

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

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## ABSTRACT

This paper presents an update on the current status of an ongoing project to develop a multi-user, Emission Inventory GIS-based tool (EIGIS). The fundamental goal behind the EIGIS is to allow a number of simultaneous users to create high-resolution area and mobile source emission inventories more efficiently. To accomplish this, EIGIS was developed using a bottom-up approach in which 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 tool can also be used to perform queries, generate reports and prepare model input files from computed emissions inventories.

EIGIS underwent a rigorous design phase involving input and feedback from a number of different stakeholder groups. This was followed by the development of an initial prototype capable of defining and calculating emissions at the activity level in the Greater Vancouver Regional District in southern British Columbia. Since that time, a number of components within the tool have been upgraded and added, including a partial revision of the underlying database structure upon which the tool is based. A next generation version of the tool is now in the development and testing phase.

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## BACKGROUND

Air quality management activities in the Fraser Delta region of 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 the Environment (BC MOE), Environment Canada, and the Northwest Air Pollution Authority in Washington State.

All LFVAQCC members are involved to some degree in emissions inventories and have some form of GIS capability and/or undertake GIS projects. In 2003, the LFVAQCC directed its member organisations to share information about their air quality related GIS activities and to explore opportunities to integrate interagency GIS work<sup>1,2</sup>. The result of this directive was to establish a mandate to develop a multi-agency GIS solution that will enhance air quality management in the LFV air shed.

The list of interested stakeholders has since grown to include the Environment Canada Pollution Data Division and of the US EPA, Emission Inventory Group.

Most anthropogenic, area source emissions estimates are based on population or employment 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. An Emission Inventory GIS-based tool, or 'EIGIS', 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 Emission Inventory GIS-based tool. The results of the feasibility assessment indicated that it was not only feasible, but also highly desirable<sup>3</sup>. Based on the feasibility assessment and subsequent reviews by other stakeholders, it was determined that a successful tool must have the following, minimal functionality:

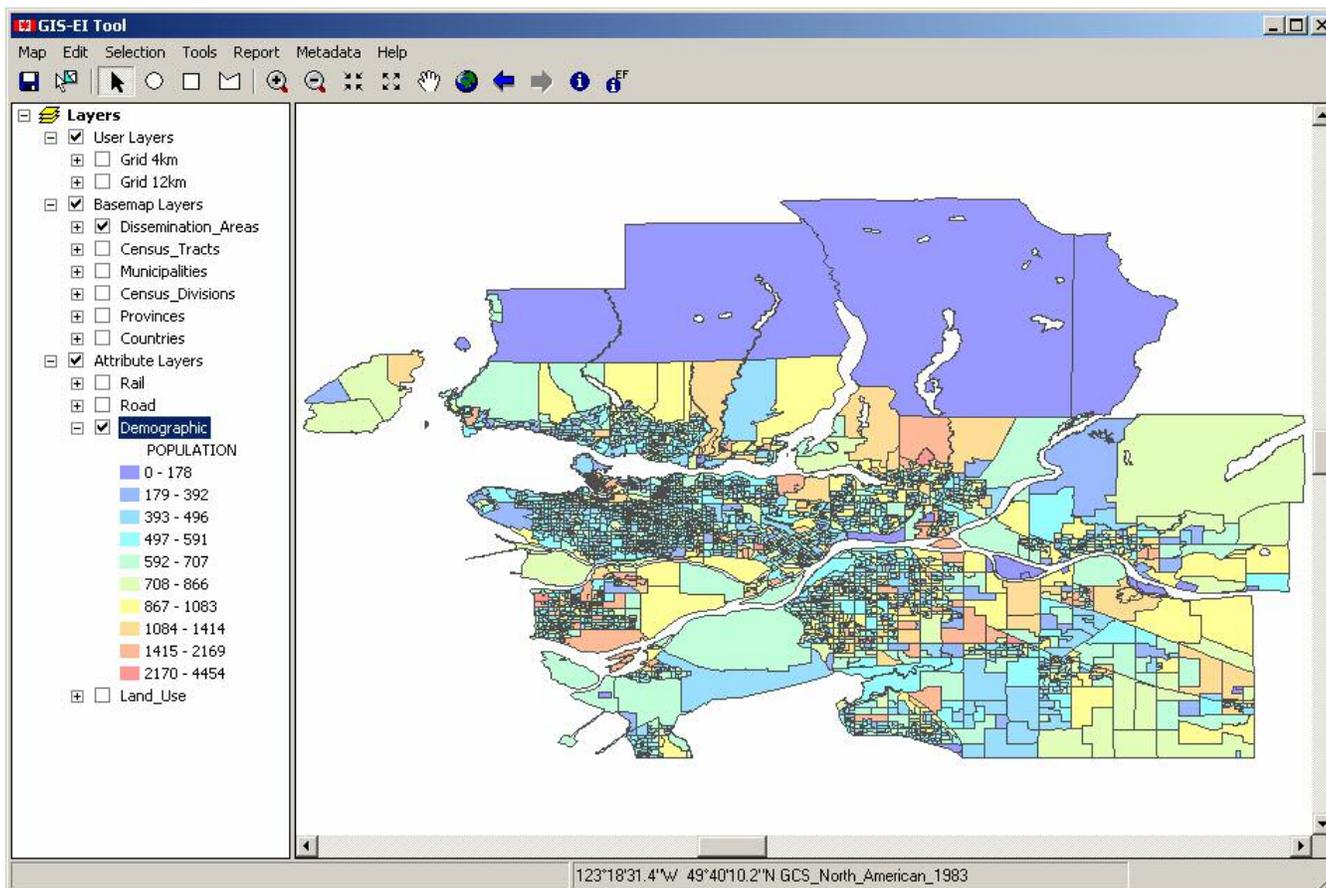
1. The ability to create emission inventories from first principles (*ab initio*) in a straightforward and automated fashion for emission sources that are dependent on demographic, land use, and land-based transportation activity data (roads/railways);
2. The built-in functionality to allow for the straightforward 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 Canada<sup>4</sup>, the EIGIS tool is being developed using the latest versions of ESRI's ArcEngine development suite, with ArcSDE to communicate with a supported enterprise database (e.g. SQL Server). The list of additional requirements and design considerations was lengthy, and is documented as part of Environment Canada's initial request for proposals<sup>5</sup> and the Phase 1 Design Document<sup>6</sup>.

Based on in-depth consultations with numerous stakeholders, it was determined that the EIGIS 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 EIGIS's success, this initial design phase and subsequent testing was identified as the most critical step.

The initial design was completed, and a prototype version of the tool and hardware/system infrastructure was developed and tested for functionality, ease of use, and system integrity for the Greater Vancouver Regional District, as shown in Figure 1. The initial prototype was capable of calculating emissions using GIS-based land use and population activity data in the GVRD.

In February of this year, a meeting was held amongst the stakeholders to go over the current status of EIGIS, and determine how to proceed. It was decided that, after some updates to the software, the stakeholders will take it upon themselves to test and gain some hands on experience using the tool within their own environments. Their comments will be compiled to determine the next set of features to be implemented within the system. The development procedure for the tool is following a new way of programming, called *Agile Development*<sup>7</sup>, where the software is developed in an iterative process, thus creating a more useable tool for the stakeholders. The current short-term goal is to have the GVRD using the EIGIS tool in the fall of 2006 to develop their 2005 emission inventory for area and mobile sources.



**FIGURE 1.** Prototype version of the EIGIS tool.

## **GIS APPROACH**

Creating emission inventories is a tedious and time-consuming task. In its simplest form, the overall goal of this development project is to reduce this effort by creating 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 attribute feature layers (to be used as activity data) and associated emission factors (including scaling factors, control factors, and activity formulae). Additional parameters that are integral to the EIGIS tool include (but are not limited to): source classification codes (SCC), SCC groups/collections, pollutants and pollutant groups/collections, etc. For the purpose of the EIGIS tool, an emission inventory is made up of a series of emission estimates (EE) for individual types of emissions, specified by unique SCCs.

In Canada and many other countries, emission inventories are typically been generated using a “top-down” approach. Using this model, emissions are calculated based on aggregate activity data (e.g., fuel consumption) for an entire country or possibly by Province or State. 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.

EIGIS, 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, land use parcel, etc.). From these emission estimates, emission inventories can be summarised (i.e. aggregated) at any level, simply by summing the appropriate emission estimates by geo-political unit (e.g. county).

Within the EIGIS tool, this bottom-up conceptual paradigm defines emission factors at the lowest common spatial denominator; the individual attribute features within a GIS layer (e.g. line

segment, polygons, etc.). In this way, all user actions within EIGIS are performed for selected attribute features only and not necessarily for the entire emission inventory. This allows for quick updates and computations by re-processing emissions calculations, reporting, etc. only over the regions (selections of attribute features) affected by the changes.

The fundamental computation upon which the EIGIS tool is built is the emission estimate of a given feature, and its equation can be simplified down to the following:

### **Emission Estimate**

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 (A) for a selected feature. An EF is identified by a combination of pollutant and SCC, where a given EF is used in conjunction with a specific activity. The feature for which the EF is being defined contains the location implicitly.

Once the emission estimates exist, the EIGIS tool can be used to export the results into various forms, including SMOKE input files<sup>8</sup> (with spatial surrogates<sup>9</sup>) and other text files which can then be used to create reports and charts using third-party software of the user's choice.

### **Activity**

Activity represents an action or process that leads to the release of pollutants to the air. Activities are drawn from demographic information, process activity data, or other spatially distributed statistics. An activity can be comprised of a single attribute or a combination of attributes from one or more attribute layers, and is based on the nature of the emission factor and availability of suitable attribute data. During stakeholder consultations, it was deemed by the potential end users of the tool to be important to define activities across multiple attribute layers. This relatively new idea is described in further detail in the next section (New Activity Mechanics). For the purposes of the EIGIS 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.

### **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 EIGIS 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:

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

where  
CE = Control Efficiency  
RE = Rule Effectiveness  
RP = Rule Penetration

Control efficiency (CE) is the percent reduction of pollutant due to the control, rule effectiveness (RE) is the percent effectiveness of the regulation in achieving its target, and rule penetration (RP) is the percentage of the emission inventory where the control is applicable. The resulting control factor

represents the multiplier to be applied to the 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. This type of global scaling is more often than not performed to assess impacts on emissions associated with policy scenarios and / or prepare inputs for air quality modelling applications. From the EIGIS perspective, these cases usually 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.

### **NEW ACTIVITY MECHANICS**

An emission estimate is only as accurate as its emission factor and corresponding activity value. Developing accurate emission factors is a science unto itself. The activity value on the other hand is simply limited only in our ability to collect statistics and to calculate activity values in ways that make the most sense to how emissions are released.

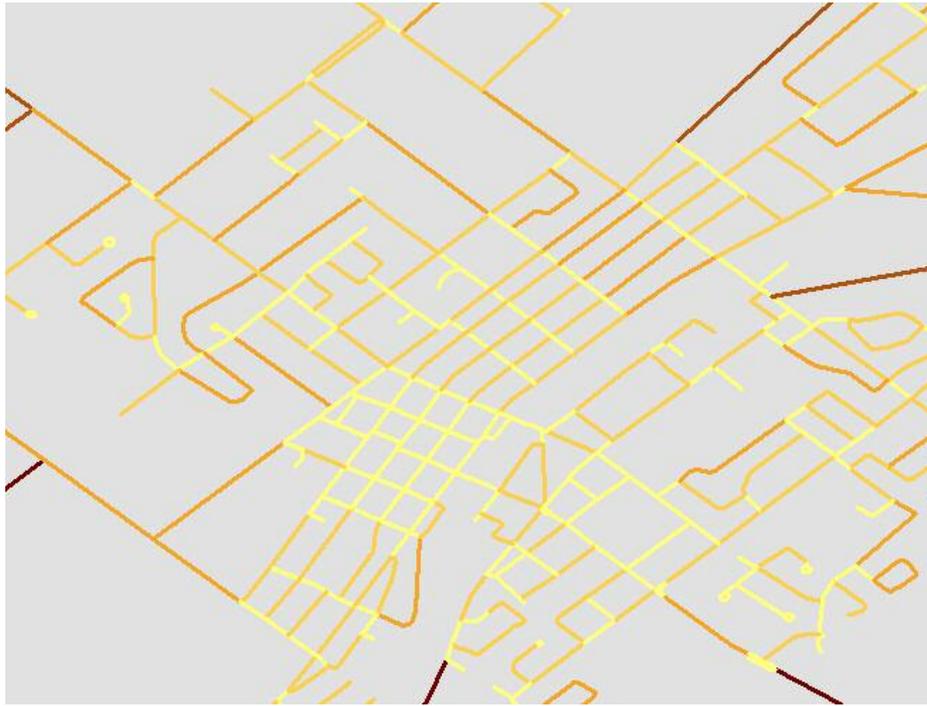
For the most part, an activity is comprised of the value of a single attribute (e.g. length of road, number of people, tonnes of fuel consumed). However, in some cases, an activity may be expressed as a function of more than one attribute and is usually some form of product (e.g. number of lanes x length of road, number of people per household). There are also times when a more complex activity is needed, created from multiple attributes from different GIS attribute layers (e.g. roads in industrial regions, people living in residential areas). More detailed examples of each case are provided below.

#### **Single Attribute Activity**

An obvious example of a single attribute activity is population, as shown in Figure 2. If the emission estimate for human respiration is to be computed, the emission factor for a desired pollutant could be entered in units of tonnes per person. The activity would simply be the number of people located within a geographic region to arrive at the total emissions of human breath from that region. This can be made more complicated by having different emission factors based on age, gender, etc., where the activity formula would point to a corresponding attribute in the same GIS layer (e.g. number of males over 55).

#### **Multiple Attribute Activity from One Layer**

It may be desirable to create an activity formula or equation that is based on multiple attributes. Perhaps for mobile emissions, the vehicle kilometres travelled is not available for some roads, and as such, an emission factor is applied that is based on the length and number of lanes in a road (i.e. Activity = length of road x number of lanes, see Figure 2). Activities defined in this manner are not limited to multiplication. An activity describing population density can be formulated as population / household. Other operators, such as addition and subtraction may also be used.



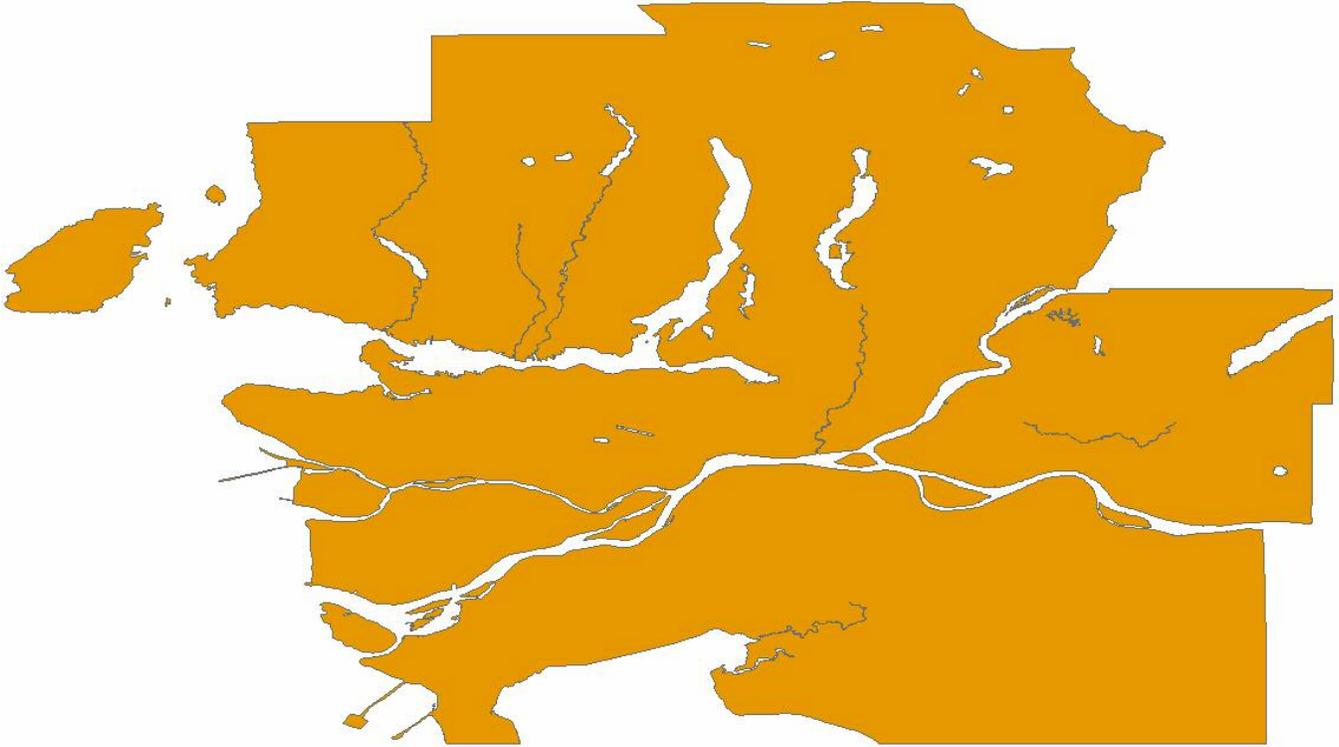
**FIGURE 2.** Multiple Attribute Activity: Single Road Layer in a 2 km by 2 km area (Activity = length of road x number of lanes).

### **Multiple Attribute Activity from Multiple Layers**

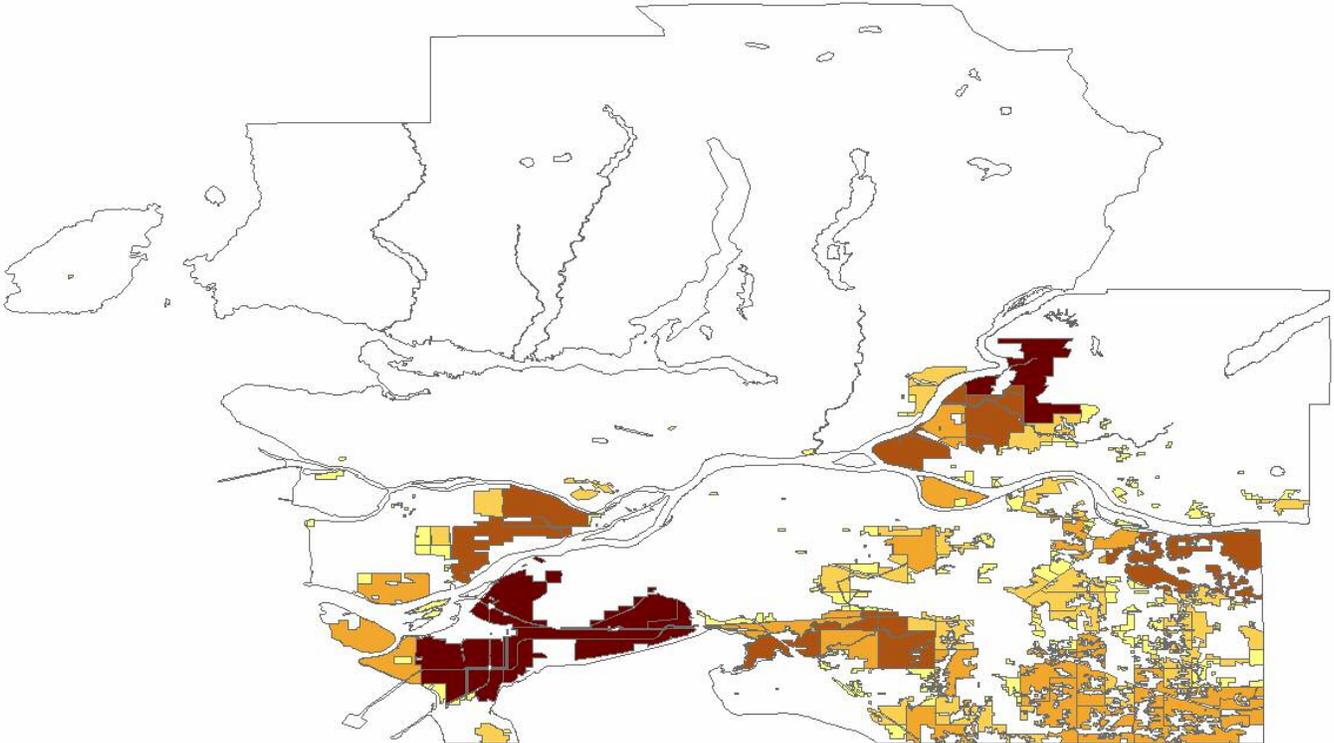
With the power of GIS at hand, it is also possible to allow for the definition of activities that span multiple GIS layers (attribute feature classes). This ability opens up a wide range of opportunities to developing complex activities for the purpose of computing emission inventories. With this approach, an emission factor can be applied to an activity that more accurately describes not only the specific values of the activity itself, but also its spatial location.

For example, emissions from livestock, such as cattle, can be applied not only to agricultural land use areas, but to land use areas specifically designated for livestock use. In the EIGIS tool, this would be accomplished by defining a livestock attribute (e.g. total cattle in a census division, see Figure 3a) cross-referenced with livestock land use areas, such that all cattle are distributed geographically within those areas, as shown in Figure 3b. The emission estimates would then be computed and linked to those areas, allowing for better spatially resolved emissions.

This also allows for potentially new methods for applying emission factors. One example is particulate matter from roads. It is known that in the winter months, snow cover can limit the amount of dust released from roads. A map of snow accumulation for a given year could be used to apply different emission factors to different portions of roads, based on the amount of snowfall. Another example might use a temperature profile with a rural land use layer to define wood burning for household heating. The possibilities are limited only by creativity of the user and availability of GIS-based attribute layers.



**FIGURE 3a.** Single Attribute Activity: Total cattle in a census division.



**FIGURE 3b.** Multiple Attribute Activity: Total cattle combined with an agricultural land use layer.

## CLOSING

Phase II of development of the EIGIS tool is nearing completion. Once finished, the tool will be used to generate improved emissions inventories using GIS-based attributes from polygon and polyline attribute feature classes. These emissions can then be exported into SMOKE-ready input files and other text formats for further analyses.

The following items have been identified for future development:

- Location independent, multi-user capability and version control
- Integration of pre-generated point and biogenic source emissions inventories
- Backcast/Forecast functionalities<sup>10</sup>
- Advanced Metadata functionality and QA/QC tools

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## **KEYWORDS**

GIS, Emission Inventories, SMOKE, Emission Factor, Canada, Activity, Shapefile

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