

Development of a Multi-User GIS-Based Emission Inventory Tool

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ABSTRACT

This paper presents an overview of the design and current status of a project to develop a multi-user GIS-based Emission Inventory Tool (GIS-EI Tool). The fundamental goal behind the GIS-EI Tool is to allow for the timely and efficient creation of regional Emission Inventories from first principles; and, to allow for the timely analysis, reporting, and model input creation of Emission Inventories by a number of simultaneous users. To accomplish this, the GIS-EI Tool must be capable of producing new or updated inventories (e.g., emission scenarios for modelling) based on changes in science (e.g., emission factors), 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, land use, etc.).

The authors, in cooperation with scientists and engineers at Environment Canada, Pacific and Yukon Region; the Greater Vancouver Regional District; and, the British Columbia Ministry of Water, Land, and Air Protection, have developed a conceptual model where Emission Inventory calculations, analyses, and reporting can be performed by multiple simultaneous users within one, comprehensive system.

Knowing that a strong conceptual design is paramount to the GIS-EI Tool's success, a rigorous design phase involving numerous iterations and consultations with different Stakeholders and potential user groups was completed as a first step. The next step focused on improving the data model (i.e., database design) and the distributed organisation of the hardware and software system and related infrastructure. A prototype version of the Tool and hardware/system infrastructure designed to calculate area source emissions using GIS-based land use and population activity data is currently being developed and tested for functionality and ease of use. Subsequent Phases of this project will focus on adding the ability to calculate emissions from other activities and GIS inputs (e.g., roads, rail), adding functionality (e.g., reporting routines, etc.), improving speed, and allowing for remote, simultaneous access by multiple users.

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BACKGROUND

Air quality management activities in south-western British Columbia, Canada, are coordinated through the Lower Fraser Valley Air Quality Coordinating Committee (LFVAQCC) whose member organisations include the Greater Vancouver Regional District (GVRD), Fraser Valley Regional District (FVRD), BC Ministry of Water, Land and Air Protection (WLAP), Environment Canada, and Northwest Air Pollution Authority in Washington State.

All LFVAQCC members have some form of GIS capability and/or are undertaking GIS projects. In 2003, LFVAQCC directed its member organisations to share information about their air quality related GIS activities and to explore opportunities to integrate interagency GIS work^{1, 2}. The underlying objective of this mandate is to develop a powerful, multi-agency GIS solution that will enhance air quality management in the LFV airshed.

Most anthropogenic, area source emissions estimates are based on population census data, land use, and land-based transportation (roads and railways). These types of ‘activity surrogates’ are particularly well suited to adapting GIS techniques to perform Emission Estimates from first principles. A GIS-based Emission Inventory Tool, or ‘GIS-EI Tool’, can also provide for the inclusion of updated emissions estimating protocols as they become available, so that a current, state-of-the-science inventory can be created in a timely and efficient manner.

In the autumn of 2003, Environment Canada commissioned a study to determine the feasibility of developing a multi-agency GIS-based Emission Inventory Tool. The results of the feasibility assessment indicated that it was not only feasible, but also highly desirable³. 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; and,
3. The capability to generate emissions data suitable for direct use in comprehensive air quality modelling systems in a straightforward and automated fashion.

Another specified requirement was that the software must be developed based upon ESRI’s ArcGIS software system. Based on recommendations from ESRI Canada⁴, the GIS-EI Tool is being developed using ESRI’s ArcEngine 9 Developer Kit, with ArcSDE 9 to communicate with a supported Enterprise database (e.g., SQL Server 2000). Additional requirements and design considerations are listed as part of Environment Canada’s initial request for proposals⁵.

APPROACH

Based on in-depth consultations with numerous Stakeholders, it was determined that the GIS-EI Tool should be developed in a multi-step fashion, the first step of which must be to focus on defining and testing a robust data model (i.e., database design) and software system. Recognizing that a strong conceptual design is paramount to the GIS-EI Tool’s success, this initial design phase and subsequent testing was identified as the most critical step.

Having completed the design, a prototype version of the tool and hardware/system infrastructure is currently being developed and tested for functionality, ease of use, and system integrity. This prototype is capable of calculating emissions using GIS-based land use and population activity data. Subsequent steps will focus on adding the ability to calculate emissions from other activity/GIS data (e.g., roads, rail), adding functionality (e.g., more default reporting routines, etc.), improving speed, and allowing for multiple users to access the system simultaneously from remote access points. Another key element to the next phase(s) of work will be to allow for versioning of Emission Inventories and all input data to be managed within the tool. This will allow multiple users to access the Tool and work on unique versions (e.g., emission scenarios for modelling) while retaining the integrity of ‘official’ or ‘sanctioned’ versions of the inventory. Using protocols inherent to ArcSDE, versioning will be extended not only to ArcGIS feature classes, but to all other supported datasets within the GIS-EI Tool (e.g., emission factor tables, SCC cross reference tables, queries, etc.).

The remainder of this paper describes the design concept behind the GIS-EI Tool and provides a brief summary of the development status to date.

CONCEPTUAL PARADIGM

Creating Emission Inventories is a tedious and time-consuming task. In its simplest form, the overall goal of this development project is to create a software program that can be used to compute, view and export Emission Inventories from user input. Key inputs required to facilitate this process include: GIS-based activity data and associated emission factors (including scaling factors, control factors, and activity formulae). Additional parameters that are integral to the GIS-EI Tool include (but are not limited to): source classification codes, source sector cross-reference tables, pollutants and pollutant groups, etc. For the purpose of the GIS-EI Tool, an Emission Inventory is made up of a series of Emission Estimates (EE) for individual types of emissions, specified by unique Source Classification Codes (SCC).

In Canada, national Emission Inventories are typically generated using a “top-down” approach. Using this model, emissions are calculated based on aggregate activity data (e.g., fuel consumption) for the entire country or possibly by Province. These emissions are then disaggregated to smaller geo-political units (e.g., Census Divisions) using spatial allocation surrogates (e.g., population statistics, land use, etc.) that are developed in a separate GIS process.

The GIS-EI Tool, on the other hand, is designed using a “bottom-up” approach. Emissions are computed for each individual feature within an integrated GIS system (e.g., by road segment, parcel, etc.). From these Emission Estimates, Emission Inventories can be summarised (i.e., aggregated up) at any level, simply by summing the appropriate Emission Estimates.

This bottom-up conceptual paradigm requires a defined lowest common spatial denominator. Having reviewed various options, emission calculations within the GIS-EI Tool are performed at the Dissemination Area level⁶ (synonymous with U.S. Census Tracts). In this way, all user actions within the GIS-EI Tool are performed for selected Dissemination Areas only, and not necessarily for the entire Emission Inventory. This allows for quick updates and computations by re-processing emissions computations, reporting, etc. only over the regions (selections of Dissemination Areas) affected by the changes.

For example, assume the population in a given town doubles from one year to the next. Using a top-down approach, an analyst would need to recompute the total regional (i.e., provincial or national) emissions for all sources that are calculated as a function of population, and then disaggregate the emissions over the entire region back down to the desired level. Using a bottom-up approach, the same analyst would simply change the total population activity number for the Dissemination Area in which the town is located. The software would then automatically re-compute all emissions in that Dissemination Area only. Any subsequent reporting, analyses, etc. would automatically be based on the updated Emission Inventory.

The same concept would apply for assessing the impacts of paving an existing unpaved road, or changing the land use of a specific parcel of land from park to residential. In another instance, the analyst may want to update an emission factor based on a recently published paper (e.g., revised emission factors for residential wood smoke that apply to the Greater Vancouver Regional District only). The same concept applies. An analyst would simply select the Dissemination Areas for which the change applies, update the emission factor and recompute the emissions.

Because there can be hundreds of thousands of combinations of Emission Factors, SCCs, Pollutants and Activities, at the Dissemination Area level, the back end or “data-engine” of the GIS-EI

Tool is managed through a relational database that is sufficiently normalised to store all of the data elements effectively, but not so normalised as to cause the application to grind to a halt when it comes time to perform the actual calculations.

Creating Emission Inventories based on individual features within a GIS to develop a regional Emission Inventory is a unique conceptual paradigm in Canada with broad reaching implications.

GIS-EI TOOL MECHANICS

The following sections provide some specific details as to the core mechanics behind the GIS-EI Tool. What is presented herein only touches on the inner complexity of the data and software model. Additional details are available in the GIS-EI Tool Design Document⁷.

Emission Estimate

The calculation of an Emission Estimate can be generalized by the following formula:

$$\text{Equation (1) } EE = EF \times A \times CF \times SF$$

where

- EF = Emission Factor
- A = Activity
- CF = Control Factor
- SF = Scaling Factor

The Emission Factor (EF) defines the magnitude of emissions that occur in response to an associated activity. An EF is identified by a combination of pollutant, SCC and location, where a given EF is used in conjunction with a specific Activity. For the purpose of the GIS-EI Tool design, all EFs are defined and stored at the Dissemination Area level.

Activity

Activity represents the action or process that leads to the release of pollutants to the air. Activities are drawn from demographic information, process activity data, or other statistics. An Activity can be comprised of a single Attribute or a combination of Attributes, and is based on the nature of the Emission Factor and availability of suitable attribute data. Fuel usage, number of people, number of bakeries, and length of a given road are some examples of Activities. For the purposes of the GIS-EI Tool, it is assumed that all necessary attribute and activity data are provided through the GIS data layers (ArcGIS feature classes). As noted previously, the Activity of interest for a specific EE is dependent upon the EF and vice versa.

For the most part, an Activity is comprised of the value of a single Attribute (e.g. length of road, number of people, tonnes of fuel consumed). However, in some cases, an Activity may be expressed as a function of more than one Attribute and is usually some form of product (e.g., number of lanes x length of road, number of people per household).

Control Factor

A Control Factor (CF) represents a governmental regulation intended to limit the maximum amount of allowed emissions for a particular pollutant. In the GIS-EI Tool, a Control Factor is a multiplier that ranges from 1 (no control) to 0 (complete control or zero emissions) and is defined as follows:

$$\text{Equation (2) } CF = 1 - CE \times RE \times RP$$

where

- CE = Control Efficiency

RE = Rule Effectiveness

RP = Rule Penetration

Control Efficiency is the percent reduction of pollutant due to the control, Rule Effectiveness is the percent effectiveness of the regulation in achieving its target, and Rule Penetration is the percentage of the Emission Inventory where the control is applicable. The resulting Control Factor represents the percent of base emissions that are emitted from each source subject to the control after the application of the regulation.

Scaling Factor

Emission engineers on occasion have the need to apply global or universal scaling factors for one reason or another. These cases more often than not reflect the need to ‘remove’ or ‘scale’ a certain Emission Estimate through the application of a conditional scaling factor that is applied to an emission calculation. To avoid deleting the Emission Estimate all together, making the emission factor or activity equal to 0, or applying an unrealistic control factor, a Scaling Factor is introduced.

A Scaling Factor can be any non-negative real number, and is treated as a generic factor that can be used to affect the type of change indicated above, without having to modify and perhaps risk altering the integrity of other parts of the Emission Inventory or Emission Estimate methodology.

Sample EE Calculations

The design of the GIS-EI Tool includes attributes that are in the form of GIS features in an ESRI Geodatabase. These features are defined at any geo-political resolution; a key to the overall design of the GIS-EI Tool. By allowing features to be defined at any resolution, the emissions can be calculated for each single feature (e.g., each road segment or parcel area). An Emission Inventory then becomes simply a collection of Emission Estimates that can be reported as Dissemination Area totals, county totals, SCC totals, etc. simply by summing the respective Emission Estimates.

The following describes how EE calculations are computed for a single attribute activity case, followed by a multi-attribute activity example. The values in the examples are not representative and were selected simply to illustrate how the calculations are performed.

Example 1: Single Attribute Case

Assume that an emission factor for NO_x for a typical locomotive is 10 kg / year per km of track (i.e., EF = 10 kg / km). Assume also that a GIS feature class for rail lines contains attributes for the length of track passing through a given location (i.e., Dissemination Area), and that the length is 100 km (i.e., A = 100 km). The Control and Scaling factors are assumed to be 1 (i.e., no control or scaling factors apply). The Emission Estimate (EE) for that segment of track (i.e., feature) is:

$$\begin{aligned} EE &= EF \times A \times CF \times SF \\ EE &= [10 \text{ kg NO}_x / \text{year} / \text{km}] \times [100 \text{ km}] \times 1 \times 1 \\ EE &= 1000 \text{ kg NO}_x / \text{year} \end{aligned}$$

Example 2: Multiple Attribute Case

Assume that an EF for NO_x for a typical automobile is 5 kg / year per km of road. Also assume that the length of the road segment in question is 25 km (from the GIS Road feature class), but that there are 2 lanes of traffic in the given location (i.e., Dissemination Area). In this case, the Activity is the product of road length and number of lanes (i.e., A = [road length] x [number of lanes]). The Control and Scaling factors are assumed to be 1. The Emission Estimate for that segment of road becomes:

$$\begin{aligned} EE &= EF \times A \times CF \times SF \\ EE &= [5 \text{ kg NO}_x / \text{year} / \text{km}] \times ([25 \text{ km}] \times [2]) \times 1 \times 1 \end{aligned}$$

$$EE = 250 \text{ kg NO}_x / \text{year}$$

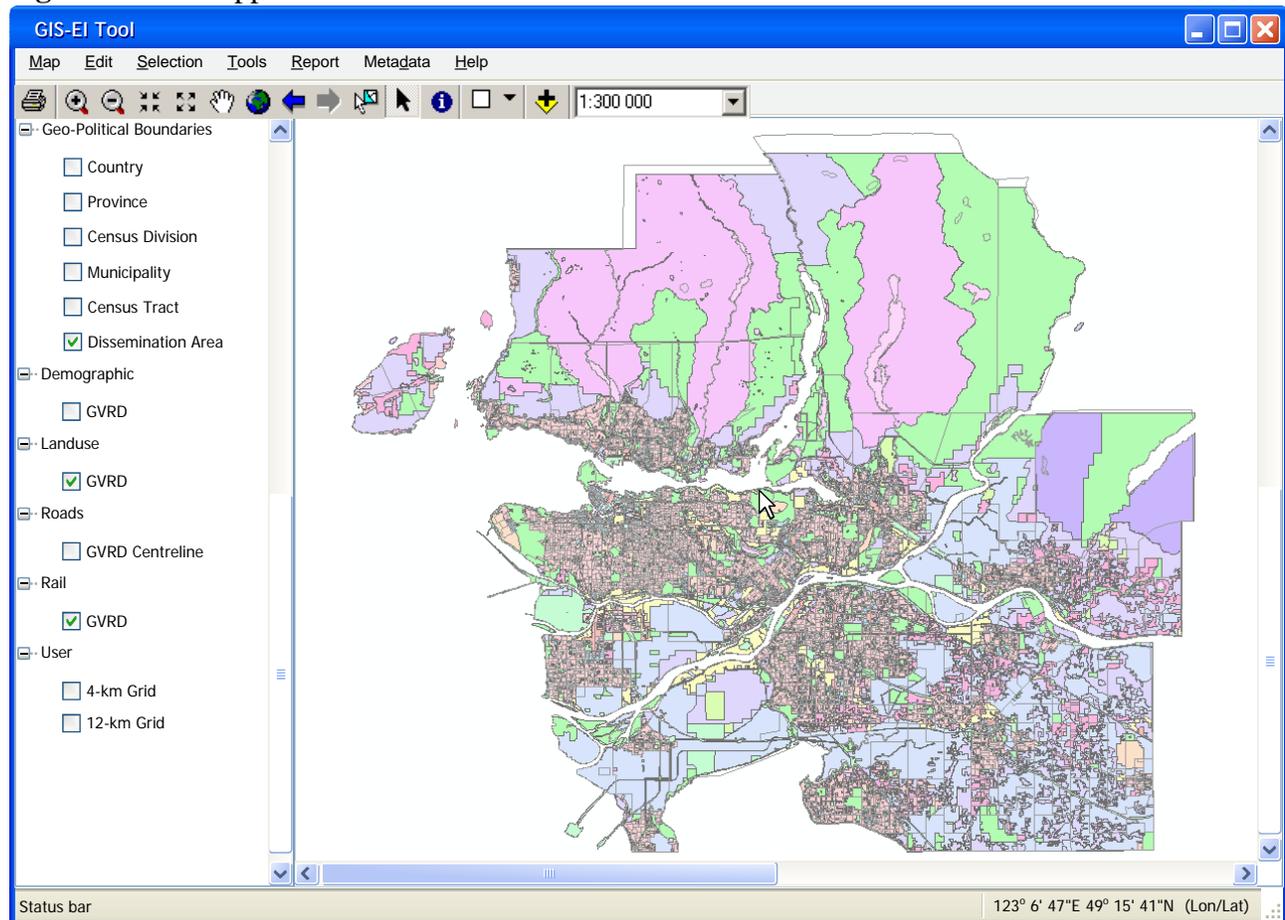
In reality, most EEs are based on fairly simple math (i.e., activities are defined by one attribute only), and are spatially consistent (i.e., the same EF can be used province or nation-wide). Nonetheless, adopting an approach to manage the EE calculation in this way allows for greater flexibility within the GIS-EI Tool and the ability to utilise location-specific emission information, assuming the requisite activity data and emission factors are available.

Once the Emission Estimates exist, the GIS-EI Tool can be used to export the results into various forms, including SMOKE input files (with Spatial Surrogates) and other text files which can then be used to create reports and charts using third-party software of the user's choice.

CURRENT STATUS

Following are some brief descriptions and “screen shots” of key elements of the GIS-EI Tool as developed to date. Figure 1 shows the main application window, which has been designed to be similar in look and feel to ESRI's ArcGIS suite of products, yet greatly simplified.

Figure 1. Main application window of the GIS-EI Tool.



Geo-Political Layers

Users interact with different geo-political layers to determine the locations for editing factors, computing emissions and extracting inventories. Geo-political feature classes are polygon-based and correspond to typical geo-political elements such as country, provincial and Dissemination Area boundaries. Collectively, they determine hierarchical order amongst the different geo-political elements, represented in terms of Dissemination Areas. Six geo-political layers are used in the current implementation of the

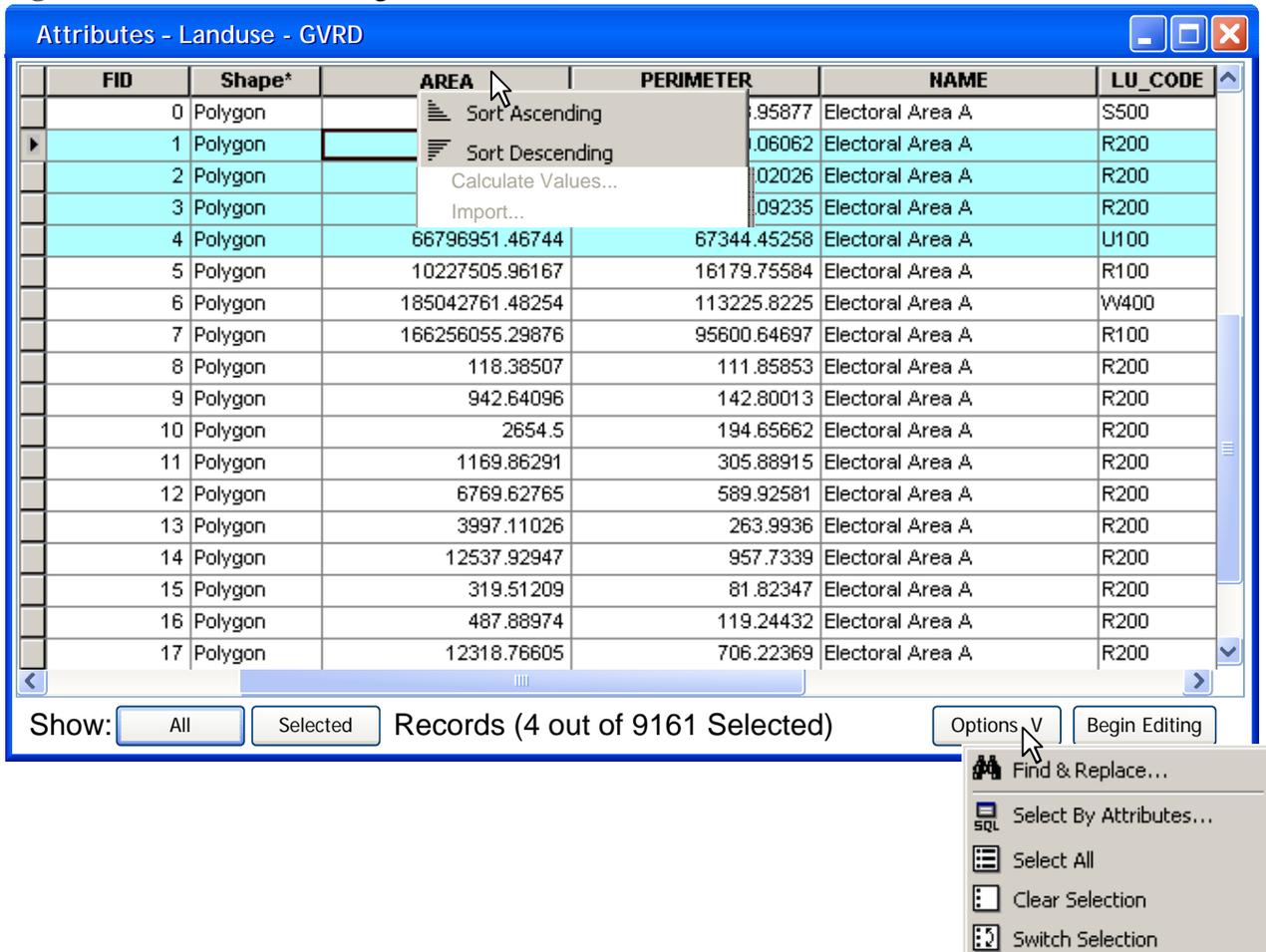
GIS-EI Tool (Country, Province, Census Division, Municipality, Census Tract, Dissemination Area). These can be expanded for integration with other geo-political groupings of Dissemination Areas or to incorporate U.S. or other unique jurisdictional entities. As shown in Figure 1, the smallest geo-political layer is the Dissemination Area (DA) and is the foundation of all other geographic units in the GIS-EI Tool (i.e., other layers are comprised of one or more DAs).

Attribute Feature Classes

Emissions in the GIS-EI Tool are computed on a per feature basis. Those features correspond to the attribute feature classes that contain all the Attribute data (e.g., Population, Housing, Road Length, etc.). They are also used in determining the Activity for a given emissions estimate. Each attribute feature class is associated with a particular geometry within the GIS (polygon, line or point), while each feature within is associated with a Dissemination Area. When first imported into the GIS-EI Tool, attribute feature classes are intersected with the geo-political Dissemination Area feature class to produce correctly proportioned attributes by Dissemination Area. The four primary feature classes currently defined within the database structure of the GIS-EI Tool are: Land Use, Demographic, Roads, Rail.

Within each feature class group there may be one or more separate GIS layers (or subtypes) that represent the individual layers within each feature class (e.g., the Roads attribute feature class can contain multiple subtypes, one for a centreline road network and a second for an EMME/2 or link-based road network). The attribute values themselves can be edited, as shown in Figure 2, allowing users to tweak values such as a feature’s population, number of lanes on a road, etc.

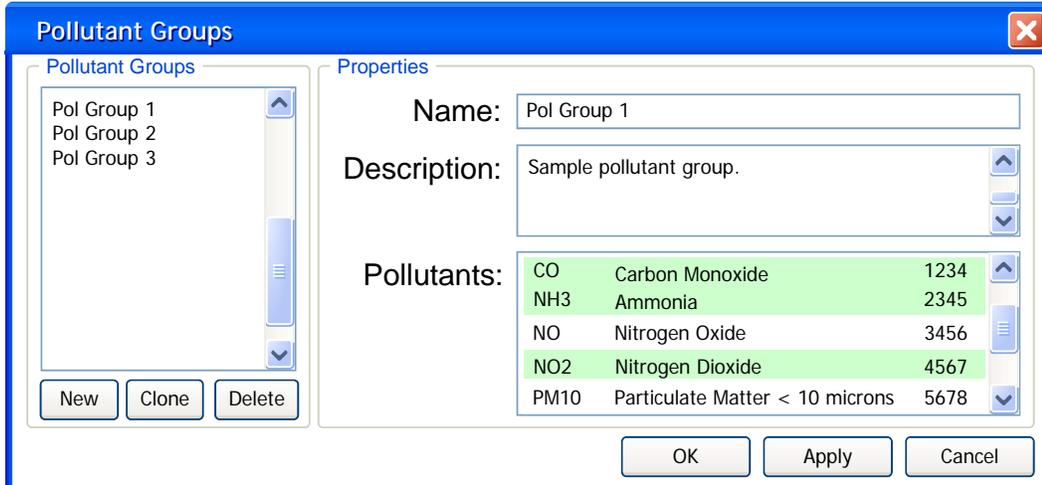
Figure 2. Window for editing attribute data.



Pollutants

Pollutant IDs are needed to associate specific Emission Factors with certain SCCs. Pollutants within the GIS-EI Tool are defined individually by their short and long names. Pollutant groups can be defined as logical groupings of a series of pollutants (e.g., Greenhouse Gases), as shown in Figure 3. Not all pollutants need to belong to a pollutant group and some pollutants may belong to many groups. Pollutant groups are primarily used for reporting.

Figure 3. Dialog for editing pollutant groups.

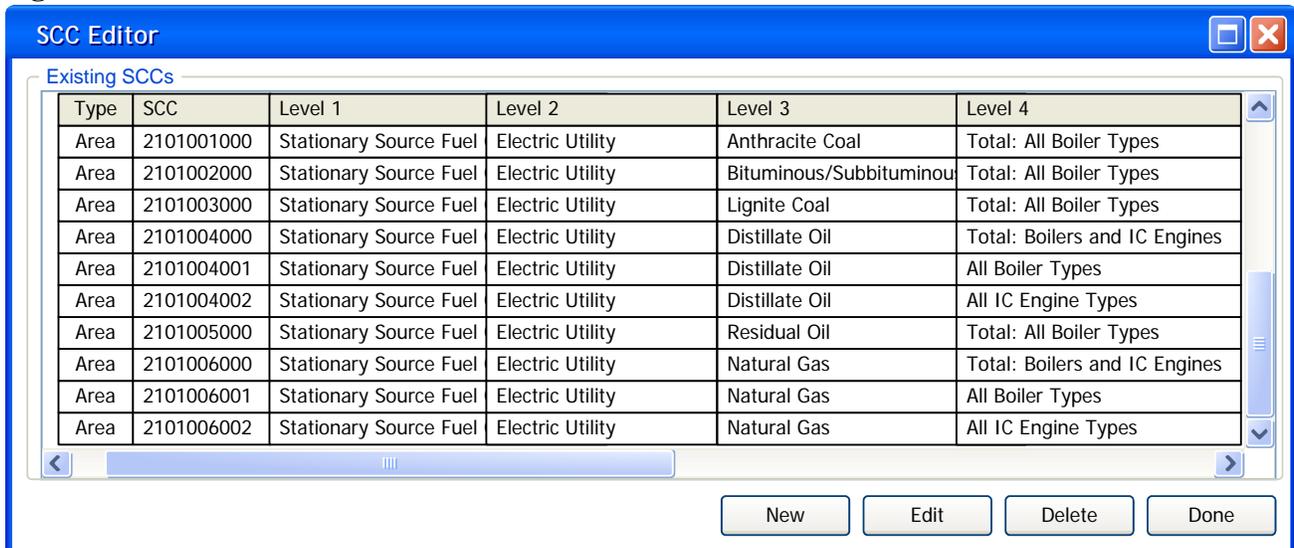


Source Classification Codes

Source Classification Codes are the mechanism used to identify the type of emissions being computed for a particular Emission Estimate and are the primary means of classifying and allocating emissions within the GIS-EI Tool. Figure 4 shows the main SCC dialog window in the GIS-EI Tool.

Users may also define unique groups of SCCs called Source Sectors for post-processing and reporting purposes. This includes industry standard (e.g., NAICS) or custom systems. Source Sector codes are mapped to a series of related SCCs, which can then be used for reporting and querying purposes. An interface to allow users to define their own unique SCCs and/or Source Sector definitions is also provided in the GIS-EI Tool, which allows emission engineers and modellers to provide their own unique codes when no other appropriate code exists (an important feature for Canadian Emission Inventories where U.S. SCCs do not accurately reflect Canadian sources).

Figure 4. Source classification codes editor.



Emission Estimates

An Emission Estimate is the base element that makes up an Emission Inventory within the GIS-EI Tool. An Emission Estimate is uniquely identified as a composite of a pollutant, SCC and a Dissemination Area. An editor is provided, as shown in Figure 5, to allow users to enter the requisite Emission Factor, Activity, Control and Scaling Factors by SCC and Pollutant. The user interface allows users to change the factors for entire regions by selecting one or more geo-political regions either graphically or from a selection query.

Figure 5. Dialog for editing Emission Factors.

The dialog box is titled "Emission Factors" and contains the following sections:

- Select the SCC:** A search bar with the text "Area - 2101001000 - Stationary Source Fuel Combustion - Electric Utility - Anthracite Co" and a "Search..." button.
- Select the Pollutant:** A table with columns "Short Name", "Full Name", and "CAS".

Short Name	Full Name	CAS
CO	Carbon Monoxide	1234
NH3	Ammonia	2345
NO	Nitrogen Oxide	3456
NO2	Nitrogen Dioxide	4567
PM10	Particulate Matter < 10 microns	5678
- Enter Emission Factor Information:** Fields for "Factor" (0.01), "Units" (tonnes / year), "Activity" (Population_Activity), and "Units" (people).
- Enter Optional Factors:** "Scalar Multiplier" (1.0 (Default)) and a calculation: "Control: 0.0 = 1.0 - [0.0] x [0.0] x [0.0]".

Buttons at the bottom: OK, Apply, Cancel.

A separate tool is provided for users to select a Dissemination Area to view all the existing Emission Factors that have already been defined. From this dialog, seen in Figure 6, users can go to the editor to make changes as necessary.

Figure 6. Dissemination Area emission factor viewer.

The dialog box is titled "Emission Factor Viewer" and displays a table of emission factors for a specific Dissemination Area.

SCC	Pollutant	Emission Factor
2101001001	CO	0.001234 tonnes/year
2101001002	NO	0.0222 tonnes/capita/year
2101001003	NO2	0.001 tonnes/capita/year
2101001005	PM10	0.4321 kg/capita/year
2101001006	PM2.5	0.2135 kg/capita/year
2101002001	SO2	0.0005 tonnes/year
2101002003	NH3	0.0095 kg/year
2101002004	VOC	0.09811 kg/year
2102001001		

Dissemination Area: 1590150003

Buttons at the bottom: Edit

Exporting

Once an Emission Inventory is computed, there are several options available to the user to export data from the GIS-EI Tool.

- Map Viewer images – graphical images from the map viewer window.
- Spatial Surrogates⁸ – computes spatial surrogates for a user-defined grid and exports them into a pre-defined SMOKE model file format.
- SMOKE Input files⁹ – exports the computed Emission Inventory for a group of selected census divisions to a SMOKE input text file (see Figure 7) as annual county (Census Division) totals.
- Emission Inventory Delimited Text files – exports the computed Emission Inventory for a group of geo-political regions to a delimited text file for reporting and analysis outside of the GIS-EI Tool.

Figure 7. Dialog for exporting to a SMOKE input file.

Report - Export EI - SMOKE

Header Information

Year:

Description:

Pollutants

Short Name	Full Name	CAS
CO	Carbon Monoxide	1234
NH3	Ammonia	2345
NO	Nitrogen Oxide	3456
NO2	Nitrogen Dioxide	4567
PM10	Particulate Matter < 10 microns	5678
PM2.5	Particulate Matter < 2.5 microns	6789

Source Classification Codes

Type	SCC	Level 1	Level 2	Level 3	Level 4
Area	2101001000	Stationary Source I	Electric Utility Anthracite Co	Total: All Boiler Types	
Area	2101002000	Stationary Source I	Electric Utility Bituminous/S	Total: All Boiler Types	
Area	2101003000	Stationary Source I	Electric Utility Lignite Coal	Total: All Boiler Types	
Area	2101004000	Stationary Source I	Electric Utility Distillate Oil	Total: Boilers and IC Engines	
Area	2101004001	Stationary Source I	Electric Utility Distillate Oil	All Boiler Types	
Area	2101004002	Stationary Source I	Electric Utility Distillate Oil	All IC Engine Types	

CLOSING

Phase 1 of development of the GIS-EI Tool is nearing completion. Once completed, this first version of the Tool will be able to compute population and land use based emissions for the GVRD region of southwestern British Columbia. These emissions can then be exported into SMOKE-ready input files and other formats. The capability to compute emissions from road and rail networks will also exist.

After the completion of Phase 1, the following items have been identified for development as part of Phase 2:

- Location independent, multi-user capability and version control
- Ability to import user-specified / external attribute feature classes
- Integration of pre-generated point and biogenic source datasets
- Backcast/Forecast¹⁰
- Completed metadata
- Advanced QA/QC tools

REFERENCES

Wakelin, T.; Rensing, M., *2000 British Columbia Emissions Inventory of Criteria Air Contaminants: Methods and Calculations*; ISBN 0-7726-5237-6, Victoria, British Columbia, October 2004.

GVRD; FVRD, *2000 Emission Inventory for the Canadian Portion of the Lower Fraser Valley Airshed*; Greater Vancouver Regional District, Policy and Planning Department, Burnaby, British Columbia, November 2003.

RWDI, *Developing A Multi-Agency GIS Emission Inventory Tool: A Feasibility Study*; RWDI West Inc. Final Report W04-130, Vancouver, British Columbia, December 12, 2003.

Peters, D., *System Design Strategies: An ESRI White Paper*; ESRI Inc., Redlands, California, July 2004.

Environment Canada, *Request for Proposal: GIS (Graphical Information System) Emissions Inventory Tool*; Solicitation No. KM759-034623/A, File No. XSB-3-00639 (015), issued February 17, 2004.

Statistics Canada, *Dissemination Area Reference Maps 2001 Census: Reference Guide*; Ministry of Industry; Statistics Canada Catalogue No. 92F-0146-GIE; Ottawa, Ontario, March 2002.

RWDI, *GIS-EI Tool Design Document*; RWDI West Inc., Guelph, Ontario, November 2004.

Boulton, J.W.; Siriunas, K.A.; Lepage, M.F.; Schill, S.K., *Developing Spatial Surrogates for Modelling Applications*; US EPA 11th Annual Emission Inventory Conference, Arlington, Virginia, June 2002.

UNC, *SMOKE V2.1 User's Manual*; Carolina Environmental Program, University of North Carolina; <http://cf.unc.edu/cep/empd/products/smoke/version2.1/manual.pdf>; Chapel Hill, North Carolina, November 2004.

GVRD, *Forecast and Backcast of the 2000 Emission Inventory for the Lower Fraser Valley Airshed 1985-2025*; Greater Vancouver Regional District, Policy and Planning Department, Burnaby, British Columbia, July 2003.

KEYWORDS

GIS, Emission Inventories, SMOKE, emission factor, Canada

ACKNOWLEDGEMENTS

The authors wish to thank a variety of individuals and groups for their technical and financial support, without whom this work would not be possible. Scientists and engineers from: Environment

Canada, Pacific and Yukon Region; Greater Vancouver Regional District; BC Ministry of Water, Land and Air Protection; Fraser Valley Regional District; and, the Northwest Air Pollution Authority in Washington State. Members of Environment Canada Pollution Data Branch have provided valuable technical guidance. ESRI Canada has been instrumental in providing technical expertise in database design and software development.