Application of an Emission Inventory GIS-Based Tool Across the Michigan/Ontario Border

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ABSTRACT

This paper presents the application of an Emission Inventory GIS-based software system called EIGIS across a geographic area covering Detroit, Michigan and south-western Ontario. The common goal behind these two related projects was to examine how EIGIS could be used to improve the current emission inventories for transboundary modelling applications.

The EIGIS software system is based on a bottom-up approach such that it is possible to produce updated or scenario inventories based on changes in science (e.g., emission factors), feature-based activity data (e.g., road traffic volumes, population density), and geography (e.g., changes in the location and/or magnitude of emissions that are based on physical characteristics of geographic features such as roads or land use). The EIGIS tool can also be used to analyze emissions data, generate reports and prepare model input files from the computed emissions inventories. Both projects involved a detailed examination of how emissions for specific sectors were being computed, and how they could be improved by adopting a bottom-up approach using EIGIS. GIS-based activity data were obtained and imported into EIGIS, which was then used to compute the emissions at the geographic feature level.

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1.0 BACKGROUND

The work described herein was performed under two separate projects that shared a number of common goals. The underlying purpose of each was to identify, assess, present options, and make improvements to existing regional emissions inventories. Although undertaken separately, these projects both fall under the general context of a collaborative, multi-year project being undertaken by Environment Canada and the United States Environmental Protection Agency (U.S. EPA), the purpose of which is to explore opportunities for greater cross-border cooperation that could improve air quality in the Detroit–Windsor airshed. The goal of this program is to enhance the exchange of information on air pollution and associated health-related impacts, as well as to support the examination of technical and non-technical issues that influence air quality management in the region.

The specific focus of this paper is on how the EIGIS tool was used to develop more accurate, better spatially resolved emissions inventories on both sides of the border. For the US portion of the study area, the project involved supporting the US EPA by evaluating different means of computing emissions, using the 2002 NEI as a benchmark. More specifically, the goal was to generate better spatially resolved emissions of both criteria and toxic compounds in SMOKE model-ready format for three source sectors across ten counties in the Detroit Metropolitan Area. The work performed for Environment Canada focused on assessing and improving the existing, provincially-aggregated, 2002 Canadian federal Criteria Air Contaminants Emissions Inventory (CAC EI) for seven sectors across six census-divisions in south-western Ontario.

The majority of the discussion in this paper is focused on the work done for the US EPA as the project was undertaken as a pilot study to assess how well the Canadian-developed EIGIS system could be adopted for use in the U.S.

In the autumn of 2003, Environment Canada commissioned a study to determine the feasibility of developing a multi-agency Emission Inventory GIS-based tool. The results of the feasibility assessment indicated that it was not only feasible, but also highly desirable[1]. Based on the feasibility assessment and subsequent reviews by other stakeholders, it was determined that a successful tool must have the following, minimal functionality:

1. The ability to create emission inventories from first principles (*ab initio*) in a straightforward and automated fashion for emission sources that are dependent on demographic, land use, and land based transportation activity data (roads/railways);

2. The built-in functionality to allow for the straightforward generation of reports on emissions in the inventory, including: maps, backcasts/forecasts, and reports;

3. The capability to generate emissions data suitable for direct use in comprehensive air quality modelling systems in a straightforward and automated fashion; and,

4. Be developed based upon ESRI's ArcGIS software system.

EIGIS has undergone two phases of development over the past two years[2, 3]. It is approaching its third phase of development wherein the results of various sample applications of the tool will be used to improve its functionality.

2.0 CURRENT EMISSION ESTIMATION TECHNIQUES

2.1 Detroit Metropolitan Area

Emissions were computed for six counties using the EIGIS software tool (Livingston, Monroe, Macomb, Oakland, Washtenaw, and Wayne) for the following source groups, which were selected following a series of analyses performed on the existing 2002 NEI data by the authors and US EPA:

- Residential wood combustion (SCCs 2104008001, 2104008002, 2104008003, 2104008004, 2104008010, 2104008030, and 2104008050);
- Industrial fuel combustion – coal (SCCs 2102001000 and 2102002000); and,
- Charbroiling (SCCs 2302002100 and 2302002200).

For each sector, the authors obtained and reviewed emission inventory methodology documents from numerous sources[4, 5, 6]. Based on this review, areas of potential improvement were identified for each source, taking into consideration specifics of the bottom-up, GIS-based emission calculation techniques that can be achieved using the EIGIS tool.

2.1.1 Residential Wood Combustion

This sector includes emissions from residential heating with wood combusted in fireplaces and woodstoves. Emissions reported in the 2002 NEI are provided for seven types of equipment, including four types of fireplaces and three types of woodstoves. National activity data were used to compute emission inventories at the county level using a well defined methodology as documented[4] and summarized[7].

This methodology was compared to what has been recently adopted by Environment Canada[5], and the Michigan DEQ[6] for the same source types. Although Environment Canada uses different emission factors, the overall approach adopted was very similar to that employed in the compilation of the 2002 NEI. The MI DEQ defaulted to US EPA emissions for this sector.

2.1.2 Industrial Fuel Combustion - Coal

This sector is comprised of emissions from the combustion of both anthracite and bituminous/sub-bituminous coals by industry. The 2002 NEI was compiled using the mass of coal consumed by the industrial combustion sector to estimate emissions at the county level[4].

Environment Canada's approach regarding industrial coal combustion is based on statistics of total fuel quantity consumed by province/territory using a similar approach as that used to compile the 2002 NEI[5]. The Michigan DEQ approach is similar but makes use of unique emission factors developed by LADCO for certain pollutants[6].

2.1.3 Charbroiling

This sector is comprised of emissions resulting from the charbroiling of various types of meat at commercial restaurants. The 2002 NEI was developed for two source categories: chain drive charbroilers; and, under-fired charbroilers. Data from the state of California and from individual counties were used to compute emission inventories at the county level as documented[4].

Environment Canada's approach regarding charbroiling considers only boneless red meat, consisting of beef, veal, and mutton/lamb; the approach is otherwise very similar to that adopted in the U.S. The MI DEQ defaulted to US EPA emissions for this sector for the 2000 NEI.

2.2 South-Western Ontario

The assessment for south-western Ontario focused on the Environment Canada Criteria Air Contaminant pollutants (CACs): Particulates (Total Particulate Matter or TPM, PM_{10}, and $PM_{2.5}$); Oxides of Sulphur (SO_X); Oxides of Nitrogen (NO_X); Volatile Organic Compounds (VOCs); and, Ammonia (NH_3). This assessment was focused geographically on six census divisions (Lambton, Middlesex, Essex, Kent, Elgin, Halidmand-Norfolk) and the following source sectors:

- Small and medium sized enterprises (Asphalt plants, Ferrous foundries, Nonferrous foundries; and, Commercial wood burning (e.g., bakeries, restaurants);
- Industrial and commercial boilers;
- Agriculture burning; and,
- Garbage burning (residential and at landfills).

The Criteria Air Contaminants Emission Inventory Guidebooks for both 2000[5] and 2002[8] published by Environment Canada, Pollution Data Division (PDD) were reviewed in conjunction with the most up-to-date version of PDD emission inventory (EI) compiler spreadsheets to determine the current methodologies employed to develop emission inventories for each source sector on a province-wide basis across Canada.

Current EI compilation methodologies were compared to a number of other sources of information from North America, Europe, and Australia in a similar but more rigorous manner than what was done for the US EPA. The results of these analyses are not described explicitly herein but are presented in RWDI's report[9].

3.0 METHODOLOGY USED TO UPDATE EMISSION INVENTORY CALCULATIONS USING EIGIS

3.1 Detroit Metropolitan Area

Although a number of potential improvement options were identified for each source sector, it was only feasible to investigate a small number of options under the scope of this project. After a review of the various options, an approach based on combining county-level activity data with higher-resolution land use data to compute emissions at the sub-county level (i.e., at the resolution of the land use data used) was adopted.

A modest level of effort was put towards finding publicly available land use data. Based on this research and discussions with the US EPA, it was determined that the 1992 National Land Cover Database (NLCD) would be the best choice as they were readily available and contained sufficient attribute data to allow for the generation of spatially-resolved emissions within EIGIS for each source group.

To compute emissions within EIGIS, GIS files containing land use attributes, political boundaries, etc. were obtained from a variety of public sources and then pre-processed (i.e., cleaned of spurious or unwanted data), re-projected to decimal degrees with a North American Datum 1983 (NAD83), and then imported into EIGIS using the "Import Attribute Layer" feature. In this way, the 1992 National Land Cover shapefiles were imported directly into EIGIS (one file per county).

Within EIGIS, emissions were calculated for all pollutants that had U.S. EPA emission factors listed either in the emission inventory document or databases provided. This included not only criteria pollutants but also a number of toxic compounds. Emission factors were compiled in a spreadsheet and then reformatted for direct import into EIGIS using the built-in Emission Factor Import functionality. The resulting emissions estimates calculated using EIGIS were compared to the 2002 NEI results at the county-level for the same pollutant and SCC combinations. For all three categories, the emission rates generated using EIGIS corresponded well with the U.S. EPA values at the county level.

3.1.1 Residential Wood Combustion

A County GIS layer was used to associate the county-wide activity data provided in Excel spreadsheet format, and then imported as individual attribute layers into EIGIS. For Residential Wood Combustion, two sources of GIS-based activity data were identified: the "wood" attribute in the US_HEAT.shp layer from the US EPA's 'official' 2003 surrogates; and, activity data in the form of total throughput of wood (i.e., amount burned) by SCC for each county in the "MI RWC_Pechan.mdb" database.

The "wood" attribute from the US_HEAT.shp 2003 surrogates layer is aggregated at the census tract level and is defined as the "number of houses using wood as the primary heating fuel". Although appropriate for some wood combustion units (e.g., home wood furnaces), it was considered inappropriate to use these activity data to compile an emissions inventory for all types of residential wood combustion sources. The activity data from the MI_RWC_Pechan.mdb database, on the other hand, more accurately reflect the amount of wood burned by type of unit, but aggregated at the county level.

Within EIGIS, a multi-layer, multi-attribute Activity for residential wood combustion was created. This was accomplished by combining the county-wide activity data from the MI_RWC_Pechan.mdb database, with the residential land use attribute from the 1992 NLCD GIS layer.

In this way it was possible to create a better spatially resolved emissions inventory for residential wood combustion sources. These same activity data can, in turn, be used by air quality modellers in combination with county-wide total emissions to spatially allocate emissions to a model grid; offering a replacement to the WOOD attribute from the US_HEAT.shp spatial surrogate file. Maps depicting the difference between the two sets of activity data are provided in Figure 1.

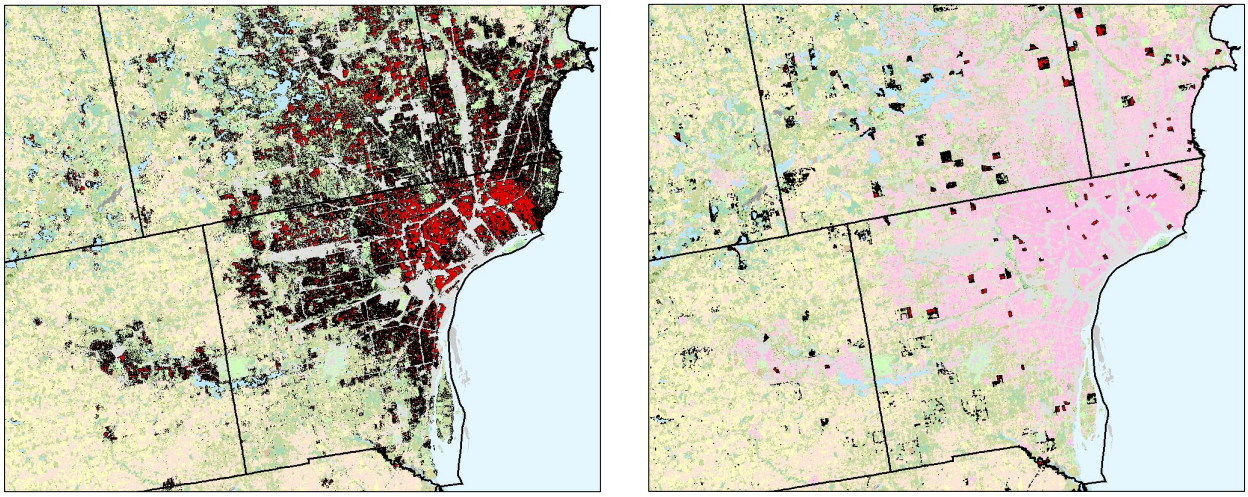

Figure 1. Left: red polygons represent residential land use from the 1992 National Land Cover Dataset used in EIGIS to generate spatially resolved emissions and surrogates. Right: red polygons represent census tracts where there are one or more homes in which wood is burned as the primary source of home heating, based on the "Wood" attribute of the US_HEAT.shp U.S. EPA spatial surrogate file.

3.1.2 Industrial Coal Combustion

Emission factors and activity data, in the form of pre-reconciled, total throughput of coal by county, were obtained from the database "Industrial coal_RWDI comp_LT comment_Sep11.xls". These were incorporated with the 1992 NLCD to develop a multi-layer, multi-attribute Activity within EIGIS for allocating county-wide throughput (and hence emissions) to land use polygons designated as industrial/commercial/transportation (see Figure 2).

For industrial boilers, U.S. EPA modellers currently use an Industrial Land shapefile from the U.S. Federal Emergency Management Agency (FEMA) that contains attribute data on the total building square footage in a census tract for buildings classified by standard industrial codes (SIC) that represent industrial operations.

After comparing and contrasting the two approaches, the U.S. EPA's current spatial surrogate layer was considered as good as or better than that generated within EIGIS using the 1992 National Land Cover Dataset. However, it was felt that with additional time and resources, the spatial allocation of emissions could be further refined by incorporating higher resolution land use information (e.g., a layer that defines industrial land use parcels only).

3.1.3 Charbroiling

Activity data, in the form of number of restaurants by county, were obtained from the spreadsheet "No restaurants in "MI_countys_by_restaurant_type.xls". As with Industrial Coal Combustion, the 1992 National Land Cover Dataset was used to develop a multi-layer, multi-attribute Activity within EIGIS for allocating county-wide emissions to land use polygons classified as industrial/commercial/transportation as shown in Figure 2.

For charbroiling, U.S. EPA modellers have adopted a "Food, Drug, Chemical Industrial (IND3)" surrogate using the same shapefile from FEMA as that used for industrial boilers, but using an attribute of total building square footage for buildings classified by the "food, drug and chemical" industrial SIC.

As with industrial coal combustion, the spatial surrogate data currently used by US EPA modellers are limited in the spatial resolution of the census tract polygons and the use of broad SIC classifications that include food, drug, and chemical industrial process, in combination with building square footage as indicators of the amount of food cooking that takes place in any census tract. On the other hand, the EIGIS activity data used to calculate the emissions (and hence spatial surrogates) are limited in the spatial resolution of the 1992 National Land Cover Dataset and implicit 'spreading' of emissions into areas classified as industrial/commercial/transportation.

The two approaches were compared and contrasted to determine which provides a more realistic spatial representation of emissions from this particular type of source. The two approaches were considered to have contrasting pros and cons. Either method can be performed within the EIGIS, although further investigation is needed to develop a better procedure, such as obtaining and incorporating higher resolution land use information that is designated as industrial only.

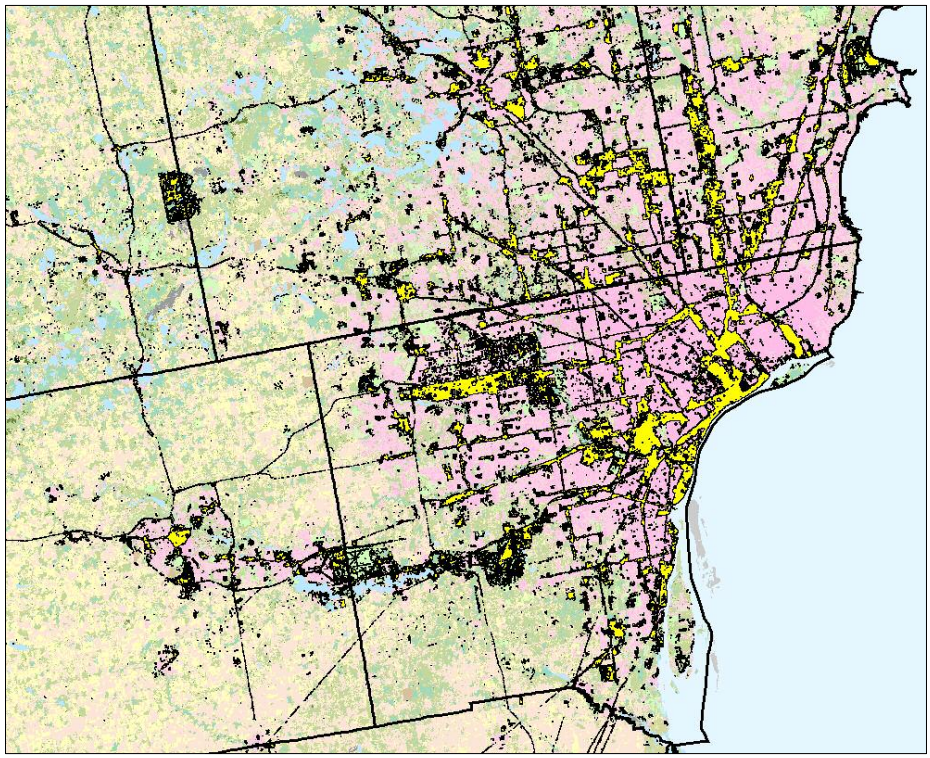

Figure 2. Areas classified as industrial/commercial/transportation land use (yellow) from the 1992 National Land Cover Dataset and used to develop multi-layer, multi-attribute Activities within EIGIS for allocating county-wide emissions associated with both industrial coal combustion and commercial cooking / charbroiling.

3.2 South-Western Ontario

3.2.1 Asphalt Plants, Ferrous Foundries, and Non-Ferrous Foundries

Although many of the individual facilities reported emissions through the Canadian National Pollutant Release Inventory (NPRI), many (for a number of reasons) did not. The preferred option selected for improving emissions from asphalt plants and foundries (ferrous and non-ferrous) involved conducting telephone surveys to characterize each facility in the study area not reporting to the NPRI. For the most part, default emission factors from AP-42 or Canadian-specific values were used as per EC PDD methodologies[8]. For non-ferrous foundries, emission factors from Australia were adopted[10].

3.2.2 Industrial and Commercial Boilers

Because the industrial and commercial boilers sector is so broad, it was not feasible to characterize each individual facility in the study area. Refinements were made by generating a multi-layer, multi-attribute activity layer in EIGIS that can be used to spatially allocate post-reconciled, provincial level emissions. The Activity layer is based on 2000 Statistics Canada data at the enumeration area level (similar to census tract) and comprised of the number of people employed in the following sectors in each census division: commercial establishments; health and educational institutions; and, government/public administration industry. These data were allocated to areas classified as "built-up" based on available land use data.

3.2.3 Commercial Wood Burning

The commercial wood-burning sector is poorly characterized over all EI jurisdictions investigated and not currently inventoried by EC PDD, owing primarily to a lack of activity data. An ideal approach to gathering activity data for this sector would involve conducting a survey of commercial establishments (i.e., restaurants and bakeries). This survey could be used to determine the percentage of restaurants that use wood for commercial purposes and the amount of wood consumed.

Lacking available activity data, emissions were not calculated. Instead, refinements were made by generating a multi-layer, multi-attribute activity layer in EIGIS using the same basic methodology as that employed for commercial and industrial boilers, but based on the number of people employed in the accommodation and food industry.

3.2.4 Agricultural Burning

Our assessment of the agricultural burning sector included the open burning of agricultural wastes and small livestock cremation. Since stubble burning does not generally occur within Ontario, these emissions were assumed to be negligible and hence not inventoried[11].

Emissions from agricultural waste burning (e.g., brush piles), were developed using agricultural activity data in conjunction with land use information to allocate emissions to agricultural lands. Agricultural activity data developed under the NAESI project (containing 240 different variables from the 2001 Census of Agriculture) were provided by PDD in GIS format and used in conjunction with GIS layers representative of different landuse activities to create a multi-layer, multi-attribute Activity in EIGIS of the total farm area (in ha), spatially allocated to agricultural lands.

Emissions were then calculated using the methodology and emission factors from CORINAIR, which assumes that the average quantity of agricultural waste burned, is 25 kg/hectare[12].

The cremation of most kinds of livestock (cows, horses, swine, sheep, etc.) is an illegal practice in Ontario; poultry being the one major exception. That being said, it is believed that most large farming operations do perform some on-site cremation of small livestock, in particular for the swine and poultry industry[11].

The cremation of both poultry and swine is performed using commercial and "homemade" combustion units. Experts estimate that there are on the order of 250 commercial poultry crematoria (most of which include secondary burners) operating across Ontario. However, best estimates indicate that for every commercial unit, there is at least one homemade unit in operation (pers. comm. VanHeyst, 2007). In the case of both poultry and swine, emissions are expected to be more of a concern for larger farm operations where cremation is performed to control the spread of disease.

Research is currently underway to develop activity data and emission factors for these types of operations. However, there were no published sources of CAC emission factors or activity data for Ontario available at the time (pers. comm. VanHeyst, 2007).

To support future work in this field, GIS-based activity data in the form of number of swine / hogs and number of poultry were obtained from the agricultural activity data developed under the NAESI project and spatially apportioned to agricultural lands within EIGIS.

3.2.5 Garbage Burning (Residential and at Landfills)

The methodologies for computing emissions from the residential garbage-burning sector had been recently updated by the PDD and both emission factors and activity data are fairly well defined. Potential improvements to this sector focused solely on improvements to the spatial allocation of emissions. Lacking a data layer specific to rural population, this was accomplished by developing an Activity layer in EIGIS that approximates the spatial allocation of the rural population base at the dissemination area level.

4.0 CONCLUSIONS

Through the process of developing emission inventories using the EIGIS software system, several general observations and recommendations can be made.

1. The EIGIS tool was easily adapted for use in the US. No changes / modifications to the application itself were required, although additional base map layers had to be imported for the US whereas these layers are pre-populated for Canada.

2. There are a number of ways to compute an emissions inventory. Some sectors warrant the level of effort it takes to adopt a bottom-up, more highly spatially resolved technique. The EIGIS system was proven to be effective for both cases (i.e., where high-resolution activity data are available at the feature level, as well as when activity data are aggregated at the county or even state / provincial level). Either way, the creation of multi-layer, multi-attribute Activity data within EIGIS proved useful in that even if the emission totals do not change, having better spatially resolved emissions is of benefit for both policy / decision making and modelling purposes.

3. There is currently no means of importing pre-computed emissions data from either area or point source datasets into EIGIS. Being able to import pre-computed point source emissions data could allow for some reconciliation processes to be performed directly within the EIGIS system. This option is being considered as a future development option.

4. The EIGIS system can be used to automate the process of calculating emissions and generating report and SMOKE, model-ready ORL or IDA input files. This functionality allows a user to modify emission factors and re-compute spatially resolved emissions in an efficient manner, streamlining the quality assurance and quality control process.

5. The GIS mapping features of the EIGIS tool provides the option for a visual QA of emission and/or activity distribution on a map at any step in the emission calculation process.

6. With additional time and resources, it is felt that the spatial allocation of emissions could be further refined using EIGIS by incorporating higher resolution land use information that contains details on a larger number of land use types (e.g., differentiates between industrial, residential, commercial, and transportation land uses, etc.). Although not necessarily available at the state level, high-resolution land use data (and other potential activity layers) are expected to be available for most major (and even some smaller) urban centres.

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