United States
Department of
Agriculture

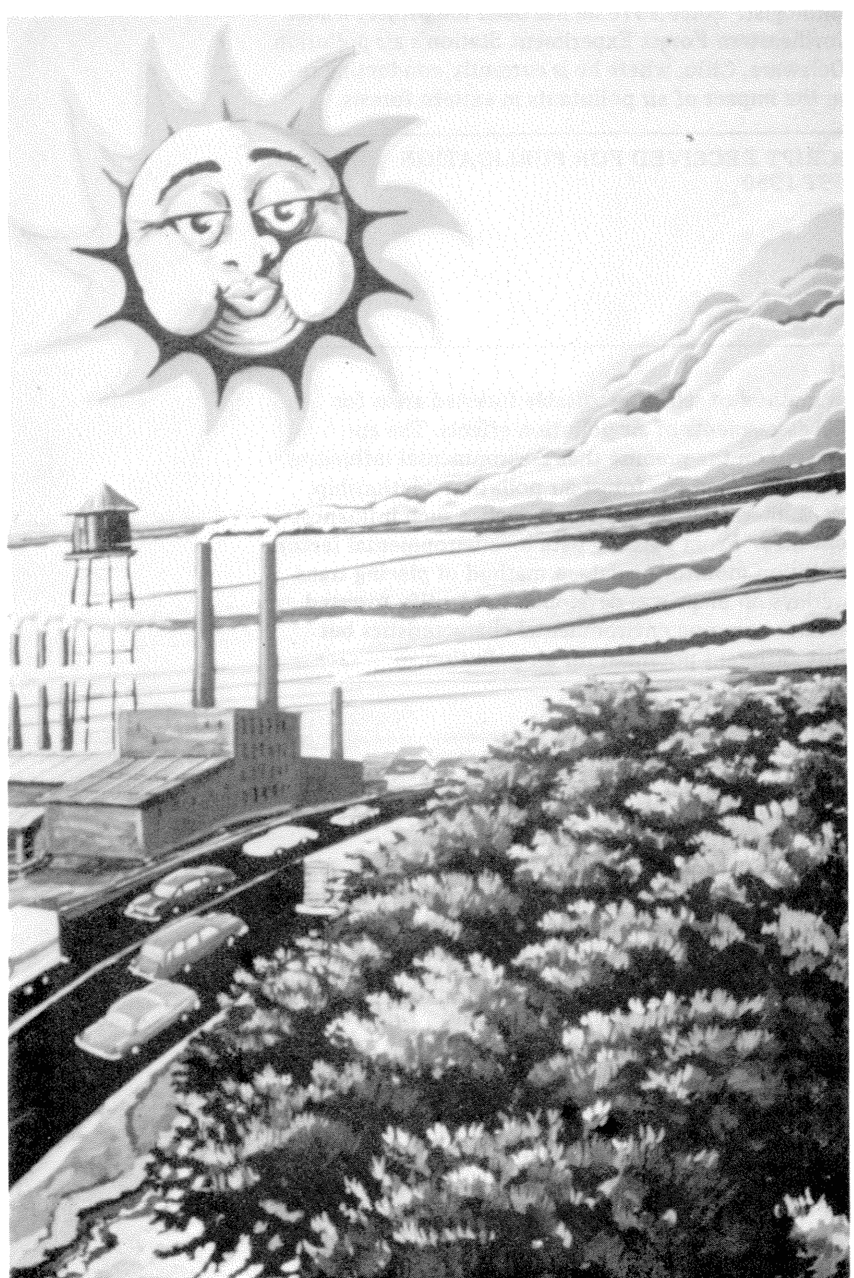
Forest Service

Research
Paper NE-472

1981

A Method of Selecting Forest Sites for Air Pollution Study

by
Sreedevi K. Bringi
Thomas A. Seliga
Leon S. Dochinger



The Authors

SREEDEVI KRISHNAMURTHY BRINGI received a B.S. degree in 1972 from Bangalore University, India and an M.S. degree in 1974 from Indian Institute of Technology, India. In 1977, she obtained an M.S. degree from The Ohio State University.

THOMAS A. SELIGA received a B.S. degree in 1959 from Case Institute of Technology, and an M.S. degree in 1961 and a Ph.D. degree in 1965 from The Pennsylvania State University. Since 1971, he has served as the Director of the Atmospheric Sciences Program at The Ohio State University.

LEON S. DOCHINGER received a B.S. degree in 1950 and a Ph.D. degree in 1956 from Rutgers University, and an M.S. degree in 1952 from Cornell University. In 1956, he was assigned to the Central States Forest Experiment Station as a plant pathologist. Since 1970 he has been the project leader of the Northeastern Forest Experiment Station's air pollution unit in Delaware, Ohio, where he is currently conducting research on the impact of air pollutants in eastern forests.

MANUSCRIPT RECEIVED FOR PUBLICATION
8 AUGUST 1980

Abstract

Presents a method of selecting suitable forested areas for meaningful assessments of air pollution effects. The approach is based on the premise that environmental influences can significantly affect the forest-air pollution relationship, and that it is, therefore, desirable to equalize such influences at different sites. From existing data on environmental factors and air pollution monitoring data, a method of placing transparent overlays on maps was developed to identify forested areas that have common environmental characteristics but significantly different potential for air pollution.

The research herein was supported by funds provided by the U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station, under cooperative agreement 23-614.

Industrial growth and extensive urbanization over the last 50 to 100 years have caused enormous increases in the rate at which pollutants are emitted into the atmosphere. Such air pollutants include: sulfur dioxide (SO_2) from the incineration and processing of fossil fuels; nitrogen oxides (NO_x) from high temperature combustion processes; hydrocarbons from the combustion of petroleum products; fluorides from mineral smelting; particulates from grinding and manufacturing sources; and oxidants, such as ozone (O_3), which are urban products of photochemical reactions in the atmosphere.

Ozone and SO_2 are widespread and have a great impact on the forest, and it is difficult to control the source of these pollutants (Dochinger and Jensen 1975). Many forest species such as pine, ash, larch, oak, aspen, and birch are susceptible to these two pollutants. For these reasons, this study was restricted to the examination of potential for air pollution associated with the occurrences of O_3 and SO_2.

In assessing the effects of air pollutants on forests, it is desirable to correlate the degree of the observed effect with the relative concentration of the air pollutants (Smith 1974). These dose-response correlations are not available in actual field situations where many environmental factors can influence forest processes, potential for air pollution, and sensitivity of forest species to pollution. Relevant environmental factors include: terrain, forest types, temperature, and meteorology. These factors are examined herein and related to the problem of site selection for assessing of the effects of air pollution on forests.

Assessment strategies must also include knowledge of the sources and types of air pollutants, the atmospheric processes governing their chemical modifications and transport, and their distribution. These factors affect the potential for air pollution in a given location and must be considered along with environmental factors in any site-selection procedure.

To study the impact of air pollution on forests, it is important to nullify the effects of environmental influences on the air pollution-forest relationship and to select forest sites where the probability of discernible effects of air pollution is highest. Our approach was to identify forested areas with common environmental characteristics but with significantly different potential for air pollution. Subsequent field measurements, at sites selected within these forested areas, may provide symptomatic differences in the effects on forests.

Our rationale led to the following objectives for this study: (1) to consider relevant environmental factors influencing forest-pollution interactions, and (2) to develop a methodology for identifying forested regions with similar environmental parameters but different air pollution concentrations.

In our methodology, potential of air pollution was determined by a mathematical steady-state dispersion model. The Climatological Dispersion Model was used to estimate long-term arithmetic, average concentrations of nonreactive pollutants or pollutants that decay by first-order chemical reactions from multiple point sources (U.S. Environ. Prot. Agency 1973). The emitted plume is assumed to have a Gaussian distribution in the horizontal direction and a uniform distribution in the vertical direction. Modifications of the basic Gaussian steady-state dispersion models are used for area sources and line sources after making suitable approximations (Ohio Environ. Prot. Agency 1975).

In general, such steady-state models are used to predict ambient pollutant levels at short distances from the source (within 100 km) when steady-state conditions exist; that is, a well-mixed layer exists and the height of the mixing layer is constant and well defined (Mukammal 1976). Care and judgment must be exercised in applying these models to situations of calm wind where there is a local flow pattern and in areas influenced by local disturbances.

The methodology to select forest regions with common environmental characteristics and significantly different potential for air pollution was implemented by an overlay technique for comparative analysis. The steps in the overlay technique are briefly outlined here and by Bringi (1978) where the application of the general methodology to the State of Ohio is discussed.

General Analysis and Overlay Sequencing for Ohio

The overlay technique is the first step in site selection of forested areas for comparable studies of air pollution. This analysis was done by selecting and interpreting 11 overlays in the sequence which follows.

Ohio was chosen for the overlay methodology since data on environmental factors and pollutant potential were available. In Ohio, this methodology can be used at various geographical scales to identify forested areas where the impact of air pollution is most likely to be seen. Since each scale of study lies within the state, the interrelationships among environmental factors appropriate to the entire state were examined.

A landform map (1:500,000) of Ohio, Division of Geological Survey, Ohio Department of Natural Resources (ODNR), was used as a base reference. The map was a framework to which each factor shown on the overlays could be referenced.

An initial sequence of three overlays defined regions of (1) common forest types, (2) physiography, and (3) soil regions. The first overlay identified the forested land areas and their major forest types. The second overlay indicated that a heavily forested area occurred in the unglaciated plateau region and consisted mainly of oak-hickory forests. The third overlay showed that the oak-hikory forest type was in the sandstone and shale soil region.

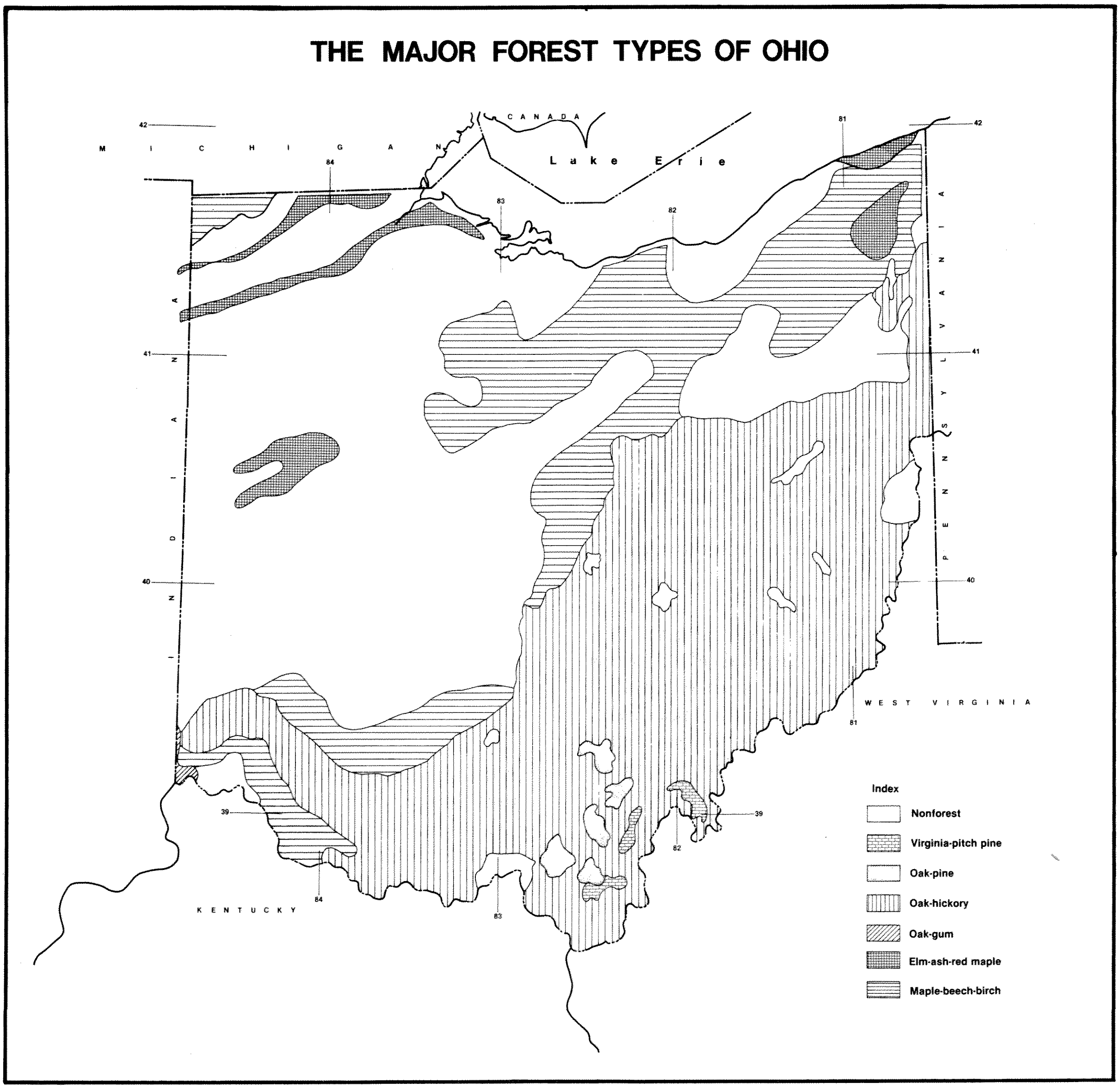
Available data on environmental factors and pollutant potential for the state were collected from atlases and reports. A total of 11 Mylar[1] overlays were made. Black Zip-a-tone symbols depicted various aspects of the different factors. A brief description of the collection and modification of data, and overlay construction for some of the relevant environmental factors and pollutant potential follows.

Ohio Forests

To map the major forest types of Ohio, data on forest land use and major forest types were collected. Data sources were a land use map by the Planning Division of the Development Department of Ohio, a map of the major forest types in Ohio (Kingsley and Mayer 1970), and a series of slides produced by computer analysis of digitized LANDSAT computer-compatible tapes. Figure 1 represents the overlay of nonforest land and the six major forest types.

[1] The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture or the Forest Service of any product or service to the exclusion of others that may be suitable.

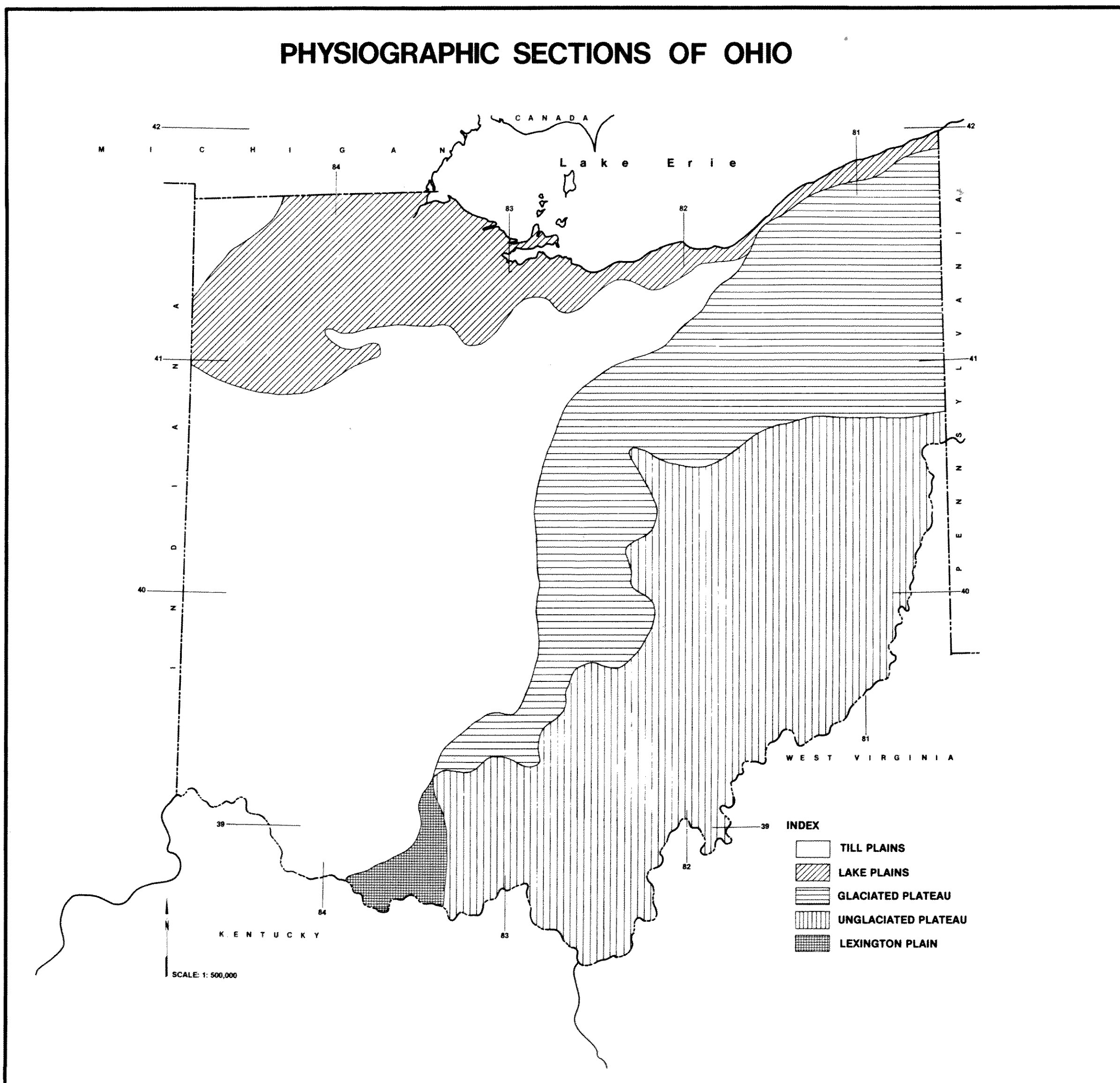
Figure 1



Terrain Factors

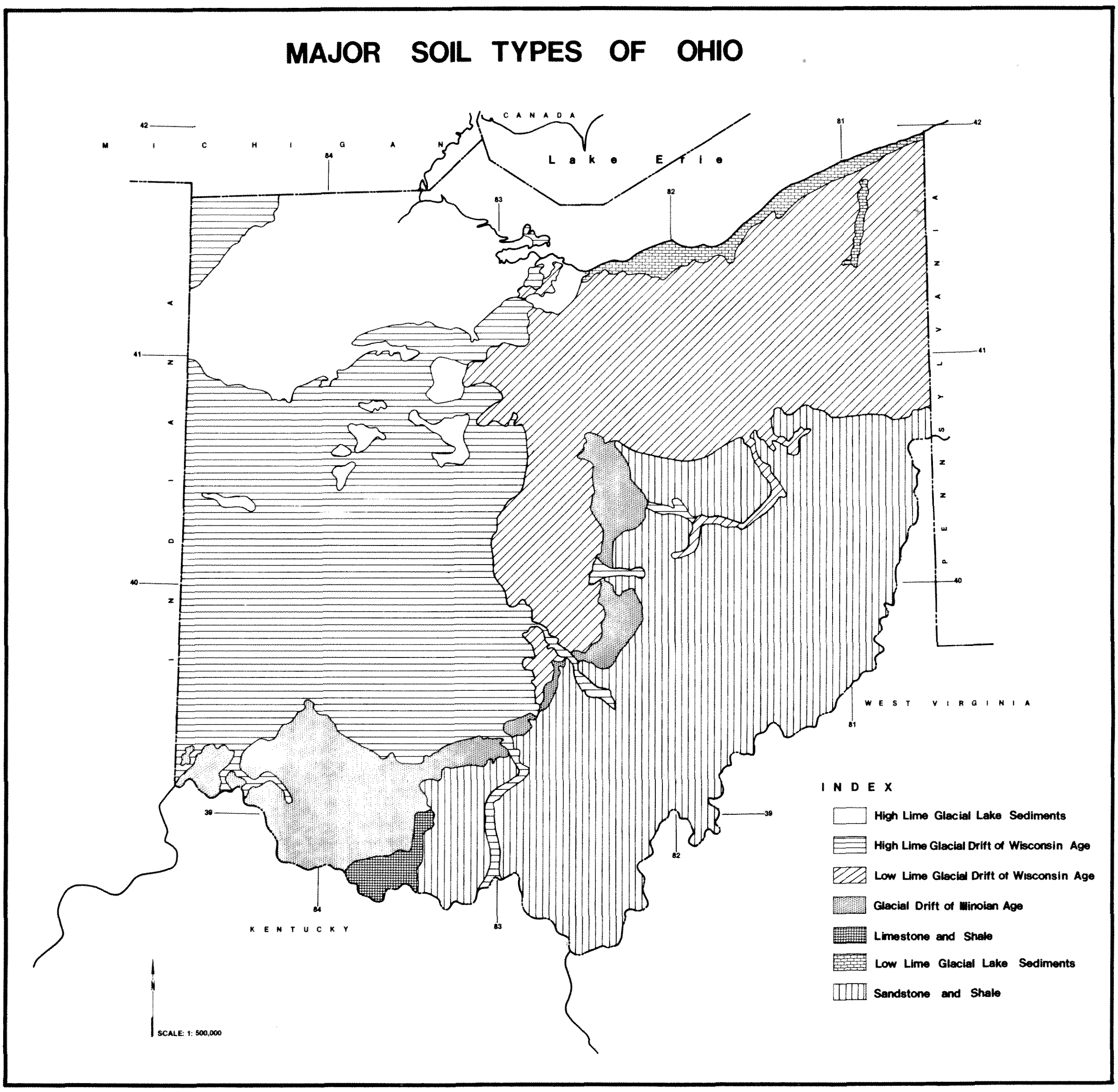
Physiographic sections of Ohio. These data were not modified because the physiographic regions in the data source were adequate. The physiographic map was enlarged photographically and a Mylar overlay prepared (Fig. 2, Ohio Dep. Nat. Resour. 1962).

Figure 2



Soil types of Ohio. Seven major soil regions were identified and used to make the overlay (Fig. 3, Ohio Dep. Nat. Resour. 1962). The major soil regions included: high lime glacial lake sediments, high lime glacial drift of Illinoian Age, limestone and shale, low lime glacial lake sediments, and sandstone and shale.

Figure 3



Climate

Precipitation. Two modifications of annual rainfall data were made — isopleths were changed from centimeter to inches and the overlay was enlarged to the base scale (Fig. 4, Ohio Dep. Nat. Resour. 1962). A similar overlay was prepared for average annual water loss for four water zones at 2-inch intervals ranging from 20 to 28 inches (Fig. 5).

Figure 4

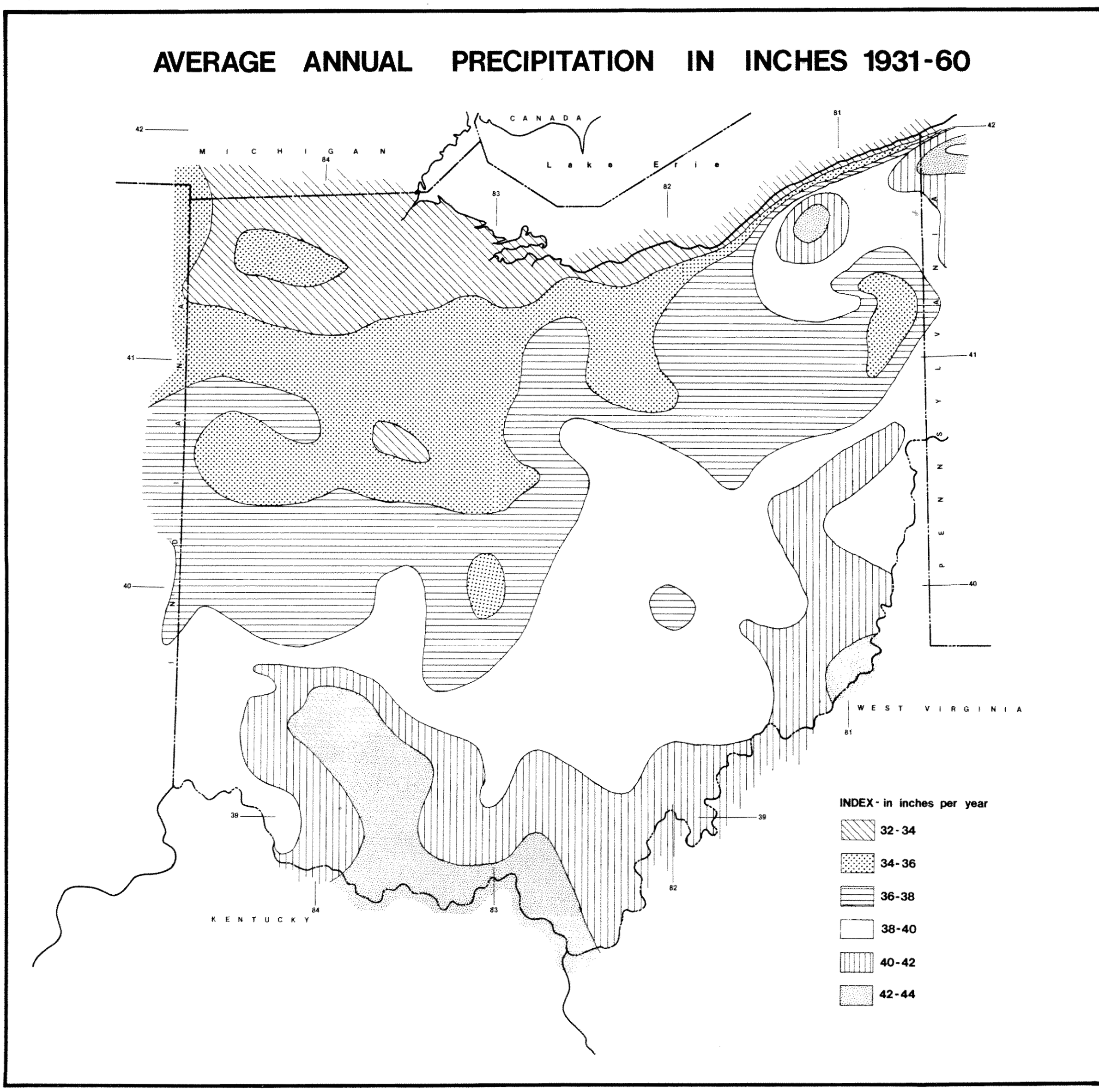
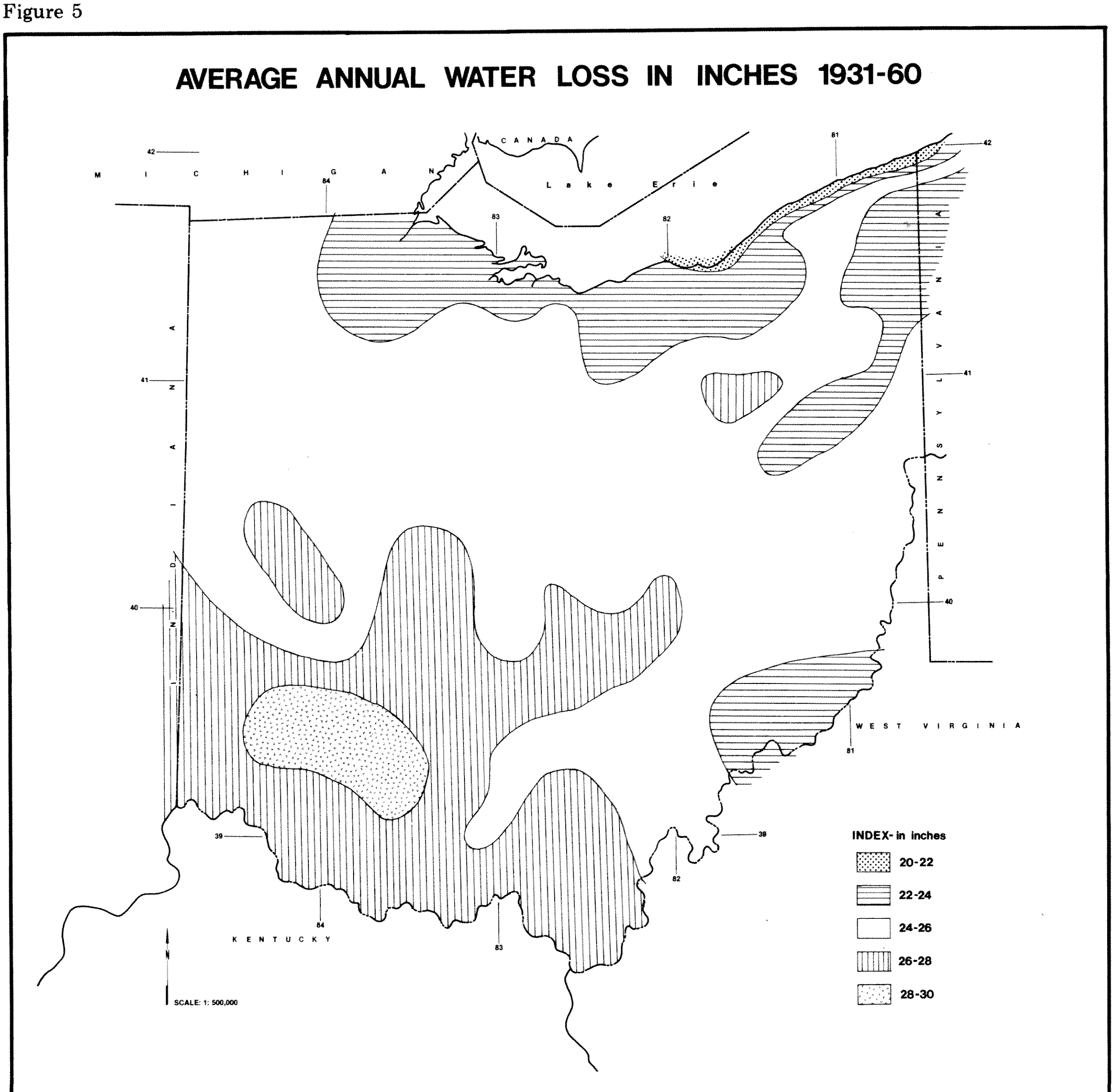
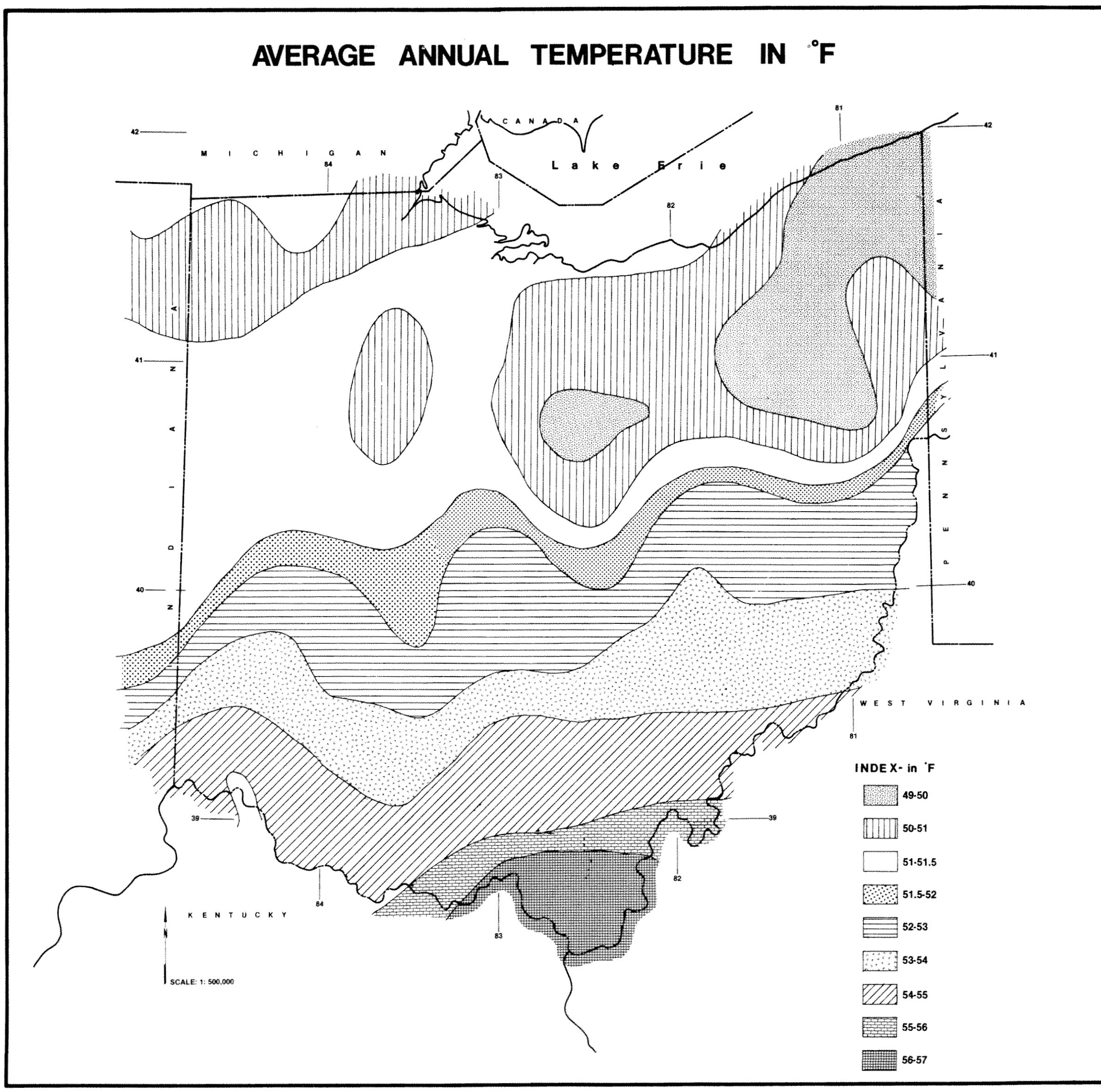


Figure 5


AVERAGE ANNUAL WATER LOSS IN INCHES 1931-60
CANADA
Lake Erie
MICHIGAN
INDIANA
PENNSYLVANIA
WEST VIRGINIA
KENTUCKY
42
41
40
39
84
83
82
81
SCALE: 1: 500,000
INDEX- in inches
20-22
22-24
24-26
26-28
28-30

Temperature. The data source was a general map of Ohio that showed the average annual temperature in degrees (F) for the years 1931-60 (Fig. 6, Ohio Dep. Nat. Resour. 1962). The temperature ranges from 49° F to 57° F were modified to 1-degree intervals, except for the 51° F to 52° F range, which was split into two zones because of its large areal extent.

Figure 6

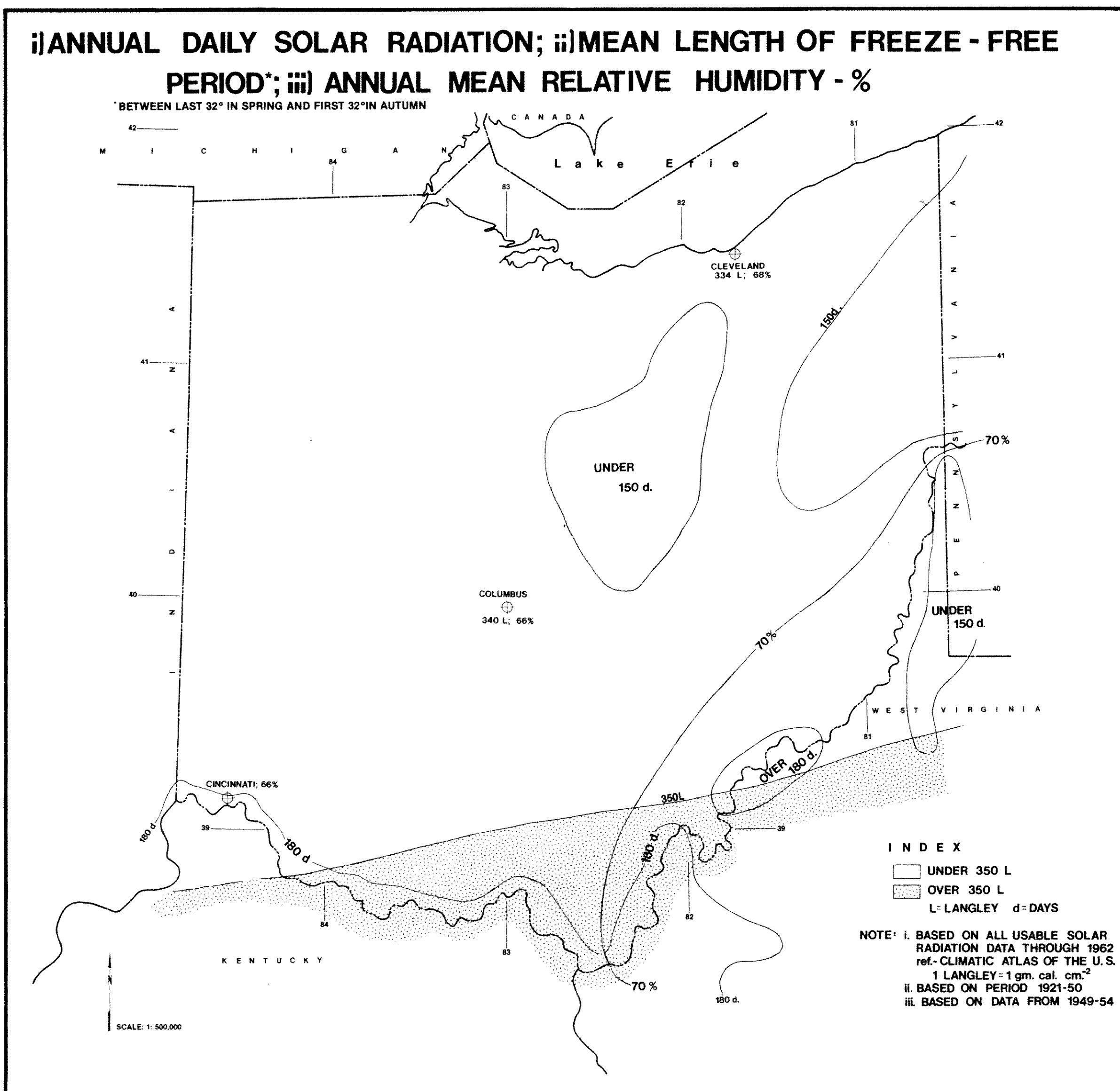


Relative humidity (RH), solar radiation, and freeze-free period (FFP). These factors, based on the period 1921-50, were placed on a single overlay (U.S. Dep. Commer. 1968). The only generalized RH curve in Ohio is the 70 percent line through the southeastern section. Solar radiation divides the state into two broad regions—the southern tip of Ohio receives more than 350 langleys (calories/cm^2/min) and the rest of the state receives less than 350 langleys.[2] The central section of the state has a mean FFP of less than 150 days. Only in the south and southeastern areas does the FFP exceed 180 days (Fig. 7).

Other related climatic factors such as evapotranspiration, days of snow cover, and severe weather phenomena were not represented on the overlays, but could be included if desired.

[2] 1 langley = 4.184 x 10^4 joules per square meter.

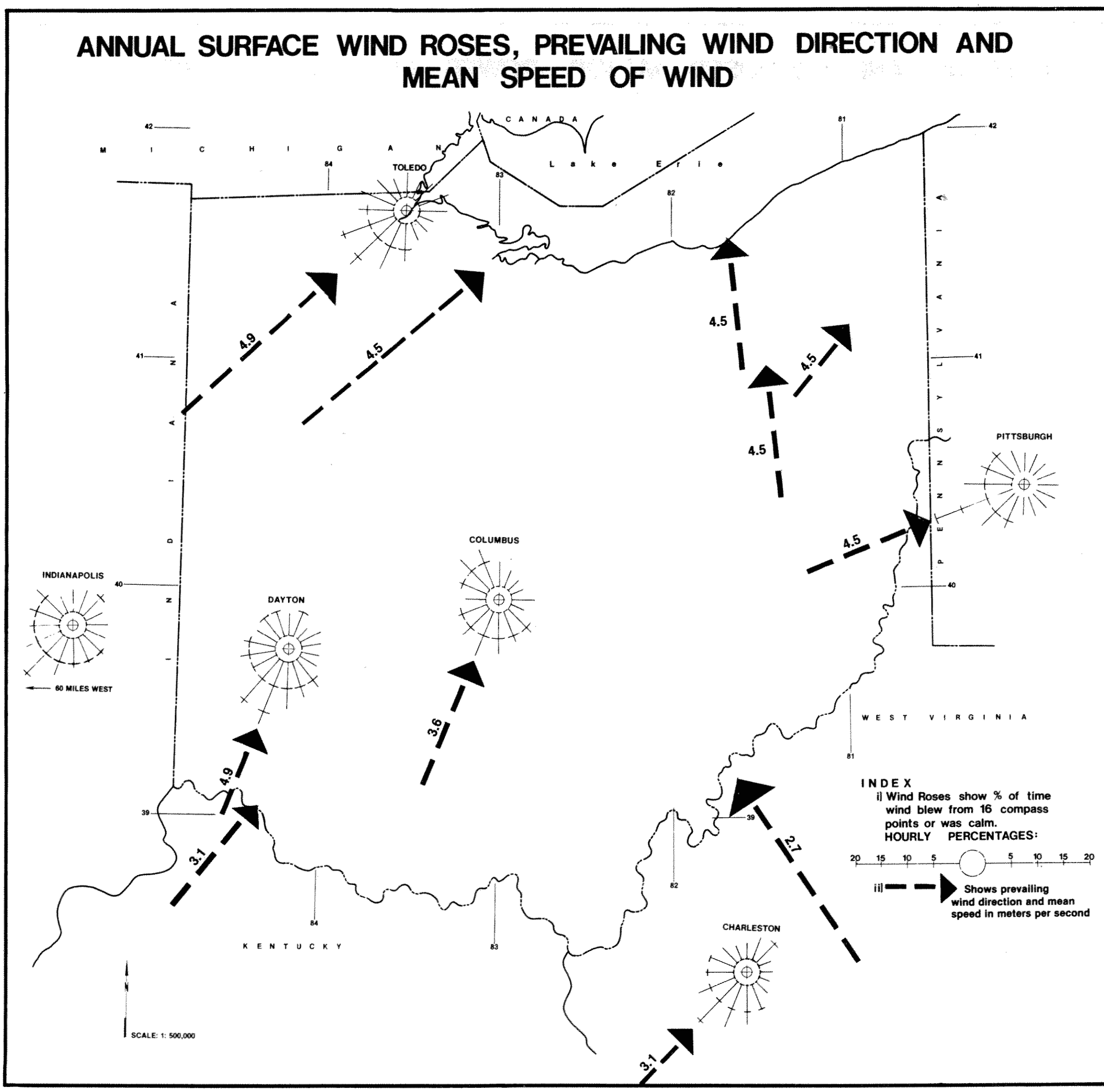
Figure 7



Meteorology

Three meteorological factors were considered: annual surface wind roses, prevailing wind direction, and mean wind speed. The mean wind speed is given in meters per second. The final environmental factor overlay (Fig. 8) depicts relevant wind data (U.S. Dep. Commer. 1968).

Figure 8

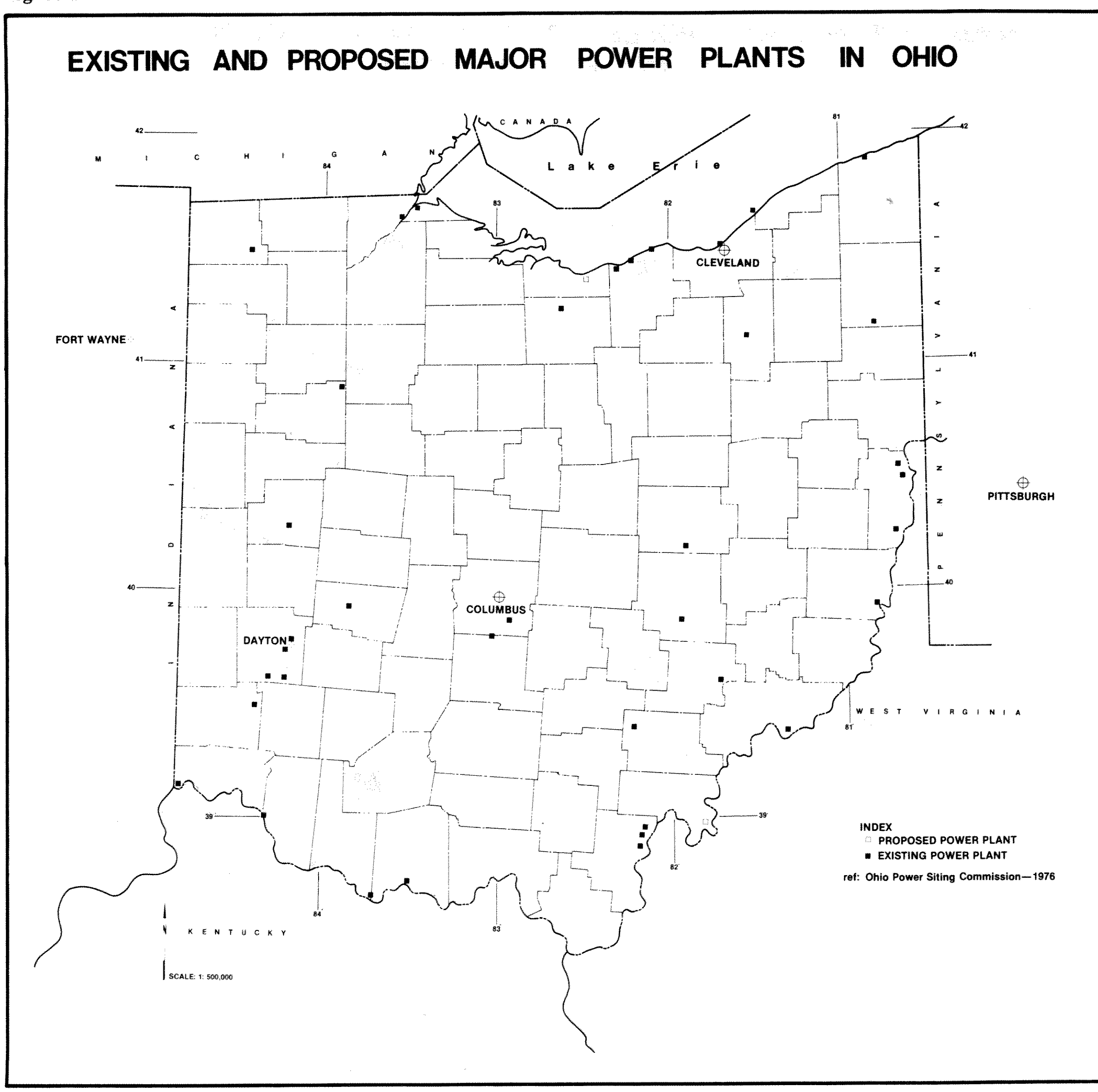


Air Pollution Potential

Consideration of air pollutants in Ohio was restricted to SO_2 and O_3. A graphic description of the air pollution potential was required for this overlay technique.

Major point sources of SO_2. Fossil fuel consumers are major sources of SO_2 emission. Thirty-eight major existing power plants and two proposed power plants were designated on an overlay (Fig. 9). Typical SO_2 emission rates for such power plants ranged from 17,000 to 430,000 tons per year. Other point sources were not included, since power plants contribute approximately 65 percent of all SO_2 emissions (U.S. Environ. Prot. Agency 1976). The remaining major anthropogenic sources are correlated with industrial centers and, therefore, could be included as necessary.

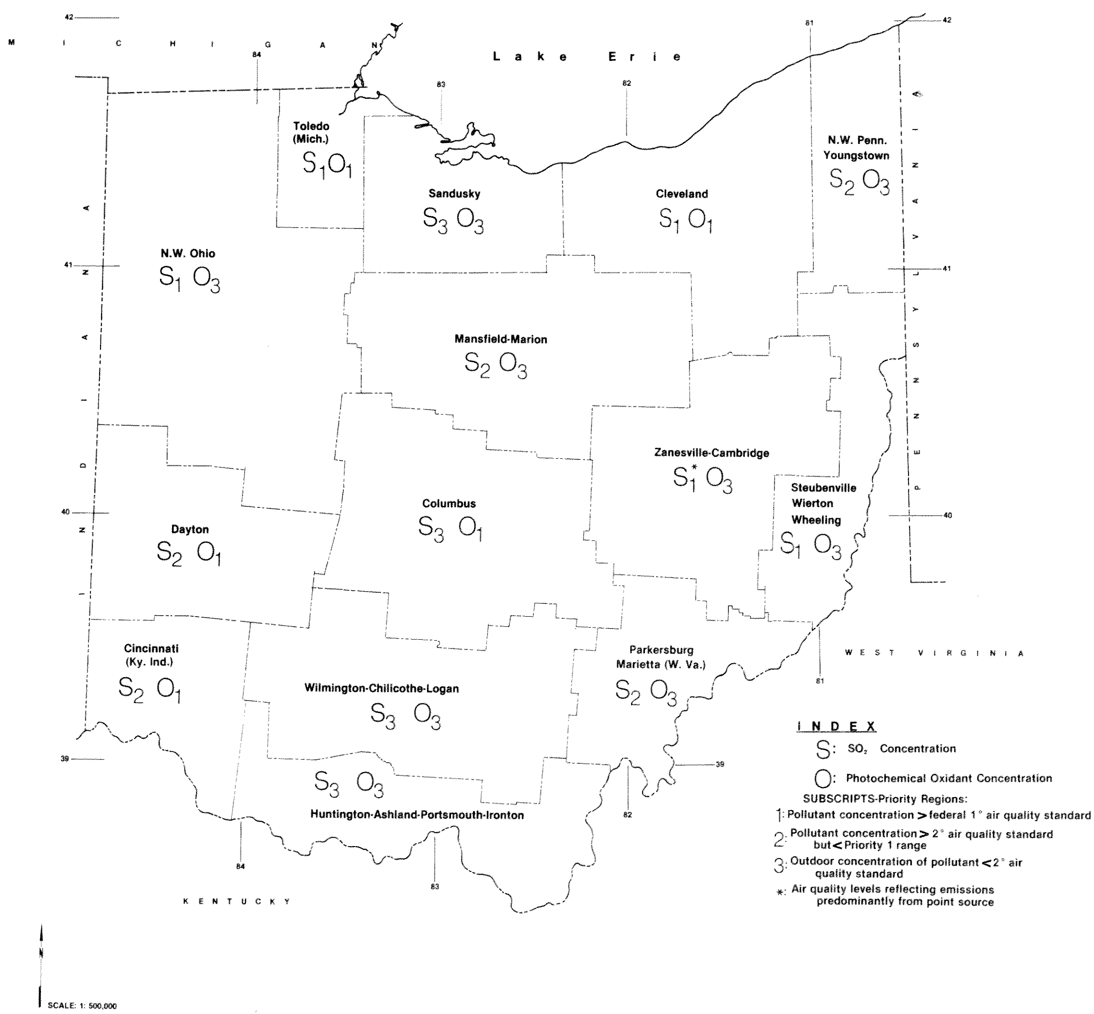
Figure 9



Federal priority classifications. Ohio has 14 Air Quality Control Regions (AQCR) set up by the U.S. Environmental Protection Agency (EPA). They were classified into priority regions 1, 2, and 3 depending on the concentrations of SO_2 and oxidants in each AQCR (Ohio Environ. Prot. Agency 1975). The priority classifications for each AQCR for both SO_2 and oxidants were then transferred onto an overlay (Fig. 10).

Figure 10

FEDERAL PRIORITY CLASSIFICATION OF POLLUTANTS BY AIR QUALITY CONTROL REGIONS

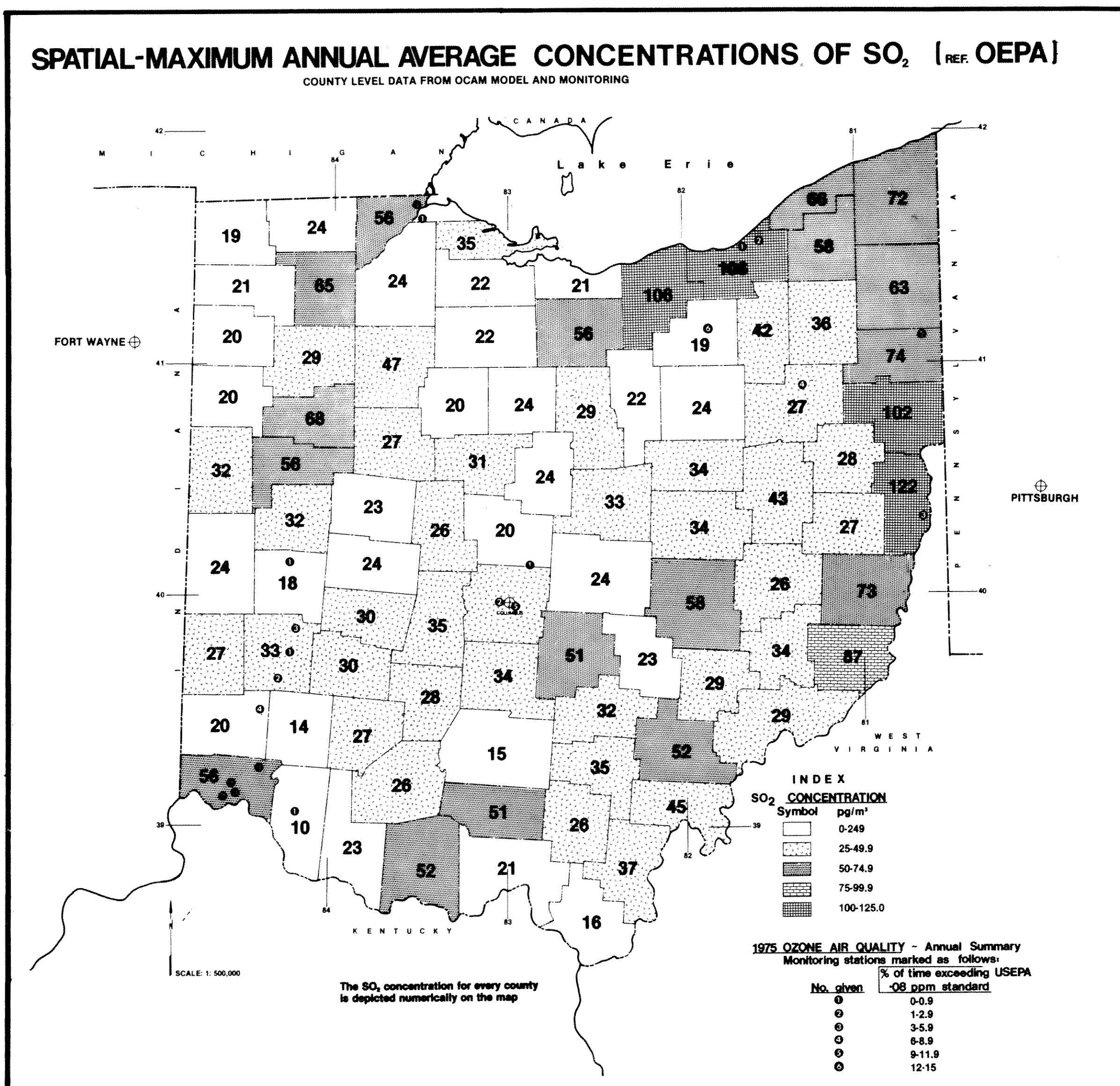


Ozone and SO_2 air quality. In making this overlay, SO_2 concentrations were shown numerically for each county, and the counties were also categorized into five groups by the range of SO_2 concentration experienced. To depict O_3 levels, the percentage of time that each monitoring station exceeded the national and state standard for ambient air quality was tallied. Ozone levels are indicated on the map by numbers ① to ⑥ indicating the range, in percent, from 0-0.9, 1-2.9, 3-5.9, 6-8.9, 9-11.9, or 12-15, respectively (Fig. 11, Ohio Environ. Prot. Agency 1975).

Jefferson and Coshocton Counties. The overlay technique was applied to the Ohio Hill Country (Kingsley and Mayer 1970). The counties of Jefferson and Coshocton exhibited areas of common environmental characteristics but different potential for air pollution.

Jefferson had annual SO_2 levels of 122 $\mu g/m^3$ and Coshocton had levels of 34 $\mu g/m^3$. After the SO_2 pollution potentials in these two counties were established, the remaining overlays were arranged and showed that three areas in both counties had similar environmental characteristics.

Figure 11



To identify suitable forest sites for comparable air pollution studies between the two counties, the locations of major point sources of SO_2 were considered so that sites could be selected both near and far from such sources. An overlay of existing and proposed power plants was used to locate the power plants in the two counties. Jefferson had four major power plants and Coshocton one.

Another relavant factor considered for forest-size selection was existing EPA air monitoring stations. Ohio had 12 air monitoring stations in Jefferson County—nine stations measured SO_2 and one measured O_3. Coshocton County had three EPA monitoring stations—two stations measured SO_2 (Ohio Environ. Prot. Agency 1975). The locations of these monitoring stations were used as guidelines in selecting forest sites.

Topographic maps of Jefferson County and Coshocton County (1:24,000) showing elevations and woodland areas along with updated Landsat land use data depicting forest areas were then used to complement the data. Another important consideration in site selection was the existing forest survey plots established by the USDA Forest Service in its continuing program of forest resource inventories in the state (Kingsley and Mayer 1970). By incorporating forest survey plots into the selection of potential forest sites, previous data on forest growth and management practices could be used in comparable air pollution studies that might be conducted.

In a final selection of test plots, further details on common characteristics of forest ecosystem type, species distribution, age class, and vigor would refine tree response data for air pollution studies on forest sites. Monitoring of O_3 and SO_2 along with measurements of meteorological factors, wind speed, and direction would also help. Detailed examination of soil properties, terrain, slope, microclimate, and influence of severe weather phenomena at each site would be important, too.

Data obtained from the application of the overlay technique to a county can also be used as guidelines to extend the methodology of forest-site selection for air pollution studies to a local geographical scale within a county.

Selection of local forest sites. The area near the major power plant in Conesville, Coshocton County, was chosen for potential sites where comparable effects of a point source on forests could be studied. The overlay technique showed that Coshocton County chiefly contained the oak-hickory forest type growing in four major soil regions. Sandstone and shale was the most prevalent soil region.

To establish field plots near the Conesville power plant, the following additional data were used:

1. Contact prints, 9 by 9 inches, of black and white U.S. Geological Survey aerial photographs of the general area of the power plant obtained from the Aerial Engineering Division of the Ohio Department of Transportation.
2. A soil map of Coshocton County depicting major soil areas obtained from the Division of Lands and Soil, ODNR.
3. U.S. Geological Survey (USGS) topographic quadrangle maps of the Conesville area depicting woodland area, elevations, and topography.
4. Computer-generated land use quadrangle sheets (from processed Landsat data) corresponding to the USGS quadrangles obtained from the Remote Sensing Group of Resource Analysis Division, ODNR. In such computer-generated land use quadrangle sheets, every symbol represents a cell of dimensions 200 x 250 feet (1 pixel). Each pixel is assigned a specific land use classification such as forest, urban area, water, agricultural land, rangeland, or barren land.

Both the USGS topographic maps and the computer-generated land use quadrangle sheets were divided into grids of 1 km squares, and each square on the grid was numbered by row (R) and column (C) (for example, 7.10 refers to R = 7, C = 10). Forest land use trends were checked with each square of the grid by overlaying the computer quadrangle sheet reproduced on acetate on the topographic map.

This overlay method helped to verify and update forest land use distribution, in which suitable forested areas were also discerned from the aerial photographs. The data from the above sources were then combined with the soil data to identify several potential forest sites located around the power plant. These sites were located on the USGS topographic maps, and their elevation and topography noted. Two distinctions were made in the elevations of the selected forest sites—lower (less than 700 ft.) and higher (700-1,500 ft.).

Location and general characteristics were recorded in a field inspection of six of these sites. All the sites seemed suitable as possible test plots. In addition to the potential sites selected around the power plant, forest survey plots and forest sites already identified in Coshocton County could also be included in the consideration of site selection for comparable air pollution studies on forests.

Applications

The general methodology is a practical technique to use existing data to identify suitable forest sites for comparable assessment studies of air pollution effects. It is applicable to many geographical scales, and therefore, should be useful in assessing both regional and local potential for air pollution impacts on forests. The methodology also applies to different time periods for assessment studies. By selecting other data bases derived from shorter time periods, the methodology can be extended to include identification of forest sites for assessing the effects of climatic variations, season influences, severe weather phenomena, short-term high level pollutant exposures, multiple pollution episodes on forest growth processes, and sensitivity to air pollution.

By developing and incorporating other suitable data bases, the methodology may also be applied to: the study of the effects of pollutants in air, water, and soil on the functioning of ecosystems; the study of forest ecosystems as sinks for pollutants; the study of air pollution effects on agricultural crops; environmental analysis; land use planning; the selection of study regions for remote sensing investigations; and the study of epidemiological effects and human population exposure to air pollutants.

It is apparent that many important problems should benefit from this type of comparative analyses. Furthermore, with recent advances in computer technology—particularly in the area of high-speed, high-volume data storage and retrieval—the data bases could be readlly accessed, processed, and displayed for many purposes beyond the scope of this work.

Conclusions

In this study, the primary objective was to select forested regions most suitable for assessments of the impact of air pollution on forests. This methodology identifies forests in regions of similar environmental parameters but with significantly different air pollution concentrations. Subsequent qualitative and quantitative field measurements should give a realistic basis for differential comparisons of foliar, growth, and productivity responses associated with air pollution effects. Correlations can then be made between the relative degrees of biological impacts and air pollution concentrations.

There are limitations in the data base of environmental factors and potential for air pollution which limit the degree of resolution that is possible in the site-selection process. Better data are needed for some of the environmental factors such as relative humidity, solar radiation, freeze-free period, and meteorology. These additional data would balance the environmental influences on forests and reduce the number of potential study sites in any given area. More statewide data are needed to improve and update the pollutant-potential maps of SO_2 and O_3 air quality. Current studies by Federal, State, and private institutions using more refined modeling techniques (U.S. Environ. Prot. Agency 1976) to estimate 24-hour maximum concentrations of SO_2 at selected receptor points around point sources may prove valuable.

Potential evapotranspiration, snowfall, severe weather phenomena, and pollutants such as particulates, nitrogen oxides, fluorides, and acid precipitation were not included in the data base. As information on these factors becomes available, they should be added to the map.

The overlay technique is manual and is limited to the consideration of a manageable and general data base. For better resolution, greater flexibility, and rapid modification of data computer graphics technology could be implemented for the manual procedures.

Literature Cited

Bringi, Krishnamurthy Sreedevi.
1978. **Methodology of forest-site selection for air pollution studies.** Atmos. Sci. Program, Ohio State Univ. Rep. AS-S-10Z (EES-511X-2). 97 p.

Dochinger, L.S., and K.F. Jensen.
1975. **Air Pollution.** *In* Forest nursery diseases in the United States. G.W. Peterson, and R.S. Smith, Jr., eds. U.S. Dep. Agric., Agric. Handb. 470. p. 107-113.

Kingsley, N.P., and C.E. Mayer.
1970. **The timber resources of Ohio.** Northeast. For. Exp. Stn. Resour. Bull. NE-19, 137 p.

Mukammal, E.I.
1976. **Review of present knowledge of plant injury by air pollution.** World Meteorol. Organ., Tech. Note 147, 27 p.

Ohio Department of Natural Resources.
1962. **Ohio hydrological atlas.** Ohio Dep. Nat. Resour., Ohio Plan Invent., Div. Water Rep. 13. p. 1-4.

Ohio Environmental Protection Agency.
1975. **Air quality monitoring sites and instrumentation of Ohio.** Ohio Environ. Prot. Agency, Air Qual. Group 192 p.

Smith, W.H.
1974. **Air pollution—effects on the structure and function of the temperate forest ecosystem.** Environ. Pollut. 6:111-129.

U.S. Department of Commerce.
1968. **Climatic atlas of the United States.** U.S. Dep. Commer., Environ. Sci. Adm., Environ. Data Serv. 80 p.

U.S. Environmental Protection Agency.
1973. **User's guide for the climatological dispersion model.** U.S. Environ. Prot. Agency, EPA-RY-73-024, 131 p.

U.S. Environmental Protection Agency.
1976. **Technical support document—sulfur dioxide control strategy for the State of Ohio.** U.S. Environ. Prot. Agency, EPA-905/2-76-002, 564 p.

☆U.S. GOVERNMENT PRINTING OFFICE: 1981-703-011

Headquarters of the Northeastern Forest Experiment Station are in Broomall, Pa. Field laboratories and research units are maintained at:

- Amherst, Massachusetts, in cooperation with the University of Massachusetts.
- Beltsville, Maryland.
- Berea, Kentucky, in cooperation with Berea College.
- Burlington, Vermont, in cooperation with the University of Vermont.
- Delaware, Ohio.
- Durham, New Hampshire, in cooperation with the University of New Hampshire.
- Hamden, Connecticut, in cooperation with Yale University.
- Kingston, Pennsylvania.
- Morgantown, West Virginia, in cooperation with West Virginia University, Morgantown.
- Orono, Maine, in cooperation with the University of Maine, Orono.
- Parsons, West Virginia.
- Princeton, West Virginia.
- Syracuse, New York, in cooperation with the State University of New York College of Environmental Sciences and Forestry at Syracuse University, Syracuse.
- University Park, Pennsylvania, in cooperation with the Pennsylvania State University.
- Warren, Pennsylvania.