

Small Computer Application of Pollutant Dispersal Models for Environmental Instruction

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Abstract

Programs were written for a small computer to utilize reported dispersal modeling equations for classroom instruction. The applications were for calculation of downwind concentrations of pollutants, for calculation and plotting of isopleths, constant pollutant concentration contours, and for calculation and labeling of positions on a scaled map of average annual pollutant concentrations. The results obtained for an actual case involving potential sulfur dioxide pollution from a proposed industrial development is reported. The proposed use of these programs for instruction in environmentally oriented courses is discussed.

Introduction

Computer models for atmospheric dispersal of pollutants have come into common use by industries and environmental agencies as a basis for decisions pertaining to industrial developments in relation to environmental protection. There appears a definite need for the incorporation of this material into environmentally related courses at the undergraduate level. This project was undertaken for this purpose and with the understanding that it should be applicable at smaller institutions such as community colleges or branch campuses with limited facilities. Consequently, the programs were developed for a small computer as would be available at almost any institution.

Since the programs were limited to a computer with small core capacity, approximately 4000 hexydecimal words, only point sources of pollutants were considered excluding line and area sources. However, the basic Gaussian diffusion equations were incorporated including plume rise calculation and including provision for wind rose data and the six standard weather stability classes.

Modeling Equations

Employing the standardized symbols for metric units, the basic diffusion equation expresses the concentration $C(\text{g}/\text{m}^3)$ of a given pollutant at a receptor position located by coordinates $X, Y, Z, (\text{m})$, with X the horizontal distance from

¹PROGRAM HPADM-BASIC, 454 statements, transportability not certified; student-run keyboard mode (I/O via keyboard/lineprinter and plotter); execution requires 4K (HP9830A 4K, 16 bit words); plotting output; instruction manual for operation of program with sample run and listing. No flow chart and minimal documentation of program. Copies of the manual (including listing) are available (\$3.00 for copying and postage; checks only—payable to Bursar, Indiana State University Evansville). Will supply only manual with listing. Chemistry Department, Indiana State University-Evansville Campus, Evansville, Indiana 47712.

the stack along the center line of the plume, Y and Z the lateral and vertical distances perpendicular to the center line, respectively. The other variables involved are the emission rate Q(g/s) of the pollutant considered, the effective height of the stack H(m), which includes the plume rise, the wind speed μ (m/s), and the standard deviations of plume concentration distributions in the horizontal and vertical directions σ_y , σ_z (m), respectively, which are functions of the downwind distance from the source and of the weather stability class. (1) The basic equation follows as

$$C = \frac{Q}{2\pi\sigma_y\sigma_z\mu} \text{Exp} \left[-\frac{1}{2} \left(\frac{y}{\sigma_y} \right)^2 \right] \cdot \left\{ \text{Exp} \left[-\frac{1}{2} \left(\frac{z-H}{\sigma_z} \right)^2 \right] + \text{Exp} \left[-\frac{1}{2} \left(\frac{z+H}{\sigma_z} \right)^2 \right] \right\}$$

Calculations for the quantities σ_y and σ_z were obtained by fitting low order polynomial approximations to published curve plots. (2). The effective stack height is obtained by adding the plume rise to the stack height. The plume rise is calculated from the Holland equation

$$\Delta H = \frac{V_s d}{\mu} \left[1.5 + 2.68 \times 10^{-3} P d \frac{(T_s - T_A)}{T_s} \right],$$

in which ΔH (m) is plume rise, V_s (m/s) is stack gas velocity, d (m) is the stack diameter, μ (m/s) is the wind velocity, p (mb) is atmospheric pressure, T_s (°K) is stack gas temperature, and T_A (°K) is the ambient temperature.

Applications of the Model

The computer employed was a Hewlett Packard model 9830A with BASIC language capability and equipped with line printer and plotter. The programs as developed were stored on a magnetic cassette tape.

The specific programs were developed to apply to a proposed industrial development near a small town in southwestern Indiana. There were already several industries in the locality, and an existing level of atmospheric pollution was apparent. The proposed new development would add significantly to the emission of several pollutants. Three programs were developed to study the impact of the proposed facility to the overall atmospheric pollution in the area.

The first program was developed to calculate the instantaneous concentration of a given pollutant at ground level at a given position for any one of the six weather stability classes and any assumed wind speed for the specified emission parameters of the facility. Provision was made for incrementing the downwind distance so that the maximum concentration and its location could be easily determined from a tabular printout.

The emission data for sulfur dioxide for the proposed plant is summarized in Table I. For a typical wind speed of 12.3 miles per hour, weather stability class D, and ambient temperature of 68° F results were obtained which are presented in Table II. By examination of Table II it is seen that the sulfur dioxide concentration reaches a ground level maximum at approximately 2.5 miles downwind from the stack. This indicates that with a southwest wind, a frequent case for the locality, the maximum pollutant concentration would occur near the center of town.

TABLE I *Emission Data of Proposed Plant*

| | |
|----------------------------------|----------------------|
| Emission rate of sulfur dioxide: | 34,391 lb/day |
| Flue gas velocity: | 274,090 cu. ft./min. |
| Stack diameter: | 9.5 feet |
| Stack height: | 250 feet |
| Flue gas temperature: | 350.6° F. |

TABLE II *Sulfur Dioxide Concentrations from Proposed Industrial Plant at Distance X from Stack*

| Distance X (miles) | Concentration of SO ₂ (micrograms/meter ³) |
|--------------------|--|
| 0 | 0 |
| 0.25 | 0.00 |
| 0.5 | 0.15 |
| 0.75 | 9.89 |
| 1 | 45.9 |
| 1.25 | 91.9 |
| 1.5 | 130. |
| 1.75 | 155. |
| 2 | 169. |
| 2.25 | 175. |
| 2.5 | 176. |
| 2.75 | 173. |
| 3 | 168. |
| 3.25 | 162. |
| 3.5 | 155. |
| 3.75 | 148. |
| 4 | 142. |
| 4.25 | 135. |
| 4.5 | 129. |
| 4.75 | 123. |
| 5 | 117. |

A second program was developed to calculate and plot isopleths which are contours of constant pollutant concentration. The isopleths only occur over a limited range of concentrations. An existing isopleth has the form of a curve symmetric about the center line of the plume. It originates at the point on the center line where the specified concentration first reaches ground level. If carried far enough downwind the isopleth eventually terminates on the center line forming a closed loop-shaped curve. Higher concentrations occur in the region within the isopleth, so that if a family of isopleths for different concentrations are plotted together they appear with successively higher concentrations approaching the center line more closely.

The same input parameters used with the previous program were applied to the isopleth program. The plotting equipment permitted adjustment of scale so that the isopleths could be plotted to the scale of an available map of the area for direct superposition. (Fig. 1) shows the results obtained for a southwest wind of 12.3 miles per hour and weather stability class D. The five isopleths plotted are for concentrations of 160, 140, 100, 60, and 20 ($\mu\text{g}/\text{m}^3$) and are superposed to

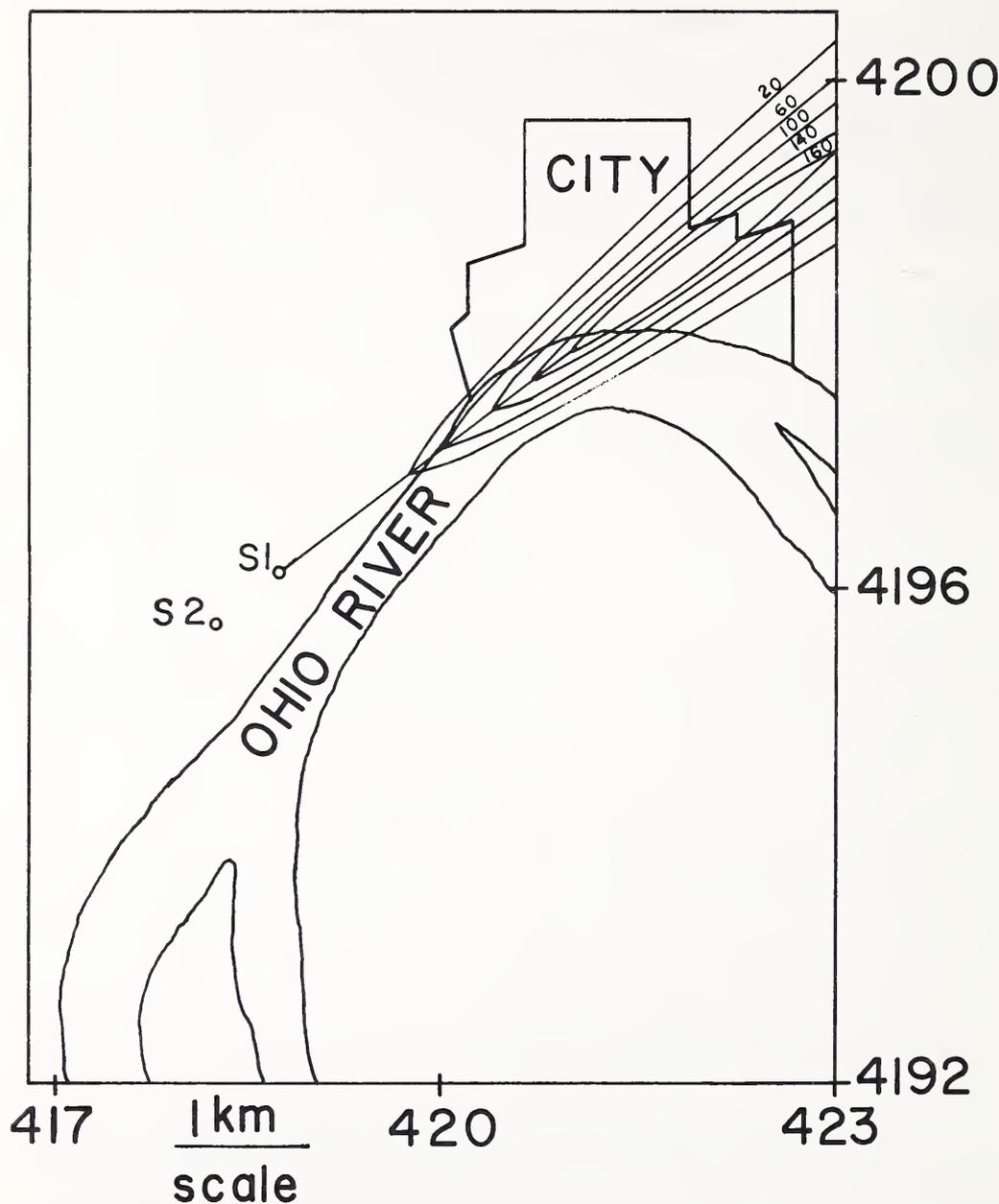


FIGURE 1. Plot of Isopleths of Sulfur Dioxide with concentrations labeled in Micrograms/m² and Axes labeled in Universal Transverse Mercator Coordinates.

scale on an area map of the locality. The maximum concentration is seen to occur in a densely populated section of the town.

Of course, it should be kept in mind that the concentrations involved are strictly instantaneous values. If extended periods are considered lower average values will occur because of variations in the wind direction.

A third program was developed to calculate the average annual concentration of a given pollutant at a given position for the average weather stability class D assumed throughout. The program incorporated averaging over frequencies of wind directions and speeds supplied by the U.S. weather department compiled from a 5-year record for the region. Provision was made

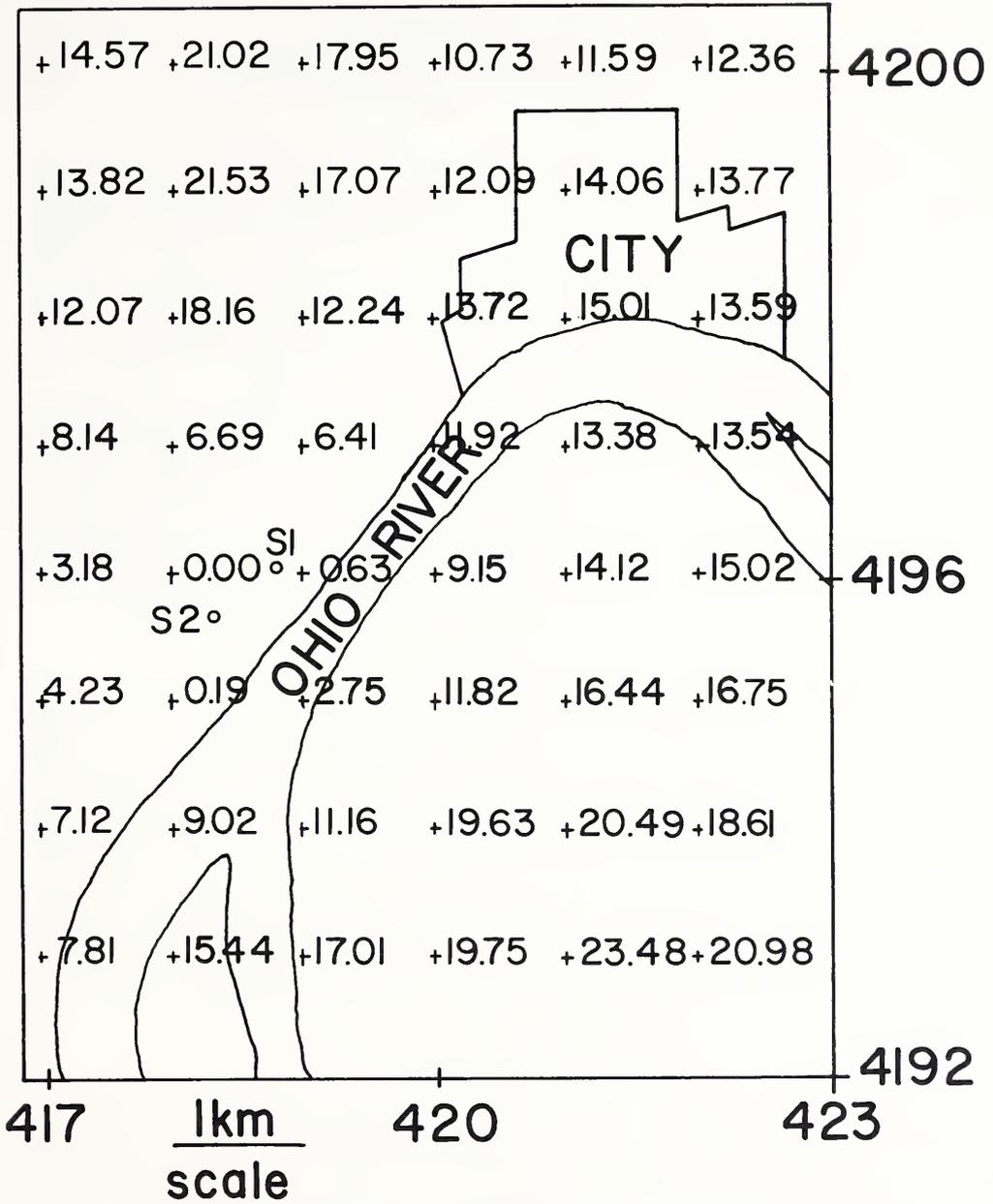


FIGURE 2. Average Annual Concentrations of Sulfur Dioxide in Micrograms/m³ with Axes labeled in Universal Transverse Mercator Coordinates.

for accumulating results from a multiplicity of sources. Emission data for the proposed new source and also for the principal existing source maintained by the same company were entered so that the combined effect of both sources could be calculated. Source and receptor positions were expressed in universal transverse Mercator coordinates. Further provision was made for incrementing the receptor position to facilitate an effective scan of the area involved. The program was extended with the capability of labeling concentrations at plotted positions on a scaled map.

A typical result obtained from this program is presented in Fig. 2. The results obtained in this form are very conveniently expressed to facilitate

locating the positions where state and federal ambient air standards would be most likely violated. In this particular case the combined emissions of the two plants are calculated to account for more than 25% of the ambient air standard for sulfur dioxide at this locality.

All results for the case studied indicate that the choices of locations of these plants were poor because frequently occurring winds from the southwest produce high concentrations of pollution in the neighboring metropolitan section. The choices of emission parameters such as the stack heights and flue gas velocities are also such that the downstream concentrations under certain atmospheric conditions can peak at the distances which correspond to the distances from the stacks to population centers in the area.

In all cases it should be kept in mind that all of these calculations are based on a statistical model and represent estimations rather than highly accurate predictions. In some cases results were compared with experimental measurements and also with reported calculations from more sophisticated programs utilizing a larger computer. The results were found to generally agree in order of magnitude but with differences as large as 100% to 200%.

Discussion

Atmospheric pollution is one of the major subject areas taken up in courses in environmental chemistry and other environmentally oriented subjects. With programs of the type presented available to a class, sufficient results can be obtained in a few afternoons from a small low-cost computer to effectively determine the environmental impact on a region from one or more point sources of pollution. The results can be presented in the classroom in the same form as shown for easy comprehension. The computer operations required can be conveniently assigned as student projects to members of the class. The overall effect should be the availability of a large amount of important information at a very low cost in time and effort.

These programs can also be used for other studies than we have reported here. The effects of various weather conditions on the magnitudes and locations of peak concentrations of pollution can be investigated in detail. If a given source is considered for a locality the effect of its location can be studied by assuming different locations and calculating the resulting pollution levels produced in the neighboring metropolitan centers. The effect of emission parameters can be investigated by assuming differing sets of values and calculating the pollution levels that result. Consequently, these programs can also be employed for individual student projects directed toward detailed investigations of more specialized topics.

Literature Cited

1. TURNER, P. BRUCE. 1970. Workbook of Atmospheric Dispersion Estimates. U.S. Department of Health, Education, and Welfare, Cincinnati, Ohio. 5-6.
2. Ibid. 8-9.