TECHNICAL ANNEX 7

Air Quality Modelling for the Pearl River Delta Region

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1 REGIONAL AIR QUALITY MODELLING SYSTEM

1.1 The Path Model

1.1.1 The PATH modelling system under the EACSB Consultancy Agreement No CE46/5 together with the meteorological and emission inventory collected in the Study will be used for all air quality predictions. The name PATH is an acronym for "Pollutants in the Atmosphere and their Transport over Hong Kong". PATH is a regional photochemical modelling system based on models previously developed in the United States. Its main components are a regional scale meteorological model (MM5), an emission processing module (EMS-95), and a multi-species photochemical air quality model (SAQM). A Visual Basic graphical user interface has been developed to facilitate the operation of the system In addition, a post-processor has been developed to assist in displaying model outputs, and a pre-processor has been developed for creating data bases and managing data used in the modelling. PATH is currently configured to run on a UNIX workstation, with the exception of the graphical user interface, which is PC-based.

2 METEOROLOGICAL MODELLING OF THE STUDY

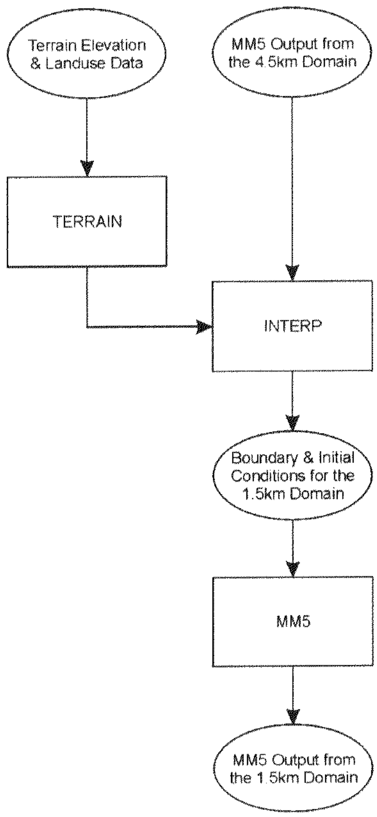
2.1 Introduction

2.1.1 The meteorological modelling had been conducted using the Mesoscale Model 5 (MM5) which is a three dimensional regional scale meteorological model developed by Penn State University and the National Center for Atmospheric Research (NCAR). The modified version of MM5, Version 2 that has been incorporated into the PATH modelling system had been used.

2.1.2 The purpose of the meteorology modelling is to provide higher resolution coverage in the PRDEZ than is currently available from previous modelling within PATH. To this end, the current PATH modelling domain with a 1.5 km grid spacing will be extended to cover major urban areas of the PRDEZ, including Guangzhou, Shenzhen, Zhuhai, Dongguan, Huizhou, Foshan, Jiangmen, Zhongshan and Zhanqing. Previously, only the HKSAR was modelled at this resolution.

2.1.3 Figure 2-1 is a flow chart showing the steps involved in MM5 modelling. These steps had been repeated for each meteorological episode, for the expanded 1.5 km resolution domain to be modelled. These steps and the model options to be used in the present study are described in the following subsections.

Figure 2-1 MM5 Modelling Methodology Steps



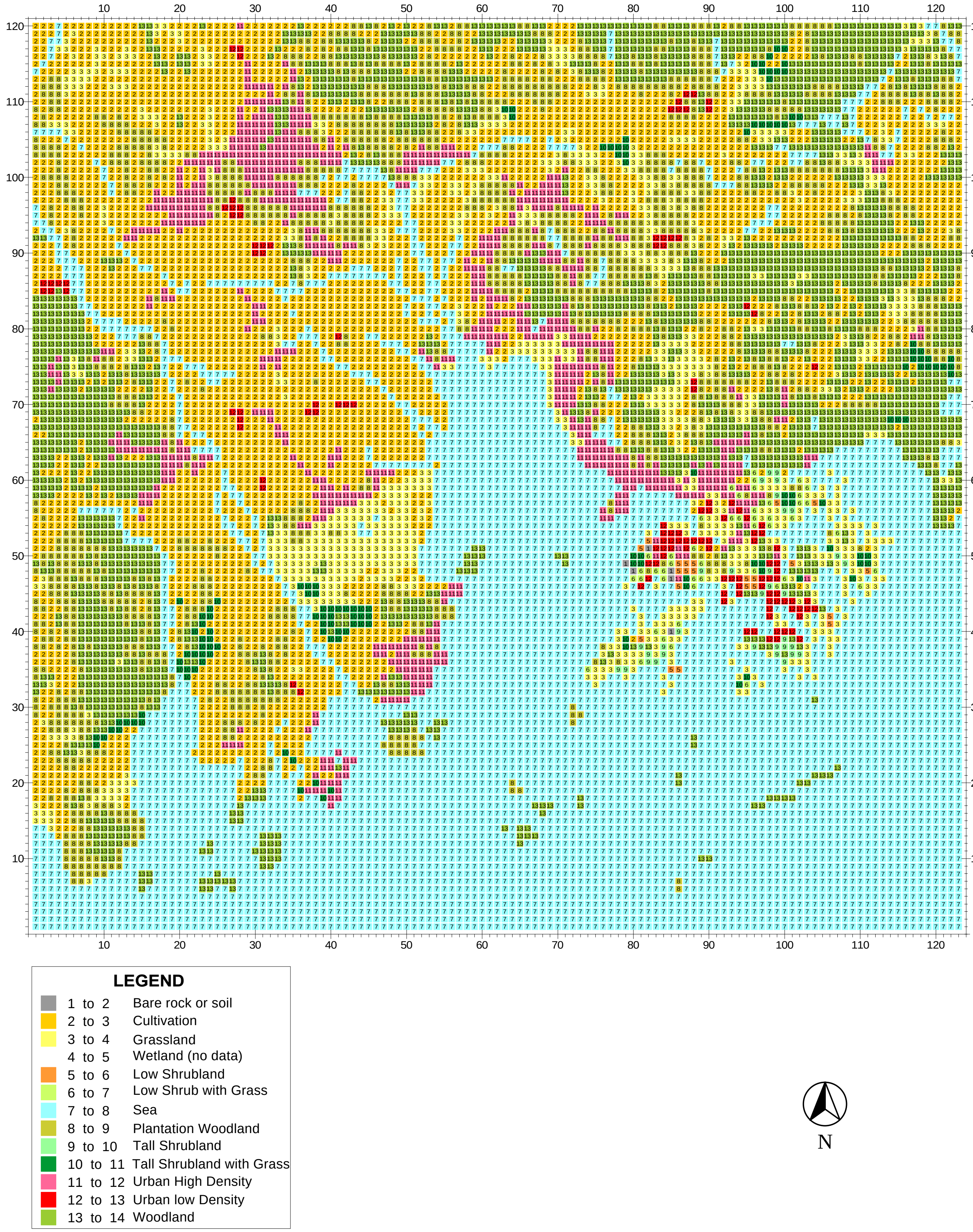
2.2 Model Domains

2.2.1 MM5 has been configured within PATH to permit modelling over a series of nested grids with the following horizontal resolutions: 40.5, 13.5, 4.5, 1.5 and 0.5 km (Physick and Noonan, 2000). The domain with the grid spacing of 40.5 km covers Southern China, extending as far as Calcutta to the west, the Philippines to the east, Shanghai to the north, and beyond Vietnam to the south. The domains with 13.5 km and 4.5 km spacing cover portions of Southern China that include the Region. The domain with the 1.5 km grid spacing covers the HKSAR and the domain with the 0.5 km spacing covers Hong Kong Island, Kowloon and part of the New Territories.

2.2.2 In the present study, the previous modelling on the domain with the 1.5 km grid spacing will be replaced with new model runs on an expanded version of that domain. Modelling on all other domains will be left unchanged. The new domain extends further westward and northward than the existing 1.5 km domain, and covers the urban areas of Guangzhou, Zhuhai and Shenzhen in the PRDEZ, as shown in Figure 2-2. It is only slightly smaller than the current 4.5 km domain. The size of the new domain is 124 grid points (184.5 km) in the east-west direction, and 121 grid points (180 km) in the north south.

2.2.3 The vertical resolution of the new runs had been the same as that used in the previous modelling. Twenty-five vertical levels ranging from 10m to 21,000m AGL had been used (Physick and Noonan, 2000). This vertical resolution was consistent with general practice in mesoscale meteorological modelling. For example, 32 vertical levels between the surface and 15,000 m were used in MM5 modelling for the SARMAP project (Tesche and McNally, 1996), Cai and Steyn (1996) used 26 vertical levels between the surface and 19,000m in their meteorological modelling for Vancouver, British Columbia, and Hedley et al. (1996) used 31 vertical levels between the surface and 25,000m.

2.2.4 The new domain had been run in a one-way nested mode. This meant that results from the simulation of the 4.5 km domain will be used to establish boundary conditions for the new 1.5 km domain, but results from the 1.5 km domain will not be fed back to the 4.5 km domain. In the previous modelling for PATH, the 4.5 km and 1.5 km domains were run in a two-way nested mode. This approach resulted in problems with conservation of mass around the outside of the inner domain and the previous consultants had to modify the meteorological preprocessor for SAQM to correct these problems before the data were put into the air quality simulation (Cope et al., 2000). In the present Study, the use of a one-way nested approach allowed to run the new 1.5 km domain without rerunning any of the larger model domains. This approach has been used with MM5 for other air quality studies. For example, one-way nests were used in the MM5 modelling of the San Joaquin Valley in California during the SARMAP study (Seaman et al., 1995).



CH2M HILL (China) Limited	**Project:** Agreement No CE106/98 Study of Air Quality in the Pearl River Delta Region		Environmental Protection Department
	Title: MM5 Model Domain for the Air Quality Study		
	Figure: 2-2	**Scale:** NTS	

2.3 Terrain and Land Use Data

2.3.1 Terrain elevation data had been the same as previously used in PATH, which are based on USGS data at a resolution of 30 seconds of arc (i.e. about 0.9km). These data had been compared with maps to ensure a proper representation of the terrain and coastline. These data had then been interpolated to the new model grid using the MM5 pre-processing program Terrain.

2.3.2 Land use data currently used in the PATH version of MM5 had been updated using GIS data for HKSAR and the PRDEZ provided by the Chinese University of Hong Kong (CUHK). These data indicated that urban land uses are much more extensive in the PRDEZ than indicated in the current land use data in PATH. The data, which were classified into 22 land use categories, had been reclassified into the 8 categories used in MM5. Table 2-1 showed the reclassification scheme to be used to arrive at the 8 categories required for MM5. The data had then been gridded using the same domain and grid spacing (1.5 km) used in MM5. The land use category assigned to each grid cell had been corresponding to the dominant land use that occurs within that grid cell.

Table 2-1 Land Use Reclassification Scheme for the MM5 Model Domain

Raw Land Use Categories		Land Use Categories for MM5 in PATH	
Code	**Description**	**Code**	**Description**
11	Paddy	2	Cultivation
12	Dry Farm Land	3	Grassland
21	Forest	13	Woodland
22	Bush	10	Tall shrubland with grass
23	Sparse Wood	8	Plantation woodland
31	High Grass-mantled Land	3	Grassland
32	Moderately Grass-mantled Land	3	Grassland
33	Low Grass-mantled Land	3	Grassland
41-43	Water	7	Sea
44	Glacier	n/a	n/a
45	Sea Shore	3	Grassland
46	Bottomland	n/a	n/a
51	City and Town	11	Urban high density
52	Other Construction Land	3	Grassland
53	Village	12	Urban low density
61	Sand	n/a	n/a
62	Gobi	n/a	n/a
63	li-alkline	n/a	n/a
64	Swamp	n/a	n/a
65	Bare Land	n/a	n/a
66	Bare-rock and Shingle	n/a	n/a
67	Other Waste Land	n/a	n/a

Note: n/a implies no land use of this type within the study domain.

2.4 Input Meteorological Data

2.4.1 When using MM5 for air quality modelling purposes, it is desirable to use an option known as Four Dimensional Data Assimilation (FDDA), also referred to as nudging. FDDA is used to ensure that numerical prediction errors do not cause simulations to drift away from actual meteorological observations. Given an equation representing the time change of a variable (e.g. velocity, temperature, humidity), an extra term is added which will help diminish differences between the model predictions and observational data or analyses. This will ensure that the model forecast does not diverge significantly. In the present Study, the FDDA will be done using available upper air observations and surface data that are within the 1.5 km resolution domain to be modelled.

2.4.2 Previously, nudging of the 1.5 km domain was performed using surface observations from 28 stations in the HKSAR operated by the Hong Kong Observatory. These data had been re-used in the present study. In addition, we had been able to obtain surface observations from three stations in the PRDEZ (Macau, Guangzhou and Shenzhen) and two upper air stations (Gaungzhou and King's Park in HKSAR). These data had also been used to nudge the simulation.

2.4.3 MM5 allows for nudging with wind, temperature and moisture data (NCAR, 1997). In the case of upper air data, all three parameters will be used. In the case of surface data, only wind data will be used, as was done previously in PATH. This approach is recommended by the developers of MM5 (Grell, et al., 1995). Surface temperature and surface moisture data are not used, due to difficulties in reliably scaling these data to the lowest vertical level in the simulation.

2.4.4 The initial and lateral boundary conditions for the 1.5 km MM5 simulations had been derived from the 4.5 km resolution simulations that have already been performed and incorporated into the PATH modelling system. The temporal resolution of the lateral boundary conditions will be one hour.

2.5 Physics Options

2.5.1 The following describes the main physics options that had been used in this Study. These options were appropriate for the 1.5 km grid spacing. They were consistent with the options used in the previous MM5 modelling within PATH. The model also had various other options that had been kept the same as in the previous MM5 modelling:

2.5.2 Nonhydrostatic assumption. This option is important when modelling at scales smaller than 5–10km as it accounts for vertical motions induced by topography or convective activity at these scales.

2.5.3 No cumulus parameterisation. Cumulus parameterisation is normally used with large grid spacing to account for formation of convective clouds at scales smaller than the grid. At high resolutions when the grid size is less than 5km, the cloud formation is resolved explicitly.

2.5.4 Cloud radiation scheme. Cooling of cloud tops via longwave radiation is a significant process affecting the regional and local thermodynamics and will be accounted for in all of the simulations.

2.5.5 Depending on the meteorological episode, either the Middle Range Forecast model (MRF) or Blackadar High Resolution (Hir) scheme for modelling the Planetary Boundary Layer (PBL). PBL schemes account for turbulence in the atmospheric boundary layer. Both the MRF and Hir scheme are first order schemes that employ non-local turbulence transport, which can handle well the physics in a convective environment. Both schemes are coupled with an interactive soil model.

2.5.6 Warm rain moisture scheme. This is an explicit scheme for predicting cloud and rain water fields, assuming that ice phase processes do not take place.

2.5.7 Moist vertical diffusion in clouds. This option applies to the simulation of turbulence in clouds where cloud water plays a role.

2.5.8 3-dimensional Coriolis force. Coriolis force arises from the earth's rotation and affects both horizontal and vertical motions in the atmosphere. With this option, Coriolis force is included in both horizontal and vertical terms of the momentum equations, as opposed to just the horizontal terms.

2.5.9 Upper radiative boundary condition. Gravity waves are an atmospheric phenomenon that MM5 is capable of reproducing. However, errors can arise when these waves meet the upper boundary of the simulation domain and are reflected downward. This option provides conditions at the upper boundary that allow gravity waves to pass through the boundary without reflection.

2.6 Modifications to the MM5 Code

2.6.1 The previous PATH modelling consultants modified the MM5 code in an effort to enhance its performance for HKSAR (Physick and Noonan, 2000). The land use categories and the look-up tables of land use parameters, such as albedo, emissivity and soil moisture, were customized for HKSAR. In addition, a term was added to the surface energy balance to account for heat generated by anthropogenic activities (electricity generation, motor vehicle activity, industry, etc.). This was done on the 1.5 km and 0.5 km domains of the PATH modelling system. A fixed value was adopted for each grid cell, with no account for diurnal or seasonal variation. Normally, MM5 does not account for anthropogenic heat flux.

2.6.2 In the present Study, we had adopted the same land use classification scheme and parameters as used in the final runs for the PATH modelling. We have also adopted the anthropogenic heat flux over HKSAR that was used previously. These data had been interpolated to our model grid.

2.6.3 For practical reasons, we had not included anthropogenic heat flux for cities in the PRDEZ. The anthropogenic heat flux in urban areas is generally modest in relation to the solar heat flux, particularly on clear sky days when high ozone levels would occur. As such, the MM5 results are expected to be no more than moderately sensitive to it. The PATH sensitivity runs on the 0.5 km domain to test the impact of the anthropogenic heat flux found that it had an impact on the penetration of sea breezes into the urban areas of HKSAR (EPD, 1999b). This impact was noticeable on the 0.5 km domain but would be much less noticeable on the large 1.5 km domain of the present study. Furthermore, the anthropogenic heat flux was treated in a fairly simple fashion, with no diurnal variation. Since this approach is unrealistic, it seems no less realistic to run MM5 in the normal fashion, with no anthropogenic heat flux.

2.7 Episodes to be modelled

2.7.1 In previous PATH modelling, 11 meteorological episodes were modelled. The episodes and the selection of them have been described in detail in the PATH model reports. Further descriptions of the episodes can be found in the PATH Validation Study (EPD 1999). All of these episodes had been selected for this study and they are listed below:

- 29-31 August 1993, 9-11 October 1994, 21-23 October 1994, 18-20 January 1995, 26-28 June 1995, 11-13 September 1995, 17-19 November 1995, 22-24 November 1995, 2-4 December 1995, 18-20 August 1996 and 11-14 November 1997.

2.8 Post-Processing of Data

2.8.1 Modelled data of the episodes had been presented graphically in a similar fashion to the presentation used in the previous model validation study for PATH (EPD 1999). We will show plots of surface wind vectors (both modelled and observed) for the 1.5 km domain, for two selected times on the last day of each episode. This will be done by processing the MM5 output using software previously developed and inputting the processed data to a commercial graphics package, SURFER.

2.9 Evaluation of Results

2.9.1 The evaluation of the results had been focused on the parameters of greatest relevance for air quality, which were the winds and temperature in the boundary layer. The previous PATH model performed a detailed validation of the results for the original 1.5 km domain (EPD 1999). The validation was performed on the simulations without FDDA, and involved comparisons of predicted and observed surface winds and surface temperature. Three criteria were used for judging the acceptability of the simulation: (1) predicted standard deviations similar to observed; (2) Root-Mean-Square Error (RMSE) between the predicted and observed values is less than the standard deviation of the observed values; and (3) comparable performance to other simulations in complex terrain. In order to apply these criteria, the following statistics were computed for wind speed and temperature: Willmot's index of agreement; the total RMSE (root mean squared error); the systematic and unsystematic portions of the RMSE; the mean and standard deviation of the observed and predicted values at the observation sites. For wind direction, the mean and standard deviation were computed, but the RMSE and index of agreement were not computed. Time series plots of these parameters were prepared. In addition, vertical plots of predicted and observed values of wind speed, wind direction and temperature were prepared for upper air observation sites.

2.9.2 Similar approaches had been used by other researchers conducting meteorological modelling for air quality studies. Cai and Steyn (1996), and Hedley et al. (1996) computed the various forms of RMSE (overall, systematic and unsystematic) and also computed Willmot's index of agreement for surface wind speed, surface wind direction and surface temperature. Guo et al. (1996) computed the mean bias (or mean residual), the mean unsigned error and the index of agreement, and they evaluated surface specific humidity in addition to surface wind speed, wind direction and temperature. Tesche and McNally (1996, 1997) computed the various forms of RMSE for surface wind speed and direction, and computed bias and normalized gross error for surface temperature and water vapour mixing ratio.

2.9.3 In the present study, the same approach as applied in the previous MM5 evaluations for PATH had been used so that the results could be compared with our model performance to previous PATH results. The available observations in Macau and the PRDEZ (4 surface stations and one upper air station) and a comparable subset of observations from HKSAR (i.e., 4 surface and one upper air station), had been used. This approach was preferable to using a larger number of surface stations from HKSAR, as the latter would lead to a biased evaluation of the overall model performance for the entire 1.5 km domain.

2.10 Sensitivity Runs

2.10.1 Additional runs of MM5 had been performed for the new 1.5km model domain to test the sensitivity of the model to Four Dimensional Data Assimilation (FDDA) and the choice of option for boundary layer simulation. Two meteorological episodes had been adopted for this purpose: August 18 – 20, 1996 (Oii) which is a high ozone event; and 18-20 January, 1995, which is a high RSP event.

2.10.2 Our primary runs for these episodes had been done using the Hir boundary layer scheme and Four Dimensional Data Assimilation (FDDA). For the sensitivity runs, each episode had been subjected to 2 additional MM5 runs. One run had make use of the MRF boundary layer scheme instead of the Hir scheme and The second sensitivity run makes use of the MRF scheme without FDDA. The second sensitivity run will make use of the MRF scheme without FDDA.

2.11 Quality Control

2.11.1 Numerous checks of input data, preprocessing steps and the MM5 outputs were performed. This included detailed checking of the data used in FDDA, checking the scripts used to generate the gridded terrain and land use data, checking the scripts used in processing initial and boundary conditions, checking the scripts for running MM5, checking the output log file for MM5 and checking the model results against observational data and previous model runs performed during the development of PATH. Standard MM5 Performance Check Sheet is shown in Table 2-2

Table 2-2 Standard MM5 Performance Check Sheet

MM5 Check Sheet			
Project No.: Project Name: Date: Run No.: Run Name:			
Item	Done By	Chk'd By	Date
Formatting of ungridded raw meteorological data for FDDA -Verify that the data have been reformatted correctly			
TERRAIN processor -Visualize model domains and ensure that appropriate areas are covered -Visualize the terrain representation and compare against a published topographical map -Visualize the landuse and coastline representation and compare to published maps -Attach hard copies of the above items			
DATA GRID (interpolates input data to grid being modelled) -Output file needs checked to see that the correct data for the proper time period have been used			
RAWINS (preprocessor for upper air and surface air data) Are all data properly incorporated?			
INTERP (interpolates input data vertically to model grid) -Are the vertical layers properly specified? -Have the expected files been generated for the appropriate dates?			
MM5 -Verify that the correct physics options are specified -Verify that the correct nudging options are specified -Verify all other options			

3 EMISSION PROCESSING

3.1 Background

3.1.1 Emission processing was performed using EMS-95, which is an emission modelling system developed by Alpine Geophysics as part of the SARMAP and LMOS regional modelling studies in the US (Wilkinson, et al., 1994). The purpose of the emission processing is to produce hourly emission data for each of the historical meteorological episodes modelled in MM5, spatially distributed within each grid cell for each model domain and speciated in a suitable format for use in the PATH air quality model, SAQM.

3.1.2 As part of the present study, a base year emission inventory for 1997 was developed for the whole study area. The pollutants in the emission inventories included: SO_2, NO_x, RSP, VOC and ammonia. The methodology for developing the inventories for the base year was described previously in Working Paper 4 entitled: *Proposed Methodology and Assumptions for Base Year Emission Inventory*. The base year inventories were also projected to four future years: 2000, 2005, 2010 and 2015. Although the emissions inventories were projected to a number of future yeas, only the 2010 future year will be modelled in the air quality simulations.

3.1.3 Although eleven MM5 episodes were modelled for the present study, only eight representative episodes were carried forward for subsequent modelling with EMS-95 and SAQM. The eight episodes modelled are:

- Episode A (November 22-24, 1995)
- Episode B1 (November 21-23, 1994)
- Episode B2 (January 18-20, 1995)
- Episode C (November 17-19, 1995)
- Episode D (September 11-13, 1995)
- Episode E (June 26-28, 1995)
- Episode F (August 29-31, 1993)
- Episode Oii (August 18-20, 1996)

3.1.4 Each of these episodes was modelled in EMS-95 and SAQM for the 13.5, 4.5, and 1.5 km model domains for the base year (1997) emission inventory. The focus of the present Study was to refine the emission inventory and model future air quality in the study area as outlined in the study brief. As such, the 40.5 km domain was not modelled in this Study as the outputs from this domain were used only as boundary and initial conditions for the 13.5 km domain. For the same reasons, the 13.5 km domain was run for the base year (1997) but not rerun for any of the future year scenarios. Therefore, for the future year (2010) business-as-usual (BAU) growth scenario and all subsequent future year emission control scenarios, only the 4.5 and 1.5 km domains were modelled.

3.2 EMS-95 Methodology

3.2.1 EMS-95 consists of four main emission modules for point, area, biogenic, and motor vehicle sources, respectively. The point sources include major combustion sources in the power generation and manufacturing sectors. The areas sources include domestic fuel consumption, dry cleaning, road surfaces, surface coating operations, industrial fugitive emissions, etc. Biogenic sources consist of emissions from soils and vegetation. The previous consultants for the PATH modelling system did not use the motor vehicle model in EMS-95, but processed the vehicle emissions outside of EMS-95 and then included the processed data with the other area sources. The same approach was adopted in the present Study.

3.2.2 Point and area emission data for the base year were processed through EMS-95 for each of the selected historical meteorological episodes as outlined above. The resultant output are hourly emission files for each episode, spatially allocated over the 13.5, 4.5, and 1.5 km model domains, speciated in a suitable format for use in the air quality model emission preprocessor, EPS.

3.2.3 The steps involved in running EMS-95 consist of running the grid definition model, followed by the point, area and biogenics models and, finally, the speciation model. As previously mentioned, the motor vehicle emission model will not be used, as vehicle emissions will be processed with the area source data.

3.3 Quality Control

3.3.1 Numerous checks of input data, preprocessing steps and the EMS-95 outputs were performed. This included detailed checking of the data used in each of the EMS-95 subroutines, checking the SAS and ARC/INFO scripts used to generate the gridded, temporalized, and speciated emissions data, checking the scripts used in processing future growth and projections, checking the batch files for running multiple EMS-95 domains / episodes, checking the output log and .lst files for the various SAS routines, and checking the outputs against raw inputs through numerous spreadsheet and hand calculations. Standard EMS performance check sheet is shown Table 3-1

Table 3-1 Standard EMS Performance Check Sheet

EMS-95 Check Sheet			
Project No.: Project Name: Date: Run No.: Run Name:			
Item	Done By	Chk'd By	Date
GRID DEFINITION MODEL Definition of the emissions modelling grid structure -Check the grid settings in the batch file, and visualize the grid to verify that it is properly defined			
POINT SOURCE MODEL Preparation of gridded, hourly emissions estimates -Verify point source lookup tables and ensure valid cross-referencing of SCC codes to temporal profiles and speciation profiles			
AREA SOURCE MODEL Reduction of annual, county-wide emissions estimates to emissions on an hourly, grid cell -by grid cell basis -Check general lookup tables and ensure valid cross-referencing of SCC codes to temporal profiles and speciation profiles -Verify cross-referencing of source data to spatial surrogate codes			
BIOGENICS MODEL Computation of estimates of biogenic emissions -Check cross-referencing of counties land-uses and plant community types -Check that land-use codes in the biogenic input files match those in the land-use coverage GIS			
SPECIATION MODEL Computation of lumped model species chemical estimates -Check look-up tables to ensure valid cross-referencing between source codes, SAROAD codes, chemical mechanism profile codes, etc			
PROJECTIONS MODEL Provides reasonable further progress projected emission estimates -Check for valid cross-referencing between source codes, growth factors and control factors			
POST PROCESSING OF DATA -Visualize and examine gridded emission data for consistency			

3.4 Model Domains

3.4.1 The EMS_95 Run Description and Grid Definition modules form the basis for all subsequent emissions processing. The run description file contains the following key information: episode date / directory name, starting date, time zone, run Ids for episode days, speciation mechanism, organic gas type, location of grid cell coordinates (i.e., center, southwest, etc.), x and y coordinates of lower left grid cell of EMS-95 domain, grid cell size, number of grid cells in x and y axes, projection system parameters and units, etc. The run description file is specifically formatted for input to EMS-95.

3.4.2 The Grid Generation model uses information from the run description file to create the emissions modelling grid structure. This process produces a GIS coverage that contains gridded political boundary information and assigns the appropriate ICELL, JCELL values for each grid cell in the EMS-95 model domain. This information is grid dependent but episode independent. The resultant GIS coverage and INFO tables are used in subsequent spatial surrogate modules in EMS-95.

3.4.3 In PATH, the EMS-95 model domains were identical to the MM5 model domains. The model domains for the air quality model, SAQM, where smaller and imbedded in the corresponding MM5 and EMS-95 model domains. In the present study, the EMS-95 model domains for the 13.5 and 4.5 km grid resolutions were reduced in size to match the corresponding SAQM domains as defined in the original PATH model runs. Because emissions processed for areas outside of the SAQM domain are not used in any way, this reduction in the EMS-95 domain sizes was done to conserve computer run times and disk storage requirements.

3.4.4 For this Study, the 1.5 km MM5, EMS-95, and SAQM domains were expanded to provide a higher resolution coverage in the PRDEZ. The 1.5 km domains were expanded from the original PATH 1.5 km domains to cover the urban areas of Guangzhou, Zhuhai, and Shenzhen. Figures 3-1, 3-2 and 3-3 show the 13.5, 4.5, and 1.5 km EMS-95 model domains plotted respectively with the political boundaries for reference.

3.5 Spatial Allocation

3.5.1 As part of the emission inventory development, emissions were calculated as tonnes per year by activity type (defined by a unique SCC or ASCT code), and by "State" or, as adopted in the present Study, a similar geo-political unit. These emissions were then broken down into emissions from individual "Counties" within each State based on available demographic information.

3.5.2 In the previous PATH modelling, HKSAR was treated as one State comprised of only one County. To improve the spatial resolution and hence apportionment of emissions to the model grid, HKSAR was divided into 18 counties which correspond with the 18 districts as discussed in the Third Comprehensive Traffic Study (CTS3). Census data for 1996 were used to allocate HKSAR wide emissions to their respective Counties (CTS3 districts). Data from the 1998 Statistical Yearbook of Guangdong were used to allocate State-wide emissions to their respective Counties in the PRDEZ. Table 3-2 depicts the unique State (STID) and County (CYID) codes adopted in the present Study.

Table 3-2 State and County ID Codes

STID	State Name	CYID	Name
1	Hong Kong	1	Central & Western
1	Hong Kong	2	Wan Chai
1	Hong Kong	3	Eastern
1	Hong Kong	4	Southern
1	Hong Kong	5	Yau Tsim Mong
1	Hong Kong	6	Sham Shui Po
1	Hong Kong	7	Kowloon City
1	Hong Kong	8	Kwun Tong
1	Hong Kong	9	Wong Tai Sin
1	Hong Kong	10	Kwai Tsing
1	Hong Kong	11	Tuen Mun
1	Hong Kong	12	Island
1	Hong Kong	13	Yuen Long
1	Hong Kong	14	Tai Po
1	Hong Kong	15	North
1	Hong Kong	16	Sha Tin
1	Hong Kong	17	Sai Kung
1	Hong Kong	18	Tsuen Wan
1	Hong Kong	20	HK Harbour
1	Hong Kong	21	HKSAR Water
10	Macau	10	Macau
10	Macau	11	Macau Harbour
20	International	10	International Water
44	PRDEZ	2	PRDEZ Estuary / Water
44	PRDEZ	10	Guangzhou
44	PRDEZ	11	Guangzhou Harbour
44	PRDEZ	20	Shenzhen
44	PRDEZ	21	Shenzhen Harbour
44	PRDEZ	30	Zhuhai
44	PRDEZ	40	Shantou
44	PRDEZ	50	Shaoguan
44	PRDEZ	60	Heyuan
44	PRDEZ	70	Meizhou
44	PRDEZ	80	Huizhou
44	PRDEZ	90	Shanwei
44	PRDEZ	100	Dongguan
44	PRDEZ	110	Zhongshan
44	PRDEZ	120	Jiangmen
44	PRDEZ	130	Foshan
44	PRDEZ	140	Yangjiang
44	PRDEZ	150	Zhanjiang

STID	State Name	CYID	Name
44	PRDEZ	160	Maoming
44	PRDEZ	170	Zhaoqing
44	PRDEZ	180	Qingyuan
44	PRDEZ	190	Chaozhou
44	PRDEZ	200	Jieyang
44	PRDEZ	210	Yunfu

3.5.3 As part of the initial emission apportionment to counties process, a GIS coverage (counties), containing political boundary information, was also produced. This coverage is used in the gridding process. The PATH political boundary GIS coverage for HKSAR provided a high degree of detail on the coastlines and the border between Hong Kong and Shenzhen. The county coverage for Mainland, however, was much more generalized. To generate one county coverage, the two coverages were joined and the State and County IDs were re-assigned for both HKSAR and mainland China as depicted in Table 3-3.

Table 3-3 Spatial Surrogate Coverages

SSC	Description	Coverage Type *	Coverage Name	SSC Value
1	Urban areas (urban - poly)	LULC	urban	URB
2	PRDEZ Census (prd_census – poly)	CENSUS	prdec_cen	P
3	HK roads (hk_rds - line)	TIGER	hk_rds	HI
4	PRDEZ roads + urban (prdec_rds – poly)	LULC	prdec_rds	HI
5	HK Marine (hk_marine - line)	TIGER	hk_marine	MAR
6	HK + PRDEZ rail (rail - line)	RAILS	rail	RR
7	HK quarries (quarry - point)	PORT	quarry	QU
8	HK fuel terminals (terminal – point)	PORT	terminal	FT
9	Cultivation (landuse - poly)	LULC	landuse	3
10	Guandong Airports (ap_base - poly)	LULC	ap_base	AP1
11	HK Airport pre-1998 (ap_base - poly)	LULC	ap_base	CLA
12	HK Airport pre-1998 (ap_base - poly)	LULC	ap_base	IDA
13	HK Airport pre-1998 (ap_base - poly)	LULC	ap_base	LNA
14	HK Airport pre-1998 (ap_base - poly)	LULC	ap_base	TOA
15	HK Airport post-1998 (ap_fut - poly)	LULC	ap_fut	CLB
16	HK Airport post-1998 (ap_fut - poly)	LULC	ap_fut	IDB
17	HK Airport post-1998 (ap_fut - poly)	LULC	ap_fut	LNB
18	HK Airport post-1998 (ap_fut - poly)	LULC	ap_fut	TOB
19	Macau Airport (ap_base - poly)	LULC	ap_base	CLC
20	Macau Airport (ap_base - poly)	LULC	ap_base	IDC
21	Macau Airport (ap_base - poly)	LULC	ap_base	LNC
22	Macau Airport (ap_base - poly)	LULC	ap_base	TOC
30	Marine Sources (marine - poly)	LULC	marine	MAR

Notes: Coverage Types - LULC = polygon, CENSUS = polygon, TIGER = polyline, RAILS = polyline, PORT = point

3.5.4 Spatial surrogates were used to allocate the county-wide emissions to the model grid cells. For example, emissions from locomotives are initially calculated by State and then apportioned to each County within the State based on the amount of locomotive activity in each County. A spatial surrogate, in this case a GIS coverage depicting major rail lines, is then used to apportion these County-wide emissions to grid cells through which the locomotives actual travel. Table 3-2 depicts the various GIS coverages developed as spatial surrogates for the current study.

3.5.5 The discussion that follows outlines the spatial surrogates used and what types of emission sources were assigned to these surrogates. Table 3-4 presents a summary of activity type (ASCT / SCC code, Description Level 1, and Description Level 2), and the spatial surrogates used (Spatial Surrogate Code). The spatial surrogate codes used in Table 3-4 are the same as those referred to in Table 3-3.

Table 3-4 Spatial Surrogate to Activity Type Cross Reference Table

ASCT / SCC	Spatial Surrogate Code (SSC)						Description Level 1	Description Level 2
	HK SAR	*PRDEZ*	*Guang-dong*	*Macau*	*Int'l Waters*	*Main-land*		
30100399	1	1	1	1	1	1	Ammonia Production	Industrial Processes
30101401	1	1	1	1	1	1	Paint Manufacture	Industrial Processes
30102712	1	1	1	1	1	1	Nitrogen Fertilizer Production	Industrial Processes
30600801	1	1	1	1	1	1	Preheater/Precalciner Kiln	Industrial Processes
30700101	1	1	1	1	1	1	Pulp and Paper Industries	Industrial Processes
31100199	1	1	1	1	1	1	Construction Dust	Industrial Processes
2103004001	1	1	1	1	1	1	Electronic Manufacture	Stationary Source Fuel Comb.
2103004002	1	2	1	1	1	1	Transportation	Stationary Source Fuel Comb.

ASCT / SCC	Spatial Surrogate Code (SSC)						Description Level 1	Description Level 2
	HK SAR	*PRDEZ*	*Guang-dong*	*Macau*	*Int'l Waters*	*Main-land*		
2103004003	1	1	1	1	1	1	Gas, Water & Sanitary Works	Stationary Source Fuel Comb.
2103004004	1	1	1	1	1	1	Communic./Printing/Publishing	Stationary Source Fuel Comb.
2103007000	1	2	1	1	1	1	Domestic/Commercial Fuel Use	Stationary Source Fuel Comb.
2104002000	1	2	1	1	1	1	Domestic Coal Consumption	Stationary Source Fuel Comb.
2104007000	1	2	1	1	1	1	Domestic LPG Consumption	Stationary Source Fuel Comb.
2104011000	1	2	1	1	1	1	Domestic Other Fuel Consump.	Stationary Source Fuel Comb.
2199006002	1	2	1	1	1	1	Domestic Fuel Comb.	Stationary Source Fuel Comb.
2201001000	3	4	4	4	4	4	Private Car/ Small Petrol Vehicle	Mobile Sources
2201070000	3	4	4	4	4	4	Large Petrol Vehicle	Mobile Sources
2201080000	3	4	4	4	4	4	Motor Cycle	Mobile Sources
2230001000	3	4	4	4	4	4	Taxi	Mobile Sources
2230060331	3	4	4	4	4	4	Pass. Van	Mobile Sources
2230060332	3	4	4	4	4	4	PLB	Mobile Sources
2230060333	3	4	4	4	4	4	LGV	Mobile Sources
2230070331	3	4	4	4	4	4	HGV	Mobile Sources
2230070332	3	4	4	4	4	4	Non FR Bus	Mobile Sources
2230070333	3	4	4	4	4	4	SD Fr Bus	Mobile Sources
2230070334	3	4	4	4	4	4	DD Fr Bus	Mobile Sources
2260005000	9	9	9	9	9	9	Agriculture	Mobile Sources
2275000000	10	10	10	10	10	10	Aircraft - General*	Mobile Sources
2275020001	13	21	21	21	21	13	Aircraft – Approach	Mobile Sources
2275050000	12	20	20	20	20	12	Aircraft – Idle	Mobile Sources
2275050001	14	22	22	22	22	14	Aircraft – Takeoff	Mobile Sources
2275060000	11	19	19	19	19	11	Aircraft – Climbout	Mobile Sources
2280003000	5	30	30	30	30	30	Marine Vessels**	Mobile Sources
2285002000	6	6	6	6	6	6	Diesel Locomotives	Mobile Sources
2294000000	3	4	4	4	4	4	Paved Road Dust	Mobile Sources
2296000000	3	4	4	4	4	4	Unpaved Road Dust	Mobile Sources
2301000000	1	1	1	1	1	1	Chemicals/Rubber/Plastic	Industrial Processes
2302000000	1	1	1	1	1	1	Food & Beverage	Industrial Processes
2305000000	1	1	1	1	1	1	Non-Metallic Mineral Products	Industrial Processes
2311000000	1	1	1	1	1	1	Construction	Industrial Processes
2312000000	1	1	1	1	1	1	Manufacture – Heavy	Industrial Processes
2325000000	7	9	9	9	9	9	Mining/Mineral Extraction***	Industrial Processes
2399000000	1	1	1	1	1	1	Manufacture - Light/Medium	Industrial Processes
2401001000	1	2	1	1	1	1	Dom/Com Surface Coatings/Thinners	Solvent Utilization
2401010000	1	1	1	1	1	1	Textiles	Solvent Utilization
2401990000	1	1	1	1	1	1	Paint Application (Based on Imports-Exports)	Solvent Utilization
2415000000	1	2	1	1	1	1	Domestic/Commercial Solvents	Solvent Utilization
2420000000	1	2	1	1	1	1	Dry Cleaning	Solvent Utilization
2425000000	1	1	1	1	1	1	Printing	Solvent Utilization
2460000000	1	1	1	1	1	1	Alcoholic Beverage Production	Solvent Utilization
2460100000	1	2	1	1	1	1	Dom/Com Aerosols	Solvent Utilization
2501050000	8	1	1	1	1	1	Fuel Terminals****	Storage and Transport
2501060000	1	1	1	1	1	1	Petrol Distribution and Handling	Storage and Transport
2505040000	1	1	1	1	1	1	Crude Oil Production	Storage and Transport
2610000000	1	1	1	1	1	1	Municipal Waste Burning	Waste Disposal, Treatment, ndRecovery
2630000000	9	9	9	9	9	9	Human Waste Rural Households	Waste Disposal, Treatment, and Recovery
2630030000	1	1	1	1	1	1	Human Waste Urban without Sanitary Facilities	Waste Disposal, Treatment, and Recovery
2801000002	9	9	9	9	9	9	Nitrogen Fertilizer Usage	Miscellaneous Area Sources
2801000003	9	9	9	9	9	9	Pesticide Application	Miscellaneous Area Sources
2801000006	9	9	9	9	9	9	Grain Drying	Miscellaneous Area Sources
2801500000	9	9	9	9	9	9	Agricultural Waste Burning	Miscellaneous Area Sources
2805010000	9	9	9	9	9	9	Animal Waste Ammonia	Miscellaneous Area Sources
2806010000	1	2	1	1	1	1	Human Sweat & Exhalation	Miscellaneous Area Sources
2230070000	3	4	4	4	4	4	Heavy Duty Diesel Vehicles	Mobile Sources
10100101	1	1	1	1	1	1	Steam Turbine (Coal)	External Comb. Boilers
10100401	1	1	1	1	1	1	Steam Turbines(H.Oil)	External Comb. Boilers
10100504	1	1	1	1	1	1	Steam Turbines(H.Oil)	External Comb. Boilers
10100601	1	1	1	1	1	1	Steam Turbines(Natural Gas)	External Comb. Boilers
10200504	1	1	1	1	1	1	Steam Turbines(Natural Gas)	External Comb. Boilers
10200602	1	1	1	1	1	1	Auxiliary Boiler (Natural Gas)	External Comb. Boilers
20100101	1	1	1	1	1	1	Gas Turbines (L.Oil)	Internal Comb. Engines
20100201	1	1	1	1	1	1	Gas Turbines (Natural Gas)	Internal Comb. Engines
30300401	1	1	1	1	1	1	Coke Production	Industrial Processes

ASCT / SCC	Spatial Surrogate Code (SSC) *HK SAR*	*PRDEZ*	*Guang-dong*	*Macau*	*Int'l Waters*	*Main-land*	Description Level 1	Description Level 2
30500623	1	1	1	1	1	1	Preheater/Precalciner Kiln	Industrial Processes
50200101	1	1	1	1	1	1	Multi-Chamber Incinerator	Waste Disposal
64630001	1	1	1	1	1	1	PVC Manufacture	MACT Source Categories
2102002000	1	1	1	1	1	1	Bituminous/sub-bituminous coal*****	Stationary Source Fuel Comb.
2102004000	1	1	1	1	1	1	Distillate oil*****	Stationary Source Fuel Comb.
2102005000	1	1	1	1	1	1	Residual oil*****	Stationary Source Fuel Comb.
2102009000	1	1	1	1	1	1	Coke*****	Stationary Source Fuel Comb.
2102011000	1	1	1	1	1	1	Kerosene******	Stationary Source Fuel Comb.
2280001000	30	30	30	30	30	30	Marine Vessels******	Mobile Sources

Notes:
** aircraft "general" used for PRDEZ only; detailed airport codes used for HK and Macau airport activities*
*** marine vessel code 5 used for Hong Kong only (HK SAR Ferry Routes)*
**** mining/mineral extraction code used for Hong Kong quarries only; "cultivation" used for all other areas*
***** fuel terminal code for Hong Kong only*
****** codes for Mainland counties only*
Marine code 30 applicable to STID/CYID = 1/20 only
All SSC codes for STID = 20 (International Water) allocated as per Macau (STID = 10) surrogates

Locomotives (SSC = 6)

3.5.6 A GIS file depicting the primary rail line in HKSAR was provided in the surrogate data prepared for the original PATH modelling. To create a comparable spatial surrogate for Mainland, major rail lines outside of HKSAR were digitized and appended to the original rail coverage for HKSAR. This surrogate was used to apportion county-wide emissions from locomotives to the model grid for all domains as shown in Figure 3-4.

Marine Vessels (SSC = 5, 30)

3.5.7 Emissions from marine sources were allocated to the model grid using the following area definitions as defined based on the emission inventory data: Macau Harbour, HKSAR Harbour and moorings, HKSAR waters (not including Harbours and moorings), PRDEZ waters (Pearl River Delta waters and Pearl River Estuary), and international waters (water area not included in the other areas but extending approximately 1 nautical mile south of the mouth of the Pearl River Delta Estuary). To simplify the modelling process, these water "bodies" were classified as "counties" in the county coverage as shown in Table 3-2. In this way, all emissions in the inventory files from marine sources other than those in the HKSAR waters were attributed to their respective "counties".

3.5.8 Because GIS files depicting detailed ferry and marine transport routes were made available in PATH, these data were also adopted in the present Study to better apportion marine emissions within the HKSAR waters. Figure 3-5 depicts the different spatial surrogates used to apportion marine emissions to the model grid (i.e., blue hatch for Harbours and emission areas, blue lines for ferry and trip routes in HKSAR Waters).

Area Sources (SSC = 1, 2, 9)

3.5.9 The spatial surrogate coverage to be used for allocating area source emissions from non population related sources (e.g., agricultural activities, biogenic emissions) was landuse. Considerable effort was put forth during the development of the PATH model to produce accurate landuse coverage for HKSAR. In the present Study, the landuse information for mainland China provided by the Chinese University of Hong Kong and used in the MM5 modelling was combined with the detailed landuse files for HKSAR developed previously to create one landuse GIS coverage of the area.

3.5.10 Table 3-5 describes the landuse categories provided in the GIS file. Landuse classes for cultivation (LU_CODE = 3), Urban - High Density (LU_CODE = 13), and Urban - Low Density (LU_CODE = 14) were used to develop spatial surrogates for the present study as discussed in more detail below.

Table 3-5 Landuse Codes and Descriptions

LU_CODE	VEGE_TYPE	Description
1	AC	Abandoned Cultivation
2	B	Bare Rock or Soil
3	C	Cultivation
4	G	Grassland
5	WA	Inland Water
6	L	Low Shrubland
7	L/G	Low Shrubland with Grass
8	M	Mangrove
9	OW	Other Wetland
10	PL	Plantation Woodland
11	T	Tall Shrubland
12	T/G	Tall Shrubland with Grass
13	U2	Urban - High Density
14	U	Urban - Low Density
15	W	Woodland

3.5.11 Areas classified as cultivation were used to apportion emissions form agricultural activities (e.g., agricultural waste burning, grain drying, pesticide application, etc.) in both the PRDEZ and HKSAR. Areas defined as Urban - High Density, and Urban - Low Density were joined to create a single "urban" landuse class. These data were used to apportion emissions from human activities in the HKSAR (e.g., solvent use, construction dust, residential fuel Comb., etc.) as shown in Figure 3-6.

3.5.12 For the PRDEZ, a simple census coverage was developed in ARC/INFO using urban and rural population statistics from the 1998 Statistical Yearbook of Guangdong in combination with the county boundaries GIS coverage, as shown in Figure 3-7. This information was used as a spatial surrogate to apportion emissions from human activities to the model grid in the PRDEZ.

On-Road Vehicular Sources (SSC = 3, 4)

3.5.13 Vehicle emissions in HKSAR were computed on a county basis based on traffic data (i.e., VKT) provided by the Consultants Team as discussed in TA5. The digital road network for HKSAR provided in the original PATH model was used to further apportion the county-wide emissions to the model grid.

3.5.14 For mainland China, a coarse digital road network was provided in the original PATH model. This coverage provided basic information on the location of the major highways but no information on urban road networks (e.g., roads in Guangzhou, Foshan, Zhongshan, etc.) where vehicular emissions are typically very high. To address this lack of detail, the coarse road network was combined with areas defined as "urban" from the high resolution landuse information. The resultant road surrogate for Mainland provides a more accurate representation of the location and extent of on-road vehicular activities (see Figure 3-8).

Airports (SSC = 10 through 22)

3.5.15 Five major airports were identified in the emission inventory for which spatial surrogates were required. In HKSAR, the base year (i.e., 1997) airport emissions were assigned to the old Kai Tai Airport. In all future year scenarios, the emissions will be apportioned to the new Chek Lap Kok Airport. The original GIS coverages provided with the PATH model included areas defining both the old Kai Tai Airport and the new Chek Lap Kok Airport. Areas of emission activities were defined for climbout, idling/taxiing, takeoff, and approach. In the present study, a similar approach was adopted for Macau International Airport.

3.5.16 Airport footprints and detailed activity data were not available for other airports in the 1.5 km study. It was assumed that the emissions from each if these airports would be released uniformly from roughly rectangular areas covering about 4.5 km^2. A spatial surrogate GIS coverage was created to allocate these emissions.

3.5.17 Figure 3-9 shows a portion of the spatial surrogate GIS coverage developed to apportion emissions from airport activities to the model grid. Shown in this figure are the surrogates for different activities at the Macau airport, the old Tai Kai Airport and new Chek Lap Kok airport in HKSAR, and the Shenzhen airport. (i.e., dark blue = landing, pink = idling, red = climbout, light blue = takeoff).

Fuel Terminals (SSC = 8) and Quarries (SSC = 7)

3.5.18 For HKSAR, spatial surrogates for fuel terminals and quarries were provided in the original PATH GIS files. Fuel terminals and quarries were allocated to the model grid using a GIS coverage with the location of these sources denoted as a single point. Emissions from these sources were then apportioned to the grid cell in which the points lie. Figure 3-10 depicts the location of the major quarries (red stars) and fuel terminals (blue triangles) in HKSAR.

3.5.19 There were no data provided on emissions from fuel terminals in the PRDEZ. Specific spatial surrogates for quarries were not available for mainland China. In the absence of this information, emissions from quarries / mining activities were allocated to the grid based on the location of cultivation activities as defined by the cultivation landuse class in the landuse coverage / surrogate. Cultivation was the most appropriate landuse class as it covers a fairly large proportion of the land area and would serve to allocate emissions from these sources outside of the built-up urban areas.

Biogenic Sources

3.5.20 The biogenics model uses information on the total amount of land mass covered by different vegetation types in a given county in conjunction with the episode specific meteorological data to calculate hourly emissions from vegetation and soil. A landuse GIS coverage depicting the different vegetation / landuse types throughout the model domain is then used to apportion these emissions to the model grid.

3.5.21 The landuse coverage developed as part of the MM5 modelling and described above was used to calculate the total area occupied by each landuse category in each county. These data, in combination with biomass emission factors from PATH were used to produce gridded, temporalized, and speciated biogenic emissions.

Major Point Sources

3.5.22 Major point sources were modelled as such, taking advantage of available information on stack parameters, geographic coordinates, emission rates, etc. for major point sources in HKSAR and mainland China. The point source processor within EMS-95 imports the point source emission inventory files and produces a GIS point source coverage. This coverage is then overlaid with the grid coverage created in the grid definition process to assign the correct grid cell information from the grid coverage to the point source file. These data are then used to create a modified point source input file that contains the pollutant emission information, as well as the state, county, and grid cell information, all of which is used in the point source emissions model.

3.5.23 Emissions from smaller, more numerous point sources were categorized as area sources in the emission inventory and apportioned to the model grid using spatial surrogates as indicated in the preceding section.

Temporalization

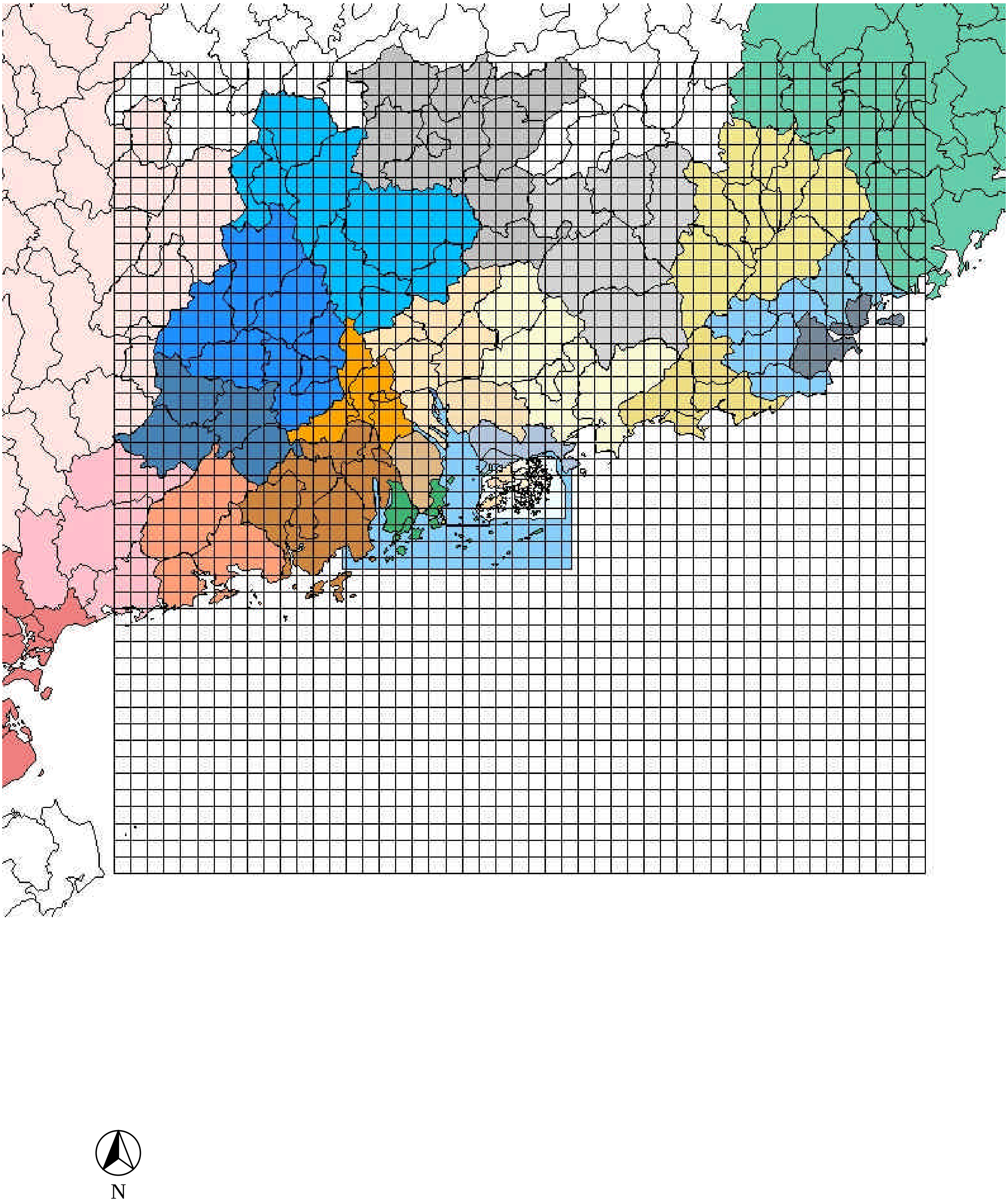
3.5.24 Temporal profiles are used to break down annual emissions into hourly emission rates based on the type of activity using cross-reference tables that define monthly, weekly, daily, and hourly activity profiles. Note that the daily temporal profiles have been chosen to always be a weekday even if the episode modelled falls on a weekend.

3.5.25 For major point sources, a common "flat" temporal profile was used for all sources (i.e., constant emissions 24 hours a day, 7 days a week, 4 weeks a month, and 12 months a year).

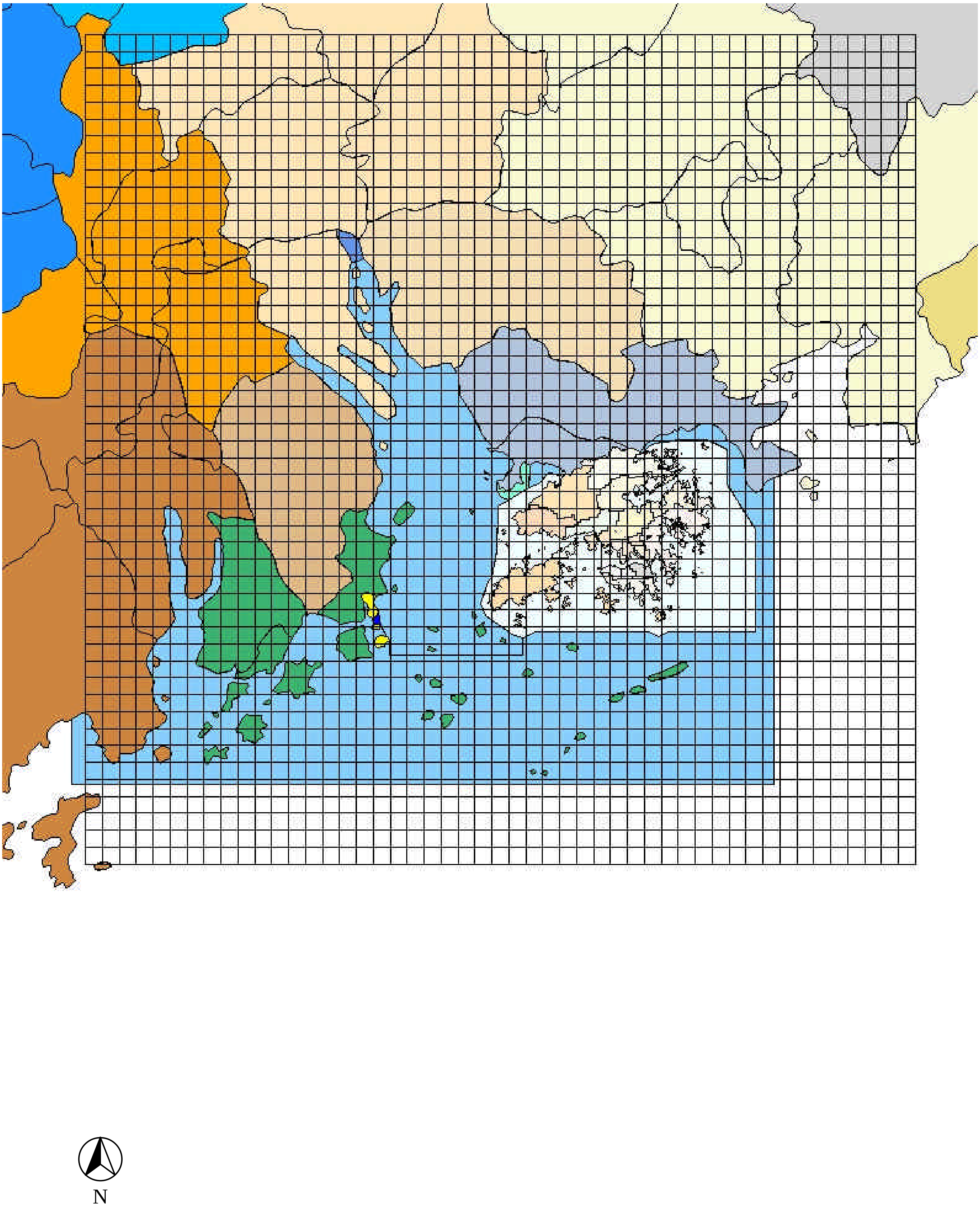
3.5.26 For area sources, including marine and motor vehicles, the same temporal factors used previously in PATH were adopted in this Study. As mentioned previously, some new ASCT / SCC codes were used in this study that did not exist in the original PATH model files. For these emission sources, temporal profiles were assigned to these sources by matching parent SCC / ASCT codes (i.e., the first 3 or 4 digits of the ASCT / SCC code) for the new sources to those in the original PATH model files. Where no match in parent ASCT / SCC codes could be found, knowledge about the type of emission source was used to assign an appropriate temporal profile to that source. In some cases, default "flat" temporal profiles were used.

Speciation

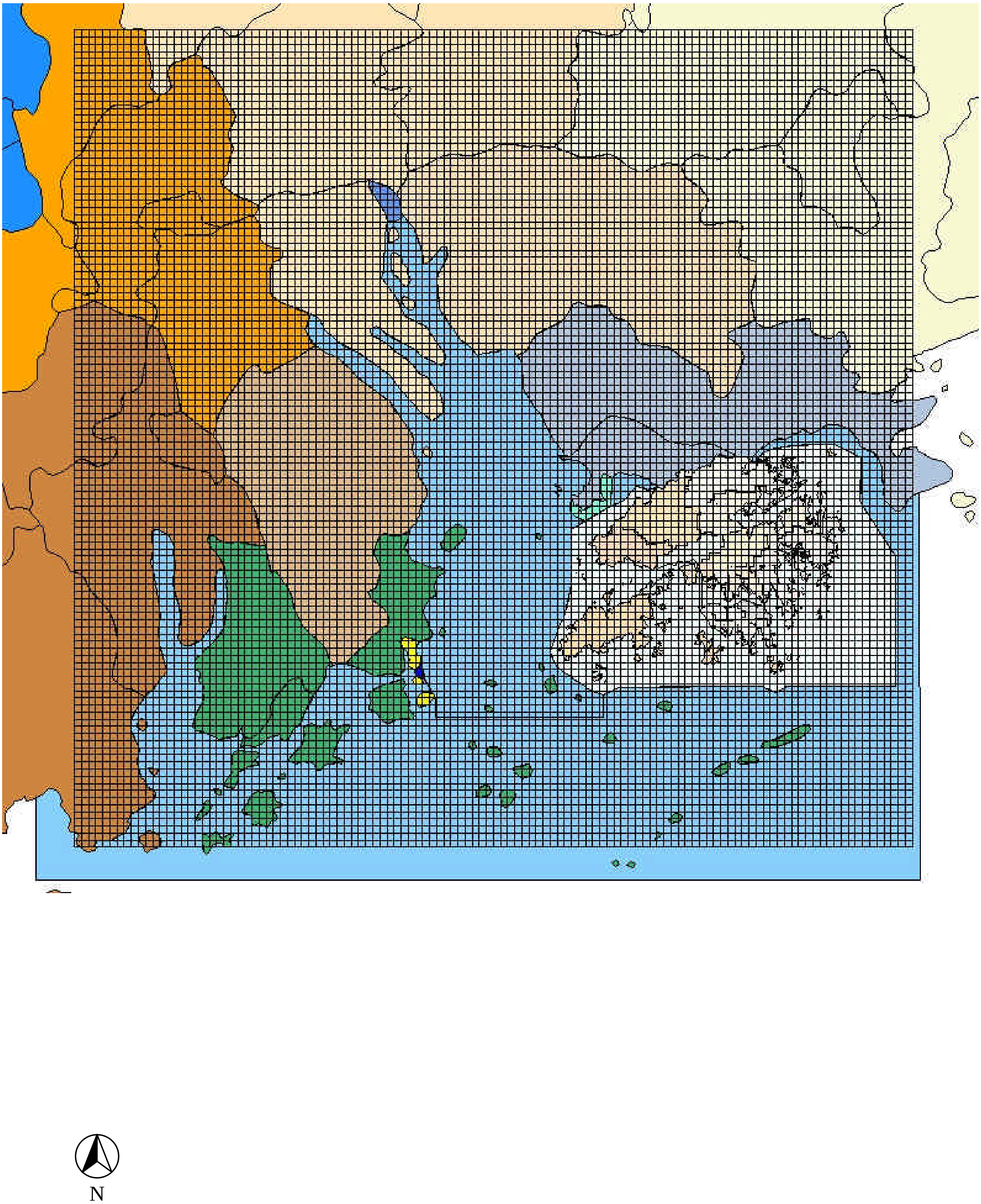
3.5.27 The present Study used the same modules for chemical speciation as used previously in PATH. Some new ASCT / SCC codes were used in this Study that did not exist in the original PATH model. For these emission sources, speciation profiles were assigned to these sources by matching parent SCC / ASCT codes (i.e., the first 3 or 4 digits of the ASCT / SCC code) for the new sources to those in the original PATH model files. Where no match in parent ASCT / SCC codes could be found, knowledge about the type of emission source (e.g., fuel being combusted, etc.) was used to assign an appropriate temporal profile to that source.



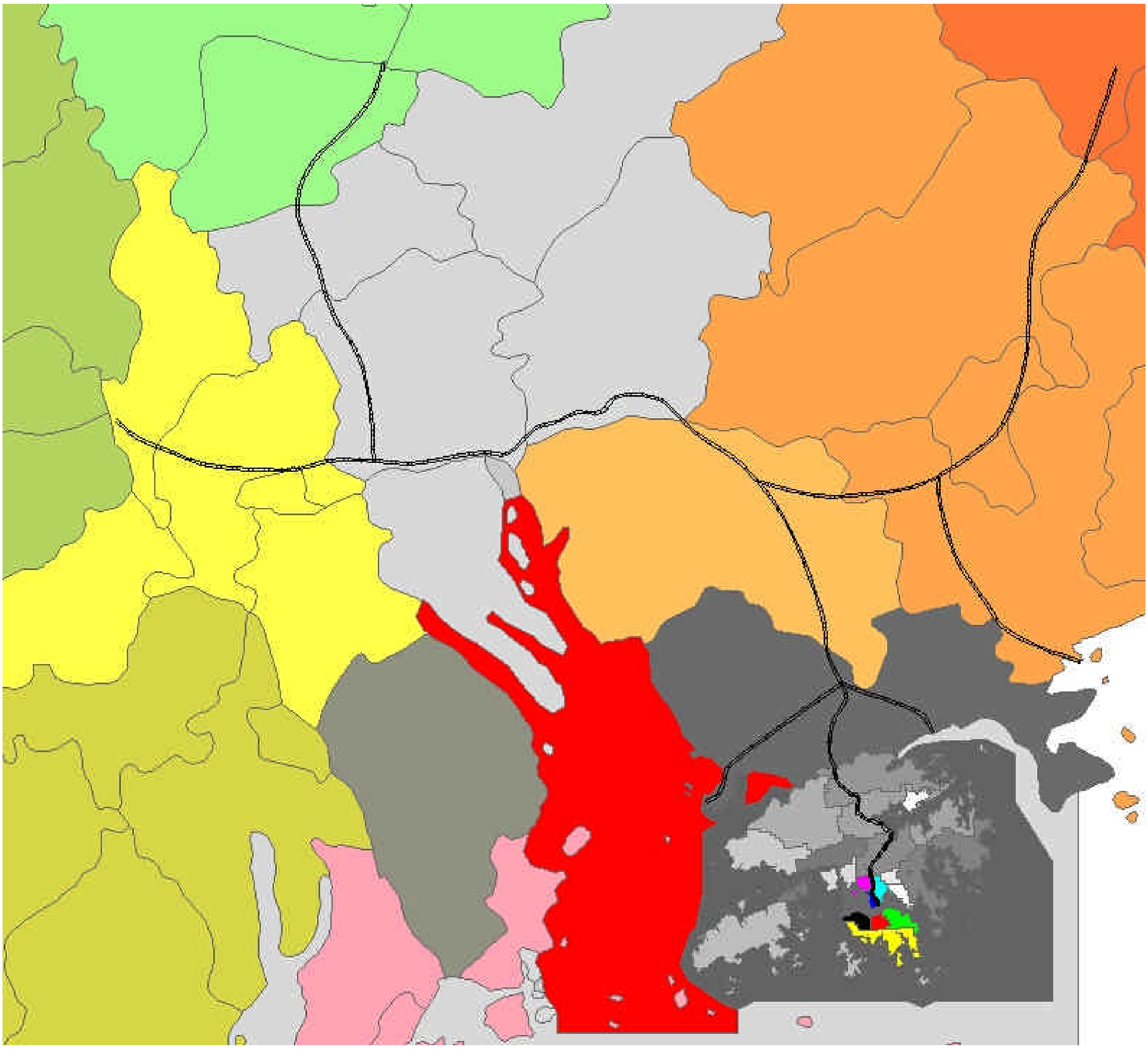
CH2M HILL (China) Limited	**Project:** Agreement No CE106/98 Study of Air Quality in the Pearl River Delta Region	Environmental Protection Department
	Title: 13.5 km EMS-95 Model Domain of the Study	
	Figure: 3-1 — **Scale:** NTS	



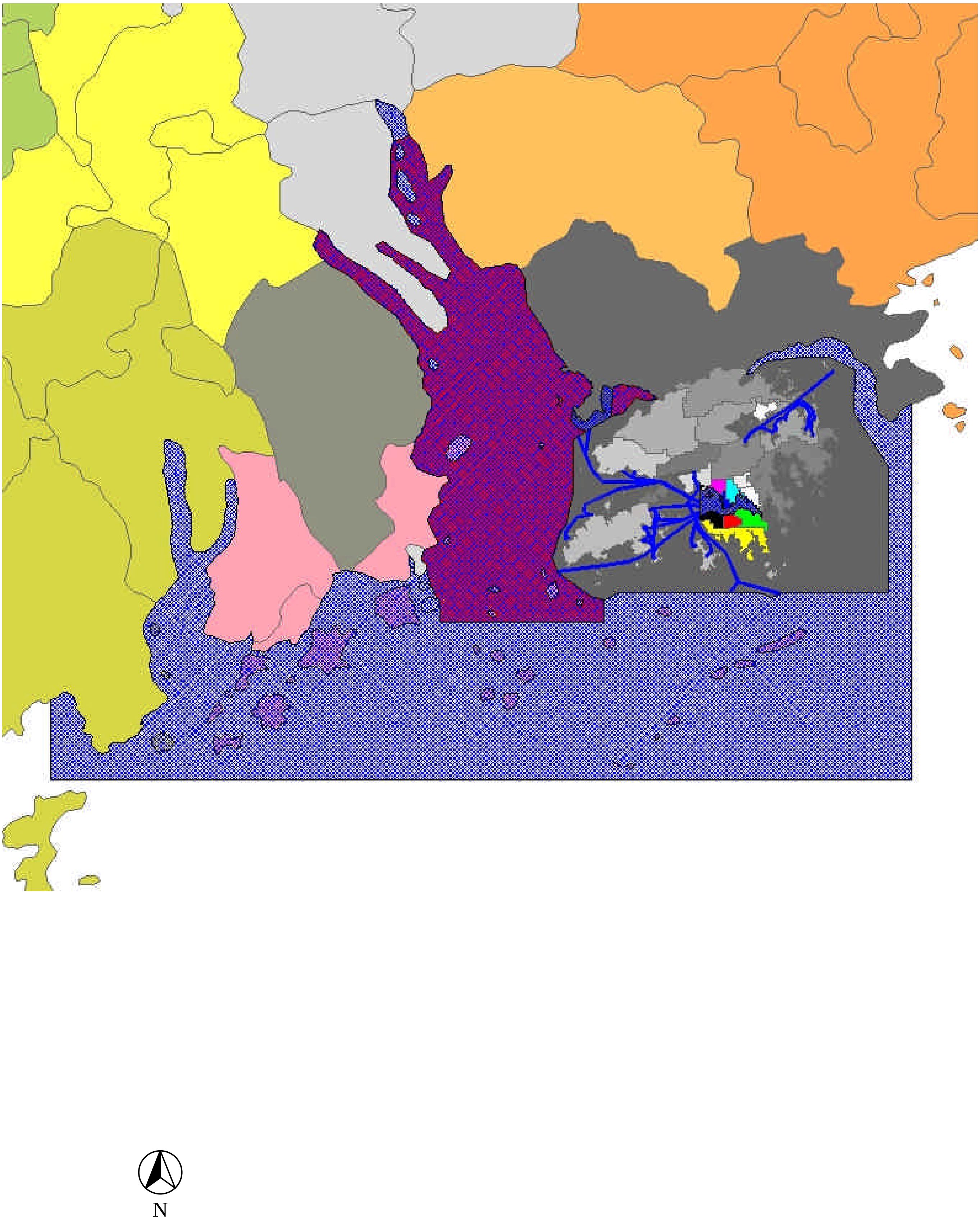
CH2M HILL (China) Limited	Project: Agreement No CE106/98 Study of Air Quality in the Pearl River Delta Region	Environmental Protection Department
	Title: 4.5 km EMS-95 Model Domain of the Study	
	Figure: 3-2 / Scale: NTS	



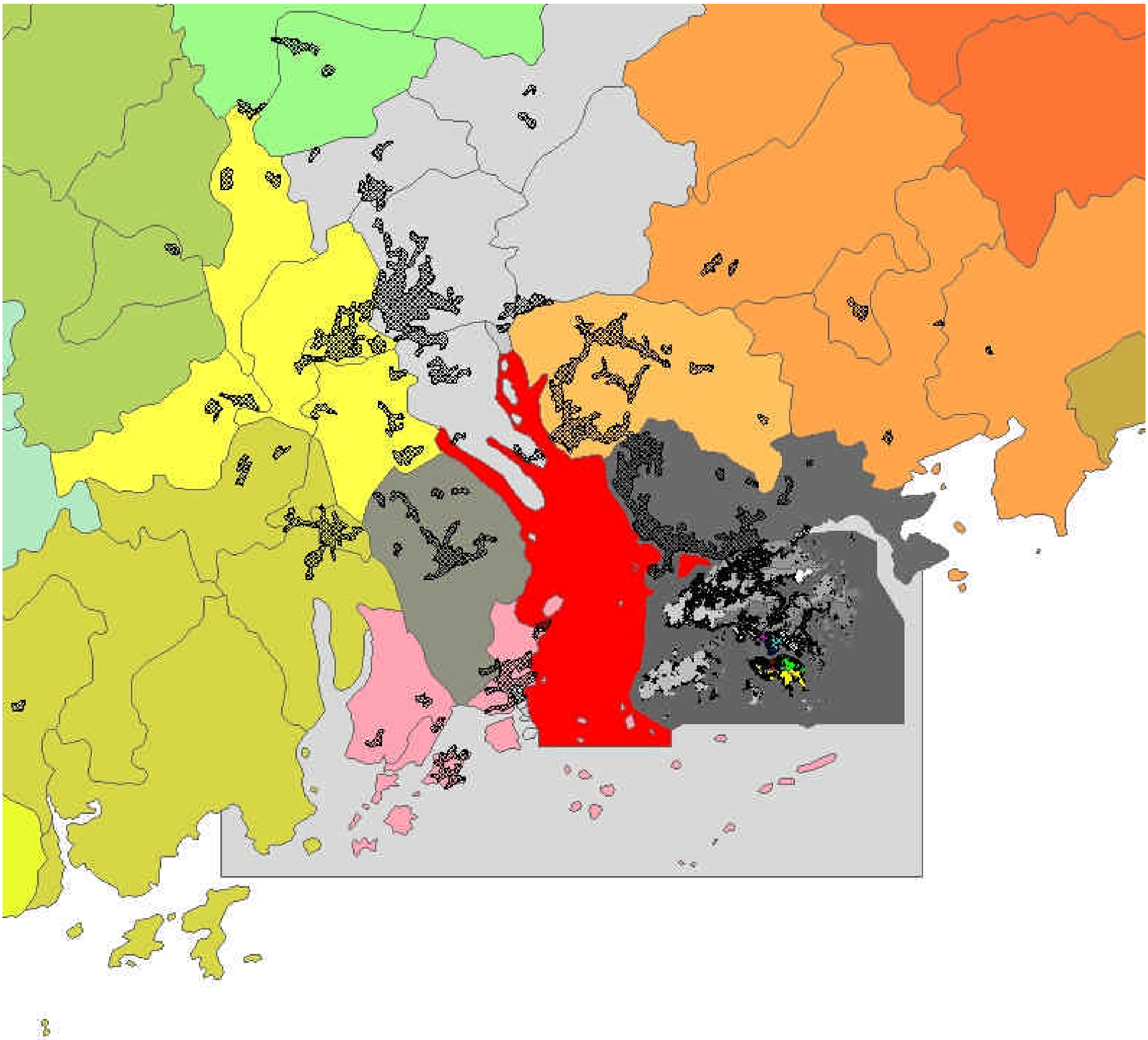
CH2M HILL (China) Limited	**Project:** Agreement No CE106/98 Study of Air Quality in the Pearl River Delta Region	Environmental Protection Department
	Title: 1.5 km EMS-95 Model Domain of the Study	
	Figure: 3-3 **Scale:** NTS	



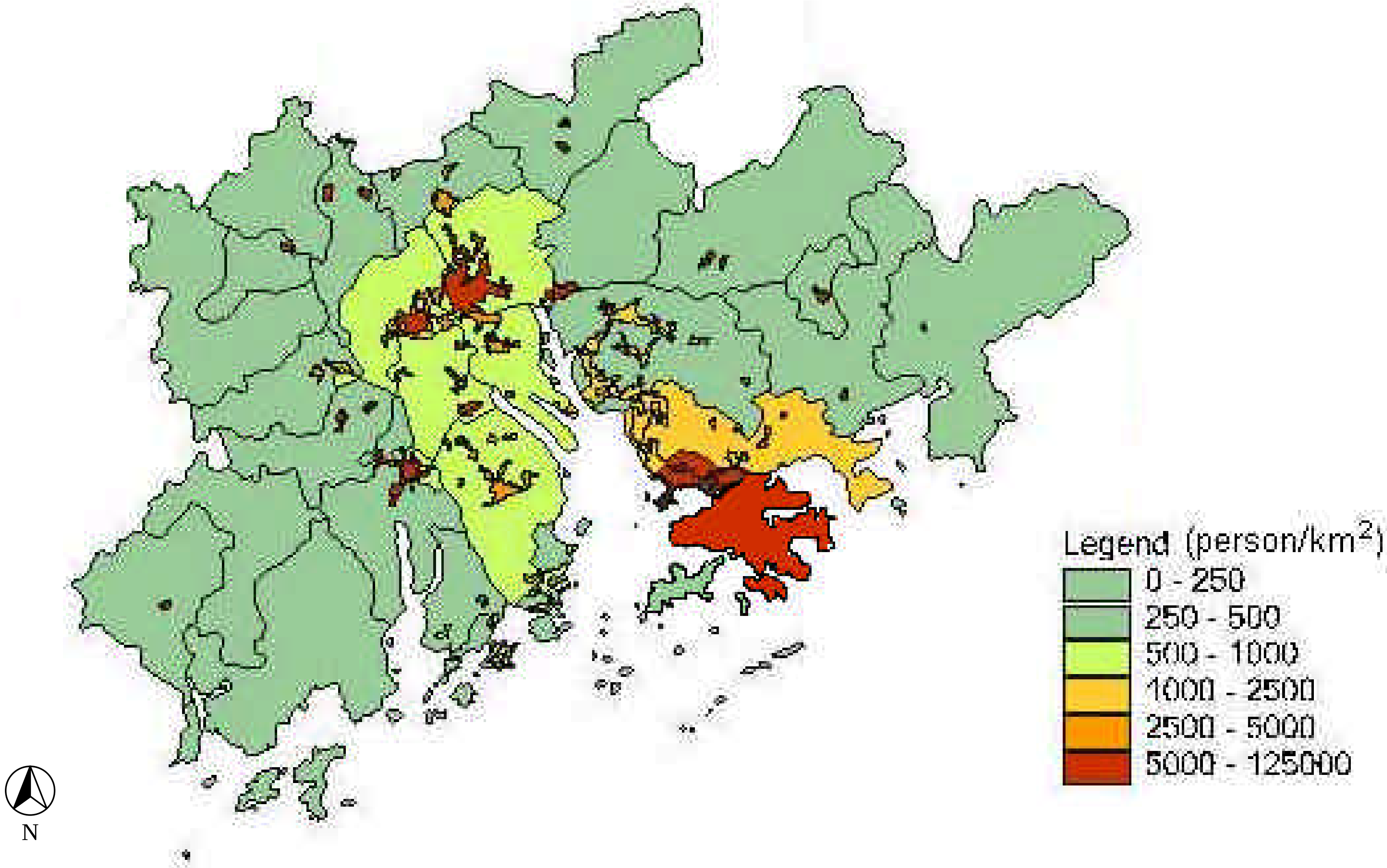
CH2M HILL (China) Limited	**Project:** Agreement No CE106/98 Study of Air Quality in the Pearl River Delta Region	Environmental Protection Department
	Title: Rail Surrogate for the Region of the Study	
	Figure: 3-4 **Scale:** NTS	



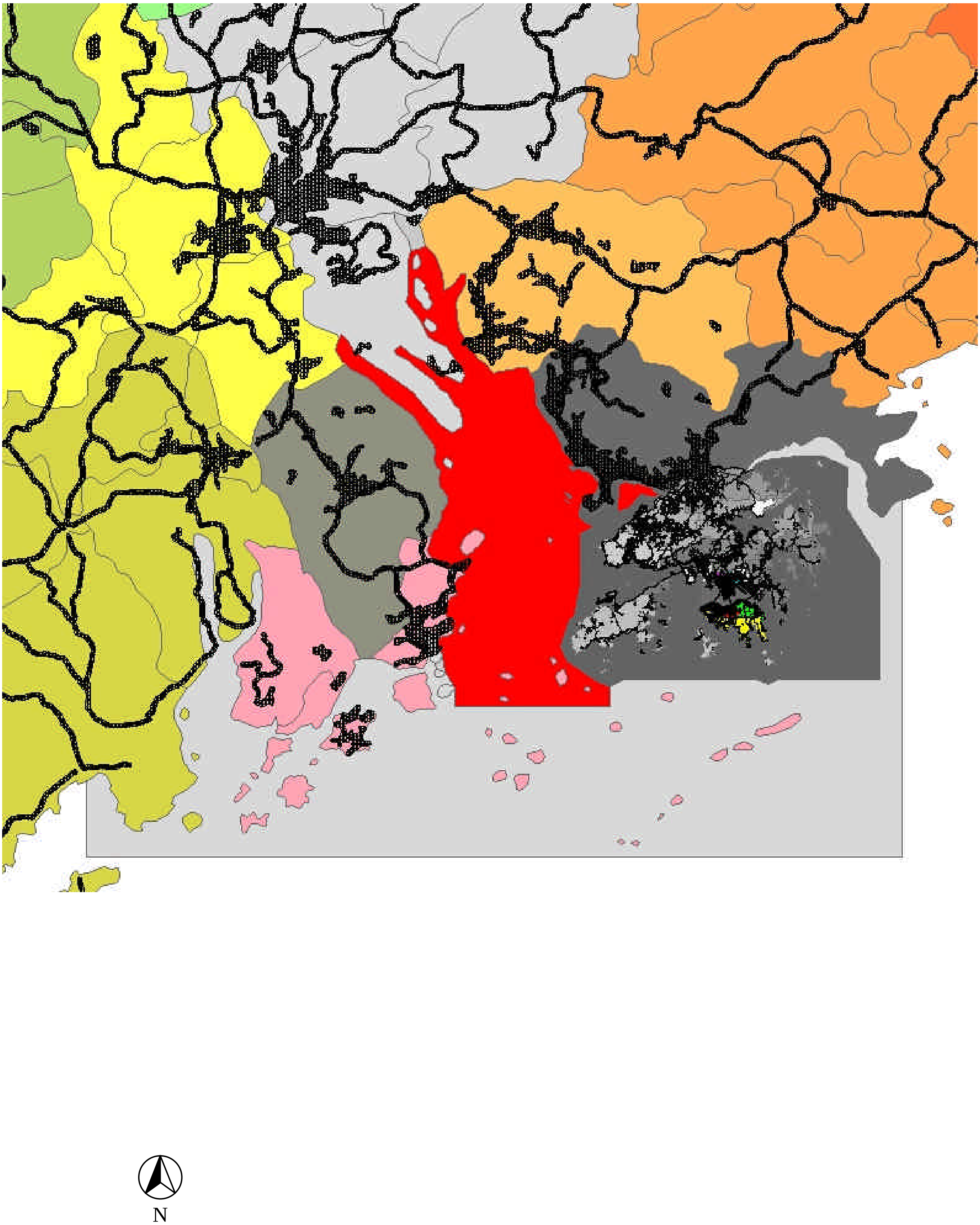
CH2M HILL (China) Limited	**Project:** Agreement No CE106/98 Study of Air Quality in the Pearl River Delta Region		Environmental Protection Department
	Title: Marine Emissions for the Region of the Study		
	Figure: 3-5	**Scale:** NTS	



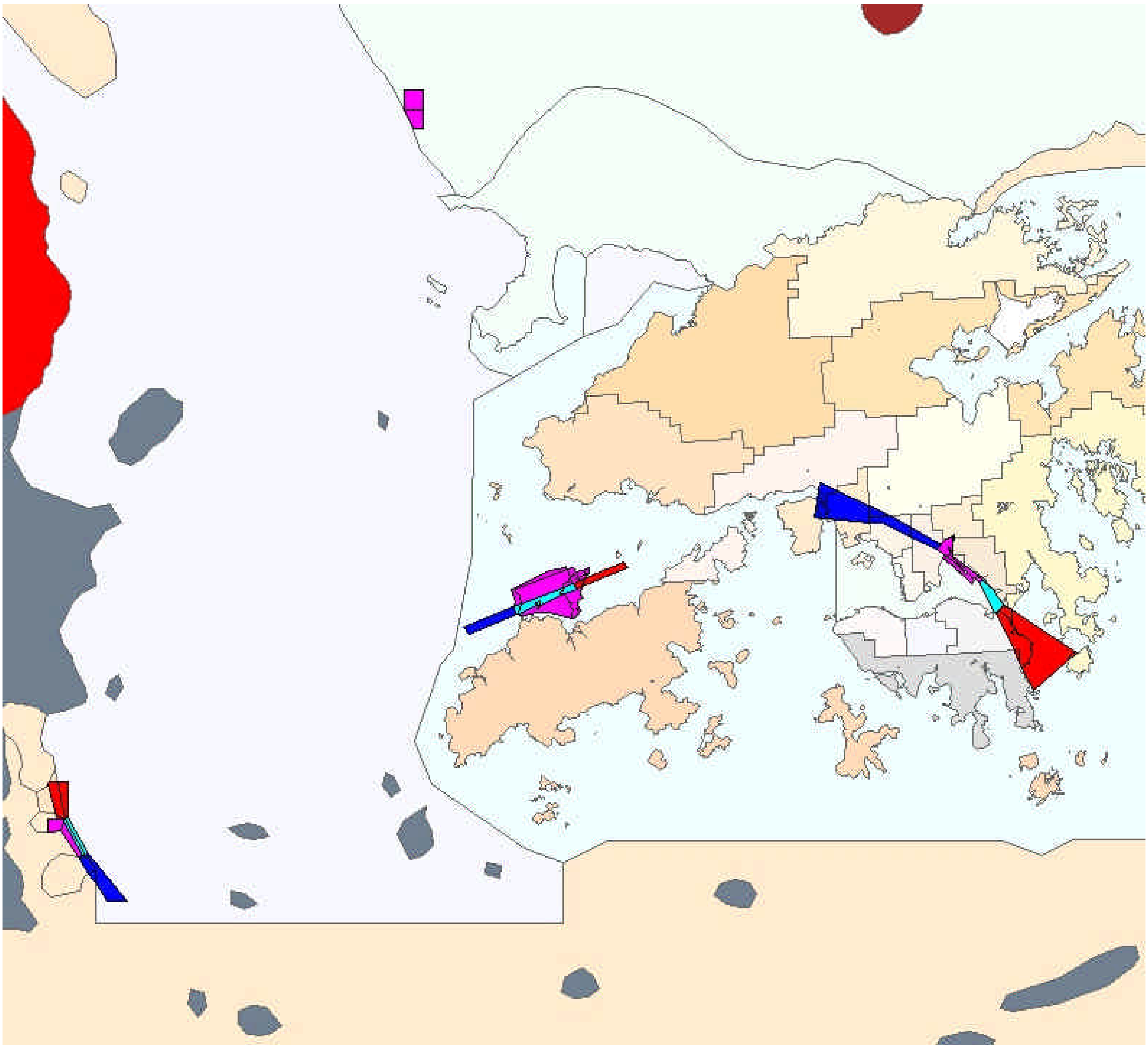
CH2M HILL (China) Limited	Project: Agreement No CE106/98 Study of Air Quality in the Pearl River Delta Region		Environmental Protection Department
	Title: County Wide Emissions for the Region of the Study		
	Figure: 3-6	Scale: NTS	



CH2M HILL (China) Limited	Project: Agreement No CE 106/98 Study of Air Quality in the Pearl River Delta Region		Environmental Protection Department
	Title: County Boundaries for the Region of the Study	Figure: 3-7 Scale: NTS	



CH2M HILL (China) Limited	Project: Agreement No CE106/98 Study of Air Quality in the Pearl River Delta Region	Environmental Protection Department
	Title: Road Surrogate for the Region of the Study	
	Figure: 3-8 / Scale: NTS	



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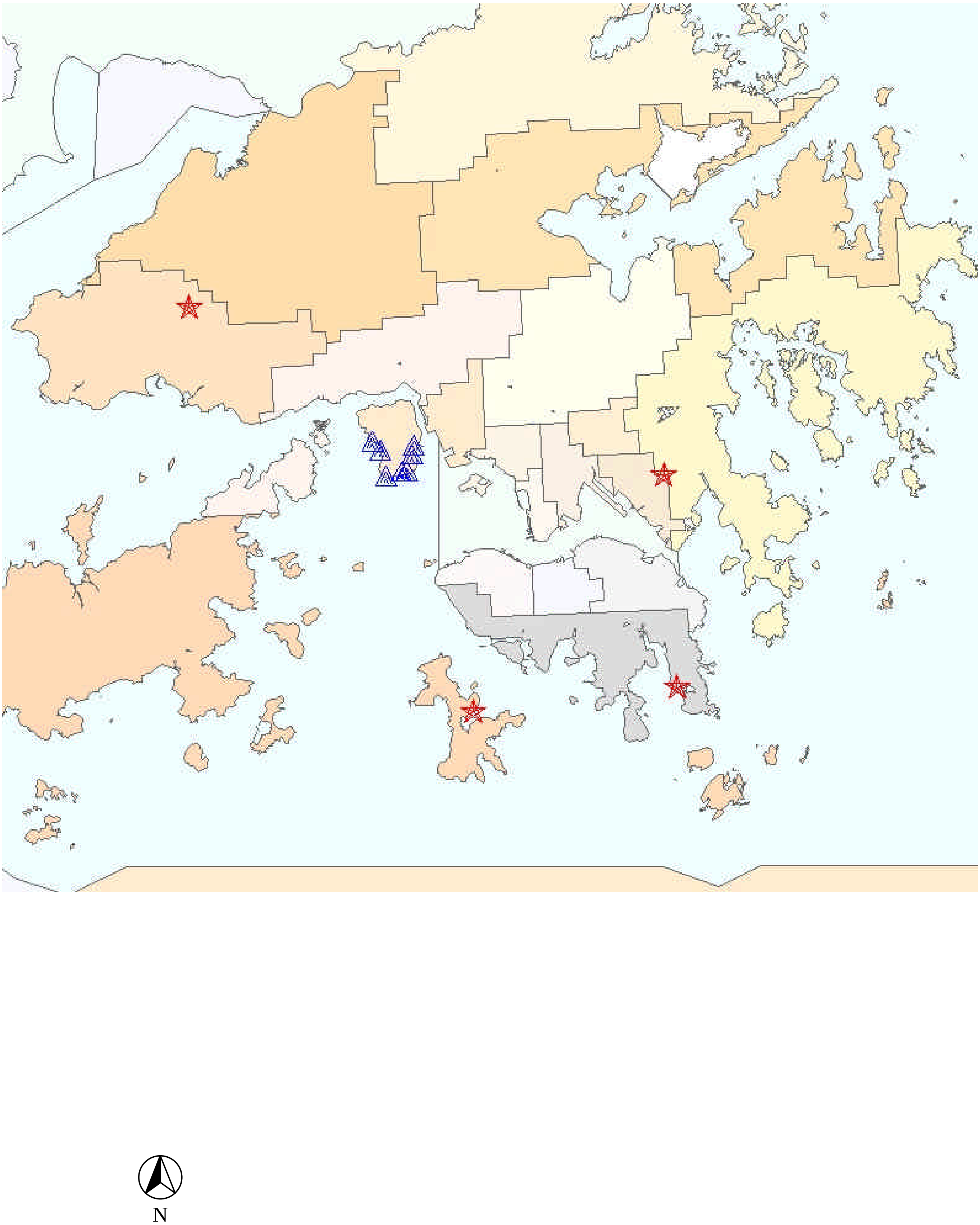
CH2M HILL (China) Limited	Project: Agreement No CE106/98 Study of Air Quality in the Pearl River Delta Region		Environmental Protection Department
	Title: Aircraft and Airport Spatial Surrogate for the Region		
	Figure: 3-9	Scale: NTS	



CH2M HILL (China) Limited	**Project:** Agreement No CE106/98 Study of Air Quality in the Pearl River Delta Region	Environmental Protection Department
	Title: Major Quarries and Fuel Terminals in HKSAR	
	Figure: 3-10 / **Scale:** NTS	

4 AIR QUALITY MODELLING

4.1 Background

4.1.1 Air quality modelling was conducted using SAQM (SARMAP Air Quality Model), originally developed by the California Air Resources Board (CARB) for use in the San Joaquin Valley Air Quality Study (Chang, et al., 1997).

4.1.2 The purpose of the air quality modelling is to provide predictions of ground level concentrations of Respirable Suspended Particulate (RSP), ground-level ozone and nitrogen dioxide under the selected meteorological episodes, for various emission years and mitigation scenarios.

4.1.3 The PATH developers made several fundamental changes to the SAQM code to meet the needs of PATH, including modules for gas-phase formation of sulfate and nitrate aerosols, transport and deposition of primary aerosol, and modifications to the diffusion algorithms (Cope et al., 2000). The modified version of SAQM was used in the present study. This version of SAQM uses the Carbon Bond IV (CBIV) chemical mechanism.

4.1.4 The PATH developers also made changes to SMPP, the meteorological preprocessor for SAQM. This preprocessor takes the output from MM5 and reformats it for input to SAQM, as well as calculating various derived meteorological parameters that are required by SAQM. SMPP was modified to eliminate some redundancy between MM5 and SAQM, calculate deposition velocities for aerosol species, and correct a mass conservation problem that arose from running MM5 in a two-way nested mode (Cope et al., 2000).

4.1.5 Modifications were also made to EPS, the emission data preprocessor for SAQM. PATH uses EPS to reformat output from EMS-95 into SAQM-ready format. The modifications were made to allow for modelling of particulate emissions and included algorithms for processing ammonia emissions and estimating sea salt emissions.

4.1.6 As indicated previously, emission processing and air quality modelling was not performed for the 13.5 km domain for any of the future year scenarios.

4.2 SAQM Methodology

4.2.1 The final output from the MM5 modelling for the 13.5, 4.5, and 1.5 km domains was processed through the PATH version of the SAQM meteorological preprocessor, SMPP. This was done for each of the eight meteorological episodes. Because the meteorology does not change for the future year scenarios, this procedure was run only once per domain, per episode.

4.2.2 The final output from the EMS-95 modelling for the 13.5 km, 4.5 km and the 1.5 km domain was processed through the PATH version of the SAQM emission preprocessor, EPS. This processor was run for all domains and episodes for the Base Year (1997). Because emissions are different for future years, EPS was re-run using the modified emissions data (i.e., grown) for the 4.5 and 1.5 km domains for each episode, for the BAU 2010 growth and control scenario.

4.2.3 SAQM was run on the 13.5, 4.5 and 1.5 km domains for each of the eight episodes for the base year, and on the 4.5 and 1.5 km domains for the future 2010 BAU growth and control scenario. SAQM was run in a one-way nested mode, consistent with the approach previously used in PATH (Cope et al., 2000). As per the PATH model, the SAQM model time step was set to one hour with the advection time step (IDT) set to 300, 150, and 60 seconds for the 13.5, 4.5, and 1.5 km domains, respectively. All other options (e.g., horizontal diffusion coefficient, cloud process options, etc.) remained the same as for the previous PATH modelling.

4.2.4 For all of the runs of this Study, there was no addition inventory of CO input into the model. However, there was CO in the 40.5 km domain inventory as background and hence exist in the subsequent runs of the lower domains. The boundary and initial conditions derived from the largest 40km domain and used as input to the 13.5 km domain run included background CO levels. In this way, CO concentrations from the 40.5 km domain runs were carried down to the 13.5, 4.5, and 1.5 km domains as background levels in the initial and boundary condition files.

4.2.5 This like many other carbon compounds in the atmosphere, CO can be oxidized by the OH radical, which ultimately leads to increased production of ozone. The role of CO in ozone formation during smog events, however, is generally considered to be minor. Although it can be present at much higher concentrations than other carbon compounds, its reactivity with the OH radical is orders of magnitude lower than some of the other compounds such as, for example, alkenes emitted by automobile exhausts and isoprene emitted by vegetation. A recent study conducted in Baltimore, Maryland, indicated that 59% lower levels of CO and 27% lower levels of anthropogenic VOC's on weekends, as compared to weekdays, led to only a 13% reduction in overall reactivity with the OH radical (Vukovich, F. M., 2000) Journal of Air & Waste Management Association. The reason for this is that isoprene from vegetation remains at sufficient levels to maintain the overall reactivity level over the weekend when vehicle traffic is reduced. This study supports the general belief that CO plays only a minor role in ozone production during smog events. In studies of the San Joaquim Valley in California using the SAQM model, it was found that 5 to 10% changes in CO emissions led to a 1-3 ppb change in simulated ozone, while 30 to 50% changes in CO emissions led to a 6-8 ppb change in ozone (pers. comm. with Saffett Tanrikulu of CARB, June, 2000). The simulated contribution of emissions in the study domain to the total predicted CO level was between 1 and 3 times the background concentration in that study. This study also indicates that the role of CO in ozone formation is relatively minor.

4.3 Quality Control

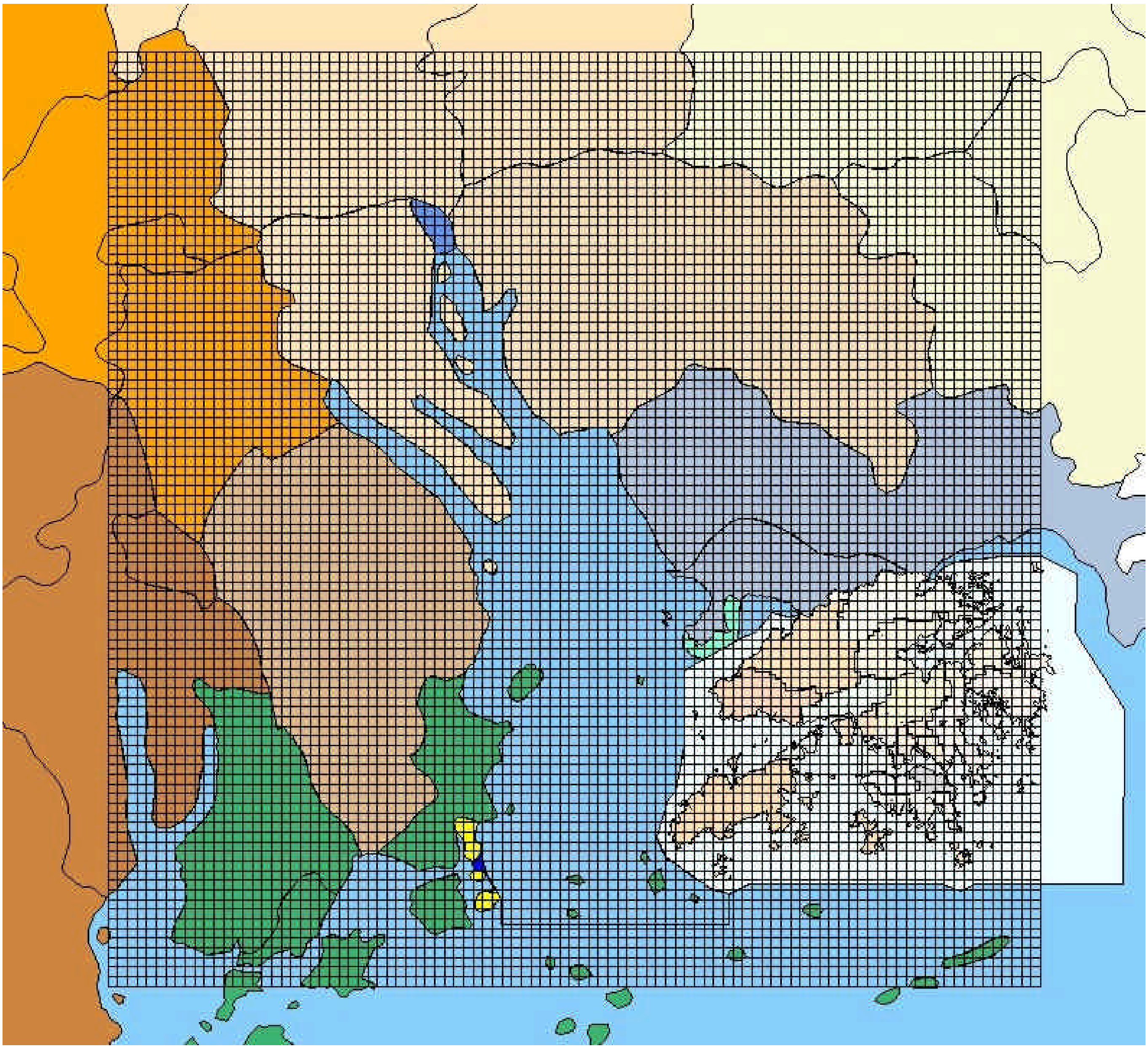
4.3.1 Numerous checks of input data, preprocessing steps and the SAQM outputs were performed. This included detailed checking of the data used in SMPP and EPS, checking the scripts used to generate the gridded, temporalized, and speciated emissions data, checking the scripts used in processing initial and boundary conditions, checking the scripts for running SAQM, checking the output log files for SMPP, EPS, and SAQM and checking the model results against observational data and previous model runs performed during the development of PATH. Standard SAQM performance check sheet is shown in Table 4-1

Table 4-1 Standard SAQM Performance Check Sheet

SAQM Check Sheet			
Project No.: Project Name: Date: Run No.: Run Name:			
Item	Done By	Chk'd By	Date
SPLITING OF MM5 FILES The MM5 files have to be split into 12-hour-simulation files before being submitted to the program SMPP -Check that the right episode and grid resolution were chosen -Check that the right number of files is produced			
PREPROCESSING OF MET DATA (SMPP) The meteorological data files produced by MM5 are converted to the format required by the air quality model -Check user control file for correct specification of parameters -Check that the two met data files containing even hour and odd hour data as well as the file containing photolysis rates have been created -Check the log file for successful completion			
CONVERSION OF EMS-95 SPECIATION FILES The EMS-95 emissions inventory data files are converted to binary unformatted files -Verify that the right episode, grid was specified -Check that binary files are created			
PREPROCESSING OF EMISSIONS DATA (EPS) The binary unformatted data files are used by the program EPS to generate SAQM ready files -Check for correct specifications of parameters -Check that the right SAQM met files associated with the particular run are identified -Check log file for successful completion			
EXECUTION OF SAQM Using information from the preprocessors, the air quality is modelled -Verify if right parameters are used in the user control file -Check log file for successful completion			
POSTPROCESSING OF DATA -Visualize and examine SAQM output for consistency			

4.4 Model Domains

4.4.1 The vertical resolution in SAQM was the same as that used in the previous SAQM modelling in PATH (15 levels) for all domains. The SAQM horizontal model grids for both the 13.5 and 4.5 km domains were the same as those used in the previous PATH modelling. The 1.5 km SAQM domain is situated within the 1.5 km EMS-95 domain and covers a 21,170 km^2 area over the heart of the Pearl River Delta. The 1.5 km SAQM domain is comprised of 97 columns by 97 rows and covers the major urban areas of Hong Kong, Macau, Shenzhen, Zuhai, and Guangzhou. The 1.5 km SAQM model domain is shown in Figure 4-1.



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Project: Agreement No CE106/98 Study of Air Quality in the Pearl River Delta Region

Title: 1.5 km SAQM Model Domain for the Study

Figure: 4-1

Scale: NTS

Environmental Protection Department

4.5 Model Runs Scenarios

4.5.1 One of the objectives of the modelling task was to predict the trends of the likely future air quality based on the future emissions formulated in the Study. Three modelling scenarios as listed below, each with its own purpose, had been performed for formulating the most cost-effective regional air quality control and for demonstrating their effectiveness in emission reduction potential.

Base year runs: 1997

4.5.2 The base year SAQM runs were performed using the Base Year (1997) emission inventory developed as part of this Study. The reason for running the base year is to provide a benchmark or baseline which can be used to examine the impacts of various emission control strategies on air ambient quality. As such, the modelling results are intended to be qualitative in nature.

Future year runs: 2010

4.5.3 A series of the control measures had been committed by the HKSAR and the Guangdong Province Government for improving the air quality in the Region. Emission inventories complied for the 2010 future year indicated there will be significant increase of emissions from the dominant sources due to the strong economic growth in the region despite the committed control measures by the Governments. The likely future air quality in the region created by the current growth and control measures shall be demonstrated by this set of model runs.

Future year runs: Trial

4.5.4 The future year Trial runs were a sensitivity test performed prior to the modelling of Control scenario. Its purpose was to study how air quality would react should a certain level of control over the emissions is exerted. In other words, it helped to demonstrate the relationship among the effect of control measures, air emissions, and air quality in this Region. The results of this trial was an intermediate steps that facilitated the formulation of suitable control measure to achieve an improved air quality in terms of general compliance with the air quality objectives and standards.

Effects of Control measures: Control scenario

4.5.5 In the formulation of suitable control measures, the emission reduction potential of the control measures were being calculated with an estimated penetration rate to demonstrate their effects on the likely future regional air quality. Without the model run results, it is not confident to conclude the proposed list of control measures and their penetration rate as being sufficient and effective to reduce the regional air quality impact down to a level that would comply with the air quality standards in the Study area. The model also helped to confirm and establish the target emission level for the Region. The effect of the proposed control measures could be visualised by the model results and at the same time the improvement of the regional air quality could be quantified.

Future year Sensitivity runs: 1) NOx-restraining & 2) No Manmade VOC scenarios

4.5.6 The future year Control scenario demonstrated that the regional air quality control measures would be improved in the future, nevertheless, a general compliance of the ozone concentration in the region still not achieved. In order to evaluate the photochemical reactions among the regional pollutants, a sensitivity run was performed to visualize the effect of drastic control measures on pollutant levels in the future. In this scenario, NOx was reduced to a minimal, showing a result that could be achieved theoretically. These control measures were selected for the most significant emission sectors such as energy, industrial processes and motor vehicles, in which a control measure penetration rate of 100% was assumed.

4.5.7 The future year No man made VOC SAQM runs were performed as another sensitivity run to demonstrate the photochemical effect of biogenic VOC and NO_x emissions on the regional ozone levels. This demonstration was done by using the same emission inventory as in the future year NO_x-restraining scenario except all of the manmade VOCs in the emission inventory were set to zero. The biogenic VOCs emissions were estimated as 207,000 tons per year based on landuse. Since the antropogenic VOCs for the future year NOx-restraining scenario is 135500 tons per year on the entire domain, the total reduction in domain-wide VOCs is then estimated to be about 40%.

4.6 Model Evaluation

Performance Evaluation

4.6.1 Extensive performance evaluations of the SAQM model were conducted by the previous PATH consultants (ERM, 1999) for the previous 1.5 km domain covering the HKSAR. The ability to perform further evaluation for the expanded 1.5 km domain in the present Study is limited for the following reasons: (1) the air quality variables of interest (RSP and ozone) were not being measured in the PRDEZ at the time of the meteorological episodes being studied; and (2) in the present Study, meteorological data from the early 1990's are being combined with emission data for 1997, which leads to results that are not directly comparable to air quality measurements taken during the episodes. For these reasons, a complete evaluation of the SAQM runs on the expanded 1.5 km domain was not performed as part of the present study. However, comparisons were made between SAQM runs for the 1997 Base Year and selected NO_2, ozone and RSP data from HKSAR as part of standard quality assurance / quality check procedures. Comparisons were made to the original PATH results over HKSAR for the 1997 Base Year results to ensure general reproducibility of model results.

Model Result Assessment

4.6.2 In this Study, the modelling results provided information on the air quality in future and under the control scenario. The analysed results also helped to assess the effectiveness of recommended control measures in achieving the air quality standards for this Region.

4.6.3 In 1997, the base year of this Study, EPD has conducted air quality monitoring at 8 stations in HKSAR located at:

- Kwun Tong
- Sha Tin
- Tai Po
- Yuen Long
- Sham Shui Po
- Central/Western
- Tsuen Wan
- Kwai Chung

4.6.4 It is observed from the air quality monitoring data that a number of stations did not comply with the air quality objectives. The non-complying stations recorded maximum pollutant concentrations in the range of 2-16% (average 8%) over the AQO limits. Therefore, to demonstrate a scenario of which the air quality would comply with the AQO in the future, one had to formulate the control measures so that the emission reduction achievable would be sufficient to lower the maximum pollutant concentrations in a comparable range. With annual NO_2, annual RSP, hourly NO_2 and hourly O_3 as indicators, modelling results showed that pollutant concentrations in terms of annual NO_2, annual RSP, hourly NO_2 and hourly O_3 would be reduced by 10-30% (average 20%). However, the predicted air quality at some locations would just meet the AQO. Thus the recommended control measures would be the minimum target for the Region.

4.6.5 For PRDEZ, historic monitoring data is not available. Therefore the monitoring results could not be assessed in the same way as for HKSAR. Based on the information concluded for HKSAR and the modelling results for PRDEZ, it was extrapolated that general areas in PRDEZ could also meet the NAAQS in term of annual RSP and NO_2, except for the hotspots with elevated pollutant concentrations.

5 REFERENCES

- Cai, X.-M. And D. G. Steyn, 1996: *Mesoscale Meteorological Modelling Study of the Lower Fraser Valley, B.C., Canada from July 17 to 20, 1985*, in Modelling of Ground-Level Ozone in the Lower Fraser Valley, Canadian Council of Ministers of the Environment (CCME), ISBN 1-896997-08-2.
- Cope, M., M. Buergers and M. Olliff, 2000: *Application of the SARMAP Air Quality Model (SAQM) to the Modelling of Air Pollution in Hong Kong for the PATH Study*, 11th Joint Conference on Applications of Air Pollution Meteorology with the A&WMA, Long Beach, California, 9-14 January, 2000.
- Chang, J. S., S. Jin, Y. Li, M. Beauharnois, C.-H. Lu and H.-C. Huang, 1997: *The SARMAP Air Quality Model, Final Report*, California Air Resources Board.
- EPD, 1997: Territory-wide Air Quality Modelling System: Proposed Modelling Events and Scenarios, Hong Kong Environmental Protection Department, Working Paper B1.
- EPD, 1999: *Working Paper E-2: System Validation*, Hong Kong Environmental Protection Department.
- EPD 1999b: *Working Paper E-3: Model Demonstration*, Hong Kong Environmental Protection Department.
- Grell, G. A, J. Dudhia and D. R. Stauffer, 1995: *A Description of the Fifth-Generation Penn State/NCAR Mesocale Model (MM5)*, NCAR Technical Note, NCAR/TN-398+STR.
- Guo, Z., N. K. Lolk and S. Douglas, 1996: *Application of the SAIMM for the Lower Fraser Valley, for 1-6 August, 1993*, Environment Canada, Vancouver, B.C.
- Hedley, M., R. McLaren, W. Jiang and D. L. Singleton, 1996: *Evaluation of the MC2-CALGRID Photochemical Modelling System*, in Modelling of Ground-Level Ozone in the Lower Fraser Valley, Canadian Council of Ministers of the Environment (CCME), ISBN 1-896997-08-2.
- NCAR, 1997: PSU/NCAR Mesoscale Modelling System Tutorial Class Notes: MM5 Modeling System Version 2, National Center for Atmospheric Research, Boulder, Colorado.
- Physick, W. L. and J. A. Noonan, 2000: *Mesoscale Modeling with MM for the Path Study (Pollutants in the Atmosphere and their Transport over Hong Kong)*, 11th Joint Conference on Applications of Air Pollution Meteorology with the A&WMA, Long Beach, California, 9-14 January, 2000.
- Seaman, N. L., D. R. Stauffer and A. M. Lario-Gibbs, 1995: A Multiscale Four-Dimensional Data Assimilation System Applied in the San Joaquin Valley during SARMAP: Part I: Modeling Design and Basic Performance Characteristics, Journal of Applied Meteorology, 34, pp. 1739-1761.
- Tesche, T. W. and D. E McNally, 1996: Evaluation of the MM5 Model for Three 1995 Regional Ozone Episodes over the Northeast United States, Southwestern Pennsylvania Clean Air Stakeholders Group.
- Tesche, T. W. and D. E. McNally, 1997: Final Evaluation of the MM5 Model for the 3-6 August 1990 SARMAP Episode over Central California, California Air Resources Board, Sacramento, CA.
- Wilkinson, J. G., C. F. Loomis, D. E. McNally, R. A. Emigh and T. W. Tesche, 1994: *Technical Formulation Document: SARMAP/LMOS Emissions Modeling System (EMS-95)*, Alpine Geophysics, AG-90/TS26.