A METHODOLOGY FOR STUDY OF URBAN AIR POLLUTION POTENTIAL

Technical Report

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A B S T R A C T

A methodology for the study of the air pollution potential of an urban area is described through the tabulation of causal relationships and a narrative presentation of the interdependence of parameters affecting the concentration of undesirable material in the air. Topics considered are climatology, physical geography, city climates, cultural characteristics, pollutant sources, ambient air surveys, and data reduction and presentation. Application of the methodology in a study of the city of Austin provides a demonstration of its usefulness in the collection, analysis, and presentation of air pollution data. Many tables, figures, and maps are included to illustrate concisely the methods and results. Airflow around buildings is described in the appendices and seventy references are included for verification and further study.

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I. INTRODUCTION

Well established interrelationships in the study of air pollution parameters are not always easy to apply in practice to county, city, town or other geographical area because of a lack of quantitative information. The objective here is to investigate the interdependent nature of several of the most important parameters, list casual relationships for easy reference, and suggest sources of data which currently exist as a consequence of man's desire to characterize his environment in terms of numbers. The methodology, if it may be so termed, will be summarized and then applied to the city of Austin, Texas, to demonstrate its usefulness and limitations.

In broad terms the topics considered will be these: climatology, physical geography, city climates, cultural characteristics, and pollutant source description. Of necessity, ambient air surveys must be included and it seems useful to suggest methods for reduction and presentation of data.

II. PARAMETERS AND INTERRELATIONSHIPS

Local Climatology

Climate is a composite or generalization of the day-to-day weather giving averages, trends, ranges, and deviations in such elements as temperature, winds, precipitation, humidity and so on. Climatic parameters usually change gradually with horizontal distance traveled, whereas weather may change from rainy to sunny within a distance of a few yards since there is no averaging time involved.

Concentrations of unwanted gases, solids, aerosols, smokes, mists, and fumes in the air are directly affected by the amount of air available for dilution, the mechanisms for mixing within the air, the speed of transport from the source to the receptor, the mechanisms of cleansing available, and the mechanisms for chemical-physical interactions. Source emission levels are also dependent on climate, as for example, the need for space heating (combustion products) in the winter. General meteorological effects on air pollution are given in

Table 1 and specific effects are outlined in Table 2. Types of inversions are described in Table 3.

Meteorological data are collected at stations all over the world. Local climatological data are available for cities in all fifty states; in Texas nineteen cities are represented. Most cities, however, have only one weather station which is usually located at the local airport, and normally, little or no data are available for other parts of the city. Climatological summaries usually characterize meteorological data in terms described in Table 4. Various techniques have been used to manipulate and present numbers in the most meaningful way; some of them will be illustrated later in application to the city of Austin.

The prime source of climatological data in the United States is the U.S. Department of Commerce, Environmental Science Services Administration, Environmental Data Service. The state climatologist, as the central collection agent, is the best source for lists of available data. The U.S. Geological Survey, water resources division, has areal rainfall distributions for some regions of the country. The Department of Commerce also publishes monthly climatological data for hundreds of cities around the world.

Physical Geography

Physical geography plays a role in air pollution studies because the physical features of the land affect the flow of air over it. Transport and dilution of entrained pollutants, therefore, are obviously affected by features of the land. The features to be considered in detail are these:

1. Topography, including mountains, hills, valleys, gorges, plateaus, plains, flats, islands, and basins.
2. Occurrence of water, including lakes, rivers, streams.
3. Surface conditions, including trees, grasses, barren ground.

Effects on Airflows. For ease of application to actual situations, the effects of topographic features are listed in Tables 5 and 6, those of bodies of water in Table 7 and those of surface conditions in Table 8. It is important in predicting the effects on air pollution to have complete accurate physical descriptions of geographical features to prevent distortions of scale. Most of the important parameters can be collected on a map of suitable scale to show the following:

1. Location (with respect to cultural features);
2. Size (length, depth, width, height, ratio of length to width, elevation above sea level);
3. Orientation (a sixteen-point compass rose should be used);
4. Shape (vertical sections may be required);
5. Surface texture (height of trees, grass, rocks, height and length of water waves);
6. Color, reflectivity (use standard colors, percent reflectivity); and
7. Percent slope (useful for degree of effect to be expected),

Pollutants and Airflow. The effects tables facilitate the formulation of useful causal relationships among pollutant sources, concentrations, and air flows such as the following for mountains, hills, valleys, and gorges:

Uplifting. Unexpected appearance of pollutants at ground level from tall stacks located upwind at lower elevations.

Diversion. Unexpected appearance of pollutants at shielded downwind locations not predicted from prevailing flow.

Venturi effect. Reconcentration of dispersed pollutants resulting from funneling of air masses. Poor mixing but high rate of transport.

Air Drainage. Transport of pollutants downward instead of upward. High concentrations from stagnation in cold air pools of various depths.

Downwash and backwash. Appearance of pollutants at ground level behind a downwind barrier formation. Appearance at ground level upwind from a source located in the backwash region.

Vertical air flow. Desirable improved dilution, unexpected direction of transport.

Eddy cells (vortices). Entrapment of pollutants in closed circulation cells from sources inside these cells or nearby.

Channeling. Transport to locations other than those predicted from "prevailing" wind directions.

High concentrations at great distances (relatively) because of poor mixing. Higher long term concentrations because directional deviation of wind less than a possible 360°.

Upslope and downslope flow. Entrainment and transport to unlikely locations up or downslope by convection flow.

Up and down-valley flow. Transport back and forth independently of prevailing winds. Possible valley entrapment and slosh effect. High concentrations because of channeling, poor dispersion.

Shielding. Area prevailing wind direction and speed not meaningful causing poor transport and poor mixing with outside air.

Effects of plateaus, plains, islands, and basins are merely variations from the vasic relationships outlined above. The same can be said for effects of surface conditions of the land.

Table 9 lists some important effects that vegetation has on air pollution and Table 10 gives effects of meteorological conditions on pollen. Common aeroallergens are given in Table 11.

Sources of Data. Information and data about features of the land in an urban area may be collected in these forms:

1. U.S. Geological Survey Topographic maps (quadrangle maps: 7 1/2-min, 1:24,000, 10 ft. contour interval; 15-min, 1:62,500, 10 ft. contour interval)
2. U.S. Geological Survey shaded relief maps
3. Aerial photographs: black-and-white panchromatic, color, color infra-red, black-and-white infra-red
4. Radar maps
5. Photogrammetric maps (stereo pairs for direct viewing)
6. City planning and highway department maps
7. Soil conservation and geologic maps of soil
8. Oblique photographs of the city
9. On-the-ground survey data

It is advisable to adjust the scale of all maps to be the same to facilitate study of interrelationships. Preparation of a set of photo-interpretative keys is useful in working with aerial photographs (Lueder 1959). Keys to principal surface features are available for infra-red photographs, both color and black-and-white (Lueder, 1959). Use of transparent map overlays facilitates experimentation with flow for different conditions.

City Climates

Munn (1966) has summarized the mechanisms which contribute to the concept of a city climate as follows:

1. Natural radiation balance is disturbed by changes in the properties of the underlying surfaces (brick, concrete, asphalt instead of vegetation).
2. Areas of buildings and canyon-like streets between them change the natural flow and turbulence of the air.
3. Water vapor balance is upset by the change from moist to dry surfaces.
4. A city emits heat and pollutants to the atmosphere.

A summary of changes produced by urban development is given in Table 12.

Heat Islands. The disturbance of the natural radiation balance along with the generation by man of heat gives rise to the formation of heat islands within a city.

Temperatures in these islands may measure up to several degrees above the adjacent suburban areas. In addition larger scale effects can result when convective circulation couples with the tendency toward increased turbulence over the city to form a cell of closed circulation above the city. Flow of air toward the inner heat island has been observed (Pooler, 1963) as has been the so-called dust dome from the closed circulation (Munn, 1966; Lowry, 1967). Table 13 gives the reflectivity of various surfaces and Table 14 gives some temperature differences of different types of surfaces in mid-morning under the sun.

Airflow. Airflow within a city is very complex because of the different heights, shapes, orientations, and densities (areal) of the buildings. One way to make comparisons is in terms of the mean wind velocities for various types of surfaces. In Table 15 are shown the relationships between undisturbed (gradient) velocity and velocity at any height for surfaces varying from open country to centers of large cities. At street level it is difficult to arrive at any generalized formulation, however. Appendix A gives a summary of principles of flow around geometric shapes; the important factors influencing the flow are these (Maccabee, 1968):

1. The height and cross-sectional shape of the building.
2. The ratio of height to a cross-section dimension, or aspect ratio.
3. Orientation with respect to the air flow.
4. Proximity to other structures or topographical features.
5. Secondary variations in body shape due to windows, cornices, parapets, penthouses, and so on.
6. The mean wind velocity profile and turbulence characteristics of the wind.
7. Wind velocity in terms of the Reynolds Number.
8. Vortex shedding frequency in terms of the Strouhal Number.

Investigators in structural design, airfoil design, windbreak and shelter belt design, and in gas diffusion around buildings have provided a wealth of information in this area (Caborn, 1965; Evans, 1957; Halitsky, 1962, 1963; Olgyay, 1963; Woodruff, et al., 1955). A review of this literature permits formulation of some useful causal relationships.

1. Greater gustiness and presence of eddy cells of all sizes provides good mixing when the wind is blowing.
2. Vertical flow up and down is very pronounced at windward and downwind faces of a building.
3. Channeling drastically changes the direction for transport of pollutants from that predicted on the basis of roof-top wind direction.
4. Channeling and venturi effects can decrease gustiness and collapse eddy cells to lower the overall mixing potential.
5. Channeling and venturi effects can sweep out pollutants quickly.
6. Downwash can bring pollutants from building tops to ground level in high concentrations in large closed cells.
7. Uplifting can occur over closely spaced buildings whose roof tops step upward in the downwind direction.
8. With light winds stagnation of air between buildings causes an increase in pollutant concentrations.

9. Direction of local flow can change drastically with a small change in the direction of incident flow and can change concentrations by orders of magnitude.

10. Changes in the location of an emitter by a few feet can change concentrations by orders of magnitude.

City Plume. Just as a point source is characterized by its plume, so can the areal source of a city cause a plume of pollutant material to move downwind from the city. Thus meteorological factors which may be favorable for lowering concentrations in the city may produce undesirable levels of pollution in the suburban and rural areas downwind. Any complete study should include the effects of the city plume.

Collection of Data to Characterize City Climate. The change in types of radiation surfaces can be mapped using aerial photographs and photo-interpretative keys mentioned earlier. Percent roofs, pavement, trees, grass, water, and the like can be determined using a grid system to organize the data.

Heat islands can be mapped by setting up recording thermometers over the city, perhaps supplemented by traverses across the city with mobile temperature sensors (Wood, 1971). Remote sensing techniques using thermal photography (not infra-red film directly) can also be used (Colwell, 1968).

A qualitative view of the dust dome for a city is obtainable by oblique aerial photography or by direct observation from high altitude. Convection airflow inward at ground level can be mapped using a network of anemometers and wind vanes (Davidson, 1967).

Basic geometry of any part of a city for air flow studies can be had through photogrammetric techniques. Stereo pairs can be viewed directly for qualitative information or a topographic map of the city blocks can be made to include not only ground contours but roof-top contours. Accuracies to within two feet can be plotted with proper photography (Barclay, 1971).

Without photogrammetry, building heights can be estimated and plotted on aerial photomaps to obtain the same information. Heights and dimensions are available from municipal inspection departments. On-the-ground surveys would expose such air channeling features as building pedestrian tunnels, transportation tunnels, elevated roadways, and overhangs. These features appearing only from the horizontal vantage point must not be overlooked.

By assuming different directions of wind across the maps, gross aspects of air flow in the city streets can be predicted and plotted as flow lines. For a given building or perhaps block of buildings, predictions can be refined only by ground or roof-top observations using smoke tracers plus wind vanes and anemometers. Wind tunnel tests with models may be required in some instances (Woodruff, et al., 1955). The city plume can be mapped using conventional air sampling techniques timed to coincide with the desired wind direction.

Cultural Characteristics

Cultural characteristics can include the following in an air pollution study:

1. Breakdown of principal occupations of the inhabitants of the city.
2. Population density.

3. Land use, planning, zoning, restrictions, ordinances.
4. Human activity cycles.
5. Transportation habits, existing and planned regulations.
6. Trends.

Principal Occupations. What the people of a city do for a living is a direct indication of (1) types of air pollution sources and amounts, and (2) attitude of the population toward air pollution. Table 16 is a check list of occupational categories normally encountered. More is said about sources in a later section. Attitudes of the municipal voting population to air pollution abatement depend a great deal on their sources of livelihood. Factory workers would be most tolerant, and supporting industry and services workers also would be, while those in government and education can afford to be less tolerant.

Population Density. Pollution of the air is a problem because the population of a city is affected by it in some manner. Pollutant concentrations should, as a consequence, be related to population density in any determination of the resources to be used for monitoring and abatement. Most large cities are divided into census tracts in which the population and area are known and densities in persons per acre can be shown on a map. Superposition of source locations and ambient quality data provide the most useful criteria for action.

Land Use Planning, Zoning, Restrictions. Linked to population density are land use planning and zoning ordinances which should be effective in controlling the location of polluting industries and in restricting the population densities by law. Maps of the master plan and land use restrictions show locations of industrial and residential areas. Trends in direction of growth can usually be determined and related to wind patterns, topography, and land features in general. It is important to determine how well master plans and zoning laws are adhered to in establishing trends since evidence indicates that much planning and zoning is done after financial commitments have already been made by industry or land developers.

Human Activity Cycles. Activity cycles that are significant in affecting pollution levels include the annual cycle the weekly cycle, and the daily cycle of people. Trends which are superimposed on shorter cycles are also important.

The dominant factor in the annual cycle reflects the average temperature which changes the heating and air conditioning requirements. Winter heating obviously increases the pollutant load from space heating. As heating requirements decrease and cause a decrease in pollutant emissions, air conditioning, in some locations, creates a heavy demand for electrical power generation with its own set of emissions.

The five-day work week cycle often means industrial emissions drop on Saturday and Sunday as do emissions from automobiles. Where fireplaces are used for pleasure, the weekend brings increased emissions from this source. Certainly population densities change dramatically when comparisons are made between, for example 9 a.m. Friday morning and 9 a.m. Saturday morning over a metropolitan area.

The daily cycle sees an overnight change in population density, heating and air conditioning required, transportation utilized, and many other parameters. Both the annual and daily cycles coincide with climatological factors to produce higher emissions at times when the atmosphere is least able to dilute them. Thus the fall season stagnating anticyclone coincides with increased emissions from space heating, and the early morning inversion coincides with increased emissions from process start-ups and automobiles.

Transportation Habits. Since the internal combustion engine can be a major source of air pollutants, the automobile traffic of a city should be characterized in terms of the following:

1. Map of freeways, expressways, arteries, streets, roads both present and planned.
2. Vehicle density map of total cars per unit time for all streets both present and planned.
3. Vehicles miles in specified grid blocks.
4. Average speed and number of stops per mile.
5. Motor vehicle registration figures.

Aircraft traffic should be described in the following terms for both departures and arrivals:

1. Type of aircraft engine, number of engines, time of day.
2. Map of principal flight tracks over the city.
3. Flights per day, week, and year.

Trends. Some important trends which should be noted for the city are these:

1. Rate of population growth.
2. Changes in population density.
3. Direction of geographical expansion.
4. Location of new residential and industrial zones.
5. Aircraft traffic congestion and plans for regional airports.
6. Expansion of a given industry, such as transistor manufacture or metal smelting.
7. Exhaustion of or discovery of natural resources nearby.

Each city will have its own unique trends driven by climate, topography, resources, etc.

Sources of Data. Cultural data discussed here can be obtained from the following sources:

U.S. Census Bureau statistics

State employment agencies

Municipal chambers of commerce

Municipal planning departments

Municipal and state transportation departments

State motor vehicle registration records

Airport administrations

Almanacs, yearbooks.

Pollutant Source Description

A complete source description includes the following:

1. Location of emitter on a map having a suitable grid system.
2. Nature of emitter such as stack, chimney, door, window, skylight, ventilator, and so on with height, length, width, diameter, shape.
3. Velocity and temperature of gas stream at the exit.
4. Time variation of emissions whether diurnal or seasonal, shutdown schedules, start-up times, holiday schedules.

5. Types of emission such as particulate or gaseous and specifically whether gases, solids, aerosols, smokes, mists, fumes, and so on.
6. Quantity of emissions such as weight per unit time at emitter, process input weights such as fuel and raw materials, or product output.
7. Abatement equipment employed.

The location information should be easily relatable to population density, land use patterns, open spaces, and greenbelts, and topographic and land surface features to facilitate determination of transport, dilution, and of areas affected. Methods for making emission source inventories are given in several Environmental Protection Agency publications (Guide for . . ., AP-76, 1971).

Types of sources have been categorized in many ways. One listing is given in Table 17. Sources of data for use in estimating emissions are listed in Table 18. Emission factors to be applied to various pollutant generating processes are given by Duprey in a 1968 version of "Compilation of Air Pollutant Emission Factors"; a preliminary revised edition is now available (McGraw and Duprey, 1971).

Ambient Air Survey

Ambient air purity for a city should be expressed in terms which are currently being used by federal, state, and municipal watchdog organizations. The current standards promulgated by the Environmental Protection Agency are given in Table 19 to illustrate both the units used and the defined acceptable levels.

For both particulate matter and gaseous material, it is best to display average ambient levels on maps of the city in the form of isopleths or differently shaded areas and to show the peak concentration points by means of suitable symbols. Diurnal and seasonal roses showing concentrations from given wind directions are useful in determination of source locations.

The type of sampling, time routines to use (random, continuous, sequential) and the number and location of stations have been studied for urban areas by Stalker, et al. (1964).

Data Reduction and Presentation

Although local climatology, topography, city climatology, cultural characteristics and pollutant sources and concentrations are each characterized by special symbols, units, charts, and diagrams, it is necessary to present all these data in a fashion which (1) permits correlation of variables, and (2) breaks down the variables into manageable parcels. Thus a uniform grid system should be developed for the city or perhaps one already in existence (voting precincts, census tracts) could be adopted. Seldom does an arbitrary equal-area grid work unless the grid blocks are small and data are computer processed.

In the use of topographic maps, the largest practical size should be used to look at airflow. Different colored contour intervals make for easy reading of the elevation differences and trends. Generous use of transparent overlays is recommended in all stages of reduction and presentation of data. Liberal use should be made of photographs to illustrate many of the features described in local climatology, physical geography, urban climatology, and source and survey locations.

It is best to use maps of the same size if several are needed for data presentation. Effects of a scale change from map to map are seldom easy to visualize. Because of practical difficulties with printing and binding, maps for reports should be 8 1/2 x 11 inches in size. Transparent overlays help in the presentation of cause-and-effect data. It would be expected that each report map would have a large map as source for more accurate or detailed information.

The variables which can be combined for study on large maps would include these sets:

1. Sources, ambient concentrations, population density.
2. Sources, wind direction, topography, bodies of water.
3. Population density, traffic density, airflow.
4. Areas of vegetation, sources, airflow.
5. Sources, land use, airflow.

Up to date aerial photographs, both oblique and vertical incidence, should be available.

Summary

The quality of air is characterized by the quantity and properties of unwanted substances that it contains. The concentration of these substances depends broadly upon the nature of the sources and the mechanisms of transport and diffusion between emitter and receptor. Climatology generalizes the day today atmospheric conditions for air flow and mixing, heating and cleansing, and for conditions favorable for chemical reactions. Physical geography describes the way in which passive and active processes in airflow are determined by physical features of the land surface. City climatology tells something about man-made effects on air flow and mixing within a city while the cultural characteristics, so closely related, reveal facts about spatial and temporal distribution of population and pollutant sources as well as attitudes and trends in the direction of change.

A methodology for investigating interrelationships has been suggested in the foregoing sections. The steps to be followed are these:

1. Formulate an objective.
2. Decide which parameters have to be included to meet the objective.
3. Review and tabulate cause-effect interrelationships among the selected parameters.
4. Tabulate sources of data and collect data.
5. Apply the established cause-effect rules.
6. State conclusions toward objective and report results.

Application to the city of Austin, Texas, follows in the next section.

TABLE 1

IMPORTANT METEOROLOGICAL

EFFECTS ON AIR POLLUTION

Meteorologic Parameter	Effects on Air Pollution
Wind speed	Pollutant concentrations downwind from emitter. Time for transport.
Wind direction	Location of pollutants after emission
Mixing dept Air temperature vs altitude	Potential for mixing and dilution.
Air temperature - ground level	Space heating requirements and consequent emissions. Electrical power generation and its emissions. Air drainage.
Hours of sunshine Daily solar radiation	Diurnal and seasonal cycles of stability and turbulence. Formation of photochemical smog.
Precipitation amount	Washout and rainout of pollutants in the air. Quantity of mobile pollutants at ground level.
Thunderstorm frequency	Local area ventilation
Anticyclone behavior	Location of stagnating air masses, occurrence of subsidence inversions, accompanying mixing and ventilation potential.

TABLE 2

SPECIFIC EFFECTS OF

METEOROLOGICAL PARAMETERS

Calm to light winds	Poor ventilation, stagnation; low level emitters produce higher ground level concentrations; high level emitters may disperse fairly well in light winds.
Moderate to strong winds	Good ventilation, low level emissions are moved out, high level emissions may cause higher ground concentrations because of bending of plume earthward.
Direction of wind	Determines location of receptors. Weather station annual averages often misleading. Seasonal averages are better, and local effects of valleys, rivers, lakes, and buildings must be considered.
Mixing depth	Greater mixing depth means higher capacity for dilution while lower means less capacity for dilution.
Air temperature vs altitude	Greater than dry adiabatic lapse means unstable air and good mixing for better dilution; isothermal lapse means mediocre mixing; inversion means stable air, poor mixing; inversion below, superadiatic above means poor mixing at ground level without a "lid;" inversion aloft, superadiatic below means good mixing at ground level with a "lid" of stable air above causing entrapment and fumigation.
Air temperature-ground level	Lower temperature means greater space heating emissions; cold air drainage increases intensity of ground level inversions; higher temperatures increase electrical power generation in many areas for air conditioning.

TABLE 2 (Cont.)

Hours of sunshine	More sunshine at ground level means greater instability caused by differential heating of surfaces and thus better mixing.
Solar radiation	Greater solar energy available seasonally and latitudenally means more chance for formation of photochemical smog.
Precipitation	Greater rainfall removes more precipitation nuclei (pollutants) from the atmosphere, washes out more suspended particulates and gases to ground surface, tends to hold down dust particles to ground surface; runoff concentrates and disposes the material collected.
Thunderstorm frequency	Frequent occurrence of extreme mixing to great altitudes coupled with rainout and washout tends to clean the atmosphere; effect may be local except for broad line of frontal storms.
Anticyclone behavior	Moving high-pressure air mass not bad; stationary anticyclone causes very reduced dilution and transport and high pollutant concentrations.

SOURCE: Meteorological Aspects of Air Pollution, U.S. Dept. of H.E.W. Training Manual, 1964.

TABLE 3

TYPES OF INVERSIONS

Radiation inversion	Caused by rapid cooling of the land surface through loss by radiation after sunset.
Advection inversion	Caused by horizontal flow of warm air across a cooler surface like a lake.
Subsidence inversion	Occurring when slowly descending air aloft in high pressure areas undergoes adiabatic warming.
Evaporation inversion	Caused by rapid cooling from evaporation after a summer rain or over an irrigated field.

SOURCE: Munn, 1966.

TABLE 4

CHARACTERIZATION OF

METEOROLOGICAL DATA

Parameter	Characterization
Wind speed	Diurnal, monthly, annual arithmetic mean speed, maximum speed, % calm, % occurrence in given speed categories.
Wind direction	% frequency of occurrence at each of 16 points of the compass, % occurrence in speed categories of same compass directions, wind roses combining the two parameters.
Mixing depth	Mean mixing depth in feet above ground level; estimated monthly values, predicted daily values.
Air temperature vs altitude	Lapse rate in degrees/unit altitude; graphical plot of degrees vs altitude.
Air temperature-ground level	Hourly readings, diurnal, monthly, annual adiabatic mean temperature; occurrence of maxima, minima, heating degree days.
Hours of sunshine	Monthly and annual mean number of hours of sunshine.
Daily solar radiation	Monthly and annual mean in langleys (g - cal/cm^2).
Precipitation	Monthly and annual mean in inches; occurrence of maxima, minima.
Thunderstorms	Number of days of occurrence monthly.
Anticyclones	Maps of principal and secondary tracks; total occurrences of 4-day + stagnation anticyclones as isopleths on a map.

SOURCE: Local Climatological Data, 1970, Austin, Texas, U.S. Dept. of Commerce.

TABLE 5

EFFECTS OF MOUNTAINS, HILLS, VALLEYS,

AND GORGES ON AIR MOVEMENT

Mountains and Hills

- Gradual uplifting of laterally moving large air masses.
- Diversion of air mass around a prominent hill in stable conditions and light winds.
- Increased wind speeds caused by venturi effect between prominent features.
- Downslope air drainage in calm cool conditions.
- Convection flow caused by south-slope heating (valley wind).
- Formation of cold air pools by damming.
- Downwash and backwash of air on the downwind side.
- Enhancement of vertical air flow (increased turbulence) over small hills located on flat plains.
- Creation of eddy cells and resulting gustiness at sharp discontinuities at base or peak.
- Channeling of winds to cause peculiar prevailing wind directions locally.
- Mean wind profile relatively steep.

Valleys and Gorges

- Channeling of winds to cause locally prevailing directions.
- Upslope and downslope air flow caused by differential heating.
- Cold air drainage up or down the valley when prevailing flow is weak.
- Increased down-valley wind velocities caused by venturi effect.
- Shielding from prevailing flows causing stagnation.
- Downwash and eddies from crosswinds.
- Eddy formation of size to fill valley cross-section and thus little ventilation with fresh air.
- Lofting of air mass at far side of valley in crosswind.

SOURCES: Davidson, 1961; Flohn, 1969; Munn, 1966.

TABLE 6

EFFECTS OF PLATEAUS, PLAINS, FLATS,

ISLANDS, AND BASINS ON AIR MOVEMENT

Plateaus

- Eddies form on the top of the plateau at the edge facing the wind.
- Eddies form on the downwind side of the plateau but below the level of the plateau.
- Lofting of air masses from lower surrounding areas.
- Draining of cold air off to lower elevations.

Plains and Flats

- Direction and speeds of flow relatively undisturbed.
- Geostrophic wind reached at relatively low altitude.
- Generally lower turbulence.

Islands

- Little of its own effect if of low relief and small compared to the body of water.
- Wind profile essentially that over the surrounding water.
- Analogous to a hill or mountain in otherwise flat terrain with effects dependent on topography.

Basins

- Pools of cold air generally form in concave terrain.
- Intensely cold stable air can collect causing an intense local inversion condition.
- Ventilation by wind highly dependent on size and on surrounding terrain features.

SOURCES: Munn, 1966; Scorer, 1958; Geiger, 1965.

TABLE 7

EFFECTS OF BODIES OF WATER

ON AIR MOVEMENT

Lakes

- Differential heating between land and water can cause daytime flow of air from over water onto the adjacent land, and night time flow of air from over land out onto the water (sea breeze-land breeze).
- In stable conditions found in stagnating anticyclones essentially the same air mass may move back and forth from over water to over land and back from differential heating.
- A lake which is cold compared to the air over it can create a local inversion above its surface. Similarly, a warm lake provides conditions conducive to formation of a steam fog.
- Smoothness of water relative to land can cause shoreline downwash and upwash effects on air flow: upwash with onshore flow and downwash with offshore flow.
- Movement of a stable air mass (inversion) from out over a lake to back over land can cause an inversion aloft over unstable air below as it moves over land.
- Smooth water surface results in a flatter surface wind profile than over most land surfaces.

Rivers and Streams

- Most rivers affect air movement as do lakes except the magnitude of the effect is much smaller because of the lower mass of water.
- Movement of water in rivers and streams tends to "wash out" the differential heating effects upon which the effects are dependent.
- Channeling over smooth river surfaces.

SOURCES: Geiger, 1965; Hewson and Olsson, 1967.

TABLE 8

EFFECTS OF SURFACE CONDITION OF

LAND ON AIR MOVEMENT

Trees and Grasses

- Mean wind profile is affected as by any other obstacle or degree of roughness.
- Increased turbulence above tops of the vegetation caused by their roughness.
- Lower mixing of air within a stand of trees because of lower wind velocities to ground level.
- Local channeling and venturi effects can occur in groves of trees.
- Blocking or damming of cold air drainage can occur from vegetation.
- Differential absorption of solar heat between vegetation covered surfaces and others gives rise to vertical air currents and improved mixing.

Barren Ground

- Mean wind profile tends to be flatter as over water surfaces but not to the same degree.
- Little resistance to cold air drainage.
- Mixing is effective to ground level.
- Differential absorption of solar heat among different colored surfaces gives rise to vertical air currents and improved mixing.

SOURCES: Geiger. 1965; Landsberg. 1958.

TABLE 9

EFFECTS OF VEGETATION

- Dampens the diurnal and seasonal temperature cycle at ground level.
- Reduces particulate matter by filtering processes.
- Reduces particulate matter by not being a source of ground dust.
- Is a source of particulate matter such as leaf parts, pollen, spores, and other aeroallergens.
- Can be a source of terpenes. carbon dioxide. carbon monoxide, perfumes, and so on.
- Absorbs solar radiation which otherwise reaches ground level.
- Releases moisture through evapotranspiration.
- Provides space for dilution of pollutants among buildings.
- Provides local circulation cells from differential heating with buildings. asphalt. etc.

SOURCES: Munn, 1966; Geiger. 1965; Hill, 1971.

TABLE 10

EFFECTS OF METEOROLOGICAL

CONDITIONS ON POLLEN

- Minimum velocity of dry air required to maintain pollen grains airborne can be as low as 0.035 miles per hour.
- Because of the low velocity required to maintain pollen in the air, its dispersal may be more dependent on air turbulence than on wind velocity.
- Release of pollen is at a greater rate on days with 90-100% sun than on days with little or no sun.
- High relative humidity causes a marked decrease in the incidence of airborne pollen.
- The number of pollen grains collected is usually highest from 6:00 a.m. to 12 noon and lowest from 6:00 p.m. to 12 midnight.

SOURCE: Shapiro, 1965.

TABLE 11

COMMON AEROALLERGENS

Aeroallergens	Source
Pollens	Wind-pollinated plants, grasses, weeds, and trees
Molds	Usually saprophytic, prevalence depending upon humidity
Danders	Feathers of chickens, geese, ducks; and hair of cats, dogs, horses, sheep, cattle, laboratory animals, and humans
House Dust	A composite of all dusts found about the home
Miscellaneous Vegetable fibers and dusts	Cotton, kapok, flax, hemp, jute, straw, castor bean, coffee bean, oris root, rye, wheat
Cosmetics	Wave set lotions, talcs, perfumes, hair tonics
Insecticides	Insecticides containing pyrethrum as a common ingredient
Paints, varnishes, and glues	Linseed oil and organic solvents

SOURCE: Finkelstein, 1959, Table 1.

TABLE 12

CHANGES PRODUCED BY

URBAN DEVELOPMENT

Atmospheric Parameter	Comparison with Rural Area
Temperature (nights)	increased 1° to 3° C.
Relative humidity	reduced 2-10%
Sunshine duration	reduced 5-15%
Radiation, total on horizontal surface	reduced 15-20%
Ultraviolet	reduced 10-30%
Heating needs	reduced 10%
Rainfall	increased 5-10%
Number of rainy days with small amounts	increased 10%
Snowfall	reduced, depends on latitude
Cloudiness	increased 5-10%
Fog and low visibility	increased 50-100%
Wind speeds	reduced 10-30%
Contaminants	
solids	increased 1000%
gaseous	increased 500-2500%

SOURCE: Landsberg, 1969

TABLE 13

ALBEDO OF VARIOUS SURFACES

Albedo (percent) of various surfaces for total Solar radiation, with diffuse reflection	
Fresh snow cover	75-95
Dense cloud cover	60-90
Old snow cover	40-70
Clean firm snow	50-65
Light sand dunes, surf	30-60
Clean glacier ice	30-46
Dirty firm snow	20-50
Dirty glacier ice	20-30
Sandy soil	15-40
Meadows and fields	12-30
Densely built-up areas	15-25
Woods	5-20
Dark cultivated soil	7-10
Water surfaces, sea	3-10

SOURCE: Geiger, 1965.

TABLE 14

TEMPERATURE DIFFERENCES TO

AIR TEMPERATURE (77°F) ON CLEAR SUMMER DAY

Type of Surface	Difference, °F
Soil surface in shade	+ 0 to 2
Leaves of oak tree	+ 4
Short grass blades (sun)	+ 11
Soil surface under short grass	+ 1 to 5
Gravel path, 1/2 cm depth	+ 7
Concrete walk	+ 10 to 15
Asphalt drive	+ 21
Iron railing	+ 28
Asphalt shingle roof	+ 30 to 33
Parked car roof	+ 40

SOURCE: Landsberg, 1958.

TABLE 15

WIND VELOCITY VARIATION WITH HEIGHT

$\frac{V}{V_{GRAD.}} = \left(\frac{h}{h_{GRAD.}}\right)^{n}$	n	h_G
Open country, flat coastal belts, small islands in large bodies of water, prairie grassland, tundra	0.16	900 ft
Wooded countryside, parkland, towns, outskirts of large cities, rough coastal belts.	0.28	1300 ft
Centers of large cities	0.40	1400 ft

SOURCE: Hinkle, 1970.

TABLE 16

OCCUPATIONAL CATEGORIES FOR A CITY

Manufacturing

Nondurable goods

- Food products
- Tobacco
- Textiles
- Apparel
- Paper
- Printing
- Chemicals
- Petroleum refining
- Rubber
- Leather

Durable goods

- Lumber
- Furniture
- Stone, clay, glass
- Primary metal
- Fabricated metal
- Machinery
- Electrical machinery
- Motor vehicles
- Other transportation equipment
- Instruments

Transportation

- Railroad
- Suburban highway passenger
- Motor freight
- Water transportation
- Air transportation
- Pipeline transportation

Communication

- Telephone and telegraph
- Radio, television

Electrical power, gas, fuel oil, sanitary services

Wholesale Trade

Retail Trade

Finance, insurance, real estate

- Banking
- Credit agencies
- Security, commodity brokers
- Insurance
- Real estate

Services

- Hotels
- Repair
- Personal
- Amusement
- Medical and health
- Legal
- Educational

Retired or incapacitated persons, etc.

- Retirement homes and hotels
- Hospitals
- Sanitaria
- Schools for blind, deaf, retarded
- Institutions for correction

Government

- Federal
- State
- Local
- Military Services

SOURCE: "National Income by Industry," p. 84, 1971 World Almanac and Book of Facts New York News

TABLE 17

TYPES OF SOURCES

Industrial processes of all types
Electrical power generation
Commercial and institutional space heating
Residential space heating
Municipal refuse disposal
Commercial refuse disposal
Open burning of refuse
Residential fireplace burning
Automobiles, trucks, buses, ships, boats, trains, aircraft
Hydrocarbon emissions from fuel handling
Sewage plants and sanitary landfills
Grass, brush, and forest fires
Pollens and dusts

SOURCE: Various Sources.

TABLE 18

SOURCES OF DATA FOR USE

IN ESTIMATING EMISSIONS

Fuel combustion, stationary (type, quantity, location)
- local building, boiler, and other permit records
- local utilities
- fuel suppliers
- large volume fuel users
- local large industries
- US Bureau of Census
- US Bureau of Mines
- Fuel associations
- petroleum marketing associations
- National Coal Association
- American Petroleum Institute

Combustion of Refuse
- municipal refuse disposal agency
- markets, department stores, hospitals incineration records
- permit files for open burning (this assumes control)

Transportation
- municipal transportation departments for vehicle density from traffic counting
- same agency for travel time maps, daily variation in flow, estimates for future flow
- Compute vehicle-miles throughout city
- state motor vehicle registration agencies for number of vehicles, breakdown by model year
- gasoline sales from oil company wholesalers of gasoline
- aircraft flight operations, type aircraft from airline guides or from airport administration; military aircraft from airbase authority

Industrial processes
- Use state and local directories of manufacturers, send questionnaires, make visits, and apply recognized emission factors to production data

Natural sources
- Grass and brush fires: fire department and weather station records for occurrences, effects, correlation with winds, drouth, etc.

TABLE 18 (Cont.)

Pollens: local pollen counts, published indices for cities, American Academy of Allergy, Allergy Foundation of America

Dusts: on-the-ground survey of construction sites, maps showing unpaved streets, regional maps showing open fields, cultivated areas; weather station records of dust transported in from great distances

Miscellaneous

Sewage plants and sanitary landfills: odors, dusts: records of complaints, on-site survey

Fireplaces: count from aerial oblique photographs made of residential areas on a sampling basis under calm wind conditions

Backyard burning: same as for fireplace

HC from gasoline bulk handling: site survey

SOURCE: Guide for Air Pollution Episode Avoidance, AP-76, E.P.A., 1971.

TABLE 19

NATIONAL PRIMARY AND SECONDARY

AIR QUALITY STANDARDS AS OF MAY 1971

	Primary		Secondary	
	$\mu g/m^3$	ppm	$\mu g/m^3$	ppm
Sulfur dioxide				
Annual arithmetic mean	80	0.03	60	0.02
Maximum 24-hour concentration*	365	0.14	260	0.10
Maximum 3 hour concentration	-	-	1300	0.50
Particulate matter				
Annual geometric mean	75	-	60	-
Maximum 24-hour concentration*	260	-	150	-
Carbon monoxide				
Maximum 8-hour concentration	10 mg/m^3	9	10 mg/m^3	9
Maximum 1-hour concentration*	40 mg/m^3	35	40 mg/m^3	35
Photochemical oxidants				
Maximum 1-hour concentration*	160	0.03	160	0.03
Hydrocarbon (nonmethane)				
Maximum 3-hour concentration* (6-9 a.m.)	160	0.24	160	0.24
Nitrogen dioxide				
Annual arithmetic mean	100	0.05	100	0.05

[1]Data are corrected to 25° and 1013 mbar (1 mbar = 100 N/m^2).

*Not to be exceeded more than once per year.

SOURCE: Federal Register, 36. 84, Part II. April 30. 1971.

III. APPLICATION TO THE CITY OF AUSTIN

Introduction

To demonstrate the usefulness of the foregoing methodology, it will be applied to the city of Austin, Texas, located in Travis County. From available data for Austin the following aspects of air pollution will be discussed:

1. Mixing potential in the air
2. Direction of movement of air
3. Cleansing mechanisms in the air-earth system
4. Effect of cultural characteristics
5. Sources and amounts of emissions
6. Ambient air quality

Mixing potential

An indication of the degree of both horizontal and vertical mixing in Austin can be seen in Figure 1 which shows the annual variation by month of average wind speed, estimated mean mixing depth, and percent of possible sunshine as well as frequency of inversions by season. On the average, the mixing potential is lowest in December and January when the percent of possible sunshine is a minimum and the average wind speeds are relatively low. It follows that the frequency of inversions rises to a high value of 30 to 35% of total hours. The data for Figure 1 appear in Tables 20 through 25. However, use of average data fails to provide an insight into the specific occurrences of poor mixing conditions on any one day in December or January, nor does it express anything about degree of mixing or the spatial variation throughout the city.

Hourly observations of wind speed, and heating conditions at the surface plus measurement of lapse conditions quickly reveal mixing conditions for any one day.

The degree of poor mixing can be expected to be worse in the low-lying areas of the city indicated by the shaded area below an elevation of 500 ft in Figure 3. Cold air drainage from the higher elevations all around would tend to intensify temperature inversions in these areas of lower elevation. A limited amount of data shows that Lake Austin and Town Lake tend to have temperatures which are, on the average, above the 24-hr average air temperature in the months of December and January (see Tables 26 and 27). These warm lakes would tend to counteract the drainage effects locally, since the lakes are main stream reservoirs (see lake descriptions in Table 28), having a width usually less than 1,000 feet. Generally speaking, even main stream reservoirs have the effect of increasing vertical air movement because of differential heating from water to land surface. Also, their smooth surfaces have little braking effect on horizontal airflow in a path very near the center of the city geographically.

Recent measurements (Wood, 1971) of temperatures around the city of Austin in late 1970 revealed cold air pools at several locations, as shown in Figure 11, caused from air drainage into local small basins. These spots might be troublesome because of entrapment of ground level emissions from refuse burning, for example. More will be said later about entrapment of emissions.

Direction of Movement of Air

The percentage frequency of wind direction for each month is shown in Figure 4 for Austin as are the percent of calm periods. There is a predominance of south to south-southeast flow throughout the year so that the annual prevailing wind is southerly as is shown by the wind rose in Figure 5. In December northerly winds barely predominate, however, as the flow in the segment NE to NW prevails 36.5% of the time while flow in the segment SE to SW occurs 36.0% of the time. Again, these wind directions are long time averages and give no indication of direction for any one day of the year.

The larger view of air movement appears in Figure 6 which shows the principle tracks of anticyclones in the winter across the United States. Pacific Maritime, Polar Continental, and Arctic Air masses move into the Austin area and on to the east and southeast in the period from October through April. This large-scale flow is responsible for the cool northerly flow over the city, while flow from the Gulf of Mexico brings warm and usually moist air causing the southerly flow in the warmer months.

Flow at ground level in the city is affected by the topography and the man-made structures. Since prevailing winds are northerly and southerly, the predicted effects of channeling are shown for these directions in Figures 7 and 8 which have been derived from Figure 2, a contour map of Austin. Channeling can be expected to change the prevailing direction to one tangent to the flow lines shown. The most pronounced effect would be in the shallow gorge formed by the Colorado River from about the mouth of Bull Creek to below Tom Miller Dam. This section tends to have a funnel-like opening to the south which narrows over Tom Miller Dam and the smooth surface of Lake Austin and terminates in the twisting valley of Bull Creek, or, turns to the northwest at that point (see Figure 2 for topography). Winds from the south would be more affected than those from the north as a consequence of the funnel shape.

Other than local channeling down creek valleys there is no other dominating feature. Certainly the surface of the river, wherever it is, because of its smoothness, tends to be a good track for winds.

Inspection of the vertical section in a north-south direction through the center of the city in Figure 9 reveals that the north-south flows encounter little in the way of natural barriers. Southerly winds experience a gentle uplifting from the 660 ft elevation south of the river to the 800 ft elevations near Balcones Research Center.

Through the use of large topographic maps of the city the natural air drainage patterns for the city were determined. Figure 10 shows the paths that cold dense air tends to follow in its gross movements under cool, calm, clear conditions in the months of November, December, January, and February. The use of long flow lines tends to give the impression that long streams of dense air can develop. In reality, because of trees, grass, buildings, bridges, and other hindrances to flow, the movement is local in nature. The slope of most creeks in the Austin area is relatively flat thus favoring collection in basins instead of large-scale flow. Variations also arise from the change in width of the flood plains of the creeks. Differential cooling also affects the magnitude of flow.

Radiational cooling of large open fields covered with short stubble provides a good source for drainage flow. Such areas detected by Wood (1971) in his temperature measurements included locations on Riverside Drive where open fields still exist and on 45th Street between Lamar Blvd. and Guadalupe Street where there are grassy fields north of the State Hospital. Other cold spots are shown in Figure 11 from Wood's measurements.

Lake and land breezes affect airflow only locally because of the relatively small size of the lakes and their river-like characteristics. Lakes Travis and Decker Lake are too far from the city proper to affect airflow. (See Figure 12.)

Table 29 which shows elevations of familiar locations in the city is useful for maintaining a proper vertical scale while referring to the flow and drainage maps.

Man-made structures in the city are the cause of complex flow and turbulence. The overall shape of the city as it has developed north and south along the Balcones Escarpment causes most of the major roadways to be oriented roughtly along a north-south direction. Channeling along the expressways, arteries, and even city streets is a common occurrence. Congress Avenue with its opening to the south causes a flow of air through the center of the central business district. The Expressway has sections at the river and at Highway 290 that bear almost true north-south. Lamar Blvd., Burnet Rd., Balcones Trail, and Airport Blvd. basically run north-south through the city to provide good pathways for flow.

Because the city blocks are not oriented true to geographic north, secondary channeling through the nominally east-west streets is enhanced. The limited number of north-south streets which tee into east-west streets causes less east-west flow, however.

Some general conclusions can be made about the channeling by buildings in the city:

1. Streets running in a northerly-southerly direction will influence the prevailing flows to move along these routes.
2. Streets moving in an easterly-westerly direction will experience a lower but more turbulent channelled flow.
3. Distinct departures in wind direction from the prevailing flow will exist more in the downtown area between 1st and 11th streets and between Neches and Guadalupe streets because of the greater heights of the structures.
4. Strong north-south flow can prevail in the uncluttered mall from 19th at University Ave. to the University Tower.
5. Similarly, strong east-west flow can prevail in the mall from Red River at 23rd across Peace Fountain to the Tower.

6. Channeling in the residential areas will not be pronounced among the low one-story buildings with much of the space filled with trees.
7. University of Texas campus buildings which are close together with many trees on the narrow separating streets cause local channeling effects only, and therefore good mixing at ground level.
8. Among new large buildings that affect air flow locally are the Cambridge Tower, Dobie Tower, LBJ Library, and the Chevy Chase Building in the University of Texas area and on Highway 183 west of IH 35.

Air flow in the immediate vicinity of buildings follows the patterns outlined in Section II of this paper. In the downtown area, the air would be very turbulent at street level with a modest breeze blowing because of downwash, backwash, and the accompanying eddy cells. Appendix B details some effects to be expected in a specific area of the city near the Federal Building.

Cleansing Mechanisms

For Austin the movement of continental cold air masses in the winter months depicted in Figure 6 is effective in moving out polluted air and replacing it with fresh clean air. These air masses seldom stagnate in the Austin area as they do in the southeast and northeast parts of the country. The map in Figure 13 shows that less than two incidents of stagnating anticyclones have occurred in the period from 1936 to 1965. Figure 14 shows that there has never been a condition of air pollution potential forecast for the city of Austin. The return flow of Gulf of Mexico air after the cold air masses have moved out is a complimentary mechanism for statewide ventilation. This southerly flow persists in the summertime also.

Normal rainfall for Austin averages about 2.7 inches per month (see Table 30). This amount of rainfall is not too low to suppress large ground level sources of dust. Thunderstorms with their high vertical and horizontal air flow occur on the average of 40 times per year. November, December, and January average only one per month, however, while April and May, which already have better mixing are high with five and seven per month, respectively. Certainly the thunderstorms which do occur are effective in cleansing the air through mechanisms of dilution, washout, and rainout. In the winter months rainfall is most often caused by warm air over-running cold to give rains covering large areas in Texas.

Rainfall over the Austin metropolitan area probably does not vary much from the long term averages recorded at the Municipal Airport weather station. Table 31 shows a comparison for the year 1968 for two locations two miles apart within the city where the difference is only 0.37 in a year with 38 inches. Short term variations can be very great, however, for thunderstorm precipitation common in the April through September period. Correlation of rainfall amounts with ground level dust sources could be made using Fire Station rainfall records, although this study was not made for Austin.

Some indication of the amount of light-scattering material in the air over Austin is given in Table 32 which lists the percent occurrence of visibility in range categories from zero to 15 miles and up. Low visibilities in the range 1/8 to 3/8 miles occur only 1.4% of the time.

Restricted visibility in Austin is caused primarily by fog in the cooler months and by smoke and haze in stagnant conditions. In periods of statewide drouth, it is not unusual to have restricted visibility from dust transported from far west Texas. Local brush fires during dry periods also limit visibility under poor mixing conditions.

Records of the nature of limited visibilities (fog, haze, smoke, dust) are available from Weather Bureau records for statistical study.

Except for the so-called Central Business District of the city (bounded by West Avenue--IH 35 and First--Nineteenth Streets), the city has a high percentage of vegetation cover. Major concentrations of vegetation are shown in Figure 15. The natural vegetation in the area west of Balcones Trail north of the river and west of South Lamar south of the river is comprised of juniper (locally called cedar), live oak, and mesquite with a ground cover of short grasses. There are varying densities of these trees in the area bounded by Lamar Blvd., Anderson Lane, Balcones Trail, and the river. Pecan and elm can be found in the lower elevations or river terraces between the Congress Avenue and Montopolis Bridges. The map in Figure 15 attempts to show the extent of vegetation in Austin.

Because of the relatively high occurrence of vegetation throughout the city, mechanisms outlined in the first section of this paper (Table 9) play an important role in the air quality for the city.

Trees, shrubs, and grasses all over the city are effective in collecting particulate matter which will fall to the ground when the leaves drop, or, for evergreens, will be washed to the ground by rainfall.

Local ground level temperatures have a lower diurnal and seasonal cycle under tree cover, differential heating from open to covered areas is enhanced, flow is more turbulent through trees, and, as a consequence, mixing is generally improved. The parks, golf courses, playgrounds, and cemeteries shown throughout the city in Figure 15 not only are not sources of emissions (man-made, undesirable) but provide space for dilution. The Capitol grounds and Pease Park are notable examples of dilution reservoirs in the central part of the city, along with Wooldridge Park between the Courthouse and Library. Camp

Mabry and Austin Memorial Park (Hancock Blvd.) in the north are large areas of vegetation unbroken by pavement and buildings. Numerous other stands of trees could be mentioned (see Aerial Maps at the City Department of Planning) that have a favorable effect upon the quality of air in Austin.

Unfavorable effects of Austin's vegetation include higher particulate levels in the fall of the year when leaves fall and are crushed by automobile traffic, higher pollen counts in the period from February through October, and higher incidence of leaf disposal by backyard burning.

It is worthwhile mentioning that the effects of vegetation vary with the time of year. The period of leaf fall with more particulates and smoke from burning coincides with the late fall stagnating conditions in the Austin area. Although live oaks drop their leaves, new leaves immediately appear so that the live oaks and junipers which abound in the area always are, for all practical purposes, in leaf with consequent perennial effects. Pollen seasons are given below in the discussion of pollutant sources.

Cultural Characteristics

Labor Force. The labor force in Austin and Travis County is primarily engaged in nonmanufacturing pursuits. Figures from the Texas Employment Commission[1] for the year 1970 show this breakdown for the workforce of 132,300 in Travis County:

Nonmanufacturing	42.0%
Government	34.6%
Other	11.1%
Manufacturing	8.73%
Unemployed	2.34%
Agricultural	1.09%

These percentages show that relatively few persons are involved in manufacturing activities which might in some way contribute to the pollution of air in Austin. Of those persons in manufacturing, Table 34 that gives the complete breakdown of occupations for 1970 shows none involved in the primary metal industries and most involved with the manufacture of machinery, transportation equipment (including boats), and professional and

[1] Annual Labor Area Work Force Report, 1970, Austin, Texas, rev. Jan. 1971, Texas Employment Commission.

scientific goods. The locations of many of Austin's industries are shown in the map of Figure 16. The Directory of Texas Manufacturers[2] lists just over 300 organizations for Travis County. Only a small number fall into the classic industry classification for potential sources of air pollution. More will be said about sources in the next section.

It follows from the above data that air pollution is not closely linked with industry in the city of Austin and that a low percentage of the working population is affected by the economics of air pollution prevention in the city.

Population Density. Population density in Austin is mapped in Figure 17 for the year 1968. Highest densities are in the University of Texas area where most of the 35 to 40 thousand students are housed in dormitories, apartments, and a variety of rooming and boarding houses. The area north of the river between Interstate 35 and Springdale Road and north to 38th Street is next with

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[2] Directory of Texas Manufacturers, 1971, Vol. 1, Bureau of Business Research, University of Texas, Austin, Texas.

small low-income, one-family dwellings on small lots. Although the central business district has a high influx and movement of people throughout the daytime hours, the density is correctly shown to be low for permanent residents. Effects of pollutants will be related to population density in a later section. More precise data for density are given in Table 35 which shows population, number of dwelling units, and gross acreage for each census tract in the city. Locations of hospitals and special schools where persons are living in high density conditions on a continuous basis are shown in the map of Figure 18.

Land Use. Land use follows the patterns illustrated on the map of Figure 19 which shows industrial and wholesale concentrations and residential areas of the city. Although broad geographical boundaries have been specified by the city for industrial areas and residential areas, the zoning tends to be after the fact, as it is in most cities. Zoning changes are relatively easy to make and there are no laws specifying upper limits on population density. Land developers usually determine the overall character of an area based on economic considerations. Industrial concentrations to the north and south mean the potential for air pollution effects is increased because of the prevailing southerly and northerly winds described earlier.

Population Growth. The trend in population growth for Austin is illustrated in Figure 20 (Basic Data, City of Austin . . ., 1971) which projects a population in excess of 600,000 in the year 2000. Figure 21 shows that the territorial growth has been primarily to the north and south in the years 1969 and 1970 with a minimum of movement to the east. The director of the Austin Planning Department forecasts that future growth will be 50 percent north of 38th Street, 25 percent south of the river, and 25 percent as higher density in the middle.[3] Development is expected in the form of large clusters which will each include shopping centers, schools, parks, etc., to the north and south. The trend of north-south geographical expansion means that the potential for air pollution problems is increased since emissions generally

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[3]Richard Lillie, Director, Austin Planning Department, in Austin American-Statesman, June 20, 1971.

will move with prevailing winds over the entire length of the city, increasing in level of concentration downwind over more parts of the city and thus affecting more people.

Motor Vehicle Transportation. Major motor vehicle transportation routes are shown in Figure 22. Mo-Pac Boulevard which is presently under construction will carry heavy traffic through areas previously not subjected to automobile emissions. The planned link from Bee Caves Road northeast across Lake Austin at Bull Creek to Highway 183 will also introduce new source patterns into the western part of the city. At the present time the heaviest traffic densities are on these streets shown in Figure 23:

Interstate Highway 35
Lamar Boulevard
Congress Avenue
Guadalupe Street
Burnet Road
Airport Boulevard
19th Street

Ben White Boulevard (from IH 35 to South Lamar)

Highway 183 (from IH 35 to Burnet Road)

A May 1968 study of vehicular traffic flow over the city[4] provides the basis for emission computations which will be described later. The study shows 24-hour weekday flow of more than 54,800 vehicles on IH 35 at 12th Street; 25,290 on Lamar at 19th Street; and 21,280 on Guadalupe at 23rd Street. At these same intersections the 1982 traffic flow is expected to be as follows: 137,700 vehicles on IH 35 at 12th St.; 16,800 on Lamar Blvd. at 19th Street.; and 46,900 on Guadalupe Street at 23rd St. The new Mo-Pact Expressway at Windsor Road is expected to carry 52,700 vehicles daily in 1982.[5]

The number of motor vehicles registered in 1970 in Travis County is as follows:[6]

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[4]Austin's 1968 Vehicular Traffic Flow. By City of Austin and Texas Highway Department.

[5]Austin Transportation Plan, 1962-1982. City of Austin, County of Travis,Texas Highway Dept. 1965.

[6]Basic Data, City of Austin and Travis County, 1971. Dept. of Planning, p. 24.

Passenger cars	132,069
Commercial trucks	24,569
Farm trucks	851
Motorcycles	5,076
Total	162,563

Thousands of additional cars flow into the city from the transient population of colleges, universities, and governmental functions. A typical hourly distribution of person trips is shown in Figure 24. Automobile emissions are discussed in a later section.

Aircraft Traffic. Scheduled airline flights into and out of the Austin Municipal Airport totalled 25,000 in 1970 and light aircraft accounted for 167,000 operations to make a total of 192,000 operations where an operation is defined as a landing or a take-off. The scheduled flights as of July 1971 appear in Table 36 and show a total of 64 departures and arrivals for one day for a mixture of aircraft types. The equipment and number of flights (one landing and one take-off) may be summarized as follows:

16 flights Douglas DC-9, 3 engines, fan jet.

9 flights	Boeing 727, 3 engines, turbofan (fan jet)
5 flights	Convair Turbojet, 2 engines, turboprop
2 flights	Beech 99, 2 engines, turboprop
32 flights	Total

Airlines represented are Braniff International, Texas International, Continental Airlines, and Rio Airways.

Detailed breakdown of the light aircraft traffic was not available for this study. Information on aircraft traffic at Bergstrom Air Force Base was also not obtained. The reconnaissance aircraft, RF-4C Phantom II is operated out of Bergstrom along with occasional four-engine jets and various piston-engine aircraft. Traffic does not compare in magnitude to that at the Municipal Airport, however.

The number of operations at the Municipal Airport increased by 25.8% from 1960 to 1965 and by 11.2% from 1965 to 1970.

Aircraft emissions are discussed in a later section. Flight tracks over the city are shown in Figure 23. Larger aircraft and increased traffic in the future may dictate the abandonment of the existing municipal airport location in favor of one more remote from the city.

Sources and Amounts of Emissions

Potential sources of undesirable emissions in Austin are listed in Table 37 and the locations of some of the sources are shown in Figure 25. Location of the light industry is shown in Figure 16 and heavily travelled streets and principal aircraft tracks are shown in Figure 21. Major sources of undesirable emissions are these: motor vehicles, electric power generating plants, home and commercial space heating units, incinerators and open burning, building materials processing and construction excavation, and natural vegetation. Examples of a quantatitive description of some of these sources follow.

Transportation. Using the vehicle counts from the May 1968 study described on page 68, the number of vehicle miles was computed for eight arbitrarily chosen geographical areas of the city. For each street, the number of vehicles passing in a 24-hour weekday period was multiplied by the miles of street for that number of vehicles. The results of summing all elements of vehicle miles is shown in Figure 26. With the values of vehicle miles travelled, the gross emissions for the areas were computed using currently accepted emission factors (McGraw, et al., 1971). Results are tabulated in Table 38. For comparison purposes, the gross emissions for the city were computed for the weekday traffic in 1975 using a growth factor of 1.26 based on the projected national average growth rate of traffic.[7] Results are tabulated in Table 39. Projections were not made by area because of the vastly different traffic distribution caused by the opening of new expressways and arteries by 1975.

Due to improved emission controls required in 1971, even with a projected increase in traffic of 26%, carbon monoxide, hydrocarbons, nitrogen oxides, and particulate matter are estimated to be substantially less then than in the year 1968.

Increased utilization of public transportation would decrease vehicle miles and emissions.

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[7] Control Techniques for CO, NO, HC Emissions from Mobile Sources, 1970, E.P.A., AP-66.

Aircraft. For the July 1971 scheduled airline traffic listed in Table 36, emissions below 3,500 feet are shown in Table 40. Emissions were estimated for light piston-type aircraft by assuming that the flight operations were evenly distributed over the year 1970. Results are shown in Table 41. It is clear from these aircraft emission figures that automobiles are a far more significant source than are aircraft in Austin: more than 98% of the total automobile plus aircraft emissions come from the automobile. Particulate emissions from scheduled jet aircraft can be expected to decrease as a program to install "smoke burners" progresses.

Space Heating. Natural gas consumption for the city of Austin is shown in Table 42 for the years 1967 through 1970. Residential usage in 1970 constituted nearly 42% of the total and practically all of this gas was burned for space heating and water heating if Austin follows national trends. Monthly residential gas consumption for 1969 is plotted in Figure 27 along with number of degree days per month. Assuming that 90% of the gas consumed was burned for space and water heating,[8]

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[8]Figures quoted from American Gas Association (Rymer, 1971) give 90% for space and water heating, 7.3% for cooking, 1.1% for clothes drying, and 1.6% for gas lights, air conditioning, refrigeration, incineration.

emissions per December day were calculated and are presented in Table 43. Since commercial and public authority usage is primarily in space heating and other combustion processes, emissions from these sources must be added to the inventory. In the year 1969, commercial-public authority consumed 53.5% and residential 41.2% of the total, or consumption was in the ratio 1.3 to 1. Assuming that the emission factors used for residential combustion also apply to the 53.5% share, emissions for December 1969 are estimated to be 1.3 times that for the residential usage. These figures are presented in Table 45 for comparison purposes.

Power Generation. Gross estimates of emissions from natural gas combustion for electric power generation are made for the year 1969 using total energy produced in kilowatt hours, generating efficiencies, and heating values for natural gas. For the year ending October 1, 1969, energy produced stood at 2.0 trillion KwH.[9] Wood (1971) reports efficiencies of 10,400 Btu/kwh at the

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[9] From Basic Data About Austin and Travis County, 1971, page 32.

Holly Street plant and 13,500 Btu/kwh at the Seaholm Plant. Using an average figure of 11,000 Btu/kwh, based on the above efficiencies, the heat energy required to produce 2.0 trillion kwh is 22 x 10^{12} Btu which, for a natural gas heating value of 1000 Btu/cu.ft., means that approximately 22 x 10^{9} cu.ft. were consumed. Table 44 shows the emissions from combustion of this quantity of natural gas in Austin's power plants. Although daily rates are shown for comparison purposes, these latter figures should be used with caution since gas consumption follows the seasonal variation in electric power demand which peaks in the summer months because of the air conditioning load.

To provide a basis for estimating emissions should oil be used instead of natural gas, emission factors for residual fuel oil in pounds per 1,000 gallons of oil burned were converted to pounds per Btu and compared to those for natural gas in the same units. For example, assuming heating values of 150,000 Btu/gal for oil and 1,000 Btu/cu.ft. for natural gas, emission factors for particulate matter are 53.3 lb and 15 lb per million Btu, respectively, for oil and gas. For the same efficiency of conversion to electric power, the oil produces 53.5/15 of 3.5 times as mucn particulate matter. Ratios for most of the materials listed in Table 44 are as follows:

Nitrogen oxides	1.8
Carbon Monoxide	0.7
Particulate	3.5
Aldehydes	2.2
Hydrocarbons	0.8
Sulfur Dioxide	1740 x S[10]

These factors show that substantial increases can be expected in four of the emissions including the emergence of sulfur dioxide as a major pollutant. Austin electric generating plants are equipped to burn fuel oil, and standby supplies of oil are maintained.

Incineration. A quantitative evaluation of emissions from incineration in the city was not attempted because no data were available to describe the number, types, and capacities of incinerators. Without any system

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[10]S is weight percent sulfur in oil; use a value of 2% for estimates.

for registration or inspection in the municipal building inspection department, no basic records are available. The municipal air pollution control agency is currently (March 1972) compiling a list of incinerators. In Austin, incinerators are used for solid waste disposal by supermarket chain stores, discount stores, hospitals, schools, department stores, and other miscellaneous institutions. One auto-burning incinerator is in operation (see Figure 25). Home fireplaces number in the thousands in the city where they are used primarily for pleasure on weekend days in November, December, and January. Burning of construction and land clearing debris, though permitted, is subject to control on the basis of the hazard or nuisance created. Open burning is not practiced or permitted at municipal and county refuse disposal sites. In summary, incineration is a persistent source of emissions in Austin but no data are available to characterize the emissions.

Hydrocarbons. Hydrocarbon emissions from the handling of gasoline can be expected at the bulk storage facilities concentrated in the southeastern part of the city near the intersection of Springdale Road and Airport

Boulevard. Similar emissions from filling of service station tanks and filling of automobile tanks occur at the more than four hundred gasoline service stations. Information on throughput was not available for computation of evaporative losses. Emission factors range from 12 pounds per 1,000 gallons of throughput for filling automobile tanks and service station tanks having splash fill to 7 pounds for submerged fill of station tanks.

Odors. By inspection of Figure 25 which shows the location of sanitary landfills and wastewater treatment plants, it is apparent that the Walnut Creek and Govalle treatment plants are located away from densely populated areas and also that the prevailing north-south air flow disperses odors over essentially unpopulated area. Furthermore, substantial population growth to the east and southeast is not expected. The Williamson Creek plant, although remotely located now, is in the path of the growth southward and is situated along the axis of the city coincident with the direction of the prevailing southerly winds. Through improved land use planning and continued good plant operation, the wastewater treatment plants can be only insignificant sources of undesirable emissions.

Sanitary landfills located in the north and south of the city share a location situation similar to that of the Williamson Creek wastewater treatment plant. These landfill sites will be filled and abandoned and cease to be sources of odor as the city spreads nearer to them. Distance is now sufficient for dilution to prevent effects on large numbers of people. The county and privately operated landfills north of Highway 290 and east of Ed Bluestein Boulevard are not in the path of the city's expansion, odors from them are dispersed over sparsely populated areas, and they can be closed when growth of the city encroaches upon them.

Except for an occasional accidental episode in a small chemical pilot plant or plastics fabricating plant, noxious emmissions from these industries are nonexistent in Austin.

Fugitive Dusts. Dusts from building material processing, excavations, and unpaved roads are usually a problem when wind speed is sufficient to lift loose material into the air. No quantitative description is attempted here except to show in Table 45 that, although the miles of unpaved streets in Austin have been diminshing in number, the figure stood at 170 miles in 1970.

Figures from the Texas Business Review[11] show that Austin ranked third in total building authorized in Texas in 1971, behind Houston and Dallas. Construction permits issued in January 1972 in Travis County (Austin SMSA) are an indication of the magnitude of construction planned in Austin. These permits show that 266 one-family dwelling units, 56 two-family units, and 341 apartment-building units are authorized. A large percentage of these building sites will be associated with excavation and other dust-producing activities.

Pollen. Little data are available to describe pollen concentrations in Austin. Practicing doctors of

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[11]Texas Business Review, XLVI, 2, Feb. 1972, p. 31 and XLVI, 3, March 1972, p. 62.

allergy detect types of pollen on sticky slides to assist in patient diagnosis. Pollen seasons in Austin are given in Table 46. The Allergy Foundation of America publishes a ragweed pollen index. The index figure is based on three factors which directly affect individual pollen exposure: length of season, maximum aerial concentration of pollen, and total pollen catch on test slides throughout the season. Although Austin is not represented on the list, the following cities and index numbers can be given: Big Spring, 5; El Paso, 15; San Antonio, 16; Brownsville, 24; Corpus Christi, 30; and Galveston, 36. Dallas is highest with 115. Since popular shade trees are sources of pollen in Austin, it is unlikely that levels of emissions will diminish in the near future. Juniper (cedar) covers vast areas to the west and east of the city making this source unmanageable also.

The emissions from automobiles, aircraft, and natural gas combustion are summarized in Table 45. Except for motor vehicle emissions which are the most significant, ranking of the other sources depends upon the pollutant being considered. Natural gas combustion ranks high as a source of nitrogen oxides and particulate, and ranks low as a source of sulfur oxides. Particulate from aircraft is of the same order of magnitude as the other sources. The effects of all sources of emission is reflected in ambient air data presented in the next section.

Ambient Air Quality in Austin, Texas

Pollutant concentrations in the air of Austin are presented in Tables 48 through 53. Except for the radioactivity levels, the data were derived from that reported by the Texas Air Pollution Control Services of the Texas State Department of Health. Examination of the data reveals that formulation of accurate generalizations about gaseous pollutants is difficult because of lack of several years of continuous data. The small geographic coverage of both gaseous and particulate samples also makes discussion hazardous at best. Nevertheless, an attempt is made in Table 54 to summarize the data, to compare it to Federal standards, and to characterize the ambient air quality relative to each pollutant. On the whole, air quality is good in Austin except for high ozone levels reported in the year 1971 at the one sampling site utilized.

Low incidence of persisting air stagnation conditions usually precludes development of generalized poor quality although night-time and early morning inversions do occur (see Table 25). Poor mixing over the period of a few early morning hours occasionally causes the formation of photochemical smog, but inversion breakup occurs consistently by mid-morning. Although data are not available for reactive hydrocarbons, it can be said that these materials exist and possibly in undesirable quantities because of the emissions from automobiles (see Tables 38 and 39).

Radioactivity in Austin's air is characterized in Tables 52 and 53 in terms of plutonium in the suspended particulate and gross beta radioactivity in the surface air, respectively. Using maximum permissible concentrations for radionuclides in air for occupational exposure for a 168-hour week,[12] the plutonium 239 activity reported falls well under the acceptable concentration. The gross beta radioactivity also falls below MPC values for unidentified radionuclides in air. (Note that the above determinations are not entirely accurate in principle

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[12]See Radiological Health Handbook, 1970 revised edition, pp. 206-209.

since the radiation dose reaching the critical organ from suspended particulate matter depends on size of particles, solubility at lung surfaces, etc. The comparisons are conservative, however.)

Summary

The quality of the air and what affects it in Austin may be summarized as follows:

1. Mixing and ventilation are good except for periods in the months of December and January.
2. There are no serious topographic channelling or stagnation problems.
3. Lakes on the Colorado River have only a local effect on air movement.
4. Low-lying regions near the river and the creeks are susceptible to cold air drainage stagnation.
5. Numerous trees and grassy areas serve as dilution and collection mechanisms but add pollens to the air.
6. There are few large industrial emission sources.
7. Industry locations north and south of the city are unfavorable because prevailing north-south

air flows transport pollutants to the population.

8. The elliptical shape of the city causes concentration of pollutants along its long axis which is coincident with prevailing wind directions.
9. There is complex channelling in areas of tall buildings and along the interregional highway with its two levels now under construction.
10. Principal emission sources are automobiles, natural gas combustion, incineration, excavations, and unpaved streets, and vegetation.
11. The ambient air condition is good with occasional periods of air stagnation and pollutant buildup.
12. Persons are affected by smokes, odors, and dusts at all times of the year at various locations in the city.
13. The attitude of the people toward air pollution abatement is good.

Recommendations

For a more nearly complete study of the air pollution potential in Austin, steps should be taken to obtain a more nearly complete and more accurate emissions inventory. Data are needed on incinerators and their emissions. Time variation of emissions is needed for automobiles and natural gas combustion, both on a daily and seasonal basis. Ambient air data are needed for more locations in the city for all pollutants of interest, and more data are needed on the amounts of reactive hydrocarbons.

Studies should be made for future emission levels from all existing sources using best estimates of population growth and shifting patterns of culture. City planners should be made more aware of the effects of climatology and physical geography upon the air pollution potential in order to optimize longrange land-use planning in the city. Large-size versions should be made of many of the maps appearing in this thesis and transparent overlays should be made to facilitate planning and studies. A rural location for monitoring ambient air quality should be established nearby for control or reference purposes.

Periodic updating of emissions and ambient air quality data should be planned for and implemented.

IV. CONCLUSIONS

A method for study of the air pollution potential of an urban area has been outlined in terms of pertinent parameters in air pollution technology, sources for data and background information, and methods of effective presentation. When applied to the city of Austin, the method has provided a series of efficient and effective checklists in the collection, analysis, and presentation of data. The details of information gathering have been demonstrated by the Austin study and deficiencies in certain data have been discovered. Use of an example city has shown that the methodology is directly applicable to a real live urban area.

TABLE 20

WINDS, AUSTIN, TEXAS

	Mean Speed	Prevailing Direction	Fastest mile Speed	Direction	Year
Jan.	9.8	S	47	N	1962
Feb.	10.2	S	57	N	1947
March	11.0	S	44	W	1957
April	10.8	SSE	44	NE	1957
May	10.1	SSE	47	NE	1946
June	9.6	S	49	SE	1956
July	8.6	S	43	SE	1969
Aug.	8.3	S	53	NW	1969
Sept.	8.0	S	45	NE	1961
Oct.	8.2	S	47	NW	1967
Nov.	9.1	S	48	NW	1951
Dec.	9.2	S	49	NW	1956
Year	9.4	S	57	N	Feb. 1947

SOURCE: Local Climatological Data, 1970, Austin, Texas. U.S. Dept. of Commerce

TABLE 21

MEAN NUMBER OF HOURS OF SUNSHINE

1931-60 Austin, Texas

January	148
February	152
March	207
April	221
May	266
June	302
July	331
August	320
September	261
October	242
November	180
December	160
Annual	2790

SOURCE: National Climatology Atlas of U.S., 1963. Sheet for Mean Total Hours of Sunshine, Monthly, Annual, U.S. Dept. of Commerce.

TABLE 22

PERCENT POSSIBLE SUNSHINE

Austin, Texas

January	48
February	51
March	54
April	53
May	58
June	70
July	78
August	77
September	69
October	67
November	58
December	51
Annual Mean	62%

SOURCE: Local Climatological Data, 1970. Austin, Texas. U.S. Dept. of Commerce.

TABLE 23

MEAN DAILY SOLAR RADIATION

IN LANGLEYS FOR SAN ANTONIO, TEXAS

(Not available for Austin, Texas)

January	279
February	247
March	417
April	445
May	541
June	612
July	639
August	585
September	493
October	398
November	295
December	256
Annual Mean	442

1 Langley = $\frac{1 \text{ Gm Cal}}{\text{Cm}^2}$

SOURCE: National Climatology Atlas of U.S., 1963, Sheet for Mean Daily Solar Radiation, Monthly and Annual. U.S. Dept. of Commerce.

TABLE 24

ESTIMATED MEAN MAXIMUM MIXING

Depths (Feet Above Surface)

Austin, Texas

December	1800
January	1570
February	2530
March	3120
April	3770
May	4170
June	4920
July	5910
August	6230
September	4820
October	3770
November	2690

SOURCE: Weather Bureau State Climatologist. E.S.S.A., Austin. Texas.

TABLE 25

FREQUENCY OF INVERSIONS AND/OR

ISOTHERMAL LAYERS BASED BELOW 500 FT.

(% of Total Hours), Austin, Texas

December	30-35
January	30-35
February	30-35
March	20
April	20
May	20
June	10-15
July	10-15
August	10-15
September	25-30
October	25-30
November	25-30

SOURCE: Weather Bureau State Climatologist, E.S.S.A.
Austin, Texas

TABLE 26

AVERAGE SURFACE POOL TEMPERATURES FOR LAKES

TRAVIS AND AUSTIN VS. AVERAGE AIR TEMPERATURE, °F

Month	Year	Air	Lake Travis Pool	Lake Travis Tail Race	Lake Austin Pool
December ('43,'62,'64)	1944	51.1	57.2 Warm	54.7	54.3 Warm
January	1963	48.7	55.7 Warm	-	53.7 Warm
February	1965	51.7	57.7 Warm	-	53.7 Warm
March	1944	66.0	62.7 Cold	59.5	64.0 Cold
April	1963	71.4	62.2 Cold	-	63.8 Cold
May	1965	66.5	63.2 Cold	-	72.6 Cold
June	1944	83.3	84.2 Warm	66.5	75.8 Cold
July	1963	85.6	81.7 Cold	-	75.6 Cold
August	1965	83.6	79.2 Cold	-	72.6 Cold
September	1944	68.9	78.7 Warm	73.3	73.1 Warm
October	1963	73.2	76.5 Warm	-	74.5 Warm
November	1965	70.4	72.5 Warm	-	72.1 Warm
12-Mo.	1944	67.4	70.7 Warm	63.5	66.7 Cold
Avg.	1963	69.7	69.3 Cold	-	69.7 Same
	1965	68.1	68.4 Warm	-	64.9 Cold

SOURCE: For Air, Local Climatological Data, 1970, Austin, Texas, U.S. Dept. of Commerce.
For Lakes, LCRA Bi-monthly Temperature Data, Lakes Travis and Austin.

TABLE 27

TOWN LAKE POOL SURFACE

TEMPERATURES VS. AVERAGE AIR TEMPERATURE, °F

Date	Air	Town Lake Pool	
March 15, 1968	57.3	59.6	Warm
May 3, 1968	74.2	68.9	Cold
July 10, 1968	82.2	82.0	Cold
August 2, 1968	84.1	87.2	Warm
November 1, 1968	55.8	90.5	Warm
January 27, 1969	53.6	79.4	Warm

SOURCE: Fruh and Davis, EHE 69-07, CRWR 40, March 1969.

TABLE 28

PHYSICAL DESCRIPTION OF LAKES

IN AUSTIN, TEXAS AREA

	Lake Travis	Lake Austin	Town Lake	Decker Lake
Normal Surface Elevation	681.1	492.8	428.9	555.0
Maximum Surface Elevation	714.1	492.8	428.9	--
Surface Area - Normal	18,930ac.	1,830ac.	--	1,300ac.
Surface Area - Maximum	29,013ac.	1,830ac.	--	1,300ac.
Capacity - Normal	1,172,000 ac.ft.	21,000 ac.ft.	--	33,940 ac.ft.
Length by River Channel Miles	63.75 mi.	20.25 mi.	5.5mi.[1]	Not on river
Maximum Lake Width	11,500ft.	1,300ft.	2,000ft.[1]	5,600 to 6,800 ft.
Location of Maximum Width	~1 mi. up from dam	~1 mi. up from dam	2,000ft. up from dam	400ft. up from dam
Retention Time	80 to 1800 days[3]	Main stream reservoir	Main stream reservoir	--
Depth	180ft.[2]	10-50ft.	30ft. Max.	65ft. at dam

NOTES: Lake Austin and Town Lake are main stream reservoirs. Decker Lake level is maintained by pumping from Colorado River below Town Lake.

[1]Scaled from a map.

[2]In old river channel, with surface at 681.

[3]Fruh el al, 1969.

TABLE 29

ABSOLUTE ELEVATIONS AND ELEVATIONS

RELATIVE TO SURFACE OF TOWN LAKE, AUSTIN, TEXAS AREA

Location	Absolute Elevation	Elev. Above Town Lake
Town Lake Surface	429	0
Barton Springs Pool	440	11
Webberville Rd. at Walnut Creek(Bridge approach)	450	21
Govalle Playground	450	21
Lamar St. at 19th St.	480	51
Lake Austin Surface	493	64
East Riverside Drive at Ben White Blvd.	530	101
Travis State School	530	101
North End, Main Runway, Bergstron AFB	541	112
Capitol Grounds	545	116
Manor Rd. at Ed Bluestein	550	121
Decker Lake Surface	555	126
Univ. of Texas, near tower	596	167
Austin State School	600	171
Municipal Airport	615	186
Austin State Hospital	650	221
Ben White Blvd. at IH 35	650	221
Northwest Pool	680	251
Ben White Blvd. at 290W	700	271
Balcones Dr. at Spicewood Springs Rd.	710	281
Lake Travis Spillway	714	285
Lamar Blvd. at Hwy. 183	760	331
Mount Bonnell	780	351
Mount Barker	840	411
North Hills Dr. at Mesa Dr.	900	471
Bee Caves Rd. at Loop 360	900	471
Mount Larson	920	491
Cat Mountain	920	491
Jollyville Plateau (HWY. 2222. Mile east of HWY. 620)	1060	631
River below Longhorn Dam	400	29

SOURCE: U.S. Dept of Interior Geological Survey Topographic Maps, 7.5 min. Series, 1966, Austin East, West. Montopolis, Oak Hill.

TABLE 30

PRECIPITATION, THUNDERSTORMS, AND RELATIVE HUMIDITY, AUSTIN TEXAS

	Precipitation							Snow Ice Pellets					No. of Days		Relative Humidity			
	Normal total	Maximum monthly	Year	Minimum monthly	Year	Maximum in 24 hrs.	Year	Mean total	Maximum monthly	Monthly	Maximum in 24 hrs.	Year	Thunderstorms	Heavy Fog	Hour 00	Hour 06	Hour 12	Hour 18
		29		29		29		29	29		29		29	29	9	9	9	9
Jan.	2.35	7.94	1968	0.07	1942	3.44	1965	0.6	7.0	1944	7.0	1944	1	4	73	78	60	57
Feb.	2.58	6.34	1958	0.28	1954	3.73	1958	0.5	6.0	1966	6.0	1966	2	3	71	79	57	52
Mar.	2.13	4.98	1945	0.22	1963	2.68	1951	0.1	2.0	1965	2.0	1965	3	2	71	79	55	49
Apr.	3.55	9.93	1957	0.10	1961	3.86	1942	0.0	0.0		0.0		5	1	78	83	59	55
May	3.71	9198	1965	0.81	1960	4.49	1970	0.0	0.0		0.0		7	1	80	87	59	57
June	3.22	11.43	1961	T	1967	6.50	1964	0.0	0.0		0.0		4	*	78	88	54	52
July	2.18	8.40	1961	0.00	1962	5.46	1961	0.0	0.0		0.0		4	*	71	86	48	42
Aug.	1.94	6.21	1966	0.00	1952	4.68	1945	0.0	0.0		0.0		5	*	70	84	48	42
Sep.	3.44	8.11	1942	0.07	1947	4.61	1942	0.0	0.0		0.0		4	1	78	86	56	55
Oct.	2.83	12.31	1960	T	1952	4.68	1945	0.0	0.0		0.0		3	2	73	82	52	53
Nov.	2.12	7.91	1946	T	1970	3.98	1946	T	1.0	1959	1.0	1959	1	2	75	81	55	57
Dec.	2.53	5.91	1944	T	1950	4.02	1953	T	T	1963	T	1963	1	4	74	80	59	58
Year	32.58	12.31	Oct 1960	0.00	Jul 1962	7.22	Oct 1960	1.2	7.0	Jan 1944	7.0	Jan 1944	40	23	74	83	55	52

SOURCE: Local Climatological Data, 1970, Austin, Texas. U.S. Dept. of Commerce.

TABLE 31

RAINFALL AT AIRPORT VS. AREA ABOVE

38th ST. IN WALLER CREEK WATER SHED, INCHES, 1968, AUSTIN, TEXAS

Month	Airport	Above 38th St.	
January	7.94	8.37	
February	1.64	1.63	
March	2.09	2.77	
April	1.87	2.49	
May	8.75	6.68	Note: Locations are approximately 2 miles apart.
June	3.10	2.90	
July	3.11	2.90	
August	0.74	0.77	
September	3.42	2.98	
October	0.60	0.58	
November	4.91	5.59	
December	0.55	0.69	
Year	38.72	38.35	

SOURCE: Local Climatological Data. 1970. Austin, Texas. U.S. Dept. of Commerce; Robbins, W.D., Annual Compilation and Analysis of Hydrologic Data for Urban Studies in the Austin, Texas Metropolitan Area. 1969. U.S. Dept. of Interior.

TABLE 32

ANNUAL VISIBILITY, AUSTIN, TEXAS

Visibility, miles	% of Time
0 to 1/8	0.7
3/16 to 3/8	0.7
1/2 to 3/4	0.5
3 to 6	5.1
7 to 15 and up	90.2
	100%

SOURCE: Summary of Hourly Observations, Austin, Texas, 1951-60, U.S. Department of Commerce, 82-41.

TABLE 33

TEMPERATURE, AUSTIN, TEXAS

	Temperature							
	Normal			Extremes				Normal heating days (Base 65°)
Month	Daily maximum	Daily minimum	Monthly	Record highest	Year	Record lowest	Year	
Jan.	60.3	40.5	50.4	86	1963	12	1963	468
Feb.	64.0	43.5	53.8	87	1962	22	1967	325
Mar.	70.6	48.7	59.7	96	1967	23	1962	223
Apr.	78.0	57.3	67.7	98	1963	35	1970	50
May	85.2	64.9	75.1	99	1967	47	1970	0
June	92.0	71.7	81.9	100	1967	53	1970	0
July	95.1	73.9	84.5	103	1964	64	1970	0
Aug.	95.6	73.7	84.7	105	1969	61	1967	0
Sep.	89.7	68.5	79.1	102	1963	47	1967	0
Oct.	81.9	59.5	70.7	95	1963	39	1970	31
Nov.	69.6	47.9	58.8	89	1963	27	1966	225
Dec.	62.8	42.6	52.7	84	1966	21	1966	388
Year	78.7	57.7	68.3	105	Aug 1969	12	Jan 1963	1711

SOURCE: Local Climatological Data, 1970, Austin, Texas, U.S. Department of Commerce.

TABLE 34

BREAKDOWN OF LABOR FORCE, AUSTIN, TEXAS

FOR THE YEAR 1970--ANNUAL AVERAGE

Civilian Work Force	132,300
Unemployment	3,100
Employment Total	129,200
Manufacturing	11,550
Durable Goods	7,250
Ordnance and Accessories	0
Lumber and Wood Products	200
Furniture and Fixtures	900
Stone, Clay and Glass Products	600
Primary Metal Industries	0
Fabricated Metal Industries	400
Machinery, Transportation Equipment, and Professional and Scientific Goods	4,050
Electrical Machinery, Equipment, and Supplies	700
Other	400
Non-durable Goods	4,300
Food and Kindred Products	1,900
Textile Mill Products	-
Apparel and Other Finished Textiles	-
Paper and Allied Products	-
Printing, Publishing, and Allied Industries	1,700
Chemicals and Allied Products	400
Petroleum Refining and Related Industries	-
Rubber and Miscellaneous Plastic Products	150
Leather and Leather Products	-
Other	200
Non-Manufacturing	55,503
Agriculture, Forestry, Fisheries	100
Mining	200
Contract Construction	8,150
Transportation, Communication and Utilities	3,150

TABLE 34 (Cont.)

Transportation and Allied Services	1,350
Communication	1,950
Wholesale Trade	3,700
Retail Trade	19,000
Finance, Insurance, Real Estate	5,700
Business and Personnel Services	8,400
Medical and Professional Services	6,750
Government	48.800
Federal	6,250
State and Local	39,550
Other Employment	14,850
Agricultural	1,450

SOURCE: Annual Labor Area Work Force Report, 1970, Austin, Texas, rev. Jan. 1971, Texas Employment Commission.

TABLE 35

POPULATION, DWELLING UNITS,

ACREAGE, AND DENSITY OF CENSUS TRACTS

Austin: April 1, 1968

Census Tract	Population	Dwelling Units[1]	Gross Acreage	Density, Persons/acre
1	7,741	2,652	2,195	3.5
2	13,183	3,837	1,486	8.9
3	13,785	5,846	2,306	6.0
4	10,324	3,988	957	10.8
5	4,375	1,948	320	13.7
6	16,859	3,211	579	29.1
7	3,759	2,124	400	9.4
8	17,022	4,975	1,338	12.7
9	12,008	3,097	979	12.3
10	6,416	1,653	595	10.8
11	3,486	1,855	621	5.6
12	3,977	1,701	625	6.4
13	18,835	5,827	2,398	7.9
14	5,434	2,256	871	6.2
15	20,451	7,062	2,841	7.2
16	22,139	7,048	2,724	8.1
17	5,673	2,603	1,470[2]	3.9
18	14,156	5,990	3,289	4.3
19	2,275	816	803[3]	2.8
20	6,899	2,209	1,513	4.6
21	24,814	8,367	4,479	5.5
22	1,490	390	734[4]	2.0
23	6,773	2,614	1,555	4.4
24	5,452	2,385	858	6.4
TOTAL	247,605	84,454	35,701	6.9

[1]As of December 31, 1968.

[2]Does not include City Park and Lake Austin frontage west of Dry Creek.

[3]Does not include Lake Austin frontage north of Tom Miller Dam.

[4]Does not include Decker Lake or Travis State School.

SOURCE: Reported in Basic Data, City of Austin and Travis County, 1971, p. 43.

TABLE 36

HOURLY SCHEDULED AIRLINE OPERATIONS

AUSTIN, TEXAS

July, 1971

Time	Departures	Arrivals	Total
6-7 a.m.		DC-9: 1 727: 1	2
7-8	DC-9: 3 727: 1	DC-9: 2	6
8-9	DC-9: 1 99: 1	DC-9: 1 727: 2 99: 1	6
9-10	727: 1	727: 1	2
10-11	727: 1 DC-9: 1 T.J.: 1	T.J.: 1 DC-9: 2 727: 1	7
11-12noon	DC-9: 1		1
12-1		727: 1	1
1-2	727: 1 T.J.: 1	DC-9: 2 T.J.: 1	5
2-3	DC-9: 2	DC-9: 1	3
3-4	DC-9: 1	DC-9: 1 727: 1	3
4-5	DC-9: 3 727: 1 99: 1	DC-9: 1 99: 1	7
5-6		DC-9: 1	1
6-7	T.J.: 1	DC-9: 1 727: 1 T.J.: 1	4

TABLE 36 (Cont.)

Time	Departures	Arrivals	Total
7-8	DC-9: 2 727: 2	DC-9: 1 727: 2	7
8-9	T.J.: 1	T.J.: 2	3
9-10	DC-9: 1 T.J.: 1	DC-9: 1	3
10-11	727: 1 DC-9: 1	727: 1 DC-9: 1	4
11-12			0
Operations			64

Aircraft Type Key:

DC-9: Douglas, 2 engines, fan jet, Pratt & Whitney JT-8D engine.

727 : Boeing, 3 engines, turbofan (fan jet), Pratt & Whitney JT-8D engine.

T.J.: Convair, 2 engines, turboprop, General Motors Allison 501-D13.

99 : Beech, 2 engines, turboprop.

SOURCE: Airline schedules from Austin Chamber of Commerce.

TABLE 37

POTENTIAL SOURCES AND EMISSIONS

IN AUSTIN, TEXAS

Source	Emission
Automobiles	CO, H.C., NO_x, SO_x, lead, aldehydes, Particulate
Aircraft	CO, H.C., NO_x, aldehydes, particulate
Electric Power Generation	
Natural Gas	NO_x, SO_x, aldehydes, particulate
Oil (standby only)	SO_x, NO_x, H.C., CO, aldehydes, particulate
Space Heating - Natural Gas	NO_x, SO_x, CO, particulate
Incineration	CO, particulate, NO_2, organic acids (acetic), SO_2, H.C. (hexane), aldehydes, ammonia
Furniture factories	
Department stores	
Supermarkets	
Institutions	
Auto salvage	
Construction debris	
Landclearing debris	
Backyard	
Home fireplaces	
Bulk Gasoline Handling	H.C.
Gasoline Service Stations	H.C.
Wastewater Treatment Plants	Odors, bacteria
Sanitary Landfill	Odors, methane, dusts
Industry	
Chemical plants	Various gases, particulates
Asphalt batching plants	Particulate, dusts, water vapor
Building materials plants (Stone, sand, cutting, polishing)	Dusts
Feed and milling plants	Dusts
Food processing plants	Odors
Ready-mix concrete plants	Dusts
Lime plants	Dusts
Building excavations	Dusts
Sandblasting of masonry buildings	Dusts, silica particles
Unpaved roads	Dusts
Vegetation	Pollens, leaf parts, spores

SOURCE: Various sources.

TABLE 38

ESTIMATED AUTOMOBILE EMISSIONS FOR

AUSTIN, TEXAS IN YEAR 1968, WEEKDAY TRAFFIC DENSITY

Area (See Fig. 26)	1	2	3	4	5	6	7	8		Emission Factor lb/1000 v-m
Thousands of Vehicle Miles/Day	164	536	414	193	209	433	296	104	2,329	-
									Total Lb/Day	
Carbon Monoxide (CO) lb/day	36,100	118,000	91,000	42,400	46,000	95,500	65,200	22,900	512,000	220
Hydrocarbons lb/day	6,750	22,100	17,050	7,940	8,600	17,900	12,200	4,280	96,000	41.2
Nitrogen Oxides (NO_2) lb/day	3,240	10,600	8,170	3.810	4,130	8,570	5,850	2,050	46,200	19.8
Sulfur Oxides (SO_2) lb/day	65	213	164	76	83	172	118	41	925	0.397
Particulate Matter lb/day	108	578	273	127	138	286	195	68	1,540	0.661
Aldehydes lb/day	130	425	328	153	166	244	235	82	1,850	0.794
Organic Acids (Acetic) lb/day	47	153	119	55	60	124	85	30	665	0.286

Emission factors are adapted from McGraw, N.J., R.L. Duprey. Compilation of Air Pollutant Emission factors. Preliminary document. E.P.A., Research Triangle Park, N.C., April 1971, p. 24.

TABLE 39

ESTIMATED AUTOMOBILE EMISSIONS FOR

AUSTIN, TEXAS IN YEAR 1975, WEEKDAY TRAFFIC DENSITY

		Emission[2] Factor lb/1000v-m
Thousands of Vehicle Miles/Day	2,935[1]	
Carbon Monoxide (CO)	388,000 lb/day	132.3
Hydrocarbons	49,400 lb/day	16.8
Nitrogen Oxides (NO_2)	45,400 lb/day	15.4
Sulfur Oxides (SO_2)	1,165 lb/day	0.397
Particulate Matter	645 lb/day	0.220
Aldehydes	2.330 lb/day	0.794
Organic Acids (Acetic)	839 lb/day	0.286

[1]Based on Projected National Average Growth Rate of 1.26 x 1968 Year Vehicle Mileage.

[2]From McGraw et al. 1971, p. 24.

TABLE 40

AIRCRAFT EMISSIONS, POUNDS PER DAY, AUSTIN, TEXAS

JULY 1971, SCHEDULED AIRLINES ONLY

Emission	DC-9 and 727	Turbojet	Total, lb/day
Particulates	415	60	475
CO	940	20	960
HC - controlled	175	-	175
HC - uncontrolled	2,950	30	2,980
SO_x	120	10	130
NO_x	415	50	465
Aldehydes	30	2	32

Using Emission factors from McGraw et al, 1971, p. 32.

TABLE 41

ESTIMATED EMISSIONS FROM LIGHT AIRCRAFT, POUNDS

PER DAY, AUSTIN, TEXAS, YEAR 1970

For 167,000 operations or 83,500 landing-takeoff cycles or 228 cycles per day for a 365 day year.

Particulates	45
CO	2,740
HC	90
SO_x	450
NO_x	45
Aldehydes	20

Using Emission factors from McGraw et al, 1971, p. 32.

TABLE 42

NATURAL GAS CONSUMPTION

AUSTIN, TEXAS, 1967-70

Year	Residential	Commercial	Industrial	Public Auth.
	(MCF - thousands of cubic feet)			
1967	4,647,000	2,244,000	589.400	4,170,000
1968	5.619,000	2,788,000	671,600	4.453,000
1969	5,683.000	2.938,000	630.000	4,582,000
1970	6,183.000	3,216.500	538.200	4,881.000
1970	41.7%	21.7%	3.6%	33.0%

Source: Hosford. 1971.

TABLE 43

ESTIMATED EMISSIONS FROM

COMBUSTION OF NATURAL GAS FOR RESIDENTIAL

SPACE HEATING, DECEMBER 1969, AUSTIN, TEXAS

December 1969 Residential Consumption[1]	723 million cu. ft.
90% Used for Space Heating or Water Heating	650.7 million cu. ft.
Converted to Daily Consumption (÷31)	20.99 million cu. ft.
Emissions[2]	lb/day
Nitrogen Oxides (NO_2)	1,050
Carbon Monoxide (CO)	420
Particulate Matter	398
Aldehydes (HCHO)	210
Hydrocarbons as CH_4	168
Sulfur dioxide[3]	12
Organics	21

[1]Hosford, 1971.

[2]Emission factors from McGraw et al, 1971, p. 11.

[3]Assuming sulfur content of 2000 grains/million cubic feet.

TABLE 44

ESTIMATED EMISSIONS FROM

COMBUSTION OF NATURAL GAS FOR ELECTRIC

POWER GENERATION, YEAR 1969, AUSTIN, TEXAS[1]

Emissions[2]	tons/year	lb/day[3]
Nitrogen oxides (NO_2)	3,190	17,905
Carbon monoxide (CO)	4.4	24.1
Particulate matter	165	905
Aldehydes (HCHO)	33	181
Hydrocarbons as CH_4	440	2,410
Sulfur dioxide[4]	6.6	36.2
Organics	44	241

[1]Year ending October 1, 1969; all plants, producing 2 X 10^9 kwh/yr.

[2]Emission factors from McGraw et al, 1971, p. 11.

[3]To be used with caution since generating level varies seasonally.

[4]Assuming sulfur content of 2000 grains/million cubic feet.

TABLE 45

COMPARISON OF SIGNIFICANT EMISSION SOURCES

AUSTIN, TEXAS - ALL FIGURES IN POUNDS PER DAY[1]

	Year 1968 Weekday Traffic	Year 1975 Weekday Traffic	July 1971 Scheduled Aircraft	1970 Light Aircraft	Dec 1969 Residential Space Heating	Dec 1969 Commercial Public Auth Space Heating	Year 1969 Electric Power Generation
Carbon monoxide	512,000	388,000	960	2,740	420	545	24
Hydrocarbons	96,000	49,400	175	90	168	218	2,410
Nitrogen oxides	46,200	45,400	465	45	1,050	1,365	17,500
Sulfur oxides	925	1,165	130	450	12	15	36
Aldehydes	1,850	2,330	32	20	210	273	181
Organic acids	665	839	--	--	21	27	241
Particulate	1.540	645	475	45	398	518	905

[1]See tables 38,39,40.41,43 and 44 and the text for important qualifying information before using these figures.

TABLE 46

UNPAVED ROAD MILEAGE, AUSTIN, TEXAS

	1960	1965	1970
Total Street Miles	690	774	934
Unpaved Miles	310	201	170
%	44.9%	25.9%	18.2%
Paved Miles	380	573	764
%	55.1%	74.1%	81.9%

SOURCE: Basic Data for City of Austin and Travis County, 1971, p. 29.

TABLE 47

POLLEN SEASONS IN AUSTIN, TEXAS

Spring	Pecan, oak, Spring elm, cottonwood, sycamore, hazelberry.
Summer-Fall	Bermuda grass, Johnson grass.
Fall	Ragweed, marshelder, Fall elm.
December-February	Juniper (commonly called cedar)

SOURCES: Allergy Foundation of America, 1966; King, 1972.

TABLE 48

POLLUTANT CONCENTRATIONS

CITY OF AUSTIN, JUNE 1967

FROM 27 SAMPLING SITES

Pollutant	Range[1]	Mean[1]	Remarks
Particulate	21-236	56(Geo)	97% Samples <125
Sulphates	1.7-18	5.4	
Nitrates	0.2-3.0	1.3	
Benzine Soluble Fraction	1.0-11.3	3.3	
Lead	<0.1-1.3	0.3	
SO_2	<0.05ppm	-	
H_2S	<0.005ppm	-	
NO_2	<0.02ppm	-	
HC (total)	5ppm	3ppm	
Aldehydes	0.002-0.006ppm	-	
Ozone	<0.01ppm	-	

[1]Micrograms per cubic meter unless noted.

SOURCE: Air Quality Survey of Austin, Texas, June 1967. Report by Texas State Department of Health. February 1969.

TABLE 49

DUSTFALL, CITY OF AUSTIN, 1970

July	Aug	Sep	Oct	Nov	Dec	
2.1	5.7	5.2	12.0	6.3	5.1	in tons/sq.mi/mo.

SOURCE: Annual Report, 1970, Texas Air Sampling Network, Texas Department of Health, Air Control Section.

TABLE 50

POLLUTANT CONCENTRATIONS, CITY OF AUSTIN

1961-1970. (Micrograms per Cubic Meter)

Pollutant		1961	1962	1963	1964	1965	1966	1967	1968	1969	1970
Suspended Particulate	Yearly Avg.	76	146	122	94	81	97	103	69	54	64
	Quarterly Avg										
	1								57	46	62
	2								61	51	66
	3								65	48	53
	4								92	71	75
Benzine Soluble-Organic	Yearly Avg.	5.4	5.5	5.5	6.2	5.6	5.8	5.5	5.6	4.2	4.2
	Quarterly Avg.										
	1								5.2	4.2	4.6
	2								5.0	3.4	2.4
	3								6.7	3.0	3.5
	4								5.3	6.3	6.4
Sulfate	Yearly Avg.								4.5	5.5	6.4
	Quarterly Avg.										
	1								4.1	4.7	4.0
	2								---	12.6	14.3
	3								7.1	2.5	4.9
	4								2.2	2.3	2.5
Nitrate	Yearly Avg.								2.5	2.1	2.0
	Quarterly Avg.										
	1								2.2	3.2	1.1
	2								---	3.0	4.9
	3								2.8	2.0	1.6
	4								2.4	0.3	0.4

TABLE 50 (Cont.)

Pollutant		1961	1962	1963	1964	1965	1966	1967	1968	1969	1970
Lead	Yearly Avg.								2.0	1.2	0.8
	Quarterly Avg.										
	1								1.4	1.7	0.3
	2								---	0.3	0.5
	3								2.6	0.8	0.4
	4								2.1	1.8	2.1

SOURCE: Annual Report 1970. Texas Air Sampling Net Work, Texas State Dept. of Health, Air Control Section.

TABLE 51

POLLUTANT CONCENTRATIONS

CITY OF AUSTIN, YEAR 1971

Location	30°17'00"N. Lat. 97°44'00"W. Long.	Pollutant:	Carbon Monoxide
Interval	6/21/71 to 9/30/71	Results: Max 1hr.	9.8μg/m³
No. of Samples	1739	Max. 8hr.	4.3
		Arith. Mean	1.3
Sampling	Continuous 1-hour	Std. Dev.	1.3
		Geo. Std. Dev.	23.42
Location	30°16'00"N. Lat. 97°44'00"W. Long.	Pollutant:	Carbon Monoxide
Interval	8/23/71 to 9/28/71	Results: Max. 1 hr.	13.2
		Max. 8 hr.	4.7
No. of Samples	229	Arith. Mean	2.3
		Std. Dev.	1.7
Sampling	Continuous 1-hour	Geo.Std.Dev.	2.47
Location	30°18'50"N. Lat. 97°42'50"W. Long.	Pollutant:	NO_2
Interval	7/20/71 to 9/29/71	Results: Max. 24hr.	178μg/m³
		Arith. Mean	69
No. of Samples	23	Est.Ann.Mean	78
		Std.Dev.	38.4
Sampling	three-day	Geo.Std.Dev.	1.9
Location	30°20'00"N. Lat. 97°45'20"W. Long.	Pollutant:	Ozone
		Results: Max. 1-hr	293μg/m³
Interval	6/20/71 to 9/30/71	Arith. Mean	50
No. of Samples	2,134	Std. Dev.	39
Sampling	Continuous 1-hr.	Geo.Std.Dev.	2.89
Location	30°18'50"N. Lat. 97°42'50"W. Long.	Pollutant:	Particulate
		Results: 24-hr. max.	116μg/m³
Interval	1/5/71 to 11/16/71	Arith.Mean	62
No. of Samples	30	Std. Dev.	21
Sampling	24-hr. samples	Geo. Mean	59
		Geo.Std.Dev.	1.4

SOURCE: Texas Implementation Plan, Jan. 28, 1972, Texas State Department of Health, Air Pollution Control Services.

TABLE 52

PLUTONIUM IN AIRBORNE

PARTICULATES, AUSTIN, TEXAS, YEAR 1970, a Ci/m^3

(a Ci is attocurie or 10^{-18} Ci)

	Plutonium-238	Plutonium-239
Jan-March	7	42
April-June	11	110
July-Sept	6	73
Oct-Dec	No Sample	No Sample

SOURCE: Radiological Health Data and Reports, 12, 3 and 6.

TABLE 53

GROSS BETA RADIOACTIVITY IN

SURFACE AIR, AUSTIN, TEXAS

January-February, 1971

(p Ci is picocurie or 10^{-12} Ci)

	No. Samples	Gross beta radioactivity (5-hour field estimate) pCi/m^3		
		Max	Min	Avg
January 1971	1	2	2	2
February 1971	5	2	1	2

SOURCE: Radiological Health Data and Reports, 12, 5 and 6.

TABLE 54

SUMMARY FOR AMBIENT AIR QUALITY IN AUSTIN, TEXAS

FIGURES ARE IN μgrams/m^3 EXCEPT AS NOTED

Pollutant	Standards Primary	Secondary	Austin Levels	Relative Air Quality
Suspended particulate	75	60	54 to 146	Acceptable for years 1968-70, earlier years fair.
Sulfur dioxide (SO_2)	80	60	Less than 150 (threshold)	No sulfur dioxide problem unless power plants use high-sulfur fuel oil in place of natural gas.
Carbon monoxide (CO)	10	10	4.3 and 4.7	Good except high concentrations can be expected on roadways in peak traffic hours.
Nitrogen dioxide (NO_2)	100	100	78	Acceptable but emissions from automobiles and power plants are substantial.
Ozone (O_3)	160	160	293	Not acceptable based on maximum 1 hr. concentration; low incidence of stagnation conditions lessens prob.
Benzene soluble fraction	None	None	4.2 to 6.2	Indicates low level of organic material in suspended particulate.
Sulfate	None	None	4.5 to 6.4	Indicates low degree of corrosiveness.
Nitrate	None	None	2.0 to 2.5	Indicates low degree of corrosiveness.
Lead	None	None	0.8 to 2.0	Relatively low but higher concentrations can be expected on roadways in peak traffic hours.
Hydrocarbons	160 (non-methane)	160 (non-methane)	No data available	June 1967 data for total hydrocarbons and aldehydes indicates relatively low concentrations at the time.
Dustfall	None	None	2.1 to 12 tons/sq.mi./month	Relatively clean if average urban value is considered to be in 30 to 50 range.

SOURCE: Tables 19, 48-51.

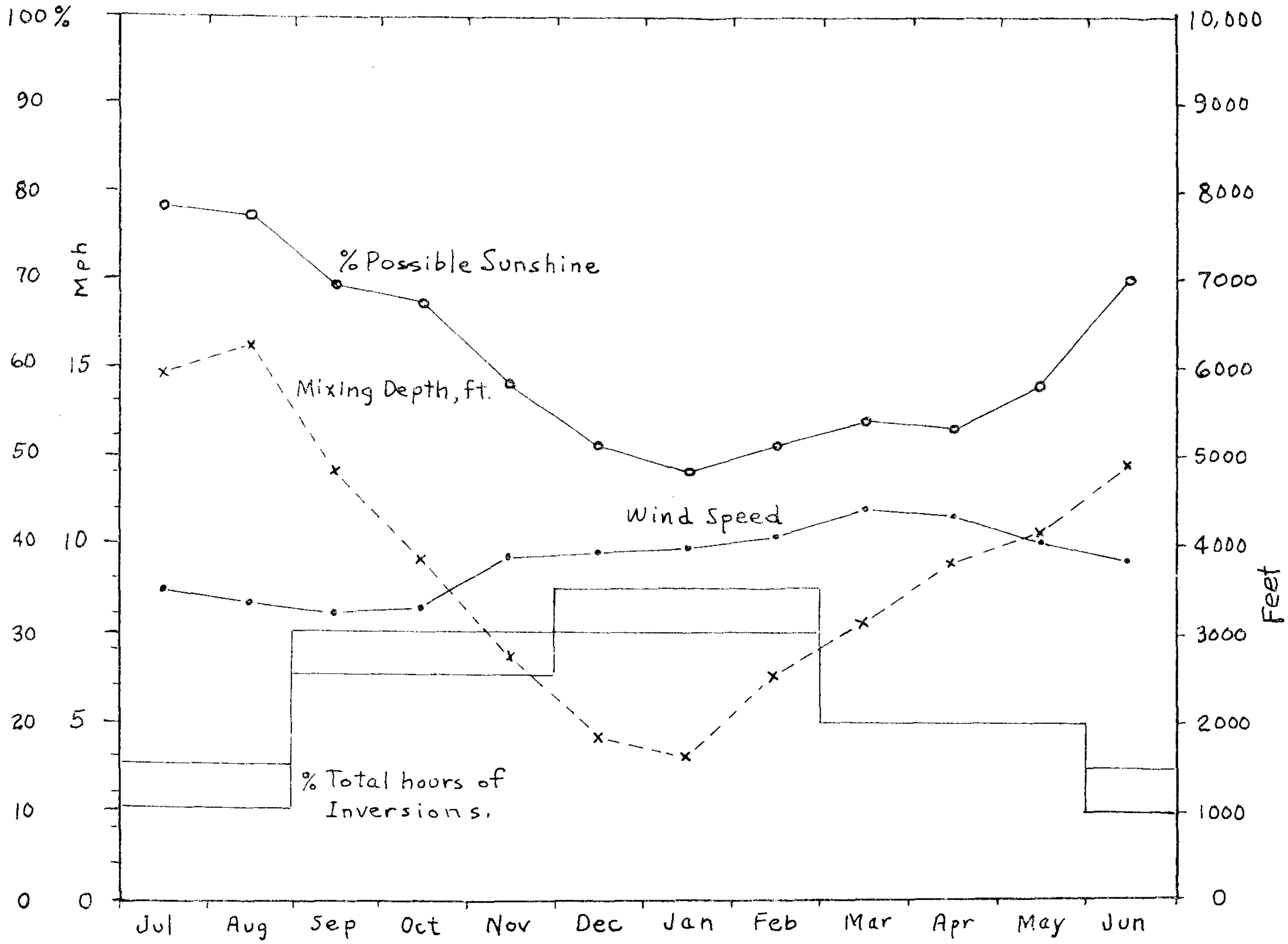


Figure 1. Annual Climatological Parameters, Austin, Texas

SOURCE: Climatological Data, Austin, Texas, 1970. U.S. Dept. of Commerce

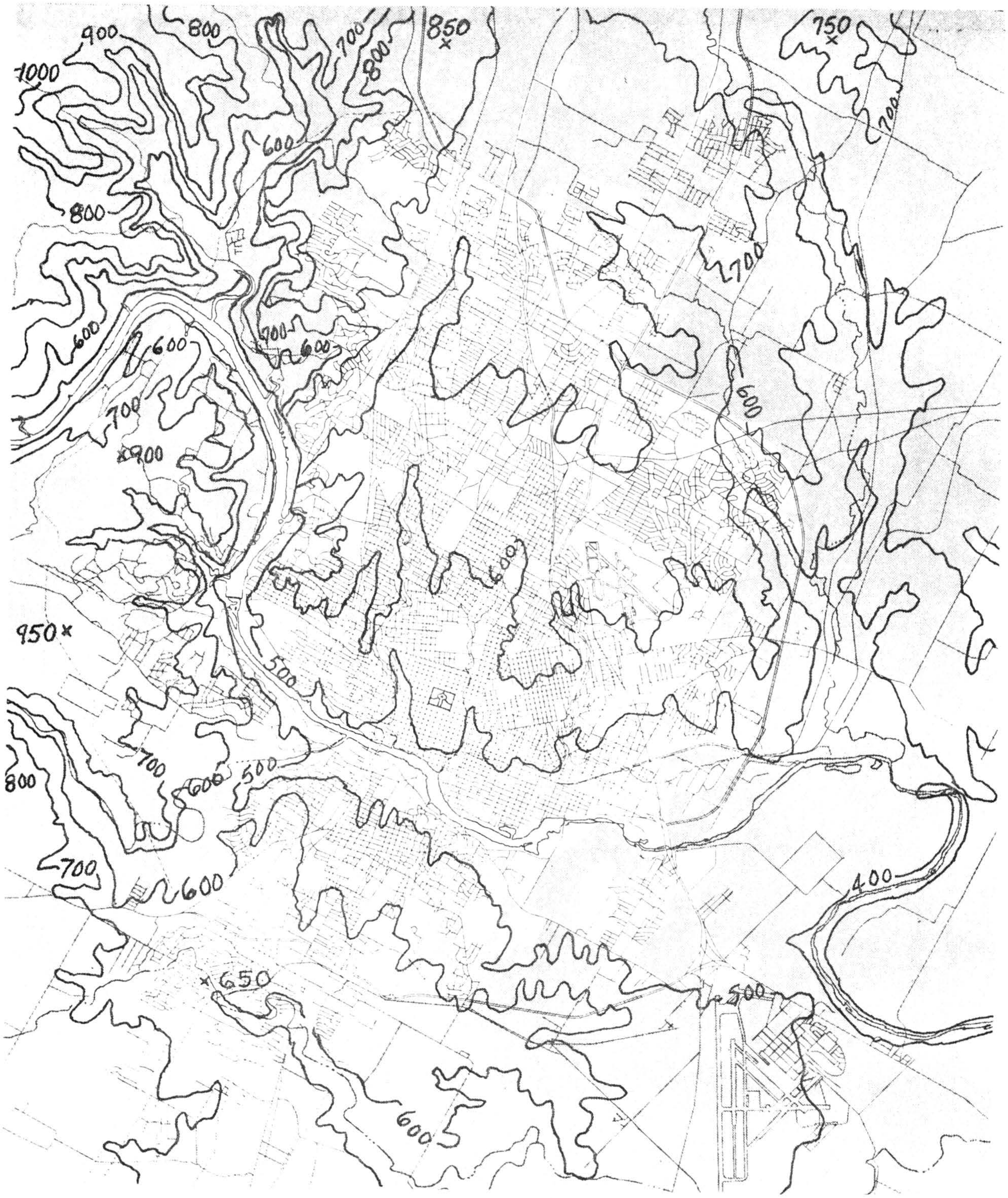


Figure 2. Topographic Map of Austin, Texas, Contour Interval 100 Feet; Scale 1" = 2 Miles

ADAPTED FROM: U.S. Dept. of Interior Geological Survey Topographic Map, NH 14-6.

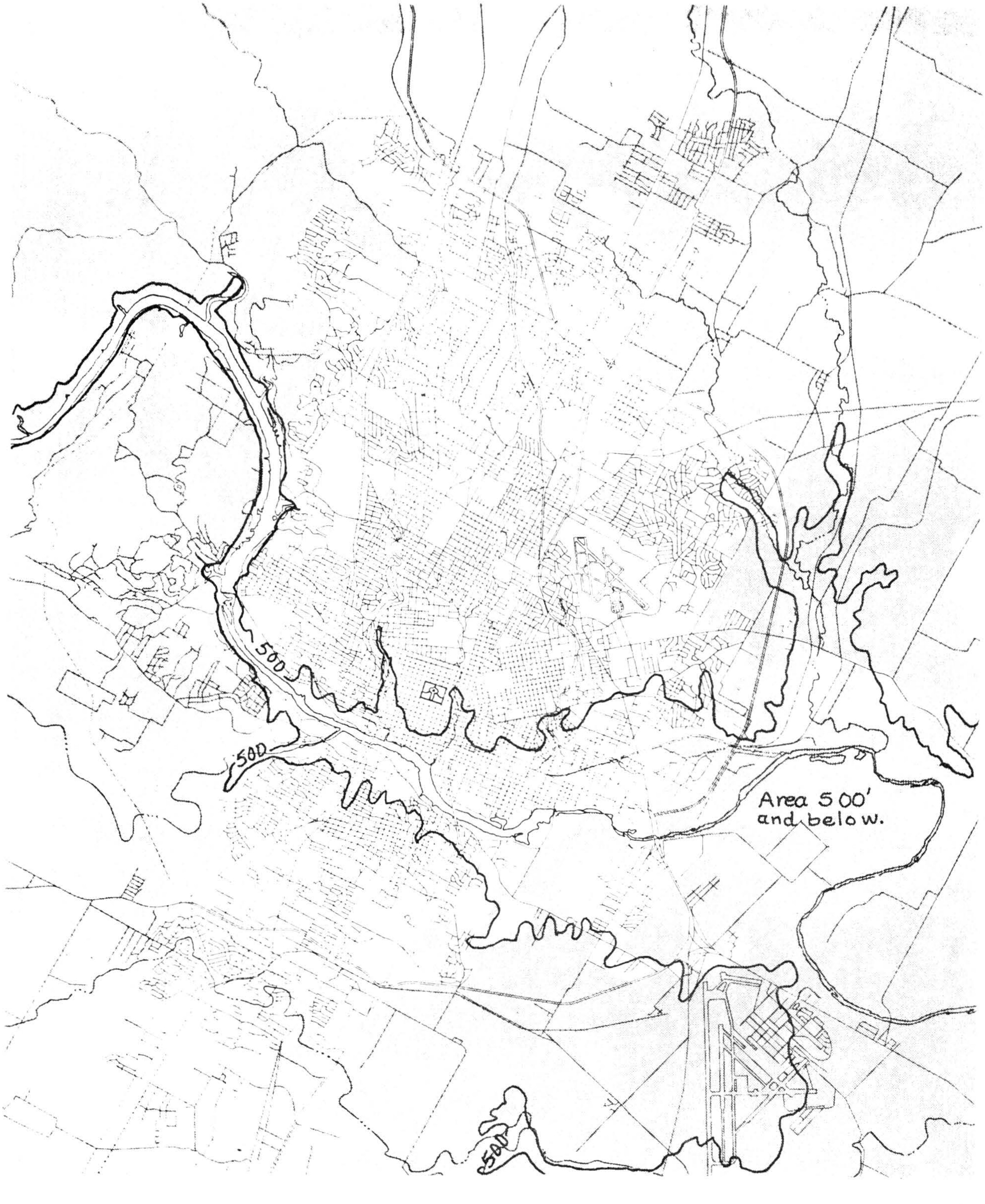


Figure 3. Area Below 500 ft. Contour, City of Austin

ADAPTED FROM: U.S.G.S. Map NH 14-6, Austin, Texas 1954.

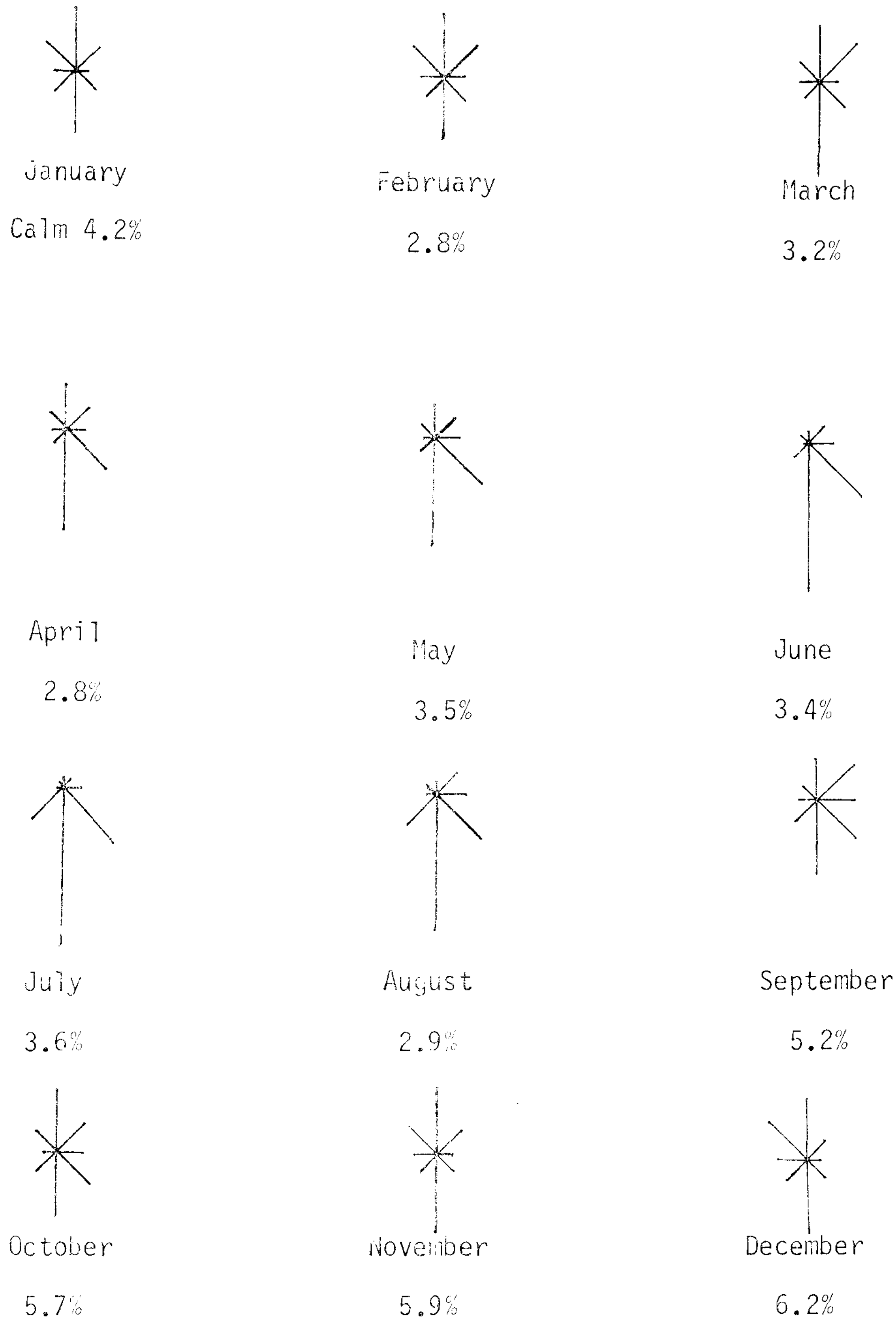


Figure 4. Monthly Wind Roses, Austin, Texas, 1951-1960

SOURCE: Summary of Hourly Observations, Austin, Texas, 1951-60, U.S. Dept. of Commerce, 82-41.

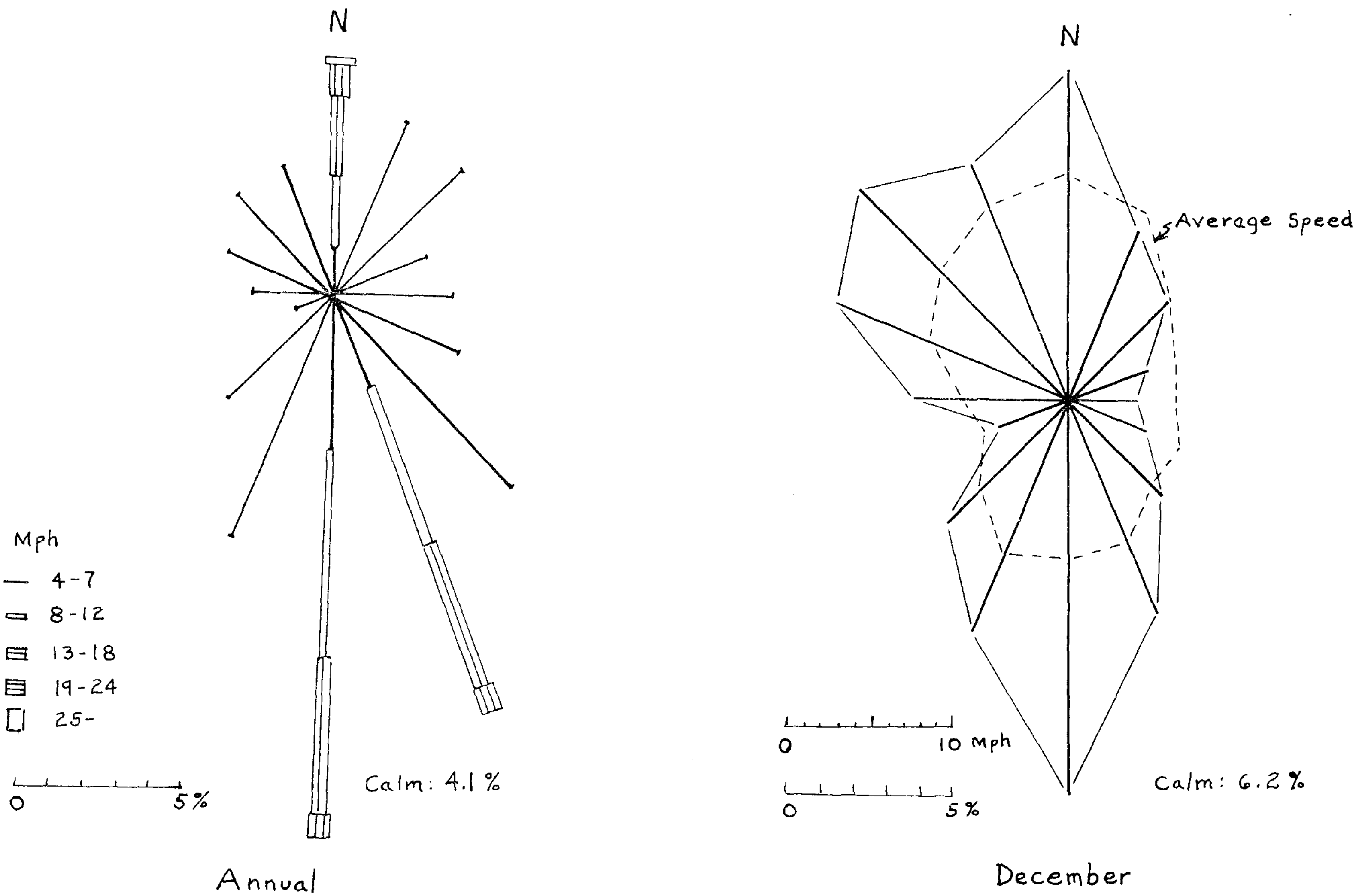


Figure 5. Wind Roses, December and Annual, Austin, Texas; 1951-1960

SOURCE: Summary of Hourly Observations, Austin, Texas, 1951-1960, U.S. Dept. of Commerce, 82-41.

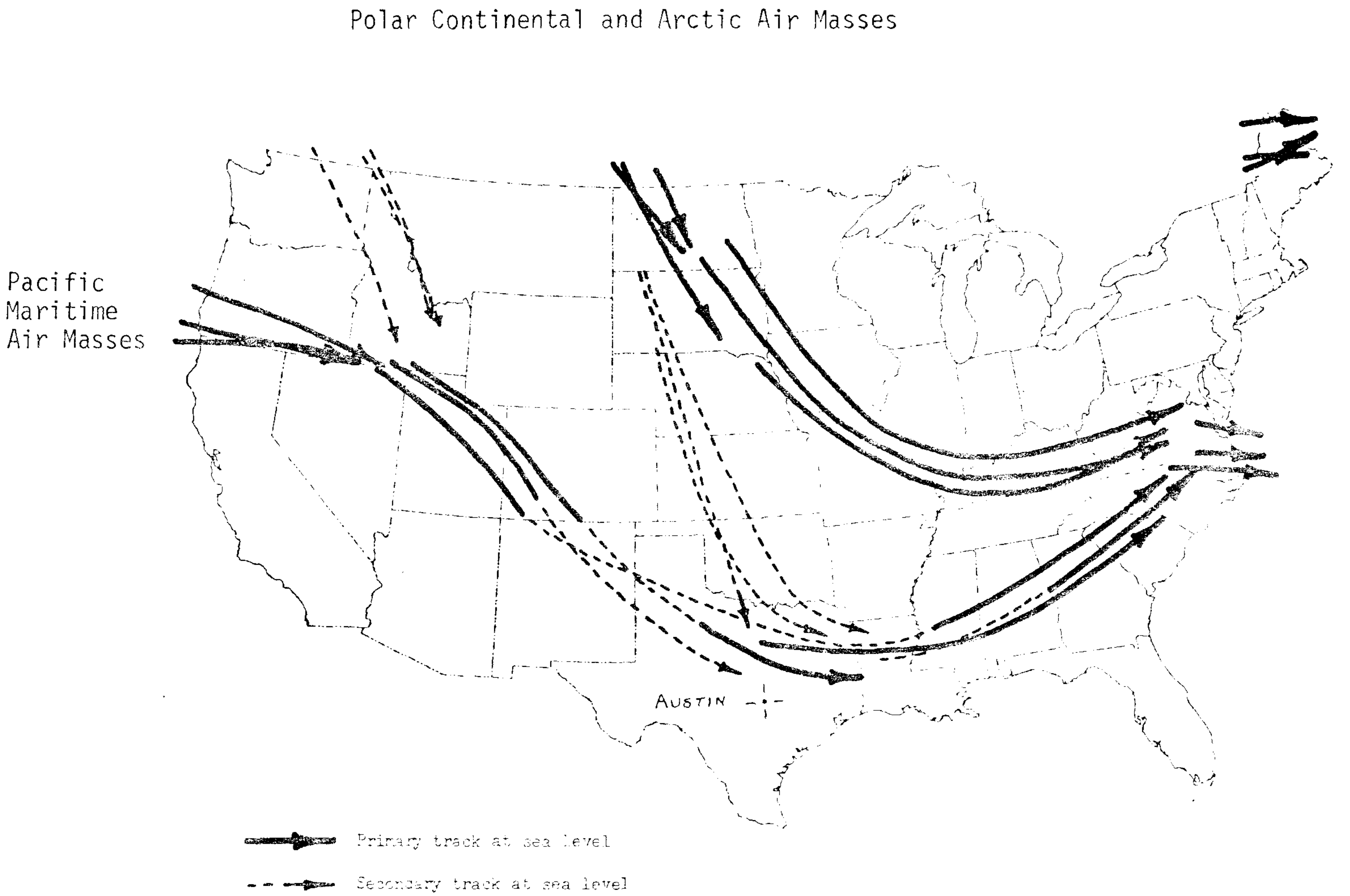


Figure 6. Principal Tracks of Anti-cyclones in Winter (December, January, February)

SOURCE: Texas State Climatologist, E.S.S.A., Austin, Texas.

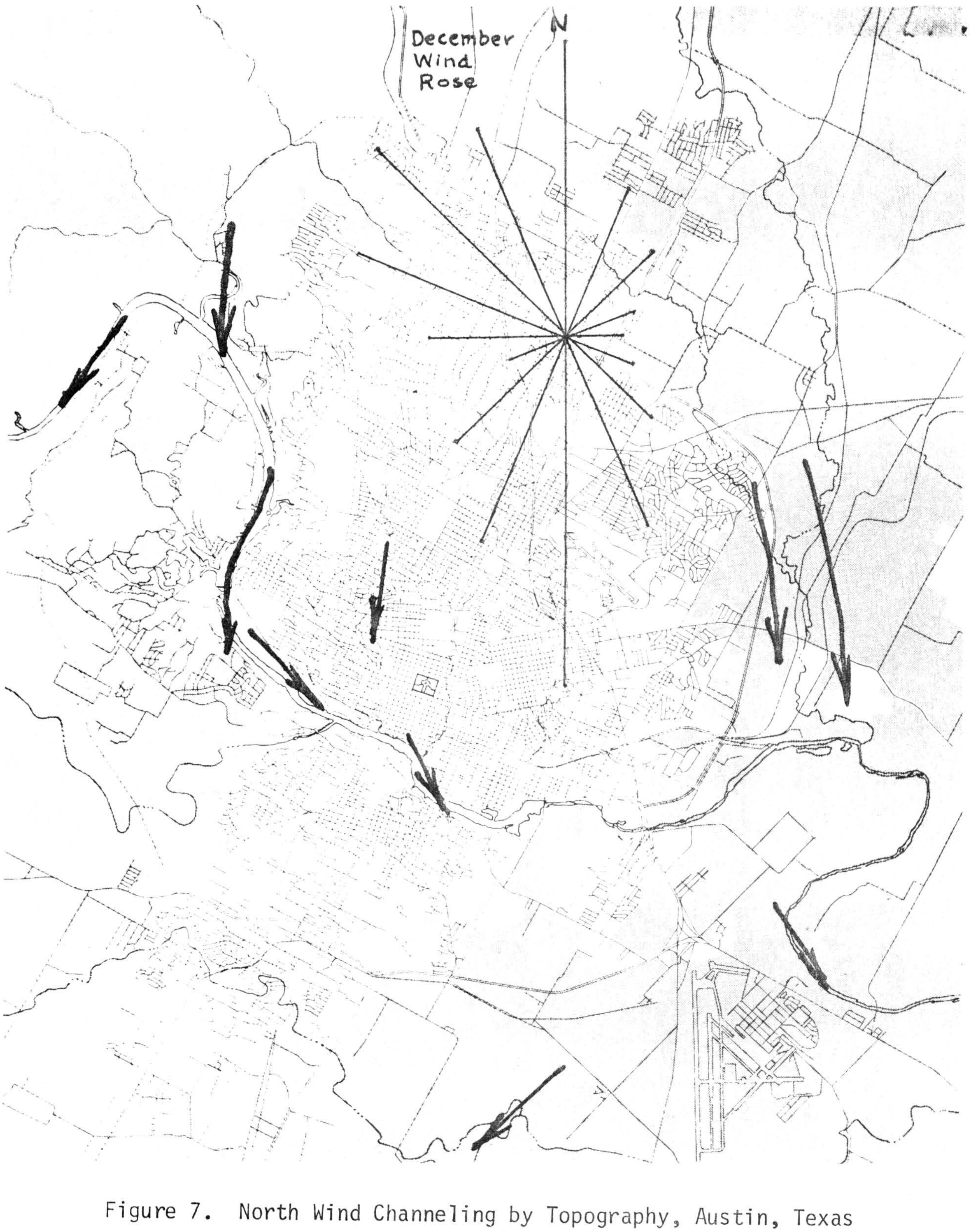


Figure 7. North Wind Channeling by Topography, Austin, Texas

Figure 8. South Wind Channeling by Topography, Austin, Texas

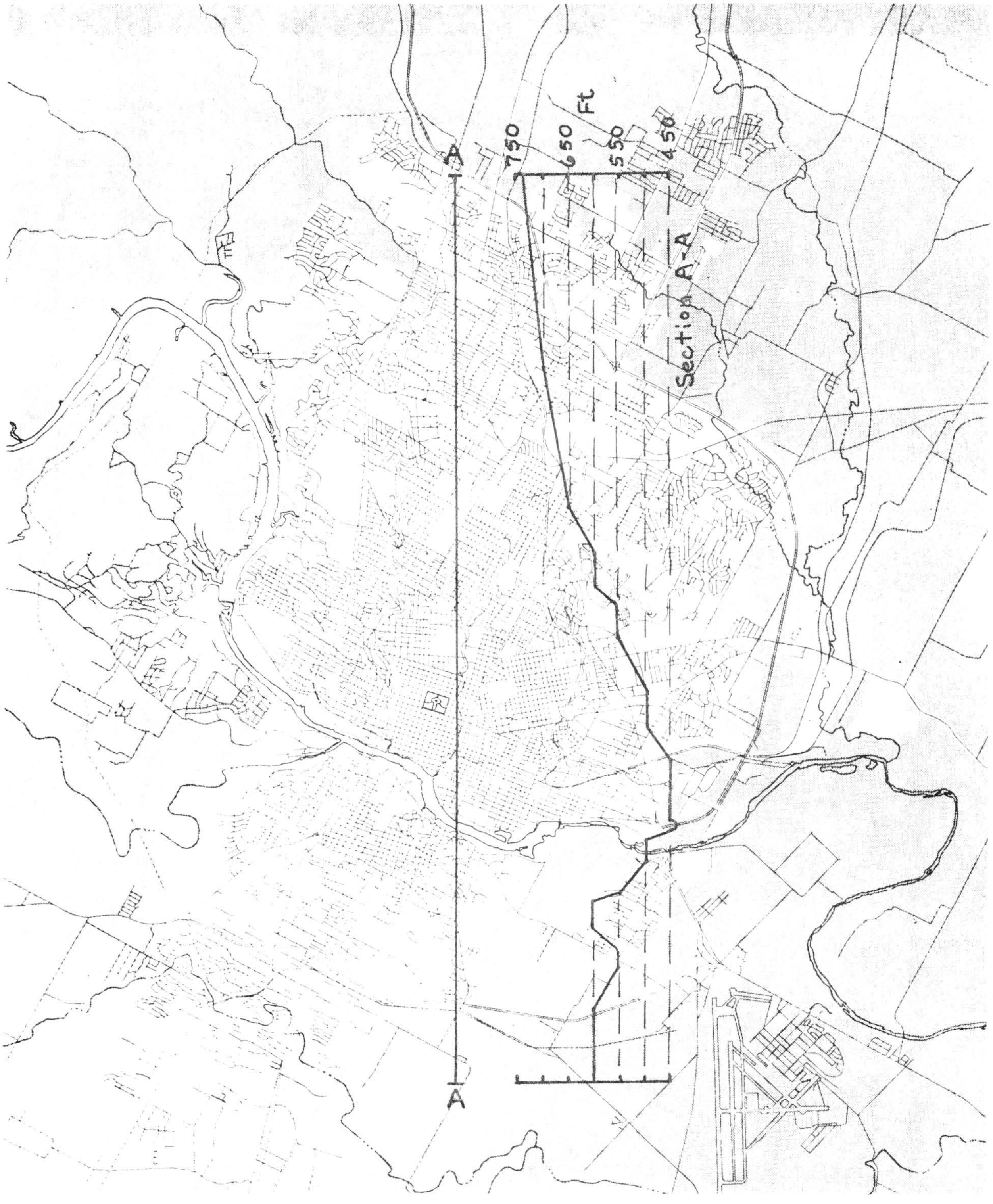


Figure 9. North-South Vertical Section through Austin, Texas

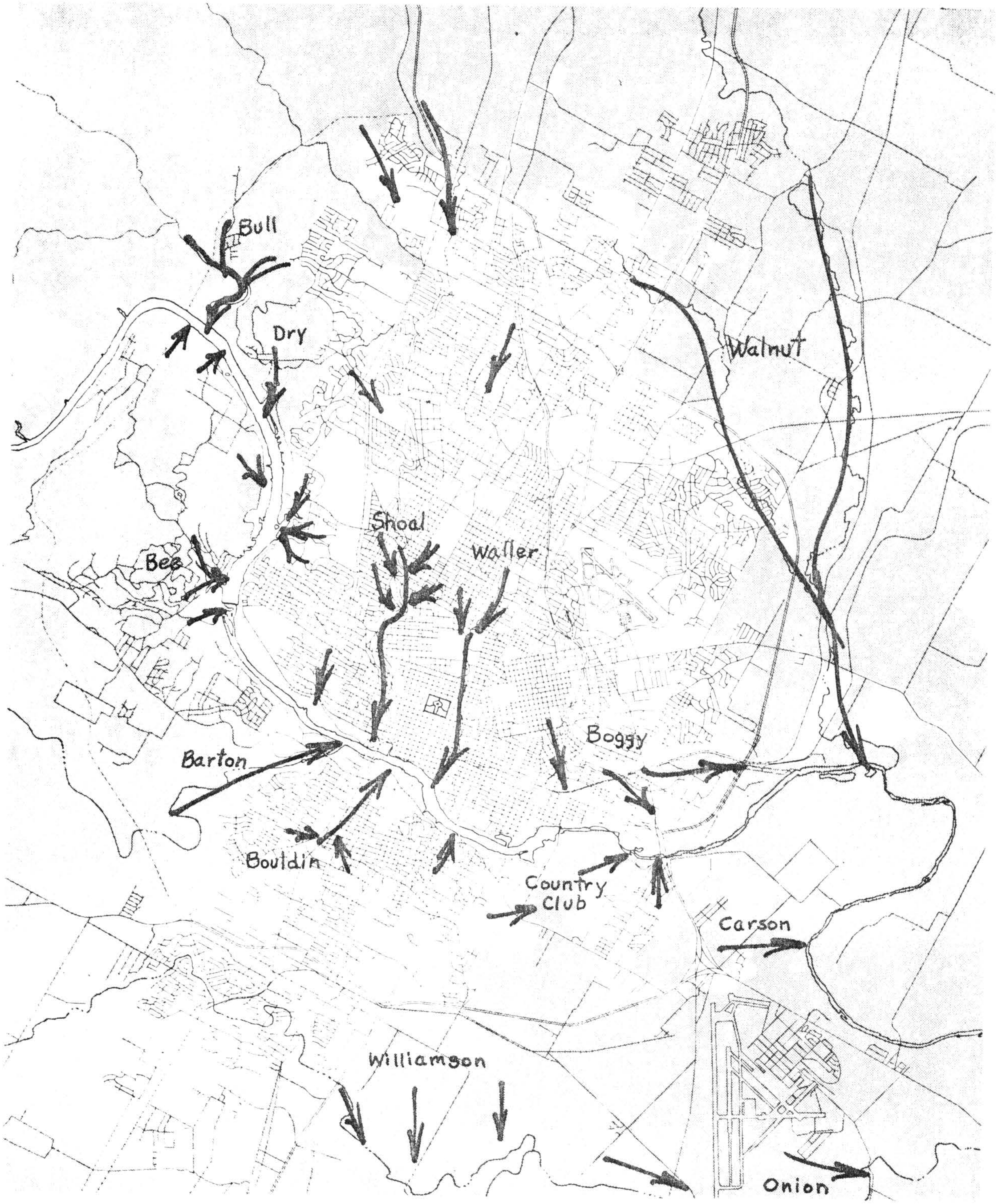


Figure 10. Cold Air Drainage Patterns in Austin, Texas, Creek Names Identify Major Flows

Figure 11. Measured Cold and Warm Areas, Austin, Texas
10:00-12:00 Midnight Aug-Dec 1970
W warm
C cold

SOURCE: Wood, J. L. Nocturnal Heat Island in Austin, Texas, U.T. Austin, Thesis, May 1971.

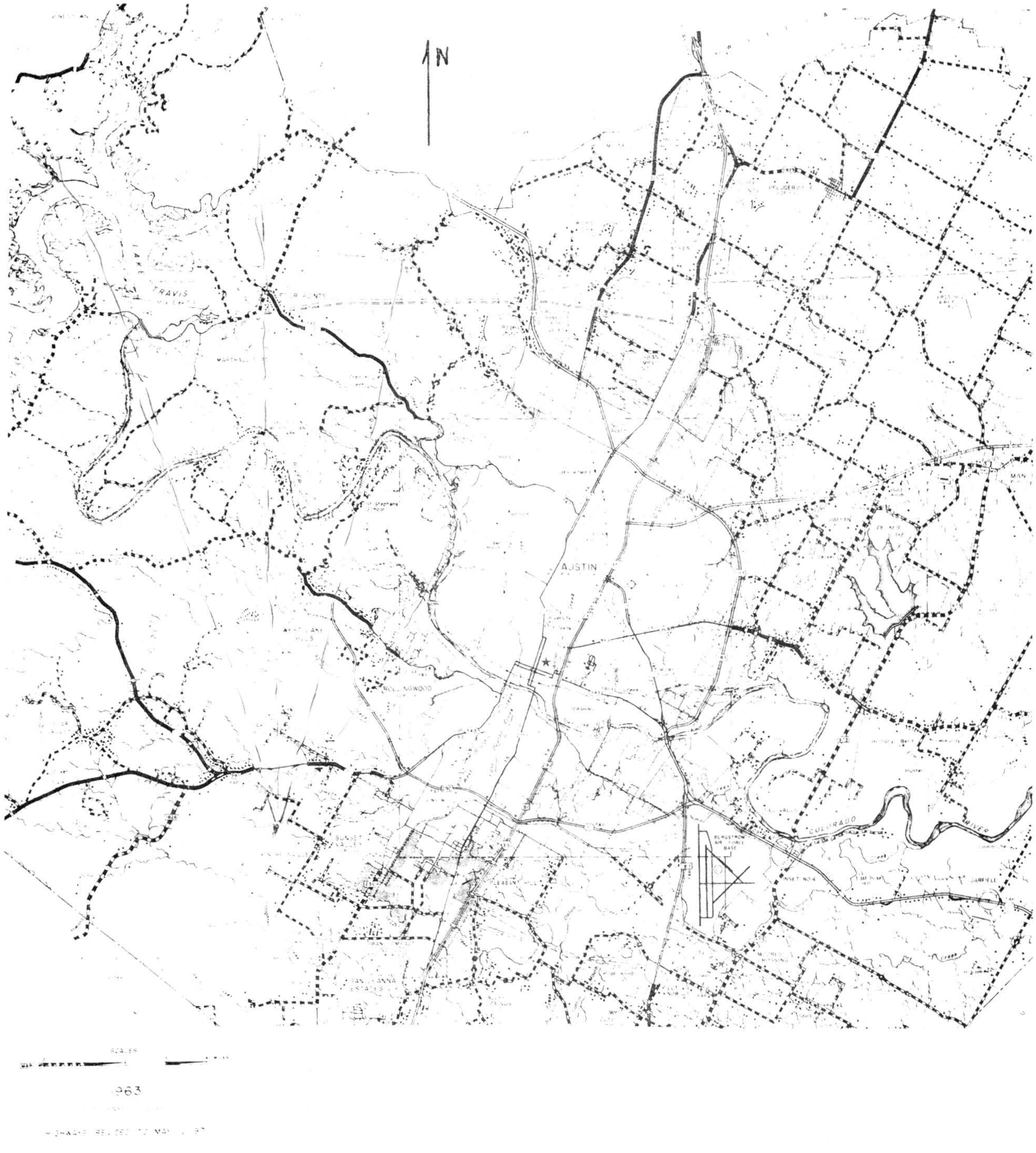


Figure 12. Austin Area Map

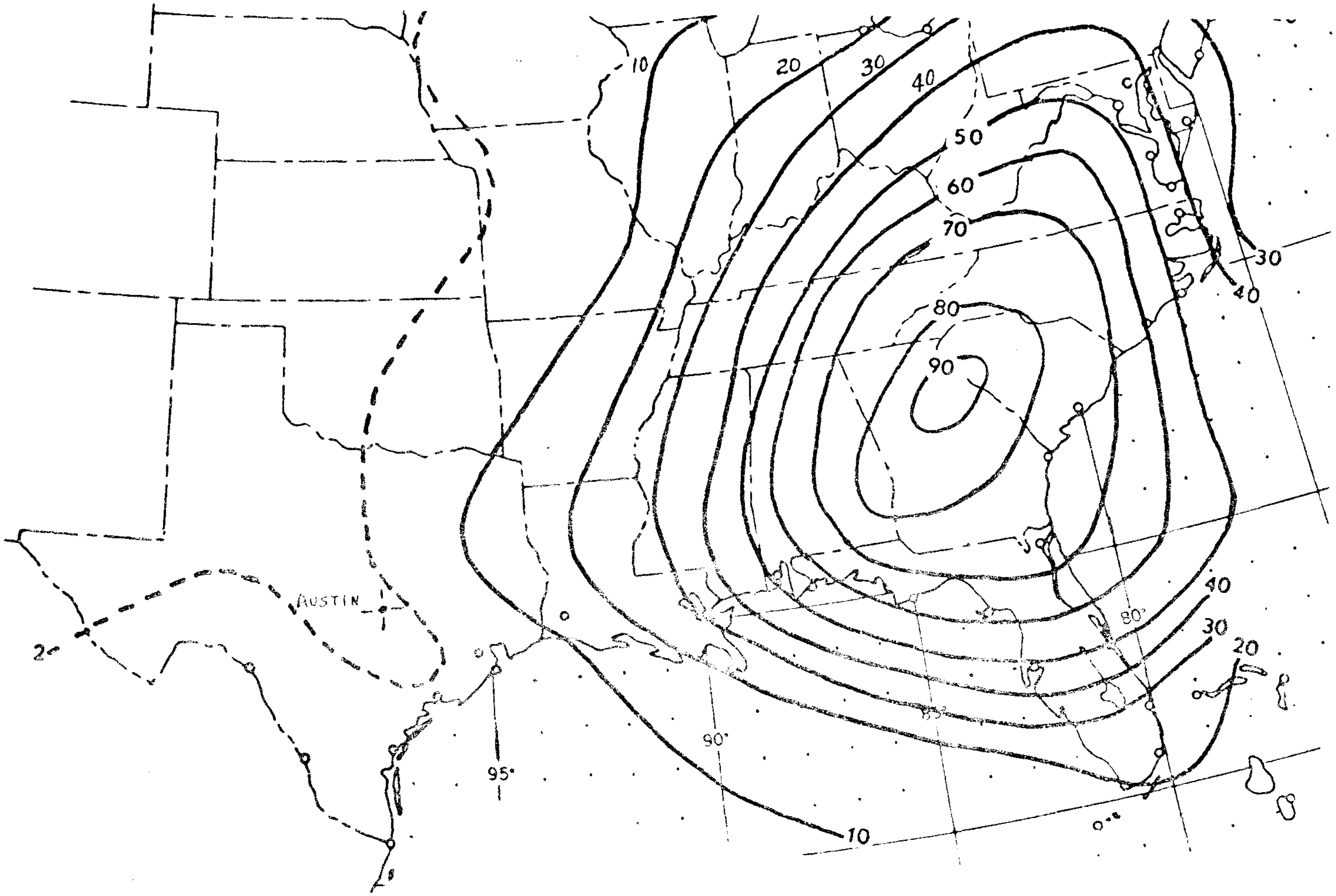


Figure 13. Stagnating Anticyclones--Total Number of Stagnation Cases (4 or more days), 1936-1965.

SOURCE: Texas State Climatologist, E.S.S.A., Austin, Texas.

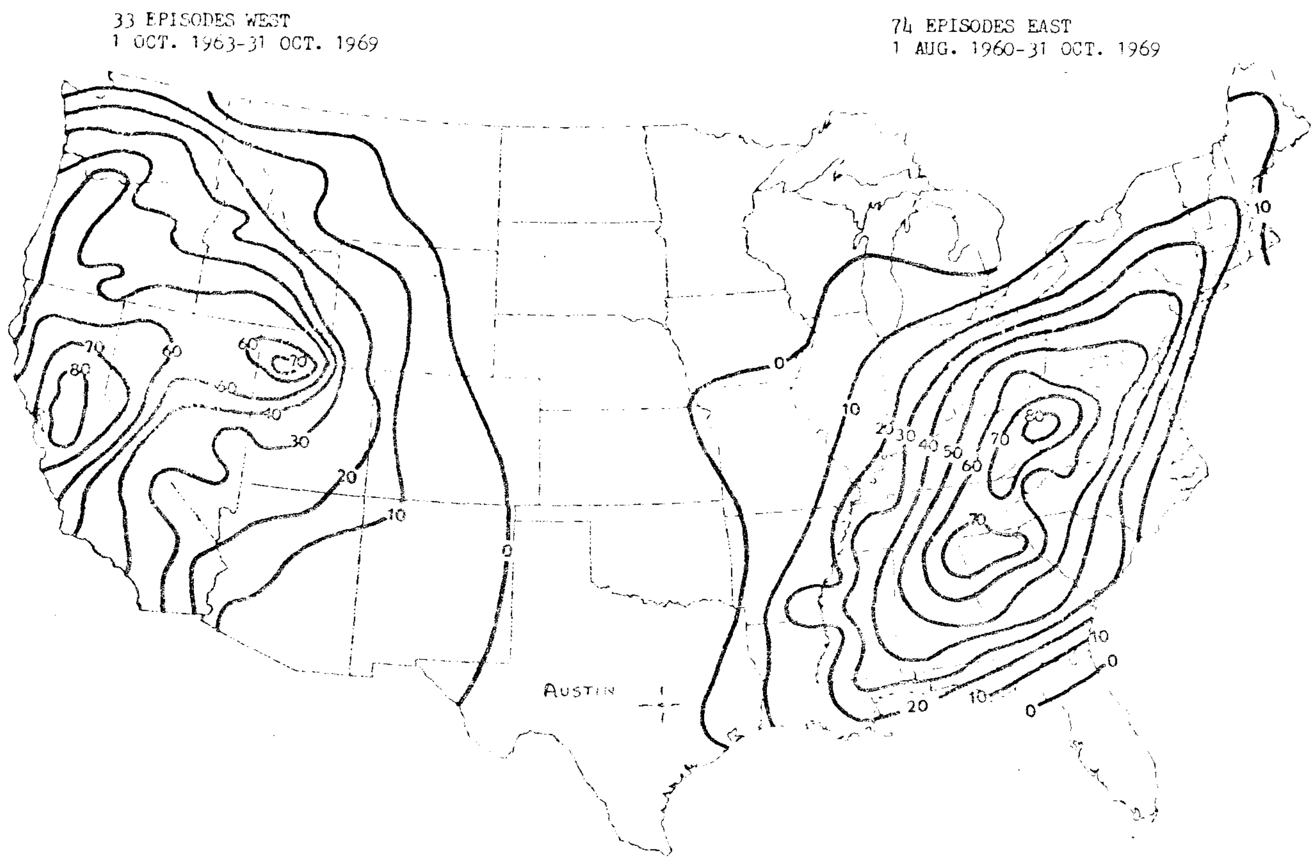


Figure 14. Air Pollution Potential Forecasts (Number of times in which stagnation conditions were expected to persist for at least 36 hours for areas at least 58,000 square miles.)

SOURCE: Texas State Climatologist, E.S.S.A., Austin, Texas.

Figure 15. Areas of Natural Tree Cover, Austin, Texas

City Owned	
Parks & Parkways	2100 ac.
Golf Courses	382 ac.
Playgrounds	222 ac.
Cemeteries	300 ac.

Areal Coverage-Dec. 1970		
Land	41,000 ac.	90.4%
Water	4,900 ac.	9.6%
Total	52,000 ac	

SOURCE: Aerial Maps and City of Austin Planning Dept.

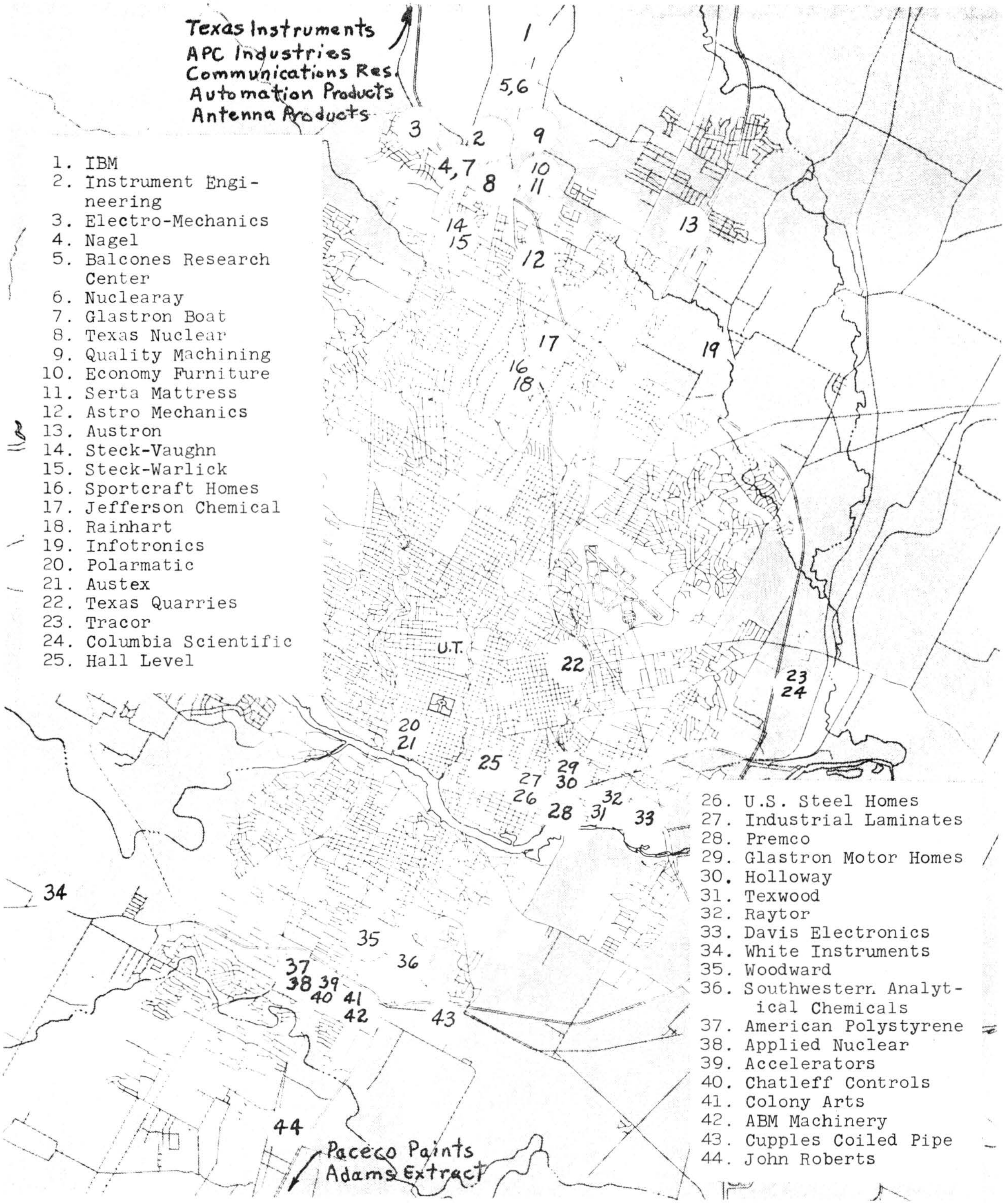
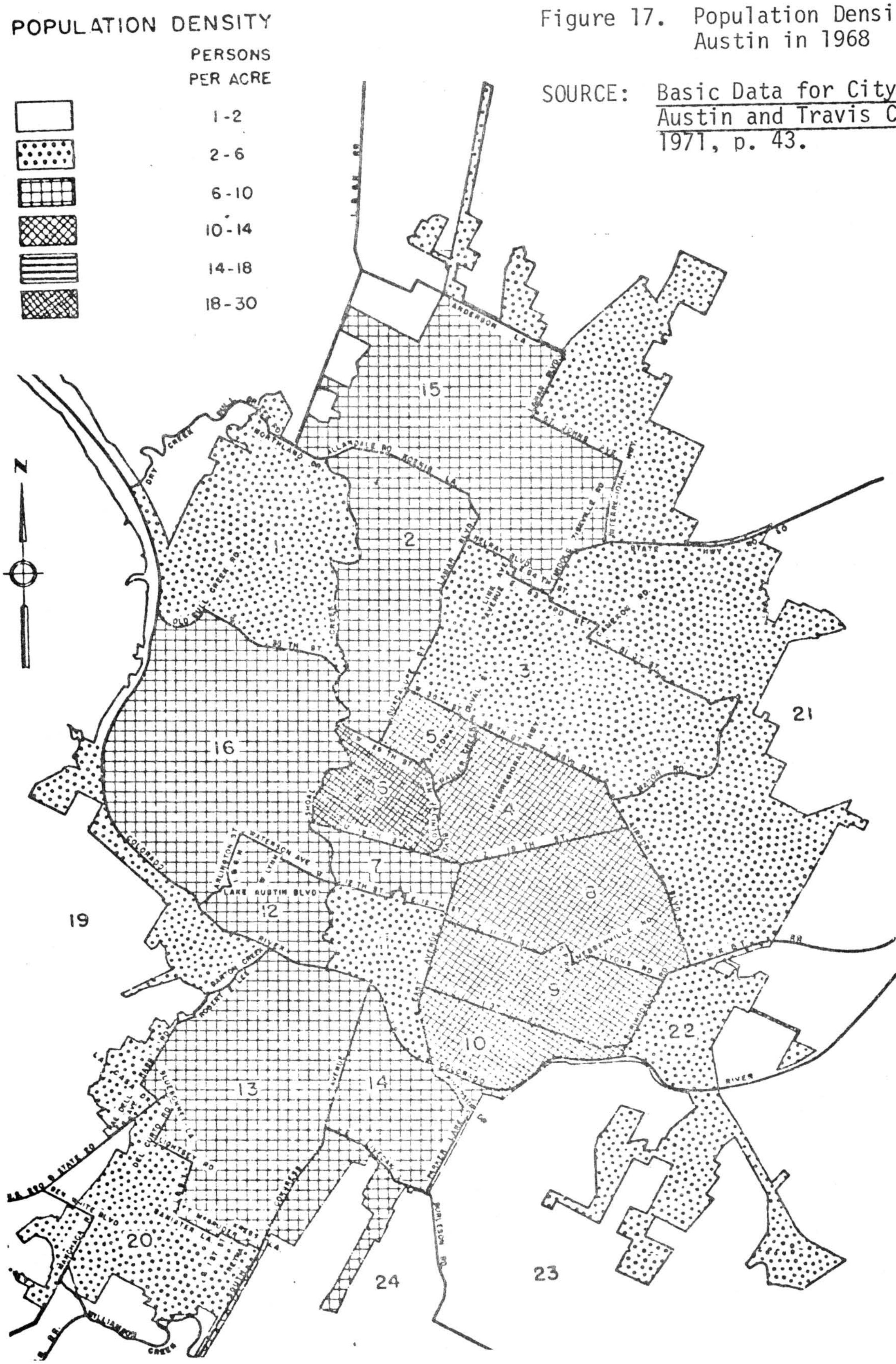


Figure 16. Location of Austin Industry

SOURCE: Austin Chamber of Commerce.

Figure 17. Population Density for Austin in 1968

SOURCE: Basic Data for City of Austin and Travis County, 1971, p. 43.



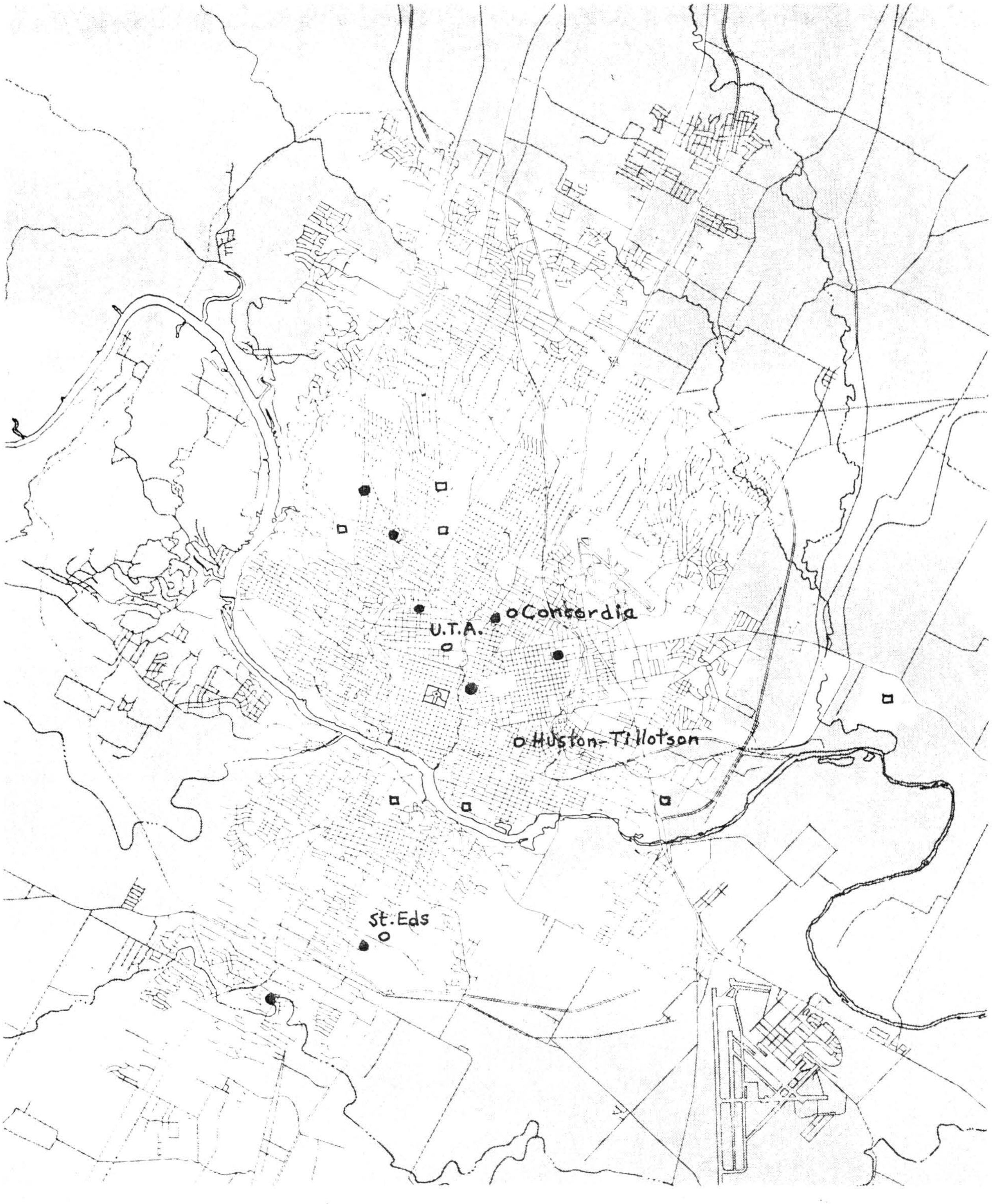


Figure 18. Dense Population Centers in Austin

- • Hospitals
- ▫ State Schools
- ◦ Colleges and Universities

20 + Nursing, Convalescent Rest and Retirement Homes are not shown.

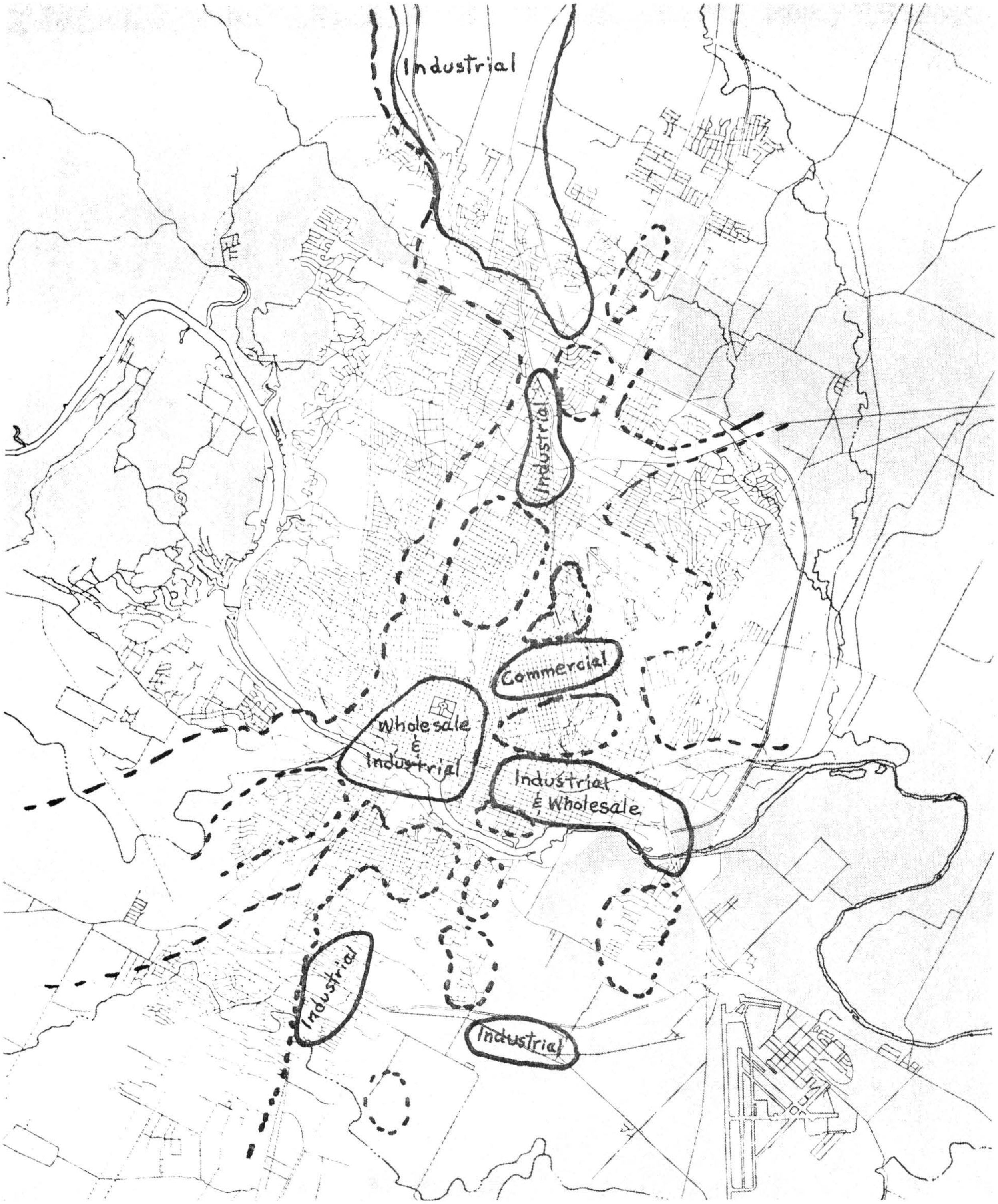


Figure 19. General Land Use Patterns in Austin

—— Industrial, Commercial, Wholesale
--- Residential

ADAPTED FROM: Use District Map, City of Austin, March 1971.

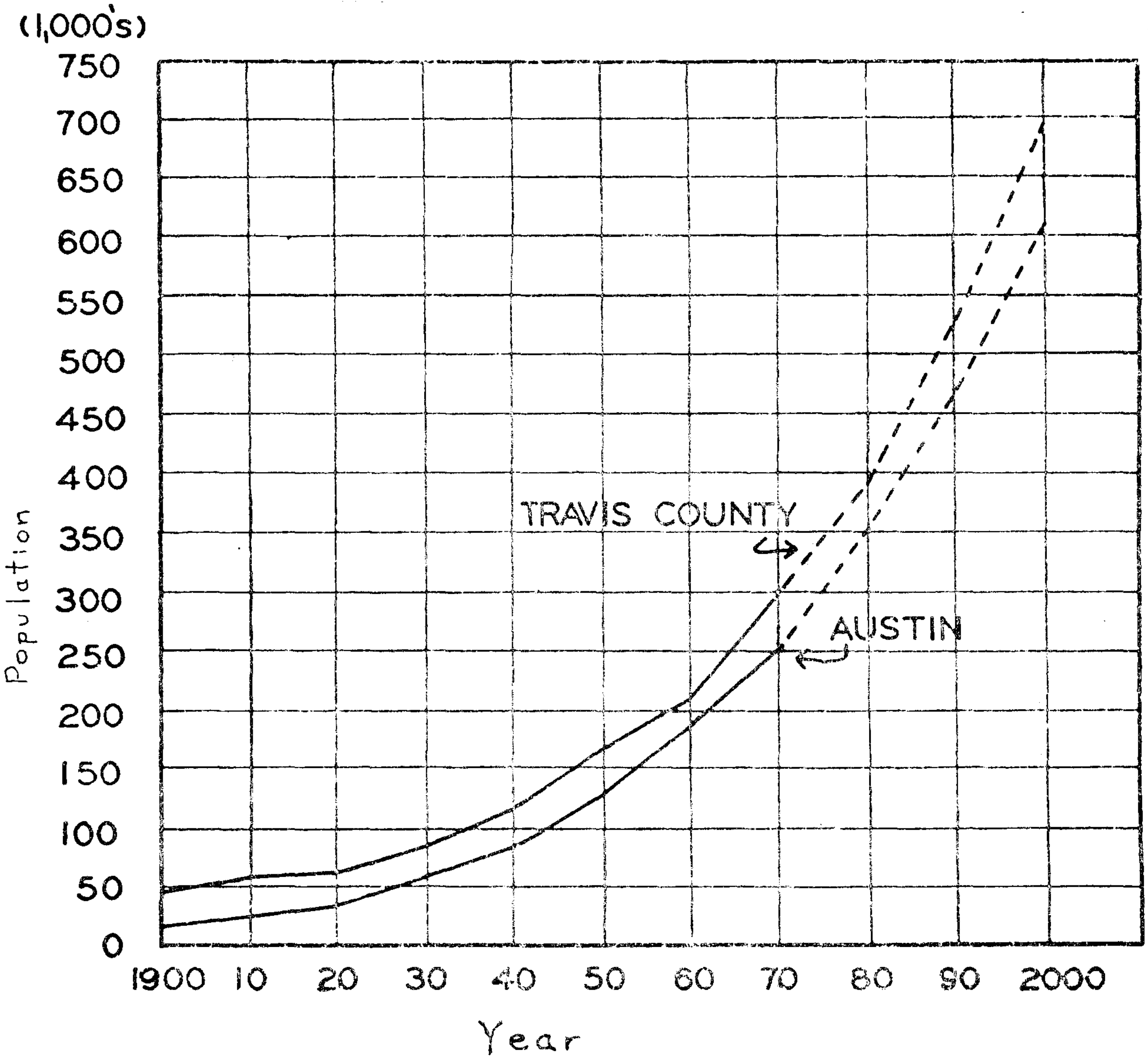


Figure 20. Population Growth for Austin and Travis County

SOURCE: 1960 and 1970 Data from U.S. Census; City and County Forecasts by Planning Department, City of Austin for Highland Lakes System, Comprehensive Wastewater Study: 1970-1990. State Forecasts by Texas Research League. Reported in Basic Data for City of Austin and Travis County, 1971, p. 7.

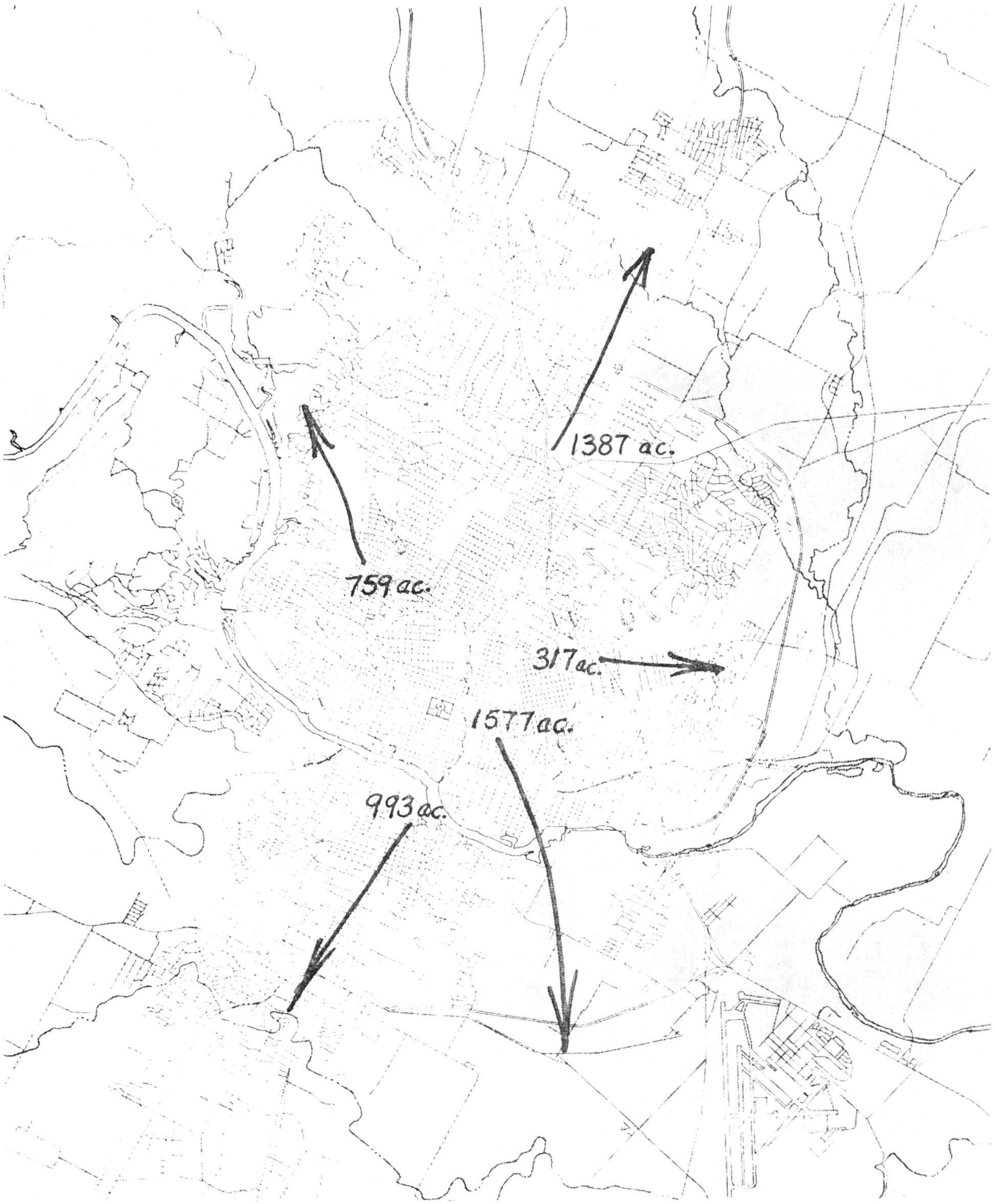


Figure 21. Territorial Growth for Austin
Acreage Annexed by Direction from Jan. 1, 1969 to Jan. 1, 1971.

ADAPTED FROM: Basic Data, City of Austin and Travis County, 1971, p. 5.

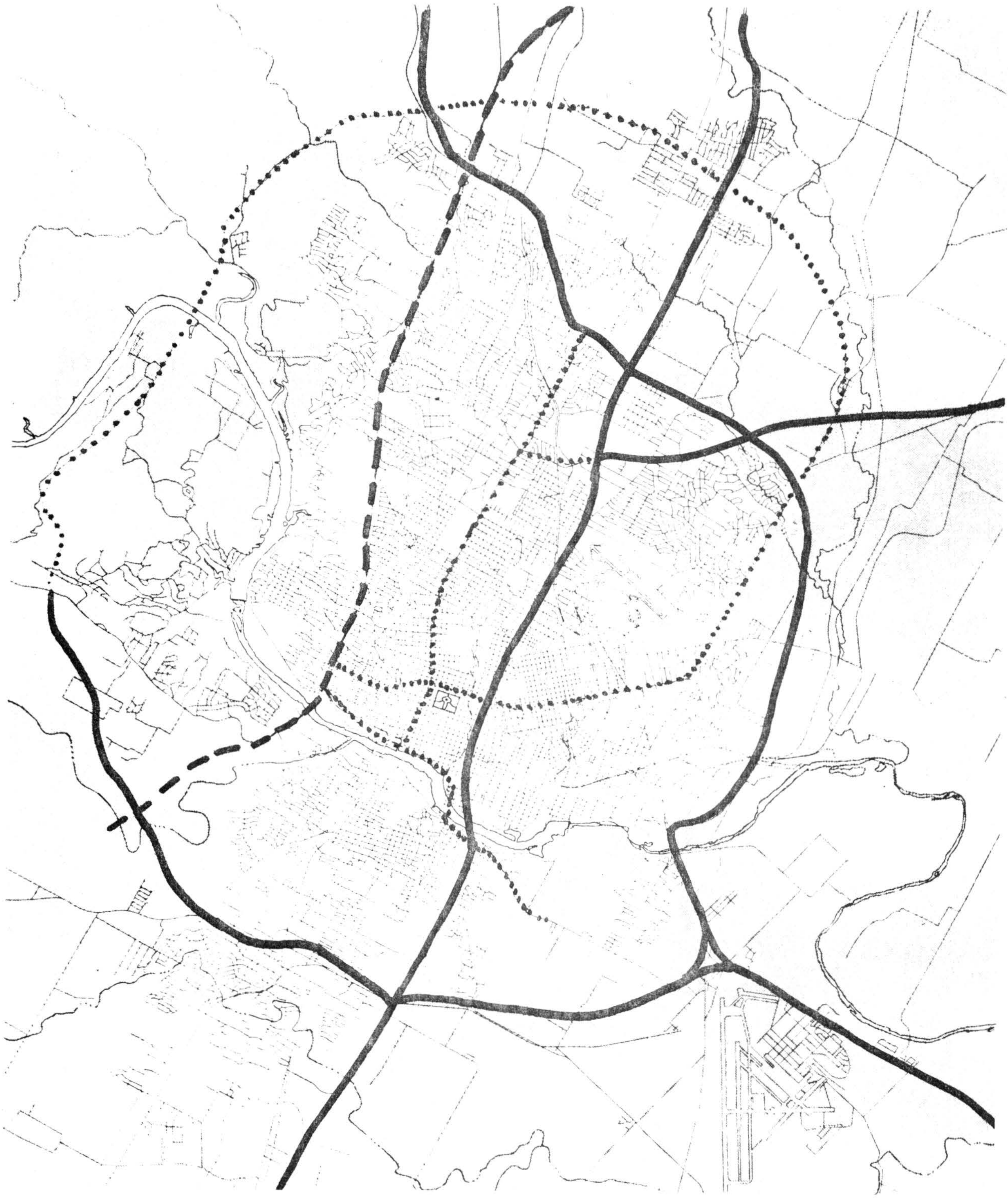


Figure 22. Expressway Plan for Austin

Existing
Under Construction
Planned

ADAPTED FROM: Expressway and Major Arterial Plan, City of Austin, April 1969.

Figure 23. Heavy Traffic Streets and Aircraft Tracks for Austin

▬ Traffic
— Aircraft

TRAFFIC MAP ADAPTED FROM: Vehicular Traffic Flow, 1968, City of Austin.

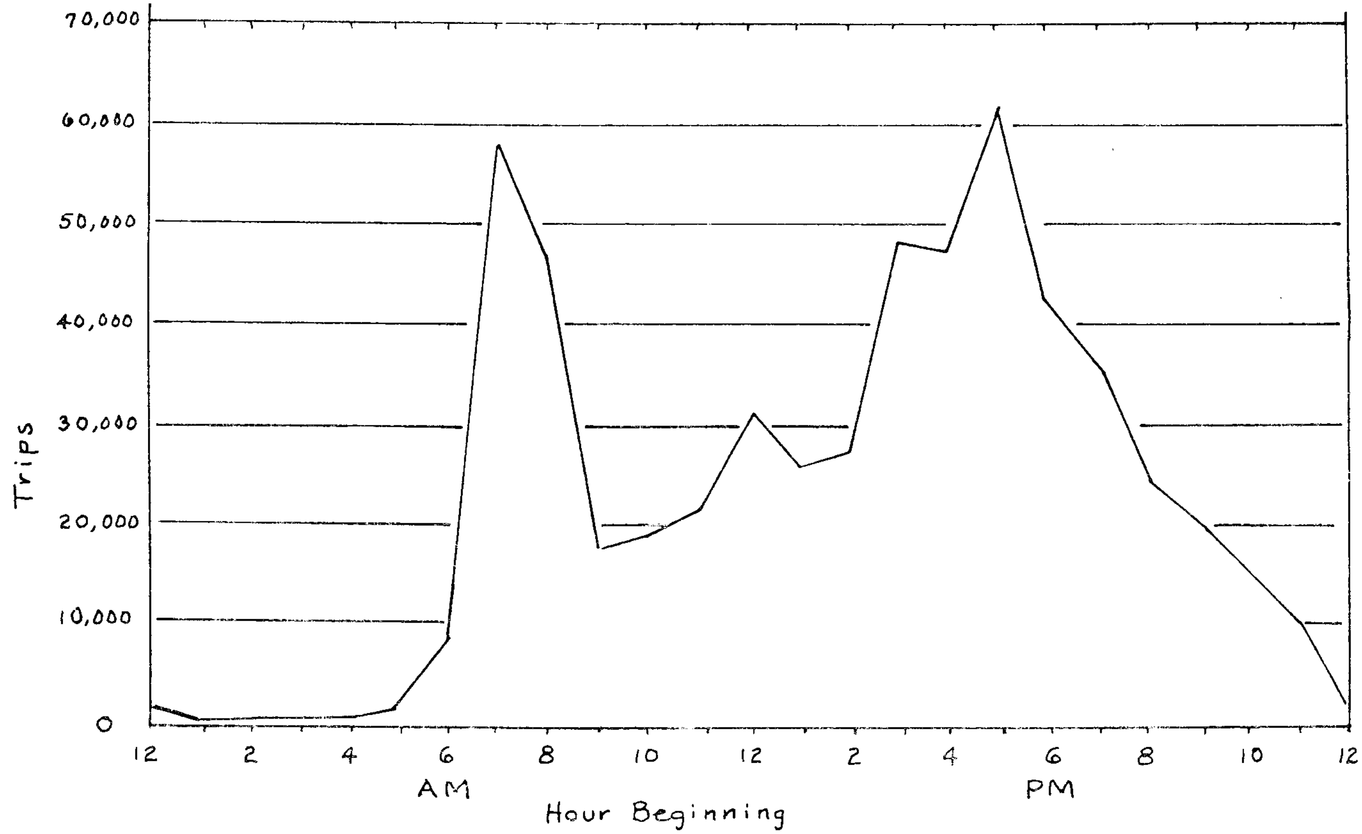


Figure 24. Hourly Distribution of Internal Person Trips, Austin, Texas, Fall of 1962

SOURCE: Austin Metropolitan Area Transportation Study, Origin Destination Survey, 1962, p. 51.

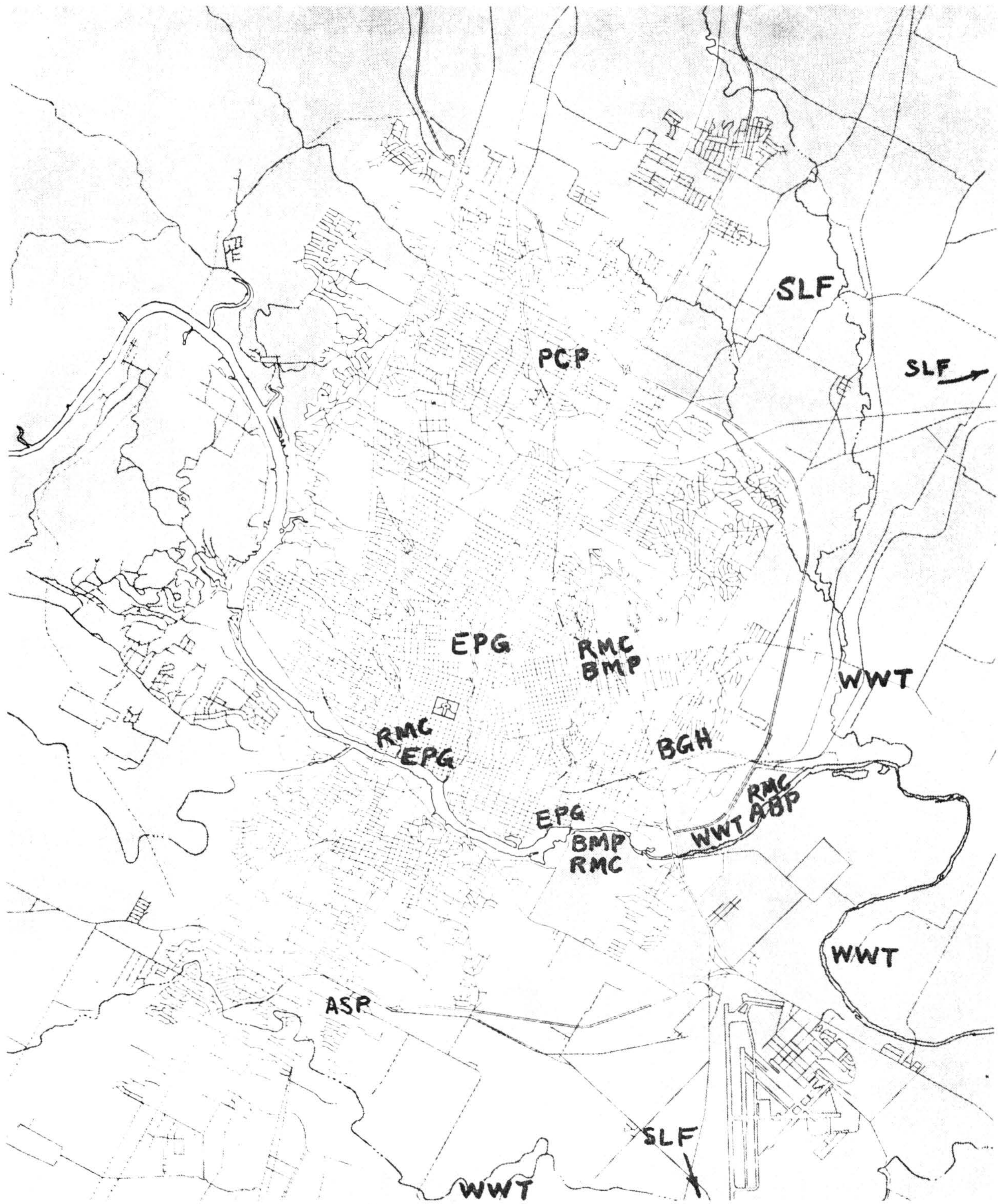


Figure 25. Some Emission Sources in Austin

ABP Asphalt Batching Plant
ASP Auto Salvage Plant
BGH Bulk Gasoline Handling
BMP Building Material Processing; Stone, etc.
EPG Electric Power Generating Station
PCP Pilot Chemical Plant
RMC Readymix Concrete Plant
SLF Sanitary Landfill
WWT Wastewater Treatment Plant

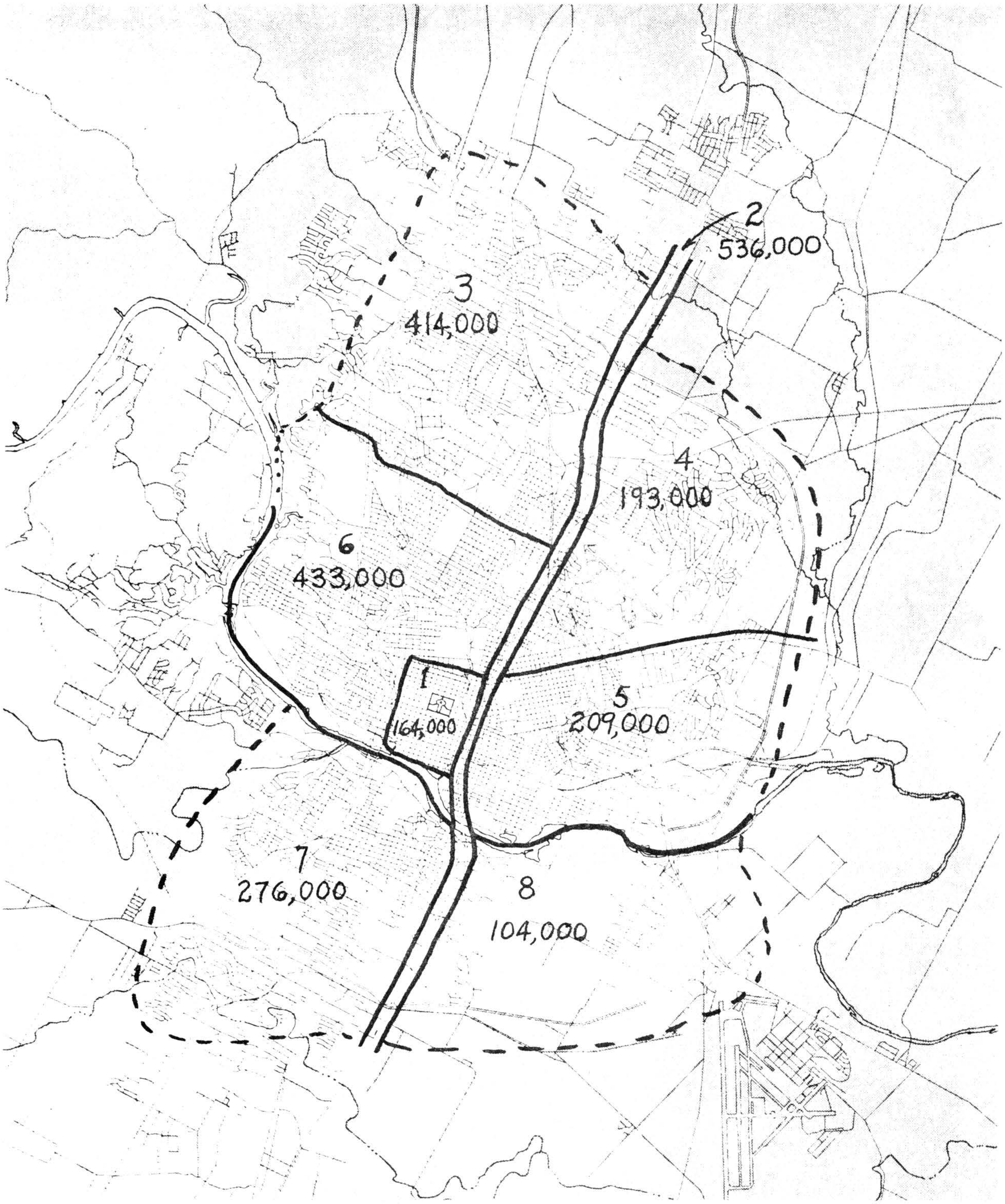


Figure 26. Average Weekday Vehicle Miles Travelled Per Day, April-May 1968
Areas arbitrarily chosen. See Table 38 for emissions.

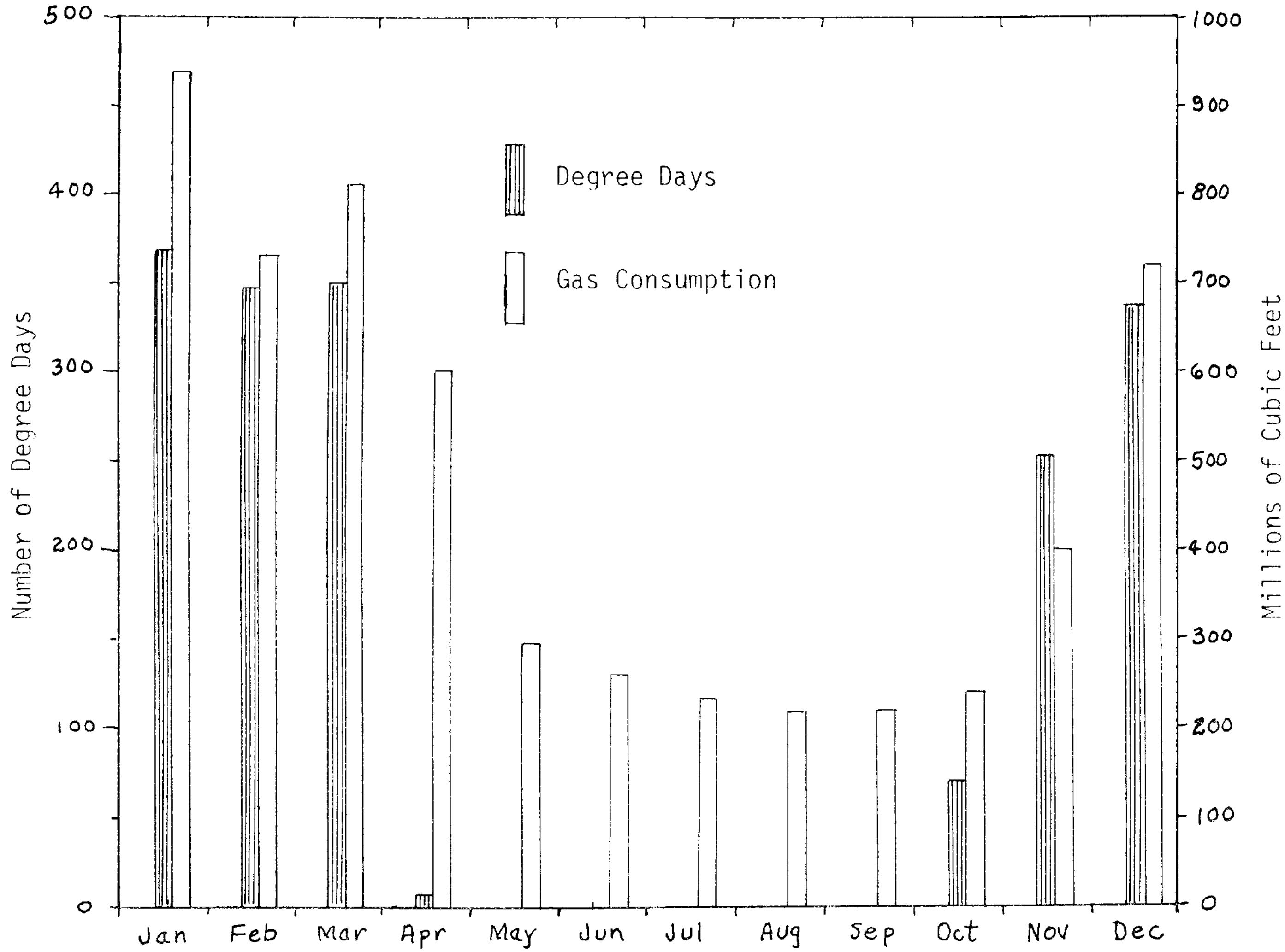


Figure 27. Monthly Residential Natural Gas Consumption and Degree Days (65 deg.F Base) for Austin, Texas for Year 1969

SOURCE: Hosford, 1971; Local Climatological Data, Austin, Texas, 1970, U.S. Department of Commerce

Figure 28. Thirty-day Average Suspended Particulate Matter, μg/m^3, June 1967, Austin, Texas

SOURCE: Air Quality Survey of Austin, June 1967.

A P P E N D I C E S

APPENDIX A

AIR FLOW AROUND SHAPES

Secondary airflow arises from the interaction of primary flow or geostrophic winds with obstacles in the path of flow, or with surface irregularities in the air-earth interface.

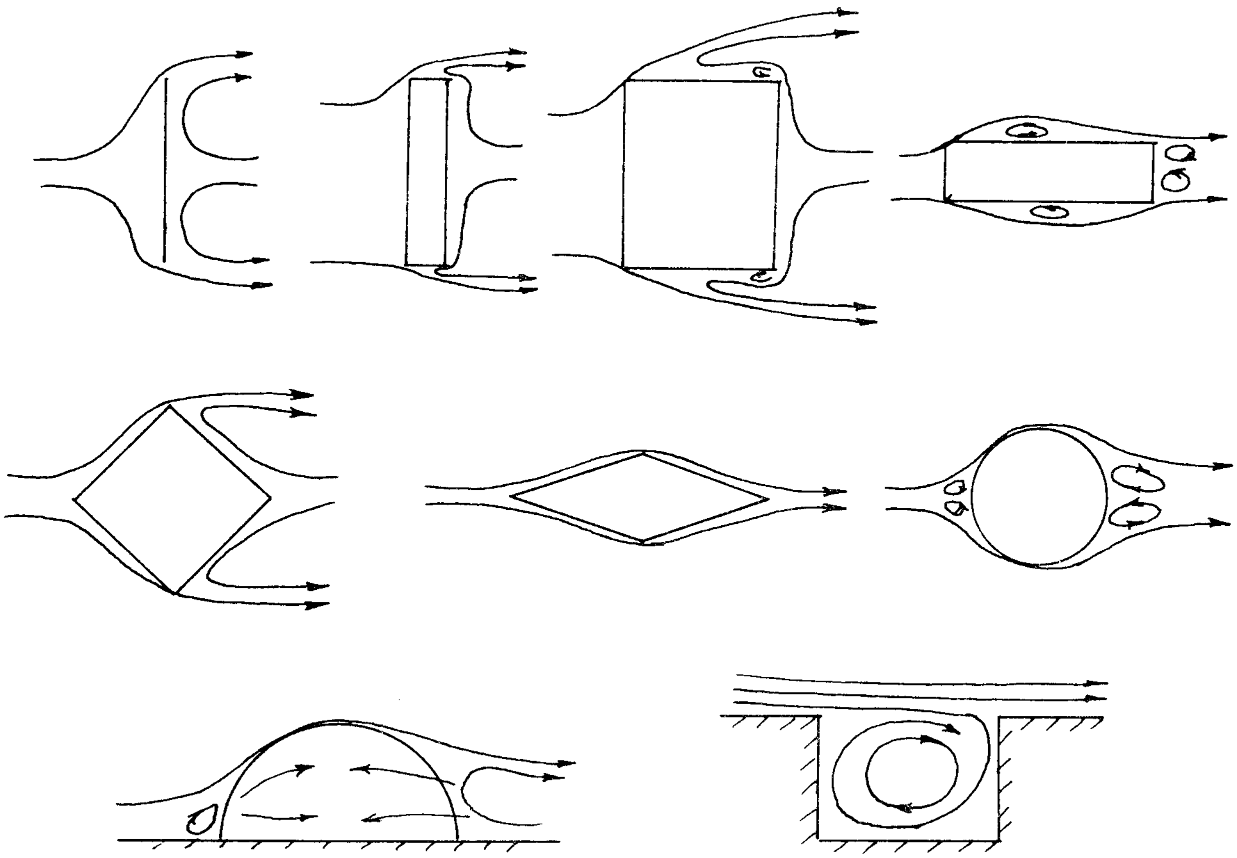
Secondary airflow is an important consideration in air pollution work because pollutant concentration levels depend directly upon flow and mixing in the vicinity of the source. Airflow may result in the unexpected appearance in space and time of unusually high or low levels of pollutants.

Halitsky (1962) has made low-speed wind tunnel measurements around basic shapes using smoke to show streamlines in laminar flow. Figure 1 shows the stream flow patterns that can be expected around most shapes encountered in structures. The flow into and out of an orifice shown in the bottom two sketches of Figure A1 is from Scorer's informative book entitled Natural Aerodynamics. Figure A2 shows streamlines for several variations in edge and corner configurations that aid further in the prediction of flow around buildings.

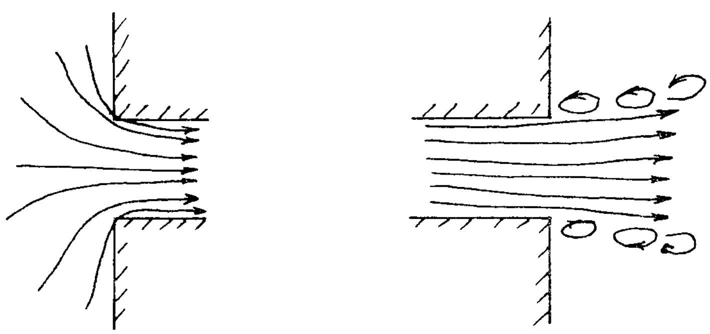
These figures lead to the generalization that flow around obstacles is accompanied by (1) creation of flows in directions greatly different from the approaching flow, and (2) the generation of closed cells of circulation called eddy cells or vortices.

Classic laminar flow around a building block is shown in Figure A3 adapted from illustrations by Smith (1968) and Munn (1966). It can be seen that the entire cube is enveloped in the cavity of closed circulation except for the windward side which may have its own small cavity. The cavity is characterized by (1) the reversed direction of flow at ground level, (2) the reduced pressure relative to the undisturbed flow, and (3) the surface of separation at which little flow occurs perpendicular to the surface.

Low-speed wind tunnel work done by Evans (1957) with a wide variety of building shapes and sizes provides a wealth of information on airflow around buildings. Figure A4 reproduces six flow diagrams from the more than one hundred reported by Evans. These sketches provide a glimpse into the complexity of airflow in showing the effect of height, roof shape, length, bottom channelling, and orientation. Evans provides a table of downwind eddy dimensions as a function of building length, type, and roof pitch. Some eddy dimensions are shown in Figure A4 to illustrate the scale of secondary flow.

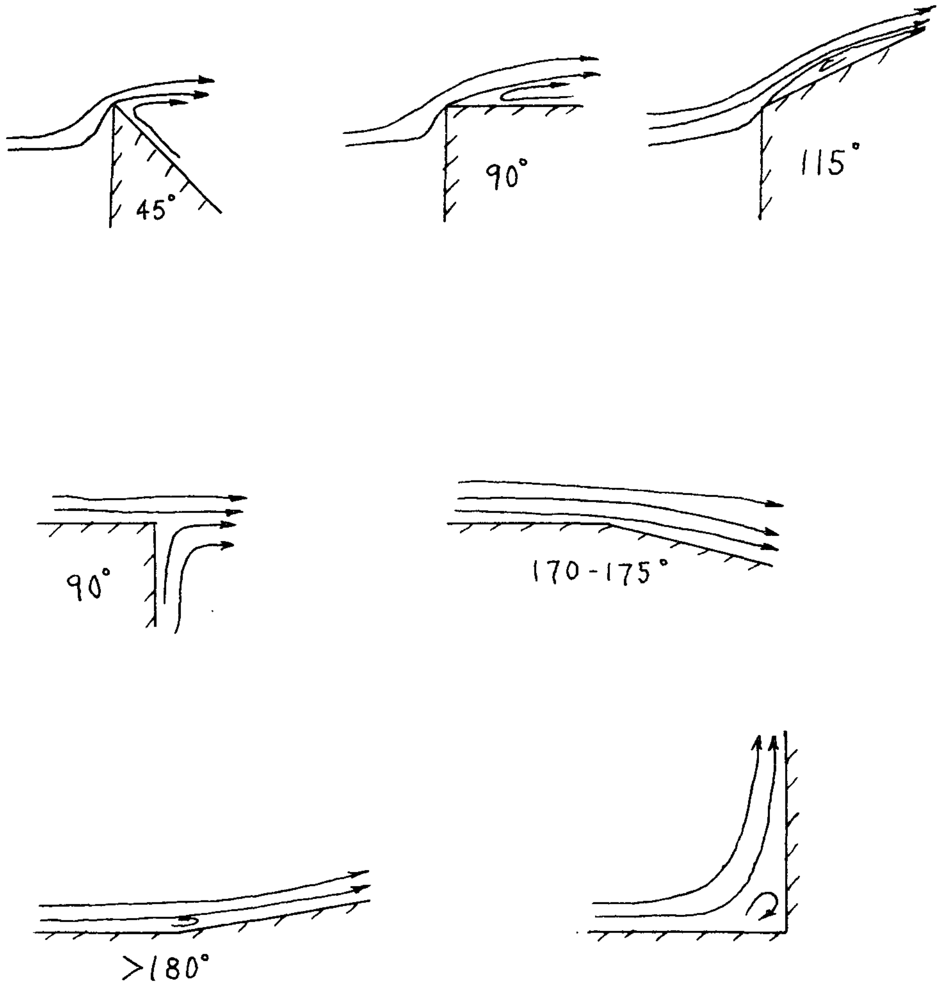


Adapted from Halitsky, 1962.



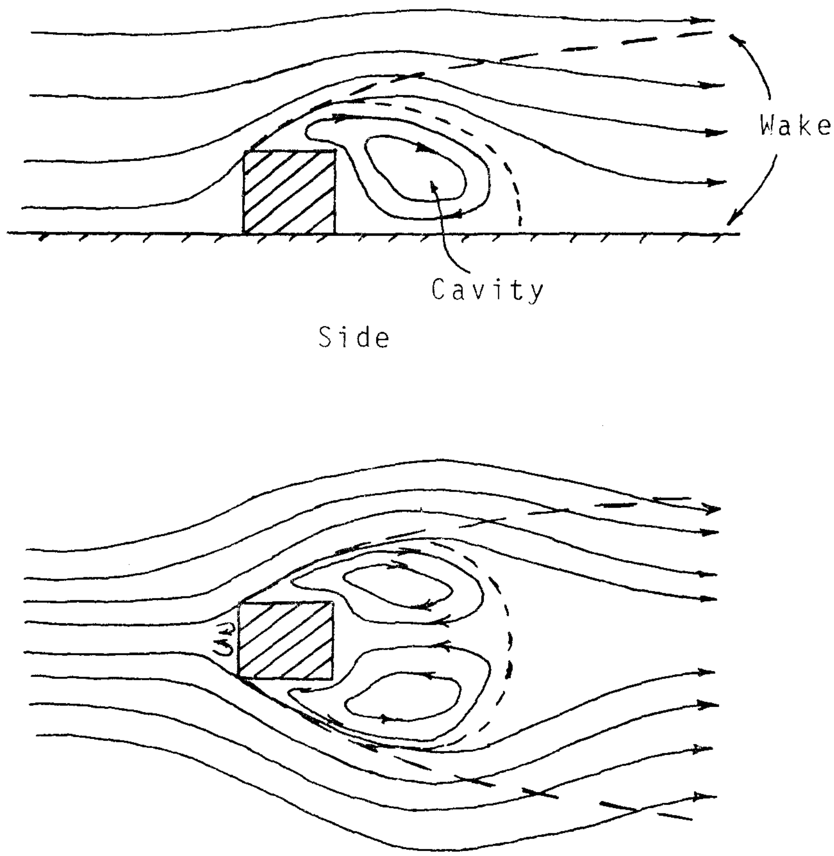
Adapted from Scorer, 1958.

Figure A1. Flow Around Basic Shapes



Adapted from Halitsky, 1962

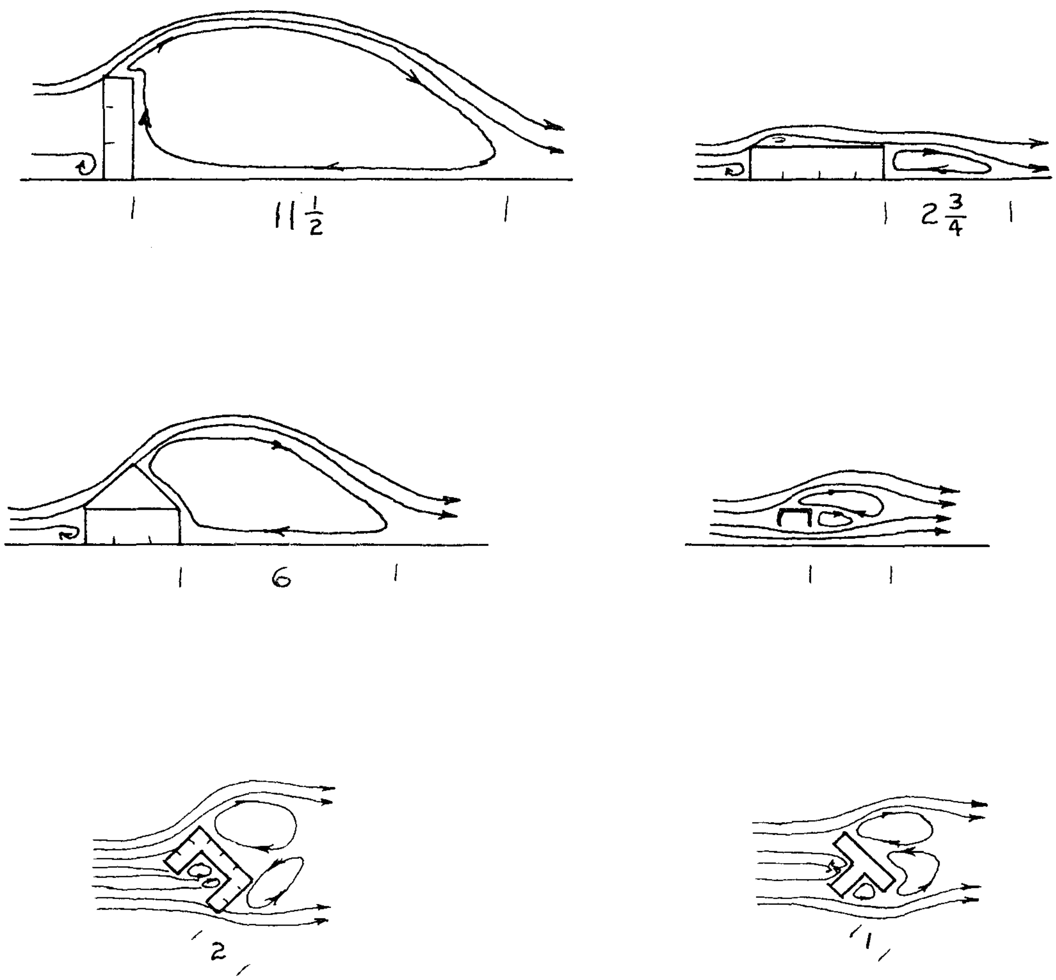
Figure A2. Flow at Edges and Corners



Top

Figure A3. Flow Around a Building

Adapted from Smith, 1968 and Munn, 1966.



Adapted from Evans, 1957.

Figure A4. Typical Flow with Cavity Dimensions

APPENDIX B

AIRFLOW NEAR THE FEDERAL BUILDING, AUSTIN, TEXAS

Flow around downtown buildings is illustrated in Figures B1 and B2 for the region near the Post Office and Federal Building. From a point south of the Interstate Highway 35 Bridge whose elevation is approximately equal to that of the street-level of the Post Office and Federal Building, the 9th Street Post Office tunnel can be seen along with practically all floors of the Federal Building. These buildings therefore have a long unobstructed run-up for a southerly wind. The flow lines of both figures are but a mere suggestion of actual flow and serve to emphasize the complexity of the secondary airflow patterns in an urban area.

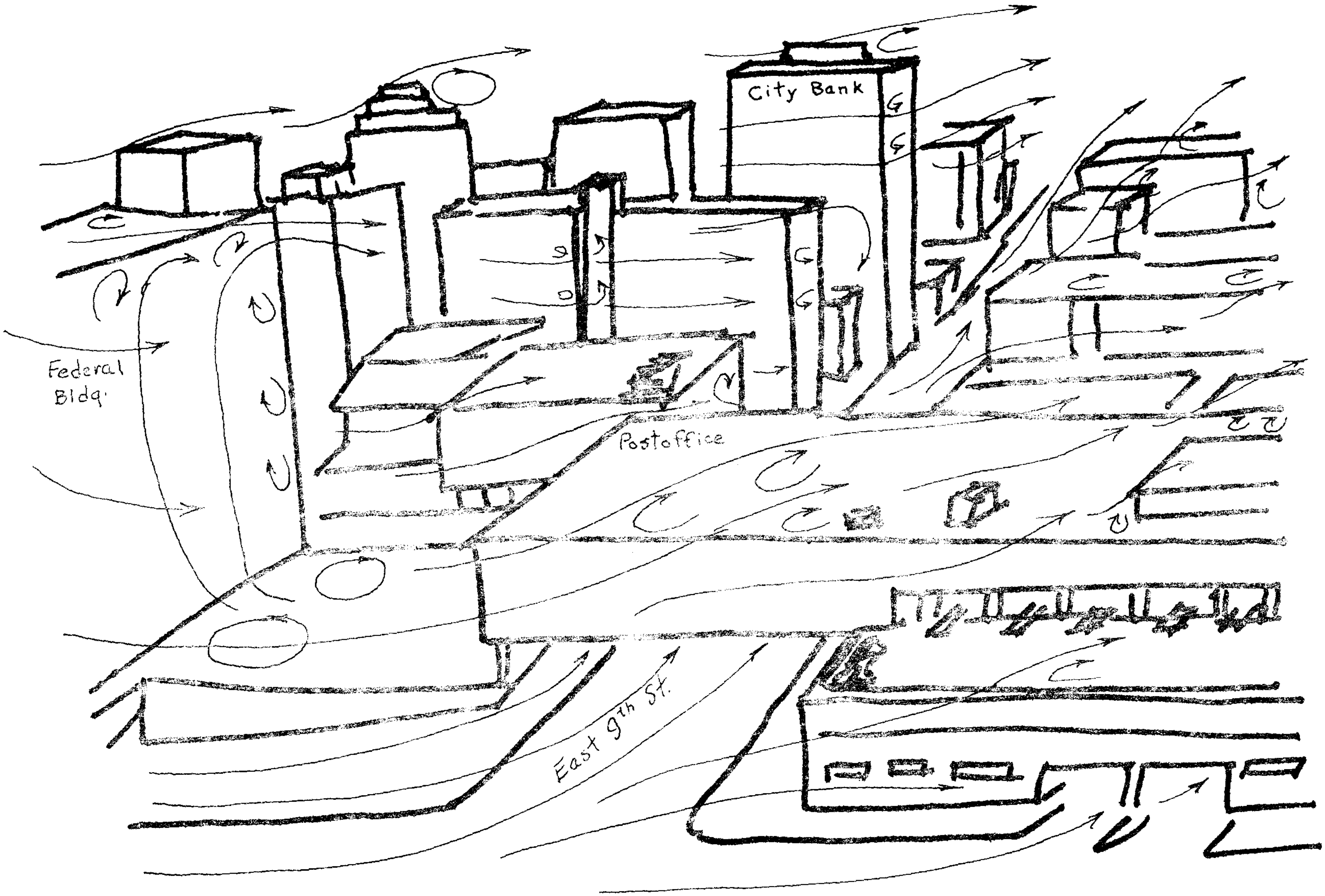


Figure B1. Flow Around Buildings in Downtown Austin, Texas for South Wind

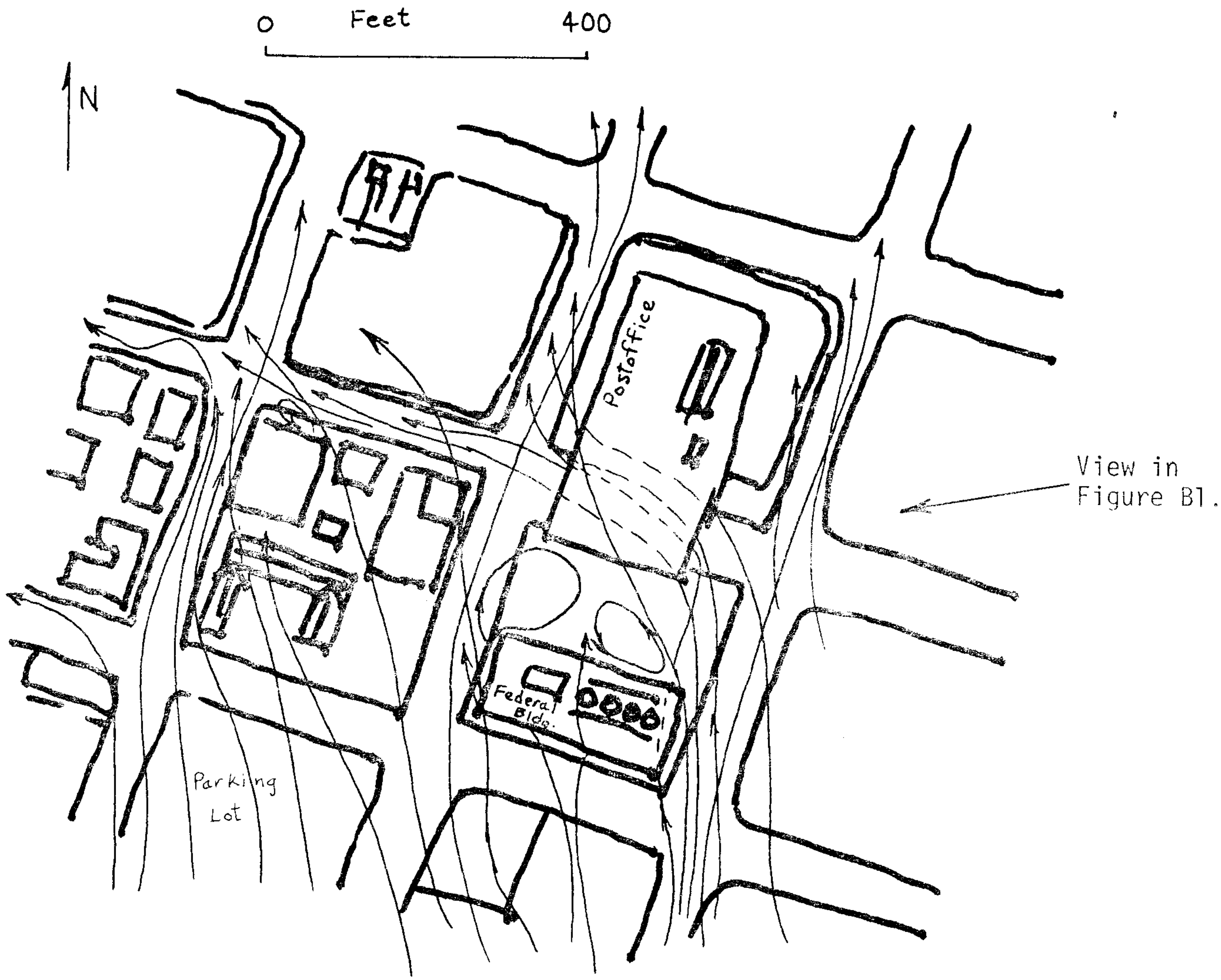


Figure B2. South Wind Channelling, Plan View, for Area Shown in Figure B1, Austin, Texas

R E F E R E N C E S

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