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Journal

JOURNAL OF THE ENVIRONMENTAL ENGINEERING DIVISION-ASCE, 103(6)

ISSN

0090-3914

Authors

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Publication Date

1977

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Peer reviewed

JOURNAL OF THE ENVIRONMENTAL ENGINEERING DIVISION

COMPUTER MAPPING OF AIR QUALITY

By David R. Boone,¹ A. M. ASCE and G. Scott Samuelson²

INTRODUCTION

The quality of ambient air is monitored throughout the United States by Federal, state, and local regulatory agencies. The data are used to provide the public, Federal, state, and local legislators, and various agencies with information on present and past air quality, and on long-term progress in meeting air quality goals. Ambient air quality data are also used to site additional monitoring stations or relocate existing ones, to initiate health advisories and episode alerts, and describe the existing air quality in environmental impact analyses required for proposed projects.

Ambient air quality data are generated by networks of discretely located monitoring stations. Once obtained, several statistical methods may be used to report the data. For example, data may be reported for each individual station, or as an average from several. In some cases, only the highest values for a given month or year are reported.

A mapping system that spatially distributes ambient pollutant concentration between the discretely located measuring points would provide an attractive option for reporting air quality data. As an example, Fig. 1 identifies the 13 air monitoring stations located in and about Orange County, California. Hourly-average oxidant concentrations are indicated for each station for a select day (June 27, 1974) and hour (1100-1159). The concentrations are expressed as parts per hundred million (pphm). Fig. 2 shows these same data transformed into a semicontinuous map. The mapping was computer generated by modeling the spatial distribution of the pollutant concentration between stations. The generation of maps at given intervals (e.g., hourly, daily, weekly, or monthly) could be used to establish informative temporal distributions as well.

Note.—Discussion open until May 1, 1978. To extend the closing date one month, a written request must be filed with the Editor of Technical Publications, ASCE. This paper is part of the copyrighted Journal of the Environmental Engineering Division, Proceedings of the American Society of Civil Engineers, Vol. 103, No. EE6, December, 1977. Manuscript was submitted for review for possible publication on January 7, 1977.

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contributions of meteorology and atmospheric chemistry. The development of such models is being actively pursued for the purpose of predicting future-year oxidant behavior (4,5,7). The state of development of these models, the computer storage and time required to run the models, and the extensive input data required suggest that alternative approaches should be explored to meet many current and short-term applications. Among the techniques available, interpolative modeling is the more attractive. The input data required for interpolative modeling are the concentrations monitored at discretely located air monitoring stations. The model then interpolates between stations to obtain the desired spatial distributions.

Since monitoring stations are not located on a regularly spaced grid, it is necessary to utilize a method that can interpolate between irregularly spaced data points. An interpolation function developed by Shepard (8) is adequate for mapping secondary pollutants such as oxidant. The derivation and adaptation of this technique is described in Appendix I. It should be stressed that factors such as wind, topography, and the location of major point and line sources are not accounted for by this method.

A major application of this type of interpolation was undertaken by the Laboratory for Computer Graphics and Spatial Analysis at Harvard University (2). This included the development and demonstration of a Synergraphic Mapping System (SYMAP). The SYMAP model is a relatively large computer program of about 6,000 records, and requires an IBM 360 or equivalent computer with a large storage space.

DESCRIPTION OF MODEL

Interpolation Model.—The present study was designed to develop a technique that could be readily adapted to small, minicomputers currently used or being acquired by regulatory agencies responsible for ambient monitoring (1). The goal was to develop a technique that is: (1) Capable of handling data input from the jurisdiction of a typical local agency; (2) simple to use; and (3) flexible enough to incorporate additional refinements as needed.

The model is designed to estimate pollutant concentration at the nodal points of a grid overlaid on the area of interest. In the present case, the study area is divided into 1.2-mile (2-km) square sections to coincide with the Universal Traverse Mercator (UTM) coordinate system.

The model mathematically interpolates data acquired at the air monitoring stations within and surrounding the study area. At each nodal point, a search radius is selected and data are discarded from those monitoring stations considered too distant to have an influence. For the examples presented herein, a radius of 19 miles (30 km) is arbitrarily selected. A weighting factor is computed for the monitoring stations located within the search radius. The calculation of the weighting factor is described in Appendix I and considers the distance and direction of the monitoring station from the nodal point in question.

Boundary Conditions.—An adequate estimate of concentration gradients requires that air monitoring stations surround each nodal point. Difficulty may be encountered at nodal points located between a monitoring station and the study area boundary. In the absence of special precautions, the estimated

concentration will be a simple extrapolation of that measured at the nearest station.

Since a simple extrapolation will not usually reflect actual conditions, input data from points outside the boundary are desirable to establish realistic gradients across the boundaries. Frequently, air monitoring stations will be located in areas adjacent to the mapping area. In the present example, five such air monitoring stations are located along the northwestern and northeastern boundaries.

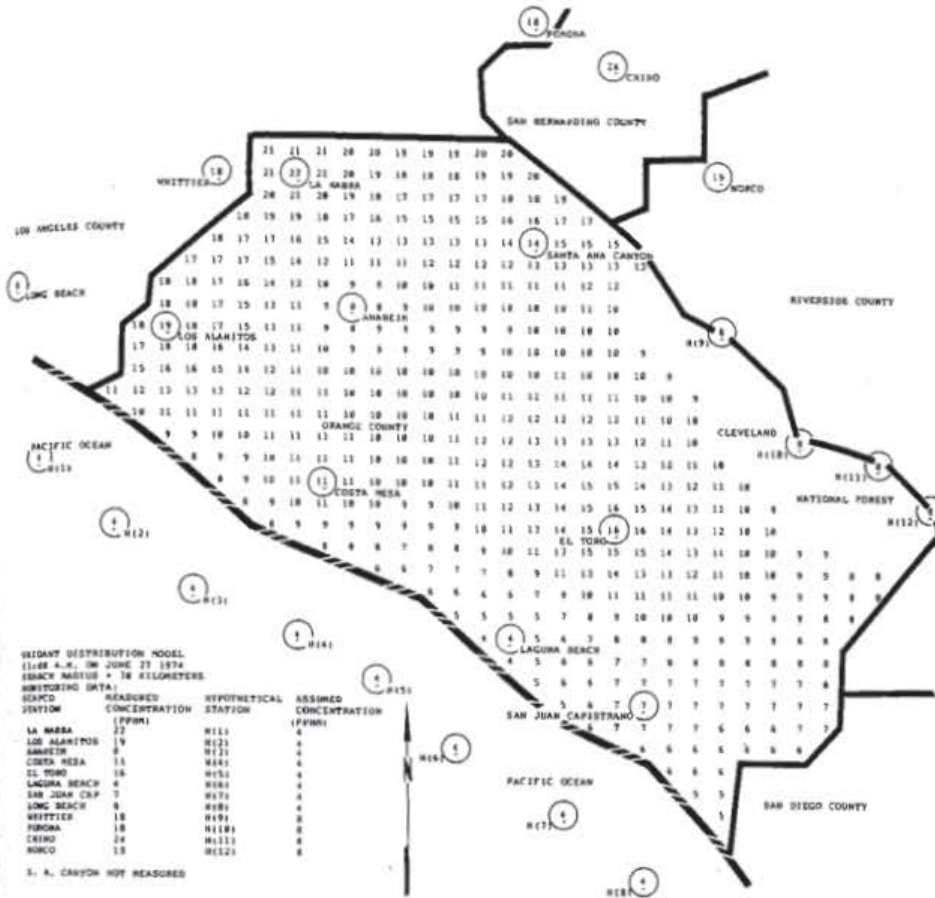


FIG. 3.—Modeling Spatial Distribution Using Hypothetical Stations

In many cases, air monitoring stations are not located adjacent to the study area. In the present example, the southwestern and eastern boundaries do not have stations outlying these boundaries. The Pacific Ocean is located along one boundary and a large, unpopulated region along the second boundary. To insure that realistic values of concentration are estimated along boundaries without the benefit of adjacent stations, a hypothetical station option is used in the present technique. Appropriate values of concentration are assigned to each hypothetical station to allow interpolation of data from stations interior to the boundary.

The hypothetical stations used in the present study are shown in Fig. 3.

At the southwestern boundary, a series of eight hypothetical stations located about 5 miles (8 km) offshore of the coast is used. Likewise, a series of four hypothetical stations is used along the eastern portion of the county. The selection of concentrations assigned to each hypothetical station depends on meteorological conditions, topography, and the spatial distribution of sources upwind. The choice of a suitable value may be based on intuitive judgment at worst, and remote monitoring along affected boundaries at best. Because of the daytime, on-shore breeze in the present example, lower concentrations are expected near the ocean and higher concentrations along the eastern boundary. Local wind patterns and inversion characteristics may cause some of these hypothetical points to experience higher pollutant concentrations than those measured at the nearest monitoring station. In actual practice, remote monitoring information along the boundary or at the hypothetical points is appropriate to establish the most representative value of concentration to assign the hypothetical station.

Results of Model Prediction.—A representative output from the model is shown in Fig. 3. The concentration at the hypothetical stations is arbitrarily selected to be 4 pphm along the ocean and 8 pphm along the eastern boundary.

Comparison of Figs. 2 and 3 reveals the effect of the boundary assumptions. In Fig. 2, the hypothetical stations have been removed. The concentrations at nodal points along boundaries without outlying hypothetical stations are simple extrapolations of inland station measurements. As expected, values along the northern boundary tend to approach measurements made at outlying stations, and concentrations estimated for interior points vary smoothly between stations. If interest is limited to the spatial distribution of air quality at nodes between stations internal to the study area, the boundary condition specification becomes less important.

APPLICATIONS

The utility of this mapping technique ranges from applications by regulatory agencies to applications by the private practitioner. As examples, four cases are presented.

Siting of Air Monitoring Stations.—A large variation in the geographic spacing between ambient air monitoring stations is common; the area selected for the present study is no exception. The distance varies from about 3 miles (4.8 km) between Whitter and La Habra, to 18 miles (29 km) between Santa Ana Canyon and El Toro. Reasons for this variation include budget restrictions, political considerations, and availability of suitable sites.

As monies become available to purchase, install, and operate additional stations, sites must be selected. The site selection will consider areas with a high population, areas with a high rate of growth, areas currently experiencing degraded air, areas that may potentially experience degraded air, and areas without adequate monitoring coverage. The generation and evaluation of air quality maps for the area would prove useful in conjunction with land-use and population distribution maps to assess sites appropriate for additional stations.

Public Information.—A primary function of local air pollution control agencies is a dissemination of air quality information to the public. Data are currently recorded in units of concentration (e.g., parts per hundred million and micrograms per cubic meter) and may be reported in units of concentration or converted

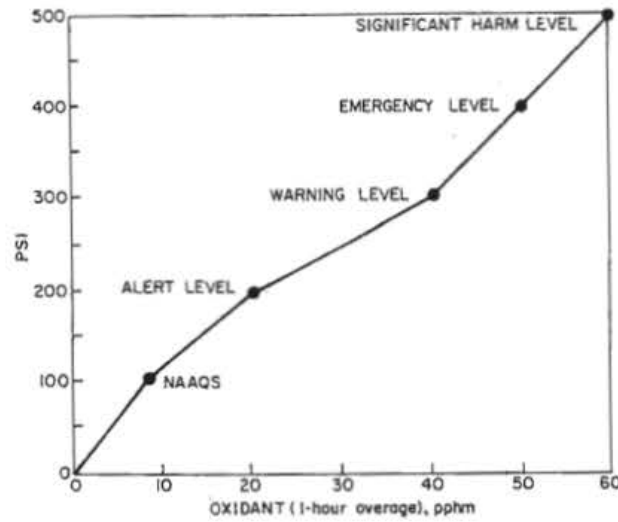


FIG. 4.—PSI Function for Photochemical Oxidant

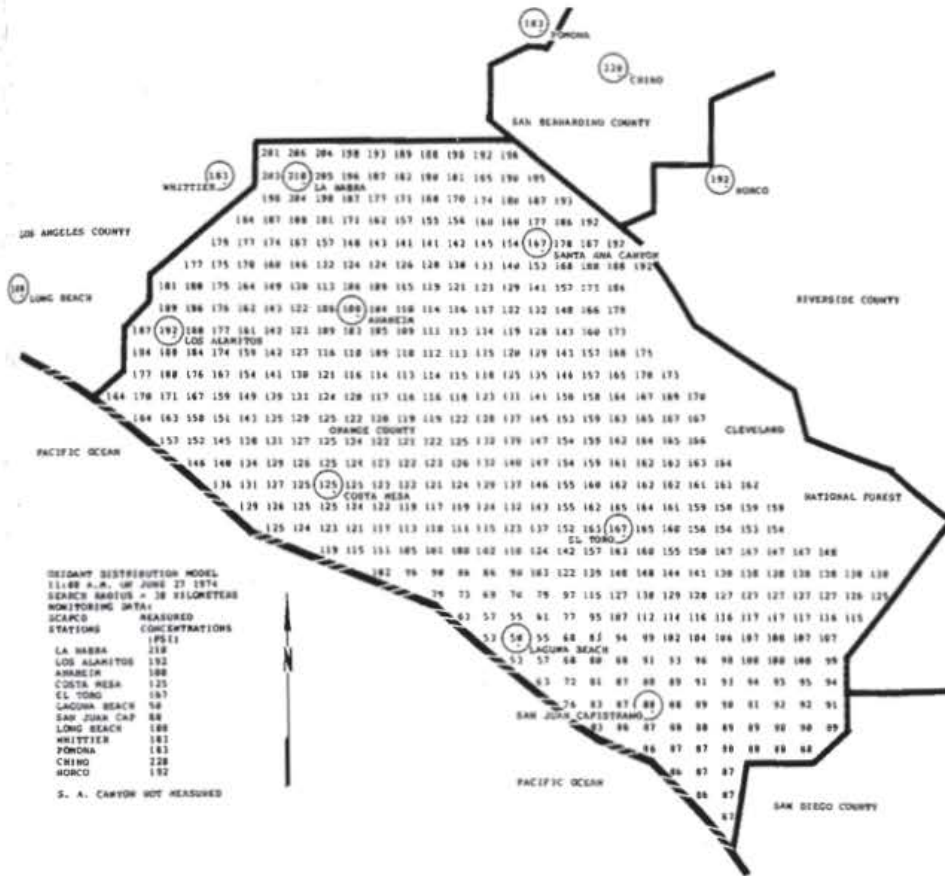


FIG. 5.—PSI Map for Public Information

to an index value. About 60% of the air pollution control agencies in the nation use some type of index system.

The index systems currently suffer from a lack of uniformity (6). To achieve uniformity, the Environmental Protection Agency (EPA) has proposed a Pollutant Standards Index (PSI) (3). The PSI uses a segmented linear function to relate measured pollutant concentrations to normalized numbers. For each pollutant, a PSI value of 100 corresponds to the appropriate National Ambient Air Quality Standard (NAAQS). Descriptor categories relating to health effects are associated with each category. Fig. 4 shows the PSI data for oxidant as an example.

In reporting the PSI, the EPA recommends computing the PSI based on measurements from the station recording the highest pollutant concentration on a given day. If appropriate, separate index values may be reported for each community using data from the appropriate monitoring station.

The portrayal of data in a map format, rather than in tabular form for a select set of stations, has several advantages in communicating to the public the daily and long-term air quality trends. For example, a map such as that shown in Fig. 5 identifies the areas impacted by elevated pollutant levels for the given hour. Similar maps showing daily or long-term averages could also be compiled.

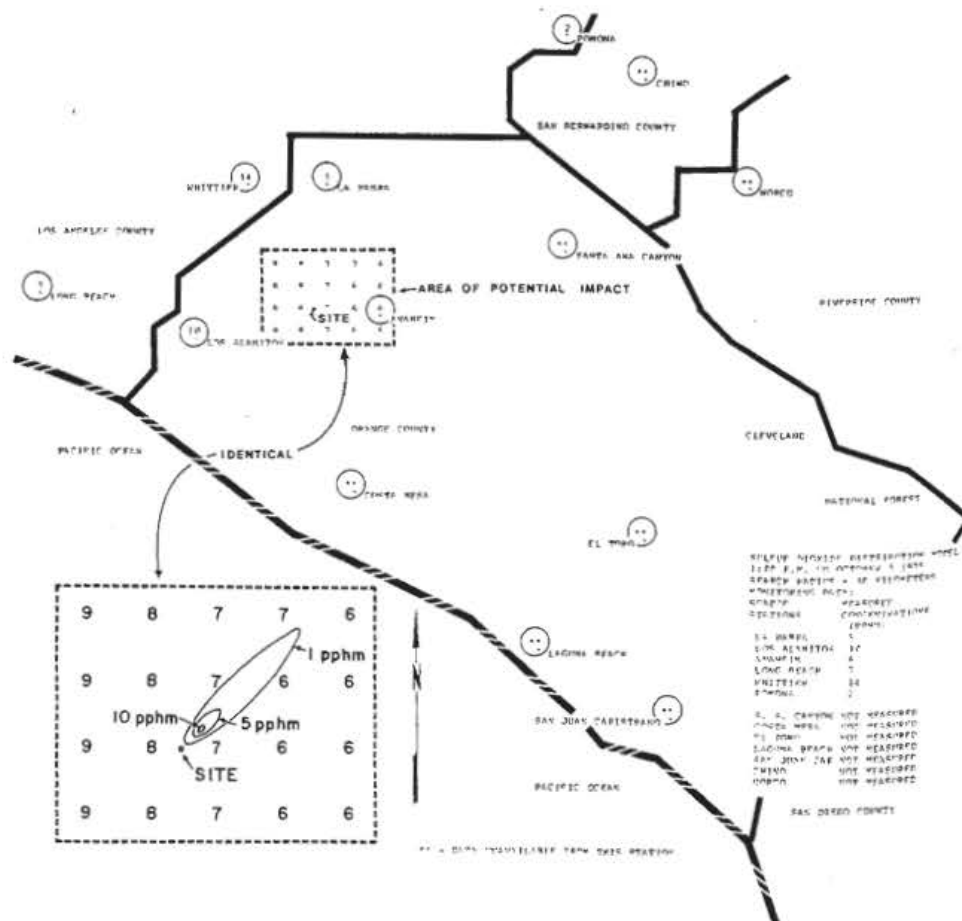


FIG. 6.—Modeling Sulfur Dioxide Background Levels

Environmental Impact.—An environmental impact analysis requires a description of the existing air quality at the site of the proposed project, and an estimate of the likely impact of the project on air quality.

The description of existing air quality currently relies upon data from the closest air monitoring station. To provide an improved description of the existing air quality at the site, mapping would be useful in estimating the variation in air quality between the closest stations.

As an example, assume that a new power plant is to be constructed at the site indicated in Fig. 6. Using data measured at nearby stations, typical worst-hour background ambient concentrations of sulfur dioxide are mapped within the area of potential impact. In the enlarged detail, the projected impact of the power plant is shown. Worst-hour contours of SO_2 concentration, calculated using Gaussian modeling techniques, are overlaid on the background concentrations. This mode of presentation fills a current void of many environmental assessment studies by considering the prevailing background levels to which the impact of the project alone will be additive. Such mapping could also provide an assessment of community hot-spots and the accumulative impact of proposed projects without the sharp cost penalty associated with full-scale regional modeling and without the information penalty of current approaches.

Trend Analyses.—Trend information is useful for projecting future-year air quality and guiding land-use and transportation planning. The development of trend information currently presents a formidable challenge to planning and regulatory agencies. However, the increasing practice of compiling and storing aerometric and air monitoring data on magnetic tapes is improving the opportunities in many states for statistical analyses. Mapping treated data provides an effective vehicle for presentation. For example, the monthly or seasonal worst-hour and mean-hour concentrations may be mapped for the commonly encountered meteorological conditions and the maps examined for evidence of short and long-term spatial and temporal trends.

SUMMARY AND CONCLUSIONS

A technique has been presented for portraying the spatial distribution of pollutants between discretely located monitoring stations by use of computer generated maps. Modeling the spatial distribution of air pollutants is achieved by two-dimensional interpolation of data recorded at the monitoring station. By using computers of a size within reach of local agencies and private practitioners, maps can be prepared for various purposes, including the siting of additional stations, public information, environmental impact studies, and trend analysis.

The utility and range of applicability of the interpolation models needs to be determined by field monitoring at points between stations and along boundaries. Incorporation of local meteorology and topography into the model are refinements appropriate for a second generation model.

APPENDIX I.—DERIVATION OF INTERPOLATION FUNCTION

A coordinate system is established with the origin at the northwest corner of the study area, coinciding with the UTM coordinate system. Unit distances

on the X and Y-axis correspond to 1.2 miles (2 km) in a north-south and east-west direction, respectively.

The initial input consists of the coordinates and pollutant concentration data for the set of actual and hypothetical station sites that are to be used in the given trial. In estimating the concentration at each nodal point $P(X, Y)$, it is desired to use only the N closest points to reduce the amount of computation. An arbitrary search radius R is selected, and those points for which the distance from $P(X, Y)$ is less than R form a subset of N points; the remaining points are temporarily disregarded. Each point I in the subset of N points has associated with it coordinates $X(I)$ and $Y(I)$, distance $D(I)$ from $P(X, Y)$, and pollutant concentration $Z(I)$.

The value of the interpolation function at $P(X, Y)$ is a weighted average of the concentrations associated with the N surrounding data points. A distance weighting factor $S(I)$ and directional weighting factor $T(I)$ are computed for each point I in the subset N as follows:

$$S(I) = \frac{1}{D(I)} \quad \text{for } 0 < D(I) \leq \frac{R}{3} \quad \dots \dots \dots (1)$$

$$S(I) = \frac{27}{4R} \left[\frac{D(I)}{R} - 1 \right]^2 \quad \text{for } \frac{R}{3} < D(I) \leq R \quad \dots \dots \dots (2)$$

$$T(I) = \frac{\sum_{J=1}^N S(J) * (1 - \cos A)}{\sum_{J=1}^N S(J)} \quad \dots \dots \dots (3)$$

Angle A is that formed by the line segments between $P[X(I), Y(I)]$ and $P(X, Y)$ and between $P[X(J), Y(J)]$ and $P(X, Y)$. The cosine factor may be evaluated as

$$\frac{\{[X - X(I)] * [X - X(J)]\} + \{[Y - Y(I)] * [Y - Y(J)]\}}{D(I) * D(J)} \quad \dots \dots \dots (4)$$

The distance and direction factors are combined into a weighting factor $W(I)$ for each point I as follows:

$$W(I) = S(I)^2 * [1 + T(I)] \quad \dots \dots \dots (5)$$

The interpolation function $F(X, Y)$ provides the estimated value of the pollutant concentration at nodal point $P(X, Y)$ as a weighted average of the concentrations $Z(I)$ at nearby data points:

$$F(X, Y) = \frac{\sum_{I=1}^N [W(I) * Z(I)]}{\sum_{I=1}^N W(I)} \quad \dots \dots \dots (6)$$

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APPENDIX III.—NOTATION

The following symbols are used in this paper:

- $D(I)$ = distance of data point I from $P(X, Y)$;
 $F(X, Y)$ = value of interpolation function at $P(X, Y)$;
 N = number of data points I where $D(I) < R$;
 $P(X, Y)$ = nodal point;
 R = search radius;
 $S(I)$ = distance weighting factor for data point I ;
 $T(I)$ = directional weighting factor for data point I ;
 $W(I)$ = combined weighting factor for data point I ;
 $X(I)$ = north-south coordinate;
 $Y(I)$ = east-west coordinate; and
 $Z(I)$ = pollutant concentration at data point I .