

Air Pollution Transport Teaching Modules

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ABSTRACT

Understanding and predicting the impact of air emissions from various sources are essential components of a typical *course* on *Air Pollution* in an engineering curriculum. Air pollution teaching modules were developed to aid instructors and students with the basic ability to model convective-dispersive transport of air pollutants emitted from point and distributed sources. The modules rely on basic “Gaussian Models” and use site specific input parameters on topography and meteorological conditions such as wind speed and direction, atmospheric stability, ambient temperature, and stack-gas properties.

Modules provide instructions to set up and/or download the necessary software for classroom teaching activity and then demonstrate the application using typical case studies at basic and advanced levels. Basic level case studies include examples on predicting, (a) the concentration profile of contaminants along the center line of the plume, (b) maximum ground level contaminant concentration and establishing the location of critical impact zones, (c) iso-concentration profiles at the ground level and at a plane orthogonal to the prevailing wind direction. At the advanced level, modules present complex problems of analyzing reactive contaminants and area emissions of volatile organic carbon from a municipal sewage treatment plant.

The modules rely on commercial software such as AIRSCAPE, SURFER, MATHCAD and public domain software like SCREEN3, that may be downloaded from the USEPA website. The modules were tested in selected undergraduate classes of the GATEWAY consortium schools for user friendliness and feedback from students were incorporated in the modules to improve their quality. In their current form these modules are ready for adoption into undergraduate engineering curricula and could very easily be extended to higher level graduate courses on air pollution.

INTRODUCTION

Air pollution teaching modules suitable for undergraduate engineering education were developed at Polytechnic (Poly) and Case Western Reserve University (CWRU) under the sponsorship of NSF Gateway coalition. These modules utilize the textbook “Gaussian Model” for transport and dispersion of air contaminants released from point sources (Wark et al, 1998). A very brief description of the basic “Gaussian Model” which is included in typical air pollution courses is outlined below. The general equation to calculate the steady state concentration of an air contaminant in the ambient air resulting from a point source is given by:

$$c(x,y,z) = \frac{Q}{2\pi u \sigma_x \sigma_z} \exp\left[-0.5 \left(\frac{y}{\sigma_y}\right)^2\right] \left\{ \exp\left[-0.5 \left(\frac{H-z}{\sigma_z}\right)^2\right] + \exp\left[-0.5 \left(\frac{H+z}{\sigma_z}\right)^2\right] \right\}$$

Where,

$c(x,y,z)$ = contaminant concentration at the specified coordinate [ML⁻³],

x = downwind distance [L],

y = crosswind distance [L],

z = vertical distance above ground [L],

Q = contaminant emission rate [MT^{-1}],
 σ_y = lateral dispersion coefficient function [L],
 σ_z = vertical dispersion coefficient function [L],
 u = wind velocity in downwind direction [$L T^{-1}$],
 H = effective stack height [L].

In the above equation σ_y , the lateral dispersion coefficient function and σ_z , the vertical dispersion coefficient functions depend on the downwind distance and the atmospheric stability class. These coefficients in meters can be obtained from the equations utilized by the Industrial Source Complex (ISC) Dispersion Model developed by USEPA (1995):

$$\sigma_y = 465.11628 (x) \tan (TH)$$

where,

$$TH = 0.01745 [c-d \ln (x)], \text{ and}$$

$$\sigma_z = a x^b$$

The constants a, b, c, d depends on Pasquill Stability categories which are defined by Turner (1995) as:

Surface wind speed at 10 m (m/s)	Day			Night	
	Incoming Solar radiation			Cloud Cover	
	Strong	Moderate	Slight	Thinly Overcast	Mostly Cloudy
< 2	A	A-B	B		
2-3	A-B	B	C	E	F
3-5	B	B-C	C	D	E
5-6	C	C-D	D	D	D
>6	C	D	D	D	D

The values for these constants for various stability classes are reported by USEPA. This concept is covered in most undergraduate classes on Air Pollution and students are expected to master this model. Teaching modules described in this paper were developed on this concept and applications for different scenario were included.

DESCRIPTION OF MODULES

Two air pollution modules were developed at Polytechnic University using proprietary software packages AIRSCAPE™ (Envirowin Software, Chicago) and SURFER (Golden Software, Inc., Golden, CO). The module developed by CWRU utilized Gaussian Models 1.1 (FiatLux Publications, Freemont, CA) and Mathcad (Mathsoft, Inc, Cambridge, MA). Modules were developed in 1995 and subsequently fine tuned in 1996.

The CWRU Air Pollution Transport Teaching Module has been reported in detail elsewhere (Jennings and Kuhlman, 1997). This paper outlines the other two Air Pollution teaching modules (Maillacheruvu and Roy, 1997). Poly modules include a “DEMO” module for point sources and an advanced module focusing on the VOC emissions from a wastewater treatment plant. In the

advanced module there are several features that could be incorporated into a classroom discussion, including estimating emissions using emission factors. A brief description of the emission factors approach, including calculations, is included in this report to provide the instructor with some background.

The instructor or student using this database/software module should be familiar with the basic principles of environmental engineering, air pollution in particular. An understanding of unit processes and unit operations is also recommended, although these can be taught simultaneously with the use of software modules developed using this package.

Features of databases and software components used in the modules

A critical component in this module is the software program AIRSCAPE. AIRSCAPE is a windows based program that inputs ISC (Industrial Source Complex) program code graphically. The Industrial Source Complex (ISC) dispersion models are developed by Environmental Protection Agency (EPA) for the purposes of conducting dispersion modeling from different type of sources. The ISCST dispersion model provides options to model emissions from a wide range of sources that might be present at a typical industrial source complex. The basis of the model is the steady state Gaussian plume equation, which is used with some modifications to model simple point source emissions from the stacks, emissions from stacks that having the effects of aerodynamic downwash due to nearby buildings, isolated vents, multiple vents, storage piles, conveyor belts etc. The ISC has short term and long term model versions to evaluate the short term and long term emission impacts. In these modules the short term version (ISCST) of ISC models is used. The ISC models support the regulatory modeling options in the default mode. These options include the use of stack-tip downwash, buoyancy-induced dispersion, final plume rise except for sources with building downwash), a routine for processing averages when calm wind occur, default values for wind profile exponents and for vertical potential temperature gradients, and the use of upper bound estimates for super-squat buildings having an influence on lateral dispersion of the plume. The model also have the option of using the non regulatory default options by specifying descriptive keyword to indicate particular application. The model provides the option of using the Urban or Rural dispersion parameters depending upon the source location. The model has the capability of calculating either the concentration values or the deposition values for a particular run. The model can calculate several short term averages in a single run as well as the overall period averages. The ISC model is designed to handle multiple point, volume and area sources. Source emission rates can be maintained constant throughout the modeling period, or may be varied by month, season, hour of the day, or other optional periods of variation. These variable emission rate factors may be specified for a single source or for a group of sources. Emission rates can be input either in default metric unit or user defined units. The ISC models also have the capability of accepting multiple receptor networks in a single run. The network may be specified as Cartesian grid receptor networks or polar grid receptor networks or a combination of the two. This particular capability allows the user to have a coarse grid over the whole modeling domain and a denser grid in the area of maximum expected impacts. The ISC models accept unformatted, sequential files of meteorological data generated by the PCRAMMET preprocessor. The model can also utilize formatted ASCII files that contain sequential hourly records of meteorological variables. But AIRSCAPE can only use ASCII formatted files. The model processes all available meteorological data in the specified input file by default, but the user has the option of specifying selected days or ranges of days to process. Alternative software packages and more recent versions of the ISC code which are now available may also be used in lieu of AIRSCAPE.

SURFER is a mapping software and has a wide range of applications in addition to the modules presented in this paper. One advantage of using AIRSCAPE is that it the results from air pollution modelling can be used as direct input to SURFER. The combination of a program that does dispersion modelling and a 3-D mapping software such as SURFER provides a powerful teaching tool in the classroom.

Module 1: DEMO Module

The following inputs are needed to develop and define the problem.

1. Source File: description, layout and emissions to be defined using AIRSCAPE
2. Meteorological data file: for the given city, area (year specific)

For the DEMO module, data from Milwaukee (year 1986) were used to create an industrial source (Simple Industrial Source Application or SISA). It may be noted that Module 1 can be developed using a similar procedure outlined below for Module 2.

Module 2: VOC emissions from a wastewater treatment plant

Publicly owned treatment works (POTW) often emit significant quantities of such criteria pollutants as NO_x , SO_x , CO and volatile organic compounds (VOCS) including hazardous air pollutants (HAP) such as benzene, toluene, phenols and chlorinated aliphatic hydrocarbons like tetrachloroethene(PCE), 1,1,1 trichloroethane, methylene chloride etc. In essence, many POTWs will be close to the major source threshold definition and must conduct a comprehensive inventory of air emissions.

The module is implemented in the following manner at Polytechnic University. Similar modules could be constructed at other schools taking advantage of the availability of wastewater treatment facilities in that region. Students who work with this module are taken on a tour of the Wastewater Treatment facility sometime over the course of the semester. This provides a connection between the classroom discussion and the real-life situation. The instructor then provides the basic background knowledge about dispersion modelling and various other necessary data.

In this module, the environmental software package AIRSCAPE is used for the Estimation of the air concentration of PCE emitted from a New York City waste water treatment plant at specified receptor locations using ISCST model and associated risk assessment using EPA's IRIS databases. The primary objective was to calculate maximum PCE concentration and associated risk. AIRSCAPE is used to input and run ISCST2 model to calculate PCE concentration in air for a calculated emission rate from various unit processes of Newtown Creek waste water treatment plant. The details of various methods of calculating PCE emission rate are described below.

PCE Emission Rate Estimation

PCE emissions from POTWs can be determined using direct measurement techniques or estimated by mathematical models or calculated by emission factors. There are advantages as well as limitations in using any of these methods.

Mathematical models have been developed to predict the fate of VOCs by various mechanisms such as volatilization, adsorption and biodegradation. They basically require POTW influent VOC concentrations and plant operational parameters as inputs. Modeling techniques can be more cost effective than direct measurement methods, because they do not generally involve field experimental procedures and the analytical costs are limited to the analysis of influent VOCs. A POTW usually has an existing database on the influent concentration of VOCs. Also, plant operational data, which serve as inputs to the mathematical models are likely to be available from existing POTW operating records. VOC emission estimates made by mathematical models, however, may not agree with direct VOC measurements unless they are calibrated for the specific POTW under consideration. It is likely that the default volatilization, adsorption and biodegradation rate coefficient values associated with each of the models may not be applicable to all POTWs. Biodegradation rate constants depend on the adaptation behavior of the microbial populations and hence are likely to be sitespecific. Currently nine mathematical models are available for estimating the emission rate of VOCs from POTWs. Among them, WATER 8, TOXCHEM+ and BASTE are

the most commonly used and accurate models, although all of the models have been found to overestimate emissions.

Emission Factor Approach:

The California Air Toxics ‘Hot Spots’ Information and Assessment Act of 1987 (AB 2588) establishes a program to develop a statewide inventory of site specific air toxic emissions of approximately 400 substances referenced in the law, to assess the risk to public of any significant health risk associated with these emissions. In response to these requirements, 25 public agencies, to date, with Publicly Owned Treatment Works (POTW) have formed a Joint Powers Agreement (JPA) to conduct a voluntary Pooled Emission Estimation Program (PEEP). The purpose of PEEP is to provide JPA members with a standardized estimation method of air emissions from liquid, solid and gas handling processes. The PEEP effort conducted source testing of 18 unit processes at 20 sites during three rounds of sampling.

The standardized methodology developed from analysis of the data collected by PEEP is an emission factor approach which can be applied to similar unit processes in any waste water treatment facility. The PEEP emission factor approach utilizes the following methodology to calculate the air emissions:

Pounds of compound A emitted to the air/unit time = (pounds of compound A entering a unit process/unit time x Emission Factor). The emission factor (EF) is the fraction of the total mass loading (ML) of the influent liquid stream which is removed from the process through volatilization to the air (E).

$$EF = \frac{E}{ML}$$

The emission factors for different unit processes were developed by PEEP based on actual field measurements.

In the existing Newtown Creek waste water treatment facility located at the border of Brooklyn and Manhattan treating an annual average flow of 310 MGD, 32 aerated grit chambers, 16 aeration tanks and 16 secondary sedimentation tanks are of concern because they expose a significant amount of open surface areas to atmosphere and emit PCE. (There is no primary sedimentation tank and sludge digestion is anaerobic i.e. sludge digestors are covered).

Example calculations of emission factors:

$$EF = \frac{E}{ML} \quad \text{OR} \quad E = EF \times ML$$

A = Totals surface area of unit process/unit operation.

Q = Flow rate

ER = Emission Rate

Aerated grit chamber:

Assuming an influent PCE concentration, C = 0.1 $\frac{mg}{L}$

$$Q = 310 \times 10^6 \times 3.78 \frac{\text{liters}}{\text{day}}$$

$$ML = QC = 1.358 \frac{gm}{sec}$$

EF = 0.0068 (from PEEP data)

$$E = EF \times ML = 9.23 \times 10^{-3} \frac{gm}{sec}$$

$$A = 25 \times 800 \times (0.3048)^2 = 1858.06 \text{ m}^2$$

Therefore the emission rate, ER may be calculated as:

$$ER = \frac{9.23 \times 10^{-3}}{1858.06} = 4.96 \times 10^{-6} \frac{\text{gm}}{\text{sec-m}^2}$$

Aeration tank:

$$ML = 1.358 - 9.23 \times 10^{-3} = 1.349 \frac{\text{gm}}{\text{sec}}$$

Volatilization:

$$EF = 0.33 \text{ (from PEEP data),}$$

$$E = ML \times EF = 0.445 \frac{\text{gm}}{\text{sec}}$$

$$A = 200 \times 800 \times (0.3048)^2 = 14864.48 \text{ m}^2$$

$$\text{so, } ER = E/A = 3 \times 10^{-5} \frac{\text{gm}}{\text{sec-m}^2}$$

Biodegradation:

$$K_s = 9.13 \frac{\text{mg}}{\text{L}}; k = 0.0062 \text{ hr}^{-1} \text{ (assumed -- from literature)}$$

$$ML \text{ after volatilization} = 1.349 - 0.445 = 0.904 \text{ gm/s} = 0.067 \frac{\text{mg}}{\text{L}}$$

Since $ML = 0.067 \frac{\text{mg}}{\text{L}} \ll K_s$, biodegradation of PCE is negligible. Further, neglecting

adsorption, the effluent concentration of PCE = $0.904 \frac{\text{g}}{\text{sec}}$

Secondary sedimentation tank:

$$ML = 0.9 \frac{\text{gm}}{\text{sec}}$$

$$EF = 8 \times 10^{-4} \text{ (from PEEP data)}$$

$$E = EF \times ML = 7.2 \times 10^{-4} \frac{\text{gm}}{\text{sec}}$$

$$A = 400 \times 800 \times (0.3048)^2 = 29728.97 \text{ m}^2$$

$$ER = E/A = 2.42 \times 10^{-8} \frac{\text{gm}}{\text{sec-m}^2}$$

Once the emissions from each unit process/operation from the wastewater treatment plant were estimated using the emission factor approach, this data was used for source input in AIRSCAPE.

Selected results from an analysis following the procedure detailed above is shown are presented here. Meteorological data for 1993 was used in these simulations. Figure 1 shows the plant layout and Figure 2 shows the positioning of the receptor locations. Figures 3 and 4 are contour maps of the highest 3-hour average concentrations for the entire year. In other words, each point on these contour maps represents the maximum 3-hour average concentrations for the year 1993. These figures should not be interpreted as a “snapshot” in time. Figures 5 and 6 are contour maps which represent the average PCE concentrations over the entire year. Again this is not a “snapshot”. A comparison between Figures 3 & 4 and Figures 5 & 6 shows that concentrations are significantly lower in the yearly averaged data. This is an expected result and presents some room for in-class discussion between an instructor and the students.

While the 3-hour average and yearly average analyses show some trends, we were also interested in obtaining “instantaneous” snapshots of PCE concentration profiles over the entire area surrounding the Newtown Creek Water Pollution Control Plant. Such an instantaneous snapshot (Figure 7) would then give the user (student or faculty) actual violations that may have occurred

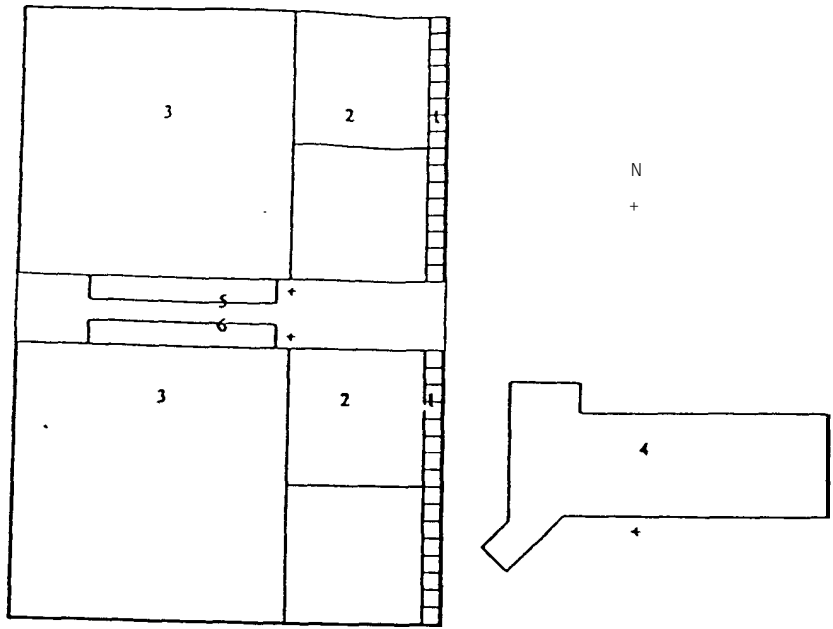


Figure 1. Top View of Newtown Creek Water Pollution Control Plant Site. (1 = Aerated Grit Chamber, 2 = Aeration Tank, 3 = Sedimentation Tank, 4 = Main Building, 5 = Service Building 1, 6 = Service Building 2)

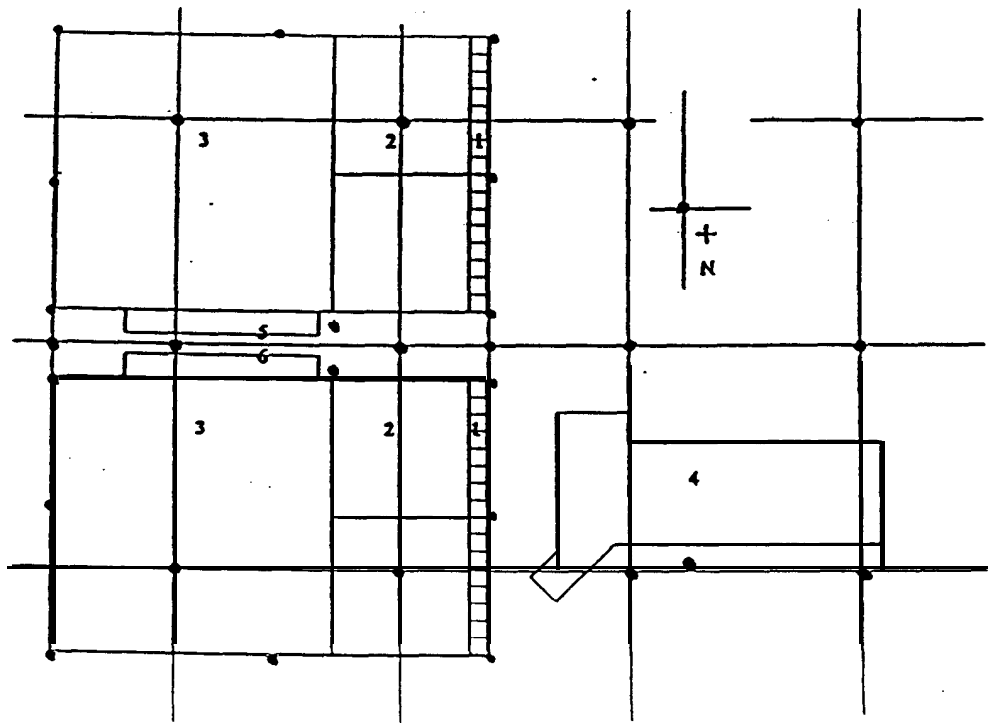


Figure 2. Top View of Newtown Creek Water Pollution Control Plant Site. (1 = Aerated Grit Chamber, 2 = Aeration Tank, 3 = Sedimentation Tank, 4 = Main Building, 5 = Service Building 1, 6 = Service Building 2; • = Receptor Locations)

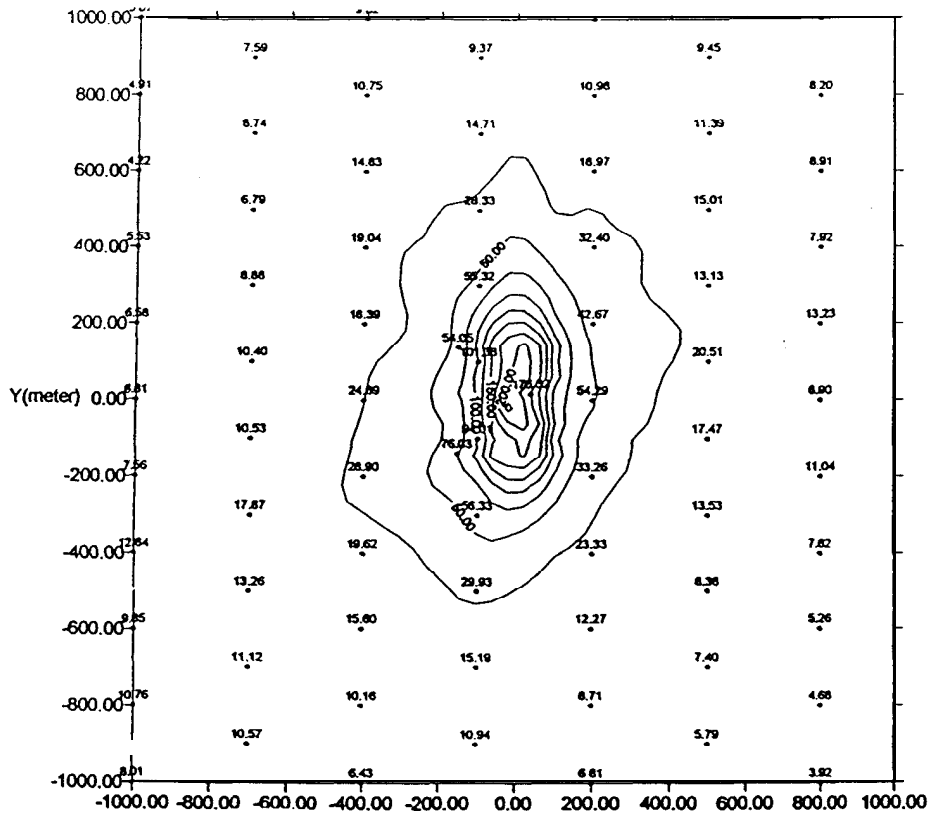


Figure 3. Contour Map of 1st Highest 3-hour Average PCE concentration in 1993 (Max conc = $246.37 \frac{\mu\text{g}}{\text{m}^3}$ on 7/132/93 at 00 hour at coordinates (-30 m, -10 m))

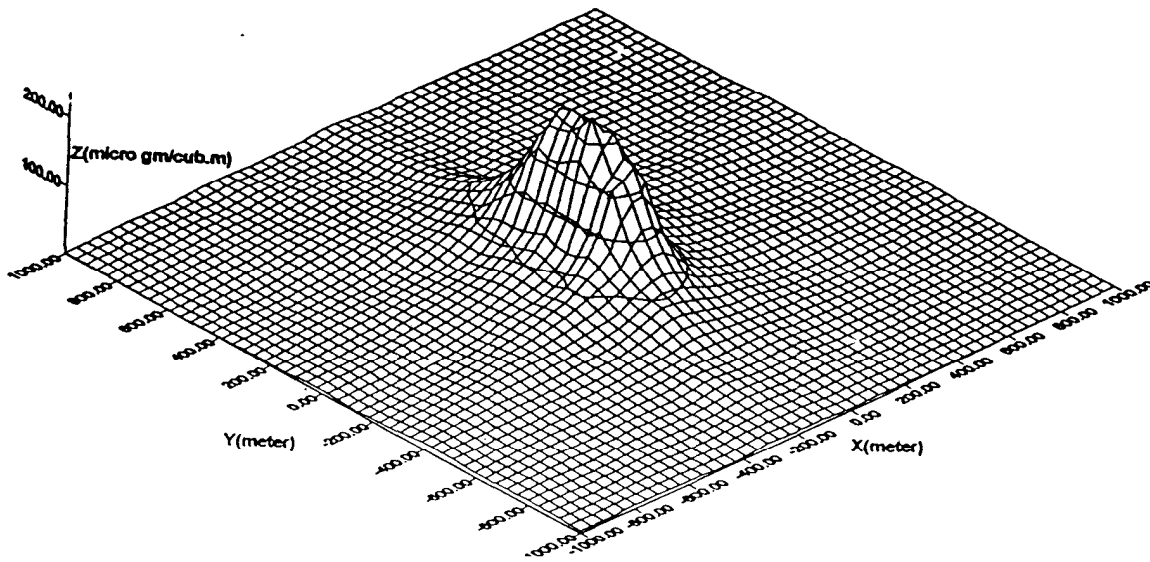


Figure 4. Surface Plot of 1st highest 3-hour Average PCE concentration 1993 (Max conc = $246.37 \frac{\mu\text{g}}{\text{m}^3}$ on 7/132/93 at 00 hour at coordinates (-30 m, -10 m))

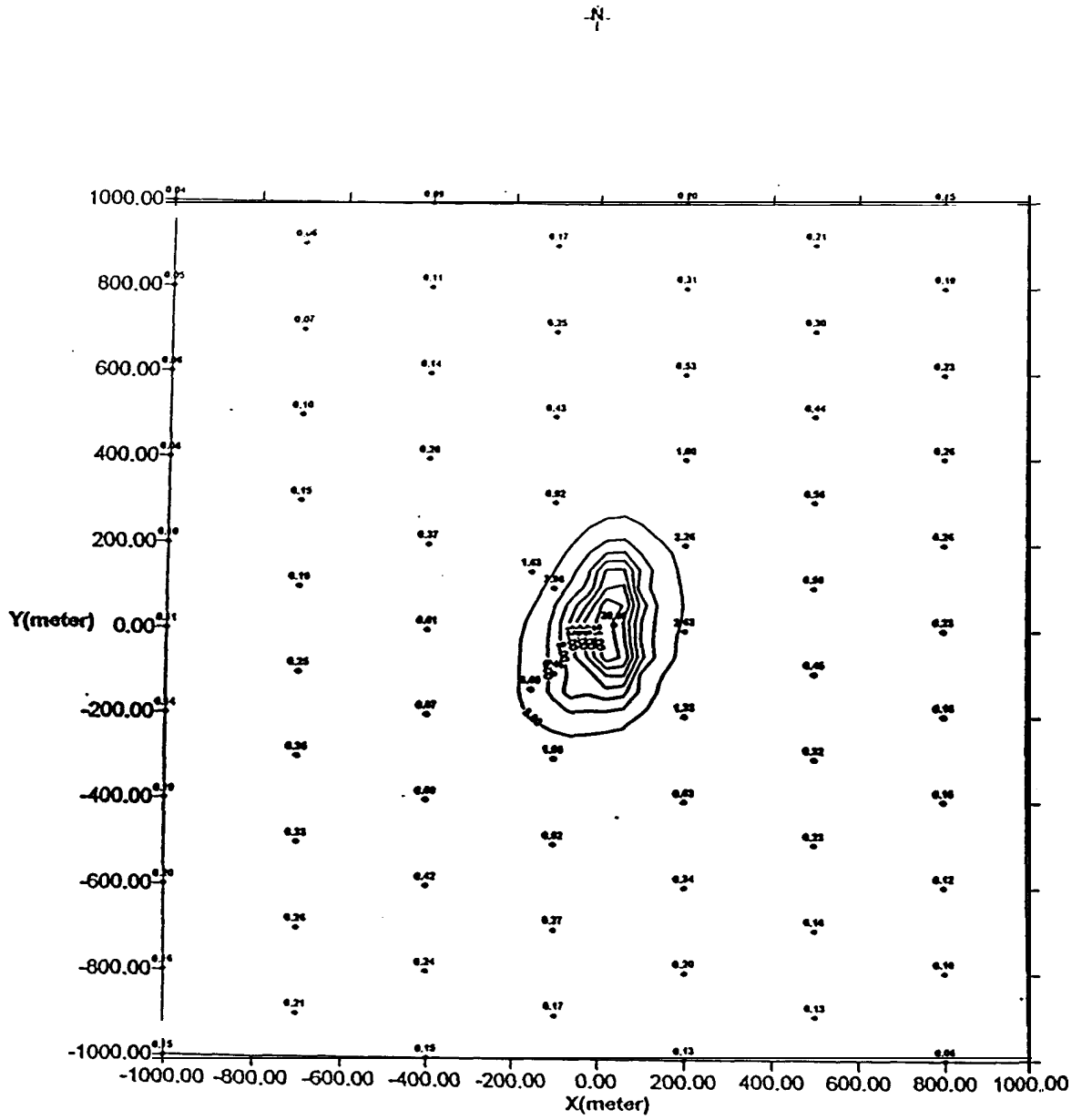


Figure 5. Contour Map of Annual Average PCE concentration in 1993 (Max conc = 27.42 $\frac{\mu\text{g}}{\text{m}^3}$ at coordinates (39.10 m, 76.20 m))

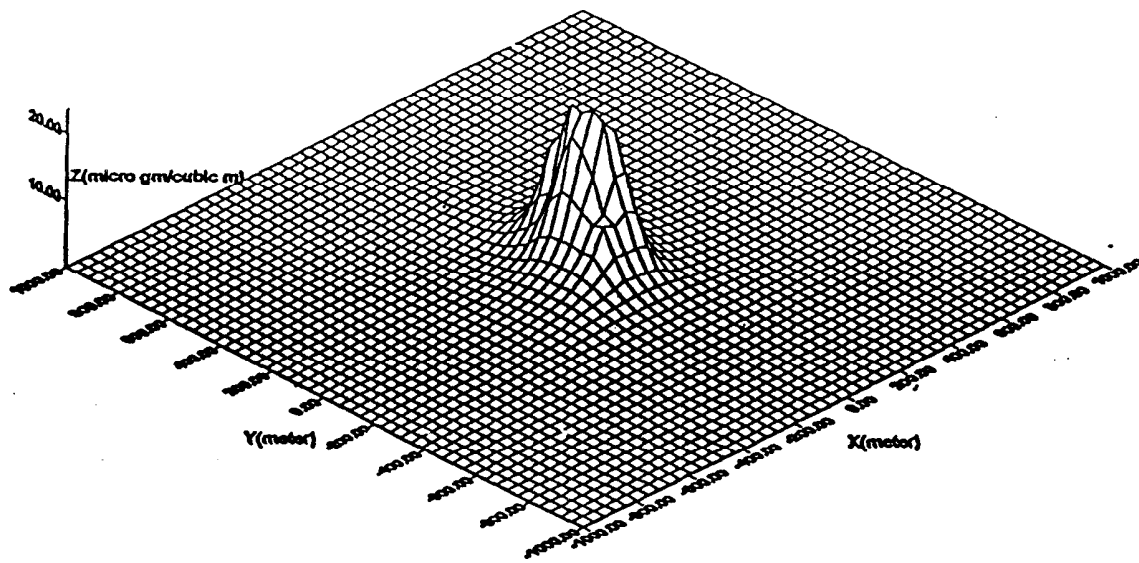


Figure 6. Surface Plot of Annual Average PCE concentration in 1993 (Max conc = $27.42 \frac{\mu\text{g}}{\text{m}^3}$ at coordinates (39.10 m, 76.20 m))

N
+

Wind Direction & Speed: 9 deg. clock wise from north. 1.543 m/s.

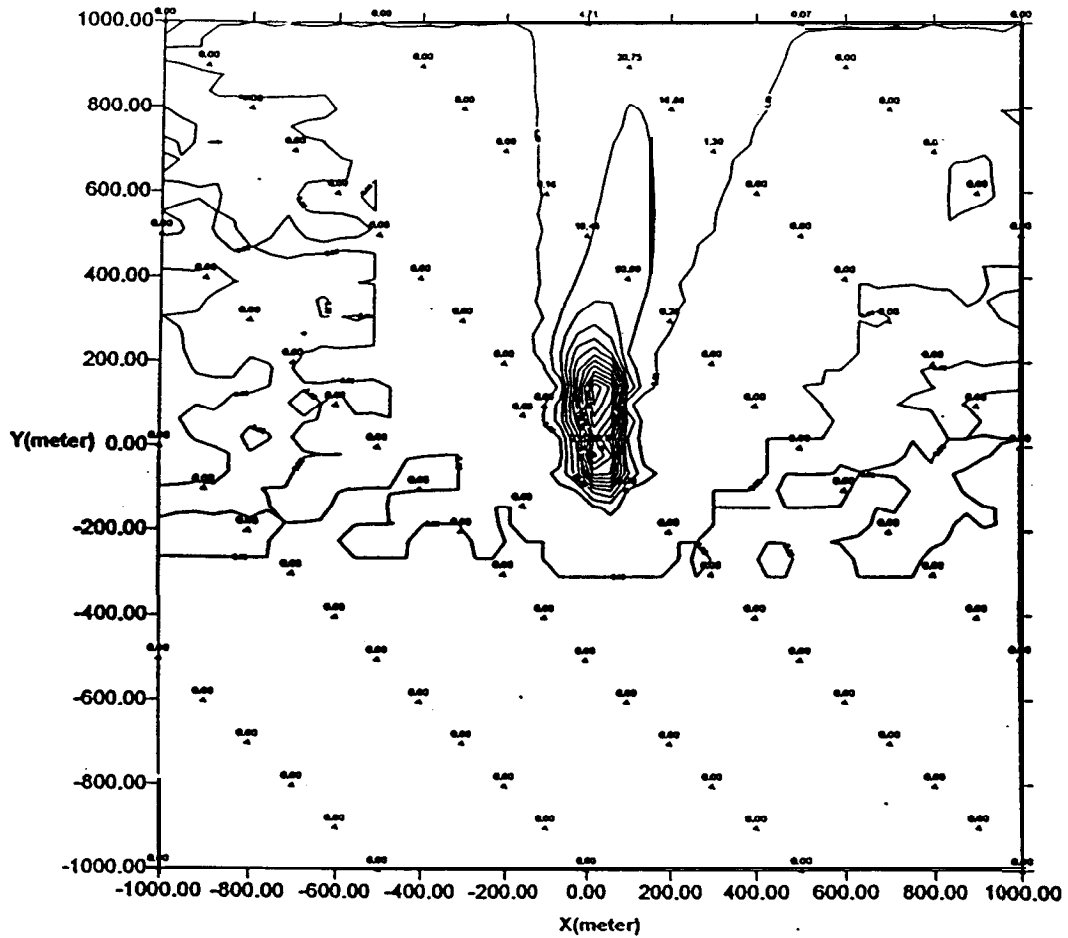


Figure 7. Contour Map of Instantaneous 1-hour average PCE concentration on 5/16/93 at 8 pm for 1st critical event (Max conc = $396.70 \frac{\mu\text{g}}{\text{m}^3}$ at coordinates (39.10 m, 137.16 m))

instantaneous concentrations (actually one hour averages) as our “critical events”. Figure 7 represents one such critical event.

What makes this module interesting is that it is based on a real-life problem. The assumptions we made in our simulation that the influent contained 0.1 ppm of PCE appears to be higher than data for other neighboring plants in the New York City area (upto 0.03 ppm). As this data becomes available, we can use it in our simulations and compare it with work that is in progress at the New York City Department of Environmental Protection. Actual concentrations of PCE are expected to be known in the next year or two. It will be interesting to our students in future years to compare results from our simulations with the actual values.

SUMMARY

The air pollution modules discussed above can be used in one of two situations: Classroom demonstration (1 lecture) or a more detailed 3-4 lecture presentation. The DEMO module is ideal for a 1-lecture presentation, particularly in a course that only introduces air pollution. The second module may be used in a class where air pollution is covered in greater detail. This second module could in fact be discussed in a wastewater treatment plant design example where VOC emissions are also accounted for. There are several opportunities for detailed discussions on different air pollution aspects, risk assessment, design and statistical significance -- depending on the level of the class and the instructor's choice.

BIOGRAPHICAL INFORMATION

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