Appendix A12 ENVIRONMENTAL SIMULATION FOR ASSESSMENT

To verify the environmental conditions after the installation of the Steel Complex, as an environmental assessment, the Study Team calculated the distribution of pollutants using a simulation which is based on surveyed data and predicted pollutant volume emitted from the Steel Complex.

1. Basic Data

1-1 Climate and Sea Conditions

1-1-1 Climate

1) Ambient temperature (°C)

Annual	mean	: 27.1
	max.	: 31.2
	min.	: 21.9

2) Barometric Pressure (hectopascal)

Annual	mean	: 1,009.4
	max.	: 1,025.2
	min.	: 992.0

3) Relative Humidity (%)

Annual	mean	: 73
	max.	: 88
	min.	: 55

4) Rainfall (mm)

Annual	total	: 244.4

5) Wind

Prevailing direction	:	East in winter
	:	West in summer
Mean scalar wind	:	Annual mean 5.0 knots

Detailed wind data is shown in Tables 12A-1-1 and 12A-1-2.

1-1-2 Sea conditions

1) Tide levels

High water level	: + 2.151 m
Mean water level	: + 1.500 m
Low water level	: + 0.849 m

2) Tidal current

Velocity (m/s)	: 0.1
Direction	: Southeast

3) Wave height

Height (m)	: mean 0.66
Period (s)	: 5 - 7

Table 12A-1-1 Frequency Percentage of Concurrent Wind Directions

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
CALM	9.6	11.0	14.9	16.5	13.8	18.4	17.8	23.0	26.7	17.7	9.2	8.3	15.6
35-36-01	4.7	6.4	7.3	7.3	6.7	3.9	2.5	1.2	1.0	1.6	1.5	3.3	3.9
02-03-04	5.4	10.3	8.0	7.4	7.8	4.3	2.1	1.6	1.8	1.7	2.1	6.7	4.9
05-06-07	7.2	9.5	9.2	10.2	9.7	9.0	5.8	2.0	5.3	4.2	4.1	9.5	7.1
08-09-10	7.7	10.1	9.0	10.9	13.1	16.0	13.1	16.8	14.9	14.4	14.3	9.4	12.5
11-12-13	7.0	5.5	7.9	8.7	9.2	18.8	23.7	29.2	19.5	14.0	12.8	8.3	13.7
14-15-16	3.1	1.9	3.7	2.6	3.7	6.9	13.8	16.6	8.4	5.2	1.9	2.2	5.8
17-18-19	4.3	4.1	6.0	3.3	4.0	4.0	5.4	4.2	5.5	4.9	2.2	1.4	4.1
20-21-22	6.1	4.7	5.3	4.7	5.7	4.0	4.5	2.4	5.5	8.0	7.8	6.8	5.4
23-24-25	19.3	8.5	7.4	6.9	7.3	5.4	4.2	1.4	5.1	13.3	17.4	15.0	9.2
26-27-28	11.6	11.5	7.9	7.5	6.3	4.3	3.2	0.8	3.6	10.6	18.1	17.7	8.6
29-30-31	8.0	8.7	7.4	7.4	6.8	2.6	2.3	0.6	1.7	3.4	7.0	7.7	5.3
32-33-34	5.8	5.2	6.3	6.0	4.2	2.7	2.0	0.6	1.4	1.3	1.9	4.0	3.4

Table 12A-1-2 Mean Wind Speed (knots)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
CALM													
35-36-01	8.3	8.5	8.9	9.5	6.5	6.4	5.7	6.7	5.9	4.5	6.9	6.1	7.0
02-03-04	7.6	7.4	8.6	8.2	7.2	5.6	4.9	4.2	4.3	6.1	4.9	6.8	6.3
05-06-07	6.6	7.4	7.6	6.9	7.2	6.2	5.6	5.4	6.1	7.2	6.1	6.5	6.5
08-09-10	7.2	6.8	7.4	6.3	8.0	7.3	6.8	7.4	7.2	7.1	6.8	6.7	7.1
11-12-13	7.4	6.8	7.2	5.9	7.4	7.9	7.3	7.7	7.3	7.8	7.5	7.8	7.3
14-15-16	5.6	5.7	7.5	4.7	6.5	6.0	6.3	6.8	6.4	6.7	5.6	5.4	6.1
17-18-19	4.7	4.0	5.3	3.1	5.0	3.8	3.7	3.8	3.4	4.1	3.5	5.2	4.1
20-21-22	4.0	3.8	4.7	3.0	4.7	3.3	3.4	3.2	3.2	3.2	3.1	3.6	3.6
23-24-25	4.1	4.1	3.8	3.9	5.7	4.2	4.0	4.0	3.5	3.9	4.0	3.6	4.0
26-27-28	4.1	4.3	3.8	4.1	5.5	4.1	3.7	4.4	3.5	4.0	4.2	3.8	4.1
29-30-31	5.0	5.5	6.5	6.6	7.7	3.7	4.0	3.8	3.8	3.5	5.4	3.5	4.9
32-33-34	6.1	8.5	6.5	6.4	7.6	5.0	4.5	3.6	4.3	3.3	5.4	4.8	5.5

1-2 Estimated Exhaust Pollutants

1-2-1 Air

Table 12A-1-3 Estimated Air Pollutant Emissions

Element	NOx			SOx		Dust
Plant	DRP	SMP	BRM	DRP	SMP	
Facility	Reformer	EAF	Reheating furnace	Reformer	EAF	
Emission value (mg/Nm^3)	69.0	7.4	205.4	2.4	2.3	5.0
Exhaust gas						
volume (Nm^3/hr)	680,000	2,100,000	73,000	680,000	2,100,000	
temperature (deg.C)	300	90	250	300	90	
Stack						
height (m)	40	20	50	40	20	
diameter (m)	5.4	6.1	3.5	5.4	6.1	

1-2-2 Noise

Table 12A-1-4 Estimated Noise Levels

Parameter	Process	Facility	Value (dB)
Noise	DRP	Reformer	95 - 105
	SMP	EAF	105
	BRM	Mill	105
	Utility	Air Compressor	95

1-2-3 Waste Water Quality

Estimated waste water quality to be discharged into the sea is shown in Table 12A-1-5.

2. Impact Prediction

2-1 Study Area

Pollutant emissions and discharge points are shown in Figure 12A-2-1.

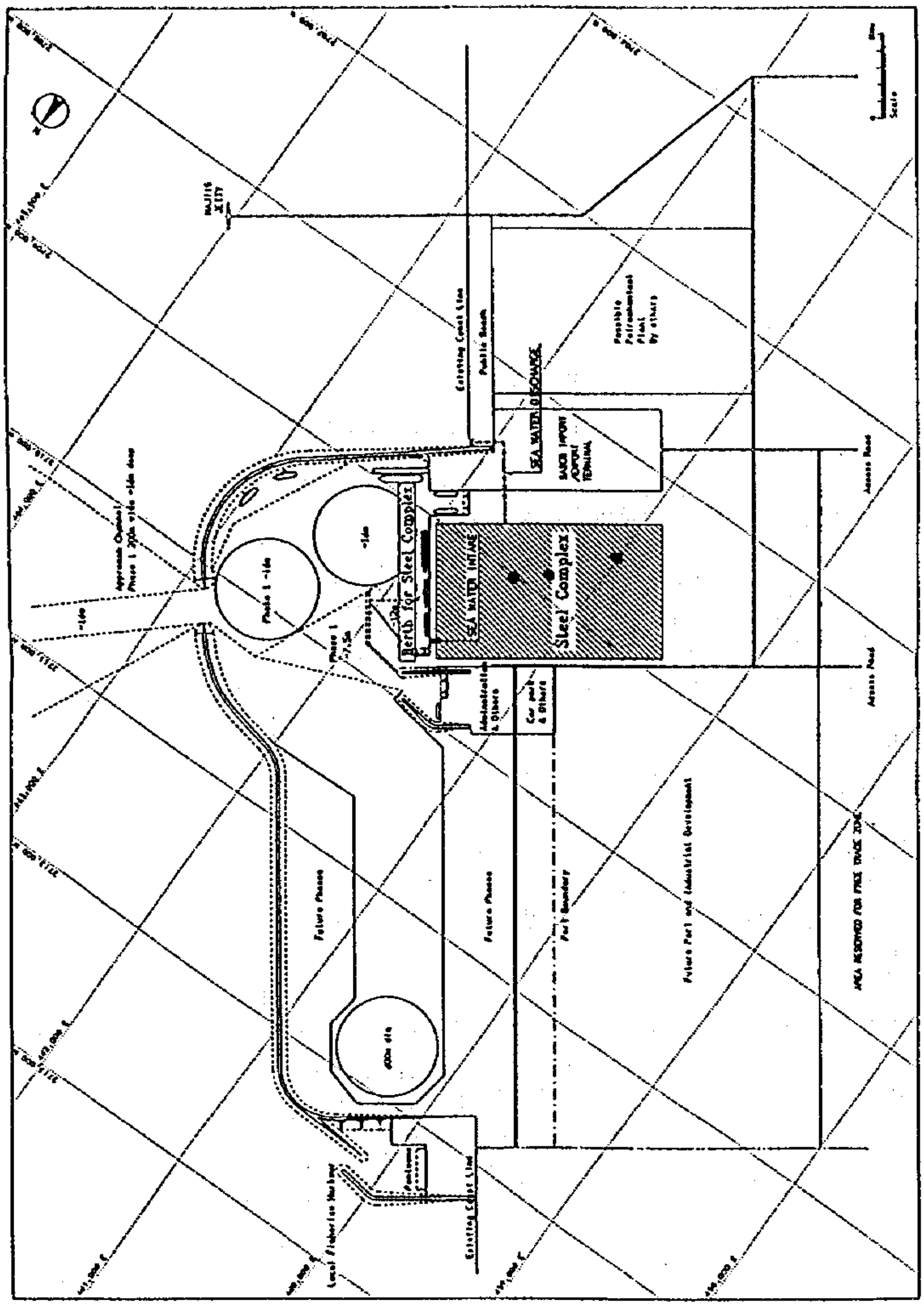


Figure 12A-2-1 Study Area

2-2 Air Quality

To estimate the effect on ambient air quality after the start of operations of the Steel Complex, annual mean NOx, annual mean SOx, and Particulates were predicted.

2-2-1 Methodology

(1) Model

A Plume equation was adopted for windy conditions and a Puff equation for dead calm and weak wind conditions.

1) Point Source Plume Equation

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

Wind direction is divided among 16 bearings for calculations, and the concentration in any direction is assumed to be uniform for long periods, therefore the following equation was adopted.

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

Where,

C(R,z): pollutant concentration at point (R,z)

R : downwind distance from source (m)

z : height of point from ground where concentration is calculated (m)

Qp : pollutant emission rate (μg/s)

u : wind speed (m/s)

He : effective stack height (m)

σ_z : vertical diffusion parameter evaluated in terms of downwind distance R (m)

2) Point Source Puff Equation (weak wind conditions)

$$C(R,z)=\sqrt{\frac{1}{2\pi}}\cdot\frac{Q_P}{\frac{\pi}{8}\gamma}\cdot\left[\frac{1}{\eta_-^2}\exp\left\{-\frac{u^2(z-He)^2}{2\gamma^2\eta_-^2}\right\}+\frac{1}{\eta_+^2}\exp\left\{-\frac{u^2(z-He)^2}{2\gamma^2\eta_+^2}\right\}\right]$$

$$\eta_-^2 = R^2+\frac{\alpha^2}{\gamma^2}(z-He)^2$$

$$\eta_+^2 = R^2+\frac{\alpha^2}{\gamma^2}(z+He)^2$$

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

Where,

C(R,z)	: pollutant concentration at point (R,z)
R	: downwind distance from source (m)
z	: height of point from ground where concentration is calculated (m)
Qp	: pollutant emission rate (μg/s)
u	: wind speed (m/s)
He	: effective stack height (m)
α	: horizontal diffusion parameter (m/s)
γ	: vertical diffusion parameter (m/s)

Correction for wind direction rate in weak wind conditions;

Wind direction divided by 16 bearings defined as i, i+1, ..., wind direction rate by measurement defined as f_i, f_{i+1}, ... Where the rate f_i of wind direction i is corrected by wind speed u and horizontal diffusion parameter α, examples:

$u/\alpha<1$, $\quad \hat{f}_i = \sum_{i=1}^{16} f_i/16$

$1\le u/\alpha<1.5$, $\quad \hat{f}_i = \left(f_{i-4}+2\sum_{k=-3}^{3} f_{i+k}+f_{i+4}\right)/16$

$1.5\le u/\alpha<2$, $\quad \hat{f}_i = \left(f_{i-3}+2\sum_{k=-2}^{2} f_{i+k}+f_{i+3}\right)/12$

$2\le u/\alpha<3.3$, $\quad \hat{f}_i = \left(f_{i-2}+2\sum_{k=-1}^{1} f_{i+k}+f_{i+2}\right)/8$

$3.3\le u/\alpha<6$, $\quad \hat{f}_i = (f_{i-1}+2f_i+f_{i+1})/4$

$6\le u/\alpha$, $\quad \hat{f}_i = f_i$

3) Point Source Puff Equation (dead calm)

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

(2) Diffusion parameters

The approximate value by Pasquill-Gofford diagram shown in Table 12A-2-1 and Table 12A-2-2 are used for the diffusion parameter σ_y, σ_z for the Plume equation of wind speeds over 1.0 m/s.

Table 12A-2-1 Pasquill-Gofford Approximations (1)

$$\sigma_y(x)=\gamma_y\cdot x^{\alpha_y}$$

Stability	α_y	γ_y	Downwind distance
A	0.901	0.426	0 - 1,000
	0.851	0.602	1,000 -
B	0.914	0.282	0 - 1,000
	0.865	0.396	1,000 -
C	0.924	0.1772	0 - 1,000
	0.885	0.232	1,000 -
D	0.929	0.1107	0 - 1,000
	0.889	0.1467	1,000 -
E	0.921	0.0864	0 - 1,000
	0.897	0.1019	1,000 -
F	0.929	0.0554	0 - 1,000
	0.889	0.0733	1,000 -
G	0.921	0.0380	0 - 1,000
	0.896	0.0452	1,000 -

Table 12A-2-2 Pasquill-Gofford Approximations (2)

$$\sigma_z(x) = \gamma_z \cdot x^{\alpha_z}$$

Stability	α_z	γ_z	Downwind distance
A	1.122	0.0800	0 - 300
	1.514	0.00855	300 - 500
	2.109	0.000212	500 -
B	0.964	0.1272	0 - 500
	1.094	0.0570	500 -
C	0.918	0.1068	0 -
D	0.826	0.1046	0 - 1,000
	0.632	0.400	1,000 - 10,000
	0.555	0.811	10,000 -
E	0.788	0.0928	0 - 1,000
	0.565	0.433	1,000 - 10,000
	0.415	1.732	10,000 -
F	0.784	0.0621	0 - 1,000
	0.526	0.370	1,000 - 10,000
	0.323	2.41	10,000 -
G	0.794	0.0373	0 - 1,000
	0.637	0.1105	1,000 - 2,000
	0.431	0.529	2,000 - 10,000
	0.222	3.62	10,000 -

The diffusion parameters α and γ used for the Puff equation of wind speeds 0.5 - 0.9 m/s (weak) are shown in Table 12A-2-3.

Table 12A-2-3 Weak Wind Condition Diffusion

Pasquil stability class	α	γ
A	0.748	1.569
A - B	0.659	0.862
B	0.581	0.474
B - C	0.502	0.314
C	0.435	0.208
C - D	0.342	0.153
D	0.270	0.113
E	0.239	0.067
F	0.239	0.048
G	0.239	0.029

The diffusion parameter α and γ used for Puff equation of wind speeds under 0.4 m/s (dead calm) are shown in Table 12A-2-4.

Table 12A-2-4 Dead Calm Diffusion

Pasquil stability class	α	γ
A	0.948	1.569
A - B	0.859	0.862
B	0.781	0.474
B - C	0.702	0.314
C	0.635	0.208
C - D	0.542	0.453
D	0.470	0.113
E	0.439	0.067
F	0.439	0.048
G	0.439	0.029

(3) Definition of effective stack height

Effective stack height is defined as follows:

Concawe equation (for windy conditions)

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

Briggs equation (for dead calm and weak wind conditions)

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

where,

Q_H (exhaust heat value, cal/s) = $\rho \cdot Q \cdot Cp \cdot \Delta T$

approximately ρ = 1.293 x 10^3 g/m^3

(density of exhaust gas at 0 °C)

Q : Exhaust gas volume per unit time (Nm^3/s)

Cp : 0.24 cal/°K g (isopiestic specific heat)

ΔT : T_G - 15

(temperature difference between exhaust gas temperature T_G and atmospheric temperature, °C)

u	: wind speed at top of stack (m/s)
$d\theta/dz$	: $dT/dz - \Gamma d$ (potential temperature gradient, °C/m)
Γd	: 0.0098 °C (dry-adiabatic temperature lapse rate)

(4) Conglomerate calculation

The concentrations calculated from each prediction equations were combined and led to an annual mean concentration pattern by using the following equation according to climatic conditions (wind direction and wind speed).

$$C = \sum_i \sum_j \left[C_u(i,j) \cdot f_u(i,j) + C_l(i,j) \cdot f_l(i,j) \right] + C_c f_c$$

C	: Annual mean concentration
$C_u(i,j)$	: Concentration in windy, wind direction i, and wind-force scale j
$f_u(i,j)$	: Occurrence ratio in windy, wind direction i, and wind-force scale j
$C_l(i,j)$	: Concentration in weak wind, wind direction i, and wind-force scale j
$f_l(i,j)$	: Occurrence ratio in weak wind, wind direction i, and wind-force scale j
C_c	: Concentration in dead calm
f_c	: Occurrence ratio in dead calm

2-2-3 Prediction conditions

(1) Climate

The climate model is based on the results of the site survey (Tables 12A-1-1 and 12A-1-2).
Monthly mean speed is used as wind speed from 12 bearings plus calm, converted to 16 bearings plus calm for wind direction.
Atmospheric stability is D (neutral).
Figure 12A-2-2 shows the ratio of monthly mean and annual mean wind directions after conversion.

(2) NO_2 conversion

According to measured data in Japan, conversion of NOx to NO_2 is defined as follows:

$[NO_2] = 0.565 \times [NOx]$

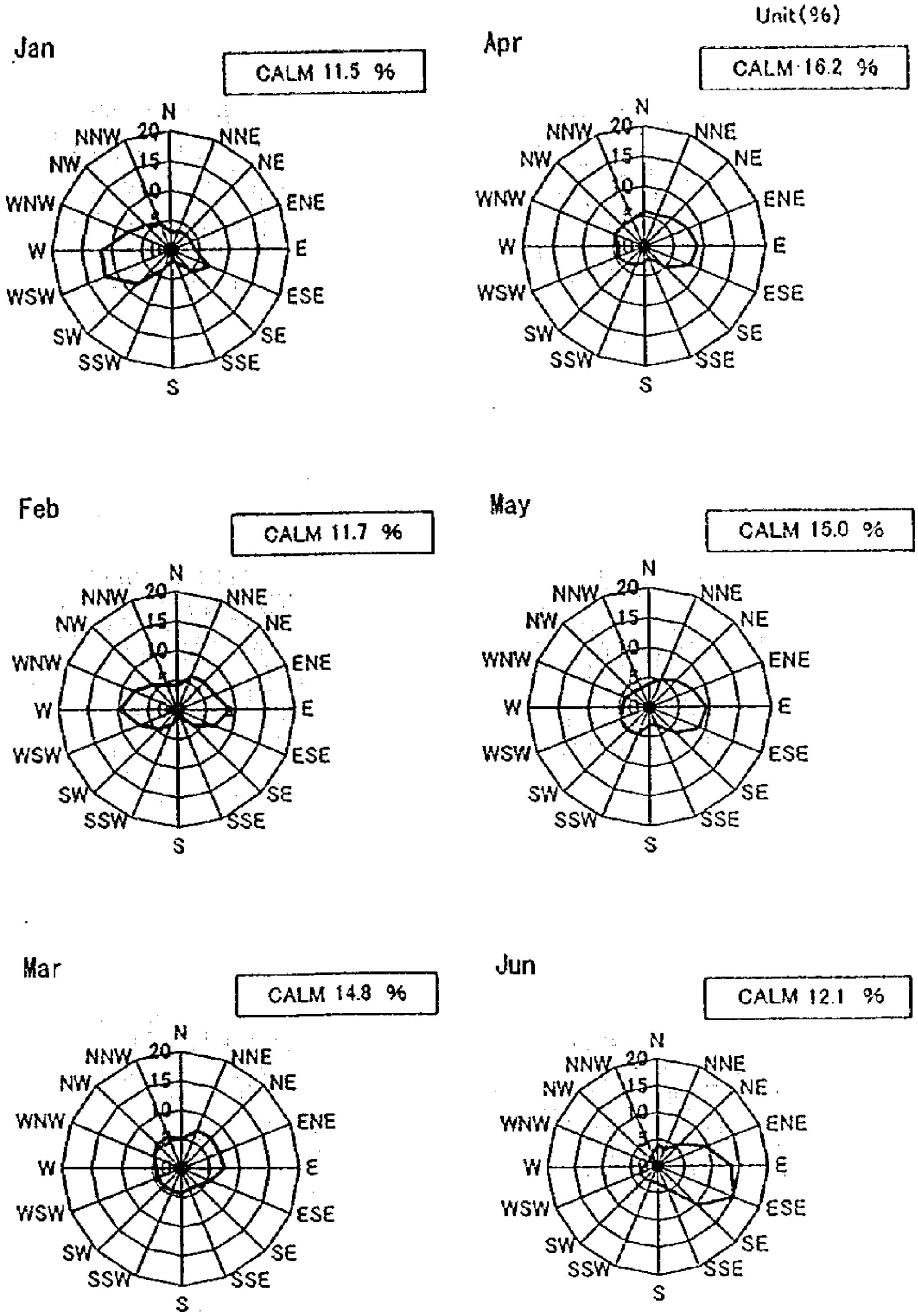


Figure 12-2-2 Wind Direction Ratio (1)

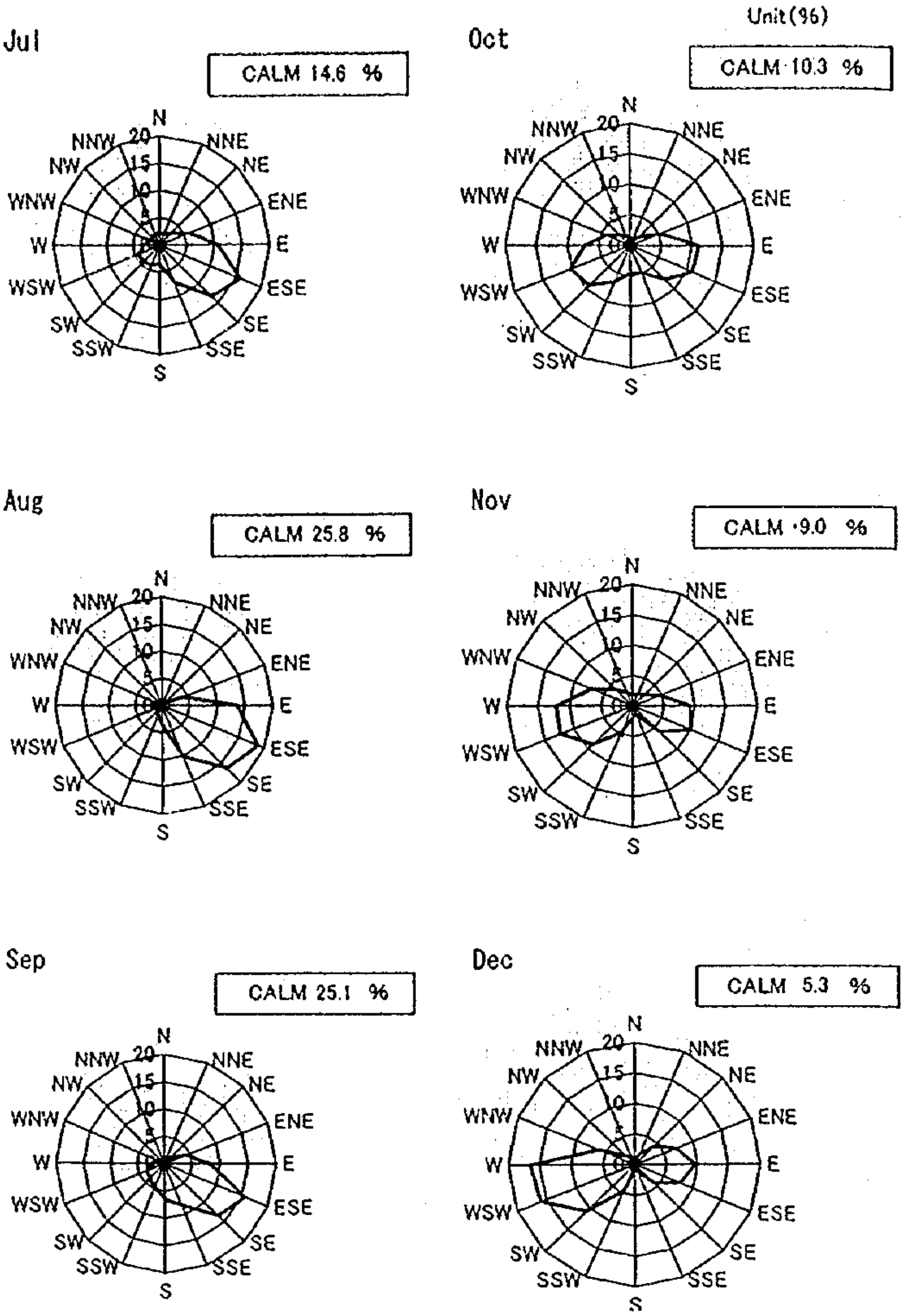


Figure 12A-2-2 Wind Direction Ratio (2)

Anual mean

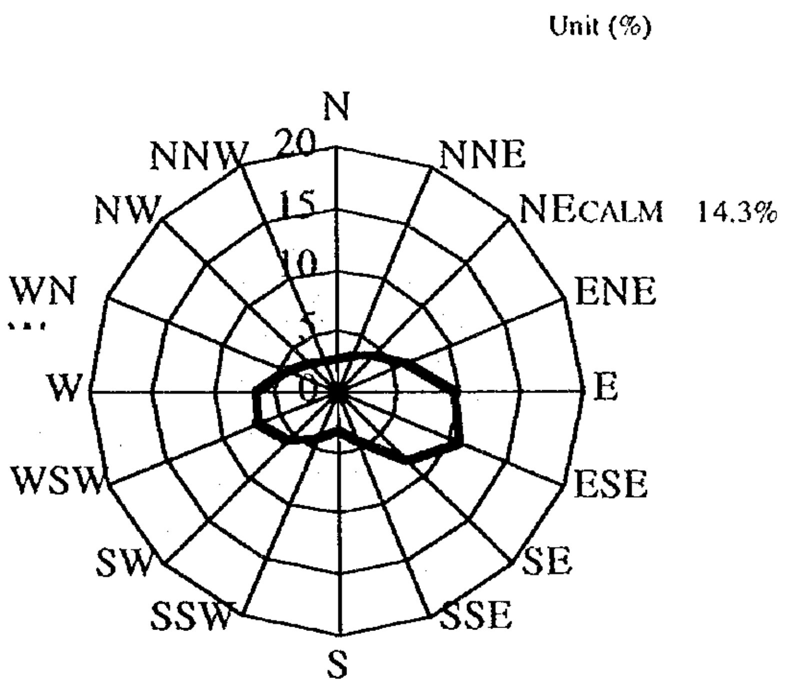


Figure 12A-2-2 Wind Direction Ratio (3)

2-3 Noise

2-3-1 Area

The prediction area is within the plant boundary shown in Figure 12A-2-3.

GENERAL LAYOUT of DIRECT REDUCTION BASED STEEL COMPLEX

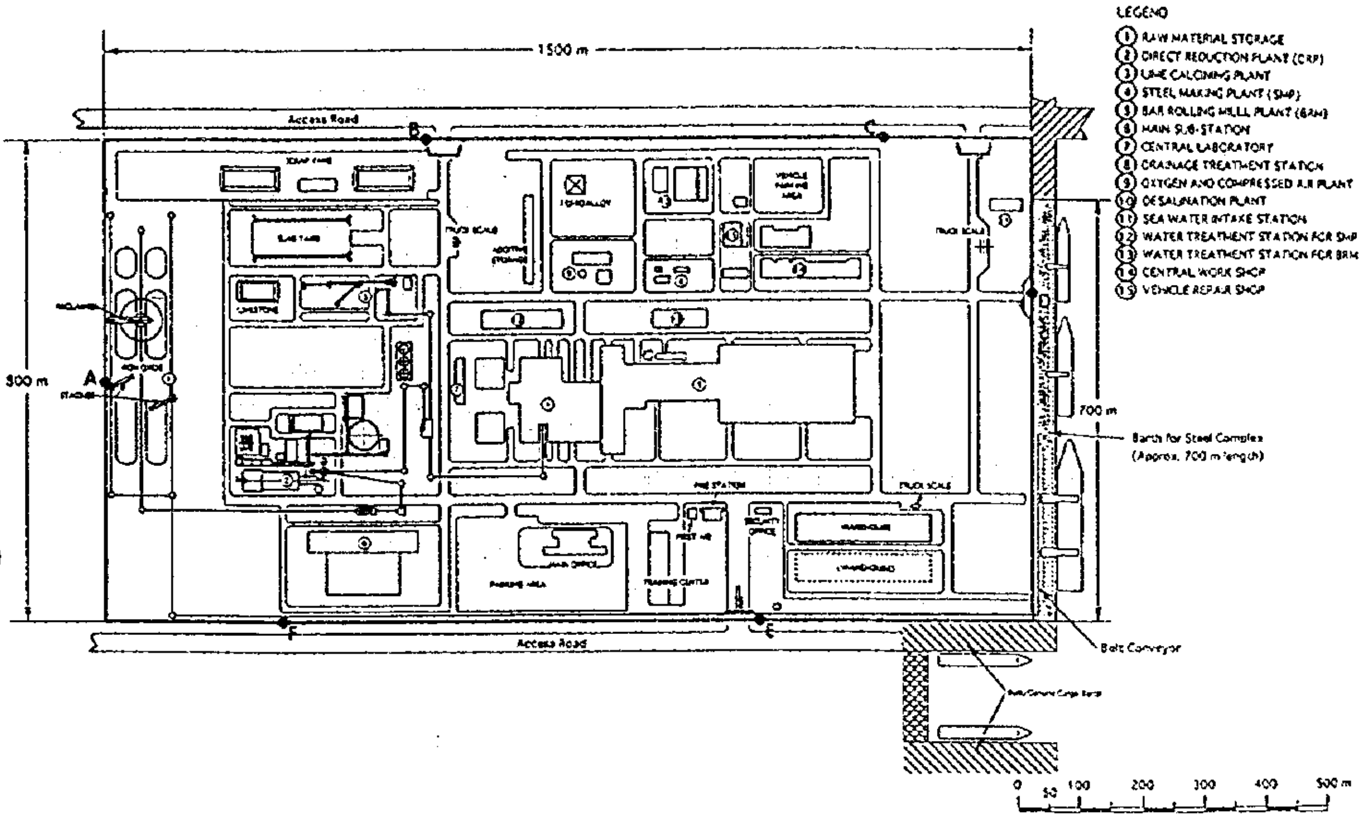


Figure 12A-2-3 Noise Areas

2-3-2 Method

(1) Calculation procedure

The calculation of noise is executed as in Figure 12A-2-4.

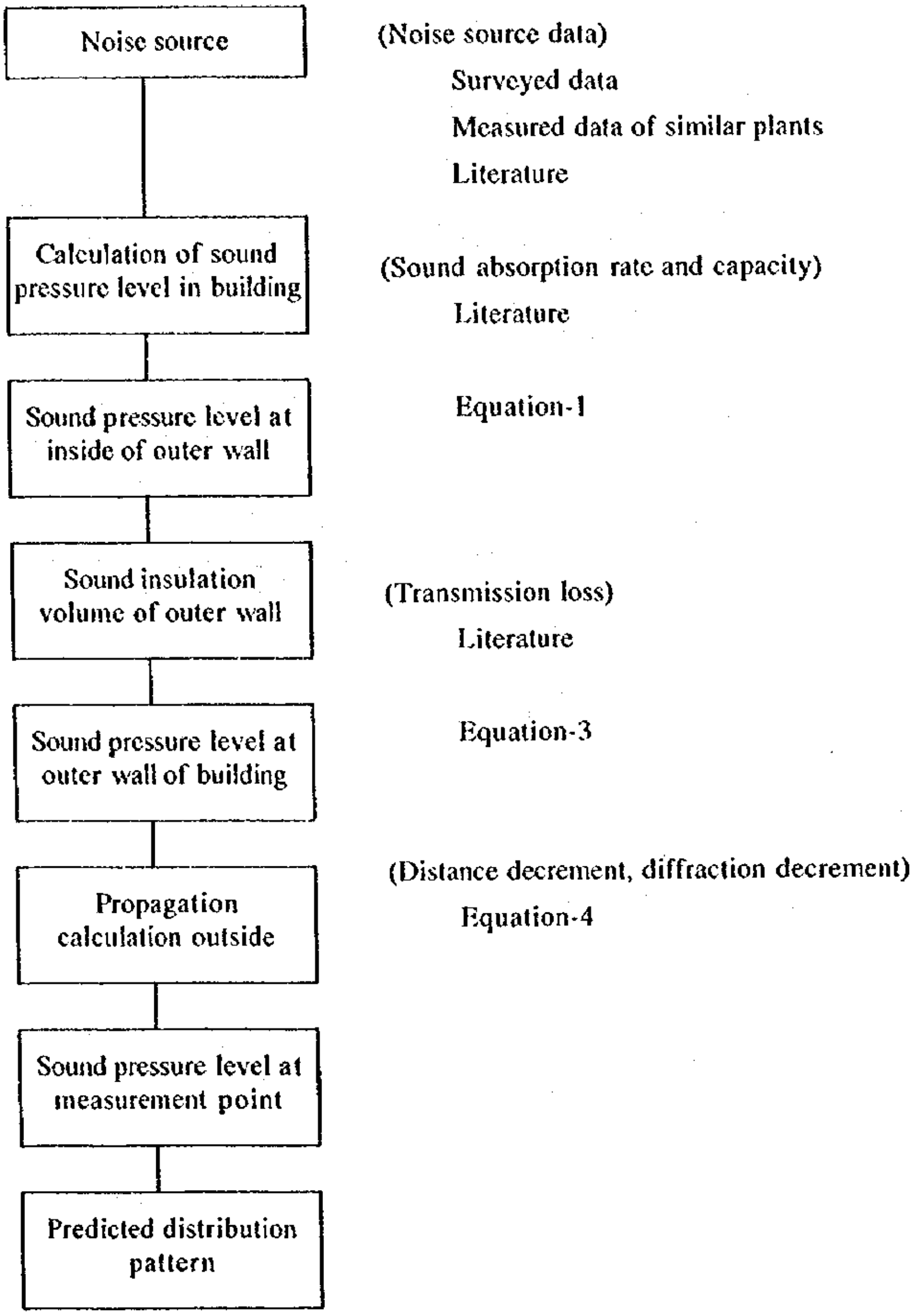


Figure 12A-2-4 Calculation Procedure

(2) Equations

1) Sound Pressure Level Equation

$$Lr = Lp + 10 \cdot \log_{10}\left(\frac{Q}{4\pi r_0^2} + \frac{4}{R}\right) \qquad \text{(dB)} \qquad \text{[Eq-1]}$$

where,

L_r : sound pressure level inside wall of building (dB)

L_p : power level of noise source (dB)

r_0 : distance between noise source and measurement point (m)

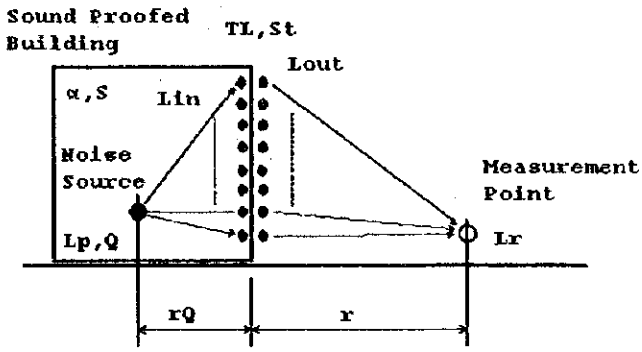
Q : directivity coefficient of noise source

R : room constant

$$R = \frac{S \cdot \alpha}{(1-\alpha)} \qquad (m^2) \qquad \text{[Eq-2]}$$

α : average absorption rate

S : total room area (m^2)



2) Sound Pressure Level Equation (outer wall)

$$L_{out} = L_r - TL \qquad \text{(dB)} \qquad \text{[Eq-3]}$$

where,

L_{out} : sound pressure level at outer wall of plant (dB)

L_r : sound pressure level inside wall of building (dB)

T L : total transmission loss (dB)

3) Outside Distribution Pattern

$$L_r = L_{out}' - 20\log_{10} r - 8 - \Delta L \qquad \text{(dB)} \qquad \text{[Eq-4]}$$

where,

L_r : sound pressure level at r(m) distance from noise source (dB)

L_{out}': sound pressure level (after correction) at outer wall of plant (dB)
(level corrected area of wall to L_{out})

r : distance between noise source and measurement point (m)

ΔL : diffraction decrement effect by barrier wall (dB)

$$\Delta L = 5 \pm 20\log_{10}\frac{\sqrt{2\pi|N|}}{\tanh\sqrt{2\pi|N|}} \qquad \text{(dB)}$$

tanh : hyperbolic tangent

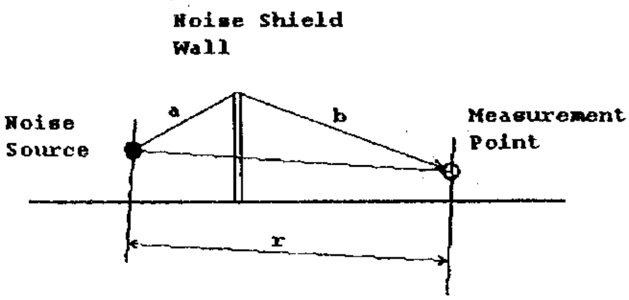
$N = \frac{2 \cdot f}{C} \cdot \delta$ $\qquad N < 0 \rightarrow \pm = (-)$

N : Fresnel's number

C : the speed of sound (340 m/s)

f : frequency (Hz)

δ : path difference (m) $\qquad \delta = a + b - r$



2-3-3 Conditions

(1) Plant facility noise levels

Four noise sources were selected for simulation as shown in Table 12A-2-5. The frequency property of noise is defined according to measured data at similar plants.

Table 12A-2-5 Facility Noise Levels

Facility	Noise level L_{eq} (dB)	Measurement point
DRP reformer	100	1 m from equipment
SMP EAF	105	inside room
BRM mill	105	inside room
Air compressor	95	inside room

Sound Power Levels are estimated in Table 12A-2-6.

Table 12A-2-6 Sound Power Levels and Frequencies

(Property A, unit: dB(A))

Facility	Sound power level	1/1 octave band center frequency (Hz)							
		63	125	250	500	1 k	2 k	4 k	8 k
Reformer	108	73	85	97	103	104	101	95	83
EAF	132	100	111	121	127	128	125	116	101
Reheating furnace	118	91	104	114	112	111	105	98	86
Rolling mill	129	90	101	114	122	126	122	113	102
Finishing yard	114	80	89	105	107	108	109	106	100
Compressor	118	83	95	107	113	114	111	105	93

(2) Plant building component materials sound characteristics

Plant buildings except the compressor room are composed of concrete floors, and corrugated sheet (t = 0.8 mm) walls and roofs. Tables 12A-2-7 and 12A-2-8 show the sound characteristics of these components. The compressor room is composed of concrete floor and walls, and corrugated sheet roof.

Table 12A-2-7 Component Material Sound Absorption Rate

unit: %

Material	1/1 octave band center frequency (Hz)							
	63	125	250	500	1 k	2 k	4 k	8 k
Corrugated sheet (0.8 t)	8	22	15	10	8	8	8	8
Concrete	1	1	1	1	2	2	3	3

Table 12A-2-8 Component Material Sound Insulation Volume

unit: dB

Material	1/1 octave band center frequency (Hz)							
	63	125	250	500	1 k	2 k	4 k	8 k
Corrugated sheet (0.8 t)	10	15	20	25	28	30	30	25
Concrete	22	26	32	37	41	46	46	41

note: safety factor = 0.8

(3) Plant outer wall noise levels

The noise levels at the plant outer walls shown in Figure 12A-2-5 are calculated from the sound pressure at the outer wall from equation-1.

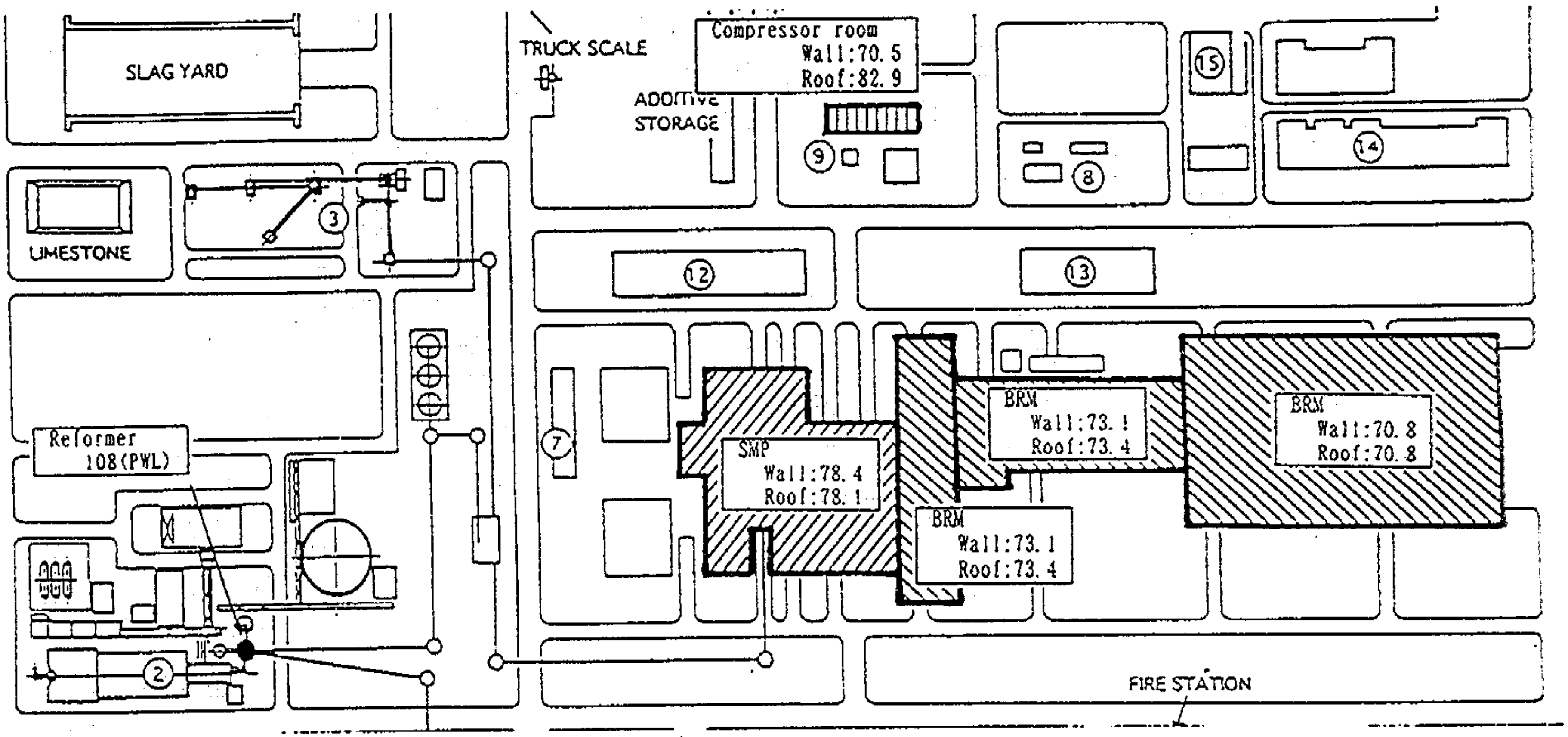


Figure 12A-2-5 Outer Wall Noise Levels

(4) Area

The area for noise level calculation is 1,500 m on the X axis and 800 m on the Y axis. The X axis is divided by 30, the Y axis is divided by 16 and height is 1.2 m on the Z axis. For outside noise transmission, the buildings between noise sources and measurement points are dealt with as sound barriers, but other facilities in the yard were not considered. Building height as a barrier is 52 m for the SMP-EAF, 12m for the air compressor and 18 m for the others.

2-3-4 Results

The predicted noise levels in the plant are shown in Figure 12A-2-6 for the DRP reformer, Figure 12A-2-7 for the air compressor, Figure 12A-2-8 for the SMP-EAF, and Figure 12A-2-9 for the BRM.

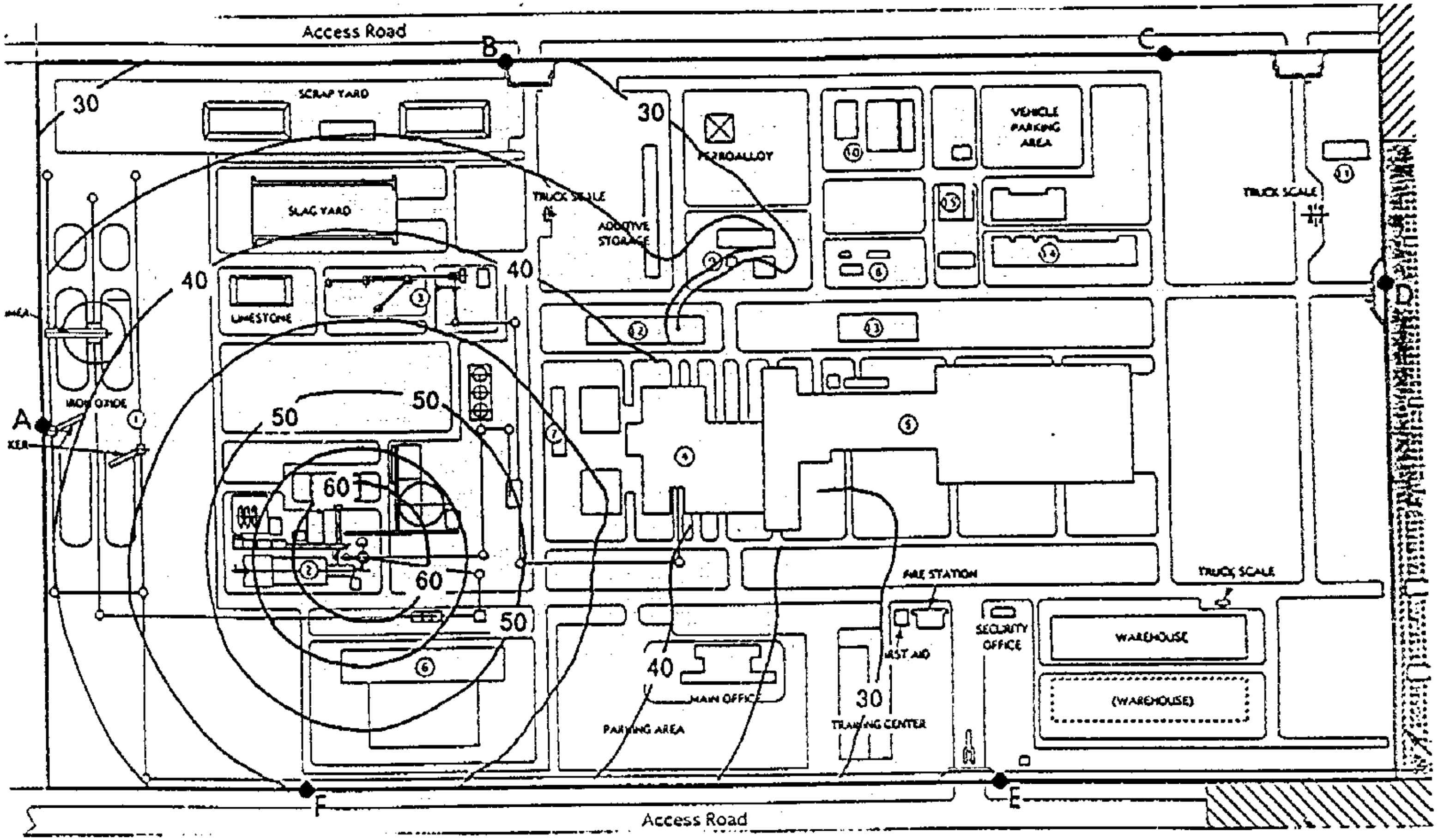


Figure 12A-2-6 Noise Distribution Pattern (DRP Reformer)

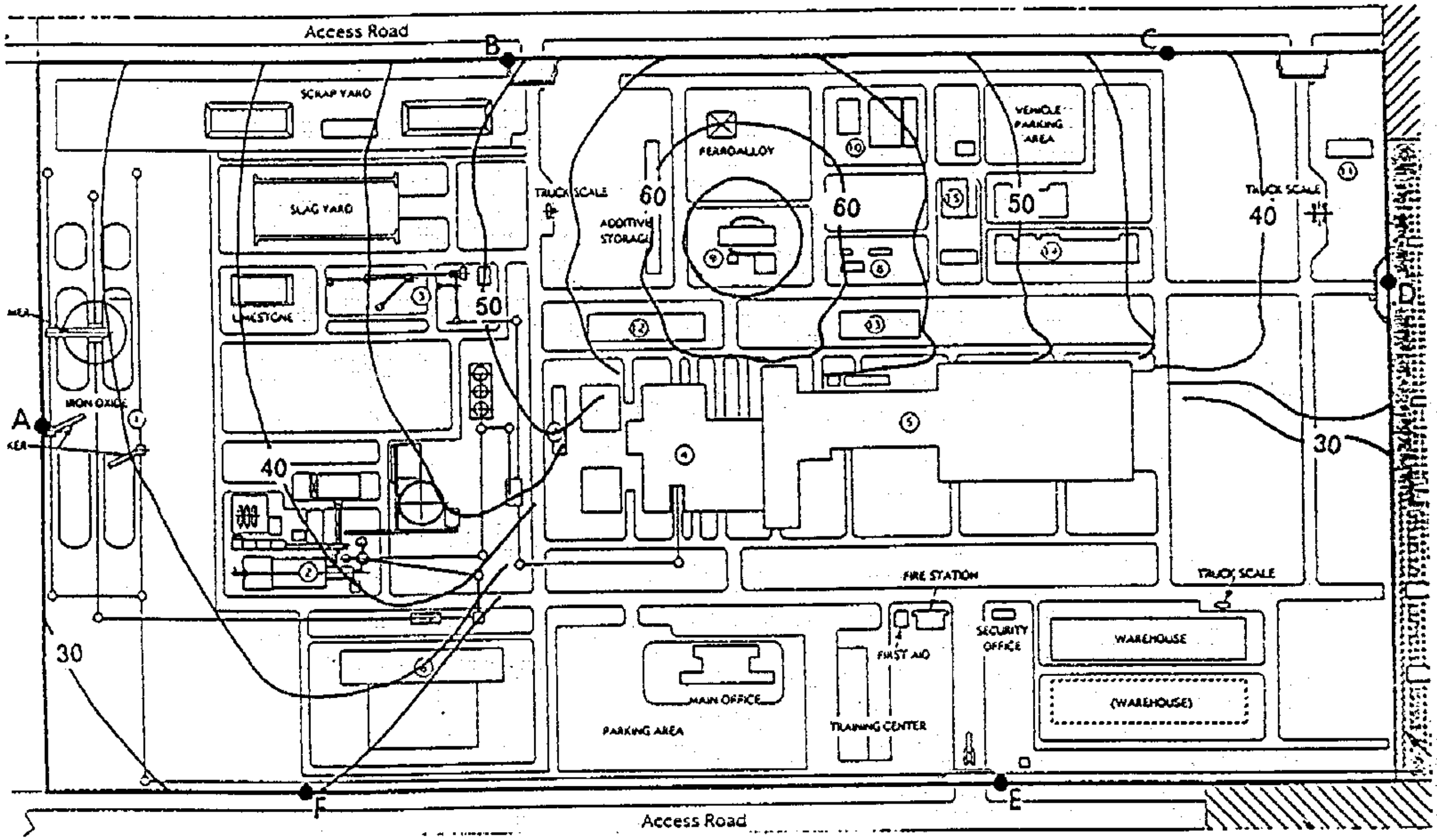


Figure 12A-2-7 Noise Distribution Pattern (Air Compressor)

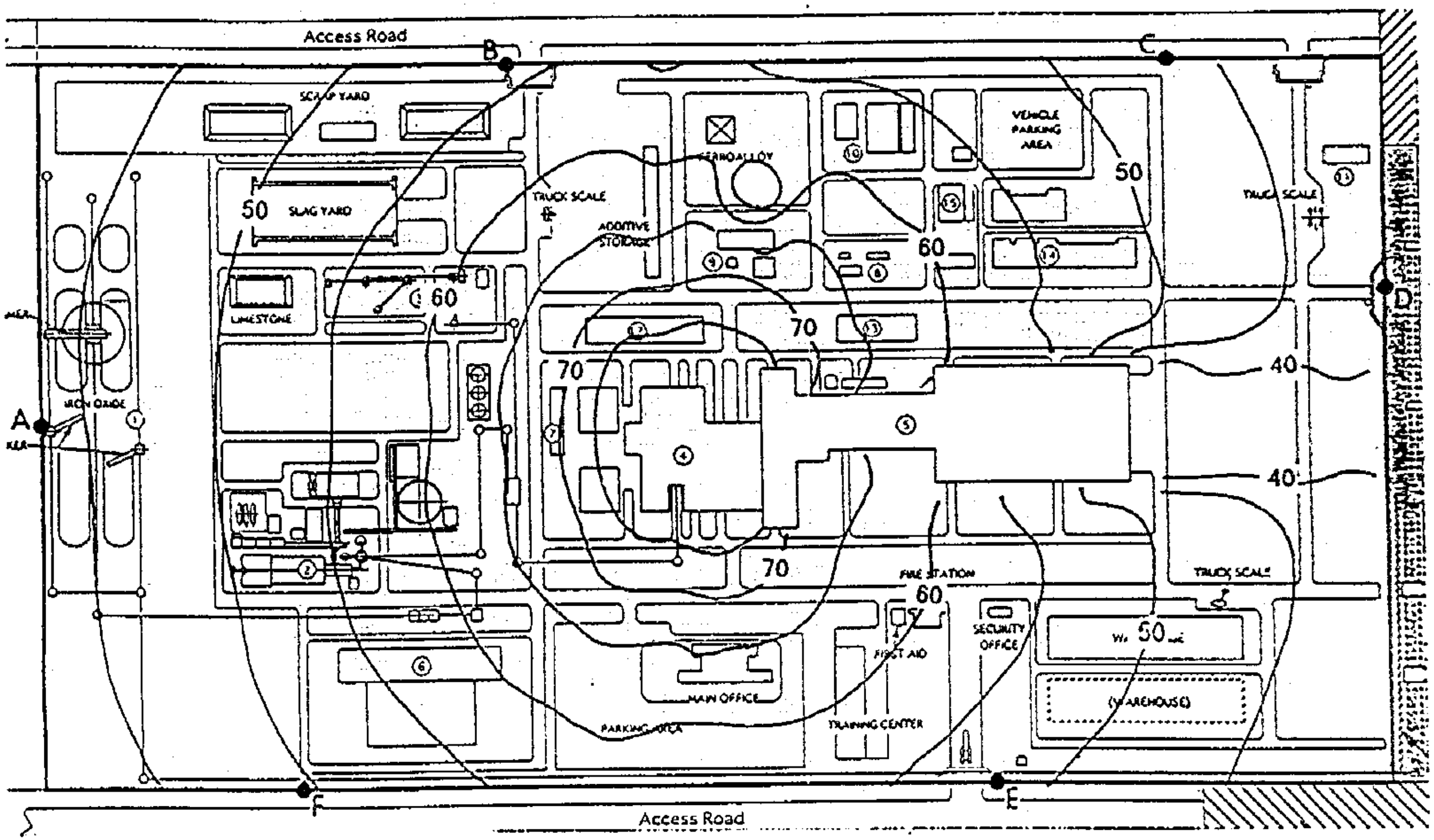


Figure 12A-2-8 Noise Distribution Pattern (SMP-EAF)

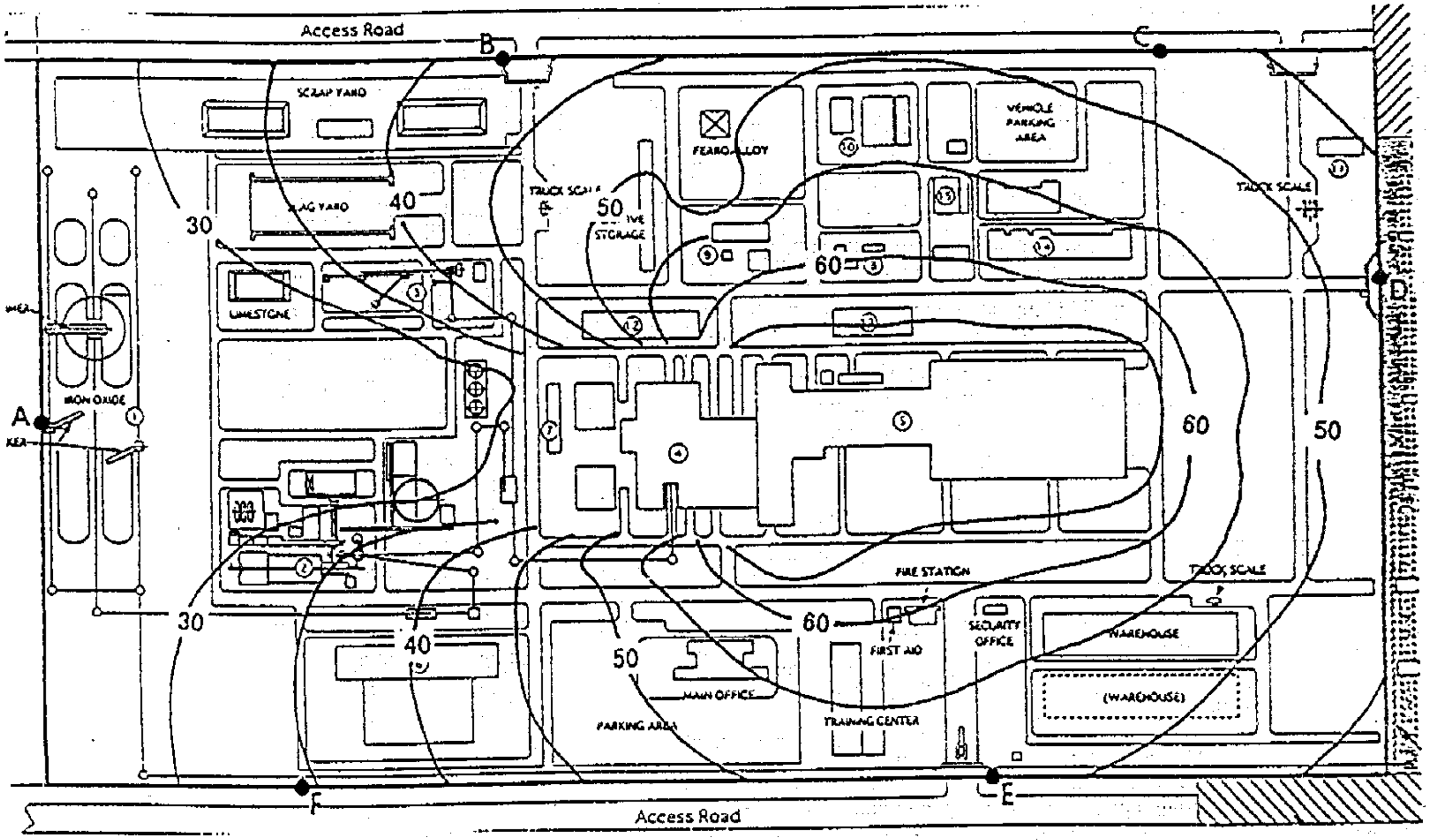


Figure 12A-2-9 Noise Distribution Pattern (BRM)

2-4 Water

2-4-1 Area

The area of sea water quality affected by waste water is shown in Figure 12A-2-10.

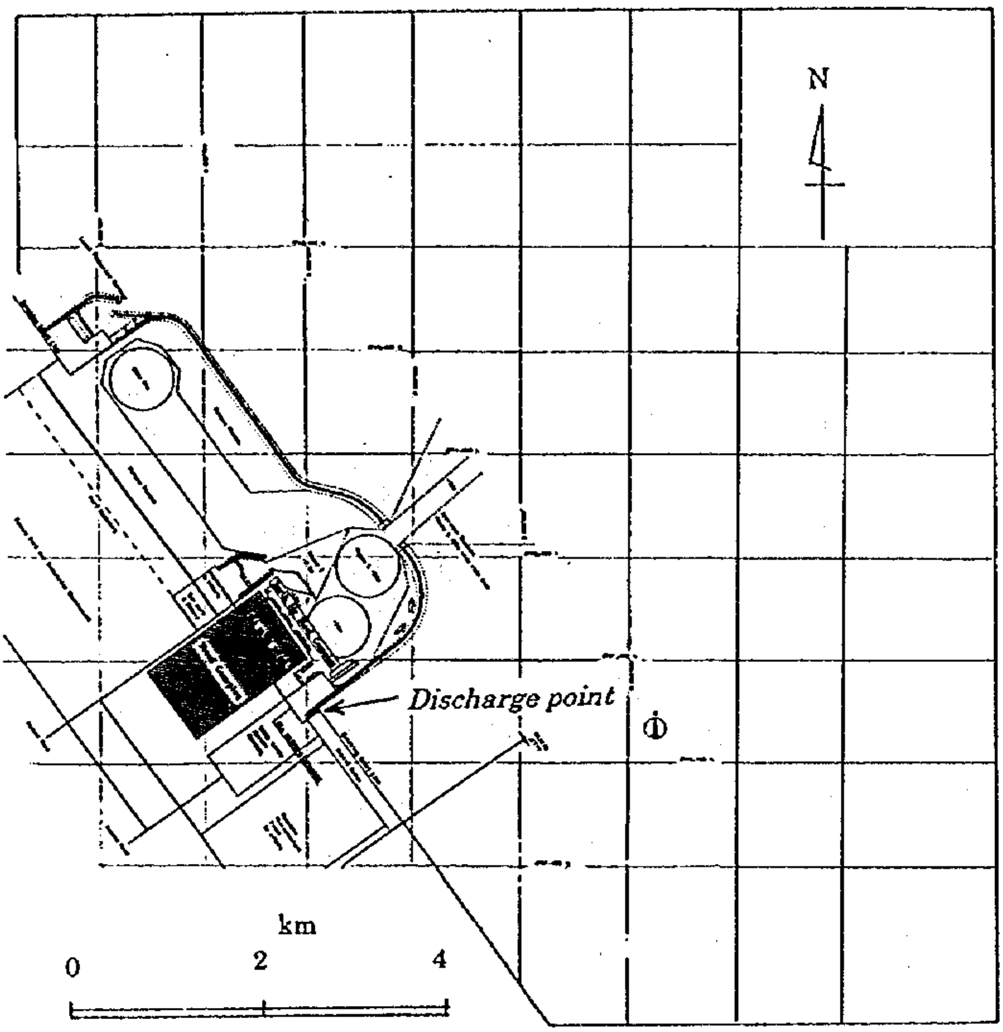


Figure 12A-2-10 Sea Water Quality Area

2-4-2 Method

For sea water with steady, unidirectional flow, the following equations were used as the governing equations in the case when effluent is discharged continuously from a point source.

Continuity equation : $\partial u_i / \partial x_i = 0$ [Eq-1]

Momentum and energy conservation equations : [Eq-2]

$$u_i \partial \phi / \partial x_i = \kappa \partial^2 \phi_j / \partial x_i^2 + S_o$$

where,

u_i : steady tidal flow rate in the i direction (m/s)

x_i : coordinates (m)

ϕ_j : tidal speed (m/s)

tidal temperature (Degree C)

κ : diffusion coefficient (m^2/s)

S_o : pressure gradient

$S_o = -\partial P / \rho \partial x_i$ in the momentum conservation equation,

$S_o = 0$ in the energy conservation equation

P : tidal pressure (Pa)

ρ : density of sea water (kg/m3)

2-4-3 Conditions

Conditions are shown in Table 12A-2-9.

Table 12A-2-9 Sea Water Conditions

Parameter	Value
Discharge water quantity	25,000 m^3/hr
Horizontal Diffusion coefficient (K)	1.0 m^2/s
Average sea water depth	5 m
Tidal direction	SE - 11.5°
Tidal speed	0.1 m/s

2-4-4 Results

The predictive result of tidal speed distribution is shown in Figure 12A-2-11.

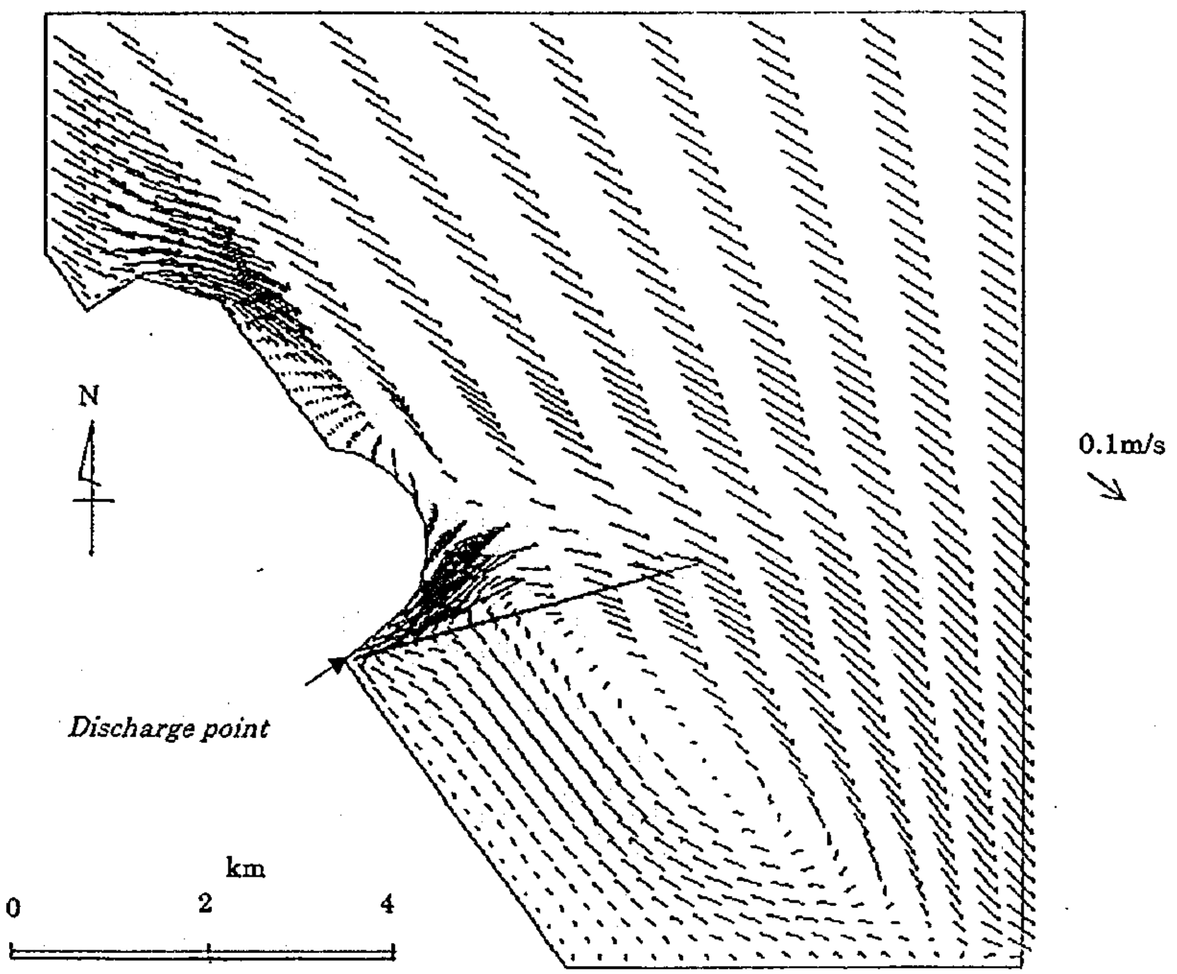


Figure 12A-2-11 Tidal Speed Result

JICA