONG INTEGRATED STEEL MILL	—	—	0.250	1.04	—	—	0.235	0.88
SENOKO POWER STATION	0.932	5.07	1.425	5.91	0.585	3.24	0.890	3.34
JURONG POWER STATION	1.274	6.96	1.274	5.27	1.055	5.84	1.055	3.96
PASIR PANJANG POWER STATION	2.607	14.24	2.607	10.78	2.965	16.41	2.965	11.14
SERAYA POWER STATION	—	—	0.409	1.69	—	—	1.860	6.99
TEKONG POWER STATION	—	—	0.078	0.31	—	—	0.072	0.27
SHELL COMPANIES IN SINGAPORE	4.409	24.08	4.407	18.24	2.802	15.51	2.802	10.53
ESSO SINGAPORE PTE LTD	0.820	4.48	0.820	3.39	1.545	8.55	1.545	5.80
SINGAPORE REFINING CO PTE LTD	0.448	2.45	0.445	1.85	0.997	5.52	0.997	3.74
MOBIL OIL SINGAPORE PTE LTD	0.281	1.53	0.274	1.13	0.319	1.77	0.310	1.17
-- REMAINING FACTORIES --	1.002	5.48	3.051	12.62	1.711	9.46	5.450	20.48
------- VESSELS -------	2.233	12.20	3.431	14.19	1.788	9.90	2.733	10.29
----- BACK GROUND -----	4.300	23.49	5.700	23.58	4.300	23.80	5.700	21.41
-------- TOTAL --------	18.306	100.00	24.178	100.00	18.066	100.00	26.619	100.00

Name of factory	(3) S.I.U.				(4) BOON LAY APARTMENT			
	1981		1990		1981		1990	
	Contributing concentration (ppb)	Contribution rate (%)	Contributing concentration (ppb)	Contribution rate (%)	Contributing concentration (ppb)	Contribution rate (%)	Contributing concentration (ppb)	Contribution rate (%)
TEKONG INTEGRATED STEEL MILL	—	—	0.217	0.45	—	—	0.317	0.70
SENOKO POWER STATION	0.631	2.27	0.960	1.99	0.544	1.88	0.659	1.69
JURONG POWER STATION	0.127	0.46	0.127	0.26	7.181	24.81	7.181	15.78
PASIR PANJANG POWER STATION	2.051	7.36	2.051	4.26	2.679	9.25	2.679	5.89
SERAYA POWER STATION	—	—	2.046	4.25	—	—	3.604	7.92
TEKONG POWER STATION	—	—	0.065	0.14	—	—	0.096	0.21
SHELL COMPANIES IN SINGAPORE	2.649	9.51	2.649	5.50	2.274	7.86	2.274	5.00
ESSO SINGAPORE PTE LTD	3.968	14.24	3.968	8.23	2.571	8.65	2.571	5.65
SINGAPORE REFINING CO PTE LTD	3.744	13.44	3.744	7.77	2.252	7.78	2.252	4.95
MOBIL OIL SINGAPORE PTE LTD	0.619	2.22	0.608	1.26	0.780	2.70	0.753	1.65
-- REMAINING FACTORIES --	7.215	25.89	22.245	46.17	4.475	15.45	14.429	31.71
------- VESSELS -------	2.555	9.17	3.803	7.89	1.892	6.54	2.784	6.13
----- BACK GROUND -----	4.300	15.44	5.700	11.83	4.300	14.65	5.700	12.53
-------- TOTAL --------	27.859	100.00	48.184	100.00	28.948	100.00	45.500	100.00

Name of factory	(5) BUKIT TIMAH FIRE ST.				(6) CHANGI AIRPORT			
	1981		1990		1981		1990	
	Contributing concentration (ppb)	Contribution rate (%)	Contributing concentration (ppb)	Contribution rate (%)	Contributing concentration (ppb)	Contribution rate (%)	Contributing concentration (ppb)	Contribution rate (%)
TEKONG INTEGRATED STEEL MILL	—	—	0.349	1.65	—	—	0.374	3.72
SENOKO POWER STATION	0.499	3.18	0.857	3.87	0.346	4.93	0.527	5.24
JURONG POWER STATION	1.406	8.98	1.408	6.28	0.576	8.19	0.576	5.73
PASIR PANJANG POWER STATION	3.071	19.58	3.071	13.71	0.372	5.29	0.372	3.70
SERAYA POWER STATION	—	—	2.166	9.68	—	—	0.329	3.27
TEKONG POWER STATION	—	—	0.112	0.50	—	—	0.130	1.29
SHELL COMPANIES IN SINGAPORE	2.420	15.43	2.420	10.80	0.282	4.01	0.282	2.80
ESSO SINGAPORE PTE LTD	0.953	6.08	0.953	4.25	0.199	2.83	0.199	1.98
SINGAPORE REFINING CO PTE LTD	0.587	3.74	0.587	2.62	0.110	1.57	0.110	1.10
MOBIL OIL SINGAPORE PTE LTD	0.219	1.40	0.216	0.97	0.085	1.21	0.081	0.64
-- REMAINING FACTORIES --	0.725	4.63	2.263	10.07	0.143	2.04	0.440	4.40
------- VESSELS -------	1.497	9.55	2.272	10.14	0.612	8.71	0.926	9.21
----- BACK GROUND -----	4.300	27.43	5.700	25.44	4.300	61.20	5.700	53.72
-------- TOTAL --------	15.677	100.00	22.405	100.00	7.026	100.00	10.047	100.00

Name of factory	(7) BEDOK POLICE STATION							
	1981		1990		1981		1990	
	Contributing concentration (ppb)	Contribution rate (%)	Contributing concentration (ppb)	Contribution rate (%)	Contributing concentration (ppb)	Contribution rate (%)	Contributing concentration (ppb)	Contribution rate (%)
TEKONG INTEGRATED STEEL MILL	—	—	0.329	2.79				
SENOKO POWER STATION	0.491	5.93	0.753	6.38				
JURONG POWER STATION	0.842	10.16	0.842	7.13				
PASIR PANJANG POWER STATION	0.470	5.68	0.470	3.99				
SERAYA POWER STATION	—	—	0.417	3.53				
TEKONG POWER STATION	—	—	0.103	0.88				
SHELL COMPANIES IN SINGAPORE	0.349	4.22	0.349	2.96				
ESSO SINGAPORE PTE LTD	0.310	3.74	0.310	2.62				
SINGAPORE REFINING CO PTE LTD	0.180	2.18	0.180	1.53				
MOBIL OIL SINGAPORE PTE LTD	0.101	1.22	0.100	0.85				
-- REMAINING FACTORIES --	0.195	2.35	0.591	5.02				
------- VESSELS -------	1.044	12.60	1.650	13.99				
----- BACK GROUND -----	4.300	51.93	5.700	48.33				
-------- TOTAL --------	8.283	100.00	11.794	100.00				

Table V-2-10 Contribution of major emission sources at monitoring stations (northerly monsoon)

Name of factory	(1) N.U.S.				(2) J.T.C. HALL			
	1981		1990		1981		1990	
	Contributing concentration (ppb)	Contribution rate (%)	Contributing concentration (ppb)	Contribution rate (%)	Contributing concentration (ppb)	Contribution rate (%)	Contributing concentration (ppb)	Contribution rate (%)
TEKONG INTEGRATED STEEL MILL	—	—	0.139	0.78	—	—	0.130	0.59
SENOKO POWER STATION	3.093	24.97	4.689	26.14	6.646	45.35	10.048	45.47
JURONG POWER STATION	1.838	14.84	1.839	10.25	0.641	4.37	0.641	2.90
PASIR PANJANG POWER STATION	0.123	0.99	0.123	0.69	0.137	0.94	0.137	0.62
SERAYA POWER STATION	—	—	0.245	1.37	—	—	0.305	1.38
TEKONG POWER STATION	—	—	0.044	0.24	—	—	0.041	0.19
SHELL COMPANIES IN SINGAPORE	0.517	4.17	0.517	2.88	0.173	1.18	0.173	0.78
ESSO SINGAPORE PTE LTD	0.481	3.88	0.481	2.68	0.605	4.13	0.605	2.74
SINGAPORE REFINING CO PTE LTD	0.285	2.30	0.285	1.59	0.385	2.64	0.385	1.75
MOBIL OIL SINGAPORE PTE LTD	0.328	2.65	0.297	1.66	0.218	1.49	0.198	0.89
-- REMAINING FACTORIES --	1.058	8.55	3.050	16.98	1.315	8.93	3.409	15.41
------- VESSELS -------	0.364	2.94	0.532	2.97	0.232	1.58	0.329	1.49
----- BACK GROUND -----	4.300	34.71	5.700	31.77	4.300	29.34	5.700	25.79
-------- TOTAL --------	12.387	100.00	17.940	100.00	14.653	100.00	22.100	100.00

Name of factory	(3) S.I.U.				(4) BOON LAY APARTMENT			
	1981		1990		1981		1990	
	Contributing concentration (ppb)	Contribution rate (%)	Contributing concentration (ppb)	Contribution rate (%)	Contributing concentration (ppb)	Contribution rate (%)	Contributing concentration (ppb)	Contribution rate (%)
TEKONG INTEGRATED STEEL MILL	—	—	0.120	0.42	—	—	0.114	0.65
SENOKO POWER STATION	6.361	38.54	9.622	34.09	3.399	32.05	6.872	39.19
JURONG POWER STATION	0.071	0.43	0.071	0.25	0.610	5.76	0.610	3.48
PASIR PANJANG POWER STATION	0.120	0.73	0.120	0.43	0.123	1.16	0.123	0.70
SERAYA POWER STATION	—	—	0.105	0.37	—	—	0.386	2.20
TEKONG POWER STATION	—	—	0.036	0.13	—	—	0.037	0.21
SHELL COMPANIES IN SINGAPORE	0.164	1.00	0.164	0.58	0.146	1.38	0.146	0.84
ESSO SINGAPORE PTE LTD	0.665	4.03	0.665	2.36	0.445	4.20	0.446	2.54
SINGAPORE REFINING CO PTE LTD	0.450	2.72	0.450	1.59	0.273	2.55	0.270	1.54
MOBIL OIL SINGAPORE PTE LTD	0.415	2.51	0.361	1.28	0.318	2.99	0.283	1.61
-- REMAINING FACTORIES --	3.691	22.35	10.444	37.00	0.815	7.69	2.304	13.14
------- VESSELS -------	0.270	1.64	0.368	1.31	0.175	1.65	0.243	1.39
----- BACK GROUND -----	4.300	26.05	5.700	20.19	4.300	40.56	5.700	32.51
-------- TOTAL --------	16.507	100.00	28.228	100.00	10.602	100.00	17.534	100.00

Name of factory	(5) BUKIT TIMAH FIRE ST.				(6) CHANGI AIRPORT			
	1981		1990		1981		1990	
	Contributing concentration (ppb)	Contribution rate (%)	Contributing concentration (ppb)	Contribution rate (%)	Contributing concentration (ppb)	Contribution rate (%)	Contributing concentration (ppb)	Contribution rate (%)
TEKONG INTEGRATED STEEL MILL	—	—	0.141	0.77	—	—	0.218	2.47
SENOKO POWER STATION	6.944	50.03	8.659	47.14	0.733	11.79	1.112	12.61
JURONG POWER STATION	0.868	6.25	0.868	4.72	0.323	5.15	0.323	3.66
PASIR PANJANG POWER STATION	0.174	1.26	0.174	0.95	0.205	3.28	0.205	2.33
SERAYA POWER STATION	—	—	0.375	2.04	—	—	0.203	2.30
TEKONG POWER STATION	—	—	0.045	0.25	—	—	0.078	0.88
SHELL COMPANIES IN SINGAPORE	0.273	1.97	0.273	1.48	0.155	2.47	0.155	1.76
ESSO SINGAPORE PTE LTD	0.383	2.79	0.383	2.11	0.105	1.67	0.105	1.19
SINGAPORE REFINING CO PTE LTD	0.242	1.74	0.242	1.32	0.063	1.00	0.063	0.71
MOBIL OIL SINGAPORE PTE LTD	0.144	1.04	0.131	0.71	0.086	1.37	0.073	0.83
-- REMAINING FACTORIES --	0.397	2.88	1.164	6.35	0.103	1.67	0.297	3.49
------- VESSELS -------	0.147	1.06	0.206	1.12	0.184	2.74	0.280	3.17
----- BACK GROUND -----	4.300	30.98	5.700	31.04	4.300	[illegible]	5.700	64.64
-------- TOTAL --------	13.879	100.00	18.359	100.00	6.283	100.00	8.818	100.00

Name of factory	(7) BEDOK POLICE STATION							
	1981		1990		1981		1990	
	Contributing concentration (ppb)	Contribution rate (%)	Contributing concentration (ppb)	Contribution rate (%)	Contributing concentration (ppb)	Contribution rate (%)	Contributing concentration (ppb)	Contribution rate (%)
TEKONG INTEGRATED STEEL MILL	—	—	0.327	2.92				
SENOKO POWER STATION	0.969	12.43	1.464	13.08				
JURONG POWER STATION	0.866	11.11	0.866	7.74				
PASIR PANJANG POWER STATION	0.266	3.41	0.266	2.37				
SERAYA POWER STATION	—	—	0.462	4.13				
TEKONG POWER STATION	—	—	0.105	0.94				
SHELL COMPANIES IN SINGAPORE	0.196	2.51	0.196	1.75				
ESSO SINGAPORE PTE LTD	0.305	3.92	0.305	2.73				
SINGAPORE REFINING CO PTE LTD	0.175	2.25	0.175	1.57				
MOBIL OIL SINGAPORE PTE LTD	0.109	1.40	0.100	0.89				
-- REMAINING FACTORIES --	0.178	2.33	0.506	4.53				
------- VESSELS -------	0.425	5.49	0.717	6.41				
----- BACK GROUND -----	4.300	55.18	5.700	50.94				
-------- TOTAL --------	7.793	100.00	11.189	100.00				

(2) Contribution rate at peak concentration points

Five peak concentration points have been selected, 4 from main islands and 1 from southern islands and the contribution rate at these 5 points have been obtained. The selected five points are shown in Table V-2-11 and Fig. V-2-8.

Table V-2-11 Peak concentration points and their SO_2 yearly average concentration

Unit (ppb)

Mesh code	Yearly average		Southerly Monsoon		Northerly Monsoon	
	1981	1990	1981	1990	1981	1990
33 - 40	42.3	56.6	20.7	32.0	73.0	91.6
33 - 44	27.1	44.0	29.0	40.6	24.3	48.7
34 - 44	28.2	43.5	33.1	46.3	21.3	39.5
33 - 45	25.4	43.2	32.6	52.5	15.2	30.0
34 - 45	24.8	40.7	31.3	49.3	15.5	28.5

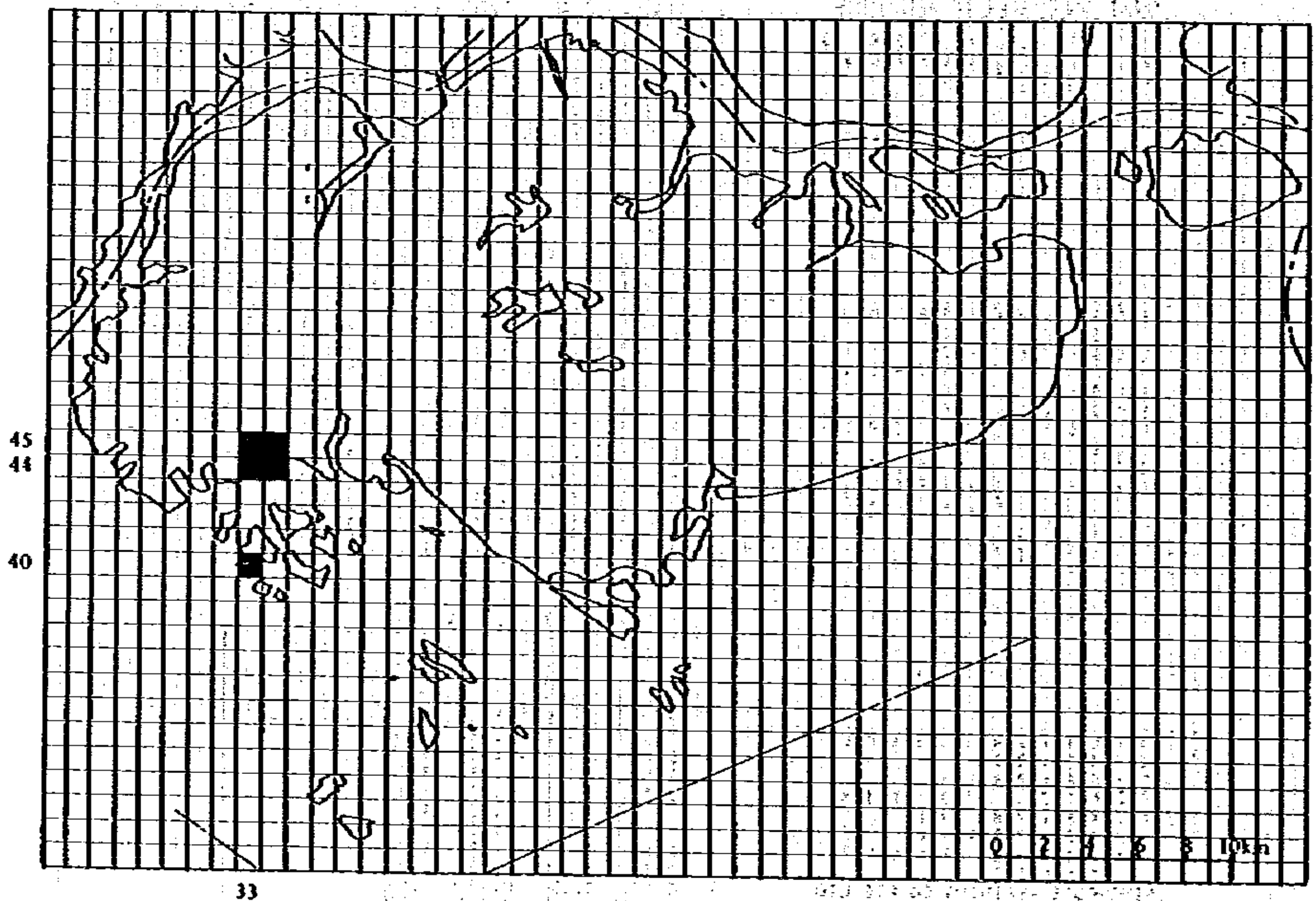


Fig. V-2-8 Peak concentration points obtained from contribution rate

Table V-2-12 to Table V-2-14 show contribution concentration and rate of 10 highest emission sources classified by season. At mesh code 33-40, where is the highest in 1990 yearly average concentration, the contribution of ESSO Singapore Private Limited is found remarkably large, which correspond 15.794 ppb in concentration and 27.8% in contribution rate.

At highest peak point of main island, mesh code 33-44, the contribution of National Iron and Steel Mills Ltd. is found large, holding 16.3% of contribution rate and 7.167 ppb in concentration.

Finally, the contribution concentration and rate of 10 highest emission sources at peak points are shown in Tables V-2-15 to V-2-17. From these tables, it is confirmed that Seneko power station is contributing in highest rate to each peak point, same as the case of monitoring stations.

Mesh code 33 — 40					
1981			1990		
Name of factory	Contributing concentration (ppb)	Contribution rate (%)	Name of factory	Contributing concentration (ppb)	Contribution rate (%)
ESSO SINGAPORE PTE LTD	15.749	37.22	ESSO SINGAPORE PTE LTD	15.749	27.81
JURONG POWER STATION	5.935	14.02	JURONG POWER STATION	5.935	10.48
SENOKO POWER STATION	2.816	6.66	SENOKO POWER STATION	4.261	7.52
SINGAPORE REFINING CO PTE LTD	2.272	5.37	NATIONAL IRON & STEEL MILLS LTD	3.050	5.39
SHELL COMPANIES IN SINGAPORE	1.286	3.04	SINGAPORE REFINING CO PTE LTD	2.272	4.01
NATIONAL IRON & STEEL MILLS LTD	1.224	2.89	SUMITOMO KAGAKU PTE LTD	2.238	3.95
SUGAR INDUSTRY OF SINGAPORE LTD	0.745	1.76	SUGAR INDUSTRY OF SINGAPORE LTD	1.855	3.28
MOBIL OIL SINGAPORE PTE LTD	0.654	1.55	THE CHEMICAL CORPN OF SINGAPORE PTE LTD	1.293	2.28
PASIR PANJANG POWER STATION	0.587	1.39	SHELL COMPANIES IN SINGAPORE	1.286	2.27
THE CHEMICAL CORPN OF SINGAPORE PTE LTD	0.380	0.90	METAL & ORES PTE LTD	0.735	1.30
- REMAINING FACTORIES -	2.433	5.74	- REMAINING FACTORIES -	7.338	12.96
------- VESSELS -------	3.936	9.30	------- VESSELS -------	4.915	8.68
----- BACK GROUND -----	4.300	10.16	----- BACK GROUND -----	5.700	10.07
-------- TOTAL --------	42.317	100.00	-------- TOTAL --------	56.627	100.00

Mesh code 33 — 44					
1981			1990		
Name of factory	Contributing concentration (ppb)	Contribution rate (%)	Name of factory	Contributing concentration (ppb)	Contribution rate (%)
ESSO SINGAPORE PTE LTD	5.464	20.17	NATIONAL IRON & STEEL MILLS LTD	7.167	16.30
NATIONAL IRON & STEEL MILLS LTD	2.877	10.62	ESSO SINGAPORE PTE LTD	5.464	12.43
SINGAPORE REFINING CO PTE LTD	2.405	8.87	SENOKO POWER STATION	3.682	8.38
SENOKO POWER STATION	2.178	8.04	SINGAPORE REFINING CO PTE LTD	2.405	5.47
SHELL COMPANIES IN SINGAPORE	1.662	6.13	METAL & ORES PTE LTD	2.075	4.72
PASIR PANJANG POWER STATION	1.239	4.56	SHELL COMPANIES IN SINGAPORE	1.662	3.78
HORIZON PAPER INDS PTE LTD	0.763	2.82	SUMITOMO KAGAKU PTE LTD	1.618	3.68
MOBIL OIL SINGAPORE PTE LTD	0.633	2.34	HORIZON PAPER INDS PTE LTD	1.492	3.39
BROADWAY ENTERPRISES PTE LTD	0.504	1.86	PASIR PANJANG POWER STATION	1.235	2.81
METAL & ORES PTE LTD	0.406	1.50	BROADWAY ENTERPRISES PTE LTD	1.144	2.60
- REMAINING FACTORIES -	2.512	9.26	- REMAINING FACTORIES -	7.482	17.02
------- VESSELS -------	2.156	7.96	------- VESSELS -------	2.840	6.46
----- BACK GROUND -----	4.300	15.87	----- BACK GROUND -----	5.700	12.96
-------- TOTAL --------	27.095	100.00	-------- TOTAL --------	43.966	100.00

Table V-2-12-(a) Contribution of the highest 10 factories at peak concentration mesh (yearly average)

Mesh code 34 — 44					
1981			1990		
Name of factory	Contributing concentration (ppb)	Contribution rate (%)	Name of factory	Contributing concentration (ppb)	Contribution rate (%)
ESSO SINGAPORE PTE LTD	5.672	20.09	ESSO SINGAPORE PTE LTD	5.672	13.04
SINGAPORE REFINING CO PTE LTD	4.146	14.68	SENOKO POWER STATION	4.458	10.25
SENOKO POWER STATION	2.946	10.43	SINGAPORE REFINING CO PTE LTD	4.146	9.53
SHELL COMPANIES IN SINGAPORE	1.727	6.12	NATIONAL IRON & STEEL MILLS LTD	3.032	6.97
PASIR PANJANG POWER STATION	1.254	4.44	THE CHEMICAL CORPN OF SINGAPORE PTE LTD	2.759	6.34
NATIONAL IRON & STEEL MILLS LTD	1.217	4.31	SUMITOMO KAGAKU PTE LTD	1.838	4.23
THE CHEMICAL CORPN OF SINGAPORE PTE LTD	0.811	2.87	SHELL COMPANIES IN SINGAPORE	1.727	3.97
MOBIL OIL SINGAPORE PTE LTD	0.550	1.95	PASIR PANJANG POWER STATION	1.254	2.88
BROADWAY ENTERPRISES PTE LTD	0.393	1.39	HUME INDS (S) LTD	0.946	2.17
HUME INDS (S) LTD	0.379	1.34	DRAGON POLY-FOAM INDS (S) PTE LTD	0.903	2.08
- REMAINING FACTORIES -	2.684	9.50	- REMAINING FACTORIES -	8.063	18.54
------- VESSELS -------	2.162	7.65	------- VESSELS -------	2.995	6.89
----- BACK GROUND -----	4.300	15.23	----- BACK GROUND -----	5.700	13.11
-------- TOTAL --------	28.241	100.00	-------- TOTAL --------	43.493	100.00

Mesh code 33 — 45					
1981			1990		
Name of factory	Contributing concentration (ppb)	Contribution rate (%)	Name of factory	Contributing concentration (ppb)	Contribution rate (%)
ESSO SINGAPORE PTE LTD	4.422	17.43	NATIONAL IRON & STEEL MILLS LTD	9.020	20.87
NATIONAL IRON & STEEL MILLS LTD	3.621	14.28	ESSO SINGAPORE PTE LTD	4.422	10.23
SINGAPORE REFINING CO PTE LTD	1.916	7.55	METAL & ORES PTE LTD	3.255	7.53
SENOKO POWER STATION	1.621	6.39	SENOKO POWER STATION	3.140	7.26
SHELL COMPANIES IN SINGAPORE	1.595	6.29	SINGAPORE REFINING CO PTE LTD	1.916	4.43
PASIR PANJANG POWER STATION	1.227	4.84	SHELL COMPANIES IN SINGAPORE	1.595	3.69
MOBIL OIL SINGAPORE PTE LTD	1.111	4.38	BROADWAY ENTERPRISES PTE LTD	1.438	3.33
BROADWAY ENTERPRISES PTE LTD	0.634	2.50	SUMITOMO KAGAKU PTE LTD	1.353	3.13
METAL & ORES PTE LTD	0.580	2.29	PASIR PANJANG POWER STATION	1.227	2.84
HONGKONG DYEING & WEAVING (S) LTD	0.444	1.75	MOBIL OIL SINGAPORE PTE LTD	1.005	2.33
- REMAINING FACTORIES -	2.078	8.19	- REMAINING FACTORIES -	6.653	15.40
------- VESSELS -------	1.815	7.16	------- VESSELS -------	2.492	5.77
----- BACK GROUND -----	4.300	16.95	----- BACK GROUND -----	5.700	13.19
-------- TOTAL --------	25.364	100.00	-------- TOTAL --------	43.216	100.00

Table V-2-12-(b) Contribution of the highest 10 factories at peak concentration mesh (yearly average)

Mesh code 34 – 45					
1981			1990		
Name of factory	Contributing concentration (ppb)	Contribution rate (%)	Name of factory	Contributing concentration (ppb)	Contribution rate (%)
ESSO SINGAPORE PTE LTD	4.431	17.90	NATIONAL IRON & STEEL MILLS LTD	4.894	12.03
SINGAPORE REFINING CO PTE LTD	2.896	11.70	ESSO SINGAPORE PTE LTD	4.431	10.89
SENOKO POWER STATION	2.213	8.94	SENOKO POWER STATION	3.740	9.19
NATIONAL IRON & STEEL MILLS LTD	1.965	7.94	SINGAPORE REFINING CO PTE LTD	2.896	7.12
SHELL COMPANIES IN SINGAPORE	1.651	6.67	THE CHEMICAL CORPN OF SINGAPORE PTE LTD	1.705	4.19
PASIR PANJANG POWER STATION	1.247	5.04	SHELL COMPANIES IN SINGAPORE	1.651	4.06
MOBIL OIL SINGAPORE PTE LTD	0.625	2.52	SUMITOMO KAGAKU PTE LTD	1.498	3.68
THE CHEMICAL CORPN OF SINGAPORE PTE LTD	0.501	2.02	PASIR PANJANG POWER STATION	1.247	3.06
BROADWAY ENTERPRISES PTE LTD	0.324	1.31	SERAYA POWER STATION	1.141	2.80
SUGAR INDUSTRY OF SINGAPORE LTD	0.315	1.27	DRAGON POLY-FOAM INDS (S) PTE LTD	1.083	2.67
- REMAINING FACTORIES -	2.551	10.32	- REMAINING FACTORIES -	8.196	20.16
------- VESSELS -------	1.734	7.00	------- VESSELS -------	2.500	6.14
----- BACK GROUND -----	4.300	17.37	----- BACK GROUND -----	5.700	14.01
-------- TOTAL --------	24.753	100.00	-------- TOTAL --------	40.682	100.00

Table V-2-12-(c) Contribution of the highest 10 factories at peak concentration mesh (yearly average)

Mesh code 33 – 40					
1981			1990		
Name of factory	Contributing concentration (ppb)	Contribution rate (%)	Name of factory	Contributing concentration (ppb)	Contribution rate (%)
ESSO SINGAPORE PTE LTD	3.900	18.89	ESSO SINGAPORE PTE LTD	3.900	12.20
SHELL COMPANIES IN SINGAPORE	2.086	10.10	SUMITOMO KAGAKU PTE LTD	2.734	8.55
SINGAPORE REFINING CO PTE LTD	0.897	4.34	SHELL COMPANIES IN SINGAPORE	2.086	6.53
PASIR PANJANG POWER STATION	0.844	4.09	NATIONAL IRON & STEEL MILLS LTD	1.981	6.20
NATIONAL IRON & STEEL MILLS LTD	0.795	3.85	SENOKO POWER STATION	1.111	3.47
SENOKO POWER STATION	0.727	3.52	THE CHEMICAL CORPN OF SINGAPORE PTE LTD	1.073	3.36
JURONG POWER STATION	0.427	2.07	SINGAPORE REFINING CO PTE LTD	0.897	2.80
MOBIL OIL SINGAPORE PTE LTD	0.426	2.06	PASIR PANJANG POWER STATION	0.844	2.64
THE CHEMICAL CORPN OF SINGAPORE PTE LTD	0.315	1.53	METAL & ORES PTE LTD	0.681	2.13
BROADWAY ENTERPRISES PTE LTD	0.223	1.08	SIME DARBY OLEOCHEMICALS LTD	0.515	1.61
- REMAINING FACTORIES -	1.802	8.72	- REMAINING FACTORIES -	5.434	16.99
------- VESSELS -------	3.909	18.93	------- VESSELS -------	5.016	15.69
----- BACK GROUND -----	4.300	20.82	----- BACK GROUND -----	5.700	17.83
-------- TOTAL --------	20.651	100.00	-------- TOTAL --------	31.972	100.00

Mesh code 33 – 44					
1981			1990		
Name of factory	Contributing concentration (ppb)	Contribution rate (%)	Name of factory	Contributing concentration (ppb)	Contribution rate (%)
ESSO SINGAPORE PTE LTD	8.738	30.09	ESSO SINGAPORE PTE LTD	8.738	21.54
SINGAPORE REFINING CO PTE LTD	3.916	13.49	SINGAPORE REFINING CO PTE LTD	3.916	9.65
SHELL COMPANIES IN SINGAPORE	2.741	9.44	SHELL COMPANIES IN SINGAPORE	2.741	6.76
PASIR PANJANG POWER STATION	2.024	6.97	SUMITOMO KAGAKU PTE LTD	2.549	6.28
SENOKO POWER STATION	0.636	2.19	PASIR PANJANG POWER STATION	2.024	4.99
THE CHEMICAL CORPN OF SINGAPORE PTE LTD	0.359	1.24	METAL & ORES PTE LTD	1.351	3.33
METAL & ORES PTE LTD	0.302	1.04	THE CHEMICAL CORPN OF SINGAPORE PTE LTD	1.222	3.01
NATIONAL IRON & STEEL MILLS LTD	0.292	1.01	SENOKO POWER STATION	0.990	2.44
MOBIL OIL SINGAPORE PTE LTD	0.288	0.99	NATIONAL IRON & STEEL MILLS LTD	0.728	1.80
SINGAPORE CLAY PRODUCTS PTE LTD	0.257	0.89	SERAYA POWER STATION	0.540	1.33
- REMAINING FACTORIES -	1.819	6.26	- REMAINING FACTORIES -	5.626	13.86
------- VESSELS -------	3.364	11.58	------- VESSELS -------	4.449	10.96
----- BACK GROUND -----	4.300	14.81	----- BACK GROUND -----	5.700	14.05
-------- TOTAL --------	29.036	100.00	-------- TOTAL --------	40.574	100.00

Table V-2-13-(a) Contribution of the highest 10 factories at peak concentration mesh (southerly monsoon)

Mesh code 34 — 44

1981 Name of factory	Contributing concentration (ppb)	Contribution rate (%)	1990 Name of factory	Contributing concentration (ppb)	Contribution rate (%)
ESSO SINGAPORE PTE LTD	9.000	27.17	ESSO SINGAPORE PTE LTD	9.000	19.42
SINGAPORE REFINING CO PTE LTD	6.543	19.76	SINGAPORE REFINING CO PTE LTD	6.543	14.12
SHELL COMPANIES IN SINGAPORE	2.849	8.60	SHELL COMPANIES IN SINGAPORE	2.849	6.15
PASIR PANJANG POWER STATION	2.054	6.20	SUMITOMO KAGAKU PTE LTD	2.812	6.07
THE CHEMICAL CORPN OF SINGAPORE PTE LTD	0.756	2.28	THE CHEMICAL CORPN OF SINGAPORE PTE LTD	2.571	5.55
NATIONAL IRON & STEEL MILLS LTD	0.684	2.06	PASIR PANJANG POWER STATION	2.054	4.43
SENOKO POWER STATION	0.665	2.01	NATIONAL IRON & STEEL MILLS LTD	1.703	3.68
MOBIL OIL SINGAPORE PTE LTD	0.338	1.02	SENOKO POWER STATION	1.013	2.19
BROADWAY ENTERPRISES PTE LTD	0.292	0.88	HUME INDS (S) LTD	0.668	1.44
HUME INDS (S) LTD	0.268	0.81	BROADWAY ENTERPRISES PTE LTD	0.662	1.43
- REMAINING FACTORIES -	1.992	6.03	- REMAINING FACTORIES -	6.070	13.10
——— VESSELS ———	3.377	10.20	——— VESSELS ———	4.689	10.12
——— BACK GROUND ———	4.300	12.98	——— BACK GROUND ———	5.700	12.30
——— TOTAL ———	33.118	100.00	——— TOTAL ———	46.334	100.00

Mesh code 33 — 45

1981 Name of factory	Contributing concentration (ppb)	Contribution rate (%)	1990 Name of factory	Contributing concentration (ppb)	Contribution rate (%)
ESSO SINGAPORE PTE LTD	6.987	21.46	NATIONAL IRON & STEEL MILLS LTD	14.796	28.17
NATIONAL IRON & STEEL MILLS LTD	5.940	18.25	ESSO SINGAPORE PTE LTD	6.987	13.30
SINGAPORE REFINING CO. PTE LTD	3.119	9.58	SINGAPORE REFINING CO PTE LTD	3.119	5.94
SHELL COMPANIES IN SINGAPORE	2.631	8.08	SHELL COMPANIES IN SINGAPORE	2.631	5.01
PASIR PANJANG POWER STATION	2.011	6.18	SUMITOMO KAGAKU PTE LTD	2.143	4.08
MOBIL OIL SINGAPORE PTE LTD	1.348	4.14	PASIR PANJANG POWER STATION	2.011	3.83
SENOKO POWER STATION	0.557	1.71	METAL & ORES PTE LTD	1.942	3.70
METAL & ORES PTE LTD	0.432	1.33	THE CHEMICAL CORPN OF SINGAPORE PTE LTD	1.456	2.77
THE CHEMICAL CORPN OF SINGAPORE PTE LTD	0.428	1.31	MOBIL OIL SINGAPORE PTE LTD	1.250	2.38
SINGAPORE CLAY PRODUCTS PTE LTD	0.196	0.60	SENOKO POWER STATION	0.902	1.72
- REMAINING FACTORIES -	1.726	5.30	- REMAINING FACTORIES -	5.616	10.68
——— VESSELS ———	2.880	8.85	——— VESSELS ———	3.975	7.57
——— BACK GROUND ———	4.300	13.21	——— BACK GROUND ———	5.700	10.85
——— TOTAL ———	32.555	100.00	——— TOTAL ———	52.528	100.00

Table V-2-13-(b) Contribution of the highest 10 factories at peak concentration mesh (southerly monsoon)

Mesh code 34 – 45					
1981			1990		
Name of factory	Contributing concentration (ppb)	Contribution rate (%)	Name of factory	Contributing concentration (ppb)	Contribution rate (%)
ESSO SINGAPORE PTE LTD	7.001	22.38	ESSO SINGAPORE PTE LTD	7.001	14.20
SINGAPORE REFINING CO PTE LTD	4.559	14.57	NATIONAL IRON & STEEL MILLS LTD	6.663	13.51
SHELL COMPANIES IN SINGAPORE	2.724	8.71	SINGAPORE REFINING CO PTE LTD	4.559	9.25
NATIONAL IRON & STEEL MILLS LTD	2.675	8.55	SHELL COMPANIES IN SINGAPORE	2.724	5.53
PASIR PANJANG POWER STATION	2.043	6.53	THE CHEMICAL CORPN OF SINGAPORE PTE LTD	2.636	5.35
THE CHEMICAL CORPN OF SINGAPORE PTE LTD	0.775	2.48	SUMITOMO KAGAKU PTE LTD	2.320	4.70
MOBIL OIL SINGAPORE PTE LTD	0.702	2.24	PASIR PANJANG POWER STATION	2.043	4.14
SENOKO POWER STATION	0.619	1.98	SERAYA POWER STATION	1.879	3.81
SUGAR INDUSTRY OF SINGAPORE LTD	0.427	1.36	SUGAR INDUSTRY OF SINGAPORE LTD	1.063	2.16
SIME DARBY OLEOCHEMICALS LTD	0.312	1.00	SIME DARBY OLEOCHEMICALS LTD	1.061	2.15
- REMAINING FACTORIES -	2.411	7.70	- REMAINING FACTORIES -	7.679	15.57
------- VESSELS -------	2.741	8.76	------- VESSELS -------	3.977	8.07
----- BACK GROUND -----	4.300	13.74	----- BACK GROUND -----	5.700	11.56
-------- TOTAL --------	31.289	100.00	-------- TOTAL --------	49.305	100.00

Table V-2-13-(c) Contribution of the highest 10 factories at peak concentration mesh (southerly monsoon)

Mesh code 33 – 40					
1981			1990		
Name of factory	Contributing concentration (ppb)	Contribution rate (%)	Name of factory	Contributing concentration (ppb)	Contribution rate (%)
ESSO SINGAPORE PTE LTD	32.542	44.57	ESSO SINGAPORE PTE LTD	32.542	35.54
JURONG POWER STATION	13.740	18.82	JURONG POWER STATION	13.740	15.01
SENOKO POWER STATION	5.777	7.91	SENOKO POWER STATION	8.726	9.53
SINGAPORE REFINING CO PTE LTD	4.222	5.78	NATIONAL IRON & STEEL MILLS LTD	4.564	4.98
NATIONAL IRON & STEEL MILLS LTD	1.832	2.51	SINGAPORE REFINING CO PTE LTD	4.222	4.61
SUGAR INDUSTRY OF SINGAPORE LTD	1.555	2.13	SUGAR INDUSTRY OF SINGAPORE LTD	3.875	4.23
MOBIL OIL SINGAPORE PTE LTD	0.976	1.34	THE CHEMICAL CORPN OF SINGAPORE PTE LTD	1.605	1.75
THE CHEMICAL CORPN OF SINGAPORE PTE LTD	0.472	0.65	SUMITOMO KAGAKU PTE LTD	1.534	1.68
HUME INDS (S) LTD	0.350	0.48	SIME DARBY OLEOCHEMICALS LTD	0.991	1.08
HORIZON PAPER INDS PTE LTD	0.344	0.47	HUME INDS (S) LTD	0.872	0.95
- REMAINING FACTORIES -	2.937	4.01	- REMAINING FACTORIES -	8.426	9.21
------- VESSELS -------	3.975	5.44	------- VESSELS -------	4.772	5.21
----- BACK GROUND -----	4.300	5.89	----- BACK GROUND -----	5.700	6.22
-------- TOTAL --------	73.022	100.00	-------- TOTAL --------	91.569	100.00

Mesh code 33 – 44					
1981			1990		
Name of factory	Contributing concentration (ppb)	Contribution rate (%)	Name of factory	Contributing concentration (ppb)	Contribution rate (%)
NATIONAL IRON & STEEL MILLS LTD	6.541	26.87	NATIONAL IRON & STEEL MILLS LTD	16.293	33.40
SENOKO POWER STATION	4.364	17.92	SENOKO POWER STATION	7.498	15.37
HORIZON PAPER INDS PTE LTD	1.639	6.73	HORIZON PAPER INDS PTE LTD	3.204	6.57
MOBIL OIL SINGAPORE PTE LTD	1.124	4.62	METAL & ORES PTE LTD	3.102	6.36
BROADWAY ENTERPRISES PTE LTD	0.957	3.93	BROADWAY ENTERPRISES PTE LTD	2.171	4.45
ESSO SINGAPORE PTE LTD	0.824	3.38	DRAGON POLY-FOAM INDS (S) PTE LTD	1.432	2.94
HONGKONG DYEING & WEAVING (S) LTD	0.684	2.81	HONGKONG DYEING & WEAVING (S) LTD	1.048	2.15
METAL & ORES PTE LTD	0.553	2.27	SINGAPORE CLAY PRODUCTS PTE LTD	0.867	1.78
SINGAPORE CLAY PRODUCTS PTE LTD	0.469	1.92	MOBIL OIL SINGAPORE PTE LTD	0.860	1.76
DUNLOP SINGAPORE SDN BHD	0.345	1.42	ESSO SINGAPORE PTE LTD	0.824	1.69
- REMAINING FACTORIES -	2.101	8.65	- REMAINING FACTORIES -	5.216	10.60
------- VESSELS -------	0.444	1.82	------- VESSELS -------	0.559	1.15
----- BACK GROUND -----	4.300	17.66	----- BACK GROUND -----	5.700	11.69
-------- TOTAL --------	24.345	100.00	-------- TOTAL --------	48.774	100.00

Table V-2-14-(a) Contribution of the highest 10 factories at peak concentration mesh (northerly monsoon)

Mesh code 34 — 44

1981 Name of factory	1981 Contributing concentration (ppb)	1981 Contribution rate (%)	1990 Name of factory	1990 Contributing concentration (ppb)	1990 Contribution rate (%)
SENOKO POWER STATION	6.178	28.96	SENOKO POWER STATION	9.340	23.67
NATIONAL IRON & STEEL MILLS LTD	1.974	9.25	NATIONAL IRON & STEEL MILLS LTD	4.916	12.46
ESSO SINGAPORE PTE LTD	0.957	4.49	THE CHEMICAL CORPN OF SINGAPORE PTE LTD	3.025	7.66
THE CHEMICAL CORPN OF SINGAPORE PTE LTD	0.889	4.17	DRAGON POLY-FOAM INDS (S) PTE LTD	1.565	3.96
MOBIL OIL SINGAPORE PTE LTD	0.850	3.98	HUME INDS (S) LTD	1.340	3.39
SINGAPORE REFINING CO PTE LTD	0.749	3.51	MALAYSIYA STEEL PIPE MFG CO PTE LTD	1.290	3.27
HUME INDS (S) LTD	0.537	2.52	BROADWAY ENTERPRISES PTE LTD	1.219	3.09
BROADWAY ENTERPRISES PTE LTD	0.537	2.52	ESSO SINGAPORE PTE LTD	0.957	2.42
MALAYSIYA STEEL PIPE MFG CO PTE LTD	0.518	2.43	HORIZON PAPER INDS PTE LTD	0.949	2.40
HORIZON PAPER INDS PTE LTD	0.485	2.27	SIGMA METAL CO LTD	0.822	2.08
- REMAINING FACTORIES -	2.917	13.68	- REMAINING FACTORIES -	7.751	19.65
------- VESSELS -------	0.439	2.06	------- VESSELS -------	0.594	1.51
----- BACK GROUND -----	4.300	20.16	----- BACK GROUND -----	5.700	14.44
-------- TOTAL --------	21.330	100.00	-------- TOTAL --------	39.468	100.00

Mesh code 33 — 45

1981 Name of factory	1981 Contributing concentration (ppb)	1981 Contribution rate (%)	1990 Name of factory	1990 Contributing concentration (ppb)	1990 Contribution rate (%)
SENOKO POWER STATION	3.130	20.63	SENOKO POWER STATION	6.312	21.02
BROADWAY ENTERPRISES PTE LTD	1.282	8.45	METAL & ORES PTE LTD	5.115	17.04
HONGKONG DYEING & WEAVING (S) LTD	0.917	6.05	BROADWAY ENTERPRISES PTE LTD	2.903	9.69
METAL & ORES PTE LTD	0.789	5.20	HONGKONG DYEING & WEAVING (S) LTD	1.405	4.68
ESSO SINGAPORE PTE LTD	0.787	5.19	DUNLOP SINGAPORE SDN BHD	0.843	2.81
MOBIL OIL SINGAPORE PTE LTD	0.776	5.11	NATIONAL IRON & STEEL MILLS LTD	0.832	2.77
DUNLOP SINGAPORE SDN BHD	0.546	3.60	ESSO SINGAPORE PTE LTD	0.787	2.62
NATIONAL IRON & STEEL MILLS LTD	0.334	2.20	DRAGON POLY-FOAM INDS (S) PTE LTD	0.754	2.51
SINGAPORE CLAY PRODUCTS PTE LTD	0.294	1.94	MOBIL OIL SINGAPORE PTE LTD	0.658	2.19
SINGAPORE REFINING CO PTE LTD	0.211	1.39	BERLI JUCKER (S) COSMETICS PTE LTD	0.593	1.97
- REMAINING FACTORIES -	1.502	9.88	- REMAINING FACTORIES -	3.721	12.41
------- VESSELS -------	0.306	2.02	------- VESSELS -------	0.391	1.30
----- BACK GROUND -----	4.300	28.34	----- BACK GROUND -----	5.700	18.99
-------- TOTAL --------	15.174	100.00	-------- TOTAL --------	30.019	100.00

Table V-2-14-(b) Contribution of the highest 10 factories at peak concentration mesh (northerly monsoon)

Mesh code 34 – 45					
1981			1990		
Name of factory	Contributing concentration (ppb)	Contribution rate (%)	Name of factory	Contributing concentration (ppb)	Contribution rate (%)
SENOKO POWER STATION	4.471	28.86	SENOKO POWER STATION	7.681	26.98
NATIONAL IRON & STEEL MILLS LTD	0.958	6.19	NATIONAL IRON & STEEL MILLS LTD	2.387	8.38
ESSO SINGAPORE PTE LTD	0.789	5.09	DRAGON POLY-FOAM INDS (S) PTE LTD	1.997	7.01
SINGAPORE REFINING CO PTE LTD	0.539	3.48	HORIZON PAPER INDS PTE LTD	0.946	3.32
MOBIL OIL SINGAPORE PTE LTD	0.516	3.33	BROADWAY ENTERPRISES PTE LTD	0.915	3.21
HORIZON PAPER INDS PTE LTD	0.484	3.12	ESSO SINGAPORE PTE LTD	0.789	2.77
BROADWAY ENTERPRISES PTE LTD	0.403	2.60	METAL & ORES PTE LTD	0.782	2.75
HONGKONG DYEING & WEAVING (S) LTD	0.291	1.88	SIGMA METAL CO LTD	0.617	2.17
MAXIM DYEING & FINISHING FTY PTE LTD	0.230	1.49	SINGAPORE REFINING CO PTE LTD	0.539	1.89
DRAGON POLY-FOAM INDS (S) PTE LTD	0.217	1.40	HONGKONG DYEING & WEAVING (S) LTD	0.446	1.57
- REMAINING FACTORIES -	1.988	12.82	- REMAINING FACTORIES -	5.268	18.85
------- VESSELS -------	0.306	1.98	------- VESSELS -------	0.406	1.43
----- BACK GROUND -----	4.300	27.76	----- BACK GROUND -----	5.700	20.02
-------- TOTAL --------	15.492	100.00	-------- TOTAL --------	28.473	100.00

Table V-2-14-(c) Contribution of the highest 10 factories at peak concentration mesh (northerly monsoon)

Table V-2-15 Contribution of major emission sources at peak concentration (yearly average)

Name of factory	Mesh code 33 – 40				Mesh code 33 – 44			
	1981		1990		1981		1990	
	Contributing concentration (ppb)	Contribution rate (%)	Contributing concentration (ppb)	Contribution rate (%)	Contributing concentration (ppb)	Contribution rate (%)	Contributing concentration (ppb)	Contribution rate (%)
TEKONG INTEGRATED STEEL MILL	—	—	0.166	0.29	—	—	0.170	0.39
SENOKO POWER STATION	2.816	6.66	4.261	7.52	2.178	8.04	3.662	8.36
JURONG POWER STATION	5.935	14.02	5.935	10.48	0.135	0.50	0.135	0.31
PASIR PANJANG POWER STATION	0.587	1.39	0.587	1.04	1.235	4.56	1.235	2.81
SERAYA POWER STATION	—	—	0.079	0.14	—	—	0.338	0.77
TEKONG POWER STATION	—	—	0.051	0.09	—	—	0.053	0.12
SHELL COMPANIES IN SINGAPORE	1.286	3.04	1.286	2.27	1.662	6.13	1.662	3.78
ESSO SINGAPORE PTE LTD	15.749	37.22	15.749	27.81	5.464	20.17	5.464	12.43
SINGAPORE REFINING CO PTE LTD	2.272	5.37	2.272	4.01	2.405	8.87	2.405	5.47
MOBIL OIL SINGAPORE PTE LTD.	0.654	1.55	0.571	1.01	0.633	2.34	0.501	1.14
-- REMAINING FACTORIES --	4.782	11.29	15.055	26.59	6.927	25.58	19.783	44.98
------- VESSELS -------	3.936	9.30	4.915	8.68	2.156	7.96	2.840	6.45
----- BACK GROUND -----	4.300	10.16	5.700	10.07	4.300	15.87	5.700	12.96
-------- TOTAL --------	42.317	100.00	56.627	100.00	27.075	100.00	43.965	100.00

Name of factory	Mesh code 34 – 44				Mesh code 33 – 45			
	1981		1990		1981		1990	
	Contributing concentration (ppb)	Contribution rate (%)	Contributing concentration (ppb)	Contribution rate (%)	Contributing concentration (ppb)	Contribution rate (%)	Contributing concentration (ppb)	Contribution rate (%)
TEKONG INTEGRATED STEEL MILL	—	—	0.173	0.40	—	—	0.170	0.39
SENOKO POWER STATION	2.946	10.43	4.453	10.25	1.621	6.39	3.140	7.26
JURONG POWER STATION	0.104	0.37	0.104	0.24	0.117	0.46	0.117	0.27
PASIR PANJANG POWER STATION	1.254	4.44	1.254	2.88	1.227	4.84	1.227	2.84
SERAYA POWER STATION	—	—	0.253	0.58	—	—	0.429	0.99
TEKONG POWER STATION	—	—	0.053	0.12	—	—	0.053	0.12
SHELL COMPANIES IN SINGAPORE	1.727	6.12	1.727	3.97	1.595	6.29	1.595	3.69
ESSO SINGAPORE PTE LTD	5.672	20.09	5.672	13.05	4.422	17.43	4.422	10.23
SINGAPORE REFINING CO PTE LTD	4.146	14.68	4.145	9.53	1.916	7.55	1.916	4.43
MOBIL OIL SINGAPORE PTE LTD.	0.550	1.95	0.471	1.08	1.111	4.38	1.005	2.33
-- REMAINING FACTORIES --	5.380	19.04	16.488	37.91	7.240	28.55	20.951	48.49
------- VESSELS -------	2.162	7.65	2.995	6.89	1.815	7.16	2.492	5.77
----- BACK GROUND -----	4.300	15.23	5.700	13.11	4.300	16.95	5.700	13.19
-------- TOTAL --------	28.241	100.00	43.493	100.00	25.354	100.00	43.216	100.00

Name of factory	Mesh code 34 – 45							
	1981		1990		1981		1990	
	Contributing concentration (ppb)	Contribution rate (%)	Contributing concentration (ppb)	Contribution rate (%)	Contributing concentration (ppb)	Contribution rate (%)	Contributing concentration (ppb)	Contribution rate (%)
TEKONG INTEGRATED STEEL MILL	—	—	0.174	0.43				
SENOKO POWER STATION	2.213	8.94	3.740	9.19				
JURONG POWER STATION	0.101	0.41	0.101	0.25				
PASIR PANJANG POWER STATION	1.247	5.04	1.247	3.06				
SERAYA POWER STATION	—	—	1.141	2.80				
TEKONG POWER STATION	—	—	0.054	0.13				
SHELL COMPANIES IN SINGAPORE	1.651	6.67	1.651	4.06				
ESSO SINGAPORE PTE LTD	4.431	17.90	4.431	10.37				
SINGAPORE REFINING CO PTE LTD	2.896	11.70	2.896	7.12				
MOBIL OIL SINGAPORE PTE LTD.	0.625	2.53	0.546	1.34				
-- REMAINING FACTORIES --	5.555	22.45	16.505	40.58				
------- VESSELS -------	1.734	7.00	2.500	6.14				
----- BACK GROUND -----	4.300	17.37	5.700	14.01				
-------- TOTAL --------	24.753	100.00	40.657	100.00				

Table V-2-16 Contribution of major emission sources at peak concentration (southerly monsoon)

Name of factory	Mesh code 33 – 40				Mesh code 33 – 44			
	1981		1990		1981		1990	
	Contributing concentration (ppb)	Contribution rate (%)	Contributing concentration (ppb)	Contribution rate (%)	Contributing concentration (ppb)	Contribution rate (%)	Contributing concentration (ppb)	Contribution rate (%)
TEKONG INTEGRATED STEEL MILL	—	—	0.204	0.64	—	—	0.208	0.51
SENOKO POWER STATION	0.727	3.52	1.111	3.47	0.636	2.19	0.990	2.44
JURONG POWER STATION	0.427	2.07	0.427	1.34	0.133	0.46	0.133	0.33
PASIR PANJANG POWER STATION	0.844	4.09	0.844	2.64	2.024	6.97	2.024	4.99
SERAYA POWER STATION	—	—	0.092	0.29	—	—	0.540	1.33
TEKONG POWER STATION	—	—	0.062	0.19	—	—	0.063	0.16
SHELL COMPANIES IN SINGAPORE	2.086	10.10	2.086	6.53	2.741	9.44	2.741	6.76
ESSO SINGAPORE PTE LTD	3.900	18.89	3.900	12.20	8.738	30.09	8.738	21.54
SINGAPORE REFINING CO PTE LTD	0.897	4.34	0.897	2.80	3.916	13.49	3.916	9.65
MOBIL OIL SINGAPORE PTE LTD	0.426	2.06	0.379	1.18	0.288	0.99	0.248	0.61
-- REMAINING FACTORIES --	3.135	15.18	11.254	35.20	2.896	9.98	10.824	26.67
------ VESSELS ------	3.909	18.93	5.016	15.69	3.344	11.58	4.449	10.96
----- BACK GROUND -----	4.300	20.82	5.700	17.83	4.300	14.81	5.700	14.05
-------- TOTAL --------	20.651	100.00	31.972	100.00	29.036	100.00	40.574	100.00

Name of factory	Mesh code 34 – 44				Mesh code 33 – 45			
	1981		1990		1981		1990	
	Contributing concentration (ppb)	Contribution rate (%)	Contributing concentration (ppb)	Contribution rate (%)	Contributing concentration (ppb)	Contribution rate (%)	Contributing concentration (ppb)	Contribution rate (%)
TEKONG INTEGRATED STEEL MILL	—	—	0.213	0.46	—	—	0.209	0.40
SENOKO POWER STATION	0.665	2.01	1.013	2.19	0.557	1.71	0.902	1.72
JURONG POWER STATION	0.122	0.37	0.122	0.26	0.136	0.42	0.136	0.26
PASIR PANJANG POWER STATION	2.054	6.20	2.054	4.43	2.011	6.18	2.011	3.83
SERAYA POWER STATION	—	—	0.396	0.85	—	—	0.691	1.31
TEKONG POWER STATION	—	—	0.065	0.14	—	—	0.064	0.12
SHELL COMPANIES IN SINGAPORE	2.849	8.60	2.849	6.15	2.631	8.08	2.631	5.01
ESSO SINGAPORE PTE LTD	9.000	27.17	9.000	19.43	6.987	21.46	6.987	13.30
SINGAPORE REFINING CO PTE LTD	6.543	19.76	6.543	14.12	3.119	9.58	3.119	5.94
MOBIL OIL SINGAPORE PTE LTD	0.335	1.02	0.314	0.68	1.348	4.14	1.250	2.38
-- REMAINING FACTORIES --	3.870	11.69	13.376	28.83	8.586	26.37	24.853	47.31
------ VESSELS ------	3.377	10.20	4.659	10.12	2.880	8.85	3.975	7.57
----- BACK GROUND -----	4.300	12.98	5.700	12.30	4.300	13.21	5.700	10.85
-------- TOTAL --------	33.118	100.00	46.334	100.00	32.555	100.00	52.525	100.00

Name of factory	Mesh code 34 – 45							
	1981		1990		1981		1990	
	Contributing concentration (ppb)	Contribution rate (%)	Contributing concentration (ppb)	Contribution rate (%)	Contributing concentration (ppb)	Contribution rate (%)	Contributing concentration (ppb)	Contribution rate (%)
TEKONG INTEGRATED STEEL MILL	—	—	0.214	0.43				
SENOKO POWER STATION	0.619	1.98	0.959	1.94				
JURONG POWER STATION	0.122	0.39	1.222	0.25				
PASIR PANJANG POWER STATION	2.043	6.53	2.043	4.14				
SERAYA POWER STATION	—	—	1.879	3.81				
TEKONG POWER STATION	—	—	0.065	0.13				
SHELL COMPANIES IN SINGAPORE	2.724	8.71	2.724	5.53				
ESSO SINGAPORE PTE LTD	7.001	22.38	7.001	14.20				
SINGAPORE REFINING CO PTE LTD	4.559	14.57	4.559	9.25				
MOBIL OIL SINGAPORE PTE LTD	0.702	2.24	0.621	1.25				
-- REMAINING FACTORIES --	6.476	20.70	18.341	39.43				
------ VESSELS ------	2.741	8.76	3.973	8.07				
----- BACK GROUND -----	4.300	13.74	5.700	11.56				
-------- TOTAL --------	31.289	100.00	47.365	100.00				

Table V-2-17 Contribution of major emission sources at peak concentration (northerly monsoon)

Name of factory	Mesh code 33 – 40				Mesh code 33 – 44			
	1981		1990		1981		1990	
	Contributing concentration (ppb)	Contribution rate (%)	Contributing concentration (ppb)	Contribution rate (%)	Contributing concentration (ppb)	Contribution rate (%)	Contributing concentration (ppb)	Contribution rate (%)
TEKONG INTEGRATED STEEL MILL	—	—	0.112	0.12	—	—	0.115	0.23
SENOKO POWER STATION	5.774	7.91	8.726	9.53	4.364	17.92	7.498	15.37
JURONG POWER STATION	13.740	18.82	13.740	15.01	0.137	0.56	0.137	0.28
PASIR PANJANG POWER STATION	0.223	0.31	0.223	0.24	0.118	0.48	0.116	0.24
SERAYA POWER STATION	—	—	0.050	0.07	—	—	0.051	0.10
TEKONG POWER STATION	—	—	0.035	0.04	—	—	0.036	0.07
SHELL COMPANIES IN SINGAPORE	0.153	0.21	0.153	0.17	0.132	0.54	0.132	0.27
ESSO SINGAPORE PTE LTD	32.542	44.57	32.542	35.54	0.824	3.38	0.824	1.69
SINGAPORE REFINING CO PTE LTD	4.222	5.78	4.222	4.61	0.263	1.08	0.263	0.54
MOBIL OIL SINGAPORE PTE LTD	0.976	1.34	0.844	0.92	1.124	4.62	0.860	1.76
-- REMAINING FACTORIES --	7.117	9.73	20.440	22.32	12.639	51.94	32.451	66.61
------- VESSELS -------	3.975	5.44	4.772	5.21	0.444	1.82	0.559	1.15
----- BACK GROUND -----	4.300	5.89	5.700	6.22	4.300	17.66	5.700	11.69
-------- TOTAL --------	73.022	100.00	91.567	100.00	24.345	100.00	48.774	100.00

Name of factory	Mesh code 34 – 44				Mesh code 33 – 45			
	1981		1990		1981		1990	
	Contributing concentration (ppb)	Contribution rate (%)	Contributing concentration (ppb)	Contribution rate (%)	Contributing concentration (ppb)	Contribution rate (%)	Contributing concentration (ppb)	Contribution rate (%)
TEKONG INTEGRATED STEEL MILL	—	—	0.117	0.30	—	—	0.115	0.38
SENOKO POWER STATION	6.178	28.96	9.340	23.67	3.130	20.63	6.312	21.02
JURONG POWER STATION	0.079	0.37	0.079	0.20	0.070	0.57	0.090	0.30
PASIR PANJANG POWER STATION	0.121	0.57	0.121	0.31	0.117	0.77	0.117	0.39
SERAYA POWER STATION	—	—	0.048	0.12	—	—	0.057	0.19
TEKONG POWER STATION	—	—	0.037	0.09	—	—	0.036	0.12
SHELL COMPANIES IN SINGAPORE	0.137	0.64	0.137	0.35	0.127	0.83	0.127	0.42
ESSO SINGAPORE PTE LTD	0.957	4.49	0.957	2.42	0.787	5.19	0.781	2.60
SINGAPORE REFINING CO PTE LTD	0.749	3.51	0.749	1.90	0.211	1.39	0.211	0.70
MOBIL OIL SINGAPORE PTE LTD	0.850	3.98	0.693	1.76	0.776	5.11	0.658	2.19
-- REMAINING FACTORIES --	7.520	35.26	20.896	52.93	5.330	35.13	15.416	51.35
------- VESSELS -------	0.439	2.06	0.594	1.51	0.306	2.02	0.391	1.30
----- BACK GROUND -----	4.300	20.16	5.700	14.44	4.300	28.34	5.700	18.99
-------- TOTAL --------	21.330	100.00	39.443	100.00	15.174	100.00	30.019	100.00

Name of factory	Mesh code 34 – 45							
	1981		1990		1981		1990	
	Contributing concentration (ppb)	Contribution rate (%)	Contributing concentration (ppb)	Contribution rate (%)	Contributing concentration (ppb)	Contribution rate (%)	Contributing concentration (ppb)	Contribution rate (%)
TEKONG INTEGRATED STEEL MILL	—	—	0.118	0.41				
SENOKO POWER STATION	4.471	28.85	7.651	26.87				
JURONG POWER STATION	0.071	0.46	0.071	0.25				
PASIR PANJANG POWER STATION	0.120	0.77	0.120	0.42				
SERAYA POWER STATION	—	—	0.095	0.33				
TEKONG POWER STATION	—	—	0.037	0.13				
SHELL COMPANIES IN SINGAPORE	0.131	0.85	0.131	0.46				
ESSO SINGAPORE PTE LTD	0.789	5.09	0.789	2.77				
SINGAPORE REFINING CO PTE LTD	0.539	3.48	0.537	1.89				
MOBIL OIL SINGAPORE PTE LTD	0.516	3.33	0.437	1.53				
-- REMAINING FACTORIES --	4.249	27.43	12.347	43.37				
------- VESSELS -------	0.306	1.98	0.405	1.42				
----- BACK GROUND -----	4.300	27.76	5.700	20.02				
-------- TOTAL --------	15.492	100.00	28.473	100.00				