Exploring the Use of Suitability Modeling to Locate Air Toxics Monitors in Massachusetts

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ABSTRACT

The goal of this analysis was to explore a GIS-based technique to assess the potentially suitable locations for monitoring air toxics pollutants emitted at landfills. Several map layers such as landfill activity, population density, and distances from other emission sources were incorporated into three different suitability modeling scenarios. The ArcGIS Spatial Analyst tool was used to perform the spatial analyses. The analyses consistently identified two potential areas for locating monitors the north of the two major landfills in the Chicopee/Springfield area. The results from these analyses are preliminary, but they demonstrate the usefulness of the spatial suitability analysis technique.

INTRODUCTION

In the United States, the most common disposal method for municipal solid waste (MSW) is burial in landfills. In 1988, the total MSW generated in the United States was 208 million tons.[1] In 1993, 62% of MSW was buried in landfills, 22% was recycled, and 15% was combusted.[2] When solid waste is placed in a landfill, gaseous and liquid emissions are produced through a variety of biological and chemical processes. Landfill gas is also emitted as decomposition reactions within the landfill produce large quantities of methane and carbon dioxide. This gas stream emitted at the landfill also contains volatile organic compounds (VOCs), many of which pose a potential hazard to human health.

The objective of this study was to explore the use of suitability mapping to identify potentially suitable locations for placing air quality monitors to measure air impacts from landfills in the Chicopee/Springfield, Massachusetts region. The Environmental Systems Research Institute (ESRI) ArcGIS software extension, Spatial Analyst, was used to perform the analyses for this study. Geographic data layers such as population density, landfill locations, and the geographic locations of other emissions sources were used to create multiple suitability model scenarios.

The suitability analysis discussed in this paper was a small part of a larger study to assess the overall air toxics monitoring network in the Chicopee/Springfield area. The objectives of the air toxics monitoring network assessment include

- quantifying ambient concentrations of air pollutants in the Springfield area and assisting the assessment of personal exposure to air pollutants;
- identifying the contribution of landfill emissions to ambient hazardous air pollutant (HAP) concentrations and providing support to the regulatory community in developing mitigation plans; and
- supporting air quality and/or human health exposure modeling.

The results of the suitability analysis may be used to help identify gaps in the existing air toxics monitoring network and to aid in the placement of future air monitoring sites.

TECHNICAL APPROACH

The GIS software, ArcGIS Spatial Analyst, was used to perform the analyses for this study. ArcGIS provides a framework for overlaying and analyzing spatial relationships among multiple map layers. Spatial analysis techniques were used to investigate relationships among geographic features and sources of air emissions with respect to the existing toxics monitoring network in the Chicopee/Springfield area. These analyses serve as a guide for placing monitors to measure the impact of landfill emissions on the surrounding region.

The GIS-based analyses were conducted using the ArcGIS software, Spatial Analyst. Spatial Analyst is a raster-, or grid-, based software package that provides a platform for working with gridded data sets. Spatial Analyst was used to produce suitability maps highlighting "suitable" geographic areas derived from weighted and combined map layers based on established criteria. There are five general steps for developing suitability models and producing suitability maps:

1. *Define the objective.* The first step in developing a suitability model is to determine the objective or scenario to be modeled. Suitability maps then help identify possible sites for placing objects (e.g., monitoring sites, roads, buildings). The first step in developing a suitability model is to determine the objective or scenario to be modeled.
2. *Identify and obtain data sets.* The second step in suitability modeling is to determine which data sets are required for the analysis.
3. *Derive data sets.* The third step is to derive new data from existing data sets. For example, if the distance from a particular geographic feature is a required input to the suitability model, distance contours can be derived from the locations of geographic features. Another type of model input layer is a density plot such as mapping the spatially distributed annual emissions from a power plant (e.g., from a dispersion model).
4. *Reclassify data sets to create a common scale.* Many different data sets containing various data units can be input into a suitability model; to create a suitability model, each layer must be classified to a common scale by reclassification of data units.
5. *Weight and combine data sets.* The final step in suitability modeling is to determine the relative importance of each data set, weight them accordingly, and then combine the data sets to produce a suitability map. Weighting the data sets defines the extent to which each data set will influence the model results.

Data Acquisition

The following data sets were used for the suitability analysis:

- Meteorological and topographical data for the region
- 2000 Census population data
- Landfill locations and emissions activity information

- On- and off-road mobile source emissions activity information
- Locations of large industrial emissions sources
- Locations of other facilities relevant to this analysis (including schools and airports)

Meteorological and Topographical Characterization of the Chicopee/Springfield Area

Meteorology and topography play an important role in the transport and dispersion of air pollutants in the Chicopee/Springfield area. The regional meteorological patterns indicate the direction and magnitude of local-scale transport within the region and help identify potential monitoring site locations downwind of emissions sources. Ideally, a highly resolved gridded wind field would be used to model wind flow patterns. Because gridded wind data were not available for use in this project, a wind rose was developed to assess the predominant wind patterns during summer 2000 and to qualitatively identify regional influence due to wind flow. Wind roses summarize the percentage of time that winds come from a particular direction and display the wind speeds by magnitude. Wind flow in the Chicopee/Springfield area is most often southerly and southwesterly.

The wind rose was incorporated into the analysis with the use of ArcGIS. A grid was created around the monitoring site where the wind data were collected. The derived grid was then divided into 16 quadrants that mirror the quadrants associated with the wind rose diagram. The grid cells in each quadrant were assigned wind speed and direction data values according to the wind rose to mimic a gridded wind field. The assigned data values were linked to the opposite quadrant in order to weight the downwind areas more heavily than the areas from which the wind was blowing.

Digital elevation model (DEM) data were obtained from the U. S. Geological Survey (USGS). The Spatial Analyst hillshade calculation was used to create a three-dimensional visualization of the regional topography. The DEM data were also used to characterize the potential topographical influence on meteorology and the distribution and transport of regional emissions. The terrain in the Chicopee/Springfield area warrants the use of gridded wind data to more accurately characterize wind patterns. Figures 1a and 1b show the wind rose and the DEM data for the Chicopee/Springfield area.

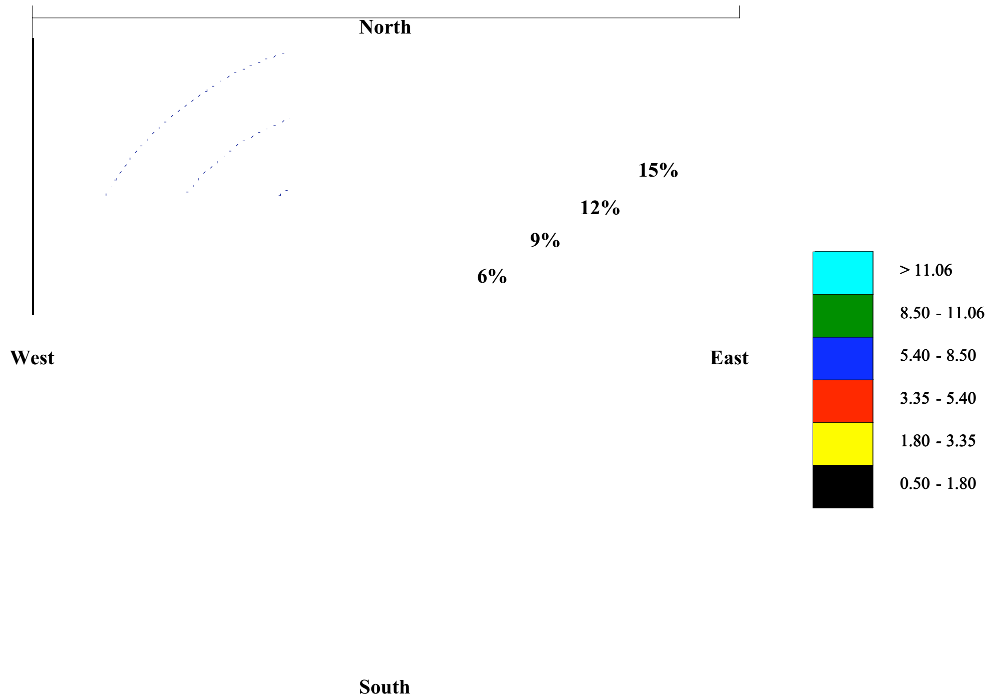

Figure 1a. Wind rose for Chicopee, May-October 2000, Chicopee/Springfield area.

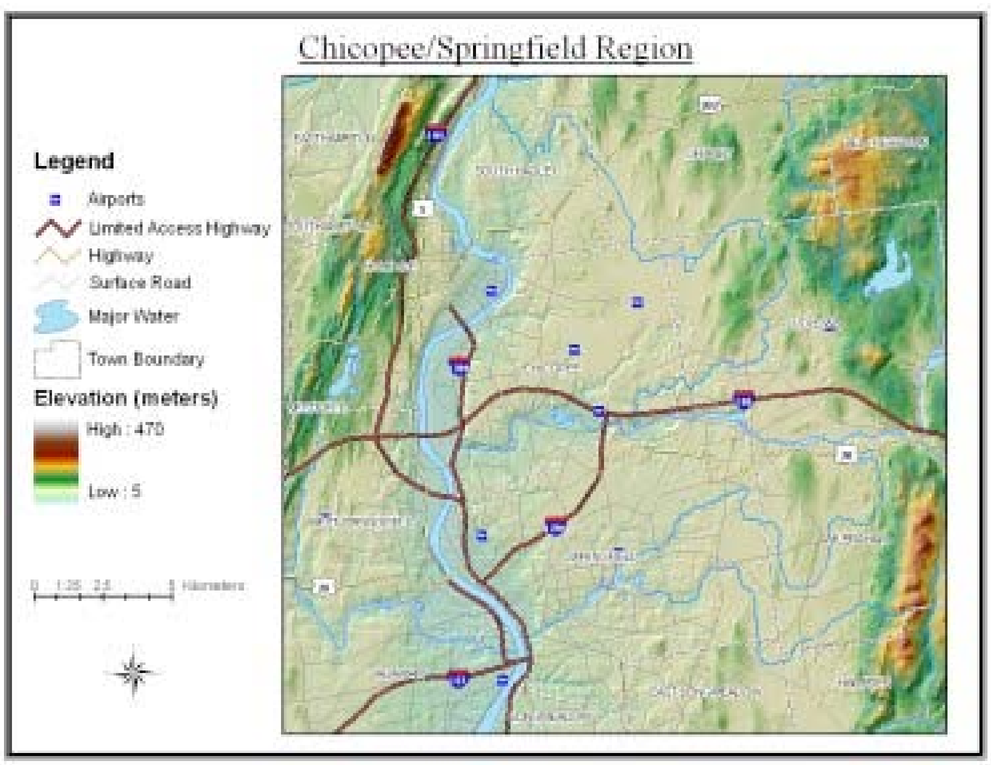

Figure 1b. DEM data for the Chicopee/Springfield area.

Population Density

Population data obtained from the 2000 U.S. Census were used to identify areas of high population density and the regional population distribution for investigating the placement of monitors to measure potential air toxics health impacts. Figure 2 shows the population density distribution in the Chicopee/Springfield area. As shown in Figure 2, the West Springfield and east Holyoke areas have the highest population densities in the region.

Population data can also be used to determine the number of people surrounding existing ambient monitors for the purpose of assessing potential community emissions exposure. Sensitive population analyses are also important when determining where to place air toxics monitors. Sensitive populations include young individuals (5 and under) and the elderly (65 and older).

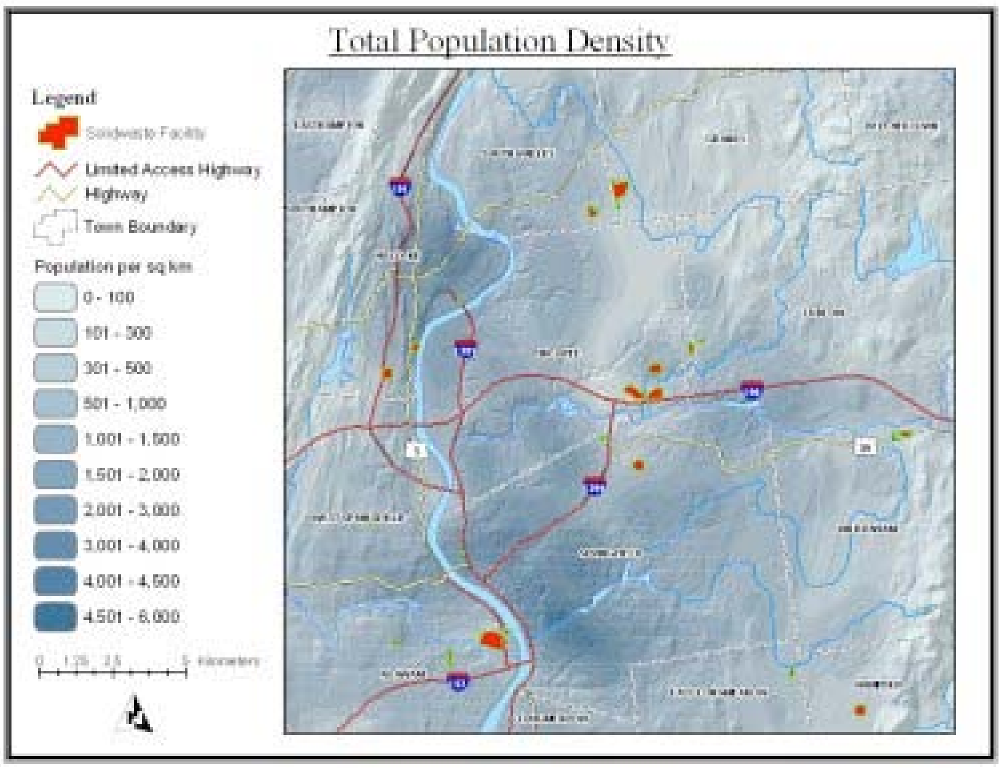

Figure 2. Total population density

Landfill Emissions Activity Data

Solid waste facility locations were obtained from the Massachusetts Department of Environmental Protection and mapped based on the annual amount of solid waste accepted at each facility. Landfill density maps were created by dividing the annual waste tonnage accepted at each facility by the area of each facility. The landfill density map was reclassified for input to the suitability model. Annual waste tonnage ingested by the landfill was used as a surrogate for emissions activity because actual air emissions were not readily available.

Figure 3 shows the locations of solid waste facilities and corresponding activity data for the Chicopee/Springfield area. As shown in Figure 3, the four highest-capacity landfills in the region are the Granby-Holyoke Landfill, the Chicopee Landfill, the Community of Massachusetts Municipal Refuse Facility, and the Pioneer Valley Landfill.

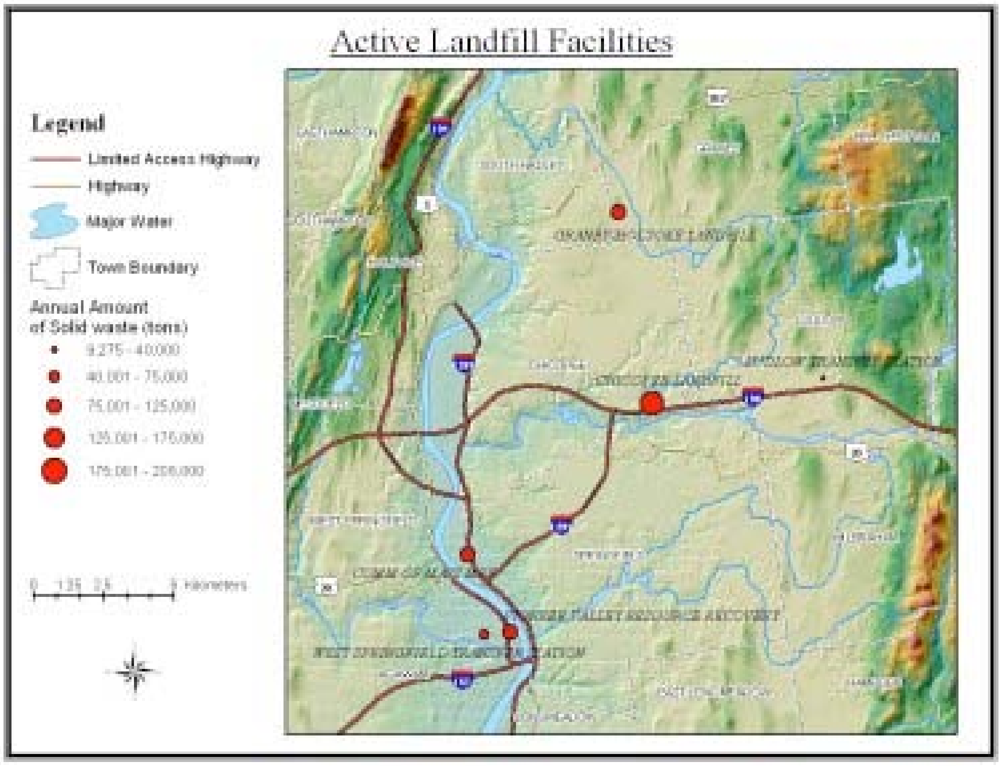

Figure 3. Location of solid waste facilities and annual waste per facility.

Mobile Source Activity Data

It is important to examine the spatial distribution of other regional emission sources such as emissions from on- and off-road mobile sources because many of the same tracer compounds emitted by landfills are also emitted by mobile sources. The locations of mobile sources, including roadways and airports, were mapped to assess the spatial distribution of mobile source emissions in the Springfield/Chicopee area (Figure 4). Road network maps containing average annual daily traffic (AADT) volume data for surface streets and highways in the Springfield/Chicopee area were obtained from the Massachusetts Department of Transportation (MA DOT). The data shown in Figure 4 represent the average number of vehicles per road segment per day. The traffic volume is an indicator of the relative mobile source activity, and corresponding emissions levels, in the Chicopee/Springfield area.

Airport locations were obtained from the U.S. Bureau of Transportation Statistics. However, airport activity data were not available. Because no airport activity data were available, the Spatial Analyst tool was used to perform distance analyses to generate distance contours surrounding each airport location. The distance calculation for the airport layer was derived using an inverse distance function ($1/r^2$).

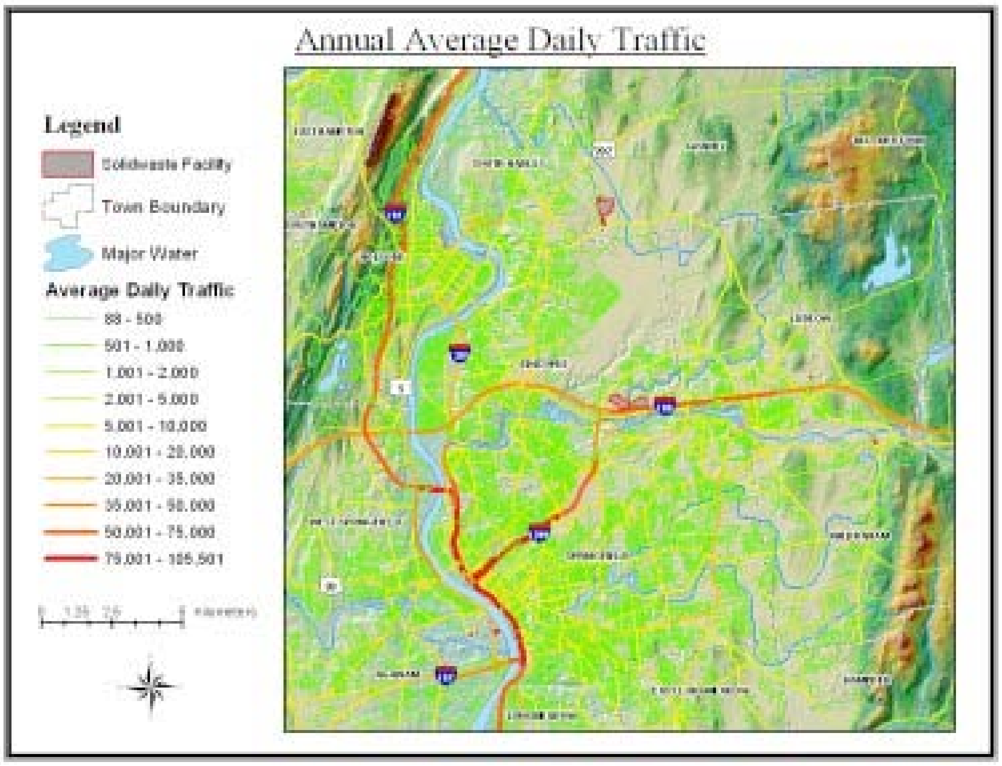

Figure 4. Annual average daily traffic.

Large industrial emissions sources

Emissions data for industrial sources were obtained from the Environmental Projection Agency's (EPA) Aerometric Information Retrieval system (AIRS) are used to map the magnitude of VOC emissions in the Chicopee/Springfield area. Figure 5 shows the location and emissions contributions of large VOC-producing industrial facilities in the Chicopee/Springfield area.

Approximately 55% of total anthropogenic VOC emissions in these counties are from mobile sources (on-road and non-road combined). Area and point sources are responsible for about 37% and 8% of countywide VOC emissions, respectively. The data shown in Figure 6 represent the distribution of anthropogenic, or man-made, sources of VOC emissions in Chicopee/Springfield area as reported in the 1996 Periodic Emissions Inventory for Massachusetts.[3]

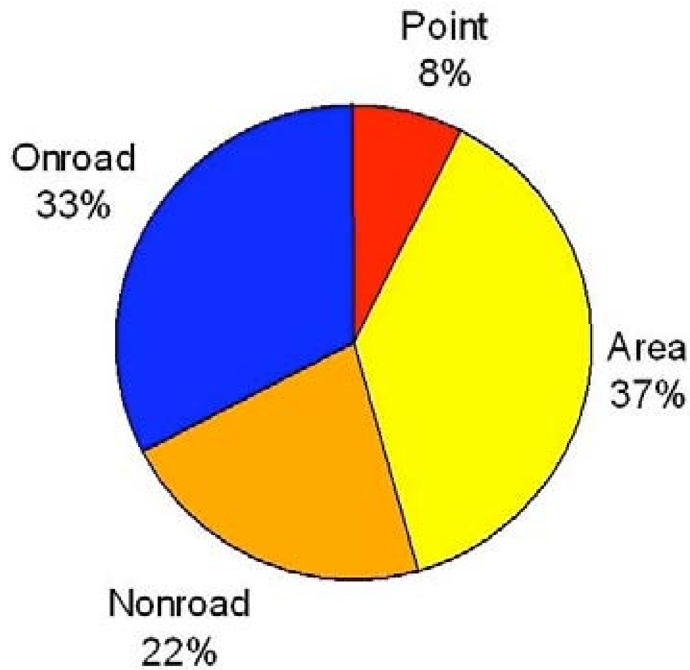

Figure 5. Distribution of anthropogenic sources of point source VOC emissions. (Daily VOC emissions by category (tons per summer day).

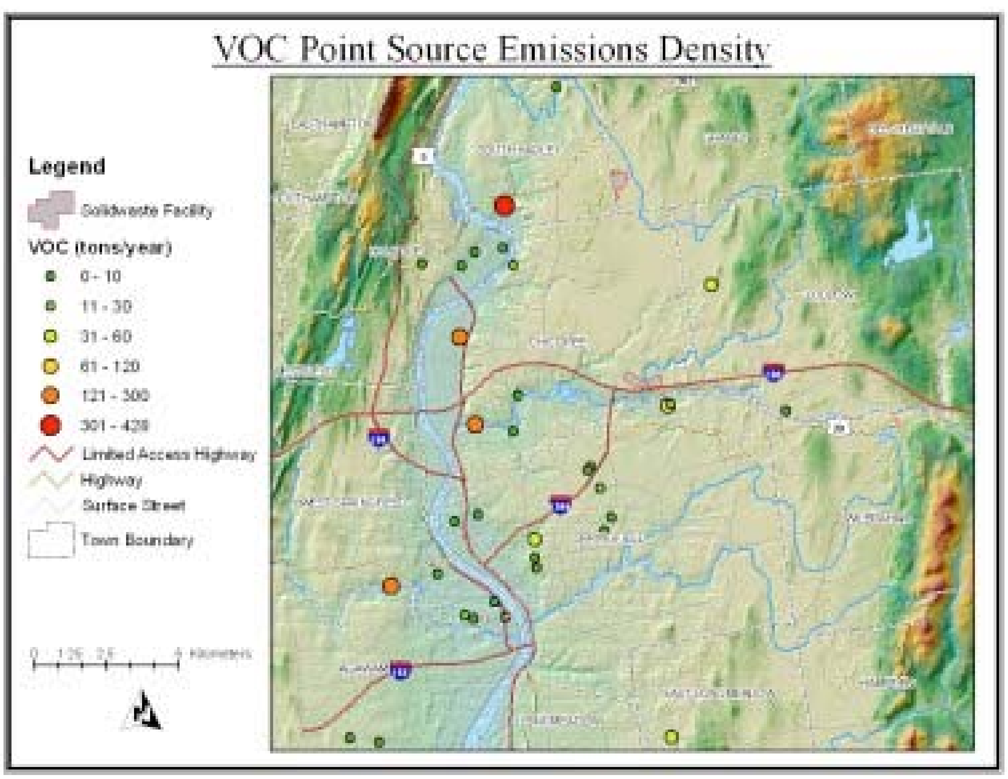

Figure 6. Location and magnitude of point source VOC emissions.

Other Data

School locations obtained from ESRI's 2000 GIS data set were included in this analysis because children are a part of the sensitive population group. Because children spend much of their time at school, the locations of schools were considered in the suitability analysis.

Model Scenarios

Three different model scenarios were defined to examine the potential placement of an air quality monitoring site: (1) base calculation, (2) proximity to landfill emissions, and (3) meteorological influences. The layers that were used to investigate different monitoring scenarios included population density, landfill emission activity data, mobile source activity data, locations of large point sources, airport locations, and school locations. Weighting criteria assigned to each map layer represent the relative importance of the layer to each model scenario. For example, the "proximity to landfill emissions" model contains a higher weighting percentage for the landfill layer compared to the mobile layer, which is a less significant layer in this model because we are more interested in placing monitors in areas to monitor impacts from landfills with as little interference from mobile sources as possible.

Because each map layer contains different data in different units, data transformations were performed to adapt the data sets to a common scale by ranking the spatial influence of each layer in the model. These ranking schemes were determined on an individual map layer basis depending on the desired influence of each layer on the model. Prior to developing each model, the map layers were reclassified to a common scale of one to ten, one being the most suitable and ten being the least suitable.

The spatial analysis map calculator was used to weight and combine individual map layers and produce a suitability model. Following is an example of a map calculator expression:

([Layer_1]*.20 + [Layer_2]*.30 + [Layer_3]*.50)

In this model, Layer_1, Layer_2, and Layer_3 represent individual map layers and decimal values are the weighting factors applied to each layer. Layer 3 is weighted most heavily because it should have the most influence in the model. The output of the map calculator is the suitability model. Tables 1 through 3 summarize the weighting schemes used for each of the three suitability models. The suitability model is displayed on a shaded scale of one to ten, one being the most suitable and ten being the least suitable.

The first suitability model, the base calculation, was developed to identify regions where landfill emissions could be monitored with respect to other factors influencing the region. Low areas of mobile source activity were given a relatively high weighting percentage because many of the same tracer compounds used to track landfill emissions are also emitted by mobile sources.

Table 1. Base calculation layers and weighting scheme.

Layer	Weighting	Weighting Criteria
Density of landfill activity data	25%	High density = more suitable
Density of total population	20%	High population density = more suitable
AADT	25%	Low traffic volumes = more suitable
Density of VOC point source emissions	10%	Far from dense point source emissions = more suitable
Distance to airports	5%	Far from airports = more suitable
Distance to schools	10%	Close to schools = more suitable

The second suitability model was developed to identify regions where landfill emissions influence is given priority in the suitability model. The objective of this model was to identify areas likely to be influenced by landfill emissions independent of influence from other emissions sources. Consequently, landfill activity data were weighted the highest in the model.

Table 2. Proximity to landfill emissions layers and weighting scheme.

Layer	Weighting	Weighting Criteria
Density of landfill activity data	50%	High density = more suitable
Density of total population	20%	High population density = more suitable
AADT	20%	Low traffic volume = more suitable
Density of VOC point source emissions	5%	Far from dense point source emissions = more suitable
Distance to schools	5%	Close to schools = more suitable

The third suitability model was developed to identify the potential directional influence of the wind. The wind influence layer depicts areas of high downwind measurements from the existing monitoring site; these areas were assigned the highest weight in the model. For example, winds were from the south about 13% of the time; therefore, the northern wind grid quadrant is weighted with 13% of the total meteorological influence.

Table 3. Meteorological influence layers and weighting scheme.

Layer	Weighting	Weighting Criteria
Density of solid waste facilities activity	25%	High density = more suitable
Density of total population	15%	High population density = more suitable
AADT	20%	Low traffic volumes = more suitable
Density of VOC point source emissions	5%	Far from dense point source emissions = more suitable
Distance to schools	5%	Close to schools = more suitable
Density of wind influence	30%	Dense area of influence (inverse of the wind rose in Figure 2-1) = more suitable

Model Results

Figure 7 shows the results from the suitability analysis for the base calculation model. The dark areas in the map indicate regions of high suitability—these are areas in which a monitor would be well=placed based on the criteria for the base calculation scenario (see Table 1). Figure 7 shows two suitable areas: Chicopee, directly north of Interstate 90, and an area close to the South Hadley/Granby border.

Figure 8 shows the results of the suitability analysis that identifies areas likely to be influenced by landfill emissions. As shown in Figure 8, the model results for this scenario identify three suitable areas. The same regions that were identified as suitable areas in the base calculation model also appear in this model. The area directly above Interstate 90 in Chicopee increased in the direction of Interstate 90 due to the reduced weighting factor assigned to the AADT layer.

Figure 9 shows the results from the suitability analysis for the model incorporating wind influence. The two suitable areas from models 1 and 2 (discussed above) also appear to be suitable in this model. The suitable area to the north of the existing monitoring site increased slightly in size compared to the suitable area near Interstate 90, which decreased in size. According to the wind rose in Figure 1A, the majority of the wind blows from the south suggesting that the region to the north of the existing monitoring site may be directionally influenced by landfill emissions; therefore, it could potentially be a suitable area to monitor emissions from a landfill. Figure 1A shows a moderate wind from the east-northeast, which resulted in a suitable area west of the existing monitor.

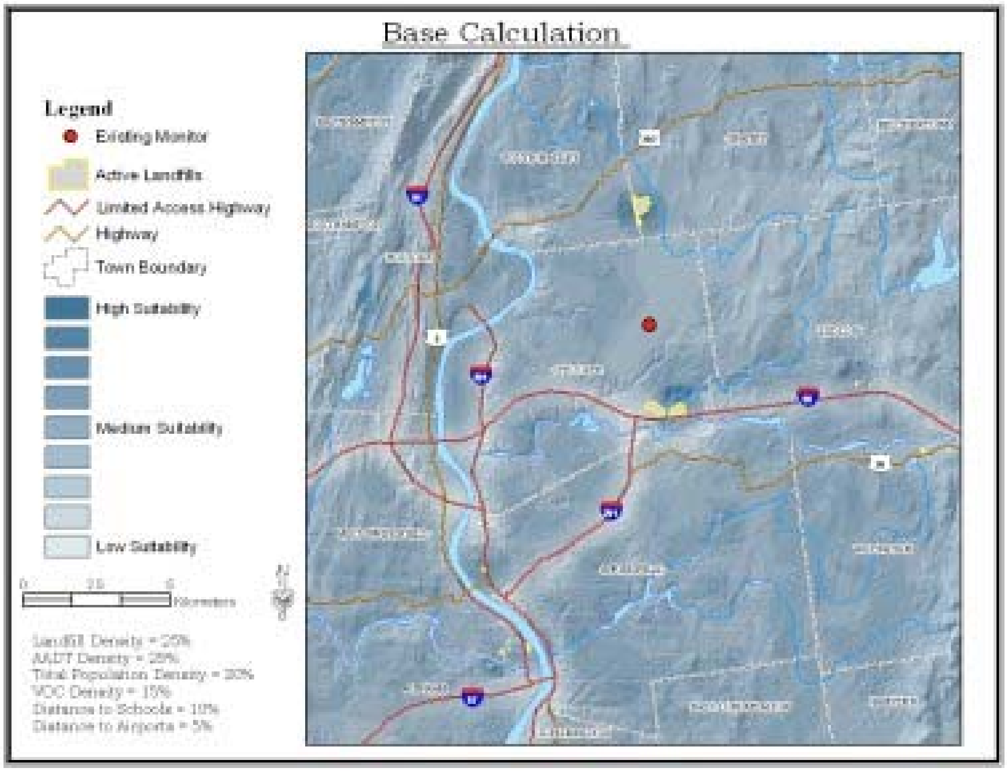

Figure 7. Base calculation model suitability analysis results.

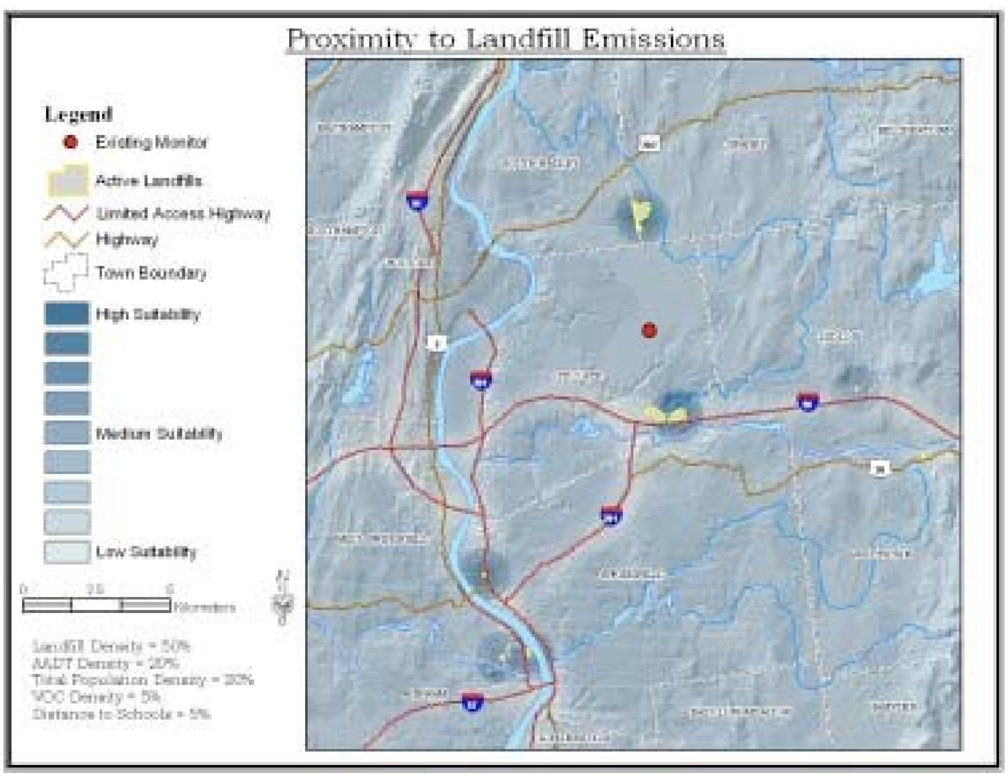

Figure 8. Suitability analysis results with more weighting given to landfill activity.

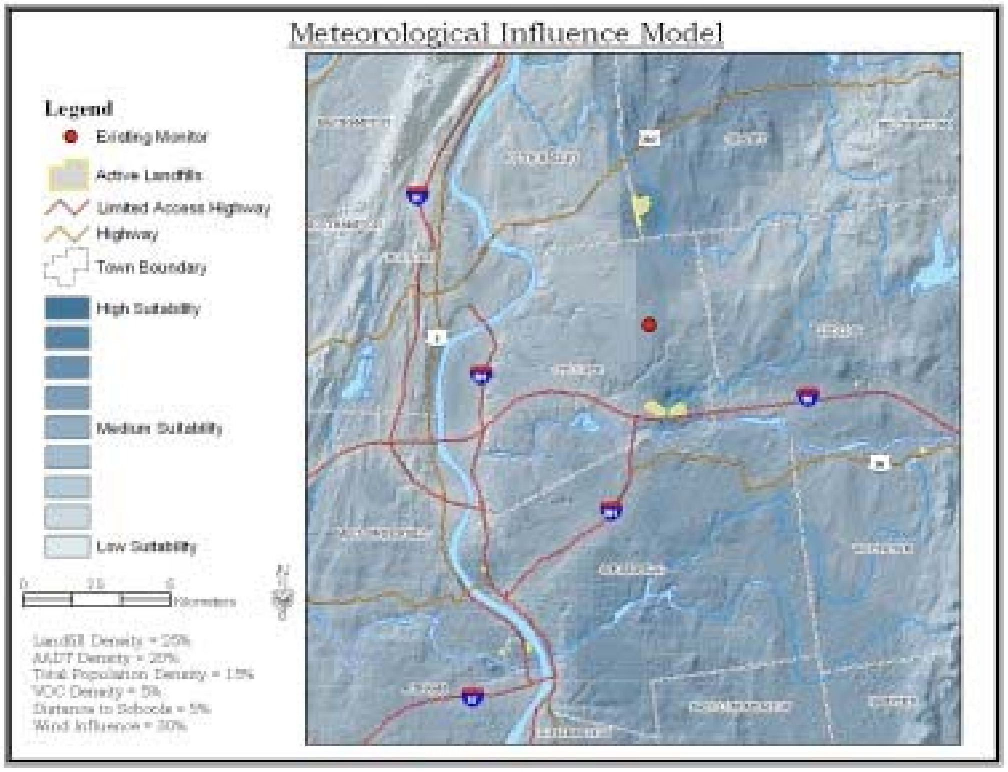

Figure 9. Suitability analysis results with meteorology considered.

CONCLUSION

Three suitability models were developed to identify possible locations for monitoring air toxics emissions from landfills. The analyses consistently identified two potential areas for locating monitors north of the two major landfills in the Chicopee/Springfield area. The results from these analyses should be considered preliminary and demonstrate the usefulness of the spatial suitability analysis technique. Several additional data sets should be considered in future suitability analyses including

- a gridded wind field to take into account the potential directional flow on an annual basis of pollutants in the region.
- actual landfill air toxics emissions data.
- more toxics emissions activity data including regional sources such as construction equipment, trains, and small industrial engines.
- land use and parcel data to determine where to place monitors considering the availability of land and land-use characteristics.

Although the Spatial Analyst suitability model identifies potential areas for placing air monitoring sites, ground-truthing should always be performed to verify the actual site suitability.

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