A PC-Based Emission Database System for the Auckland Region

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ABSTRACT

An emission database system was developed on Microsoft Access for the Auckland, New Zealand region. The system was developed as part of the Auckland Air Emissions Inventory Upgrade conducted in 2000 for the Auckland Regional Council. The emission system was used for spatial and temporal allocations, speciation and projection of emissions for the Auckland inventory.

The system was designed for modelling emissions of carbon monoxide, carbon dioxide, oxides of nitrogen, sulphur dioxide, total suspended particles and volatile organic compounds. It was used to estimate emissions for 1998 and project emissions to 2011 and 2021. Emissions were estimated for two grids with resolutions of 3 km and 1 km, covering the whole Auckland region and Auckland central business district respectively.

The system was used to output data for use in photochemical modelling and export spatial data to a geographical information system (GIS). Input data for modelling can be generated for a weekday or weekend in any particular season. Gridded annual or hourly emissions can be generated for importing into a GIS.

The system allows easy changing of emissions data, such as for annual updates and modelling scenarios, and generation of data for use in modelling or GIS. The system accepts data for point sources, area sources, motor vehicles and biogenic sources. The emission data for each source consist of five components: annual emissions, spatial data, temporal data, projection factors and speciation data. The data in each component can be updated independently.

INTRODUCTION

Producing inventory data for air quality modelling in the past was very much an ad hoc process in which some Fortran programs were written to reformat inventory data for use in air quality models. Such programs were often written for use in a specific airshed and their use for other airsheds often required significant modification of the programs. Using such systems to produce input data for air quality models requires skill in programming, and considerable effort and time.

In 1993, GEMAP[1] was developed to process inventory data for photochemical modelling. GEMAP was renamed to EMS-95[2] when Alpine Geophysics took over the role of its development. EMS-95 is built on SAS® and ARC/INFO™ which runs on a UNIX workstation. EMS-95 differs significantly from other emissions modelling systems in that it automates the spatial processing of emissions by using a geographical information system (GIS) ARC/INFO. Although no programming skill is required to use EMS-95, a broad knowledge of UNIX, SAS and ARC/INFO is required to properly operate the system.

In Australia, various emission inventory data systems were developed for the National Pollutant Inventory[3]. However, these systems were developed for generating outputs of gridded annual emissions and did not produce outputs for air quality models.

In 1999, the Auckland Regional Council in New Zealand contracted Environment Protection Authority of Victoria to prepare an inventory of emissions to air, which was an update of previous work done for an 1993 inventory[4] based on spreadsheets and Fortran programs to generate model input data. The project required development of an emission database system which was user friendly, with outputs compatible with a GIS, specifically ArcView®, and the Calgrid urban dispersion model. The database developed was called the Auckland Emission System. Because of the need to be user friendly and compatible with ArcView, the system was developed on Microsoft Access®, which was widely available on personal computers.

This paper describes the design of the Auckland Emission System. The Auckland emissions inventory will be presented to illustrate the results obtained from the system.

OVERVIEW OF THE AUCKLAND EMISSION SYSTEM

General Overview

As well as being a database for accumulation of inventory data, the Auckland Emission System was designed to spatially distribute, temporally allocate, and speciate emissions for use in photochemical modelling. Emissions can be generated for a weekday or weekend in any particular season. Gridded annual or hourly emissions are also generated for importing into a GIS.

The system allows easy changes to be made to emissions data, such as for annual updates, different assumed scenarios, and generation of data for use in modelling or GIS. Point sources, area sources, motor vehicles and biogenic sources are covered. The emission data for each individual source consists of five components:

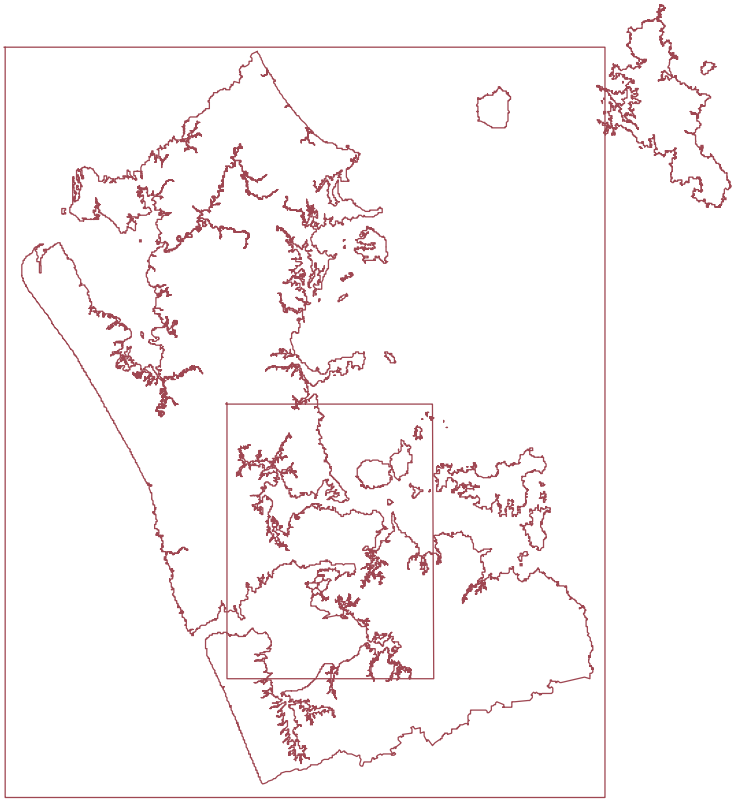
- annual emissions of each pollutant,
- spatial data to allow emissions to be allocated to grid cells,
- temporal data giving the diurnal, weekday/weekend and seasonal variation,
- projection factors defining emissions growth in future years, and
- speciation data which describes, for example, the chemical composition of organic matter in terms of photochemically active compounds, and the size distribution of particulate matter.

The data in each component can be updated independently, which allows great flexibility in data manipulation.

The Auckland Emission System provides emission estimates for carbon monoxide (CO), carbon dioxide (CO_2), oxides of nitrogen (NOx), sulphur dioxide (SO_2), total suspended particles (TSP) and volatile organic compounds (VOC). It estimates emissions for 1998 and projects emissions to 2011 and 2021. Emissions are estimated for two grids with resolutions of 1 and 3 km, as shown in Figure 1.

Although the system is developed to meet the requirements of the Auckland air emissions inventory upgrade, it can easily be redesigned to allow entries of different pollutants, projection years and grid dimensions.

Figure 1. Map showing the extents of the 3 km spacing (outer) and 1 km spacing (inner) grids in Auckland.



The User Interface

Figure 2 shows the menus of the Auckland Emission System. The Data menu allows viewing, entry or editing of data for industry, area source, motor vehicle, biogenic source and speciation. The Edit menu is a standard Access menu and contains various commands for editing records. The Quality Assurance menu performs quality assurance checks on data to ensure their completeness and consistency in the system, and reports sources that have problems. The Report menu produces summary reports for annual and daily emissions of various emission sources. The Export menu exports various types of GIS data and data for photochemical modelling. The toolbar is a standard Access toolbar and contains shortcuts to menus and some other Access functions.

When an item is chosen from the Data menu, a form is opened for viewing, entry or editing of data. Figures 3 and 4 show examples of the forms used for entering industry data. The data elements of various emissions sources are described in the following sections.

Figure 2. The menus of the Auckland Emission System.

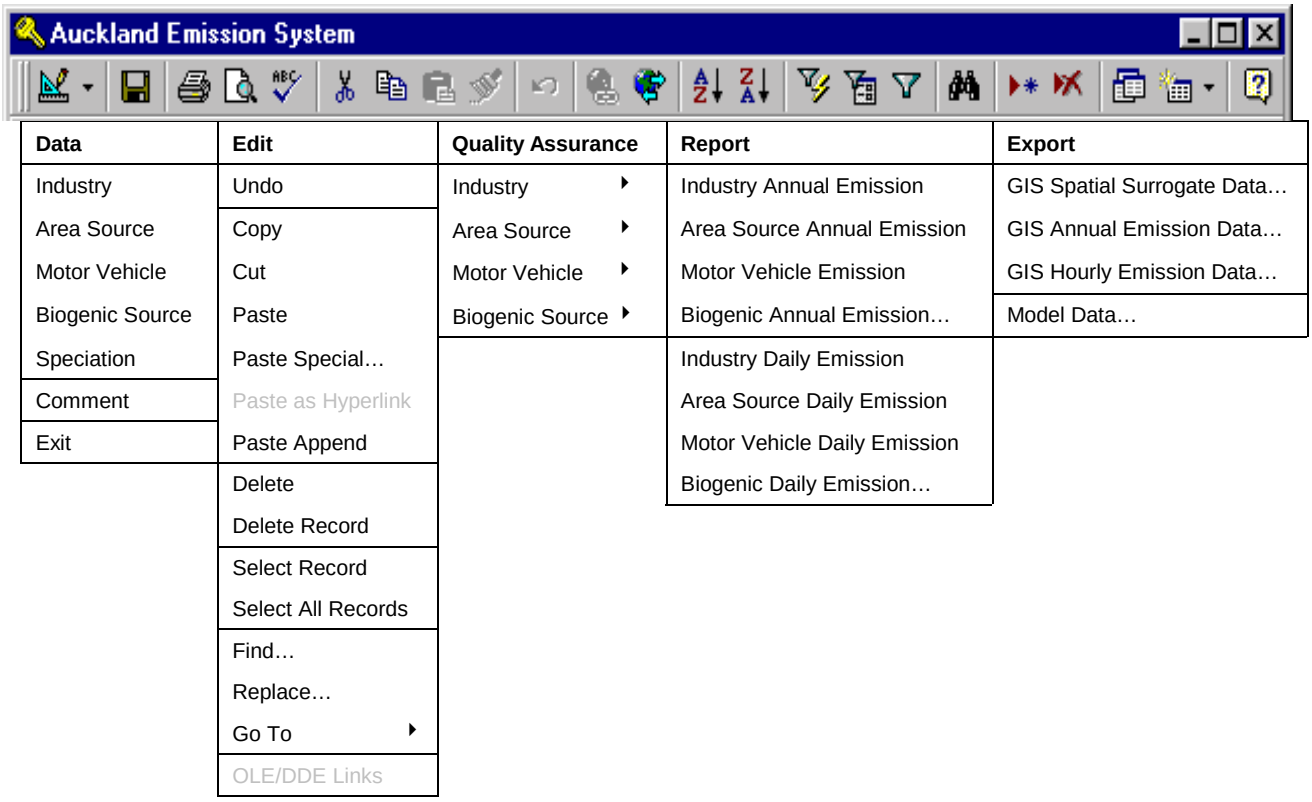


Figure 3. Form for entering operating schedule for an industrial site.

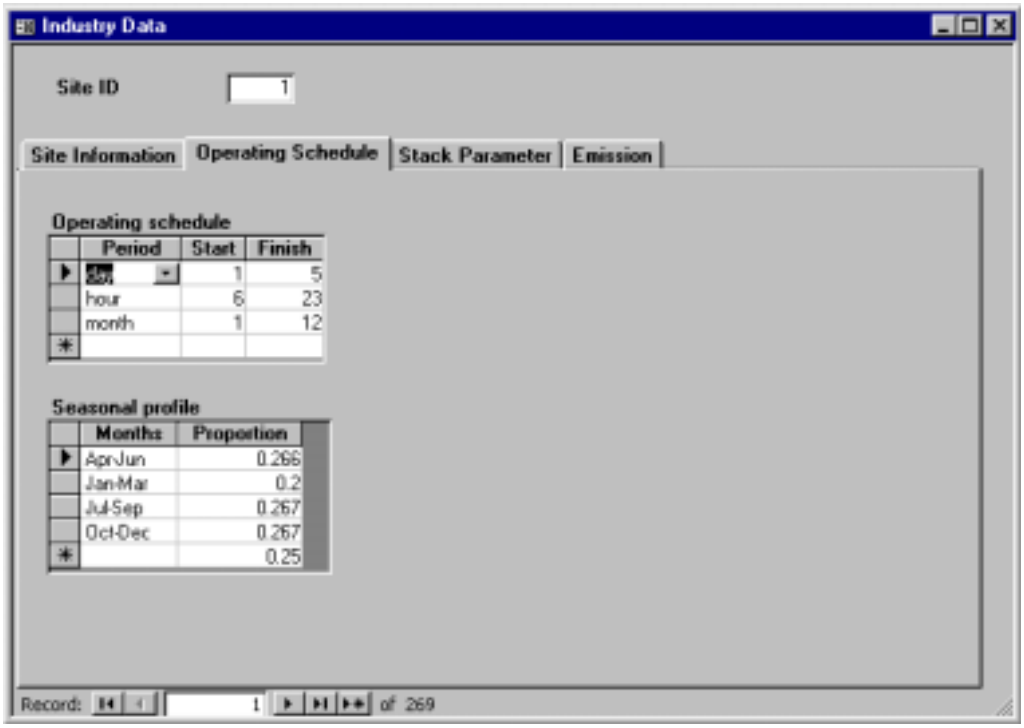
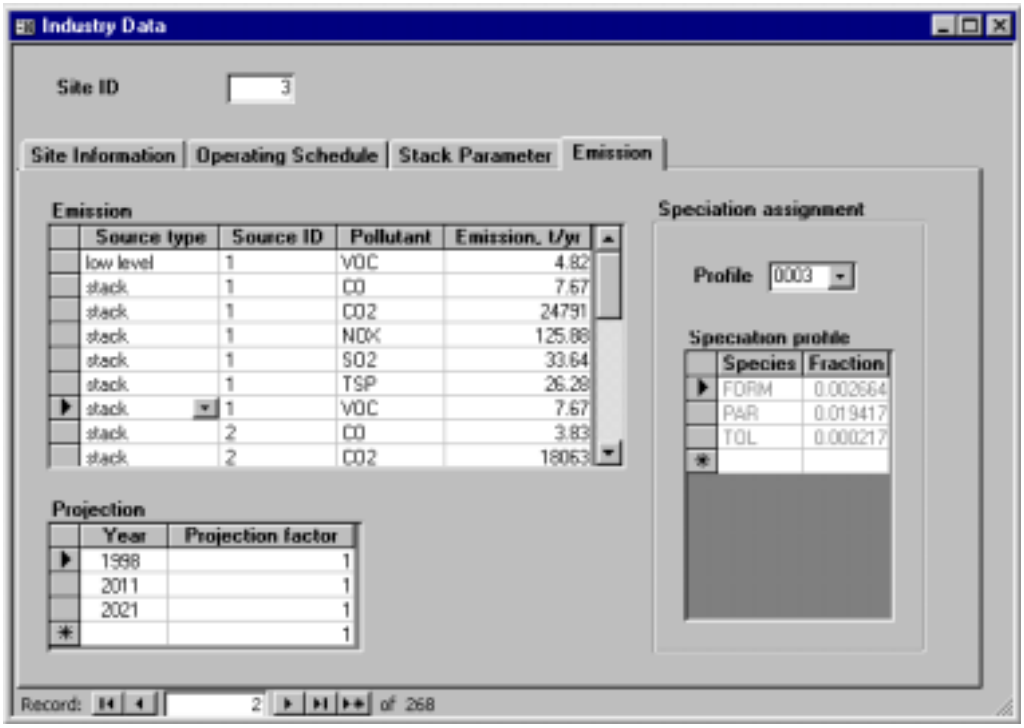


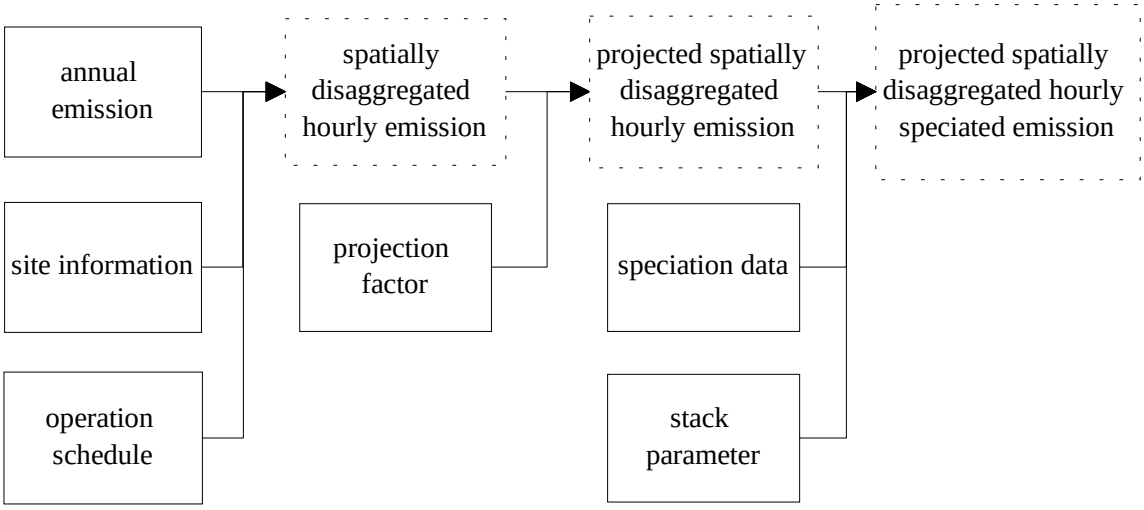
Figure 4. Form for entering industrial emissions.



Industry

Figure 5 shows the data elements (solid boxes) and data flow to produce the emissions estimates (dotted boxes) for industry.

Figure 5. Data flow diagram for industrial emissions.



Industry emissions are spatially disaggregated to grid cells for low level sources, such as tanks and fugitives, and to points for stacks. The site information contains the coordinates of the facilities. The annual emissions are disaggregated into hourly emissions by applying temporal factors derived from the operation schedule. Projected emissions are then obtained by applying the projection factors of a given year to the emissions of the base year (see Equation 1). In the Auckland

Emission System, the base year is 1998 and the same projection factor is used for all pollutants for a given facility. The projection factor is always 1 for 1998.

Equation (1) $$E_h = A \times S/13 \times D \times H_h \times P$$

where

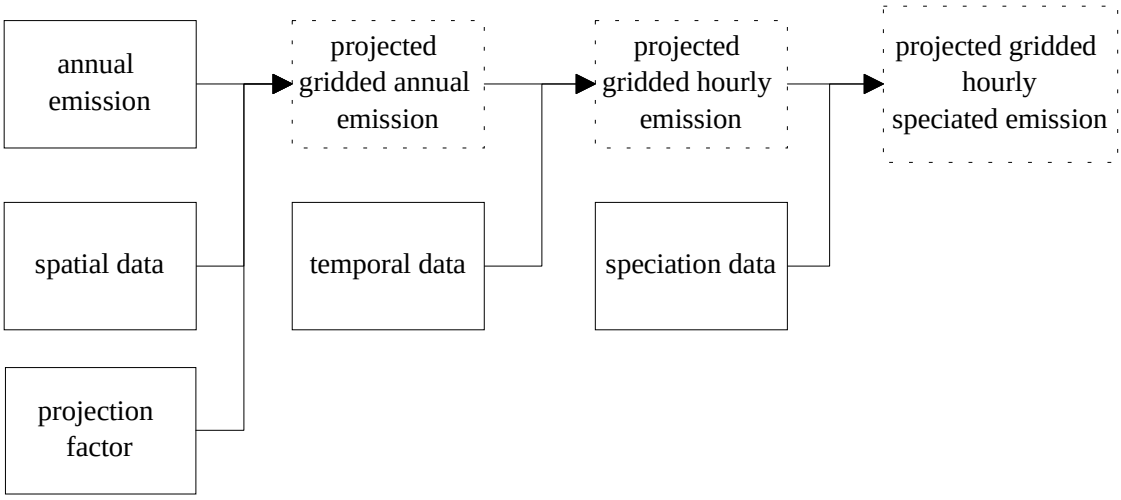
E_h = hourly emission for hour h (t/h),
A = annual emission for the base year (t/y),
S = seasonal temporal factor,
13 = number of weeks per season,
D = daily temporal factor for weekday or weekend day,
H_h = hourly temporal factor for hour h, and
P = projection factor for a given year.

Speciation is discussed in the Section "Speciation".

Area Sources

Figure 6 shows the data flow diagram for area source emissions.

Figure 6. Data flow diagram for area source and motor vehicle emissions.



Area source emissions estimates are allocated to grid cells through the application of spatial surrogates, such as population. Each area source (s') which has been assigned to a spatial surrogate (s) can be allocated to grid cells (c) through the application of the following equation:

Equation (2a) $$G_{y,t,c,s'} = A_{s'} \times R_{y,c,s} \times P_{y,t}$$

where

$G_{y,t,c,s'}$ = projected gridded annual emission (t/y),
$A_{s'}$ = annual emission over the whole Auckland region in the base year (t/y),
$R_{y,c,s}$ = gridded surrogate ratio,

$P_{y,t}$ = projection factor,
y = index for year
t = index for pollutant,
c = index for grid cell,
s = index for spatial surrogate,
s' = index for an area source, and

Equation (2b) $\sum_{c} R_{y,c,s} = 1$, for all years y and spatial surrogates s

where the sum is over the whole Auckland region.

The gridded surrogate ratios can be different for different years to allow for changes in the spatial distribution of spatial surrogates in future years. The sum of the spatial surrogate ratios is usually not 1 for the 1 km spacing grid but should be the same as that for the same area in the 3 km spacing grid.

The projected gridded hourly emission is obtained by:

Equation (3) $E_h = G \times S / 13 \times D \times H_h$

where

E_h = the projected hourly emission for hour h (kg/h),
G = projected gridded annual emission (kg/y),
S = seasonal temporal factor
13 = number of weeks per season,
D = daily temporal factor, and
H_h = hourly temporal factor for hour h.

Motor Vehicles

The data flow diagram for motor vehicle emissions is the same as that for area source emissions (see Figure 6).

The projected gridded annual emissions are calculated according to the following equation:

Equation (4a) $G_{y,t,c,r,v,e} = A_{t,r,v,e} \times R_{y,c,r} \times P_{y,t,r,v,e}$

where

G = projected gridded annual emission (t/y),
A = annual emission in the base year (t/y),
R = gridded spatial surrogate ratio,
P = projection factor,
y = index for year,
t = index for pollutant,
c = index for grid cell,
r = index for road type (including congestion level),

v = index for vehicle type (including fuel type),
e = index for process (exhaust or evaporative), and

Equation (4b) $\sum_{c} R_{y,c,r} = 1$, for all years y and road types r

where the sum is over the whole Auckland region.

The spatial surrogate ratios are proportional to gridded vehicle kilometres travelled (VKT) and can be different for different years to allow for change in the spatial distribution of VKT in future years. For the 1 km spacing grid, the sum of the spatial surrogate ratios is less than 1 but should be the same as that for the same area in the 3 km spacing grid.

The projection factor depends on pollutant, road type, vehicle type and process since legislation and technology affect emissions of different pollutants, vehicle types and processes differently.

The projected gridded hourly emission is obtained by:

Equation (5) $E_{y,t,c,h,v,e} = \frac{S_{t,e} \times D_{w}}{365} \times \sum_{r} \left(G_{y,t,c,r,v,e} \times H_{y,h,r,w} \right)$

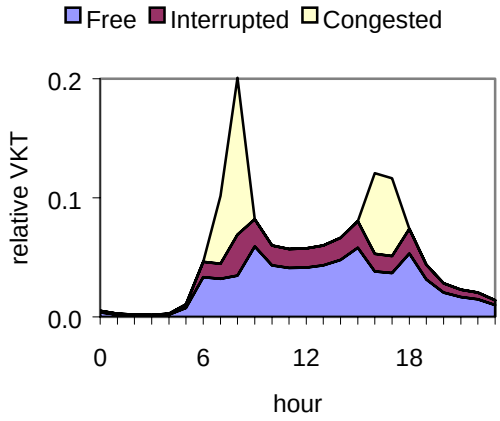
where

E = projected gridded hourly emission (t/h),
S = seasonal adjustment factor,
D = daily adjustment factor,
365 = conversion from annual to daily emission,
G = projected annual emission (t/y),
H = hourly temporal factor,
h = index for hour,
w = index for weekday or weekend day,

and other indices are the same as those in Equation 4.

The seasonal adjustment factor depends on pollutant and process since the emission factors are affected by temperature differently. The daily adjustment factor is different for a weekday and weekend day since traffic volumes are different on weekdays and weekend days. The hourly profile is also different for a weekday and weekend day since weekdays have more pronounced peak hours. The hourly profile can be different for different years to allow for spread of peak hour traffic in future. The hourly profile depends on road types and congestion levels. Figure 7 shows the contribution of VKT of different congestion levels to the hourly profile of central urban roads in Auckland. Note that the hourly temporal factor of congested mode is zero outside peak hours.

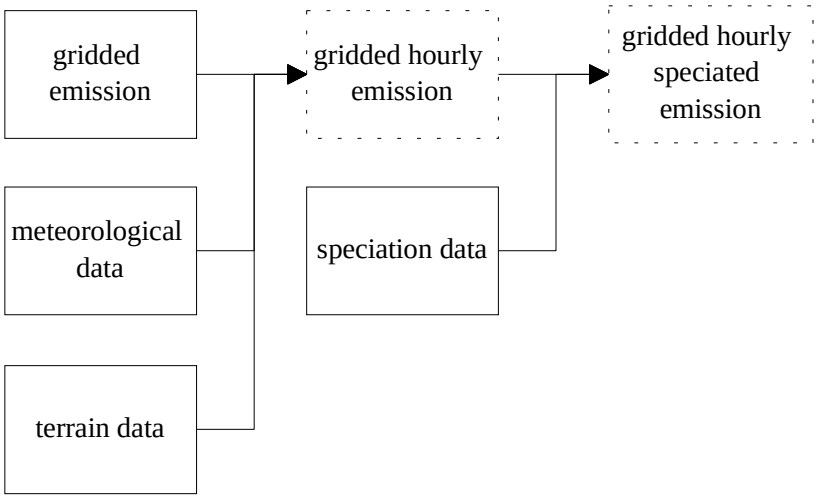
Figure 7. Hourly profile for VKT on weekday and central urban roads in Auckland.



Biogenic Sources

Figure 8 shows the data flow diagram for biogenic emissions.

Figure 8. Data flow diagram for biogenic emissions.



The gridded emissions are estimates at standard conditions (30°C and 1000 µE/m²/h). The gridded, standardised biogenic emissions are temporally allocated and adjusted using the meteorological data (solar radiation and temperature) and terrain data. The following equation is used:

Equation (6) $$E_{t,c,s,h} = \sum_{u} \left(G_{t,c,u} \times H_{t,c,s,h,u} \right)$$

where

E = gridded, hourly biogenic emission (g/h),
G = gridded, standardised biogenic emission (g/h),
H = biogenic adjustment factor for temperature and solar radiation

t = index for pollutant,
c = index for grid cell,
u = index for land use,
s = index for season, and
h = index for hour.

The adjustment factors for VOC are estimated from the formulations developed by Guenther et al.[5] and Lamb et al.[6], and NOx from Galbally and Weeks[7] and Duffy et al.[8] The adjustment factor depends on pollutant, land use, solar radiation and temperature. Solar radiation is different for different seasons and hours, but, for a given season and hour, is assumed to be the same throughout the Auckland region. Temperature is different for different grid cells, seasons and hours, and is estimated by the following equation:

Equation (7) $$T_{c,s,h} = T_s^{min} + T_{s,h}^{rel} \times \left(T_s^{max} - T_s^{min}\right) - 0.01 \times L_c$$

where

T = average seasonal gridded hourly temperature (°C),
T^{min} = average daily minimum temperature (°C),
T^{max} = average daily maximum temperature (°C),
T^{rel} = relative hourly temperature, normalised to lie between 0 and 1,
0.01 = lapse rate for temperature reduction with height (°C/m),
L = height above sea level (m),
c = index for grid cell,
s = index for season, and
h = index for hour.

Speciation

In speciation, a pollutant is split into the individual components which comprise the pollutant. For VOC, the component can be any volatile organic compound, such as benzene, hexane, toluene, etc. In the Auckland Emission System, NOx is speciated into NO and NO_2. TSP is speciated into PM_{10} and $PM_{2.5}$. CO and SO_2 are not speciated and the total mass is exported for use in photochemical models. CO_2 is not used in modelling photochemical ozone and so is not speciated or exported in modelling data.

A compendium of VOC species profiles has been assembled by the USEPA[9]. A profile can contain more than a hundred discrete compounds. For photochemical models, it is computationally prohibitive to model the chemistry for all discrete compounds. Instead, the discrete compounds are lumped together based on their carbon bond structure. This method of lumping discrete compounds is known as the Carbon Bond IV (CB-IV) mechanism[10].

VOC is speciated into the lumped-model species through the application of a lumped-model species split factor. Equation (8) identifies the formula for computing the CB-IV split factor:

Equation (8) $$s_{p,l} = w_l \times \sum_d \frac{f_{p,d} \times n_{l,d}}{w_d}$$

where

s = CB-IV split factor (grams of lumped-model species/gram of VOC),
w = molecular weight (g),
f = mass fraction of discrete volatile organic compound in a profile (grams of discrete volatile organic compound/gram of VOC)
n = the assignment of lumped-model species to discrete volatile organic compound (moles of lumped-model species/mole of discrete volatile organic compound),
p = index for VOC profile,
l = index for CB-IV lumped-model species and
d = index for discrete volatile organic compound.

The gridded, hourly emissions from an emission source are speciated using the split factors by applying Equation (9).

Equation (9) $$E_l = \frac{E_t \times s_{t,l}}{3600}$$

where

E_l = gridded, temporally allocated, speciated emission (g/s),
E_t = gridded, hourly emissions (g/h),
s = lumped-model species split factor,
3600 = conversion from hour to second,
l = index for lumped-model species, and
t = index for pollutant.

Quality Assurance

The Auckland Emissions System contains commands to perform quality assurance checks for data in the system. For industry, quality assurance is performed to find sites with missing coordinates, operating schedule, seasonal profile, stack parameters, projection factors or speciation assignment. It also reports sites which are outside the 3 km spacing grid.

For area sources, quality assurance is performed to find sources with missing projection factors or speciation assignment, and spatial surrogates with missing data for one or more years or grids. The system also checks the consistency between the 1 km spacing grid and the same area in the 3 km spacing grid of spatial surrogate ratios for area sources and motor vehicles, and of emissions for biogenic sources.

RESULTS

The gridded annual emissions, which were obtained from the Export menu of the Auckland Emission System and produced on ArcView, are illustrated in Figures 9-12 for industry, area sources, motor vehicles and biogenic sources, respectively. Area sources and motor vehicles contribute most of the VOC emissions although the distribution of emissions from area sources is more widespread than that from motor vehicles.

Figure 9. Gridded annual emission of VOC from industry in the Auckland Region in 1998.

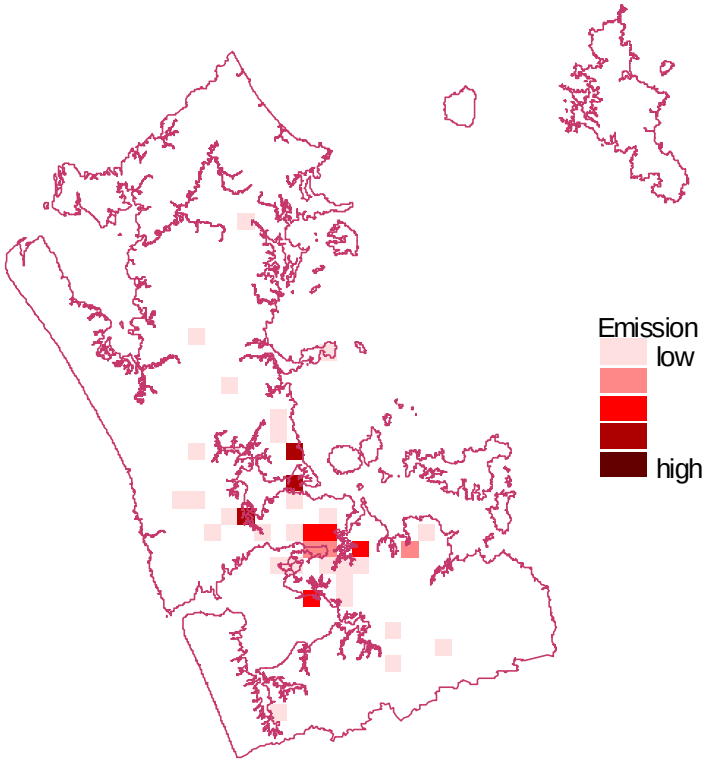


Figure 10. Gridded annual emission of VOC from area sources in the Auckland Region in 1998.

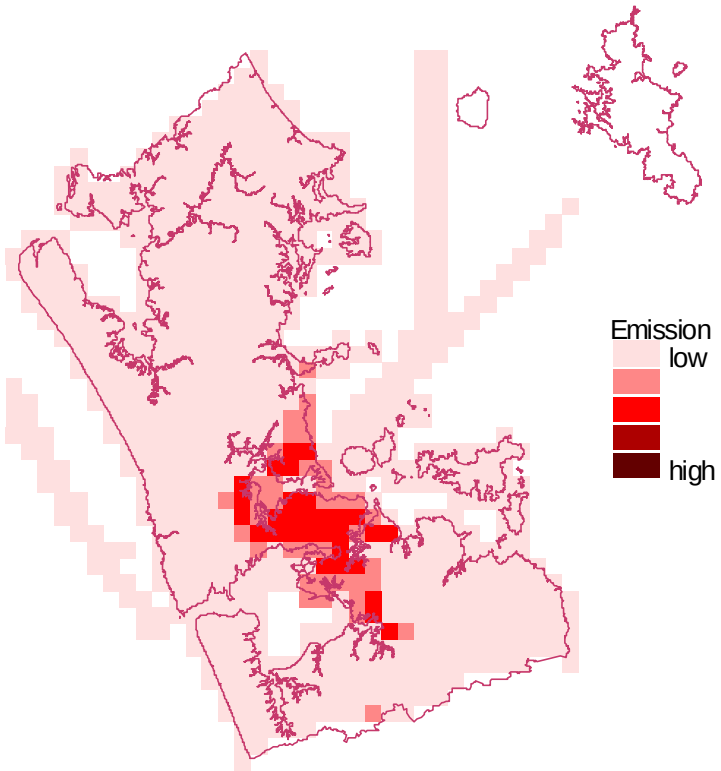


Figure 11 Gridded annual emission of VOC from motor vehicles in the Auckland Region in 1998.

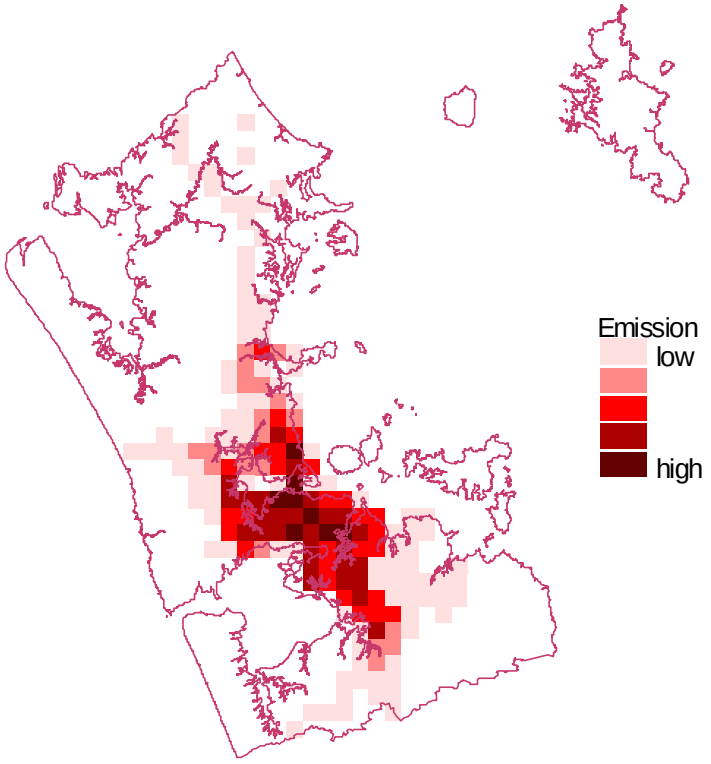
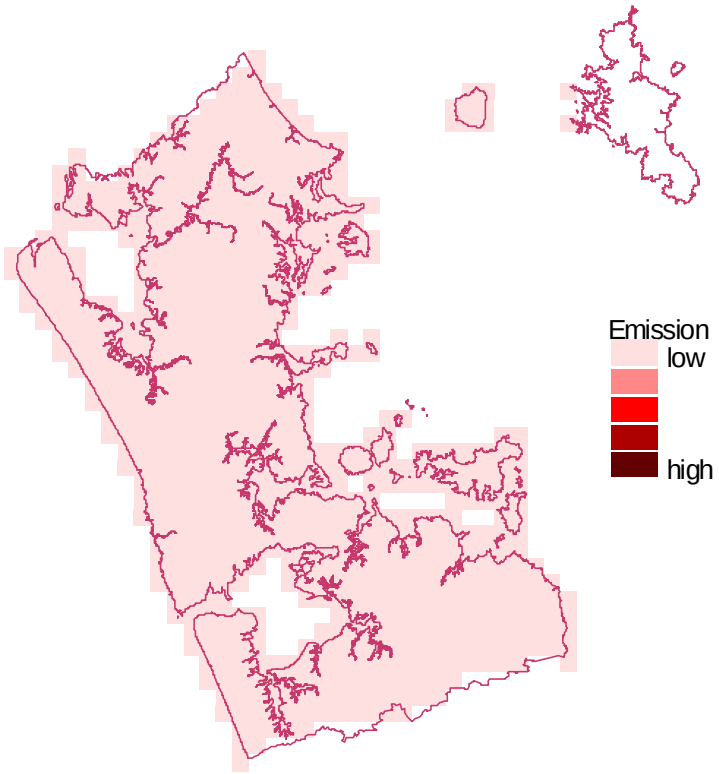


Figure 12. Gridded annual emission of VOC from biogenic sources in the Auckland Region in 1998.



CONCLUSIONS

The Auckland Emission System was successfully applied to the Auckland Region inventory upgrade. Results demonstrate the system's capabilities as a comprehensive emissions modelling system in both urban-scale (1 km spacing grid) and regional-scale (3 km spacing grid) domains. By contrast, in the 1993 inventory, emissions were available only for the regional scale domain.

The system is capable of producing a comprehensive emission inventory, which includes industry (point sources), area sources, motor vehicles and biogenic sources, and produces output for air quality modelling. In the 1993 inventory, results from only area sources and motor vehicles were available for air quality modelling. Although emissions from point sources and biogenic sources were estimated for the 1993 inventory, they were not provided in a format that could be used by the air quality model.

The system can be used to project emissions to future years and generate different scenarios for different air quality policy settings. The results of these different scenarios can be summarised in reports and GIS data produced by the system. The results can also be exported for use in air quality models to see the effect of the different scenarios on air quality. The system will be used to aid the model simulation of Auckland's air quality, and the simulation of pollution levels under different future population growth and emissions control scenarios[11].

The Auckland Emission System demonstrates the feasibility to develop a user friendly and also powerful emission system on a personal computer (PC). Because the system is developed on a PC, the cost of hardware and software, and the level of expertise required are low compared to UNIX system alternatives. The system at the moment allows spatial data, which are produced on a GIS, to be entered to the system. The system could be developed to invoke a PC-based GIS program for spatial processing and import the processed data. It is also possible to develop the system so that it estimates emissions from activity data and emission factors, rather than requiring the user to estimate the emissions outside the system.

REFERENCES

1. Radian Corporation. *GEMAP System Documentation (Draft)*, Prepared for Lake Michigan Air Directors Consortium, Des Plaines, IL, and The Valley Air Pollution Study Agency, Technical Support Division, Sacramento, CA, USA, 1993.
2. Emigh, R.A.; Wilkinson, J.G. *The Emission Modeling System (EMS-95) User Guide*, Alpine Geophysics, CO, USA, 1997.
3. Environment Australia. *National Pollutant Inventory, Data Definition and Transfer Protocol, Version 1.4.3*, Environment Australia, Canberra, Australia, 1999.
4. Auckland Regional Council. *Auckland Emissions Inventory – Final Report*, Technical Publication No. 91, Auckland Regional Council, Auckland, New Zealand, 1998.
5. Guenther, A.B.; Zimmerman, P.R.; Harley, P.C.; Monson, R.K.; Fall, R. "Isoprene and Monoterpene Emission Rate Variability: Model Evaluation and Sensitivity Analyses", *J. Geophys. Res.*, 1993, 98, 609-617
6. Lamb, B.; Gay, D.; Westberg, H.; Pierce, T. "A Biogenic Hydrocarbon Emission Inventory for the USA Using a Simple Forest Canopy Model", *J. Atmos. Environ.*, 1993, 27A, 1673-1690.
7. Galbally, I.E.; Weeks, I.A. *Natural Emissions of Hydrocarbons, Nitrogen Oxides, Carbon Monoxide and Sulfur Gases in the Kooragang Island Region of Newcastle, NSW*, CSIRO Division of Atmospheric Research, Aspendale, Victoria., Australia, 1992.

8. Duffy, L.; Galbally, I.E.; Elsworth, M. “Biogenic NOx Emissions in the La Trobe Valley”, *Clean Air*, 1988, 22, 196-198.
9. USEPA. *VOC/PM Speciation Data System - Version 1.50*, United States Environment Protection Agency, Research Triangle Park, NC, USA, 1992.
10. Gery, M.W.; Whitten, G.Z.; Killus, J.P.; Dodge, M.C. “A Photochemical Kinetics Mechanism for Urban and Regional Scale Computer Modeling”, *J. Geophys. Res*., 1989, 94, 12925-12956.
11. Gimson, N.R. “Urban Airshed Modelling in Auckland: Recent Developments”, In *Proceedings, 15th International Clean Air and Environment Conference*, Clean Air Society of Australia & New Zealand, Eastwood, New South Wales, Australia, 2000, pp 68-72.

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KEYWORDS

Emission Database System
Emission Modelling
Auckland Region