6. Model Simulation

6.1 ATMOS2

The ATMOS2 model primarily developed for the RAINS-Asia project was used for the simulation of sulfur deposition in Thailand. The ATMOS2 model is a multi-layers forward trajectory Lagrangian puff-transport model.

6.1.1 Model Establishment

The major changes or tunings of ATMOS2 model for adoption to Thailand are as follows.

- Use of Local Precipitation Data
- Regional and Urban Grid System
- Calibration of Wet Deposition Coefficient

Basically, ATMOS2 uses CDC/NCEP reanalysis data as its meteorological inputs. However, after the examination of collected rainfall amounts and monthly patterns of precipitation data, the local precipitation data were used for the grid points around Thailand.

Because the pollutant emission sources concentrated around BMR and were investigated in more details, the pollutant sources are compiled into the urban grid system with 0.1 degrees resolutions and the urban options of ATMOS2 model was used. The regional grids with 1.0 degrees resolution were used for the remaining regions.

After the comparison of calculated values with the measurement data, the original wet scavenging coefficients were calibrated by multiplying 1.5 times for the improvement.

As a result, the simulation model shows relatively good coincidence with the measured wet deposition data at each stations as in Table 6.1.1.1.

Table 6.1.1.1 Comparison of Simulation Results with Measurements

	OEPP	TMD	ERTC	Khao Laem Dam
Precipitation (mm/year)	1144.3	975.0	941.3	881.3
Calculated (mg-S/m^2/year)	833.0	744.2	498.8	25.7
Measured (mg-S/m^2/year)	776.9	777.8	573.6	87.0

6.1.2 Simulated Results of Acid Deposition

The acid deposition simulations were conducted for the base year (year 2000), the target year (year 2011) and the control case (year 2011 with the control).

The total sulfur depositions for the urban area and the whole Thailand in each year and case are shown in Figure 6.1.1.1 to Figure 6.1.1.6.

1) Sulfur Deposition in Whole Thailand

Among the regional grids except the urban area, the most total (wet and dry) deposition of 959 mg-S/m^2 appear in the grid over Chaochoensao and Chonburi provinces in year 2000 and will increase to 1185 mg-S/m^2 in year 2011. This deposition under the BaU case will reduced to 1030 mg-S/m^2 by the control and the most deposition under the control is 1126 mg-S/m^2 around Rayong province.

2) Sulfur Deposition in Urban Area

The most total deposition of 3329 mg-S/m^2 appear in the grid over Bangkok and Samutprakan provinces in year 2000, and more than 2000 mg-S/m^2 area covered the almost all area of Bangkok province.

The most deposition in the grid of Bangkok province will slightly decrease to 3062 mg-S/m^2 in year 2011 according to the pollutant source change in the future. However, more than 2000 mg-S/m^2 areas will remain in the most part of Bangkok.

The deposition under the BaU case will relatively decrease to 2380 mg-S/m^2 by the control. The areas with more than 2000 mg-S/m^2 total depositions will also shrink.

3) Comparisons with Critical Load

"Critical Load" is one of the indices of damages by acid depositions to eco-systems, but there are various criticisms on its adoption to Asia regions. So, the critical load is not used as target values for emission controls, but used as reference values for comparisons with simulated depositions (Supporting Report, Chap.5.1, Chap.9.1).

Comparing the simulated sulfur depositions over Chachoengsao and Chonburi provinces in year 2000, year 2011, and year 2011 under the control with 25% critical values, 58%, 66%, and 61% of reductions are necessary.

In urban areas, the maximum depositions in year 2000, year 2011, and year 2011 under the control are corresponding to the 82%, 80%, and 74% of necessary reductions.

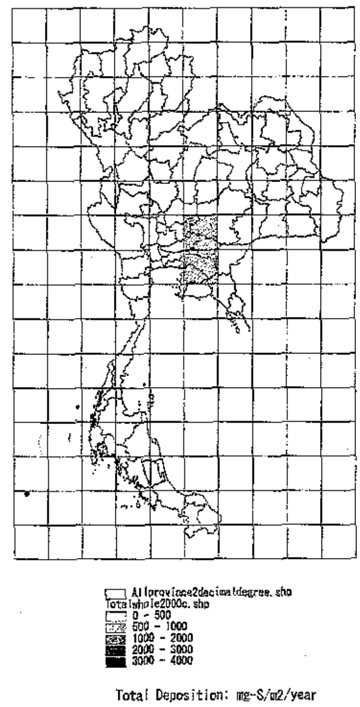


Figure 6.1.1.1 Total Deposition in Whole Thailand of Year 2000

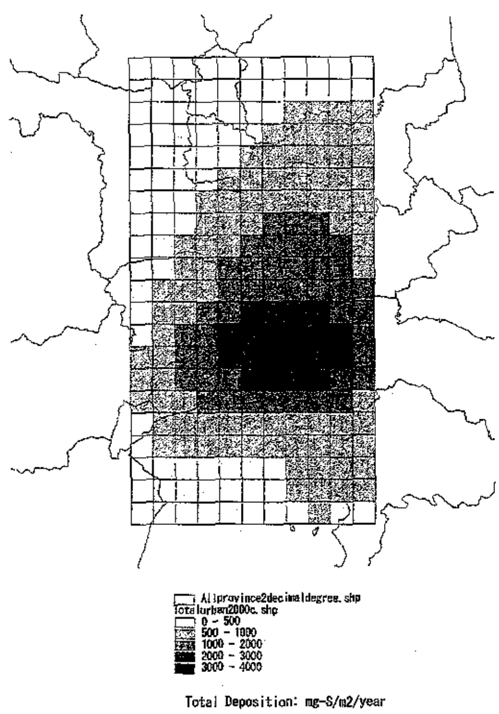


Figure 6.1.1.2 Total Deposition in Urban Area of Year 2000

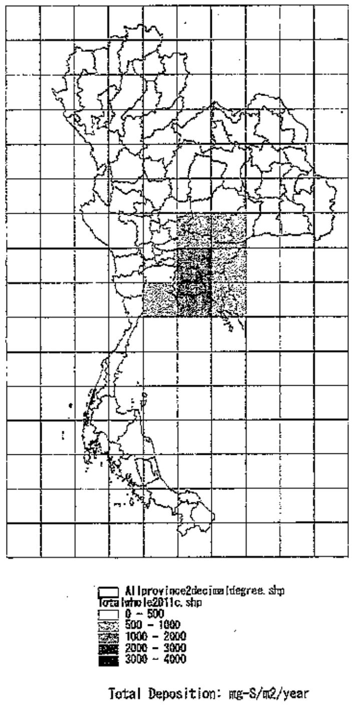


Figure 6.1.1.3 Total Deposition in Whole Thailand of Year 2011

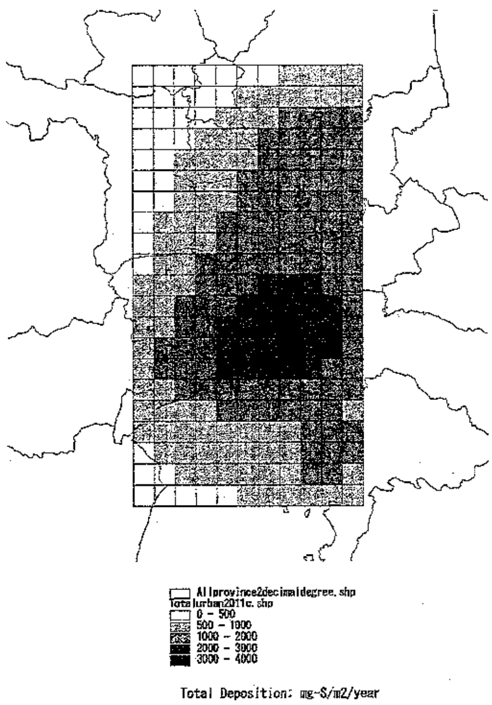


Figure 6.1.1.4 Total Deposition in Urban Area of Year 2011

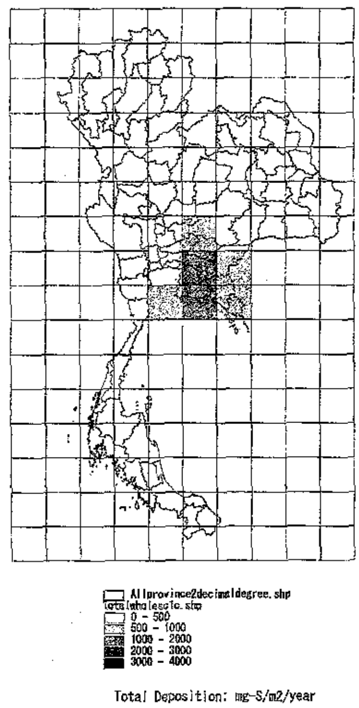


Figure 6.1.1.5 Total Deposition in Whole Thailand of Year 2011 with The Control

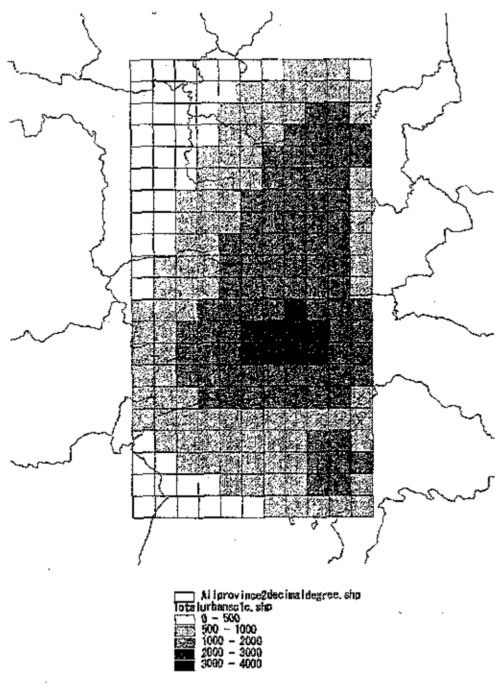


Figure 6.1.1.6 Total Deposition in Urban Area of Year 2011 with The Control

6.2 Airviro

6.2.1 Emission Inventory in the BMR

6.2.1.1 Emission Inventory of the Base Year in the BMR

The SOx emission maps of the base year (year 2000) in the BMR are shown in Figure 6.2.1.1 to Figure 6.2.1.3. SOx point source emission occupies over 90 percentage against the total emission. In particular, high SOx emission areas of point sources are located around the Chao Phraya River and the central area of Samut Sakhon. SOx area sources in the Bangkok province show relatively higher values than other provinces. SOx line sources are located in the major roads of the Bangkok central to suburbs.

The NOx emission maps of the base year (year 2000) in the BMR are shown in Figure 6.2.1.4 to Figure 6.2.1.6. High NOx emission areas of point sources are located around the Chao Phraya River. NOx area sources have low emission values. Among area sources, the emission for the Bangkok province, the west area of Samut Sakhon and the railways are a relatively higher value. NOx line sources have a high percentage against the total emission. In particular, major roads from the Bangkok central to suburbs and the ring road in suburbs show higher emissions than BMR central.

6.2.1.2 Emission Inventory of Future Year in BMR

The SOx emission maps of the future year (year 2011) in the BMR are shown in Figure 6.2.1.7 to Figure 6.2.1.9. The SOx emission of point sources for the year 2011 in the Bangkok province is lower than the year 2000. SOx emission distribution of point sources and line sources for the year 2011 do not change from the year 2000.

The NOx emission maps of the future year in the BMR are shown in Figure 6.2.1.10 to Figure 6.2.1.12. Compared with year 2000, NOx emission of the future year decreases around the Chao Phraya River. NOx area sources of the Samut Sakhon province for the year 2011 are increased from the year 2000. The NOx line sources of the Bangkok province are decreased from the year 2000, but high emission areas appear in new major roads and the new outer roads of suburbs.

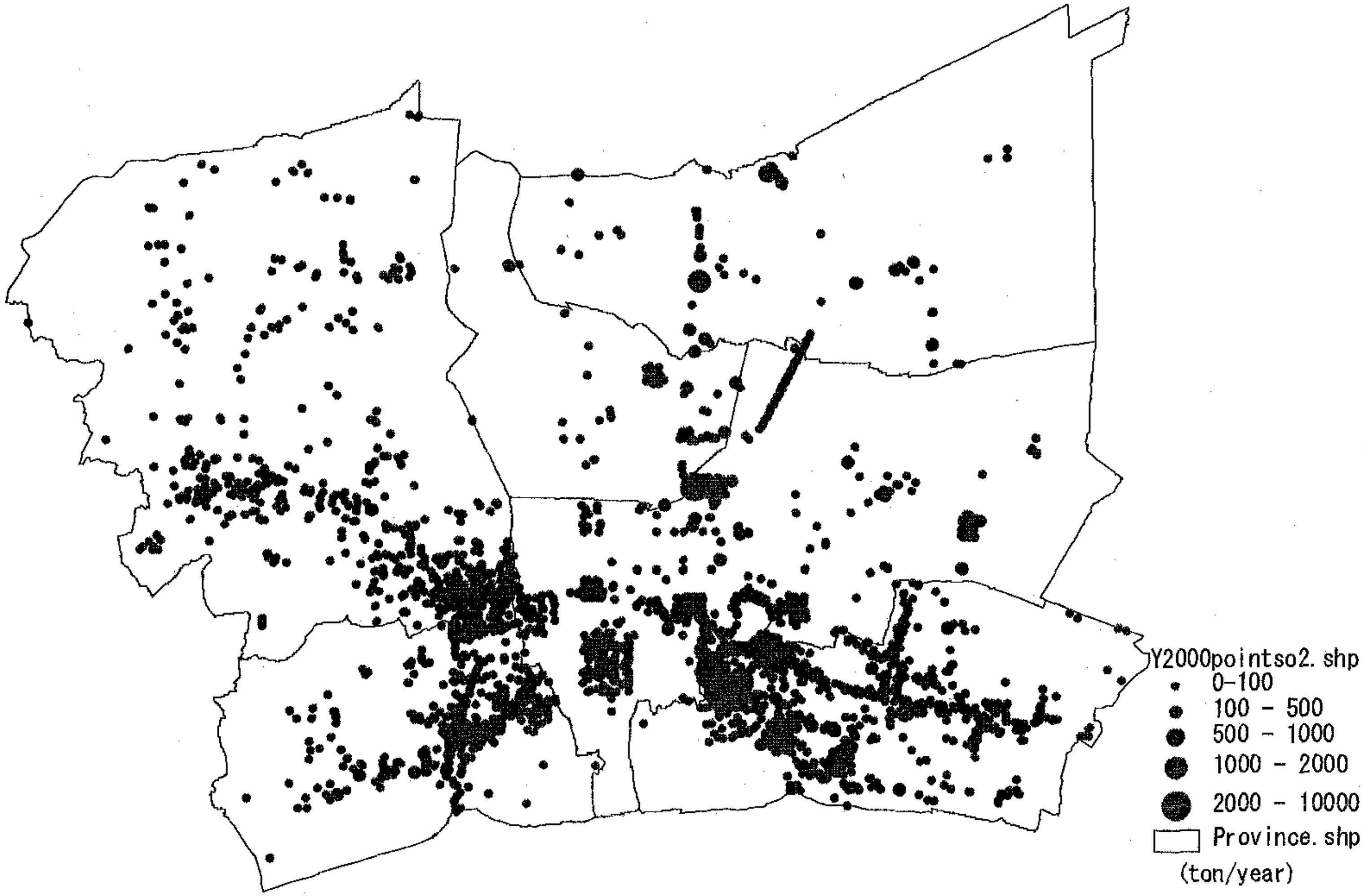


Figure 6.2.1.1 SOx Emission Inventory of Year 2000 in BMR (Point Source)

Figure 6.2.1.2 SOx Emission Inventory for the Year 2000 in the BMR (Area Source)

Figure 6.2.1.3 SOx Emission Inventory for the Year 2000 in the BMR (Line Source)

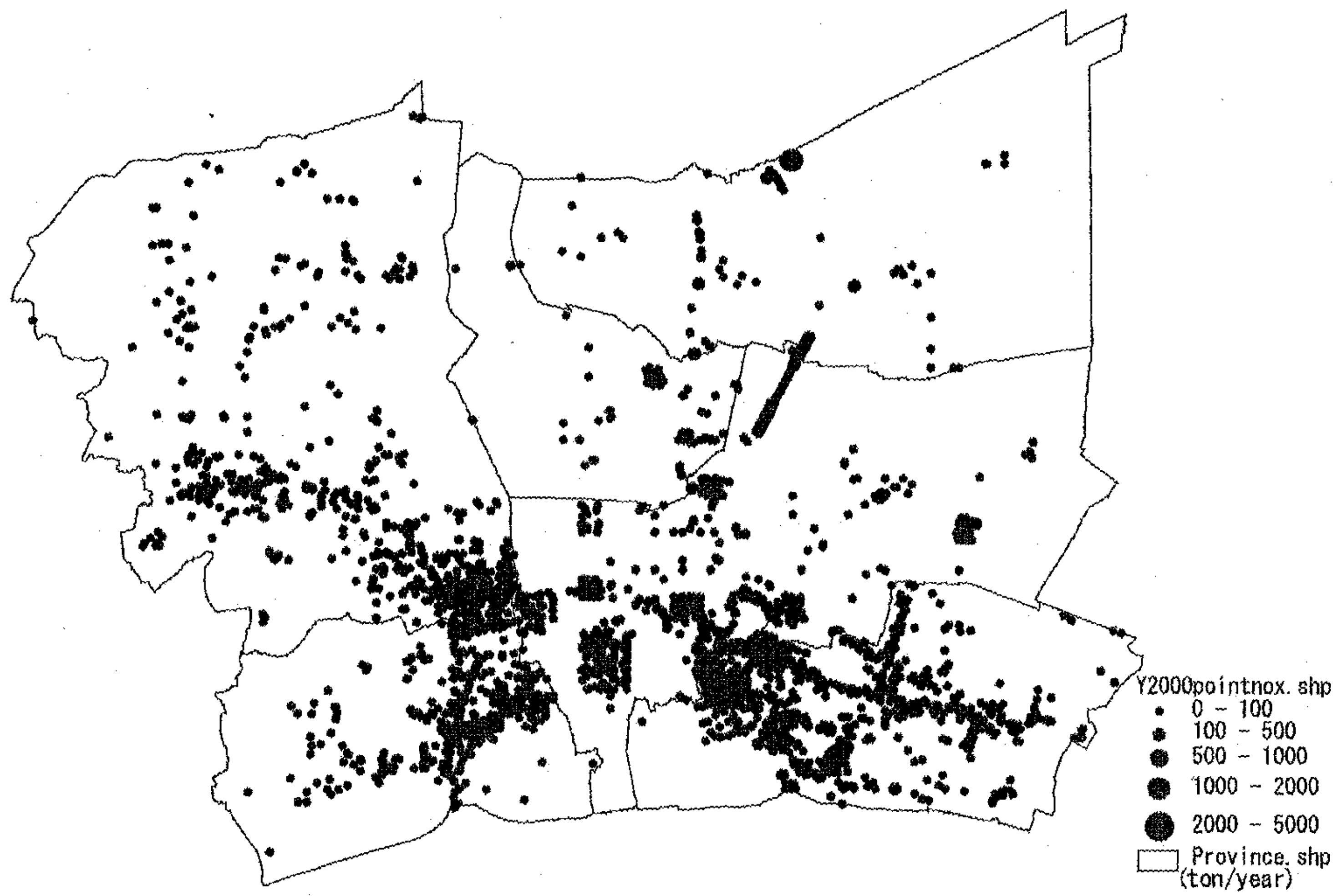


Figure 6.2.1.4 NOx Emission Inventory for the Year 2000 in the BMR (Point Source)

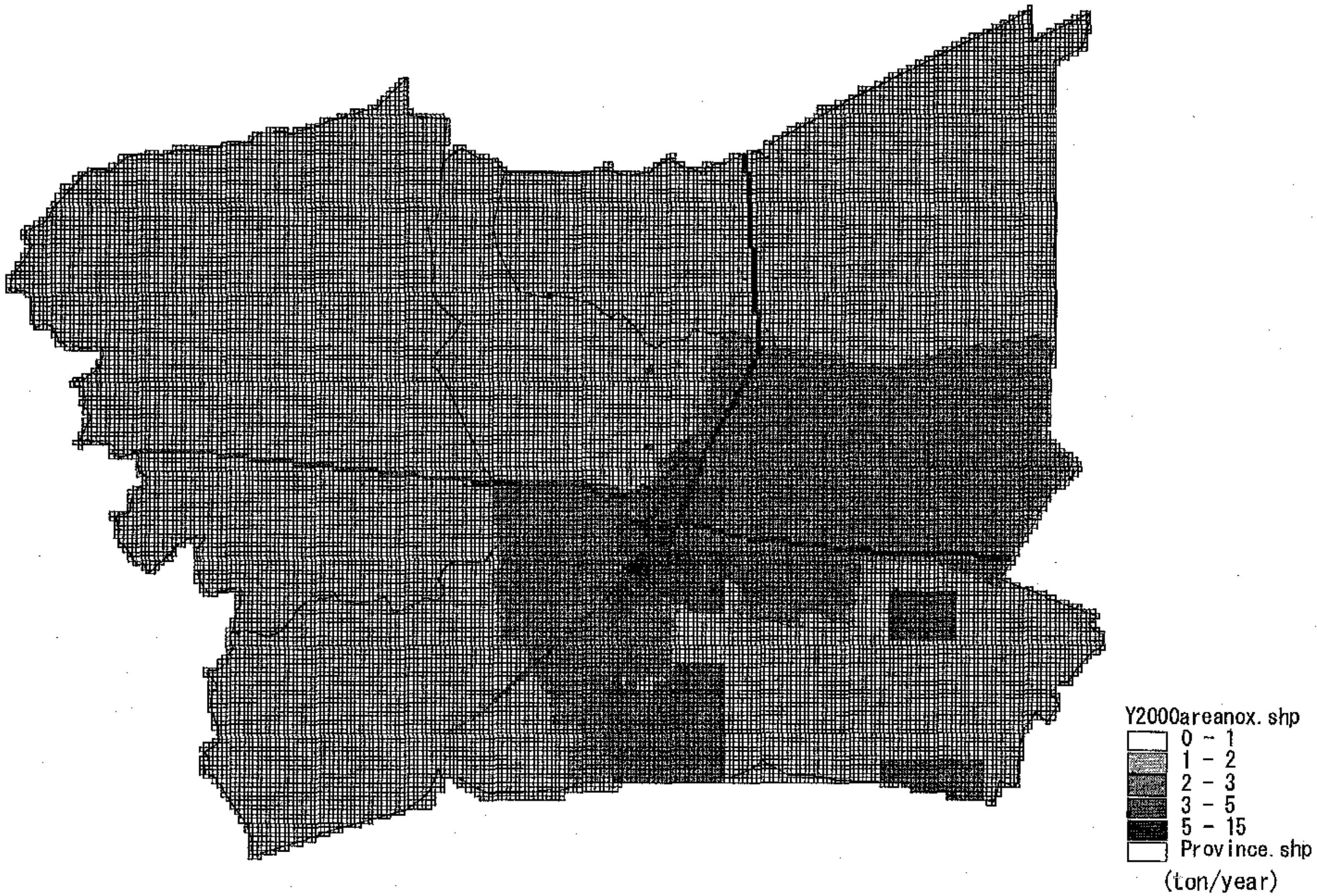


Figure 6.2.1.5 NOx Emission Inventory for the Year 2000 in the BMR (Area Source)

Figure 6.2.1.6 NOx Emission Inventory for the Year 2000 in the BMR (Line Source)

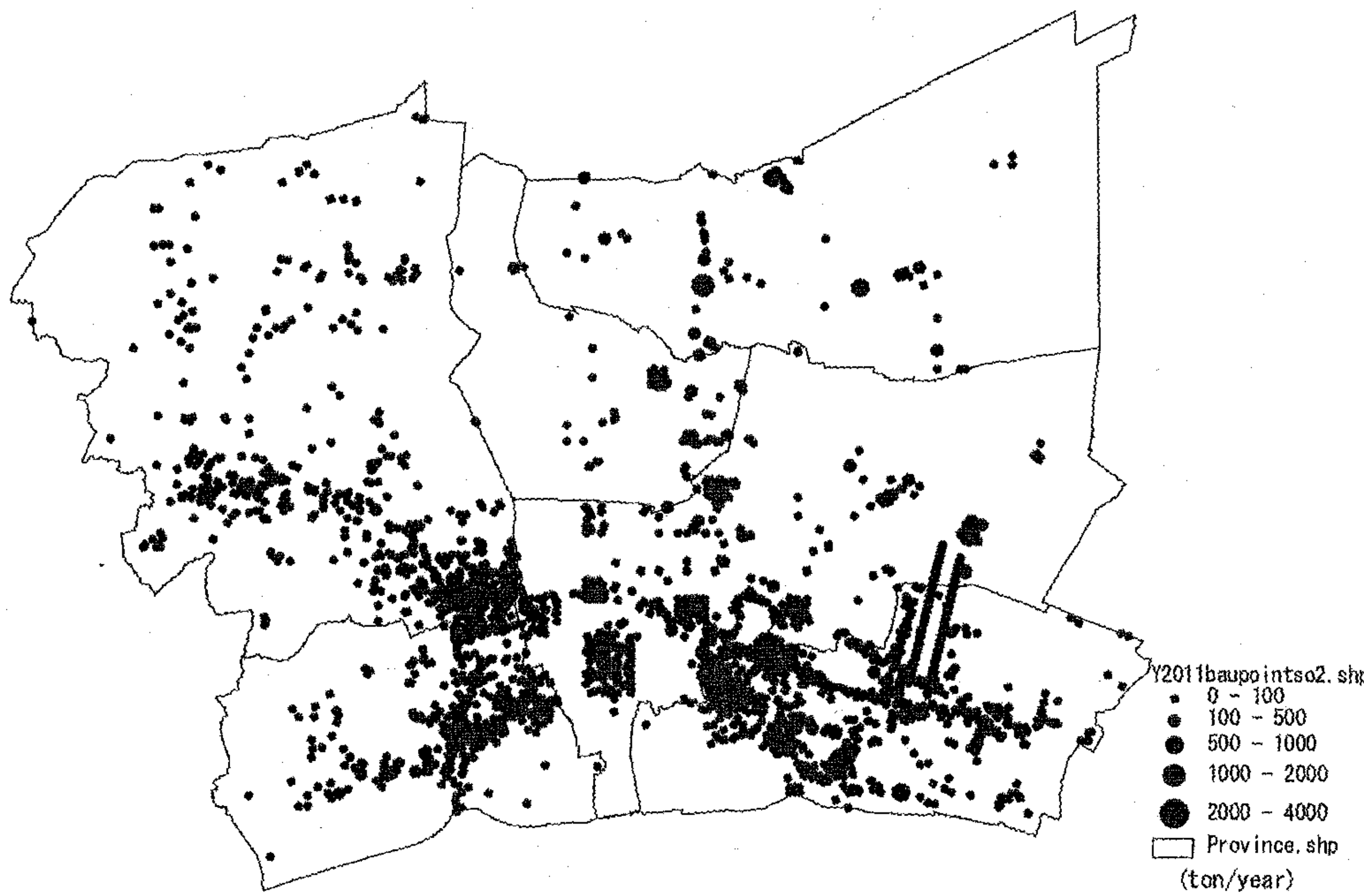


Figure 6.2.1.7 SOx Emission Inventory for the Year 2011 Bau in the BMR (Point Source)

Figure 6.2.1.8 SOx Emission Inventory for the Year 2011 Bau in the BMR (Area Source)

Figure 6.2.1.9 SOx Emission Inventory for the Year 2011 Bau in the BMR (Line Source)

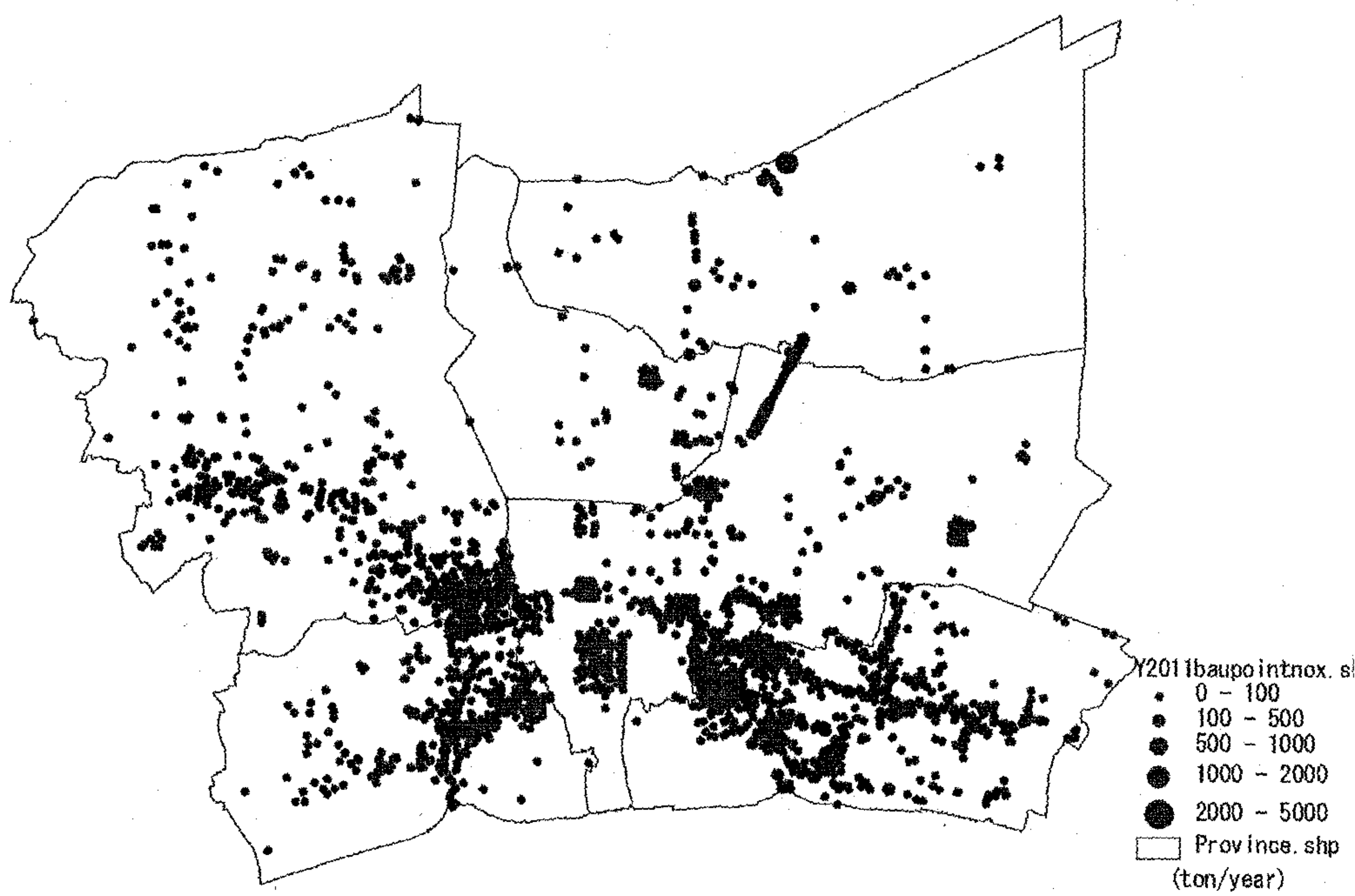


Figure 6.2.1.10 NOx Emission Inventory for the Year 2011 Bau in the BMR (Point Source)

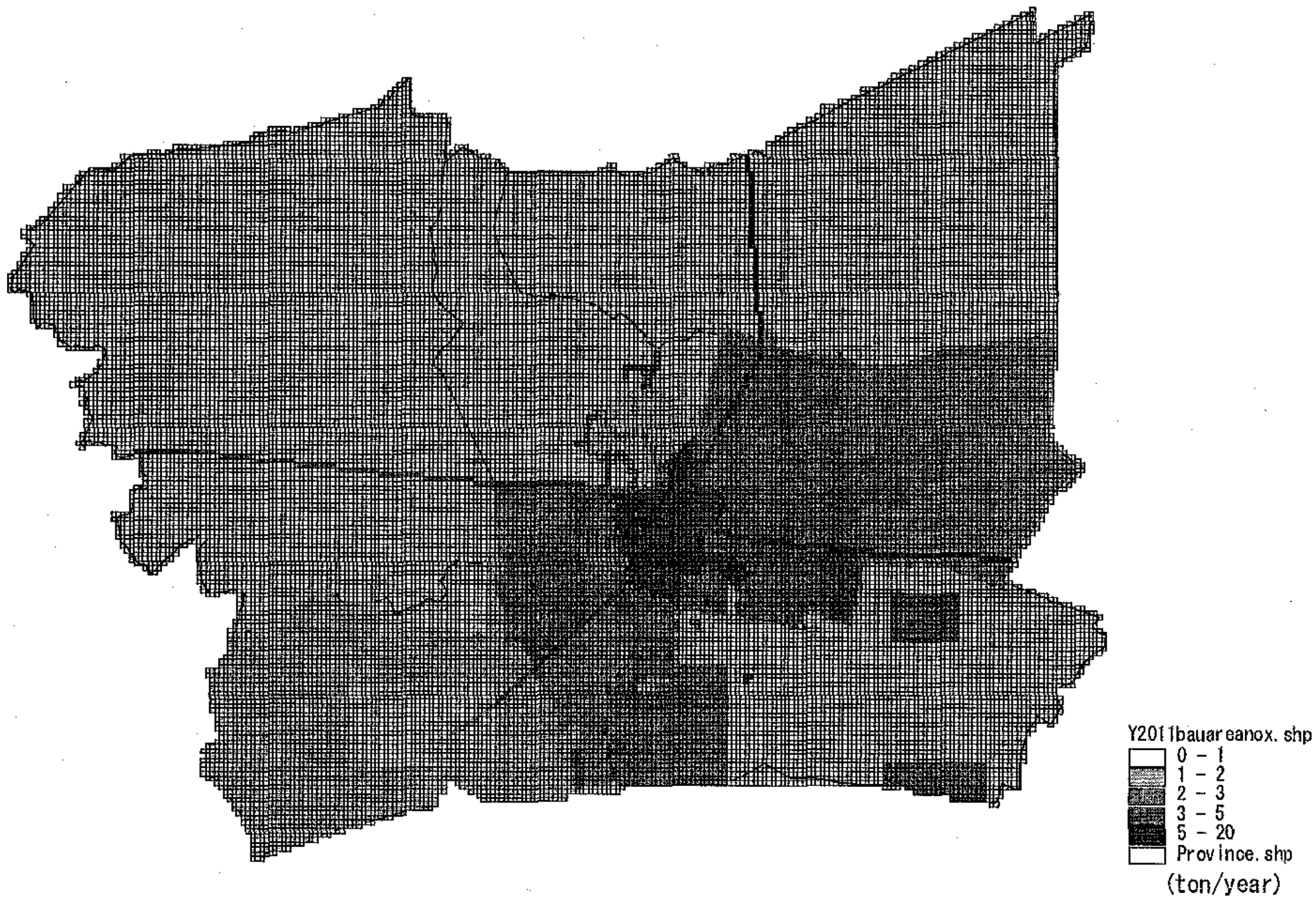


Figure 6.2.1.11 NOx Emission Inventory for the Year 2011 Bau in the BMR (Area Source)

Figure 6.2.1.12 NOx Emission Inventory for the Year 2011 Bau in the BMR (Line Source)

6.2.2 Conversion Formula for SO2 and NO2

The target pollutant of simulation is NOx. However, the target pollutants of the Thai Ambient Standard and the WHO Ambient Standard is NO2 concentration. Therefore, calculation values are converted from NOx into NO2. The conversion formula is decided by NOx and the NO2 annual mean values of monitoring data. The NO2 conversion statistical formula is as follows.

$[NO2]=3.191\times[NOx]^{0.508}$

[NO2]: NO2 Annual Mean Concentration

[NOx]: NOx Annual Mean Concentration

The SOx inventory included the contents of sulfate, the simulation results are cut by 5% from the SOx calculation value.

$[SO2]=[SOx]\times0.95$

6.2.3 Evaluation

The evaluation compares the annual simulation with the ambient annual standard. As Table 6.2.3.1 shows, the WHO standard has the SO2 and NO2 annual standard, but the NO2 standard of Thailand does not have the annual standard. Preparation of the Thailand target annual standard for NO2 is necessary. The target annual standard is 40ppb based on the hourly standard of Thailand and the formula that is the relation between the maximum hourly value and the annual mean value.

$$\text{NO2 Thai Target Annual Standard} = 0.335 \times \text{Thai Hourly Standard} - 16.98$$
$$= 0.335 \times 170(\text{ppb}) - 16.98$$
$$= 40\ (\text{ppb})$$

Table 6.2.3.1 Ambient Air Standards of Thailand & Guidelines for Air Quality of WHO

	10 Minutes		1 Hour		24 Hours		1 Year	
	mg/m^3	ppb	mg/m^3	ppb	mg/m^3	ppb	mg/m^3	ppb
SO_2								
Thailand	—		0.78	300	0.30	120	0.10	40
WHO	0.5	175	—		0.125	44	0.05	18
NO_2								
Thailand	—		0.32	170	—			(40)
WHO	—		0.2	98	—		0.04	20

* Thai Target Annual Standard is 40ppb based on above method.

6.2.4 Simulation Result of the Base Year and the Future Year in the BMR

6.2.4.1 Model and Simulation Condition

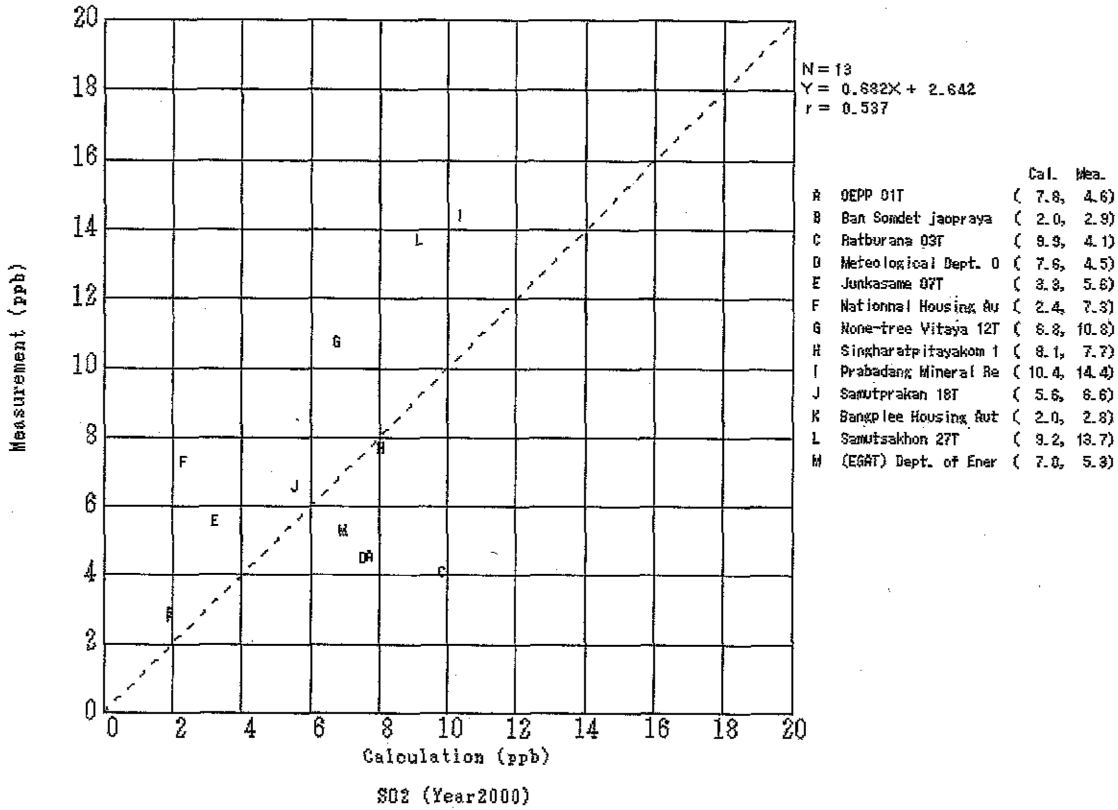
The Airviro Grid Model is a Eularian three-dimensional model. Also, the model can operate the process of transportation and diffusion. The simulation conditions are as follows.

Items	Conditions
Target Area	94km×70km Horizontal Grid : 500m Vertical Layers (7 Layers) Total Calculation Mesh: 188×140×7
Target Pollutants	NOx、SOx
Target Year	Base Year (Year 2000), Future Year (Year 2011)
Meteorological Data	Meteorological Data of Chatujak Bangkok
Emission Inventory	Stationary Source and Mobile Source

6.2.4.2 Simulation Result of the Base Year in the BMR

The simulation results for the year 2000 in the BMR are shown in Figure 6.2.4.1 to Figure 6.2.4.3. As Figure 6.2.4.1 shows, the SO2 calculation values of some stations are underestimated to the measurement values. On the whole, the SO2 correlation between the calculation and the measurement shows a relatively high value. The NO2 correlation shows a very good value.

The SO2 concentration map for the year 2000 is shown in Figure 6.2.4.2. The SO2 high concentration area is similar to the emission distribution of large point sources. In particular, SO2 high concentration areas appear around the Chao Phraya River and Samut Sakhon. The NO2 concentration map for the year 2000 is shown in Figure 6.2.4.3. The NO2 high concentration area is similar to the emission distribution of the major road sources. In particular, NO2 high concentration areas appear in the ring roads in suburbs.



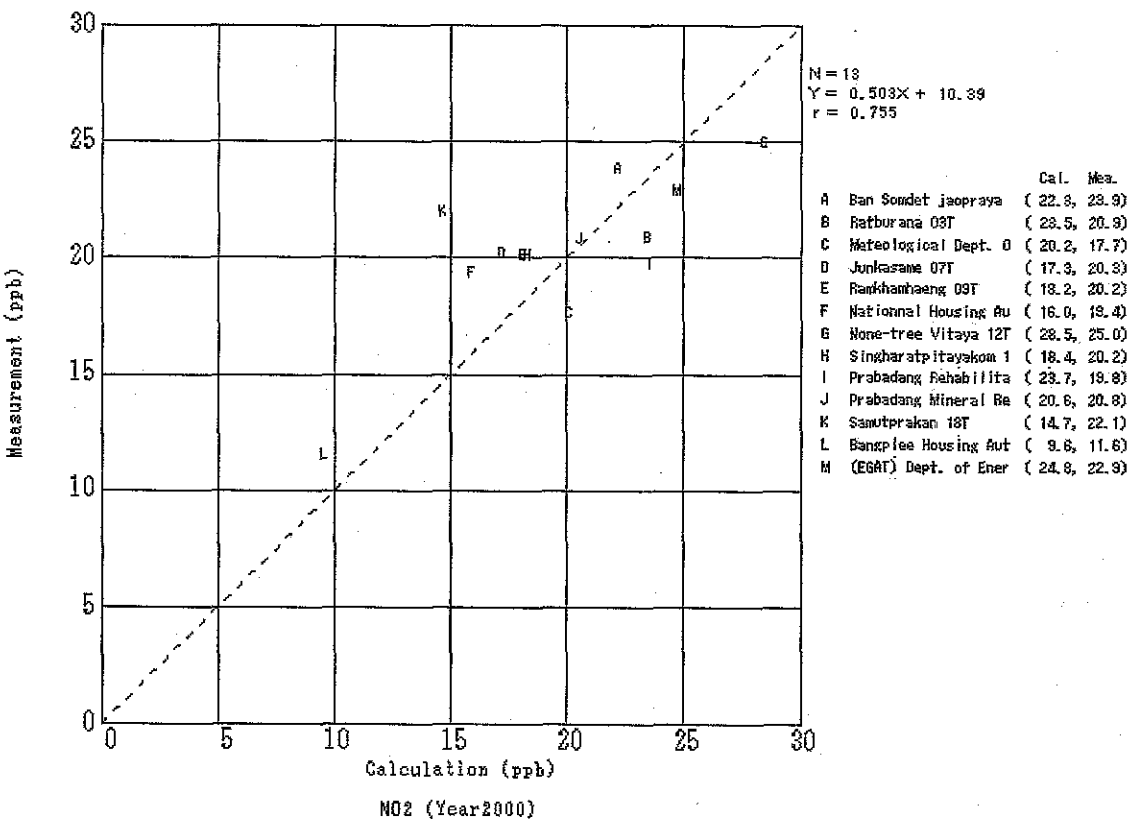


Figure 6.2.4.1 Comparison of Calculation value and Monitoring Data (Year 2000)

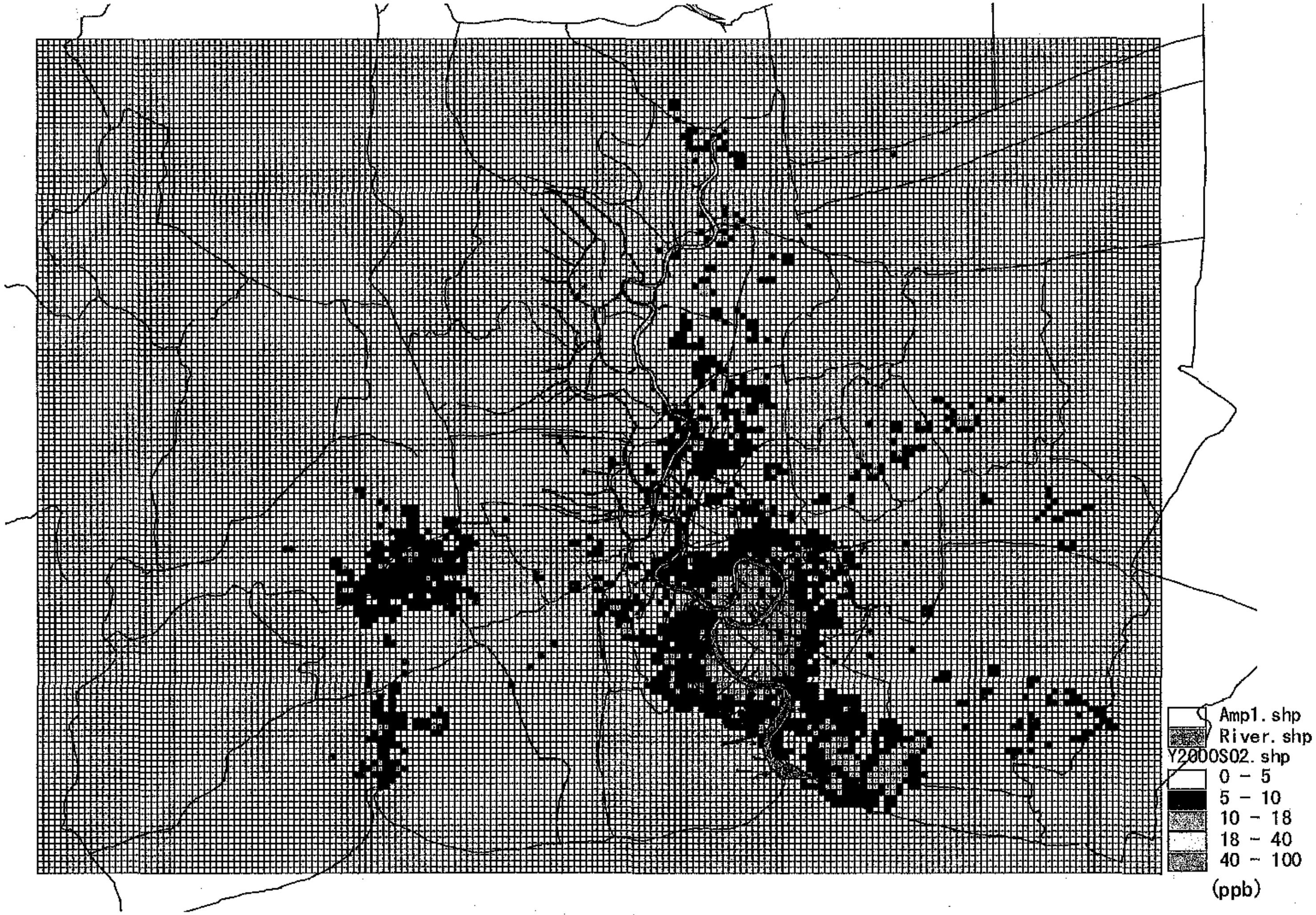


Figure 6.2.4.2 SO2 Concentration Map for the Year 2000 in the BMR

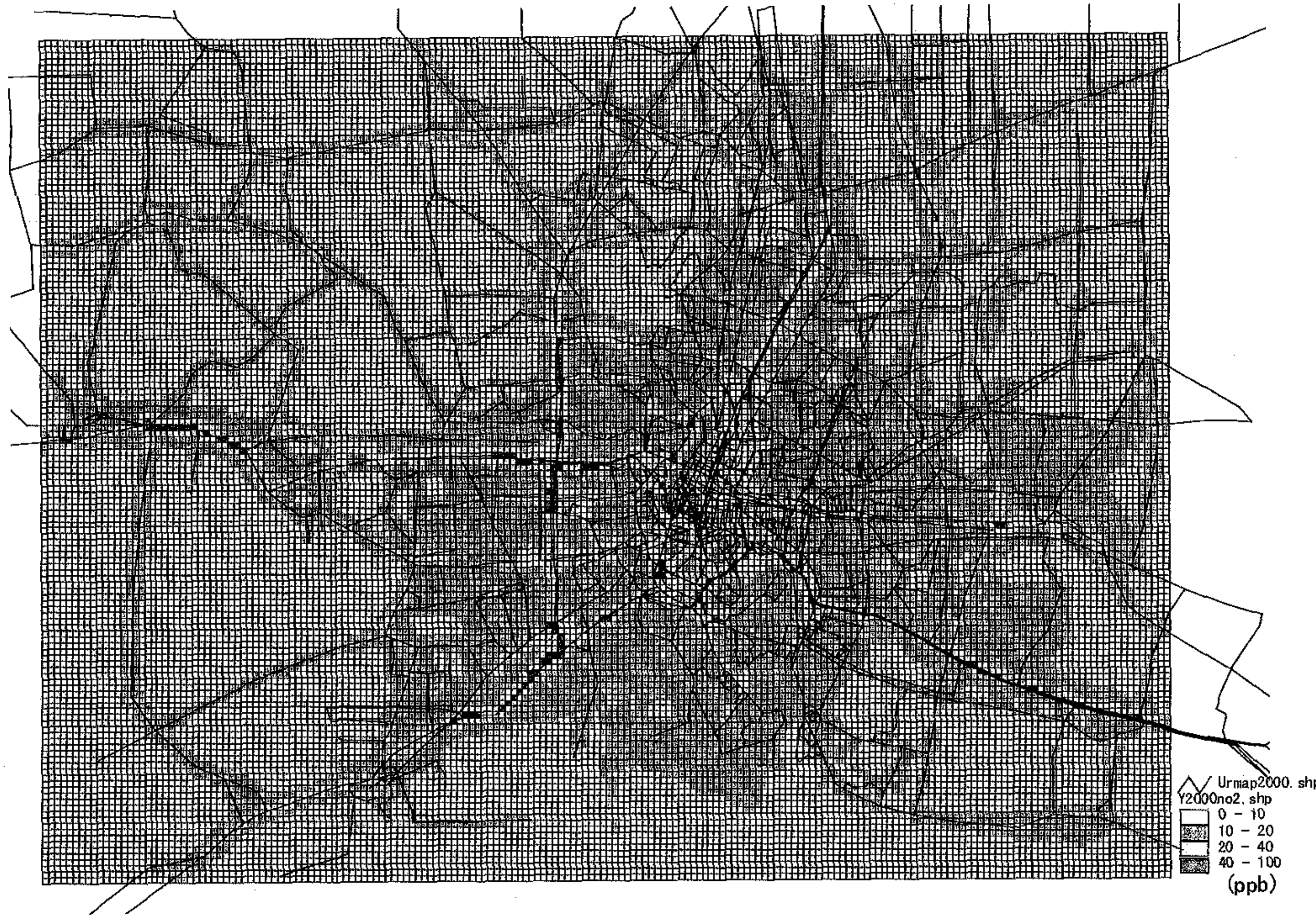


Figure 6.2.4.3 NO2 Concentration Map for the Year 2000 in the BMR

6.2.4.3 Simulation Result of the Year 2011 in the BMR

The SO2 and NO2 concentration maps for the year 2011 are shown in Figure 6.2.4.4 and Figure 6.2.4.5. Compared with the year 2000 simulation, the 18ppb exceed calculation grids of SO2 concentration in the year 2011 are increased. The NO2 high concentration areas appeared around the new ring roads in the year 2011. However, on the whole the 20ppb exceed grids of NO2 concentration decreased.

Comparisons of the year 2011 simulation results with the ambient annual standard of Thailand and the WHO for each grid is shown in Table 6.2.4.1. 3 grids of SO2 and 60 grids of NO2 exceeded the Thailand standard. 230 grids (0.8%) of SO2 and 2127 grids (8.1%) of the NO2 exceeded WHO standard. The maximum of SO2 and NO2 is 72.5ppb and 54.3ppb. The number of NO2 exceed calculation grids is more than SO2, but the NO2 maximum is lower than SO2.

Table 6.2.4.1 Comparison of Simulation Results with the Ambient Annual Standard

Item	Number of Exceed Grids / Total Number of Grids	
	Thailand Standard (SO2,NO2: 40ppb)	WHO (SO2: 18ppb, NO2:20ppb)
SO2	3/26320	230/26320
NO2	60/26320	2127/26320

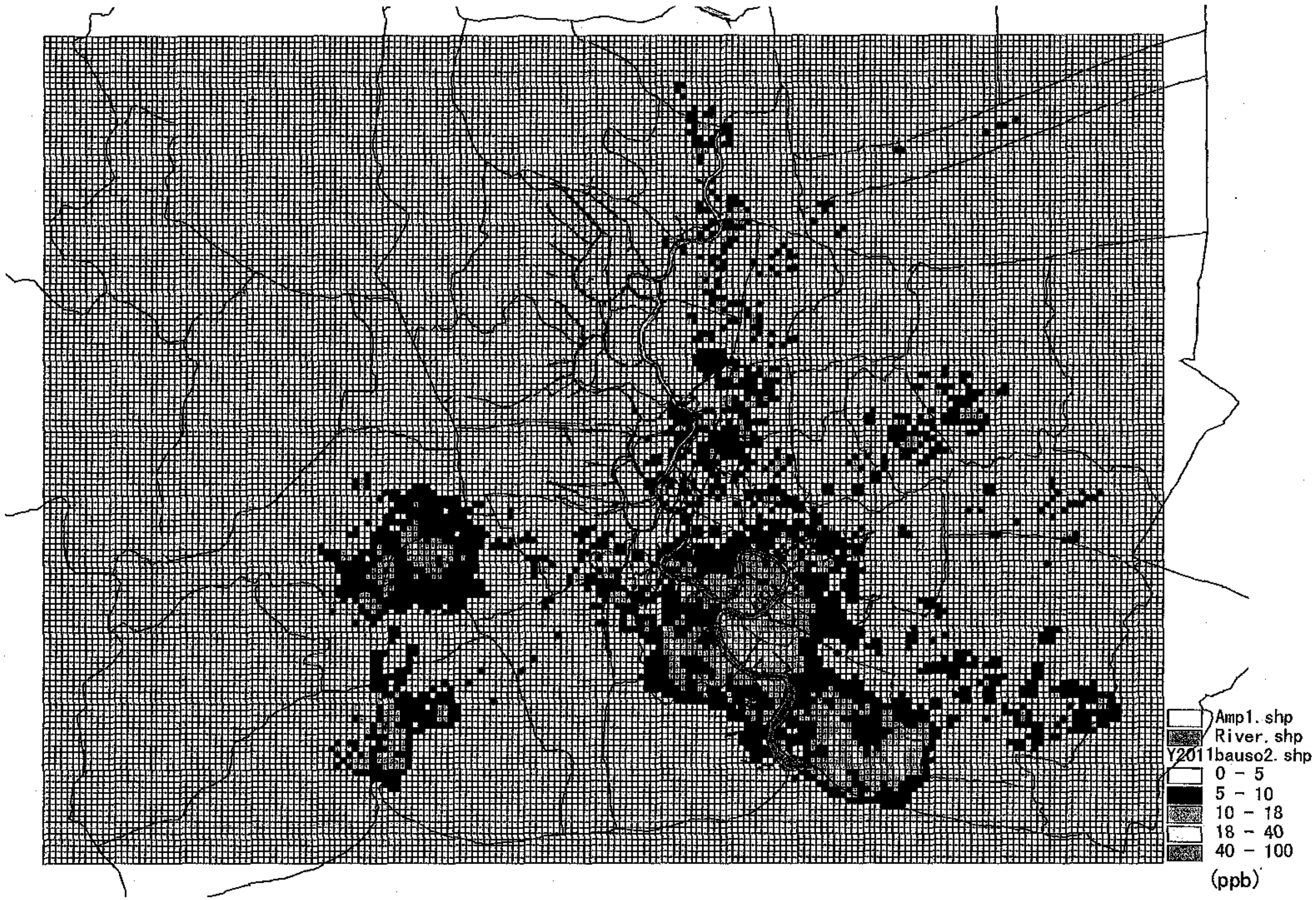


Figure 6.2.4.4 SO2 Concentration Map for the Year 2011 in the BMR

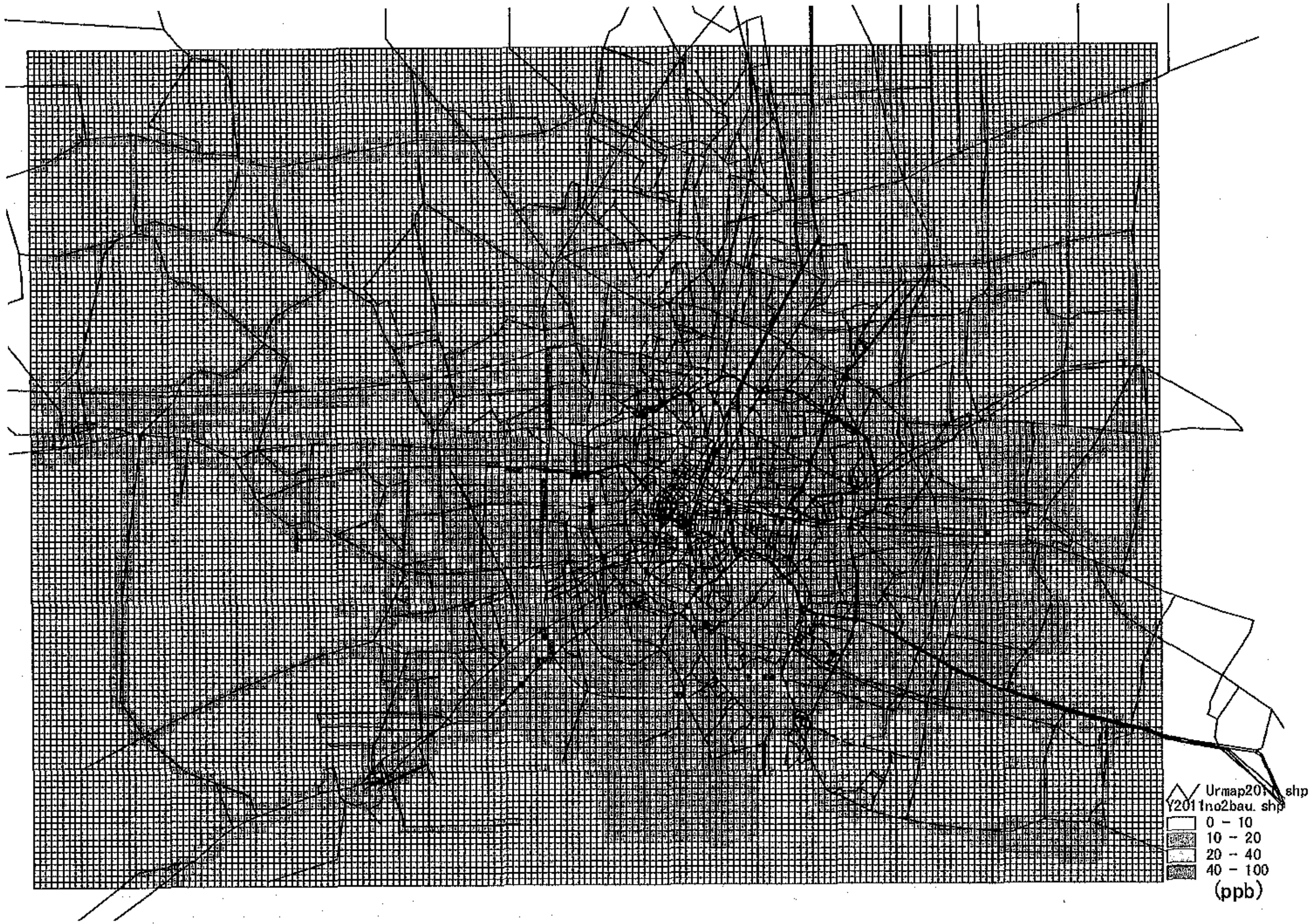


Figure 6.2.4.5 NO2 Concentration Map for the Year 2011Bau in the BMR

7. Evaluation of Acid Deposition and Air Quality

Acid deposition and ambient air pollution data are collected and analyzed. After the validation of the model by actual monitoring results, the current and future conditions are simulated by ATMOS2 model for the country, and Airviro model for the BMR. Based on these outputs, the evaluation of acid deposition and ambient air pollution of the country and the prioritization of issues are next steps for preparing countermeasures.

7.1 Acid Deposition

In the year 2000, 4 monitoring sites data were available for the evaluation of acid deposition. The situation of acid deposition is summarized as follows.

- SO_4 and NH_4 ion concentrations of the urban site were higher than the rural and remote sites;
- On the other hand, concentrations of Cl and Na ion in the remote site were not as high;
- It may be regarded that the main source of SO_4 and NH_4 ions in and around urban area is human activity. And also it causes increased sulfur and nitrogen deposition;
- Concentrations of Cl ion and cation were almost the same value in 4 monitoring site. Generally speaking these ions are not influenced by human activity so much;
- pH in the urban site was lower than in the rural and remote sites, and
- The decrease of pH may be caused by human activities.

According to monitoring results, it can be regarded that human activities caused additional sulfur and nitrogen deposition, and decrease of pH in rain water. However, because of the current diversity of understanding for the effect of acid deposition on the environment by human activity, it is necessary to study what type of mitigation should be introduced.

7.2 Ambient Air Pollution

7.2.1 Evaluation Method

For evaluation, in the first place, Thailand ambient air quality standard for SO_2 and NO_2 was adopted as the criterion. Moreover, on consideration that the ambient air quality standard shall be modified and improved in the light of scientific and technological progresses and changes in economic and social conditions of the country (NEQA, B.E. 2535), the WHO guidelines for SO_2 and NO_2 were taken into consideration.

Pollution Control Department, Ministry of Natural Resources and Environment has been conducting ambient air quality monitoring in the country. The validated SO_2 and NO_2 data for the year 2000 by PCD monitoring network were objects for evaluation. Chapter 1 describes the results of the evaluation.

After validation of the model, the simulation results of the 2011 BAU Case were utilized for evaluation. For the country, the concentrations of SO2 of respective grids were simulated by ATMOS2 model. For the BMR, the concentrations of SO_2 and NO_2 of respective grids were simulated by Airviro Model. The grid size of the country was 0.1 degree by 0.1 degree (10km x 10km) for urban area and 1.0 degree by 1.0 degree (100km x 100km) for other area. That of the BMR was 500m by 500m. The simulation results of the 2011 BAU cases were utilized for the evaluation.

7.2.2 Evaluation of SO_2 Concentration

Based on the monitoring results (Chapter 1) and the simulation analysis (Chapter 6), the atmospheric SO2 concentration was evaluated.

7.2.2.1 Other than the BMR

Evaluation results were summarized in Table. 7.2.2.1. According to monitoring data, all stations satisfied Thailand ambient air quality standard and the WHO guideline. In 2011 BAU case, SO_2 was lower in other than BMR area than the BMR area. Therefore, the area other than BMR was not current target for preparing countermeasures.

Table 7.2.2.1 Evaluation of SO_2 Concentration, Other than BMR

	Thailand Ambient Air Quality Standard			WHO Guideline	
	1 Hour Value	24 Hour Ave.	Yearly Ave.	24 Hour Ave.	Yearly Ave.
Value : ppb	300	120	40	44	18
Evaluation at Monitoring Stations, 2000	Satisfied	Satisfied	Satisfied	Satisfied	Satisfied
Evaluation of All Grids by ATMOS2, 2011 BAU	ATMOS2 is not adequate for evaluation of attainment of the air quality standard. (However, the simulation results imply that the yearly average of SO_2 is high in the BMR.)				
Evaluation by Airviro	Airviro is not a simulation model for the whole country.				

7.2.2.2 The BMR

Concerning the BMR, the evaluation results are listed in Table 7.2.2.2. Although Thai standard was satisfied by the monitoring and simulation results for the year 2000, it was not satisfied by the 2011 BAU simulation case. The WHO guideline was not satisfied in the year 2000 by the monitoring and simulation results, and was not satisfied in the year 2011 by BAU simulation case. It is necessary to prepare countermeasures for SO_2.

Table 7.2.2.2 Evaluation of SO_2 Concentration, the BMR

	Thailand Ambient Air Quality Standard			WHO Guideline	
	1 Hour Value	24 Hour Ave.	Yearly Ave.	24 Hour Ave.	Yearly Ave.
Value : ppb	300	120	40	44	18
Evaluation at Monitoring Stations, 2000	Satisfied	Satisfied	Satisfied	6 out of 24 Stations did not Satisfy.	Satisfied
Evaluation by ATMOS2, 2011 BAU	ATMOS2 is not adequate for evaluation of the attainment of air quality standard. However, the simulation results imply the yearly average of SO_2 is high in the BMR.				
Evaluation by Airviro, 2000 Base Case	All grids satisfy the yearly average standard.			107 grids (0.4%) do not satisfy the yearly average guideline.	
Evaluation by Airviro, 2011 BAU case	3 grids do not satisfy the yearly average standard.			230 grids (0.9%) do not satisfy the yearly average guideline.	

Total grid: 26,320

7.2.3 Evaluation of NO_2 in the BMR

According to the monitoring result, Thailand ambient air quality standard was satisfied, and respective WHO guideline was not satisfied in the year 2000.

The simulation analysis showed that both Thailand standard and the WHO guideline were not satisfied in the year 2000 and 2011 by BAU Case. The results are summarized in Table 7.2.3.1. It is necessary to prepare mitigation measures.

Table 7.2.3.1 Evaluation of NO_2 Concentration, the BMR

	Thailand Ambient Air Quality Standard	WHO Guideline	
	1 Hour Value	1 Hour Ave.	Yearly Ave.
Value : ppb	170	98	20
Evaluation at Monitoring Stations, 2000	Satisfied	Not Satisfied	Not Satisfied
Evaluation of All Grids by ATMOS2, 2011 BAU	ATMOS2 is not a model for simulation of NO_2.		
Evaluation by Airviro, 2000 Base Case	91 grids (0.3%) show higher simulation value than 40 ppb*.	2,452 grids (9.3%) do not satisfy the yearly average guideline.	
Evaluation by Airviro, 2011 BAU	60 grids (0.2%) show higher simulation value than 40 ppb*.	2,127 grids (8.1%) do not satisfy the yearly average guideline.	

Total grid: 26,320

* For NO2, Thailand ambient air quality standard is 170 ppb, this value corresponds to yearly average of 40ppb by correlation analysis of actual monitoring data.

7.3 Prioritization

The evaluation of acid deposition and ambient air pollution showed that the target area for mitigation in the whole Thailand was the BMR. It is necessary to introduce SO_2 and NO_2 mitigation measures for the BMR.

In order to prepare countermeasures for acid deposition and ambient air pollution, points of issue are improvement of SO_2 concentration and NO_2 concentration in the BMR. Both are issues for Bangkok and its vicinities. The concentration of human activities is accompanied with a considerable amount of pollutant discharge, sulfur oxides and nitrogen oxides. Thus air pollution is taking place. In the following chapter, reducing measures for sulfur oxides and nitrogen oxides are discussed.

Currently, it is under discussion what is valid criterion for recognizing the effect of acid deposition in East Asia. For reference, if the idea of critical load (Supporting Report, Chapter 9) and 25% risk ratio value of critical load by BC/AL approach(RAINS-Asia Project) are adopted, the simulation by ATMOS2 shows following result (Supporting Report Chapter 6). In the year 2011 BAU case, the deposition values of almost all grids in the BMR exceed a critical load. It means deposition exceeds natural vulnerability. This is the case for Eastern and Central region also. The ratios of simulation value by critical load are approximately 5 in the BMR and 3 in the Eastern and Central regions. In order to mitigate deposition, if the idea of critical load is applied, the possible scale of countermeasure will surpass the scale of SO2 and NO2 mitigation in the BMR. It is necessary to follow critical load approach in future.

8. Countermeasures for SO_2 in the BMR

8.1 Methodology

In the year 2000, all monitoring stations in the BMR satisfied Thai ambient air quality standard for SO_2 in the BMR. Concerning WHO guideline, 6 out of 24 stations in the BMR did not satisfy the daily average and all stations satisfied the yearly average guideline. Airviro simulation shows that 107 grids did not satisfy WHO guideline in 2000. In the 2011 BAU case, 3 grids did not satisfy Thai standard, and 230 grids did not satisfy WHO guideline. It is necessary to study countermeasure. In this Chapter, the countermeasures for SO_2 is investigated as shown in Fig. 8.1.1.1.

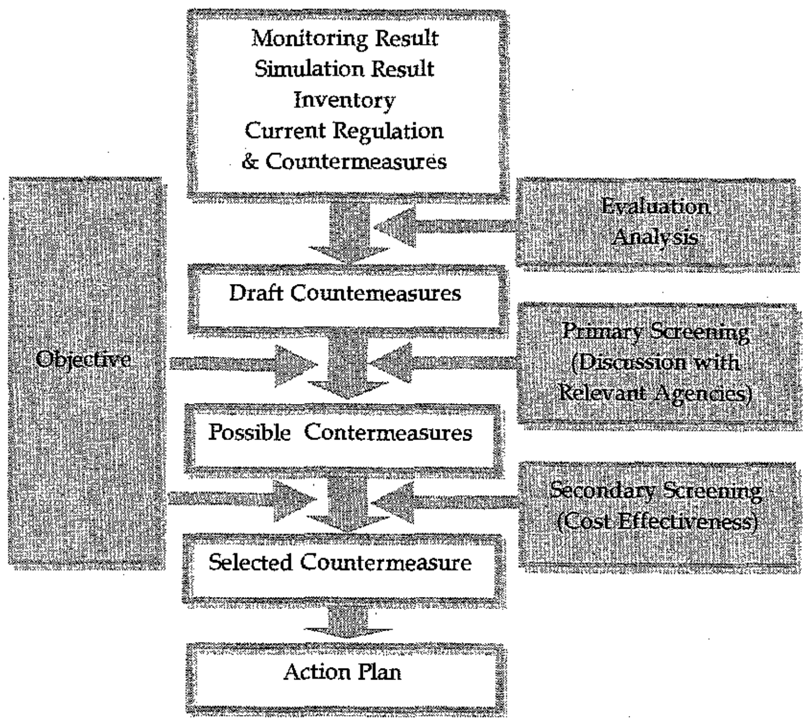


Figure 8.1.1.1 Methodology for Studying Countermeasures

8.2 Summary of SOx Emission in the BMR

The SOx emission share of the manufacturing sector is 67% in the year 2000 and 92% in the year 2011 BAU Case. In the year 2011 BAU Case, fuel for the power stations in Bangkok will be all converted to natural gas. So, the share of the manufacturing sector will increase significantly. The share of fuel oil is 90% in the year 2000 and 88% in the year 2011 BAU Case.

In order to mitigate SO_2 in the BMR, the target of emission source is SOx of manufacturing sector and from fuel oil.

It is important to regard the differences of emission characteristics between the whole Thailand and the BMR. Concerning the whole Thailand, the SOx emission from coal and lignite is considerable. In the year 2000, the share of coal and lignite are 6.7% and 18.7%. And in the year 2011 BAU case, the shares are 26.6% and 17.8 % respectively. The increase of coal in the year 2011 is significant. However in the BMR, the share of coal and lignite is not considerable and that of fuel oil is dominant.

8.3 Current Mitigation Measures

The current SO_2 emission standard is depicted in Table 8.3.1.1. The specification of sulfur content in petroleum products is another regulation standard. The condition of approval of the EIA report is important for mitigation. Following these regulations, various measures are introduced, i.e. FGD, the low SOx emission production plant, and the introduction of low sulfur lignite.

Table 8.3.1.1 SO_2 Emission Standard

Sources			Standard Value		Remark
H_2SO_4 production*			1,300mg/Nm3 or 500ppm	O_2: 3.5%	
Heavy Oil as Fuel*			1,250ppm	O_2: 3.5%	For Bangkok, Samutprakan, Nonthaburi, Pathumthani, Nakhonpathom, Samutsakhon, Chonburi, Rayong, Pechaburi, Songkhla, Prachuap Khiri Khun, Krabi, Phuket
New Power Plant*, **	>500MW	Coal	320ppm		Existing units of Bang Pakong, South Bangkok, North Bangkok, Surat Thani, Lan krabu, Nong Chok, Sai Noi, Wang Noi, Num Phong and Mae Moh power stations are enforced respective emission standard**.
		Oil	320ppm		
		Gas	20ppm		
	300 - 500MW	Coal	450ppm		
		Oil	450ppm		
		Gas	20ppm		
	<300MW	Coal	640ppm		
		Oil	640ppm		
		Gas	20ppm	O_2: 7%	
Steel Industry**	New & Existing		800ppm	O_2: 7%	
Municipal Waste Incinerator**	1-50 ton/day		30ppm		
	>50 ton/day		30ppm	O_2: 7%	

* Ministry of Industry
**Ministry of Science, Technology and Environment

8.4 Countermeasures

In order to satisfy the SO_2 air quality standard and guideline, the reduction of SOx emission amount from stationary sources is the first priority. For the reduction of SOx emission, draft countermeasures are the reduction of sulfur content in fuel oil, the installation of flue gas desulfurization plant, the fuel shift from high sulfur fuel (fuel oil, coal and lignite) to natural gas, and the utilization of lower sulfur coal and lignite.

8.4.1 Reduction of Sulfur Content in Fuel Oil

Fuel oil is a major energy source in the BMR. And fuel oil is a major source of SOx in the BMR. Reduction of the sulfur content in fuel oil is one of the draft countermeasures.

In order to reduce the sulfur content in fuel oil, based on Enhancement and Conservation of National Environmental Quality Act (NEQA), B.E. 2535, it is necessary to introduce more stringent SO_2 emission regulations and corresponding sulfur concentration specifications of fuel oil for the BMR. In order to satisfy more stringent specification, refineries will modify their production configuration if necessary. And refineries will supply low sulfur fuel oil to consumers in the BMR.

8.4.2 Flue Gas Desulfurization

Flue gas desulfurization is a direct SOx emission reduction method. SOx in flue gas is removed by the abatement plant and the removed sulfur is treated as a by-product or waste. In Thailand, power stations and some industry installed FGD.

In order to enhance FGD, based on Enhancement and Conservation of National Environmental Quality Act (NEQA), B.E. 2535, it is necessary to introduce more stringent SO_2 emission regulations for the BMR. Currently, the emission standard for heavy oil as fuel is 1,250ppm (O2=3.5%) for the BMR. On the contrary, the actual sulfur content in fuel oil in the year 2000 is 1.7%. Then the SOx concentration in flue gas is approximately 1,000ppm (O_2=3.5%). Consequently almost all factories need not introduce abatement measures for fuel oil consumption now.

After the introduction of a more stringent SO_2 emission regulation, there will be some factories that will regard it to be better to shift to lower sulfur fuel than installation of FGD. Moreover, in some cases, factories will move to other provinces or stop operation after consideration of the installation and operating cost of FGD.

8.4.3 Fuel Shift to Natural Gas

Natural gas is an important energy source for Thailand, and domestic gas fields supply the majority of it.

The fuel shift, from high sulfur content fuel such as fuel oil, coal and lignite to natural gas is a direct SOx emission reduction method. Although the sulfur content in natural gas is 9.5 ppm as H_2S, this amount is almost negligible compared to the sulfur content in other fuels. The current sulfur content of fuel oil, coal, and lignite are 1.7%, 0.5%, and 2.0% respectively. Thai Government encourages fuel shift to natural gas in industrial sector.

Natural gas is a competitive fuel in Thailand. However the supplying area for natural gas is limited. The supply of natural gas is possible in the area around the natural gas pipeline. Accordingly the ubiquitous regulation for introduction of natural gas in the BMR is not adequate for policy. The introduction of natural gas should be left to economic mechanism. Currently there is some scope for supplying capacity in the BMR. Moreover there is a future pipeline plan for the BMR.

8.4.4 Utilization of Lower Sulfur Coal and Lignite

The sulfur content of coal and lignite are regarded as 0.5% and 2.0% for industry. SOx emissions from coal and lignite are generally large. Concerning power stations, there is an emission regulation for coal and lignite firing. Currently, other than power station, coal and lignite firing plants are not regulated.

In order to have lower sulfur coal and lignite, based on Enhancement and Conservation of National Environmental Quality Act (NEQA), B.E. 2535, it is necessary to introduce more stringent SO2 emission regulation for the BMR.

8.4.5 Cleaner Production and Energy Saving

Cleaner Production (CP) and energy saving are win-win measures. It is not only ecological but also profitable. Concerning the quantitative effect of CP, it cannot be estimated at present. Energy saving, which is sometimes one of the major components of CP, is effective. With all efforts and entire implementation of policy, the estimation of the maximum effect of energy saving is regarded as approximately 1% per annum (NEPO, 2002).

Therefore, in this study, CP and energy saving are not regarded as specific countermeasure but as general supposition for estimation of energy consumption in the year 2011. The energy saving effect from 2000 to 2011 is regarded as 2%, considering the energy elasticity described in Chapter 2.

8.5 Selection of Countermeasures

According to the evaluation of current and 2011 BAU conditions, the objectives of countermeasures are summarized as follows.

- Based on Airviro simulation, Thai ambient air quality standard of SO_2 (yearly average) will be kept in the year 2011.

- Based on Airviro simulation, the grids exceeding WHO guideline of SO_2 (yearly average) will be reduced in the year 2011 compared to the year 2000.

8.5.1 Primary Screening of Countermeasures

3 aspects are reviewed and shown in Table 8.5.1.1.

Table 8.5.1.1 Primary Screening

	Reduction of Sulfur Content in Fuel Oil	**Flue Gas Desulfurization**
Policy & Administrative Aspect	- Necessity of new or stringent regulations - Introduction of a supporting mechanism for refineries - Necessity of consistency with other regulations - Increase factor of administration costs	- Necessity of new or stringent regulations - Introduction of supporting mechanisms for FGD installation - Necessity of consistency with other regulations - Increase factor of administration costs
Social Aspect	- Pressure for financial status of refineries - Factor for fuel oil price increase - Logistics for supplying different quality fuel oil for the BMR and other areas	- Cost increase factor for factories - Some factories without installation space will stop production or move to outside of the BMR
Technological Feasibility	- Feasible - Considerable Reduction of SOx	- Feasible - Introduction of fuel shift by some factories - Considerable Reduction of SOx

	Fuel Shift to Natural Gas	**Utilization of Lower Sulfur Coal & Lignite**
Policy & Administrative Aspect	- Introduction of more beneficial incentives - Unnecessary of regulation - Accordance with current government policy to enhance introduction	- Necessity of new or stringent regulations - Necessity of consistency with other regulations - Increase factor of administration costs
Social Aspect	- Risk of gas leak from pipeline	- Difficulty of steady supply - Short life of many domestic coal mines - Difficulty of development of new coal mine, due to matter of social acceptance - Tendency of price increase
Technological Feasibility	- Feasible - Considerable reduction of SOx	- Feasible - Small reduction of SOx

According to the table, because of small reduction effect of SOx, utilization of lower sulfur coal and lignite cannot be regarded as adequate countermeasure for the whole BMR. Coal is abundant energy source in the world and has potential for wider utilization. And environmental problem of coal consumption can be mitigated by appropriate countermeasure. However, currently there is the difficulty for developing new coal mine in Thailand due to public acceptance. It is not regarded as easy to supply lower sulfur coal and lignite steadily.

8.5.2 Cost Estimation

The investment amounts and yearly costs for 3 countermeasures are summarized in Table 8.5.2.1. The method of estimation is summarized in Supporting Report (Chapter 6). SOx reduction amount of countermeasures is supposed to be 10,000ton per annum in this estimation.

Table 8.5.2.1 Cost Estimation

	Approx. Investment Amount (MBht)	Approx. Annual Cost (MBht/y)	Approx. Annual Cost (Bht/y/SO2 Reduction ton/y)
Reduction of S in Fuel Oil	600 to 2,500	200 to 1,000	20,000 to 100,000
Flue Gas Desulfurization	1,100 to 4,400	300 to 1,200	30,000 to 120,000
Fuel Shift to Natural Gas	900 to 3,500	90 to 400	9,000 to 40,000

The yearly cost includes repayment, depreciation, maintenance and the energy saving merit. According to the cost estimation, the fuel shift to natural gas is the most effective measure of the three. Moreover, it has possibility to be applied for CDM project.

8.5.3 Secondary Screening of Countermeasure

Concerning three measures, environmental impact, financial issue and cost effectiveness are summarized as Table 8.5.3.1.

Table 8.5.3.1 Secondary Screening

	Reduction of S in Fuel Oil	Flue Gas Desulfurization	Fuel Shift to Natural Gas
Environmental Impact	- Reduction of SOx - Improvement of air quality - Necessity of adequate treatment of by-product or waste(removed sulfur)	- Reduction of SOx - Improvement of air quality - Necessity of adequate reatment of by-product or waste (removed SOx)	- Reduction of SOx - Reduction of smoke - Improvement of air quality - Land alteration by laying pipeline
Financial Issue	- Large investment amount - Large yearly cost - Necessity of Government support to refineries	- Large investment amount - Large yearly cost - Necessity of Government support to introduction	- Less investment amount comparing to other measures - Less yearly cost comparing to other measures - Necessity of incentive for introduction
Cost Effectiveness	- Less effective, comparing to shift to natural gas - Factor for cost increasing	- Less effective, comparing to shift to natural gas - Factor for cost increasing	- Most effective of three countermeasures - With energy saving merit

According to the investigation for environmental impact, financial issue, and cost effectiveness, the fuel shift to natural gas is selected as countermeasure for SO_2 in the BMR

8.5.4 Effect of Countermeasure

The effect of the most effective method, i.e. the shift to natural gas is estimated by Airviro simulation with a SOx reduction of 30% of the industrial SOx emission. The simulation results for the 2000 Base Case and the 2011 BAU Case for SO2 are described in Chapter 6. Concerning the shift to natural gas case (Control Case), the result of simulation is depicted in Fig. 8.5.4.1.

The number of grids exceeding the standard and guideline is summarized in Table 8.5.4.1.

Table 8.5.4.1 Exceeding Grid Number

	Exceeding Thai Ambient Air Quality Standard	Exceeding WHO Guideline
	Yearly Average : 40ppb	Yearly Average : 18ppb
2000 Base Case	0	107
2011 BAU Case	3	230
2011 Control Case	1	35

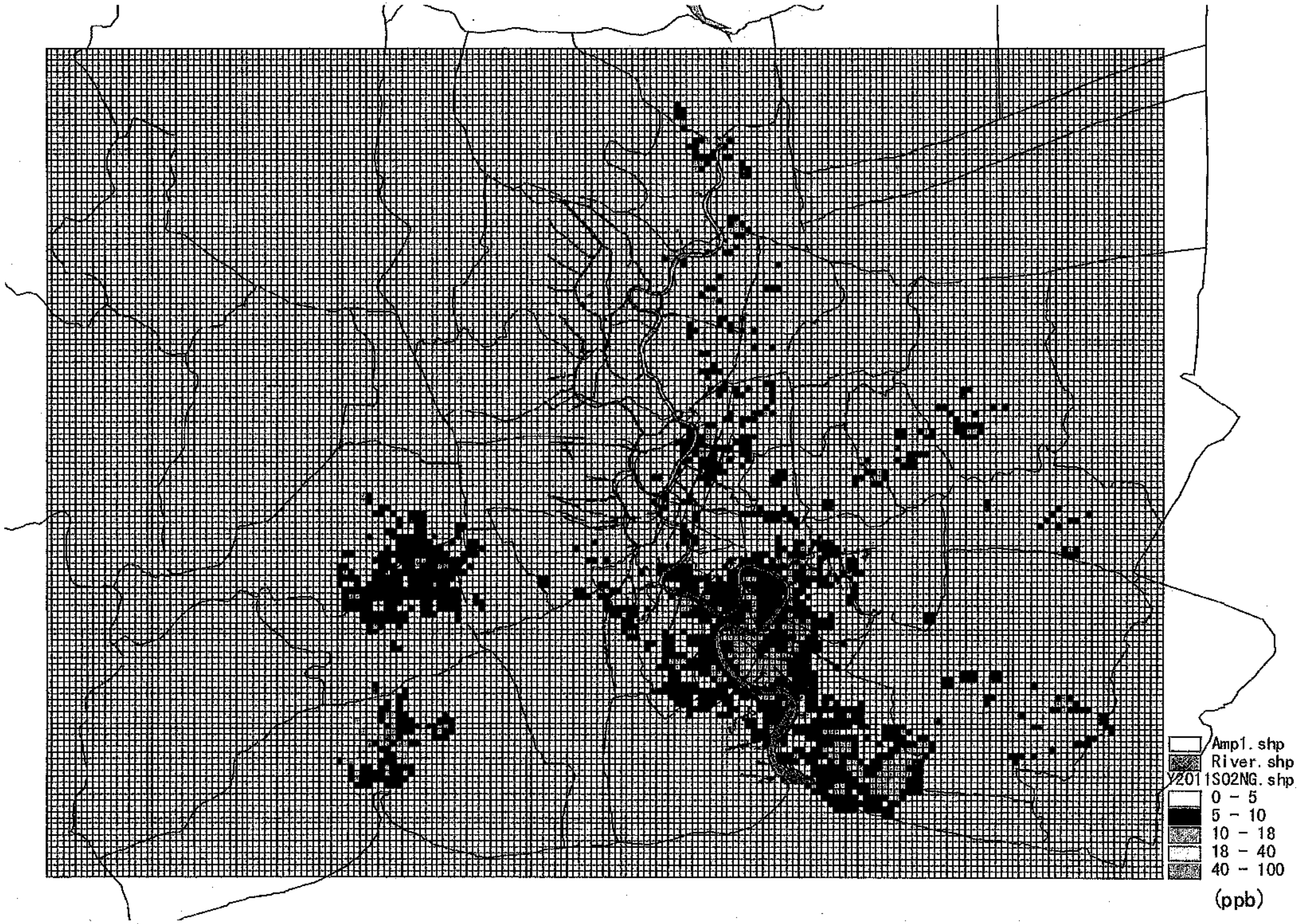


Figure 8.5.4.1 2011 Control Case : Shift to Natural Gas