A GIS-based Atmospheric Dispersion Modeling Project for Introductory Air Pollution Courses

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Students enrolled in introductory air pollution courses can have difficulty understanding or visualizing dispersion modeling using the Gaussian plume equation. They can also be challenged by the changing nature of the plume as it travels downwind and combines with other plumes within a given area. Calculations by hand or in a spreadsheet generally focus on manipulating one or two variables and may only plot one plume in one dimension. To address such limitations, several years ago we developed a customized application integrating a Geospatial Information Science (GIS) program, specifically ESRI's ArcMap 9.1, with a Matlab script. When used together with specified atmospheric and source parameters for a Gaussian plume, these programs enabled the graphical display of a grid of downwind concentrations on a map. Recently we conducted a comprehensive redesign of the project using only ESRI's ArcGIS 10.0 for both concentration calculations and plotting. The project scenario asks teams of approximately four students, who comprise a "company", to locate several new cement factories and power plants within a given city, calculate the pollutant uncontrolled emissions rate, and identify mitigation techniques (e.g., increased stack height or incorporation of pollution control devices) to meet the US National Ambient Air Quality Standards (NAAQS). Using a custom interface in ArcGIS 10.0, students vary atmospheric stability conditions, stack heights, wind speed, and calculated controlled emission rates to create an array of downwind plume concentrations from all existing and new sources, which are plotted on a city map. Since costs increase for higher stacks and more effective control devices, students attempt to locate sources in a manner that will minimize costs. In ArcGIS 10.0, multiple plume concentrations are then summed and the resulting impacts on four major urban categories (residential, schools, religious complexes, and hospitals) are quantified and depicted. The student company with the most optimized solution (i.e., lowest total cost) that meets the NAAQS for PM_{10}, the chosen pollutant, under given atmospheric conditions is awarded the bid. While the application creates a relatively simple model of the dispersion process, it helps students visualize dispersion on a macro-scale, and the specific effect of the variation of each parameter on downwind concentrations. Post-project assessment data indicates that all students (n=10) consider themselves knowledgeable on how to use the Gaussian dispersion model to solve for downwind pollutant concentrations. Additionally, 80% of students surveyed post-project indicated that the dispersion project increased their knowledge of Gaussian dispersion modeling for air pollutants. Students also reported that this project increased their familiarity with ArcGIS and that the project is a useful interdisciplinary coupling of environmental engineering and GIS.

(1) Introduction

Many introductory air pollution courses incorporate atmospheric dispersion into their curriculum. One common approach for determining downwind pollutant concentrations is the Gaussian dispersion model.[4] Due to time constraints and conflicting project requirements, many courses do not incorporate a laboratory or project concerning Gaussian dispersion. Our experience has indicated that traditional techniques, such as hand calculations or spreadsheets, can make it difficult for some students to visualize effects of modifying variables within the Gaussian dispersion equation (e.g., stack height, wind speed, etc.).

To address this shortfall, several years ago instructors in the Department of Geography & Environmental Engineering at the United States Military Academy (USMA) created a custom application that merged Matlab and ArcGIS. This application enabled undergraduate students to visualize the cause and effect relationship between changing input variables in the Gaussian plume equation, and the resultant downwind plume concentration. By changing inputs such as the stack height, wind speed, atmospheric stability, and the source emission rate, the custom application created a geo-referenced grid of plume concentrations aligned to a map. The approach provided an opportunity for two unique disciplines within our academic department, Geospatial Information Science and Environmental Engineering, to collaborate and develop a method for students to visualize the effects of dispersion while simultaneously becoming more familiar with information technology.[5] In 2012, an upgrade to the ArcGIS program at our university, from version 8.3.1 to 10.0, forced us to relook the application's scope and structure. The changes to the application and resulting modifications to the project's structure and requirements are described in this paper.

While the authors have created a unique, custom application in ArcGIS that is easy for students to use, it is important to note that other studies have also incorporated GIS and dispersion modeling. Many of these studies can easily be found in journal publications or on-line and were designed to meet a specific real-world need. Table 1 provides a brief summary of five such studies, each for a unique environmental purpose. Table 1 is by no means inclusive, as many studies and applications exist; however, very few have been designed for the purposes of incorporation into an introductory air pollution course.

Table 1 – Representative sampling of studies and projects that incorporate GIS and dispersion modeling.

Title	Researchers	Synopsis	Available From:
Development of a GIS-Based Complex Terrain Model for Atmospheric Dust Dispersion[1]	Dr. K. Jerry Allwine, Pacific Northwest National Laboratory. Managed by the Strategic Environmental Research and Development Program	Project estimates the contribution of Department of Defense activities on ranges and training areas to particulate air quality.	http://www.serdp-estcp.org/Program-Areas/Resource-Conservation-and-Climate-Change/Air-Quality/RC-1195/RC-1195/(modified)/27Apr2012

Table 1 continued

A GIS Enabled Air Dispersion Modeling Tool for Emergency Management[7]	Stephen D. Jakala, Department of Resource Analysis, Saint Mary's University of Minnesota	Paper documents a GIS-enabled air dispersion model used in emergency management operations	http://www.gis.smumn.edu/Grad Projects/JakalaS.pdf
Using GIS and Dispersion Modelling Tools to Assess the Effect of the Environment on Health[3]	Helen Crabbe, Ron Hamilton, Nuria Marchin, Middlesex University	Feasibility study to integrate health and air quality information into GIS. Project uses ADMS Urban.	Available in *Transactions in GIS*, June 2000, Volume 4, Issue 3, pages 235-244.
Predicting urban traffic air pollution: A GIS framework[6]	G. Gualtieri, M. Tartaglia, Applied Meteorology Foundation	Paper presents a model for the evaluation of air pollution caused by road traffic that is integrated with GIS.	Available in *Transportation Research Part D: Transport and Environment*, September 2008, Volume 3, Issue 5, pages 329-336.
A GIS-based atmospheric dispersion model[2]	N. Bozon, C. Sinfort, B. Mohammadi, University of Montpellier, France	Paper presents an air pollution prediction tool used to model agricultural pesticide dispersion.	Available in *STIC & Environnement, Calais: France*, hal-00468863, version 31 March 2010.

(2) Methods

Gaussian Plume Equation

The Gaussian plume equation models downwind dispersion of pollutants from a point source (i.e., a stack) at the origin of a local coordinate system (x,y,z=0) based on the assumption that wind velocities have many random, turbulent eddies. These random fluctuations will disperse the pollutant away from the plume centerline, resulting in a normal or Gaussian distribution of concentrations in both the vertical (z) and crosswind (y) directions. Assuming a constant wind in the x direction, a non-reacting pollutant, and total reflection from the ground, the concentration of pollutants downwind at any point x, y, and z can be predicted with the following equation:[4]

$$ C = \frac{Q}{2\pi u \sigma_y \sigma_z} \exp\left(-\frac{y^2}{2\sigma_y^2} \right) \left\{ \exp\left(-\frac{(z-H)^2}{2\sigma_z^2} \right) + \exp\left(-\frac{(z+H)^2}{2\sigma_z^2} \right) \right\} $$

Q = *source emission rate [g/s]*
u = *wind speed [m/s]*
y = *crosswind distance from stack of point of interest [m]*
z = *vertical height of point of interest (0 for ground-level concentration)[m]*
H = *effective stack height [m] (includes plume rise)*
σ_y = *horizontal stability parameter [m]*
σ_z = *vertical stability parameter [m]*

The horizontal and vertical stability parameters can be estimated using Pasquill-Gifford curve fits from Turner (1969):

$$\sigma_y = e^{(I_y + J_y \ln(x) + K_y (\ln(x))^2)}$$

$$\sigma_z = e^{(I_z + J_z \ln(x) + K_z (\ln(x))^2)}$$

The coefficients I, J, and K are variables of the atmospheric stability conditions.[8,9]

Custom Interface in ArcGIS 10.0

We designed a custom interface in ArcGIS 10.0 to solve the equation above for an array of ground-level pollutant concentrations. The user enters the atmospheric stability class (A-F), stack heights, wind speed, and pollutant emission rate; given this data, the program calculates concentrations downwind and plots them on a city map. The user can enter multiple plumes at once, and if plumes overlap the program sums the concentrations and displays the result. The following paragraphs describe how to use the custom interface in ArcGIS 10.0.

After opening the program, students are first required to modify each stack by changing stack parameters. Students modify each stack individually by changing the stack height and entering their calculated controlled emissions rate. Figure 1 shows a screen shot of the interface in ArcGIS that students use to update stack parameters.
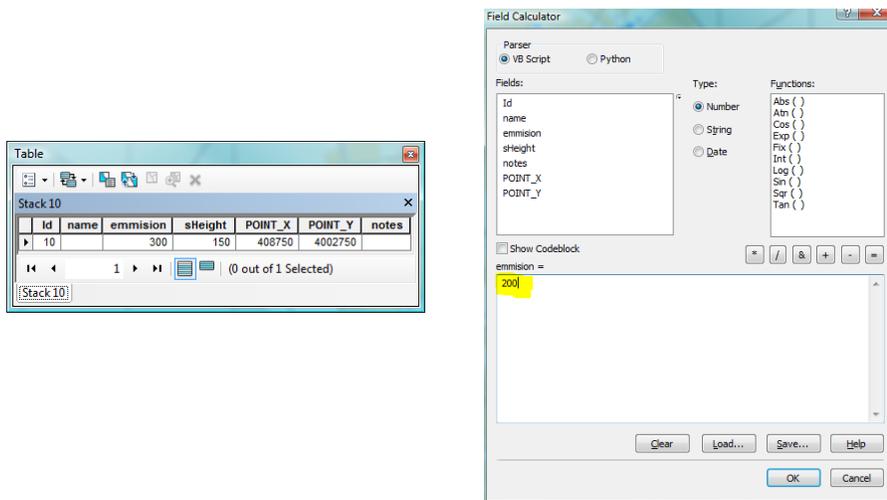

Figure 1: Interface in ArcGIS 10.0 that allows students to modify stack parameters. Students first open the attribute table for a desired stack (left picture) and right click on the heading of the stack characteristic they want to change. The table on the right then appears which allows students to update the stack height ("sHeight") and emissions rate ("emission").

Once student teams have modified the attributes of a stack, they can create a plume from that stack to determine if further modifications (e.g. increase the stack height) need to be made to meet the US National Ambient Air Quality Standards (NAAQS). Figure 2.A shows a screenshot of the "Create Plume" tool, which allows students to update the wind speed and the stability class. Students could also modify the height at which pollutants are measured; however, students are instructed to keep a value of "1" for ground-level concentrations. Figure 2.B shows a screenshot of a plume created in ArcGIS. Different colors represent the intensity of the pollutant concentration within the plume. The color purple is the highest pollutant concentration, while light yellow is the lowest discernible pollutant concentration.
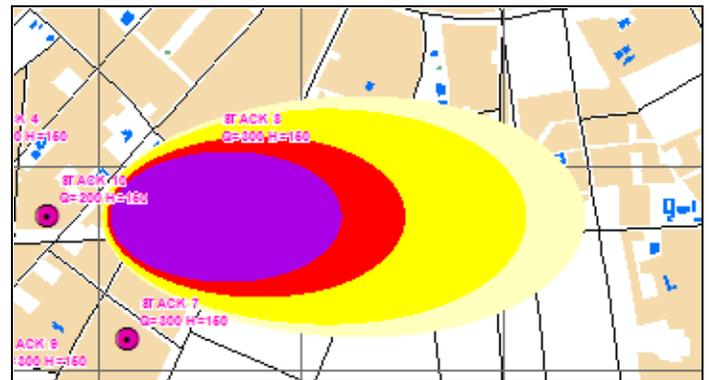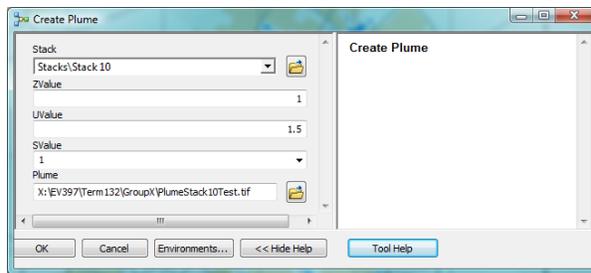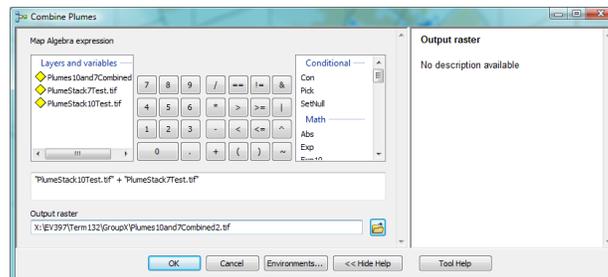

Figure 2.A and 2.B: Interface in ArcGIS 10.0 that allows students to create a plume. Students first open the "Create Plume" tool (left picture) and modify the required characteristics (wind speed is "UValue", stability class is "SValue"). Once the students click "OK", a plume similar to the one depicted in the right picture appears.

When students are satisfied with the characteristics of each stack, they can create a combined plume to determine if the combination of pollutant sources exceeds the NAAQS for the chosen pollutant in any given area. Figure 3.A shows a screenshot of the "Combine Tool" plume in ArcGIS. In this tool, students use a simple algebraic expression to add pollutant concentrations from multiple plumes together. The tool allows for students to add pollution sources together to determine if the entire plume exceeds the NAAQS in any part of the city. Figure 3.B shows a screenshot of two combined plumes.
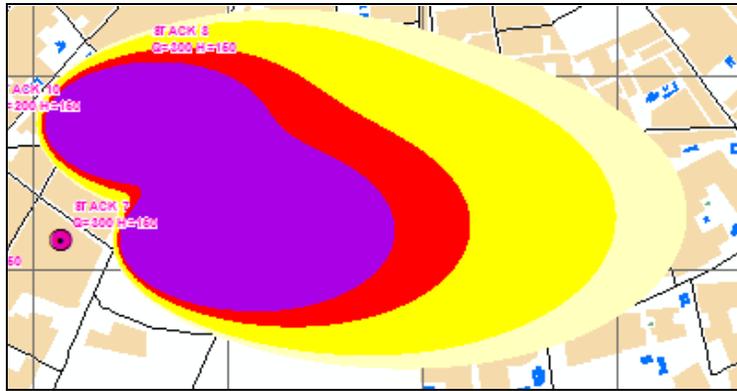
Figure 3.A and 3.B: Interface in ArcGIS 10.0 that allows students to combine plumes. Students first open the "Combine Plume" tool (top picture) and add the plumes that they want to be included in the combined plume. Once the students click "OK", a combined plume similar to the one depicted in the picture appears.

Once the combined plume is created, students compare the application output data for residential areas, schools, mosques, and hospitals with the NAAQS for the chosen pollutant. If the combined plume exceeds the NAAQS in any area, then the student team will need to redesign one or more stacks to decrease the overall pollution. Figure 4.A and 4.B show screenshots of the "Calculate Impact" tool and the resulting application output.
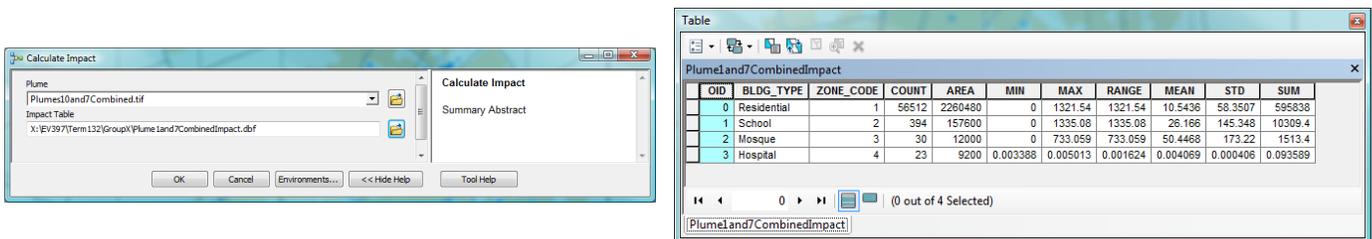
Figure 4.A and 4.B: Interface in ArcGIS 10.0 that allows students to calculate impacts. Students first open the "Calculate Impact" tool (left picture) and chose the plume file for which they want to determine impacts. Once the students click "OK", a table showing the results similar to the right picture is created.

(3) Project Description

Our dispersion project is one of two projects that students complete as part of USMA's air pollution engineering course. The dispersion project is given to students during the final 10 lessons of the 40-lesson course, and students are allocated approximately 15 days to complete the project. The project is worth 7.5% of the student's total grade. We allocate two 55-minute

classes in our Department's GIS computer laboratory to familiarize students with ArcGIS 10.0 and portions of the project that require use of the application.

Our dispersion project is broken into four parts labeled A, B, C, and D. Parts A through C are completed individually and involve hand calculations, an excel model, and a short scenario in ArcGIS. Part D, the focus of this paper, is a team-based project that extensively uses the ArcGIS application.

Project Parts A-C

Our air pollution course uses Cooper and Alley's "Air Pollution Control: A Design Approach" (4th edition)[4] as its primary text. Part A of the project consists of selected questions from the textbook that can be calculated by hand. These questions serve as reinforcement to the material taught in-class. Part B asks students to answer questions in a given excel spreadsheet. In the spreadsheet, students can manipulate variables within the Gaussian dispersion equation and gain a numerical response. The excel spreadsheet serves as a primer for parts C and D as students are able to gain a sense of how manipulating one variable can affect the resulting pollutant concentration at varying distances downwind.

Part C is designed for students to do an individual run with the ArcGIS application. Students are given an emission rate, wind speed, stack height, the plume rise, and atmospheric conditions. They are then asked to determine the maximum ground-level concentration of a pollutant downwind using the ArcGIS application. Once they determine the concentration using the application, the students are given additional questions that they can calculate by hand, such as convert the determined pollutant concentration from a mass ($\mu g/m^3$) to a volumetric concentration (ppm), and determine what percent reduction in emissions is required for the pollutant source to meet the 24-hour average National Ambient Air Quality Standard for the given pollutant.

Project Part D Description

Project Scenario

The students are first divided into teams of 3 or 4, which become a contracting company. To increase interest, students are given a scenario applicable to graduates of USMA. In the scenario, an international company, arbitrarily named CementWorld, is looking to expand cement production in developing countries and is specifically exploring the possibility of constructing three cement factories in Arbil, Iraq. To support CementWorld's operations, they must supplement available power generation in the city by also building a 100-MW coal power plant. Additionally, the City of Arbil has asked CementWorld to construct a 250-ton municipal solid waste combustion facility as a measure of good faith. These five facilities serve as new pollution sources of PM_{10}, the chosen pollutant for the project, that the students must design. Student companies are required to submit a bid that meets the below listed requirements and is lower than the other student teams.

Requirement 1: Identify Locations

Students are given 16 plots of land of varying prices from which they are required to purchase five for the construction of the cement factories and power plants. Four additional plots of land are given to the students with pre-existing PM_{10} pollution sources (see Tables 2 and 3) that contribute to overall air pollution in Arbil. The price of each plot corresponds to its proximity to the existing pollution sources. Plots of land that are close to existing sources are less expensive than those plots that are in relatively more pristine areas; since one objective of the project is to keep ambient pollution levels low in all areas, land in the more pristine areas is more desirable. Table 2 outlines the available plots of land and price for each. Figure 5 depicts some of the plots available for purchase on a map of Arbil, Iraq.

Table 2: Plots of land available for purchase and plots that have pre-existing pollution sources.

Plot 1	$120,000	Plot 11	$60,000
Plot 2	$100,000	Plot 12	$120,000
Plot 3	$60,000	Plot 13	$120,000
Plot 4	$120,000	Plot 14	Paper Mill
Plot 5	$140,000	Plot 15	$100,000
Plot 6	$120,000	Plot 16	$100,000
Plot 7	Incinerator	Plot 17	Metal Shop
Plot 8	$140,000	Plot 18	$100,000
Plot 9	$140,000	Plot 19	$75,000
Plot 10	Tire Factory	Plot 20	Unusable

Table 3: Characteristics of existing air pollution sources in Arbil, Iraq.

Description	Location	Current Effective Stack Height (m)	Current PM_{10} emissions rate (g/s)
Incinerator	Plot 7	80	10
Paper mill	Plot 14	75	15
Tire factory	Plot 10	70	12
Metal shop	Plot 17	60	10

Requirement 2: Facility Design

As mentioned, students are required to design five facilities: three cement factories, a 100-MW coal power plant, and a 250-ton municipal solid waste combustion facility. For each facility, students must design the stack height and the controlled emissions rate of pollutants given specific wind speed and atmospheric stability conditions.
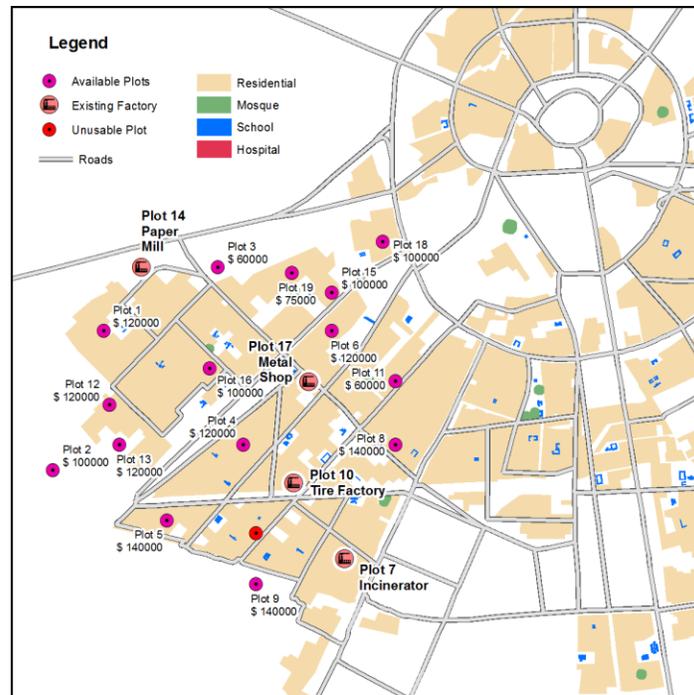
Legend

- Available Plots
- Existing Factory
- Unusable Plot
- Roads
- Residential
- Mosque
- School
- Hospital

Plot 14
Paper Mill

Plot 3
$ 60000

Plot 18
$ 100000

Plot 15
$ 100000

Plot 19
$ 75000

Plot 1
$ 120000

Plot 17
Metal Shop

Plot 6
$ 120000

Plot 16
$ 100000

Plot 11
$ 60000

Plot 12
$ 120000

Plot 4
$ 120000

Plot 2
$ 100000

Plot 13
$ 120000

Plot 8
$ 140000

Plot 10
Tire Factory

Plot 5
$ 140000

Plot 7
Incinerator

Plot 9
$ 140000

Figure 5: a visual depiction of several plots of land available for purchase in Arbil, Iraq.

According to the Gaussian dispersion equation, changing the stack height will vary dispersion and corresponding pollutant concentrations. For example, if the stack height is lowered from the some baseline height, then the pollutant concentration near the stack will increase. Conversely, if the stack height is increased, then the pollutant concentration near the stack will decrease. In this project scenario, the baseline stack height is 50 meters. If students elect to decrease pollutant concentrations by increasing the stack height, then the cost is $10,000 for each additional 10 m of stack height. Due to regulations in Arbil, stacks are restricted to a maximum of 110 meters in height.

In addition to designing the stack height, students must design the maximum controlled emissions rates for each factory and power plant. Specifically, students are required to calculate the percent reduction of emissions necessary to meet the US New Source Performance Standards (NSPS, Table 4). Once student teams calculate the required percent reduction to meet the NSPS, they choose a particulate matter control device. The cost of each control device varies, and students must decide whether it is more cost effective to purchase one device or to place several devices in series. Table 5 outlines the costs for each particulate matter control device. Once students choose a pollutant control device, they must then recalculate the actual emissions rate (since the required percent reduction does not always exactly match the percent reduction of the control device) prior to entering the data into the ArcGIS application.

Table 4: Uncontrolled emissions rates and the US New Source Performance Standards (NSPS)

Pollutant Source	Uncontrolled Emissions Rates	New Source Performance Standard[1]	Additional Information Provided to Students
Cement Factory	37.5 lbs of PM_{10} produced from 75 tons of clinker (30-day rolling average)	The NSPS (circa 2010) for new source Portland cement limestone kilns is 0.01 lbs PM_{10} per ton of clinker (30-day rolling average)	N/A
100-MW Coal Power Plant	1.2 tons PM_{10}/day	0.015 lb/million BTU heat input	Thermal efficiency is 40%
250 tons/day (large) Municipal Solid Waste Combustion Plant	2 g PM_{10} per dscm of gas produced (corrected to 7% O_2)	20 mg/dscm corrected to 7% O_2	1 ton of MSW produces 10^5 dscm of gaseous pollutants (corrected to 7 % O_2)

[1] Available from Table 1.3 in Cooper and Alley, "Air Pollution Control: A Design Approach" (4th Edition).

Table 5: PM Control Devices and their costs.

PM Control Device	% Reduction of PM_{10}[2]	Cost (Projected, 5-yr)[1]
Reverse Air Baghouse	92%	$800,000
Pulse Jet Baghouse	98%	$1,400,000
Cyclone	85%	$600,000
ESP	99%	$1,800,000

[1]Students are informed the 5-year projected costs include initial capital for materials, construction, labor, operation (to include energy), and maintenance costs over the first 5 years of operation. If students elect to place 2 or more devices in series, they must add 10% to the projected total cost per device to account for the additional energy required (assumed due to pressure drop between devices). The costs of the devices are somewhat arbitrary so that other factors, such as the price of land and reduction in stack height, also significantly contribute to the total cost.

[2]The values for percent reduction are similar to those seen in industry and used in example problems students have worked from Cooper and Alley, "Air Pollution Control: A Design Approach" (4th Edition).

Requirement 3: Modeling, Visualizing, and Analyzing Results in ArcGIS

Students are required to use the ArcGIS application to create the factories or power plants on the five plots of land that they decide to purchase and determine the resulting downwind pollution from the combined plume. To do so, students must create each pollutant source, or "stack," individually and then model all pollutant sources, to include the four existing sources, in a combined "super-plume." The combined plume cannot exceed the US National Ambient Air Quality Standard for PM_{10}, which is 150 μg/m^3 over an averaging time of 24-hours[4], in any area within the city. Students must optimize the design by determining which combinations of land plots, stack heights, and emissions reductions they can combine to meet NAAQS at the least cost.

Students are encouraged to follow the provided student tutorial, which thoroughly explains how to input information directly into the ArcGIS application. The tutorial specifically covers how to open and set-up ArcGIS, how to change parameter values for a given pollutant location (which we call a "stack"), how to create a plume from a selected stack, how to combine individual plumes into a single super-plume, and how to calculate the impact of a plume on the local area.

Final Written Requirements for Part D and Project Grading

Students are required to submit a formal proposal to CementWorld. The formal proposal includes an executive summary that succinctly describes the most important information that the students want CementWorld to know, such as costs, stack heights and locations, selected control devices, etc. Students are also required to submit a printed map of Arbil that visually depicts each team's stacks and the combined plume. Students also submit a table that outlines costs, pollutant emissions from each of the five new sources, and the impact, or pollutant concentration on the four main urban categories: residential, schools, mosques, and hospitals. Last, students are required to submit an appendix showing the calculations for emissions rates and percent pollution reduction (uncontrolled to controlled emissions). The calculations need to show how the team met the NSPS for the cement factories, the coal power plant, and the MSW incinerator. Students also are required to explain why they selected a certain PM control device to gain the percent reduction required to meet the NSPS.

(4) Project Results and Assessment Data

Students were able to pick up the application quickly. As mentioned, we allocated two class periods to learning the basics of ArcGIS and the dispersion application in USMA's GIS laboratory prior to executing the project itself; these proved extremely helpful. In the lab periods, instructors gave a brief introduction and then allowed students to work through a provided tutorial on their own with the remaining time.

Since there are several different means to reducing costs within the scenario, no student team came up with the same solution. Indeed, the instructors did not attempt to determine if there is one ideal solution that optimized costs. In academic year 2013-2014, the cost of successful student plans was rather close. Surprisingly two teams submitted the same lowest bid, but arrived at the dollar value with different solutions. Unsuccessful projects generally did not complete math computations correctly prior to entering data into ArcGIS, and therefore came up with faulty solutions. To remedy this problem in the future, one student suggested that each team validate their computations with the instructor prior to entering data into the ArcGIS application during Part D of the project.

Project assessment data comes from a survey given to the students pre-project and post-project. The pre-project survey consisted of two questions, while the post-project survey consisted of five questions. Students were asked to answer the questions on a Likert Scale of 1

to 5, with 1 being the lowest and 5 being the highest score possible. Questions and results are indicated in Table 6.A and 6.B.

Table 6.A: Pre-project survey (n=14).

Question	Likert Scale	Response (# and %)
I understand how to apply the Gaussian dispersion model to solve downwind pollutant concentrations.	1 – Not at all 2 – Not well 3 – Neutral 4 – Well 5 – Very Well	0 (0.0%) 1 (7.1%) 4 (28.6%) 8 (58.1%) 1 (7.1%) **Average:** 3.64
I am familiar with ArcGIS	1 – Not at all 2 – Have used it once or twice, but don't understand the program 3 – Somewhat familiar 4 – Familiar 5 – Very familiar	10 (71.4%) 0 (0.0%) 2 (14.3%) 2 (14.3%) 0 (0.0%) **Average:** 1.71

Table 6.B: Post-project survey (n=10).

Question	Likert Scale	Response (# and %)
I understand how to apply the Gaussian dispersion model to solve downwind pollutant concentrations.	1 – Not at all 2 – Not well 3 – Neutral 4 – Well 5 – Very Well	0 (0.0%) 0 (0.0%) 0 (0.0%) 5 (50.0%) 5 (50.0%) **Average:** 4.50
I am familiar with ArcGIS	1 – Not at all 2 – Have used it once or twice, but don't understand the program 3 – Somewhat familiar 4 – Familiar 5 – Very familiar	1 (10.0%) 2 (20.0%) 4 (40.0%) 3 (30.0%) 0 (0.0%) **Average:** 2.90
The Air Pollution course project increased my familiarity with ArcGIS	1 – Not at all 2 – A little 3 – Somewhat 4 – Yes 5 – Yes, a significant amount	1 (10.0%) 3 (30.0%) 0 (0.0%) 5 (50.0%) 1 (10.0%) **Average:** 3.20
The dispersion project increased my knowledge of Gaussian dispersion modeling for air pollutants	1 – Not at all 2 – A little 3 – Somewhat 4 – Yes 5 – Yes, a significant amount	1 (10.0%) 1 (10.0%) 1 (10.0%) 4 (40.0%) 3 (30.0%) **Average:** 3.70
Dispersion project is an effective means of integrating two academic disciplines (GIS and Environmental Engineering	1 – Not at all 2 – A little effective 3 – Somewhat effective 4 – Effective 5 – Very effective	0 (0.0%) 3 (30.0%) 0 (0.0%) 4 (40.0%) 3 (30.0%) **Average:** 3.70

The results from the pre- and post-surveys indicate that the project was successful in allowing students to better understand the Gaussian dispersion model. The average Likert value for Question 1 increased from 3.64 pre-project to 4.50 post-project. Additionally, the percentage of students indicating that they understand how to apply the Gaussian dispersion model "well" or "very well" increased from 64% pre-project to 100% post-project.

The survey results also indicate that the project was successful in allowing students to become familiar with ArcGIS. The average Likert value for Question 2, concerning the student's familiarity with ArcGIS, increased from 1.71 pre-project to 2.90 post-project. This increase shows that the project was relatively successful in accomplishing its objective of exposing environmental engineering students to a new discipline. The project was not designed to make students experts in ArcGIS, so the 2.90 post-project Likert value is not surprising.

Additionally, as indicated in Table 6.B, post-project survey results indicate that the project allowed for 60% of students to increase their familiarity with ArcGIS and 80% of students to increase their knowledge of Gaussian dispersion modeling. In addition, 70% of students felt that the dispersion project was an effective coupling of GIS and environmental engineering.

The updated application did have some minor complications, primarily dealing with the errant location of plumes after students changed the stack characteristics on some plots of land. The number of problems was few and the students affected were seemingly random. Most of the problems were resolved by simply closing and restarting the application.

(5) Implementation at Other Universities

To successfully implement this project at other universities, instructors will need to have a computer laboratory with ArcGIS 10.0 installed. The ideal student to computer ratio is 1:1. If required, students may complete the in-class laboratories as pairs; however, learning will likely be degraded as each student will not have the opportunity to explore the program and the custom application. In addition to space in a computer laboratory, instructors will have to develop a custom application that is the same, or very similar, to the one presented in this paper. Questions concerning details of the design of the application can be addressed to the authors. Last, instructors should allocate one or two class periods in the computer laboratory for students to learn and begin to execute the project requirements. Additional time outside of class will also be required; therefore, students will need to have access to the computer lab outside of course hours.

(6) Conclusion

Students in introductory air pollution courses can have difficulty understanding or visualizing air pollution dispersion using the Gaussian plume equation. This paper presents a successful way to integrate air pollution dispersion into ArcGIS 10.0 using a scenario that interests students. While the application creates a relatively simple dispersion model, it helps

students visualize dispersion from both individual sources and combined sources that hand-calculations and excel spreadsheets cannot. Results from student surveys indicate that the project helps them understand the dispersion modeling process and also become familiar with another academic discipline.

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