AIR POLLUTANT EMISSIONS RELATED TO LAND AREA – A BASIS FOR A PREVENTIVE AIR POLLUTION CONTROL PROGRAM

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE

AIR POLLUTANT EMISSIONS RELATED TO LAND AREA - A BASIS FOR A PREVENTIVE AIR POLLUTION CONTROL PROGRAM

J. D. Williams, J. R. Farmer, R. B. Stephenson,
G. G. Evans, and R. B. Dalton

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
CONSUMER PROTECTION AND ENVIRONMENTAL HEALTH SERVICE
NATIONAL AIR POLLUTION CONTROL ADMINISTRATION
Durham, North Carolina

July 1968

The APTD series of reports is issued by the National Air Pollution Control Administration to report technical data of interest to a limited readership. Copies of APTD reports may be obtained upon request, as supplies permit, from the Office of Technical Information and Publications, National Air Pollution Control Administration, U.S. Department of Health, Education, and Welfare, Ballston Center Tower No. 2, 801 North Randolph Street, Arlington, Virginia 22203.

National Air Pollution Control Administration Publication No. APTD 68-11

ABSTRACT

Advances in technology have made it possible to establish zoning performance standards, which will prevent air-use land-use conflicts. In the past, such standards were based on source capability and were uniformly inadequate. Now, because of the ability to predict air pollution levels, standards that accomplish both preventive and control aims can be applied.

Land area, as used for urban planning purposes, reflects the diffusion capability of the air in many areas. With the growing computer capability and greater knowledge concerning the diffusion of pollutants in the air, prediction systems are within practical application range. An example of the output information from such a diffusion model is discussed.

KEY WORDS: air pollution, air quality, air-use plans, diffusion model, land use, performance standards, zoning

AIR POLLUTANT EMISSIONS RELATED TO LAND AREA--
A BASIS FOR A PREVENTATIVE AIR POLLUTION CONTROL PROGRAM

Before the turn of the century, the traditional and in some instances the only way a community could alleviate air pollution problems was by controlling the location of air pollutant sources by source type. Although a source such as an "ironworks" would release the same quantity and type of pollutants regardless of location, people recognized that it was possible to arrange sources spatially so that receptor areas were more likely to be open spaces or undeveloped land rather than residential or otherwise developed districts.

Unfortunately, and for a multitude of reasons, the control of source location did not always eliminate air pollution as a community concern. Other influences were at work. As population grew, industry expanded, and technology blossomed, source location became an impractical solution and other means of control became necessary. Control of the source itself through technical devices developed as the prevailing philosophy for control, as it still is today.

In the past, control of source location was accomplished largely by royal decree or dictatorial fiat; now much the same thing is attempted by the instrument of zoning. Although zoning has never been directed solely at controlling air pollution, those who were its early spokesmen certainly had air pollution in mind.

Zoning in the United States is a rather recent development, with the first comprehensive zoning ordinance being enacted in 1916 by New York City.[1] The concept of districting permissible land uses legislatively (zoning) was first upheld by the U.S. Supreme Count in the landmark case of Euclid versus Ambler Realty Company in 1926. The majority opinion, handed down by Justice Sutherland,[2] stated, "A nuisance may be merely a right thing in the wrong place,--like a pig in the parlor instead of the barnyard."

The principles enunciated in the Euclid case covered what Richard May[3] has described as the first era of zoning, "a period of control by location only." The basic zoning tool of this era, which is still in vogue, is the "use list." Such a list indicates quite specifically the land uses that are allowed or prohibited in each zoning district. Since industry has become highly diversified and source control devices have become more sophisticated, industry types and air pollution are no longer bedfellows by definition alone. Many new industries - unknown and unimagined 30 years ago are strictly nonpolluters. Attractive, often idyllic, industrial parks are commonplace in the modern community. They can be good neighbors while employing people and paying taxes. The use-list approach, furthermore, cannot adequately take into account the size of either the pollutant source or the plot of land on which the source is located. For example, a large cattle lot would be treated the same as a small one even though the small lot was on a site ten times larger than the site of the large one. The use list has, with time, become an over-simplified means of controlling air pollution and is not sufficient for today's needs.

As a reaction to the inflexibility of the use list, several innovations in zoning practices have brought us to a new era in the development of zoning; emphasis is now placed on the performance level of activities rather than just on the actual use of the land. This is the concept of performance standards.

Dennis O'Harrow,[4] Executive Director of the American Society of Planning Officials, outlined the basic performance standards concept in his 1951 paper entitled, "Performance Standards in Industrial Zoning." The paper presented 11 categories for which it was felt standards should be developed:

1. noise
2. smoke
3. odor
4. dust and dirt
5. noxious gases
6. glare and heat
7. fire hazards
8. industrial wastes
9. transportation and traffic
10. esthentics
11. psychological effects

Standards for each of these 11 categories, suitably based on the physical facts involved, would provide the maximum freedom to an air pollutant source planning to locate in any particular air pollution basin and would at the same time assure optimum conditions for residential and other land uses in that same basin. Obviously, the setting of standards based on the physical phenomena involved is difficult and time consuming, but the air pollution category seems to lend itself well to this type of treatment.

The Chicago zoning ordinance adopted in May 1957 was the first in the country to apply a full scale of performance standards to industrial zoning for a large urban area.[5] Since then over 200 communities have adopted performance standards covering categories originally suggested by O'Harrow. Ideally, of course, zoning performance standards should cover each of the four air-pollution-oriented categories: smoke, odor, dust and dirt (particulates), and noxious gases. Many ordinances, however, deal only with smoke and particulates; and many more, unfortunately, apply only to the industrial districts of the community and not to commercial or residential zones, which often contribute significant quantities of pollutants to the atmosphere.

The validity and appropriateness of zoning performance standards depend upon the diffusion capability of the atmosphere, which in turn, is best reflected, for planning and zoning purposes, by the size and nature of the land area from which the pollutants are emitted. If standards apply only to what is emitted and if they bear no relation to the concentration of pollutants already in the atmosphere or to the land area involved, air pollution could be intolerable even though all sources were fully controlled to a technically feasible level. In other words, if technical feasibility rather than the diffusion capability of the air is the principal guiding policy, increases in numbers and sizes of sources would cause a continuing deterioration of the air quality.

Actually, the traditional zoning concept of districting permissible uses and the more recent concept of location according to operational characteristics are neither in conflict with each other nor are they mutually exclusive; they tend, in fact, to reinforce one another. The one merely controls the location of uses, whereas the other prescribes the allowable levels of operation and conduct of the uses.

In summary, zoning grew out of a need to limit the creation of nuisances; it did this by providing a means whereby types of land uses could be separated from conflicting uses while providing the land owner and developer with an element of security as to the future use of property. To some extent it helped the community plan services and facilities, but it did not provide for the increase in air pollutant source size or concentration of sources on a given unit of land, both of which diminish the quality of the community-wide air supply.

The development of land-use control techniques for air pollution control purposes during the past 50 years leads to the conclusion that we are now ready to proceed to a balanced use of regulatory programs and planned air use, of which zoning performance standards are a part. Such a program is directed toward accomplishing air quality goals that are based on the effects of air pollution.

The increased demand by the people for a cleaner environment and the increased capability of control devices to limit the emission of pollutants at the source have made the use of performance standards both more necessary and more appropriate. Their implementation is further warranted by recent advances in establishing air quality criteria, measuring air quality, and determining the atmospheric diffusion capability.

The importance of meteorological parameters in city planning has been known for a long time. Leavitt[6] described the way Stalingrad in Russia was laid out in two sections perpendicularly aligned to the prevailing wind direction, resulting in a more favorable windward and a less favorable leeward side to the town. Hilberseimer[7] states that when prevailing winds are so distributed that the section of pollution dispersion does not exceed half a circle, a ribbon-like community is possible. If the dispersion area does exceed half a circle, only fan-shaped communities can be formed. Communities should be separated from each other by the extension of the polluted area. A study by Demarrais[8] reported the meteorological information for the Tulsa Metropolitan Area could be used in setting zoning performance standards and requirements. The importance of meteorological considerations in planning was also discussed by Rihm[9] and Neiburger[10].

The location of sources on the basis of prevailing winds is a simple and straightforward approach; however, it will not be effective in many real situations. A more sophisticated treatment is necessary in cases where the meteorology and topography complicate and abet the air pollution problem. Such a technique utilizes a meteorological diffusion model, which is a mathematical description of the meteorological transport and diffusion process during a particular period, and an inventory of emissions which yields estimates of air pollutant concentrations at specific locations.

Several models have been developed; each considers essentially the same parameters, but in a different manner or time-scale. The complexity of the models varies from very simple hand calculations, described by Clarke,[11] to a complex computer program, described by Turner.[12] Several other models are also described in the literature.[13-17]

The basis for the mathematical treatment of an air pollution basin is easily understood if the basin is thought of as an area within which pollutants are emitted and receptors are affected by distance and diffusion conditions. The boundaries of the basin are defined in a pollutant-concentration - effects concentration manner since the concentration of pollutants decreases with increasing distance from the source or sources, even though the source area itself may be specifically defined. For a certain air pollution concentration (air quality) at any point within the basin, only a certain quantity of pollutants (emissions) can be put into the air.

There are two major considerations regarding the amounts of pollutants that may be emitted. First, a high pollutant emission rate will produce an excessively high concentration in a limited area. Any air pollutant receptor exposed to such pollutant concentrations could find this exposure undesirable even though conditions in the rest of the basin would be satisfactory. Second, when averaged over a considerable period of time, the air quality will be the same over relatively large areas. Air pollution effects are associated with each of the described conditions, and control should be designed for the appropriate time-concentration conditions (or other pollutant dosage indicators) selected from statistical frequency-distribution diagrams of pollutant concentrations to prevent both high-concentration, short-exposure and low-concentration, long-exposure effects. The prevention of high-concentration, short-exposure effects applies to any source regardless of location. The prevention of low-concentration, long-exposure effects may apply to any source, but is more apt to apply to those sources significantly affecting the same receptor areas.

A diffusion model has many potential uses. It can assist in prediction of pollutant concentrations on a day-to-day basis for air pollution warning and alert systems. It can help regulatory programs justify certain regulations by determining the proportion of air pollution concentrations attributable to each source or type of source. It can help in selection of sites for major pollutant sources and effective planning of new cities or renewal of existing ones. It can help define the limits of control districts. It can help in the preparation of air-use and land-use plans to preserve or achieve clean air while at the same time allowing industrial and other related developments.

Because of the many calculations, diffusion models can be applied to multisource problems only by means of computer programs. The program being used for illustration purposes herein calculates long-term average (season or year) ground-level pollution concentration in parts per million (ppm) at one or more receptor points from a single source. The required inputs to the model are the grid coordinants of pollutant sources, grid coordinants of receptor points, stack heights of sources, pollutant emission rates, and meteorological data. This particular diffusion model is still under development and has not been validated by field data as yet. It is being validated, but in the meantime its use is limited to analysis of certain problems only.

The model was programmed for the IBM 1130 digital computer FORTRAN IV language. The meteorological data used in the example were from Lambert Field in St. Louis, Missouri. The meteorological conditions of other areas would not be directly comparable to those presented. The emission data were selected arbitrarily and do not represent any community in the United States. The example uses sulfur dioxide as the pollutant, but the model is not limited to that pollutant alone. Any gas or small sized particulate can be treated, although inaccuracies in the model and differences in pollutant behavior such as decay rates and secondary pollutants resulting from reactions in the air must be allowed for when interpreting the results.

The example utilizes the meteorological data shown in Figure 1, the area shown in Figure 2, and the data in Table 1. The city, highly simplified and hypothetical for demonstration purposes, has a population of 2,000,000 people and encompasses 165 square miles. The land is zoned for industrial, commercial, multifamily residential, and single-family residential use.

The area has two power plants. Plant A is situated on a 20-acre plot and has a 100-meter stack. The plant burns both coal and residual fuel oil and has a generating capacity of 1000 megawatts. Power plant B burns coal only, is located on a 5-acre plot, and has a generating capacity of 500 megawatts. It has a 50-meter stack. The rates of emissions in grams per second and equivalent tons per acre per month are shown in Table 1.

Table 1. CHARACTERISTICS OF EXAMPLE CITY[a]

Source type	Sulfur dioxide emission, g/sec	Sulfur dioxide emission, tons/acre/mo
Commercial	655	1.14×10^{-3}
Industrial	2,280	0.53×10^{-3}
Residential		
Multifamily	70	0.034×10^{-3}
Single family	--	--
Power plant A	4,660	665
Power plant B	2,340	1,348

[a]Total area, 105,600 acres; population, 2,000,000.

Figure 3 indicates the predicted sulfur dioxide concentration at ground level from all sources. Note that the highest concentration falls over part of the commercial area and extends in the direction of the industrial area encompassing power plant B and extending in the direction of power plant A. Note also the sulfur dioxide sampling station near the center of the commercial area.

Figure 4 shows the contributions of the power plants only. They account for 50 percent of the sulfur dioxide concentrations in the central part of the area. To a considerable extent, this is caused by the 50-meter stack height of power plant B.

Figure 5 shows the industrial contribution, which extends out from the industrial area. The industrial pollution pattern indicates that an adjacent buffer zone would be advantageous.

Figure 6 indicates the contribution of the multifamily residential area to sulfur dioxide concentrations at ground level. Because of low stack heights, the commercial area contributes significantly to sulfur dioxide concentrations at ground level in the central zone. Figure 7 indicates these contributions to be approximately 40 percent of the total concentrations. If the problem in this area is to be solved, emphasis must obviously be placed on control of commercial emissions and power plants, at least the one with a relatively low stack located in the residential and multifamily area.

A sulfur dioxide sampling station located in the center of the commercial area could provide a check on the predicted concentrations of the meteorological diffusion model. The model can predict the ground-level concentrations contributed by the pollutant emissions from each source or source category. If the sum of the concentrations from each source or source category equals the actual concentration measured at the sampling station, the model can be considered valid and considerable trust can be placed in its predictions. In real situations, however, several sampling stations are required to validate a model for a particular area. Since one of the major uses of the predictions is to indicate the relative amounts of pollution caused by certain sources or categories of sources, the prediction system has considerable immedi ate use. As time goes on and results of research can be applied, more effective diffusion models will lead to greater use and reliability.

Additional community experiences will also improve the validity of diffusion models and in time will lead to application of cost analysis and related decision-making facts. It must be repeated, however, that this model as presently constituted is still in the development stages and applies to long-term averages. Not all effects are associated with long-term averages; in fact, the effect on vegetation may result from only a 30-minute exposure. The engineering analysis and application must, therefore, take into account short-term as well as long-term effects.

A computer programmed diffusion model can be part of the "cement" between regulatory and urban planning agencies as well as state and local levels of government. It will help make decisions for clean air for urban areas and provide for the logical development of industrial and other resources.

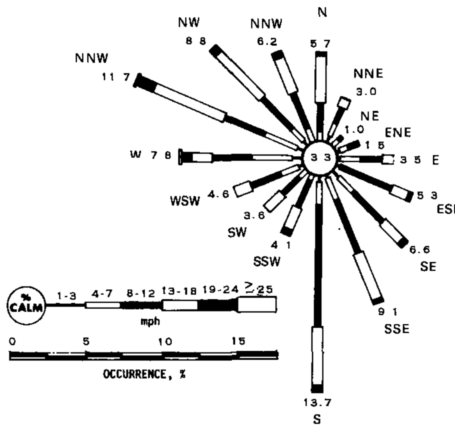

Figure 1. Percentage frequency of wind direction at Lambert Airport in St. Louis, Mo., Dec. 1, 1964 Feb. 28, 1965.

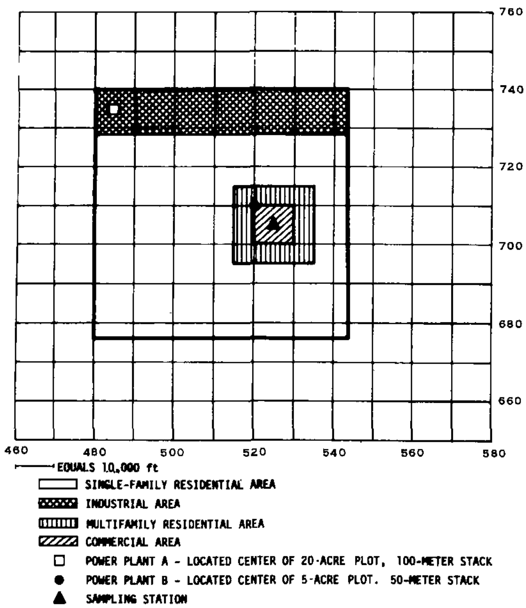

Figure 2. Model city layout.

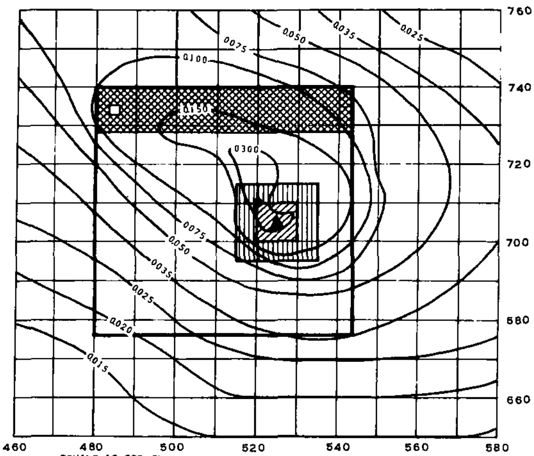

Figure 3. Predicted total SO_2 concentration (ppm) from all sources for 3-month period Dec. 1, 1964 - Feb. 28, 1965.

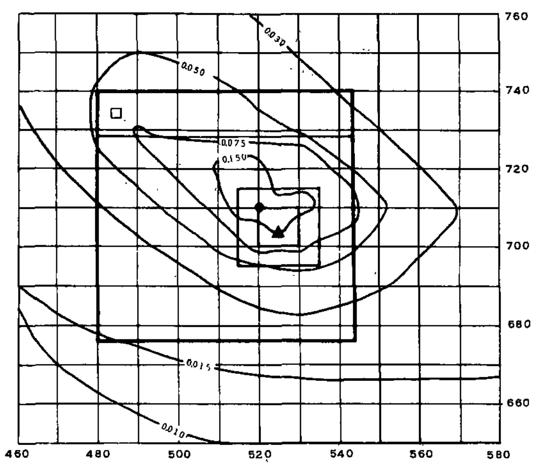

Figure 4. Predicted SO_2 concentration (ppm) from public utility power plants only for 3-month period Dec. 1, 1964 Feb. 28, 1965.

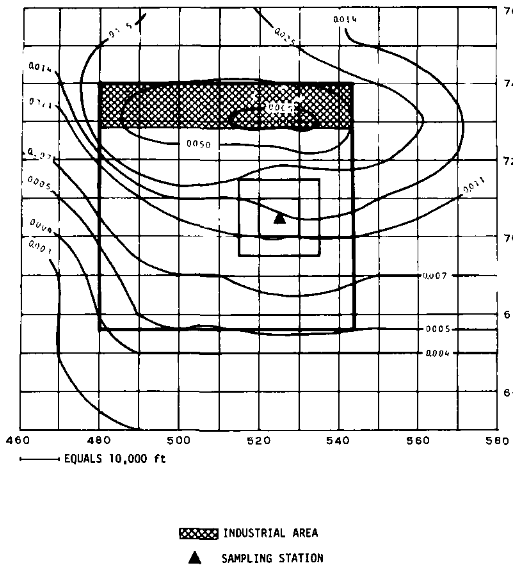

Figure 5. Predicted SO_2 concentration (ppm) from industrial sources only for 3-month period Dec. 1, 1964 Feb. 28, 1965.

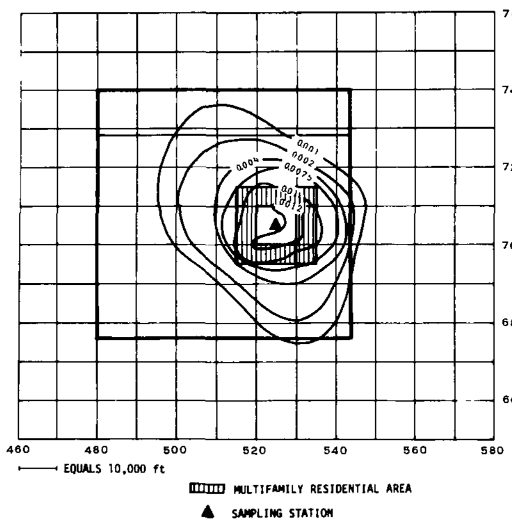

Figure 6. Predicted SO_2 concentration (ppm) for 3-month period Dec. 1, 1964 - Feb. 28, 1965, from multifamily residential area only.

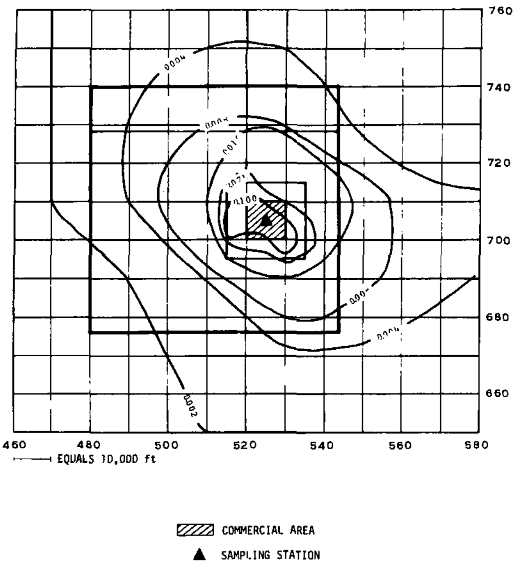

Figure 7. Predicted total SO_2 concentration (ppm) for 3-month period Dec. 1, 1964, to Feb. 28, 1965, from commercial area only.

REFERENCES

1. Haar, C. M. Land-use planning: casebook on the use, misuse, and re-use of urban land. Little, Brown and Company, Boston. 1959. p.148.

2. Ibid., p.162.

3. May, R., Jr. The proper role of planning and zoning in air pollutions controls. Presented at the National Conference on air pollution, Washington, D. C. 1958. p.1.

4. O'Harrow, D. Performance standards in industrial zoning. American Society of Planning Officials. Chicago. 1954.

5. Schulze, E. E. Performance standards in zoning. JAPCA, 10:156-60. 1960.

6. Leavitt, J. M. Meteorological considerations in air quality planning. JAPCA, 10:246-50. June, 1960.

7. Hilberseimer, L. The nature of cities. Paul Theobold and Company, Chicago. 1955.

8. DeMarrais, G. A. Meteorology for land development planning in the Tulsa metropolitan area. Technical Report A61-5, U.S. Department of Health, Education, and Welfare, Cincinnati, Ohio. 1961.

9. Rihm, A., Jr. Air pollution and urban planning. Health News. New York State Department of Health, Albany, N. Y. Nov. 1962. pp.15-19.

10. Neiburger, M. Meteorological aspects of air pollution control. Yale Scientific Magazine. Jan. 1967.

11. Clarke, J. F. A simple diffusion model for calculating point concentrations from multiple sources. JAPCA, 14:347-52.

12. Turner, D. B. A diffusion model for an urban area. J. Applied Meteorology, 3:83-91. Feb. 1964.

13. Lucas, D. H. The atmospheric pollution of cities. Int. J. Air Pollution, 1:71-86. 1958.

14. Meade, P. J., and F. Pasquill. A study of the average distribution of pollution around Straythorpe. Int. J. Air Pollution, 1:60-70. 1958.

15. Pooler, F. A. Prediction model of mean urban pollution for use with standard wind roses. Int. J. Air and Water Pollution, 4:199-211. 1961.

16. Koogler, J. B., et. al. A multivariable model for atmospheric dispersion predictions. JAPCA, 17:211-14. April 1967.

17. Miller, M. E., and G. C. Holzworth. An atmospheric diffusion model for metropolitan areas. JAPCA, 17:46-50. Jan. 1967.