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A GUIDE FOR CONSIDERING AIR QUALITY IN URBAN PLANNING

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Water Programs
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

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A GUIDE FOR CONSIDERING AIR QUALITY IN URBAN PLANNING

by

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SUMMARY

A Guide for Considering Air Quality in Urban Planning is intended to provide information to the planning community that will facilitate the incorporation of air quality considerations into the planning process.

The guide is presented in eight sections. Basic information concerning air quality design criteria, source categories of air pollution, and natural physical phenomena affecting the dispersion of pollutant emissions, and the relative impact of these factors on the planning process, are discussed in Section 2.

Section 3 presents an overview of the air quality impact-land use planning process, including a five step procedure for its implementation. Briefly, the individual steps are as follows:

1. Establishing air quality baseline for the planning area
2. Defining the tolerance of the planning area toward receiving additional pollutant emissions as a function of air quality standards, existing air quality, and air quality maintenance policies
3. Determining acceptable industrial and transportation activities which may be added to existing land use as a function of the pollutant tolerance of the planning area and generalized pollutant emission rates
4. Distributing industrial and transportation land use within comprehensive land use plan(s) using generalized dispersion patterns of major air pollution sources and spatial patterns of existing air quality to locate land use activities
5. Evaluating the air quality impact of the plan(s), modifying land use as required by compliance evaluation with the air quality standards

Within this procedural framework, applications of air quality criteria to planning decisions are defined at various levels of detail. Though this procedure comprises a reasonable first estimate of the procedures that plan-

ners can use to determine air quality implications of plan design decisions, the application and interpretation of these procedures are subject to several conditions which limit their general applicability. Some limitations are discussed in Section 9.

Sections 4 and 5 provide the basis for translating air quality planning parameters into preliminary plan designs in terms of industrial land use and transportation activity. Section 4 presents a procedural scheme for defining the tolerance of a planning area toward receiving additional pollutant emissions. Section 5 contains procedures for determining acceptable industrial and transportation activities in terms of air quality for a planning area.

Section 6 contains examples of planning situations to clarify the procedures involved in determining allowable emissions for a planning area. Section 7 presents information relative to the dispersion patterns of major source configurations so that the placement of land use associated with preliminary designs (generated as a result of determining acceptable industrial and transportation land uses) can be compatible with local air quality considerations. Procedures relative to the distribution of those land use activities address the relationship between existing air quality and the siting of new land use activities. Location-sensitive analyses are illustrated in three case studies.

Section 8 presents a methodology which provides for the air quality impact evaluation of comprehensive urban plans. This methodology, designated as the AQUIP system, is a completely operational computerized procedure and has been used in the evaluation of alternative land use plans for the Hackensack Meadowlands of New Jersey.

Section 9 summarizes the documents' contents and discusses some limitations of the applications and interpretation of the procedures described. It is concluded that the procedures can be useful to the planner since they provide a means of rapid estimation of the air pollution potential of preliminary industrial/transportation land use plans, are simple to apply and reduce the susceptibility of "final" designs to major changes in land use required by compliance with the air quality standards.

1. INTRODUCTION

1.1 Objectives

This document is intended to provide information to the planning community that will facilitate the incorporation of air quality considerations into the planning process. Air pollution impacts resulting from different land use activities are discussed, including generalized emission characteristics of principal urban activities, associated meteorological and topographical phenomena affecting pollution diffusion, and simplified procedures for relating pollutant emissions to ground level air pollution concentrations.

It is assumed that the primary users of the air quality planning guide will be members of agencies responsible for the overall planning efforts of regional and subregional areas. This guide is specifically addressed to planners with little or no technical background in air quality analysis, but with sufficient technical ability to follow basic procedures for quantifying the relationships between land use and ambient air quality. The current state of the art in Air Quality Impact and Land Use Planning is reflected in this document. The technique described will probably be modified and refined as more understanding of the relationship is gained.

While the regional planner would be best suited to use the tools outlined in the document, the information presented may find application in agencies with more diverse interests. Industrial councils, transportation planners, zoning boards, and the like may find that particular areas of the guide provide them with sufficient information to make policy decisions which are cognizant of air quality considerations. Simplification of the interaction between land use and air quality should enable interested citizens and advocate planners, having a minimum of background in air quality analysis, to be aware of generalized consequences of planning decisions.

More sophisticated, detailed, and precise tools for evaluating the impact of land use activities upon air quality are available. The technique described in this document should not serve as a substitute for consultation with local air pollution control experts, particularly in areas where air pollution is or may be a significant problem.

This document is not intended for use by air quality control agencies and other organizations that should have sufficient professional expertise to carry out air quality planning determinations of a much more sophisticated nature. Neither is this guide intended to be used as a tool for environmental litigants, because such litigation should depend on more specific studies of individual air quality parameters.

Where approaches or numerical estimates are not otherwise referenced, they are based upon the professional experience of the authors. Section 1.3 provides a glossary of terms used in the Guide and should be consulted as necessary by the reader.

1.2 Overview

Patterns of land use and their accompanying activities have a major impact in determining the type and amount of air pollution generated over a region. Historically, specification of land use has been comparatively insensitive to air quality considerations. Recent public concern for environmental quality has fostered attempts to improve air quality through direct control of the sources of air pollution. Specifically, the current focus of these attempts is on emissions control and more efficient fuel utilization. However, this type of approach does not by itself address the broad-based problems of planning for long term air quality.

The most fundamental determination of air quality levels over which operational control can be exercised is the specification of land use. Land use activities, including specific emission sources, can be associated with a rate of pollution discharge. Specification of the types and amounts of residential, commercial, industrial and transportation activity which are consistent with air quality criteria, form the basis for generating urban configurations which are compatible with acceptable levels of air quality.

In order to achieve an equitable and realistic level of management of the air resource, it is necessary to define and implement within the planning process a methodology, corresponding analytic tools, guidelines and standards and an appropriate data base that will permit land use and transportation planning that is compatible with acceptable air quality levels.

In this way, planning for air quality will be simultaneously a constraint and a directive for planning new development. Consideration of air quality factors has not been a direct input into the planning process. Though air quality considerations represent a limit on the freedom to designate amounts, types and locations of land uses, it is expected that air quality impacts of development will be considered simultaneously with other planning criteria in designating future land use activities.

The air quality of an urban environment depends upon:

1. The ability of the environment to disperse, transform, and remove pollutant loadings generated by urban land use activities.
2. Pollutant source characteristics
3. Background pollutant concentrations.

The capacity of the air basin over a region to disperse, transform and remove atmospheric pollutants depends upon a variety of factors, including the amount and type of pollutants emitted, and meteorological and topographical characteristics of the region.

Pollutant source characteristics include the quantity of emissions and the physical location and configuration of sources. Sources are generally referred to as point, line and area sources. Point sources represent major, identifiable sources within a region, such as industry or municipal incinerators. Line sources represent emissions from motor vehicles along principal highways and emissions from aircraft. Area sources represent clusters of small, individual sources within a region such as emissions from heating plants in residences and small buildings. Distinctions are also drawn between direct and indirect sources of pollution. Direct sources are those which emit pollutants as a result of activities inherent in their operations (e.g., industrial facilities, housing facilities, etc.). Indirect sources represent a major facility that spawns various emission sources, such as transportation-related activity at an airport or shopping center.

Source emissions are in turn determined by land use category or source type, level of activity or process rate, type and amount of fuel used, source controls and activity schedules (see the glossary at the end of this chapter for an explanation of these terms). These elements may be specified to greater detail depending on the type of land use or source type involved. For example, for a given industry, its stack height and smoke temperature would be specified. A source, such as a highway, may be additionally defined as elevated, depressed or at-grade. Each of these parameters contributes to the determination of pollutant source characteristics.

Land use encompasses not only the type of activity intended for land areas, but the physical interrelationship between and among various activities and the type of ground cover on the land. Therefore, land use affects both pollutant source characteristics and the ability of the environment to disperse pollutants.

Background air pollution may be defined as that level of pollutant concentration not directly attributable to an identifiable source or combination of sources within the planning area. Background concentrations may be relatively constant over the planning area, or they may vary significantly within it. It is generally not possible to determine future background pollutant levels with a high degree of accuracy. Consequently, it is necessary to have air quality data available with which to assess the air quality impact of planning decisions relative to projected background air pollution.

1.3 Glossary of Terms

Activity, Activity Level	Basic land use and transportation planning units of intensity of use, e.g., vehicles per day on a highway, acres of residential land use, square feet of industrial plant space.
Air Quality Baseline	Pollutant concentration data of sufficient quality and quantity to satisfactorily define existing air quality.
Air Quality Contour	See reference "Isopleth."
Air Quality Control Region	Geographic regions (generally a state or metropolitan area) established for the purpose of air quality analysis under the Clean Air Act.
Air Quality Criteria	Factors that represent a basis for decision-making; for example, EPA Criteria Documents summarize effects of specified pollutants and formed the basis for setting federal ambient air quality standards.

Air Quality Estimation or Projection	The calculation of current or future air pollutant concentrations at specified receptor points resulting from the action of specified meteorological conditions on specified emissions.
Air Pollution Loading	Calculation of maximum allowable emissions averaged over an area as a function of emission density (regional emissions/regional area).
Ambient Air	That portion of the atmosphere, external to buildings, to which the general public has access.
Ambient Air Quality	Concentration levels in ambient air for a specified pollutant and a specified averaging time period within a given geographic region.
Ambient Air Quality Standard	A level of air quality established by federal or state agencies which is to be achieved and maintained; primary standards are those judged necessary, with an adequate margin of safety, to protect the public health; secondary standards are those judged necessary to protect the public welfare from any known or anticipated adverse effects of a pollutant.
AQUIP	An acronym for Air Quality for Urban and Industrial Planning, a computer-based tool for evaluating air pollution impact of land use and transportation plans.
Atmospheric Dispersion Model	A mathematical procedure for calculating air pollution concentrations that result from a specified array of emission sources and a specified set of meteorological conditions.
Average Receptor Exposure	A measure of the average impact of air quality levels on a specific type of receptor; the measure is equal to the integrated receptor exposure divided by the total number of receptors in the study region.
Background Air Quality	Levels of pollutant concentrations within a study area which are the result of emissions from all sources other than those incorporated in the model for the study area.
Background Emissions	The emissions inventory applicable to the background region; that is, all emission sources not explicitly included in the model for the study area.

Climatology	The study of long term weather as represented by statistical records of parameters such as winds, temperature, cloud cover, rainfall, and humidity which determine the characteristic climate of a region; climatology is distinguished from meteorology in that it is primarily concerned with average, not actual, weather conditions.
Concentrations	A measure of the average density of pollutants usually specified in terms of pollutant mass per unit volume of air (typically in units of micrograms per cubic meter), or in terms of relative volume of pollutant per unit volume of air (typically in units of parts per million).
Degree Days (Heating Degree Days)	The sum of negative departures of average daily temperature from 65°F; used to determine demand for fuel for heating purposes.
Emission Factor	A numerical conversion factor applied to fuel use and process rates to determine emissions and emission rates.
Emissions	Effluents into the atmosphere, usually specified in terms of weight per unit time for a given pollutant from a given source.
Emissions Inventory	A data set describing the location and source strength of air pollution emissions within a geographical region.
Emissions Projection	The quantitative estimate of emissions for a specified source and a specified future time.
Equivalent Ambient Air Quality Standards	Air quality levels adopted in this study to permit analysis of all air pollutants in terms of annual averages; in cases where state and federal annual standards do not exist, the adopted levels are based on the extrapolation of short period standards.
Fuel Related Sources, Fuel Emissions	Fuel related sources use fuel to heat area, or to raise a product to a certain temperature during an industrial process, or for cooking in the house; they produce fuel emissions. (See also, Non-Fuel Related Sources).
Fuel Demand, Fuel Use Propensity	The amount of fuel needed to fulfill the total heat requirement (space heating plus process heating); use of a particular fuel or fuels that determines the actual amounts of various fuels used to satisfy the heat requirement.

Heading: glossary entries.

<u>Heating Requirements</u> — The amount of heat needed for:

Space heating - heat needed to warm an enclosed area, such as the floor space of a school in winter, to a desired temperature; the heat content or value of the fuel used and the outside temperature define the space heating requirement.

Non-space heating, process heating - heat needed to raise a product to a certain temperature during an industrial process or for cooking (with gas) in the home; it is generally not related to outside temperature.

Percent space heating (or percent process heating) - the relative proportion of a fuel or its heat content that is used for space heating (or process heating).

<u>Impact Measure (or Parameter)</u> — A *quantitative representation* of the degree of impact on air quality or specific receptors resulting from concentrations of specified pollutants.

<u>Influence Region for an Area</u> — The geographical region containing the emission sources responsible for at least 90% of the ground level concentrations (averaged throughout the area) of all pollutants considered. For an individual source or group of sources, the influence region may be defined as that area within which air quality is affected by that particular source, or group of sources.

<u>Integrated Receptor Exposure</u> — A measure of the total impact of air quality levels on specific receptors; the measure is equal to the summation over all grid cells within the study region of the number of receptors times the concentration levels to which they are exposed.

<u>Isopleth</u> — Contours of constant levels of concentration for a specific pollutant.

<u>Land Use Intensity</u> — The level of activity associated with a given land use category; for example, the population density of residential areas.

<u>Land Use Mix</u> — The percent of total study region area allocated to specific land use categories.

<u>Meteorology</u> — The study of atmospheric motions and phenomena.

Microscale Air Quality	The representation of air quality in a geographical scale characterized by distances between source and receptor ranging from a few meters to a few hundred meters.
Non-Fuel Related Sources, Process Emissions, Separate Process Emissions	Sources that do not burn fuel primarily for heating purposes or do not burn fuel at all, including transportation sources, incineration, and certain industrial processes; emissions produced by non-fuel related sources. (See also, Fuel Related Sources).
Normalized Concentration	A concentration of a pollutant that is made independent of one or both of the dependent variables (i.e., wind speed, or source strength). For example, a concentration normalized by source strength would have the units of concentration divided by source strength. Therefore, given a concentration normalized by source strength for a given configuration, an actual concentration may be obtained simply by multiplying by the appropriate source strength.
Process Rate	Process rate is a unit measure of the productivity of a manufacturing plant. The unit may be used to estimate or compare industrial activity (e.g., the process rate of a steel mill might be expressed as tons of steel produced per day). As used in previous studies the term may also refer to a specific unit of process rate.
Receptor	A physical object which is exposed to air pollution concentrations; objects may be animate or inanimate, and may be arbitrarily defined in terms of size, numbers, and degree of specificity of the object.
Receptor Point	A geographical point at which air pollution concentrations are measured or predicted.
Regional Air Quality	The representation of air quality in a geographical scale characterized by large areas; for example, on the order of 50 square kilometers or greater.
Schedule	The number of hours per year a fuel burning activity will consume fuel; used to determine heating requirements.

Source	Any stationary or mobile activity which produces air pollutant emissions.
Source Geometry	Sources categorized for modeling purposes as a point, line, or area source, defined as follows: Point source - a single major emitter located at a point. Line Source - a major highway link, denoted by its end points. Area source - a rectangular area referenced to a grid system; includes not only area-wide sources, such as residential emitters, but single emitters and highway links deemed too small to be considered individual point or line sources.
Stability Class	A classification of atmospheric stability conditions based on surface wind speed, cloud cover and ceiling, supplemented by solar elevation data (latitude, time of day, and time of year).
Stability Wind Rose	A tabulation of the joint frequency of occurrences of wind speed and wind direction by atmospheric stability class at a specific location.
Total Air Quality	The air quality at a receptor point resulting from background emission sources and from emission sources specifically within the study area.

2. PLAN DESIGN FACTORS

In this section, basic information pertaining to the relationship between land use and air quality is presented. Specifically, three topics are discussed:

- The National Ambient Air Quality Standards
- Sources of Air Pollution
- Natural Phenomena Affecting Air Quality

Each of these factors are essential to a general understanding of the interrelationships between land use and air quality, and thus, to the formulation of land use plans which are compatible with acceptable air quality levels. Therefore, information contained in this section addresses background information necessary to implement the air quality impact-land use planning methodology which is detailed in Sections 3 through 8. Though some of the concepts addressed are highly complex, such as meteorological phenomena affecting air quality concentrations, these concepts have intentionally been simplified in order to extract information that will be most instrumental to the planner in determining the impact of land use plans relative to air quality.

2.1 The National Ambient Air Quality Standards

Air quality standards are important to the planner because they represent not only legal mandates for air quality, but also specific design criteria for the planning process. That is, they comprise both a set of constraints and guidelines of which the planner must be aware in the specification of land use types and configurations. The National Ambient Air Quality Standards (NAAQS) now in use are a direct result of the Clean Air Act Amendments of 1970. These standards, as defined in 40 CFR Part 50, are presented in Table 1. As shown, standards exist for six individual pollutants, specified by concentration, averaging time and frequency. The standards specify that the maximum concentrations are not to be exceeded more than once a year. In addition, both primary and secondary standards are indicated. Primary standards are those that are requisite to protect the public health and

Table 1. NATIONAL AMBIENT AIR QUALITY STANDARDS

(Established Pursuant to the Clean Air Act of 1970)

Pollutant	Period of Measurement [a]	Primary Standard		Secondary Standard	
		$\mu g/m^3$ [b]	ppm [b]	$\mu g/m^3$ [b]	ppm [b]
1. Carbon Monoxide (CO)	8 Hours	10,000	9	Same	Same
	1 Hour	40,000	35	Same	Same
2. Hydrocarbons (HC) (non-methane)	3 Hours	160	0.24	Same	Same
3. Nitrogen Oxides (NO_2)	Year	100	0.05	Same	Same
4. Photochemical Oxidants (O_x)	1 Hour	160	0.08	Same	Same
5. Sulfur Oxides (SO_x)	Year	80	0.03	None	None
	24 Hours	365	0.14	None	None
	3 Hours	None	None	1,300	0.5
6. Total Suspended Particulates (TSP)	Year	75	-	60	-
	24 Hours	260	-	150	-

(a) Concentrations are averaged over each period of measurement. The annual TSP concentration is a geometric mean of 24-hour samples; all other concentrations are arithmetic mean values. Standards for periods of 24 hours or less may not be exceeded more than once per year.

(b) Units of measurement are micrograms per cubic meter ($\mu g/m^3$) and parts per million (ppm).

secondary standards, the public welfare. In some instances, individual states have instituted air quality standards that are more stringent than the federal standards. In these cases, the planner should design according to the state standards because in general, state air pollution control agencies will be responsible for the final review and approval of land use plans relative to expected air pollution impact.

Because compliance with the standards is mandatory for each of the time periods specified, it is important that planning decisions be based upon air quality data reflecting these time periods. Therefore, sufficient data should be examined to establish hourly, daily, and annual trends of individual pollutant concentrations. A brief discussion of the individual pollutants and their respective time frames, as addressed by the standards, follows. The sources for each of these pollutants are discussed in Section 2.2.

Carbon Monoxide

The standards for carbon monoxide are given in terms of annual maximum concentrations averaged over 1 and 8 hour time periods, indicating that short duration exposures to this pollutant are most critical. Because the prime contributor of carbon monoxide emissions is the automobile, one would expect diurnal (daily) variations in CO levels to correlate fairly well with variations in traffic densities. Consequently, air quality data required for planning decisions involving vehicular transportation should be examined for the one hour periods involving morning and evening peak hours and for the eight hour period including the evening peak hour. Of the two, the 8-hour standard has been generally seen to be more difficult to meet; therefore, where limitations on data analysis exist, the planner should favor exclusion of the one hour periods rather than the eight hour. Possible exceptions to this may occur in considering air quality data for areas close to facilities having high, but intermittent traffic densities associated with their use. In particular, sports and/or recreation complexes, industrial parks, commuter-oriented schools and colleges, and mass transportation facilities, airports, bus and train terminals, and the like, may all exhibit traffic patterns that make considerations of the one hour period of paramount importance in examining carbon monoxide levels relative to the standards.

Hydrocarbons and Photochemical Oxidants

The standard for hydrocarbons is given as an annual maximum concentration for a specific 3 hour average, i.e., 6 AM to 9 AM. This morning time period is specified because it is during this period that meteorological conditions are generally most favorable for initiating the formation of photochemical oxidants. The intent here is to limit oxidant formation by limiting hydrocarbon concentrations in the atmosphere during the time when oxidant formation is most probably initiated.

Photochemical oxidants differ from other pollutants in that they are not emitted directly to the atmosphere, but are produced by chemical reactions among hydrocarbons and oxides of nitrogen in the presence of sunlight. The precise nature of these reactions in the atmosphere is unknown because there are so many variables involved. Photochemical oxidants are a regional problem in that the contribution of the pollutant emissions from a single facility to the concentration of photochemical oxidants in the vicinity of that facility cannot be determined. This is due not only to the complexity of the chemical reactions, but also to the time lag of up to several hours between emissions of hydrocarbons and oxides of nitrogen and formation of the photochemical oxidants. During this interval, pollutants are able to disperse considerable distances from their sources.

The oxidant standard is given in terms of an annual maximum one hour average concentration. Generally, oxidant concentrations are highest in the early afternoon. In terms of the planning process, the planner should note that a credible model for predicting oxidant concentrations has yet to be developed. Thus, it is especially important that both oxidant and hydrocarbon data be available in order to empirically define the relationship between the two. A predictive model for hydrocarbons can then be employed to estimate oxidant levels for anticipated land use.

Nitrogen Dioxide

Nitrogen dioxide has perhaps the least complex standard of all the pollutants. The annual arithmetic mean concentration specified in the standards makes consideration of nitrogen dioxide relatively straightforward, because only the one number (the annual average) need be considered for this pollutant.

Sulfur Dioxide

Standards for sulfur dioxide are expressed as annual maximum concentrations of 3 and 24 hour averaging periods, in addition to annual arithmetic mean concentrations. Complexity of the standards for sulfur dioxide indicate that this pollutant has been demonstrated to have both short term as well as long term exposure effects. Because industrial activity is, in most cases, responsible for the majority of sulfur dioxide emissions, the planner must, therefore, be especially careful in the specification and placement of industrial land uses.

Particulate Matter

Particulate matter in the atmosphere consists of tiny solid particles small enough to remain suspended in the air, often for hours or days, before settling out due to their own weight, or raining out in snow or rain storms. Industrial, transportation, and heating sources all contribute to the observed concentration of particulates. Total suspended particulate concentrations are regulated by an annual maximum, specified over a 24-hour period, and by an annual geometric mean concentration. Again, the concern here is for both long and short term exposure to the pollutant.

2.2 Sources of Air Pollution

There are only two means by which the atmosphere of a given planning area may receive pollution:

1. Through the direct emission and consequent dispersion of pollutants from sources within the planning area

2. Through the transport of pollutants, generated elsewhere, into the planning area by natural atmospheric processes.

Both mechanisms of air quality degradation reflect the effects of what should be considered as primary plan design factors influencing an area's air quality. An area's pollutant *source characteristics* (quantity of emissions and configuration of sources) may be determined from the mix of land use categories and intensity of land use activities. Background levels of pollutants as used in this Guide refer to that level of pollutant concentration not directly attributable to an identifiable source or combination of sources within the planning area. Therefore, pollutants both generated by and transported into the planning area may be used as criteria for defining the tolerance of existing air quality to additional pollutant emissions. Background levels of pollutants may also be useful in locating both sources and receptors of air pollution to minimize the air pollution impact of a given land use configuration.

General Source Categories

For the purpose of defining the relationships between land use and air quality as planning design parameters, it is most appropriate to consider the following categorization of land use as potential sources of air pollution: transportation, industry, and other sources. Specification of the mix, intensity and locations of these three land use types, when coupled with ambient conditions of meteorology, climatology, and topography, will determine concentrations and spatial patterns of all pollutants emitted in the planning area.

The most publicized air pollution source category is transportation, particularly motor vehicular transportation. The burning of fossil fuels in internal combustion engines used by automobiles, trucks, and buses has created a serious air pollution problem for highway-oriented urban areas. Similarly, airport operations contribute heavily to air pollution, although their impact is usually limited to the vicinity of the facility itself. Rail transportation also contributes, although on a relatively minor scale, to air pollution. Transportation activity as a whole is a major source of carbon monoxide, oxides of nitrogen, hydrocarbons, and photochemical oxidants.

The second major category of air pollution sources is the general group of industrial emitters. Industrial sources of air pollution are responsible for emissions of SO_2, particulates, NO_X, hydrocarbons, and to a limited extent CO. These result both from the burning of fossil fuels for heat and power and from the physical or chemical processes that are indigenous to specific industrial operations. Additionally, industries often dispose of solid waste by incineration.

Table 2. GENERAL SOURCE CATEGORIES OF AIR POLLUTION

I. Industrial Sources

A. Space heating of industrial buildings

B. Process heating

C. Separate process emissions

D. Solid waste disposal

II. Transportation Sources

A. Automobiles

B. Gasoline trucks and busses

C. Diesel trucks and busses

D. Diesel rail vehicles

E. Electric rail vehicles

F. Aircraft and airport operations

III. Other Pollutant Sources

A. Incineration of solid waste

B. Space heating of commercial buildings

C. Space heating of residential facilities

D. Space heating of institutions (schools and hospitals)

E. Evaporative losses from petrochemical service operations (gas stations, fuel oil delivery, etc.)

F. Agricultural crop dusting, plowing

G. Forest fires and urban fires

Finally, there is a category of other pollution sources that may have a significant role in determining overall air quality. This group includes residential, commercial, and institutional facilities. Their accompanying fuel needs for space heating and public solid waste disposal facilities represent substantial contributions to an area's air pollution. In particular, municipal incineration generates large amounts of highly visible pollutants, primarily particulates. Except for large scale public solid waste facilities, individual sources within this category, in comparison with industrial and transportation sources, are relatively minor with respect to their impact on regional air quality. Large scale solid waste facilities require individual air quality analyses that should not be attempted by the planner.

Table 2 presents the sources of pollutant emissions by the three general categories of urban land use discussed above. These three activity categories are usually classified by point, line and area source configuration-type to represent emissions from the different activity categories. The relationships between industrial and transportation activities and their emission characteristics are discussed in further detail in Section 5, where procedures for selecting industrial and transportation plans, compatible with acceptable air quality levels, are presented.

Background Air Pollution

Background air pollution may be defined as that level of pollutant concentration not directly attributable to an identifiable source or combination of sources within the planning area. Background concentrations may be relatively constant over the planning area, or they may vary significantly within it. It is generally not possible to determine future background pollutant levels with a high degree of accuracy. Consequently, it is necessary to have air quality data available with which to assess the air quality impact of planning decisions relative to projected background air pollution.

For purposes of this and the following discussion it may be worthwhile to clarify the intended meaning of the terms "area" and "region." In planning, "region" implies a large area, the size of a multi-county or metropolitan area or Air Quality Control Region (AQCR); a subregion is still fairly large (larger than a suburban political jurisdiction). An "area" on the other hand can be of any size. It may be a few square blocks within an urban area, a town within a metropolitan region, a complete city, or a whole region. Of course the size of the area under consideration will determine details of the information required by and, in some cases, the basic approach to individual planning studies. To a large degree, these will manifest themselves as questions related to background pollution concentrations.

If the background levels of pollution are high within a planning area, as is usually the case in urban regions, then the potential air pollution resulting from sources within the planning area by itself may be only a small percentage of the total air pollution. As a result, land use planning may not be an effective means of reducing air pollution levels within the planning region. On the other hand, where it is not possible, for whatever reason, to prohibit growth in a region with high background levels, it may be possible to determine the types and amount of development that will keep regional levels of air pollution within standards. In particular, if the spatial variations in background concentrations are significant, then it is essential to carefully locate land use activities relative to such concentration patterns.

Low background pollutant concentrations within a planning area may occur in two ways. First, the planning area may be located within a non-urbanized or non-industrialized area; and secondly, the planning area itself may encompass a sufficiently large portion of the urban region so that the relative influence of background concentrations is low. The result, in either case, is that the percent variation in expected pollution concentrations among alternative land use plans, or planning decisions, may be relatively large. Under such circumstances, land use planning can be effective in reducing regional pollutant concentration levels.

2.3 Natural Phenomena Affecting Air Quality

The concentration of atmospheric pollutants observed at different locations depends on more than just the quantity of pollutants emitted at the various sources. The atmosphere is the agent that transports and disperses pollutants between sources and receptors. Consequently, the state of the atmosphere helps to determine the concentrations of pollutants observed at receptors. Unlike emissions sources, which can be controlled, the state of the atmosphere is not at present susceptible to man's control.

Some skill has been attained, however, in predicting the future state of the atmosphere. Since the meteorological conditions that favor high concentrations of pollutants are known, severe air pollution episodes can therefore be forecast.

In general, three parameters are used to describe atmospheric transport and dispersion processes. These are wind speed, wind direction, and atmospheric stability. For emissions at a given source, a higher wind speed provides the pollutants with a greater air volume within which to disperse. This causes ground level pollutant concentrations, other things being equal, to be inversely proportional to wind speed.

Horizontally, the wind direction is the strongest factor affecting pollutant concentrations. For a given wind direction, nearly all the pollutant transport and dispersion will be downwind. Wind direction determines which sector of the area surrounding a source will receive pollutants from that source. The influences of wind speed and direction on pollution dispersion volumes and hence, on ground level concentrations are illustrated in Figures 1 and 2.

Atmospheric stability directly affects the vertical dispersion of atmospheric pollutants. Unlike wind direction and wind speed, atmospheric stability cannot be measured directly. Atmospheric stability is a measure of air turbulence and may be defined in terms of the atmospheric temperature profile where ambient temperature is a function of height above ground level. When the temperature decreases rapidly with height, vertical motions in the atmosphere are enhanced, and the atmosphere is called unstable. An unstable atmosphere, with its enhanced vertical motions, is more effective for dispersing pollutants, and because of the large volume of air available for the spread of pollutants, ground-level concentrations can be relatively low. When the temperature does not decrease rapidly with height, vertical motions are neither enhanced nor repressed and the stability is described as neutral. Under these conditions, pollutants are also allowed to disperse vertically in the atmosphere, although not as rapidly as for the unstable case.

When the temperature decreases very little, remains the same, or increases with increasing height, the atmosphere is called stable. Under these conditions, the atmosphere inhibits the upward spread of pollutants. Upward-moving smoke, which rapidly assumes the temperature of the surrounding

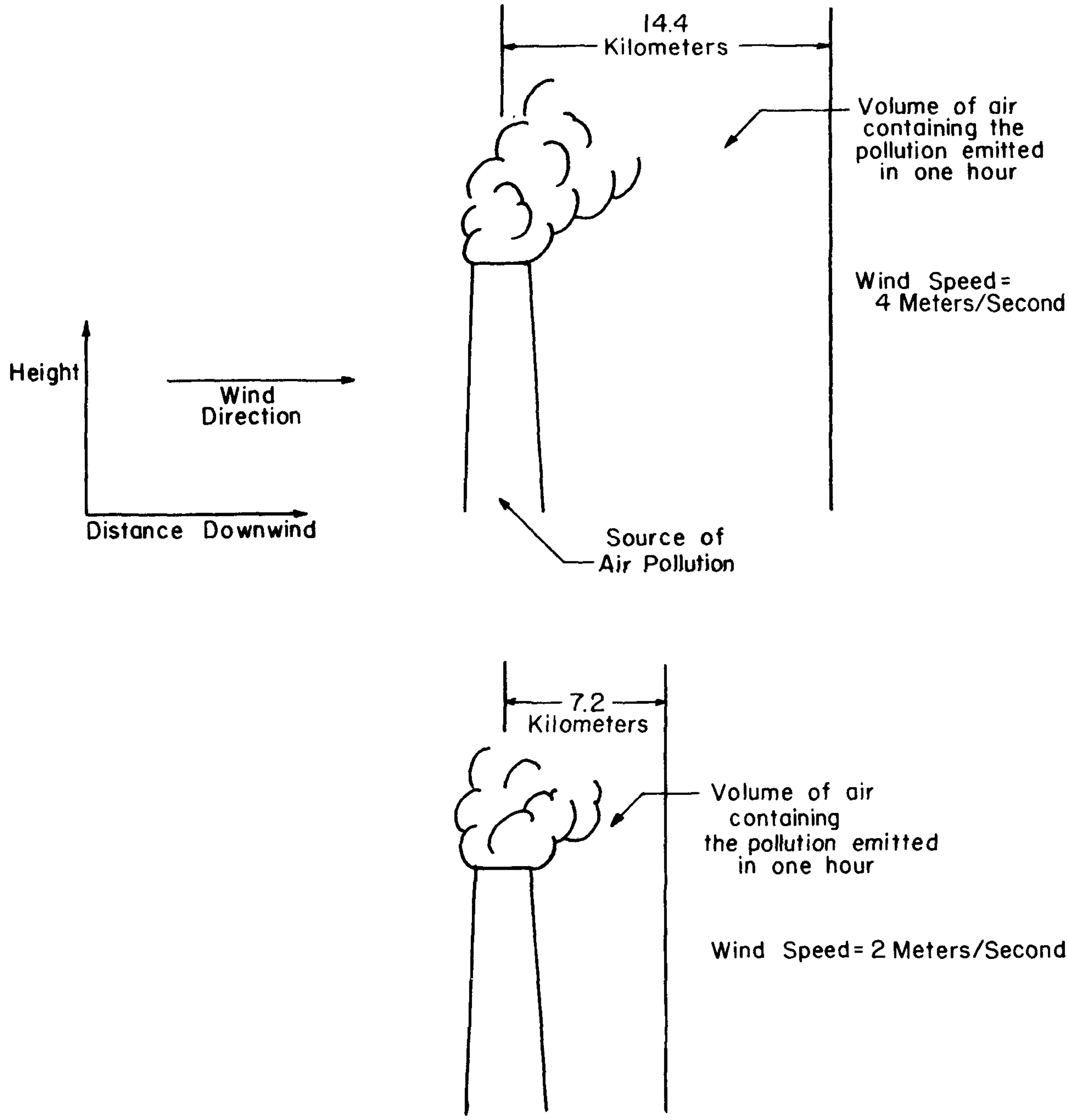

Figure 1 The influence of wind speed on ground level pollutant concentrations

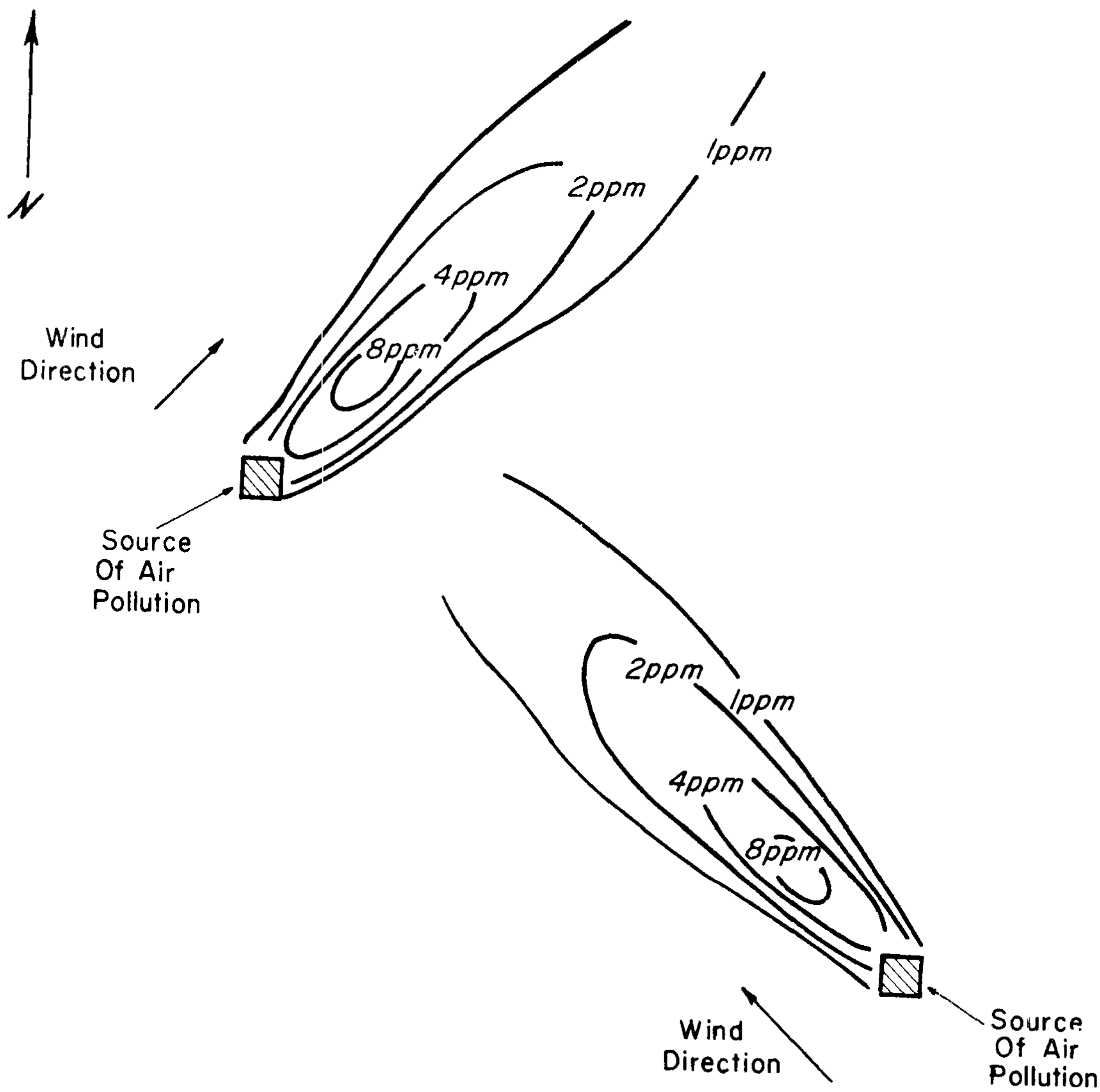

Figure 2 The influence of wind direction on ground level pollutant concentrations

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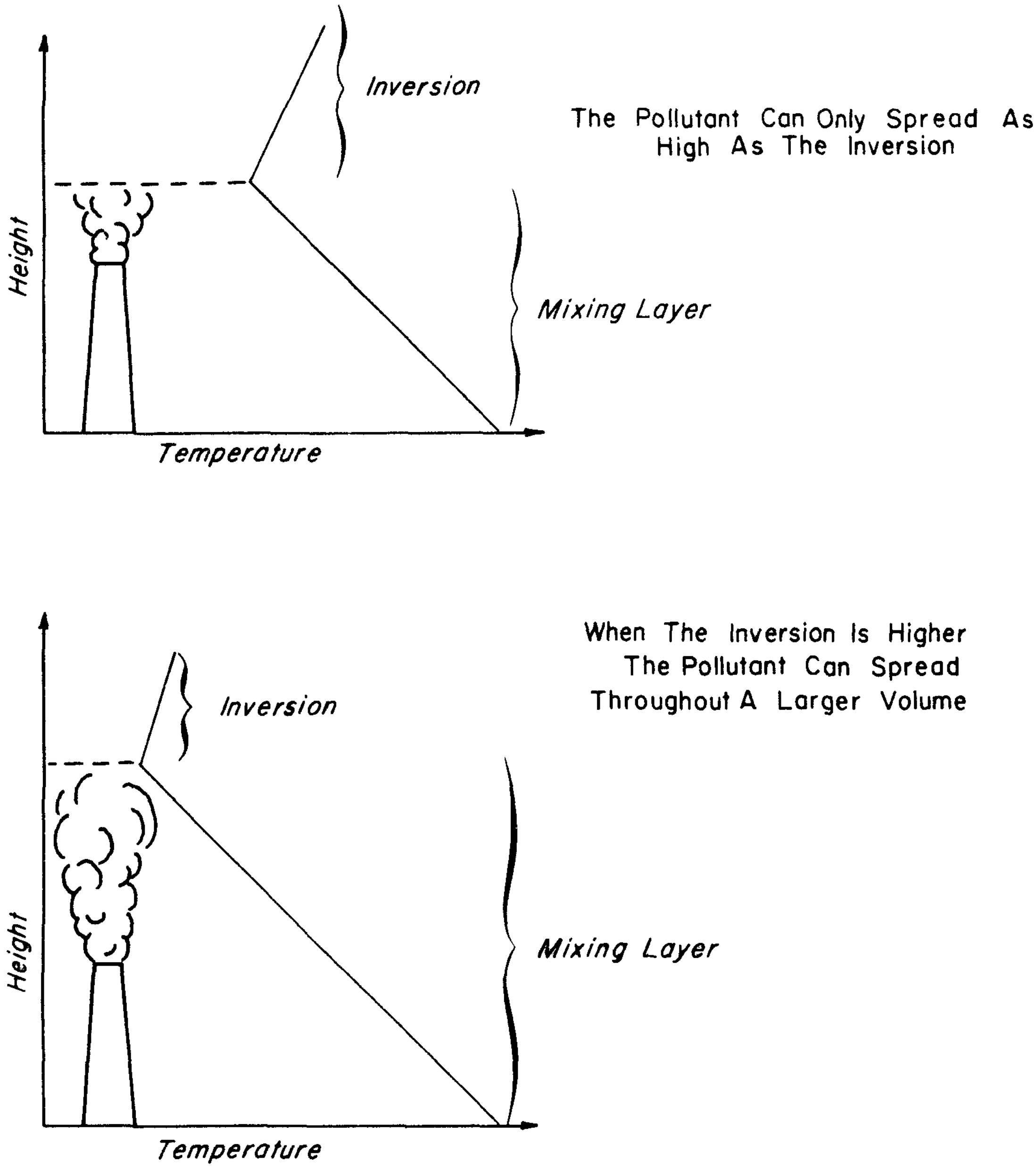

Figure 3 The influence of atmospheric stability on ground level pollutant concentrations

air, reaches a point where it is colder, and hence denser, than the air above it, so it can rise no further. This suppression of upward motions effectively forms a lid beneath which pollutants can disperse freely. The weaker the temperature decrease with height, the higher is the lid. The extreme case is an inversion, when the temperature increases with height. Often, clouds are topped by a stable or inversion layer, which stops their vertical growth.

The well-mixed layer beneath a stable layer is called the mixing layer. When it extends to the ground its vertical extent is known as the mixing height or the mixing depth. Generally, turbulence is enhanced in the early morning hours as the sun heats the ground and temperature decreases with height causing unstable conditions. At night, as the earth cools, temperature increases with height causing less turbulence and stable atmospheric conditions. Figure 3 illustrates the influence of atmospheric stability on ground level pollutant concentrations.

Wind speed, wind direction, and atmospheric stability will vary greatly with time. For a certain location, some combinations occur more frequently than others. The planner should obtain such information about his region so that he can take the meteorology of air pollution into account during the planning process.

Where detailed meteorological records have been kept for a year or more, a stability wind rose can be calculated. This wind rose is a set of tables, one for each stability class (ranging from very stable to very unstable), listing the frequency of occurrence of all possible combinations of wind speed and wind direction. Figure 4 shows a sample wind rose for Newark, New Jersey. Such wind roses are available for many locations in the United States from the National Climatic Center in Asheville, North Carolina. It should be noted that topographical features such as mountains, hills, valleys, bodies of water, buildings, and other terrain features can change airflow patterns resulting in unexpected pollution effects.

Near a large body of water, local sea breezes influence the spread of pollutants. Early in the morning, when the air is still or the wind is off the land, pollutants can accumulate over their sources or downwind of them. Later in the day, when a local sea breeze develops, a fresh breeze blows in the direction from the water toward land. This breeze brings with it not only the pollutants emitted from the sources at this time of day, but also those accumulated earlier in the day, because they are carried back

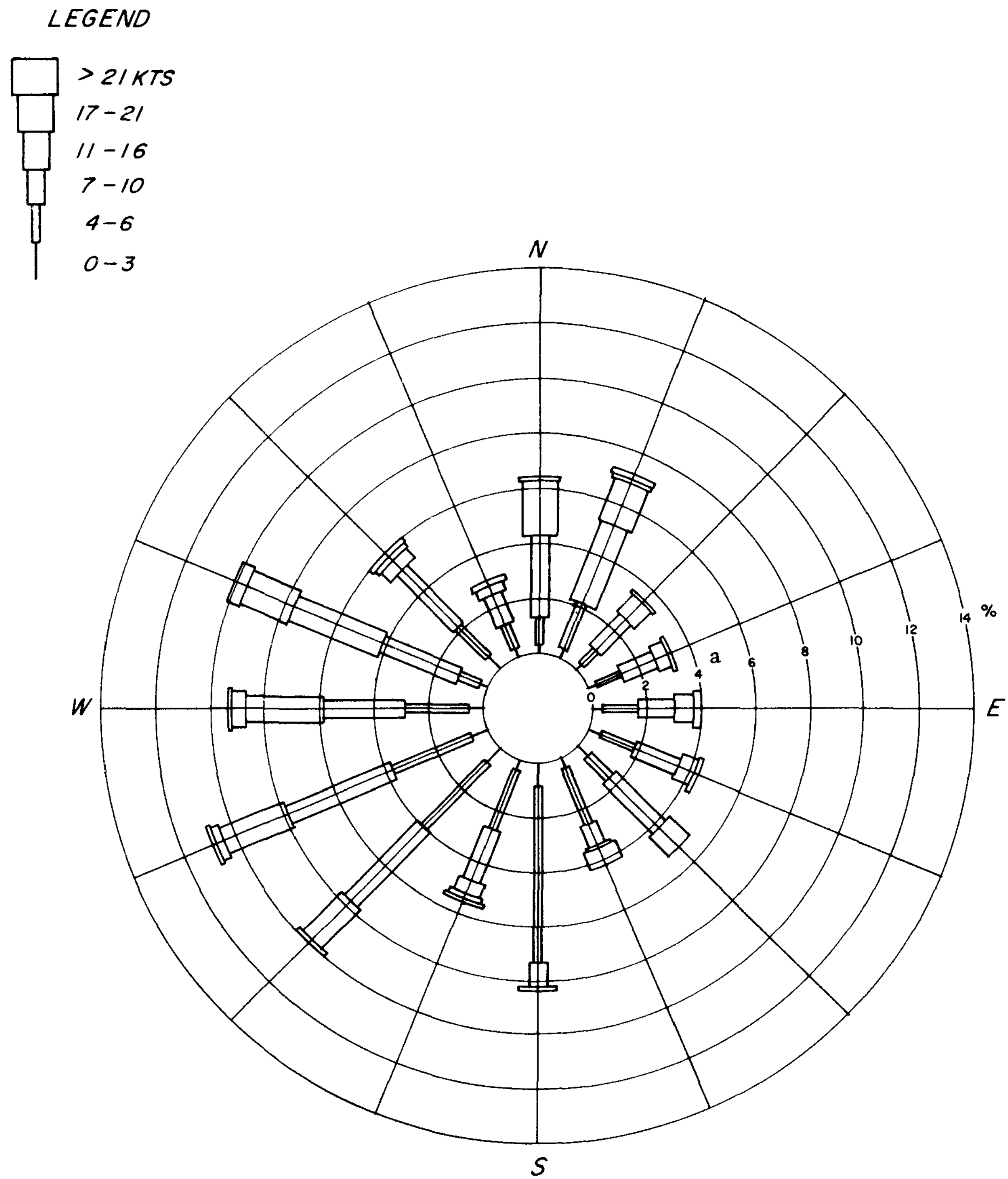

Figure 4 The stability wind rose for Newark International Airport

[a]Concentric percentage circles indicate frequency of occurence (e.g., easterly winds occur 4% of the time during the year)

from water to land. Unexpectedly high pollutant concentrations can occur near the shore when the high pollutant loading blows past. In addition to this effect, which generally occurs close to land, the seabreeze itself can penetrate as far inland as 40 miles or more.

Mountains and valleys have characteristic airflow patterns, too. In the evening, as the earth and the air close to the earth cools, the coldest air will sink into the lowest part of the valley, as illustrated in Figure 5. This creates a stable inversion layer because lighter, warmer air stays above the valley. In this way, pollutants are trapped in the valleys all night. During the daytime when heating occurs, the air in the valley is warmed and rises, permitting the pollutants to escape (Figure 6). Unfortunately, this heating and upward motion does not always occur. During periods when high pressure settles over a region and the air is stagnant, the atmosphere is stable all day long, and pollutants continue to accumulate in the valley. Some of the worst episodes of air pollution have occurred in mountain chains like the Appalacians, where industries are located in the valleys between adjacent hills.

In cities, buildings form the topography. Where rows of tall buildings front on narrow streets the air flows through the streets as though they were canyons. Since ventilation is determined by building configuration, many distortions in wind, and hence pollution flows, take place in a city. Figure 7 shows an example. Air flows over a building and into a street downwind of it. The lines show the direction of airflow. The building, because the air cannot flow through it, creates an obstruction in the pattern of the smooth airflow. Downwind of the building, an eddy, or circular movement of air at variance with the main airflow, is formed in its wake, such as the one shown in the figure. This eddy can trap pollutants emitted by cars in the street, and can cause concentrations of pollutants, for example, carbon monoxide, to be as much as three times higher on the side of the street further downwind than at the site of pollutant origin.

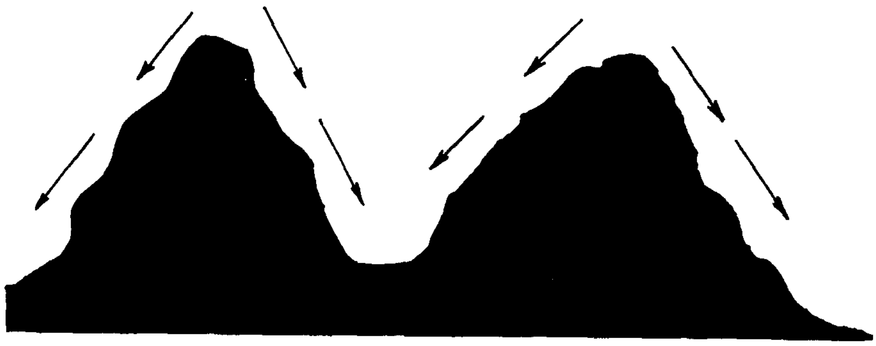

Figure 5 Nighttime airflow into valleys

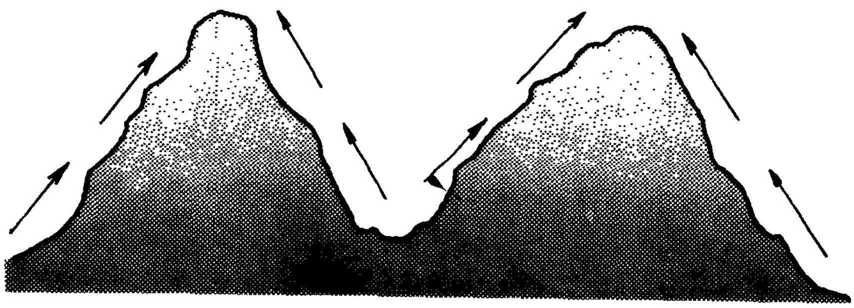

Figure 6 Daytime airflow out of valleys

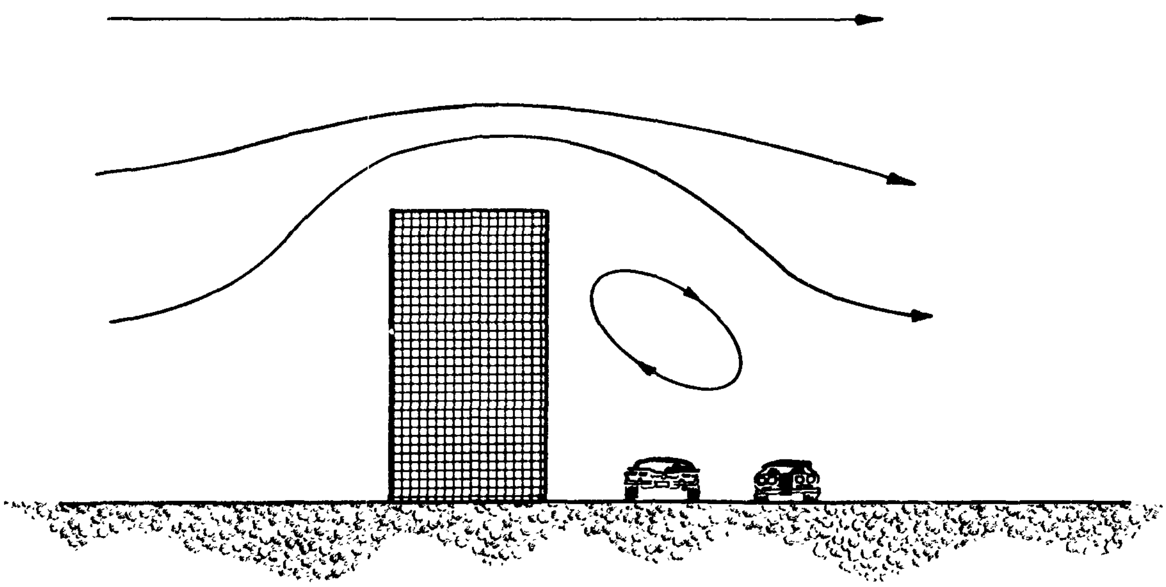

Figure 7 Airflow around and in the wake of a building

3. THE PLANNING PROCESS AS A DESIGN SYSTEM FOR ACCEPTABLE AIR QUALITY

The objective of this section is to provide a procedural framework for incorporating the consideration of air quality into the planning process as a basic planning design parameter in formulating and evaluating land use and transportation plans. The methodology presented here may be viewed as a sifting process in which the planner avoids potential air pollution problems by applying air quality criteria to design decisions throughout the plan's development. This effectively reduces the necessity of having to introduce major changes involving either the mix, intensity, or location of land uses because the "final" plan is found to be incompatible with acceptable air quality. Specific procedures, analytical tools, and appropriate data for applying air quality criteria to the planning process are presented in the following sections of this document. These elements, together with the methodology, form a design system for "building" acceptable air quality into comprehensive planning.

Figure 8 presents the procedural outline of the air quality impact land use planning process. As indicated, implementation of the logic flow may be accomplished through the performance of the following five steps:

1) Establishing the air quality baseline
2) Defining the tolerance of the planning area toward receiving additional pollution
3) Determining acceptable industrial/transportation mix(es) and intensity(ies)
4) Distributing industrial/transportation land uses within comprehensive land use plan(s)
5) Evaluating the air quality impact of the plan(s)

It must be noted at this point that the procedure indicated above is not intended as an all-encompassing determination of the optimal air quality impact land use configuration. Rather, it is an iterative, air quality oriented planning methodology that will help the planner arrive at a satisfactory overall plan. Furthermore, it is not suggested that the entire procedure be applied to every planning situation where air quality is expected to be a factor, nor is it recommended that the planner rigorously

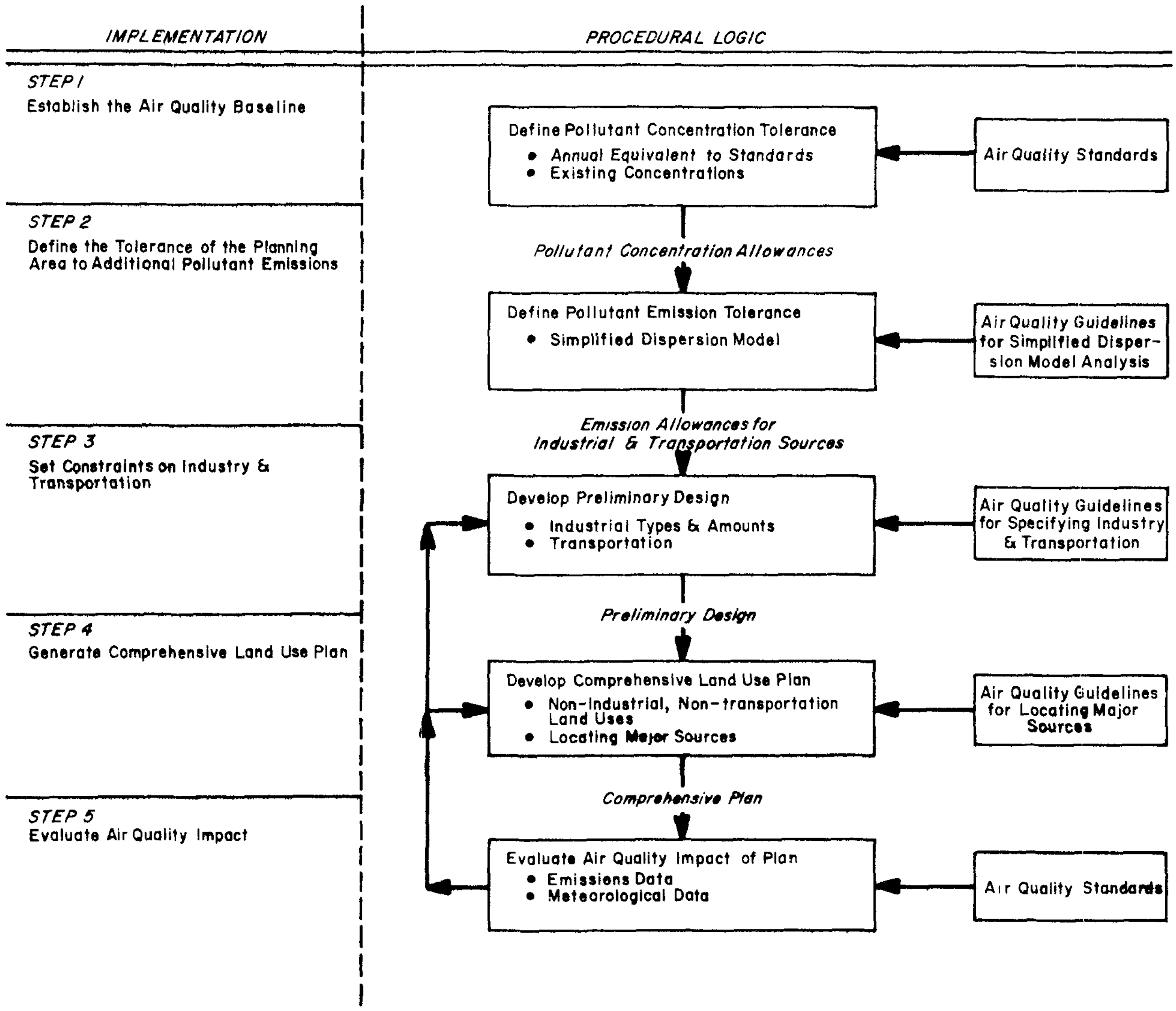

Figure 8 The air quality impact-land use planning process

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pursue air quality goals to the exclusion of other planning concerns. The position that air quality criteria occupies, relative to other planning criteria, will vary depending on the priorities and needs of a specific planning region and the capabilities of agency personnel. It is assumed that the extent to which the air quality - land use planning methodology is employed and the level of detail sought at each step in the process will be tailored to the needs of individual planning regions. A brief discussion of the individual steps follows.

1) Establishing the Air Quality Baseline

The first step in the air quality impact - land use planning process is to define existing regional air pollutant concentrations. The purpose of this step is to determine an air quality baseline for the planning area. Because the entire decision-making process relative to air quality is directly affected by this determination, it is important that the planner use air quality data that is the most accurate, complete, and representative information available. In most cases, state air pollution control agencies have operational air quality monitoring systems and have been collecting air quality data for the past few years. Where this is not the case, or where such data are judged not to be consistent with the requirements of planning decisions, it may be necessary to seek the services of an air pollution specialist with air quality monitoring capabilities. In any event, results of this data gathering should be in the form of concentration averages for the time periods specified in the standards, both averaged over the entire area and in terms of spatial variations expressed as isopleths, which are contours of constant levels of pollutant concentration. A more detailed discussion of the individual pollutants and their respective time frames of interest has been presented in Section 2.1.

2) Defining the Tolerance of the Planning Area Toward Receiving Additional Pollution

Having established the air pollution baseline, the allowable increase in air pollutant concentrations for each pollutant within the planning area should be determined. In addition to the improvement of air quality in areas where NAAQS are exceeded, recent federal court decisions have interpreted the intent of the Clean Air Act of 1970 as including the maintenance of present air quality levels where these levels are not in violation of the secondary air quality standards. Although regulations have been proposed for preventing degradation of existing air quality, there are as yet no federal policies as to what constitutes a permissible increase in concentration.

Among the alternative methods proposed by the U.S. Environmental Protection Agency is a plan to prevent significant deterioration by establishing, for nationwide application, a maximum allowable increment in air quality above the baseline air quality for SO_2 and particulates. This plan also incorporates New Source Performance Standards (Federal Register, Vol. 36, No. 247, December 23, 1971) stipulations that all new or modified sources employ best control technology.

Another plan proposed would indirectly prevent significant deterioration of air quality by preventing significant increases in emissions by calculating a ceiling emission rate based on emission density. Since these and other alternative proposed plans to prevent significant degradation impose restrictions on the use of the air resource, restrictions are simultaneously imposed on the use of land. Policies relative to nondegradation and regulations for complex sources adopted by EPA will have varying land use implications for different regions, depending on the present level of air quality in specific localities.

In any case, allowable concentration increases must be related to corresponding allowable increases in pollutant emissions. This relationship is established through the use of an atmospheric dispersion model, a model based on quantitative descriptions of the transport and dispersion of pollutants in the atmosphere. Air pollutant dispersion models can be of use in mapping portions of an urban area or community where an increase in emissions from new economic activity is permissible. The models can also indicate the amount of increase allowed for each pollutant and each time-averaging period for which there is an air quality standard. General background information about the types of dispersion models available and their relative utility to the planner are presented in Section 4. A simplified dispersion model which may be employed in this step of the process is also presented.

3) Determining Acceptable Industrial/Transportation Mixes and Intensities

The purpose of this step is to provide the planner with constraints for the most heavily polluting land uses, i.e., industry and transportation, based upon the tolerance of the planning area to their generalized emission characteristics. To accomplish this objective it is necessary to relate the increases in pollutant emissions allowed, calculated in Step 2, to different industrial and transportation category mixes and intensities. Examination of the possibilities relative to other planning concerns enables the planner to postulate one or more preliminary inventory alternatives, as indicated in Figure 8. Background information and a set of procedural guidelines for quantifying generalized relationships between industry and vehicular transportation activities and their emission characteristics, are presented in Section 5.

4) Distributing Industrial/Transportation Land Uses With Alternative Comprehensive Land Use Plan(s)

At this point in the process, the planner has defined one or more possible industry-transportation mix alternatives for the planning area, each of which is cognizant of acceptable levels of air quality. Individual alternatives represent upper limits to industrial and transportation related land use for the type of mix specified. Ideally, in defining each alternative, not only has air quality been addressed, but other pertinent planning constraints as well. Consequently, the complete set of alternatives should encompass the entire spectrum of what is considered to be both desirable and feasible in terms of alternative preliminary plan designs. The planner must now spatially distribute these industrial/transportation land use alternatives within comprehensive land use plans. Inasmuch as this involves the placement of land uses within the planning area, the spatial contours of existing pollutant concentrations, as well as the dispersion patterns of anticipated emissions, must be considered if local violations of the air quality standards are to be prevented. This is especially important where spatially averaged regional pollutant concentrations are expected to be close to standards.

Generalized dispersion characteristics that may be used to locate industrial land use and major motor vehicle corridors within the planning area are presented in Section 7. In addition, the planner may wish to employ a numerical simulation model to determine the specific pollutant dispersion patterns of important individual sources in the microscale. Since most planning agencies do not have this type of modeling capability, the services of an air pollution specialist should be sought to implement these studies.

5) Evaluating the Air Quality Impact of the Plan(s)

Despite the fact that plans generated by performing the preceding four steps have been formulated with an eye toward air quality, the planner should recognize that an air quality impact evaluation of the plan(s) is a mandatory final step in the process. This is primarily due to the generalized nature of the emissions information required to make a priori air quality determinations of anticipated land use and to the assumptions required by the simplified dispersion model analysis indicated in Figure 8. However, by specifying land uses through the performance of Step 4, the planner has necessarily generated planning data of sufficient detail to perform a much more extensive examination of air quality impact. In addition, spatial variations of expected pollutant concentrations for a given plan as a whole (which are not quantifiable to this point) must be examined if the air quality standards are to be met everywhere within the planning area. Section 8 presents an evaluative methodology for examining the air quality impact of comprehensive land use alternatives. Due to the rather sophisiticated nature of the indicated analyses, it is not recommended that the planner perform these evaluations. Rather, the services of an air pollution specialist with extensive modeling capabilities should be sought.

3.1 Factors Affecting Industrial Emissions

Industrial emission sources are quite widely varied. Although Section 5 proposes a means of estimating industrial emissions, it is important for the planner to recognize those variables affecting emission rates from individual industrial sources so that the capabilities and limitations of the tools suggested here are fully realized.

Generally, an industrial source may emit pollutants by any or all of the following ways. First, most industries burn fossil fuels to provide space heat for the physical plant, and to provide energy (either in the form of heat or electricity) for the operation of plant components. Secondly, individual industrial processes may have byproducts which are vented into the atmosphere as a form of waste disposal. Finally, industries may incinerate their own solid waste, again releasing the combustion products into the atmosphere.

Emissions from Fuel Use

Energy requirements for industrial operations may be specified in terms of mechanical/electrical power requirements, operational heat energy requirements, and space heating requirements. Operational heat and power requirements are generally dependent on equipment used, production rate, and activity schedule. The amount of energy required to heat a given facility is generally a function of the building volume (but often floor area is used since this data is easier to obtain), local climatology, and the architectural or engineering design of the individual building with respect to both heat retention and heating efficiency.

Floor area of a plant will generally be related to employment and/or production rates for a given industry. Each employee may be expected to require a minimum amount of working area depending upon his function. A specified production rate may require a determinable employment and equipment level which in turn dictates a need for floor space. Generally, industries are similar enough that these space requirements are reasonably consistent for firms manufacturing the same product.

The amount of energy required to heat a predetermined floor area is dependent upon local climatology. Specifically, the number of degree days of heat required per unit volume is an energy consumption parameter. A factory in Minnesota, identical in all respects to a factory in Southern California, will require substantially more space heating during the course of a year. This is particularly true in winter months when outside temperatures may differ as much as 40°F.

The design of a given facility will certainly be a factor in its heating requirements. A poorly insulated building with high ceilings (and thus a large enclosed volume per square foot of floor area) will be much less efficiently heated than a building with properly sealed doors, windows, and fixtures, and with lower, insulated ceilings. In addition, inefficiencies of heating, ventilating, and air-conditioning systems due to either poor design, economic expediency, or poor maintenance will significantly increase heat energy requirements for a given structure.

The nature of the heat energy source used bears greatly upon the emissions from an industrial source. Current fuel supplies consist of four major fossil fuel categories:

1) Coal
2) Residual Oil
3) Distillate Oil
4) Natural Gas

Each of these fuels is primarily a hydrocarbon compound. Whenever hydrocarbon fuels are burned, gaseous oxidation products are formed. Optimum combustion of these fuels results in water vapor, carbon dioxide, and nitrogen; all normal atmospheric constituents. If the combustion process is not optimal, or if impurities exist in the fuel, burning may produce carbon ash, unburned hydrocarbons, as well as sulfur and various metallic compounds. The fuels listed above have a decreasing level of sulfur and ash content, hence an increasing tendency to produce cleaner combustion products. Unfortunately, the cost of heat energy from the four fuels is inverse to their cleanliness.

Process Emissions

Industrial process emissions are related to the individual physical or chemical processes required to manufacture a given product, and may be quantified (as with fuel use emissions) by process rate and activity schedule. In particular, air quality in the vicinity of a given plant may be sensitive to differences in operational modes (i.e., high intensity - short duration operation as opposed to low intensity - continuous operation), so that the specification of industrial types in areas where air quality is already a concern should involve consideration of the time frames of industrial operations, as well as the quantity of individual pollutants, relative to existing air quality temporal trends.

Solid Waste Disposal

Solid waste disposal may, or may not be a major consideration in the total emissions from a given industry. Many industries which produce large volumes of solid waste may find it economically desirable to have an incinerator on site. Since solid waste disposal is not a necessary function of any single activity, it may cause the relative emissions of plants with similar activities and production capacities to vary greatly.

Planners should consult local air pollution officials to ascertain policies on incineration since local policy with respect to incinerator operation will have effect on emissions within his region. In those areas where solid waste disposal is tightly controlled, emissions will be lower than those that would be estimated by using the guidelines presented in the following section.

Regardless of the source of emissions, there are any number of emission control devices and strategies which can be employed to minimize the impact of industry on air quality. While the specification of industrial emission controls is primarily an engineering and regulatory question, planners designing new land use patterns should favor the imposition of such controls for all new facilities. Conversely, new facilities should not be permitted to use inferior controls with the expectation that local atmospheric dispersion will be adequate to ensure compliance with the air quality standards.

3.2 Factors Affecting Transportation Emissions

Emissions associated with transportation sources account for a major portion of air pollution in urban areas. Air quality characteristics of five major categories of urban ground transportation are discussed below, including a brief discussion of the individual categories as they affect air quality considerations in the planning process. The five modes of ground transportation discussed include:

1) The automobile
2) Gasoline trucks and buses
3) Diesel trucks and buses
4) Electric mass transit
5) Diesel transit

Major urban transportation systems should be examined both on an aggregate and on a component basis to ensure that operational designs and the choice of transportation modes are consistent with air quality requirements. In most cases, major transportation projects require Environmental Impact Statements, as outlined in the National Environmental Policy Act (NEPA) of 1969, for which air quality assessments are necessary. Nevertheless, it may be helpful for the planner or the decision-maker to have some broad guidelines when considering alternative transportation modes. Section 5 discusses a means of estimating emissions resulting from transportation sources.

Potential air pollution problems associated with transportation sources, notably the automobile mode, may be particularly accentuated in areas of: (1) high density development, (2) pedestrian and bicycle traffic, and (3) sensitive receptors.

Where the density of development is high, particularly where highrise buildings are present, air quality is measurably impaired by high-density automobile traffic. Lack of adequate street ventilation due to the obstruction of natural airflows may significantly decrease the dispersion of automotive pollutants so that the same levels of emissions may result in higher pollutant concentrations.

Although it may be obvious that automobiles are incompatible with pedestrian and bicycle traffic on the basis of safety and efficiency of movement, planners should be aware that placing traffic volumes adjacent to walkways may expose the pedestrian to pollutant concentrations above air quality standards. This exposure is often accentuated in areas of high density development, as previously described.

Automobile traffic may be incompatible with several land use activities which are commonly termed "sensitive receptors." With respect to air quality, residential areas, generally containing a large number of sensitive receptors, should not be located adjacent to roadways with high traffic volumes. Exposures are possible in two major areas. Dwellings near high-volume roads may be exposed to peak hour traffic emissions in excess of hourly standards (for CO in particular). Since residences are occupied for long periods, residents could be exposed to 8-hour concentrations in excess of standards as well. Medical facilities are susceptible for the same reasons as residences. Additionally, however, they often contain persons who have lower resistance to air pollutants. Elementary schools and other similar institutional buildings are sensitive receptors since children are densely grouped for long periods of time. Recreational facilities are often sensitive receptors. They are particularly sensitive where there is heavy physical exertion since increased respiration rates cause the intake of pollutants to be sharply increased over a short time span.

3.2.1 Emission Characteristics by Transportation Mode

Automobiles

Travel by automobile represents the most significant mode of travel in the United States. As such, its polluting characteristics have received a substantial amount of study. Although the existing data on emission characteristics of automobiles are far from complete, we now have a reasonable understanding of expected emission rates for given operating conditions. As shown in Table 3, vehicle speed, vehicle age, driving cycle characteristics and operating temperature affect the amount of carbon monoxide, hydrocarbon and oxides of nitrogen emissions resulting from automobile travel.

Table 3. EMISSION CHARACTERISTICS FOR GASOLINE POWERED VEHICLES

VEHICLE CHARACTERISTICS	CO EMISSIONS[a]	HC EMISSIONS	NO_x EMISSIONS
1. AVERAGE VEHICLE SPEED	As average vehicle speed increases CO emissions decrease.	As average vehicle speed increases HC emissions decrease.	NO_x increases with average vehicle speed.
2. ACCELERATION	The more variable the speed, the higher the emission rates. Cruising at speed minimizes CO, stop and go increases emissions.	During acceleration or deceleration emission of hydrocarbons increased	No substantial effect
3. IDLING	Vehicle idling maximizes CO emissions.	During idling hydrocarbon emissions are maximized.	No substantial effect.
4. COLD STARTS	Cold starts increase CO emissions. After warming up exhausts are cleaner. Emissions, when the vehicle uses its choke (high air/fuel ratio), are particularly heavy.	As with CO, HC emissions increase a fuel/air ratio increases. Cold starts and operations with choke activated increase this fuel/air ratio.	No substantial effects.
5. VEHICLE AGE	As the vehicle engine and pollution controls become older its production of CO per mile increases.	HC emissions increase as vehicle engine and emission controls deteriorate with age.	No substantial deterioration effect.
6. OPERATING TEMPERATURE	No substantial effect.	No substantial effect.	NO_x emissions increase with combustion temperatures.

[a]All comments pertain to emissions per unit time (except as noted)

[b]Based on Figure 3-1-1-1, "Average Speed Correction Factors for All Model Years," Compilation of Air Pollution Emission Factors, Environmental Protection Agency, April 1973.

Gasoline Trucks and Buses

The gasoline-powered trucks and buses exhibit emission characteristics like those for automobiles, but at larger volumes per vehicle. They are considered separately, however, because they serve a different transportation need than automobiles. Buses, which exhibit emission characteristics most like those of automobiles, are far more efficient in terms of pollutant per passenger mile. Volumes of trucks and buses are generally quite a small fraction of total traffic. Proposed emissions regulations, however, will make these heavy duty gasoline-powered vehicles a more important source of emissions in the future. While auto emission levels are to be reduced to less than 10% of pre-emission control levels (Ref. 6, Table 3.1.2-1), heavy duty emissions will remain at levels from 24 to 58% (Ref. 6, Table 3.1.4-3) of pre-control levels. As a result a heavy duty truck will emit as much NO_X as 9 automobiles, as much HC as 18 automobiles and as much CO as 45 automobiles. These ratios indicate that each year after 1976 trucks and buses will be the source of a larger and larger percentage of total vehicular emissions. At some time between 1985 and 1995 the emissions from heavy duty vehicles will be more than half of all transportation emissions, unless control regulations are revised. Comparative analysis of emission rates for the transportation mode categories is shown in Table 4. Gasoline buses are included in the comparisons.

Diesel Trucks and Buses

Since the engineering aspects of the diesel engine differ markedly from those of the gasoline engine, there are significant differences in the polluting natures of the two power sources. While the pollutants produced by diesels are basically the same as those from gasoline engines, the proportions differ. Because of the higher temperatures of combustion, emissions of NO_X from diesel engines are substantially higher than in gasoline engines. CO emissions, on the other hand, are minimal.

Unlike gasoline-powered vehicles, there are only three operating variables that affect the exhaust output of diesels. They are engine speed (rpm), and fuel use, which are interdependent, and vehicle age. Diesel trucks and buses use similar engines and have similar operating

Table 4. COMPARISON OF TRANSPORTATION EMISSIONS BY PASSENGER VEHICLE AND PASSENGER MILE OF TRAVEL

EMISSIONS PER VEHICLE MILE (GRAMS)

Pollutant	Auto	Gas Bus	Diesel Bus	Diesel Rail	Electric Rail with Coal	Electric Rail with Gas	Electric Rail with Oil
CO	85.00	130.0	20.41	6.35	0.91	negl.	0.01
HC	9.50	19.0	3.36	4.54	0.37	negl.	1.09
NO_X	6.17	10.0	33.57	6.80	37.19	0.05	35.38
SO_2	0.18	0.85	2.45	5.90	13.97	0.02	27.21
Particulates	0.30	0.26	1.18	2.27	29.30	0.73	3.44

EMISSIONS PER PASSENGER MILE (GRAMS)

Pollutant	Auto	Gas Bus	Diesel Bus	Diesel Rail	Electric Rail with Coal	Electric Rail with Gas	Electric Rail with Oil
Assumed Passenger(s)/ Vehicle	1.5	30.0	30.0	60.0	60.0	60.0	60.0
CO	56.6	4.3	0.7	0.1	0.02	negl.	negl.
HC	6.3	0.6	0.1	0.08	0.01	negl.	0.02
NO_X	4.1	0.3	1.1	0.1	0.6	negl.	0.6
SO_2	0.12	0.03	0.08	0.1	0.2	negl.	0.5
Particulates	0.20	0.01	0.04	0.04	0.15	0.01	0.06

NOTE: All emission rates pertain to urban conditions for the current National Vehicular Age Distribution Mix, 1960 and earlier to 1973 model years.

An Interim Report on Motor Vehicle Emissions, Kircher and Armstrong.[3]
Compilation of Air Pollutant Emission Factors.[5]

characteristics. For this reason emission factors for trucks and buses are similar and are not currently differentiated by vehicle type; all diesel vehicles are considered to emit similar pollutant loads. Emission characteristics for diesel buses are listed in Table 4.

Diesel Rail Vehicles

Since the diesel rail vehicles are all fairly similar in emissions characteristics, very little individual analysis is warranted. The major differences are the sizes of the power plants, the load capacity/efficiency relationship (i.e., the weight of the payload being hauled versus the engine size required to pull the load), and the operation characteristics. Rail designs allow more work per amount of fuel consumed since the need for acceleration and the noncruising mileage are minimized. Since operating conditions are nearly uniform, rail engine deterioration is reduced also. Quantitative emission comparisons, including diesel rail vehicles, are shown in Table 4.

Electric (Rail) Transit

The nature of electric (rail) transit systems makes it impossible to include them in a simple analysis of vehicular pollutants. For the rule-of-thumb estimates that may be made using this document it is safe to assume a negligible emissions burden.

Electric rail vehicles do not burn fossil fuels. Instead they use electric power generated at a plant not necessarily in the area being studied. The burning of fuels at a power plant to provide electric power to transit vehicles is commonly considered an indirect or secondary impact, but the calculation of these indirect emissions and their impact is quite complex, and should not be attempted without the benefit of advice from an air quality control agency.

Summary of Transportation Emissions by Type

Recognizing the general polluting characteristics of the various modes of urban transportation, the planner requires comparative values to weigh the air pollution advantages of one mode over another. It can be readily concluded that gasoline-powered vehicles are the major sources of both CO and HC on a *per capita* basis because of their limited passenger capacities. Similarly, it should be noted that diesel vehicles emit larger volumes of NO_X, SO_2, and particulates. Lastly, it can be seen that electric rail transit using natural gas supplied power emits almost negligible levels of all five of the compared pollutants. In any case, all comparisons by vehicle mile seem quite unrealistic when comparing urban modes. Emissions per passenger mile of urban travel probably offers a more viable means of comparing transportation modes.

Table 4 points up several facts about the comparative emission rates per passenger mile of the various transportation modes. The automobile has the highest emission rate for each of the pollutants associated with transportation-related land use. For CO, its emissions are a factor of 13 greater than the second worst emitter, which is the gasoline bus. It has a rate of emitting HC that is a factor of 10 greater than that for the gasoline bus, which is second. For NO_X, it is the largest unit emitter by a factor of 7 over electric rail. For SO_2 and particulates, it again has the worst emission rates with electric rail being second, depending on the power plant supplying electric power.

Because automotive vehicular traffic is the largest contributor to transportation-related pollutant emissions, a means of estimating these emissions for consideration in the air quality impact-land use planning process is contained in Section 5.

4. RELATING POLLUTANT EMISSIONS TO AIR QUALITY

Thus far, typical pollutants and their principal source categories have been discussed, including general meteorological and topographical factors which affect the behavior of pollutants in the atmosphere. In addition, emission characteristics of industrial and transportation source categories have been discussed. Having determined existing air quality levels within the planning area, within the context of the Air Quality Impact - Land Use Planning methodology, the planner must now define the tolerance of the planning area toward receiving additional pollution which would result from new land use. To do this, it is necessary to translate pollutant emissions into air pollution concentrations for a planning area. The relationship of pollutant emissions to air pollution concentrations is most effectively established through the use of an atmospheric dispersion model, a model based on quantitative descriptions of the transport and dispersion of pollutants in the atmosphere.

4.1 The Dispersion Models

There are many kinds of dispersion models, varying in complexity and utility, but basically, three general types can be identified:

1) Box models

2) Gaussian plume models

3) Numerical simulation models

Each type of model is significantly different in approach from the others and each represents a very different level of sophistication. Consequently, results of the various model types may find application in providing different kinds of air quality information, of varied utility, for the planner.

The least sophisticated of the model types and that which provides the least detail of air quality information is the box model. This type of model is of maximum utility to the planner in making <u>preliminary</u> policy and design decisions on a <u>regional</u> or <u>subregional</u> scale. Most especially, it lends itself very well to defining the tolerance of a given area to the more heavily polluting land use categories such as industry and transportation in terms of air quality standards. The mathematical computations required by a regional scale box model analysis are limited to simple hand calculations.

Gaussian plume models are the next step upward in terms of level of sophistication and can provide very detailed air quality information. This type of model has been in operational use for a considerable period of time, and has been, and is still being used with success where it is appropriately applied. These models usually consider both point and area sources. The gaussian plume model is of considerable utility to the planner as an evaluative tool for considering alternative land use and transportation plans in terms of their impact on the air quality of a region. On a regional or subregional scale, a gaussian plume analysis of air quality requires the use of a high speed digital computer along with a rather comprehensive emissions and meteorological inventory. Use of this type of model is therefore generally both expensive and time consuming. In addition, because of the assumptions necessary in all models of this type, great care must be taken in analyzing and evaluating their results. However, gaussian plume models offer the planner the opportunity to examine in considerable detail the air quality implications of postulated land use and transportation configurations, individually or combined as a whole.

Numerical simulation models are the most sophisticated of the dispersion models and are still in a relatively formative stage. They can provide very detailed two and three dimensional pictures of the spatial patterns of pollutant concentrations on relatively small physical scales. For this reason, this type of model is most applicable to determining the localized air quality impact of individual sources such as a highway or power plant, or an emitter of other than the six typical pollutants. Invariably, numerical simulation models require the use of a high speed digital computer. However, because they are generally applied to individual sources they require not nearly so much input data as the gaussian plume models. Their maximum utility to the planner, at this point in time, is in the design and placement of large individual sources of pollution. However, advances in computer technology and numerical methods may soon make it possible to employ numerical simulation models in the capacity presently served by gaussian plume models. This would represent a significant increase in state of the art of dispersion modeling because simulation models are operationally more flexible and more tolerant of variations in source design geometry than are the gaussian models.

4.2 Model Utility

As described in the preceding section, the planner has available three different types of models with which to relate pollutant emissions to air quality concentrations. Each type of model provides different kinds of air quality information for the planner and each requires different planning information from the planner. Furthermore, the level of detail of information available during the planning process and necessary for the dispersion models suggests that maximum model utility may be attained by applying each of the models to a specific procedural step of the methodology presented in Section 3.

Box Models

Box models, the most general of the model types in terms of level of detail, are suited for use in step 2 of the procedure, defining the tolerance of the planning area toward receiving additional pollution. (Refer to Figures 8 and 9). As indicated in Section 2, this step allows for the determination of air quality constraints on land uses, based on the determination of existing levels of air quality.

Allowable pollutant concentration increases are then transformed into allowable increases in pollutant emissions through application of a box model analysis. A model of this type for use in this procedure is presented in Section 4.3.

Gaussian Plume Models

Gaussian plume models are most applicable to detailed air quality examinations of comprehensive land use configurations and are therefore best suited for use in step 5 of the procedure, the evaluation of the air quality impact of alternative plans (refer to Figure 8). Section 9 presents an air quality impact evaluation methodology for comprehensive land use plans within which the use of a typical gaussian plume model is specified.

Numerical Simulation Models

Because of the significance of the spatial variations of pollutant concentrations in the microscale, and the implications these variations have relative to the placement of air pollution sources, numerical simulation models are most suited to be used in step 4 of the procedure, distributing industrial/transportation land uses within comprehensive land use plans. Examples of applications of this type of model are discussed in Section 7.

4.3 A Simplified Urban Dispersion Model

The model presented here is a meteorologically constrained simplification of that presented by Holzworth,[2] which has been demonstrated to obtain good correspondence between predicted and observed mean concentrations for each of several urban study areas. Although the model is an approximation of the complex physics involved in atmospheric dispersion processes, it is nevertheless consistent with the general nature of information exchanged at the point of its application within the planning process. As such, it provides a means of quantifying the relationships between pollutant concentrations and pollutant emissions that are required by step 2 (defining the allowable increase in pollutant emissions) of the procedure illustrated in Figure 9.

Most often, the planner will want to use the air quality standards, as defined in Section 3.1, as criteria in planning for acceptable air quality. However, because violations of the 1, 3, 8, and 24 hour standards are generally localized and occur in an area of several city blocks, and because the level of detail of planning data at this point in the process is, in any event, insufficient to generate meaningful air quality information for these time frames, it is suggested that the planner use the equivalent annual arithmetic mean air quality standards presented in Table 3. It must be cautioned here that the concentrations cited in the table are not intended for use as compliance criteria for the standards. Rather, they are design values for simplifying the implementation of step 2.

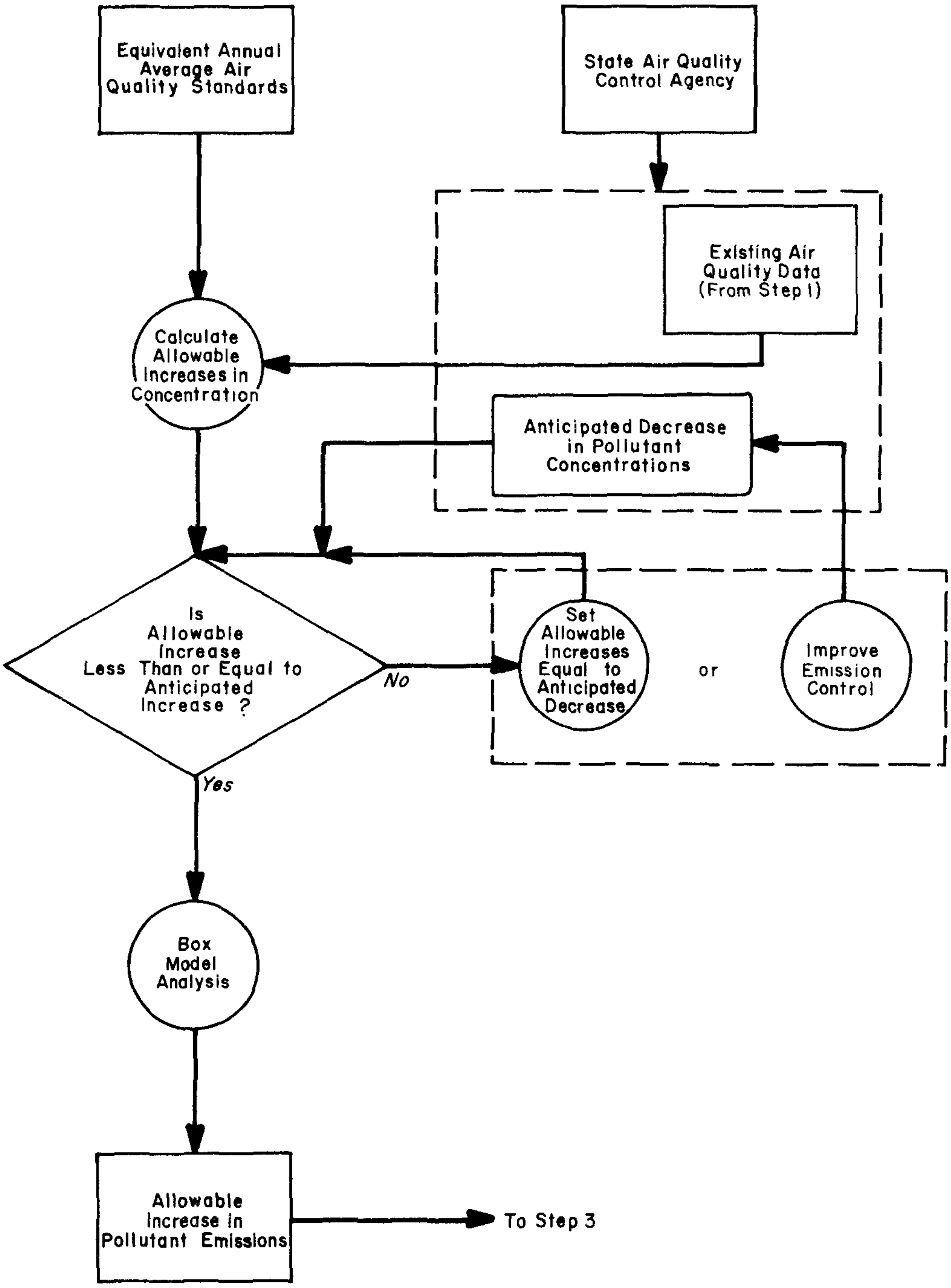

Figure 9 Step 2 in the air quality impact-land use planning process; defining the tolerance of the planning area to additional pollutant emissions.

Existing air quality data used in step 2 (defining tolerance of area toward receiving additional pollution) should be in the form of annual mean concentrations of the individual pollutants. As will be recalled from Section 2, existing air pollutant concentrations have been compiled in this form as a result of step 1 which established the air quality baseline.

Having defined the required inputs, implementation of step 2 proceeds as schematically illustrated in Figure 9. The differences between pollutant concentrations presented in Table 5 and existing pollutant concentrations are compared with anticipated decreases in pollutant concentrations resulting from either imposed emission controls or land use relocation, as specified by state pollution control agencies. If these differences are equal to or less than the anticipated decreases, they may be considered as allowable increases in pollutant concentrations. If this is not the case (i.e., if the differences are greater than anticipated decreases) the planner has two possible courses of remedial action. He can either re-adjust the differences (i.e., set them equal to anticipated decreases) or, where the pressures for development are severe, he can call for the imposition of emission controls on existing sources within the planning area. However, it is to be noted that the implementation of a federal non-degradation policy and accompanying standards would impose a specific mandate for increases in pollutant emissions allowable in areas where air quality is currently at or above the NAAQS. In all cases, the end result is a set of allowable pollutant concentration increases which are compatible with both the Federal Ambient Air Quality Standards and the intent of the Clean Air Act Amendments of 1970, as interpreted by the Federal Courts.

The model treats the planning area as one large continuously emitting ground level source having a uniform average area emission rate ($\overline{Q}$). Spatial variations within the area are not accounted for. Model results are presented graphically, as shown in Figure 10, in terms of an average normalized concentration (see Section 1.3, Glossary of Terms) in seconds/meter ($\overline{\Psi}/\overline{Q}$, i.e., a concentration ($\overline{\Psi}$) in g/m^3 averaged over the planning area and normalized by the area emission rate ($\overline{Q}$) in $g/m^2/sec$), as a function of ventilation length. The ventilation length used to determine the normalized concentration is taken to be the longest straight line distance through the planning area (ranging from 10 to 100 km).

Table 5. EQUIVALENT ANNUAL ARITHMETIC MEAN AIR QUALITY STANDARDS[a]

Pollutant	Standard ($\mu g/m^3$)
Carbon Monoxide	1425.0
Hydrocarbons (non-methane)	160.0
Nitrogen Oxides (NO_2)	100.0
Sulfur Oxides (SO_2)	60.0
Total Suspended Particulates	60.0

[a] The Hackensack Meadowlands Air Pollution Study, Task 2 Report[4].

Implementation of the model requires that the planner determine, from Figure 10, the normalized concentration for the planning area and then apply this concentration to the following formula to obtain pollutant emissions.

$$E = (C/N)A \qquad (1)$$

where

E = annual mean allowable increase in emission rate (~~grams~~ µg/second)

C = annual mean allowable increase in pollutant concentration (grams/meter^3)

N = annual mean normalized concentration (second/meter), from Figure 10.

A = study area of the planning region (meter^2).

As indicated, the variables expressed in the equation are all in terms of annual means. Meteorological parameters, specifically mixing depth and wind speed, used to generate the curve shown in Figure 10 were specified as estimates of annual averages and should be fairly conservative (worst case conditions) for most areas within the contiguous United States, as is consistent with the intended application of model results. However, given the appropriate level of expertise, it is conceivable that the planner may wish to calibrate this model to the specific meteorological conditions of the region of interest, in order to obtain a more case-specific model application. Since annual average ventilation flows will, in general, not be consistent with the longest straight line distance through the area, model results will again be conservative.

As with other air quality considerations, implementation of the model within the planning process is required on a pollutant by pollutant basis. Because pollutant concentrations used in the analysis are derived from equivalent annual mean concentrations of the standards (refer to Table 5), the single curve given in Figure 10 is equally applicable to each of the individual pollutants. Illustrative examples of model applications within the planning process are presented in Section 6.

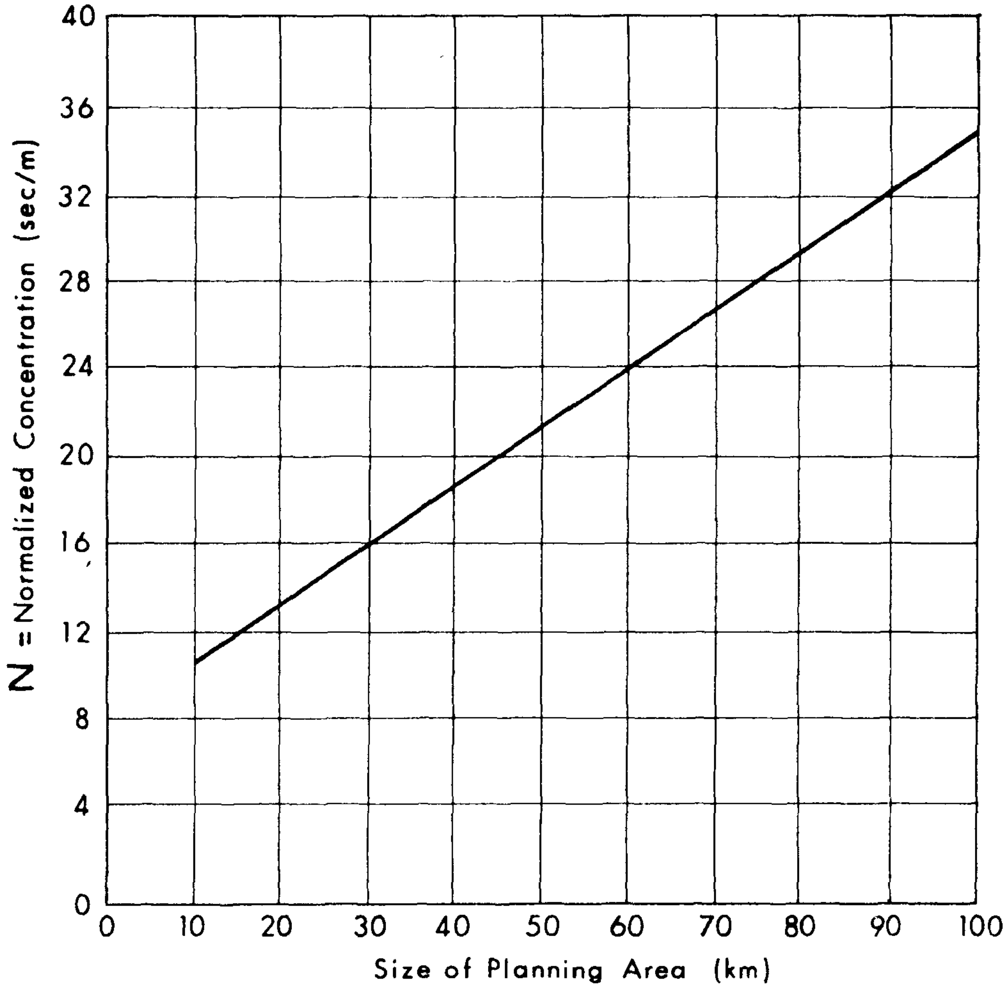

Figure 10 The relationship between annual mean pollutant concentration[a] (averaged over area and normalized by emission rate) and ventilation length[b]

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[a] Applies to all pollutants.
[b] Holzworth[2].

5. RELATING ALLOWABLE EMISSION INCREASES TO A SELECTION OF INDUSTRIAL AND TRANSPORTATION LAND USES

Having determined the tolerance of the planning area toward receiving additional pollution in terms of allowable emissions, industrial/transportation land use schemes appropriate to the designated allowable pollution increase can be devised. This section describes a set of procedures for selecting industrial/transportation plans which are consistent with basic air quality planning goals. As indicated in Figure 8, in Section 2, this procedure requires that the planner transform increased allowable emissions into a preliminary inventory list of industrial/transportation land use activities. This land use design (or several, as the case may be) must then be specified in terms of upper limits to postulate amounts of:

1) Specific industrial land use components.
2) Motor vehicle activity.

As indicated in Figure 11 input to Step 3 consists of allowable increases in annual mean emissions for each of the pollutants. The planner now begins to specify types and amounts of industry which are consistent with basic planning goals and relates them to air quality limits.

Often, future industries locating within an area as well as such precise information as the projected number of employee-hours, will be unknown during the initial stage of the planning process. Generally, however, basic types of industries or characteristics of industries that may locate in the planning area may be projected by observing existing industries and their relationships with other industries that would tend to locate nearby. Industry types can also be projected by noting rapid growth industries, by studying the characteristics of the city as compared to the needs of various industrial types, and by applying location or economic-base theory. In addition, although most localities distinguish only between heavy and light industry for zoning and other regulatory purposes, many areas are contemplating performance zoning, which would distinguish among industries by their nuisance characteristics, including air pollution emissions. Therefore, it may be possible to prescribe or limit by means of air pollutant emissions criteria, the types of industries and their locations that would be allowed in order to meet air quality standards and policies.

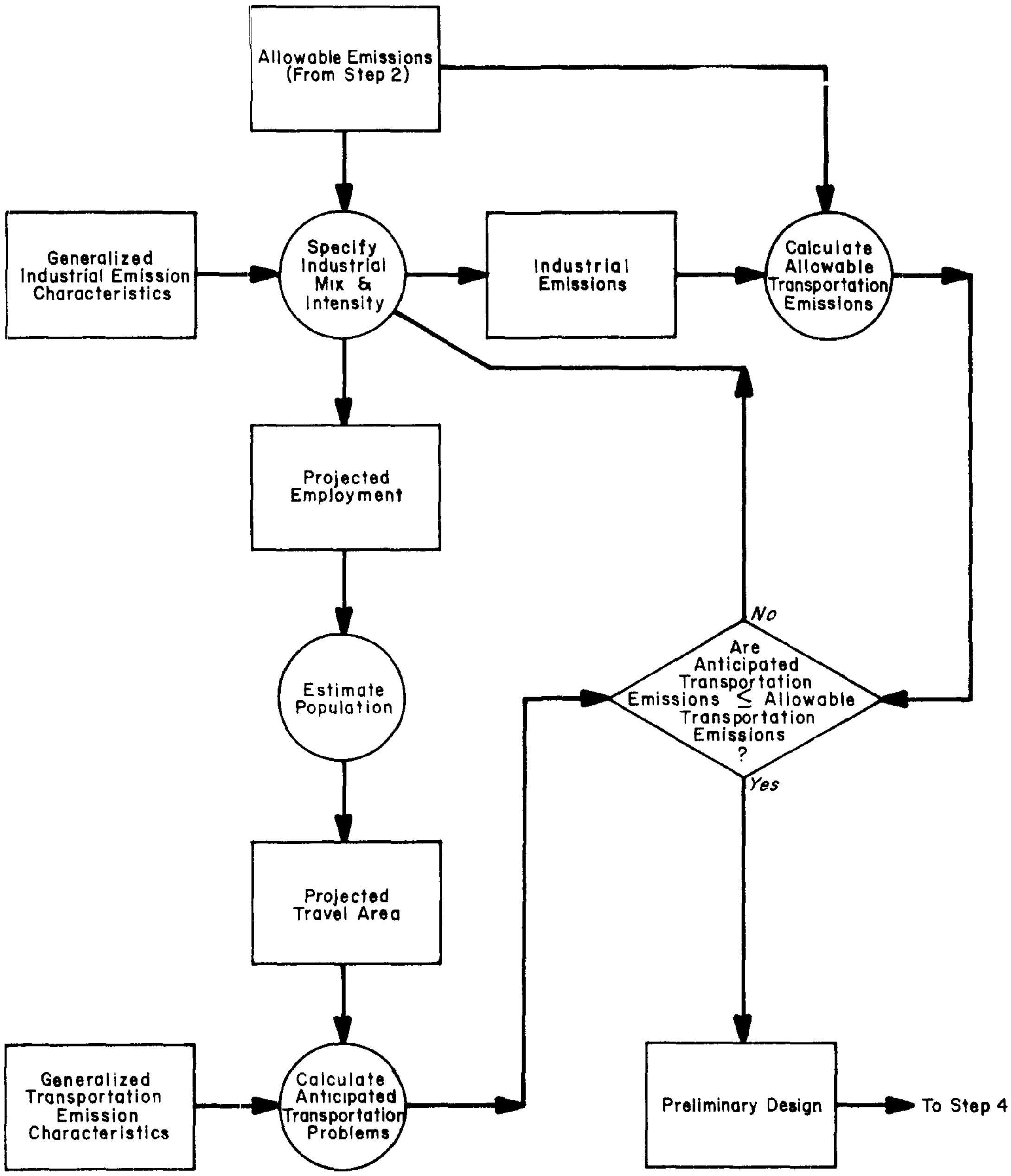

Figure 11 Step 3 in the air quality impact-land use planning process; setting constraints on industry and transportation

Generalized emissions characteristics and a procedure for estimating annual mean pollutant emissions for various industrial categories are presented in Section 5.2. For each industry specified, the planner reduces allowable increases in emissions by the appropriate amount until the residual is estimated to approach anticipated emissions from additional transportation demand. General rules of thumb for estimating this point, by pollutant, prior to examining transportation demand are as follows based upon prior work and the professional experience of the authors:[8]

- Carbon Monoxide - reserve approximately 90 to 95% of total allowable increases in CO emissions for transportation.
- Hydrocarbons - reserve approximately 60% of total allowable increases in HC emissions for transportation
- Nitrogen Oxides (NO_2) - reserve approximately 50% of total allowable increases in NO_2 emissions for transportation.
- Total Suspended Particulates - reserve approximately 5% of total allowable TSP emissions for transportation.
- Sulfur Dioxide - since SO_2 is not related to transportation, it is not necessary to reserve any portion of its allowable emissions.

As indicated in Figure 11 the residual emissions are, in effect, allowable transportation emissions. Having already specified an industrial mix and its corresponding component intensities, however, these allowable transportation emissions cannot necessarily be independently specified. That is, an increase in industrial activity will result in an increase in transportation demand. If this increased demand results in emissions which exceed the residuals, the planner should either examine alternative modes of transportation, find ways to reduce vehicle miles traveled (VMT) or readjust industrial mix and intensity accordingly, recalculate anticipated industrial emissions, and find the new corresponding residuals. Generalized vehicular transportation emission rates with which to estimate transportation emissions are presented in Section 5.4.

While the above procedure does not directly address the problem of increased emissions from non-industrial, non-transportation sources, the generally conservative nature of the box model analysis is anticipated to account for these sources. In addition, comprehensive evaluation of "final" plans will conveniently point to concentrations of pollutants in excess of the standards, so that an iterative adjustment of industry and transportation for compliance with standards will correspondingly satisfy the emission requirements of other land uses.

5.1 Estimating Industrial Emissions

This section provides the basis for tracing cumulative emission estimates for a specified industrial mix, as required in Step 3, through a set of industrial pollution index codes and generalized emission rates.

Table 6 is a very general guide for reference prior to hypothesizing an industrial mix. It is intended to give the planner a qualitative estimate of the potential to pollute for each of several major industrial categories. Two digit Standard Industrial Classification (SIC) codes representing the indicated major industrial manufacturing groups are listed in ascending order. The five columns to the right of the index column contain single letter codes indicating the pollution potential for each of the five major pollutants. As indicated, the letter code "A" indicates that the industrial group is a "light industry" (i.e., an industry which pollutes very little) with respect to the given pollutant. These industries are generally clean and air quality need not be a major consideration in their specification. Conversely, letter code "B" indicates a "heavy industry" (i.e., one that may be expected to have substantial emissions for the given pollutant). The "B" codes indicate that some care should be taken when placing the industry because they may not be compatible with adjacent sensitive receptors. Likewise, clusters of more than one "B" coded industry could present significant regional air quality problems. Code "C" indicates a "problem industry." A "C" coded industry would be one that should be individually studied by an air quality expert so that its impact on its community is both minimized and acceptable.

The planner should be aware in his use of Table 6, that there is a great amount of variance in polluting potential among the industries within any set of two digit SIC coded industries. For this reason care should be taken in the use of Table 6. It is a general guideline and should be used as such. It should not be used as an index for making significant air quality decisions.

Table 6. GENERAL EMISSION CHARACTERISTIC OF INDUSTRIES BY SIC[a]

Pollutant Classification Code

"A" indicates industry of the given SIC presents no air quality problem for the pollutant considered.

"B" indicates only a finite number of the given industry may be located in a given area. Care should be taken in location process.[b]

"C" indicates a critical industry with respect to air quality Expert advice should be solicited in choosing and locating these sources.

Industry Type	SIC	SO_2 Emission Class	Particulate Emission Class	CO Emission Class	HC Emission Class	NO_X Emission Class
Food Products	20	B-	B	A	A	B-
Textiles	22	B+	A	A	B	B
Apparel	23	A	A	A	B	B+
Lumber & Wood	24	A	A	A	A	A
Furniture	25	A	A	A	A	A
Paper Prod.	26	C	B-	A	B	C
Printing & Publishing	27	A	A	A	C	A
Chemical	28	B-	B	B	B	B-
Petroleum	29	C	C	C	C	C
Rubber & Plastics	30	B+	A	A	B+	B+
Leather Prod.	31	B	A	A	B-	A
Stone, clay & Glass	32	B	B	A	A	B
Primary Metals	33	B	B	B-	A	B
Fab. Metals	34	A	A	A	B-	A
Machinery	35	B+	B+	A	B+	B+
Elec.Machinery	36	B+	A	A	A	A
Transport.Equip.	37	A	A	A	B+	A
Prof.,Scient. Precision made Inst.	38	A	A	A	A	B
Misc. Manu.	39	B+	A	A	B	B+

[a] Air Quality for Urban and Industrial Planning (Extension),Final Report[1]

[b] B+ indicates a range closer to the "A" classification
B- indicates a range closer to the "C" classification
Note that each of these categories covers a wide range of values.

Table 7 provides a means of estimating emissions resulting from a given mix of industries. The table consists of estimated generalized emissions by pollutant and letter code. From this table the planner may calculate numerical estimates of industrial pollutants. The units are in terms of grams of pollutant emissions per employee and per hour of plant operation. By multiplying this unit emission by the employed intensity (employee-hour per year), a total annual emission is estimated for each industrial source. These estimates are applied to the selection of industrial/transportation land use schemes in Step 3. Sample calculations for the procedure described above are presented in Section 6.

5.2 Estimating Transportation Emissions

As indicated in Figure 11, determination of capable industrial/transportation land use schemes requires that transportation demand estimates, in the form of average daily traffic (ADT) or vehicle miles of travel (VMT) per day, be related to annual average anticipated transportation emissions. Table 8 provides emission rates for both urban and rural vehicular use where 'urban' implies stop and go traffic patterns with an average route speed under 45 mph, and 'other' implies traffic patterns with anticipated average route speed exceeding 45 mph. It is not suggested that the table be used to estimate emissions for specific transportation configurations since the figures are very generalized, emission rates being representative of typical vehicular mixes.

Annual average emission values for anticipated demand may be calculated as follows:

$$E = (365) \{[(R)(A)(L)]_u + [(R)(A)(L)]_o \qquad (2)$$

where

E = annual average emissions (grams)

R = emission rate (from Table 8) (grams/mile)

A = estimated average daily traffic (ADT)

L = estimated vehicular miles traveled per vehicle trip per day

and the subscripts u and o define the traffic pattern (i.e., 'urban' or 'other').

Application of the emissions calculated to the Step 3 procedure is accomplished as indicated previously. Sample calculations of the above procedure are presented in Section 6.

Table 7. GENERALIZED INDUSTRIAL EMISSION RATES[a]

(GRAMS OF POLLUTANT PER EMPLOYEE-HR.)

Industry Type	SO_2	Particulates	CO	HC	NO_X
A	6	5	2	6	6
B+	24	15	22	20	18
B	75	86	75	53	46
B-	176	220	220	198	132
C	530	660	1320	595	350

[a] Air Quality Pollution and Industrial Planning (Extension), Final Report[1] These numbers are based upon fragmented data documented in the above reference. The use of this table for significant air quality studies and decisions is not advised at this time due to the preliminary nature of the emissions estimates.

Table 8. GENERALIZED VEHICULAR TRANSPORTATION EMISSION RATES

(grams/mile)					
Pollutant	Traffic Pattern	1975	1980	1985	1990 & Later
CO	Urban	60	36.5	25.0	23.8
	Other	35	14.2	9.8	9.3
HC	Urban	7.66	4.1	2.7	2.5
	Other	5.66	2.0	1.3	1.2
NO_X	Urban	4.9	2.8	1.8	1.6
	Other	-	4.2	2.7	2.4

Emission rates pertain to the following vehicular mix:

- 90% Automobiles and light-duty vehicles
- 10% Heavy-duty Trucks
- Current National Vehicular Age Distribution, pre-1960 and 1960 through 1973.

Source: United States, Environmental Protection Agency, Compilation of Air Pollutant Emission Factors, Office of Air Programs, Publication No. AP-42, February 1972; Revised, April 1973.

6. ILLUSTRATIVE EXAMPLES

In order to clarify the procedures involved in implementing the Air Quality Impact-Land Use Planning Process through and including the specification of constraints to industry and transportation (step 3), the following sections are presented to illustrate calculations required by steps 2 and 3. The first example begins with a set of annual average pollutant concentrations for an existing land use configuration and runs through the procedures involved in step 2 (refer to Figure 9). The second example takes the emissions calculated in the first example and postulates an industrial mix, along with traffic constraints, as indicated in step 3 (refer to Figure 11). The examples are presented as illustrative matter only and are neither intended to restrict the application of, nor limit procedural variations to the methodology presented in Section 2.

6.1 Determining Allowable Emissions

In conjunction with the requirements of establishing an air quality data base for a planning area, the following annual average pollutant concentrations have been established from data supplied by the state air pollution control agency:

Pollutant	Annual Average Concentration ($\mu g/m^3$)
SO_2	48.0
NO_x	5.0
CO	810.0
HC	133.0
TSP	37.0

As indicated in Figure 9, initial 'allowable' increases in pollutant concentrations are determined merely by subtracting the annual average concentrations indicated above from the equivalent annual average standards presented in Table 5.

Pollutant				'Initial' Allowable Increases ($\mu g/m^3$)
SO_2	60.0 -	48.0	=	12.0
NO_X	100.0 -	5.0	=	95.0
CO	1425.0 -	810.0	=	615.0
HC	160.0 -	133.0	=	27.0
TSP	60.0 -	37.0	=	23.0

From the state pollution control agency, it has been learned that existing air quality levels are anticipated to be decreased by 1990 (the plan design period) by the following amounts due to a uniformly applied strategy of emission controls across the state:

Pollutant	Anticipated Decrease in Pollutant Concentrations ($\mu g/m^3$)
SO_2	9.0
NO_X	130.0
CO	580.0
HC	19.0
TSP	13.0

At this point, there are two possible courses of action: add the anticipated decreases to the initial allowable increases, or adopt the anticipated decreases as allowable increases. In the former case the planner would be designing up to the tolerance of the standards and, in the latter, designing to maintain present levels. Bearing in mind recent court cases involving the degradation of existing air quality, the latter course of action is taken.

Pollutant	Allowable 'Final' Increases ($\mu g/m^3$)
SO_2	9.0
NO_X	95.0
CO	580.0
HC	19.8
TSP	13.0

As indicated in Figure 9, a box model analysis is required to translate these allowable concentration increases to corresponding increases in pollutant emissions. It has been determined that the longest straight line distance through the planning area is 27 kilometers. Applying this number to the graph in Figure 10, the annual average normalized concentration is determined to be 15.8 (seconds/meter). The study area of the planning region is 405 km^2 so that annual average increases in pollutant emission rates, calculated from equation (1) are as follows:

Pollutant	Annual Average Allowable Emission Rate Increase (grams/second)
SO_2	2.31
NO_X	24.35
CO	149.72
HC	5.07
TSP	3.33

In terms of total annual increases to existing emissions, increases (multiply by 3.1536×10^7 seconds/year) are:

Pollutant	Annual Average Allowable Increase in Emissions (Grams)
SO_2	7.28×10^7
NO_X	76.79×10^7
CO	469.06×10^7
HC	15.99×10^7
TSP	10.50×10^7

As indicated in Figure 9, these values represent the output of step 2. The following section demonstrates their use in step 3.

6.2 Constraining Industry and Transportation

As a result of previous survey work, the planner has determined that the following industries desire to locate within his planning area. These industries are for illustrative purposes only and as such are hypothetical.

	Industry	SIC	Projected Employment	Annual Hours of Operation
1.	Apex Shoes	31	1500	4000
2.	Balto Furniture, Inc.	25	1200	8700
3.	Cello Rubber Products	30	6000	6000
4.	Diamond Lumber Co.	24	20	1800
5.	Excello Shirts	23	240	6000
6.	Franklin Petroleum	29	60	8700
7.	Gellow Steel Products	33	500	7600
8.	Halon Optical, Inc.	38	2000	8700
9.	Inter Food Products	20	4000	6100
10.	JEM File Cabinets	34	4000	4400
11.	Kowalsky's Wooden Widgets	24	300	4000
12.	Levrett Instruments	38	20	2000
13.	Malten Moltens, Inc.	33	300	4000
	Total		20,140	72,000

It must now be determined which of these industries may be allowed within the planning area without exceeding the annual average allowable increases in emissions already defined for this example. These allowable emissions are not to be totally allocated to industry, but must also cover increased transportation emissions from the additional demand created by increased industrial activity. As indicated in Section 5, a priori estimates of emissions from additional transportation activity may be made as follows:

Pollutant			Annual Average Allowable Increase in Emissions Reserved for Transportation (Grams)
SO_2	[7.28 x 10^7] x [0.0]	=	0.0
NO_X	[76.79 x 10^7] x [.5]	=	38.40 x 10^7
CO	[469.06 x 10^7] x [.9]	=	422.15 x 10^7
HC	[16.0 x 10^7] x [.6]	=	9.59 x 10^7
TSP	[10.5 x 10^7] x [0.05]	=	.525x 10^7

Subtracting these values from the total allowable emissions yields annual average allowable industrial emissions.

Pollutant			Annual Average Allowable Increase in Industrial Emissions (Grams)
SO_2	[7.28 x 10^7] - [0.0]	=	7.28 x 10^7
NO_X	[76.79 x 10^7] - [38.40 x 10^7]	=	38.39 x 10^7
CO	[469.06 x 10^7] - [422.15 x 10^7]	=	46.91 x 10^7
HC	[15.99 x 10^7] - [9.6 x 10^7]	=	6.40 x 1C^7
TSP	[10.50 x 10^7] - [.525 x 10^7]	=	9.975 x 10^7

The process of specifying industrial mix is now initiated. Table 6 of Section 5.2 indicates that Franklin Petroleum (Industry Number 6 above) is coded 'C' with respect to each of the 5 pollutants. Since the planning area is already close to air quality limits, the planner elects to eliminate this industry from the list of possibilities. The remaining 12 industries are all considered to be viable choices for the planning area so that the planner now calculates the emissions from each (using Table 7 of Section 5.2) and consequently subtracts these emissions from allowable industrial emissions until the residuals approach zero. It should be noted that the sequence of these industries does not represent a "priority ranking." That is, industries would not necessarily have to be eliminated from the bottom-up.

ANNUAL POLLUTANT EMISSIONS

(GRAMS X 10^{-7})

Industry	SO_2	NO_X	CO	HC	TSP	
1.	7.25	5.1	1.84	6.4	9.975	Allowable industrial
	-0.45	-0.036	-0.012	-1.18	-0.03	Projected emissions
	6.83	5.064	1.828	5.22	9.945	Residual
2.	-0.0626	-0.0626	-0.0208	-0.0626	-0.0522	Projected emissions
	6.73	5.0	1.808	5.158	9.893	Residual
3.	-0.864	-0.648	-0.072	-0.72	-0.18	Projected emissions
	5.874	4.352	1.736	4.438	9.713	Residual
4.	-0.000216	-0.000216	-0.000072	-0.000216	0.00018	Projected emissions
	5.873	4.351	1.735	4.437	9.713	Residual
5.	-0.864	-0.02592	-0.00288	-0.07632	0.0072	Projected emissions
	5.864	4.325	1.732	4.36	9.705	Residual
7.	0.285	-0.1748	-0.836	-0.0228	-0.3268	Projected emissions
	5.58	4.15	0.896	4.337	9.37	Residual
8.	-0.104	-0.313	-0.0348	-0.104	-0.087	Projected emissions
	5.476	3.838	0.8612	4.233	9.283	Residual
9.	-4.29	-3.16	-0.0488	-0.1464	-2.064	Projected emissions
	1.182	0.67	0.8124	4.087	7.219	Residual
10.	-0.105	-0.105	-0.352	-3.484	-0.088	Projected emissions
	1.077	0.565	0.4604	0.603	7.131	Residual
11.	-0.0072	-0.0072	-0.0024	-0.072	-0.006	Projected emissions
	1.005	0.5578	0.458	0.5318	7.125	Residual
12.	-0.00024	-0.00072	-0.0008	-0.00212	0.0002	Projected emissions
	1.004	0.557	0.457	0.529	7.124	Residual
13.	-0.09	-0.00552	-0.264	-0.0072	-0.1032	Projected emissions
	0.903	0.5518	0.193	0.522	7.02	Residual

Having accounted for all industries from the list of possibilities, and aware that the CO residual is approaching zero, allowable transportation emissions must now be compared with those calculated from projected transportation demand estimates.

Because the residuals from allowable industrial emissions have not gone identically to zero, the planner may add them to the allowable transportation emissions.

Pollutant			Annual Average Allowable Increase in Transportation Emissions (Grams)
SO_2	$(0.0) + (.903 \times 10^7)$	=	$.903 \times 10^7$
NO_X	$(38.40 \times 10^7) + (.5518 \times 10^7)$	=	38.9518×10^7
CO	$(422.15 \times 10^7) + (.193 \times 10^7)$	=	422.343×10^7
HC	$(9.6 \times 10^7) + (.522 \times 10^7)$	=	10.122×10^7
TSP	$(.525 \times 10^7) + (7.02 \times 10^7)$	=	7.545×10^7

It has been estimated that the increase in industrial employment will represent 35% of the increase in total population, so that:

$$\text{Total increase in population} = \frac{20{,}080}{.35} \approx 60{,}000 \text{ (minus petroleum company)}$$

Projections by auto insurance companies and transportation planning agencies estimate the average per capita miles travelled for work, shopping, recreation, and secondary trips to be 7,000 miles/year.

Projected travel is anticipated to be 85% vehicular with a 1.72 persons per vehicle occupancy rate, and 15% mass transit. Total annual vehicular travel in miles is, therefore, estimated as follows:

$$\text{persons} \times \frac{\text{Total passenger miles}}{\text{Person - year}} \times \frac{\text{Passenger miles by motor vehicle}}{\text{Total passenger miles}}$$

$$\times \frac{\text{Vehicle miles}}{\text{Passenger miles by vehicle}} = \frac{\text{Vehicle miles}}{\text{Year}}$$

$$(60{,}000) \text{ people} \times (7{,}000) \text{ miles/person} \times .85 \times (1/1.72) \frac{\text{Vehicles}}{\text{Person}}$$

$$\approx 2.1 \times 10^8 \text{ vehicle miles per year}$$

Of this 2.1×10^8 miles of travel, it is estimated that 80% will be under urban (stop and go, low average speed) conditions and 20% non-urban or expressway conditions. Applying Table 8 to equation (2) of Section 5.2 anticipated transportation emission rates are estimated as:

Pollutant			Annual Average Anticipated Transportation Emission Rates (Grams/Vehicle Mile)
NO_X	(.8)(1.6)+(.2)(2.4)	$\cong$	1.8
CO	(.8)(23.8)+(.2)(9.3)	$\cong$	20.9
HC	(.8)(2.5)+(.2)(1.2)	$\cong$	2.2

Multiplying these emission rates by the average annual VMT yields the annual average anticipated increase in transportation emissions:

Pollutant			Annual Average Anticipated Increase in Transportation Emissions (Grams)	Net Allowable Increase (Grams)
NO_X	$(1.8) \times (2.1 \times 10^8)$	=	4.18×10^8	3.90×10^8
CO	$(20.9) \times (2.1 \times 10^8)$	=	43.89×10^8	42.23×10^8
HC	$(2.2) \times (2.1 \times 10^8)$	=	4.62×10^8	1.012×10^8

Comparison of these anticipated emissions with allowable transportation values indicates that both CO and NO_X may marginally exceed the non degradation goals set at the beginning of the problem. In fact the estimates show that the national ambient air quality standards may be exceeded under the proposed industrial and transportation mix. In this case the planner may seek air quality expertise from his state or local air quality agency to study the potential problem.

If desired the planner may also adjust his postulated industrial mix such that NO_X and CO emissions will be reduced, and recalculate air quality levels at a lower level of industrial activity. By this iterative process the planner may redesign his industrial mix, incrementally eliminating emissions, until his calculated emissions meet his air quality goals.

7. THE INFLUENCE OF SOURCE CONFIGURATION

Thus far, procedures have been outlined for establishing the air quality baseline in a planning area (Step 1), defining allowable emission increases (Step 2) and establishing acceptable industrial/transportation land use designs (Spep 3). Step 4 addresses the spatial distribution of industrial/transportation designs generated within comprehensive plans. The purpose of this section is to demonstrate how differences in the placement and design of major air pollution sources can be used to minimize the air quality impact of a given mix and intensity of land uses in the implementation of Step 4 (refer to Figure 8).

As indicated in Figure 12, the input to this step consists of specified types and amounts of industrial and transportation related land use. On an individual basis, the effect of each major air pollution source within these categorical sets is physically limited to a loosely defined area surrounding the source. This area may be designated as the influence region or air pollution impact area of that source. Because pollutant concentrations from individual and physically separated sources are directly additive at those points where their respective influence regions overlap, and because background pollutant concentration patterns are further superimposed on these concentrations, the placement of major sources relative to one another, as well as to background concentration patterns, is critically important to the determination of local air quality levels within the planning area. Furthermore, the locations of land uses which are not generally associated with air quality problems but which may be important as receptors of air pollution, are important in considering the air quality impact of a given land use configuration.

Where sufficient engineering data for a given source exist (in terms of stack height, flue gas rates and temperatures, etc.), or where a particular source or group of sources is anticipated to have a particularly significant impact on air quality, the planner may wish to employ a numerical simulation model (or in some cases a gaussian plume model) to explicitly define region of influence. Where this is not the case, the information presented in the following sections may be used as a guide for locating individual land uses consistent with air quality requirements.

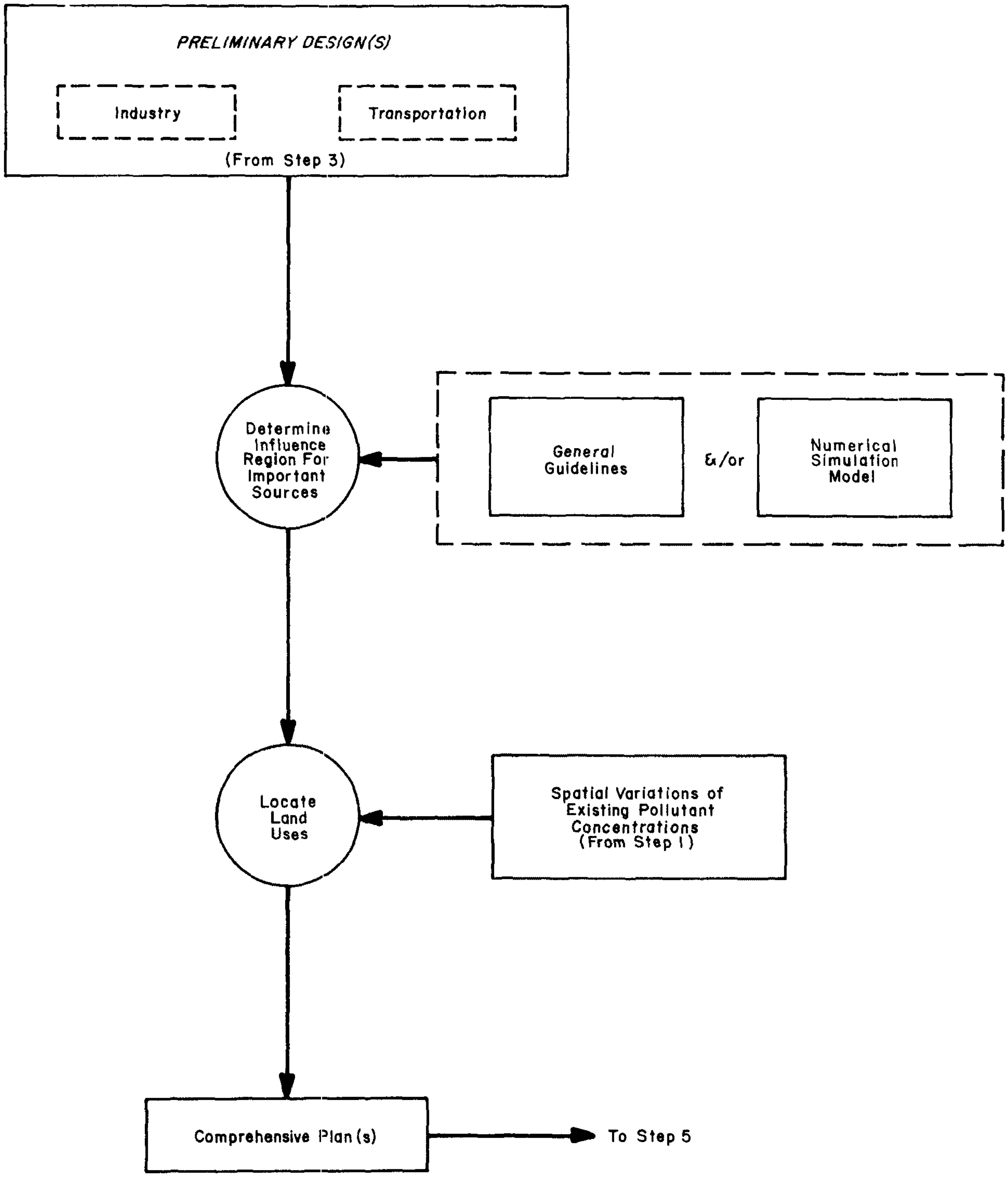

Figure 12 Step 4 in the air quality impact-land use planning process; generating alternative comprehensive land use plans

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7.1 Industrial Sources

In order to evaluate the effects of land use planning on air quality in terms of the location of pollution sources within the planning area, several studies were undertaken that utilized a gaussian diffusion model, MARTIK (developed by Environmental Research & Technology, Inc.), to determine the pollutant concentration patterns for a variety of source configurations. MARTIK is highly flexible and accepts emissions data from point (e.g., single stack), line (e.g., highway), and area (e.g., an industrial complex) sources. A regional area was simulated, with a 25 by 25 grid cell system. Each grid cell was 1 km on a side, so that the total area was 625 km^2. The simple source configuration used for the studies together with 100 evenly spaced receptor points were placed within this area. Contours of pollutant concentrations were then drawn over the entire grid. This procedure allows the pollutant concentration to be estimated at any point inside the region by interpolation with the aid of the contour lines. Locations for sensitive receptors can be selectively chosen from such studies, as well as the most appropriate locations for additional sources. These points are illustrated in the studies described in this section.

In studies concerned with the environmental impact of air pollution, two basic types of temporal conditions are evaluated: average case and worst case. Average case conditions simulate air quality for a given combination of sources, emissions, and meteorological conditions, usually specified as annual average values. They can be useful in estimating the long-term exposure of a planning region to atmospheric pollutants.

Worst-case conditions simulate the extreme in pollutant concentrations for a particular situation. In a study of this type, the MARTIK model uses a single wind speed class, wind direction, and stability class. The frequency with which these worst-case conditions occur can be estimated from the annual average stability wind rose. Worst-case conditions are modeled for several reasons. First, ambient air quality standards set by government regulatory agencies are expressed as worst-case hour, three-hour, and eight-hour averages. Estimation of worst-case conditions determines whether a given land use plan can be expected to comply with present or proposed air quality standards. Second, the placement of sensitive receptors (schools, hospitals, etc.) depend on worst-case conditions, because such receptors contain persons who are particularly sensitive to the adverse health effects of short-term exposure to high dosages of atmospheric pollutants. Children, the very active, the ill, and the elderly are especially susceptible.

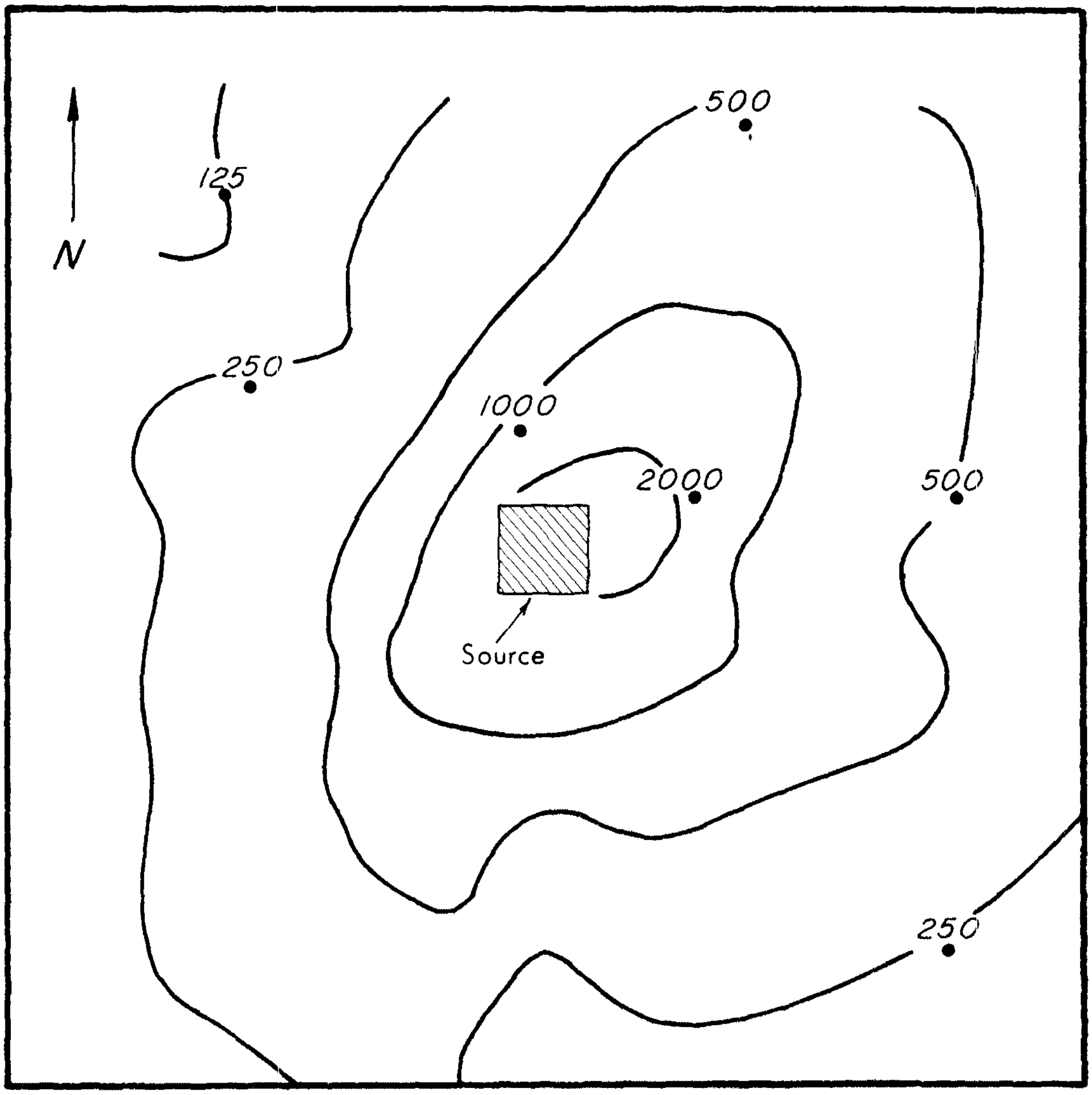
For the following case studies, the ground-level concentrations of atmospheric pollutants are expressed so as to be independent of pollutant. Emissions and concentrations are assumed to be linearly related, so that in a given case study, doubling the emissions with all other factors held constant would result in doubled concentrations throughout the grid. The studies themselves are intended to be illustrative only. Although MARTIK and the procedures described have been used extensively in operational decision-making, the purpose here is to show the basic influence of land use geometries on air quality.

Case Study No. 1

The first sensitivity study is aimed at investigating the relative effects on air quality of clustered versus dispersed area sources. In the context of regional planning, this is related to the problem of locating the industrialized areas of a planning region so as to minimize the adverse effects of air pollution on the rest of the region. Figure 13 shows a planning region within which the emissions sources are confined to a small area in the center of the planning region, and can be treated by the dispersion model, MARTIK, as one area source. The contours are lines of constant annual average pollutant concentration (isopleths). They were selected so that, as one approaches the source, each new contour line encountered represents a doubling of concentration. All other things being equal, lowering the point of release of pollutant emissions results in the dispersion envelope, or plume, contacting the ground in a shorter downwind distance. Since the dispersion of pollutant material is a fraction of distance downwind of the release point, the maximum ground level concentration resulting from a given source will increase with decreasing stack height. The annual wind rose for Newark International Airport was chosen as a typical wind rose. The effects of using a particular wind rose show up as asymmetries of the contour lines. For example, in Figure 13 the contours are elongated from southwest to northeast because southwest winds occur more frequently at Newark Airport than winds of other directions.

The alternative to clustering industry in a planning region is to disperse it. In contrast to Figure 13, Figure 14 shows four area sources, the sums of whose areas and emissions are equal to the area and emissions of the single area source in Figure 13. The most striking difference between the two land use configurations is the absence of the highest concentration values in Figure 14 that appear in Figure 13. In fact, the maximum grid point concentration (870) in the case of the dispersed sources has been reduced by a factor of 2.4 from that in the clustered industry plan (2123). At the same time, the minimum grid point value increases by a factor of 1.8 from the clustered plan (80) to the dispersed plan (142). Thus, there are two main points to be noted in this first case study:

1) Dispersion of industry decreases the highest annual mean pollutant concentrations (those observed close to the sources) compared to concentrating the same emissions sources.

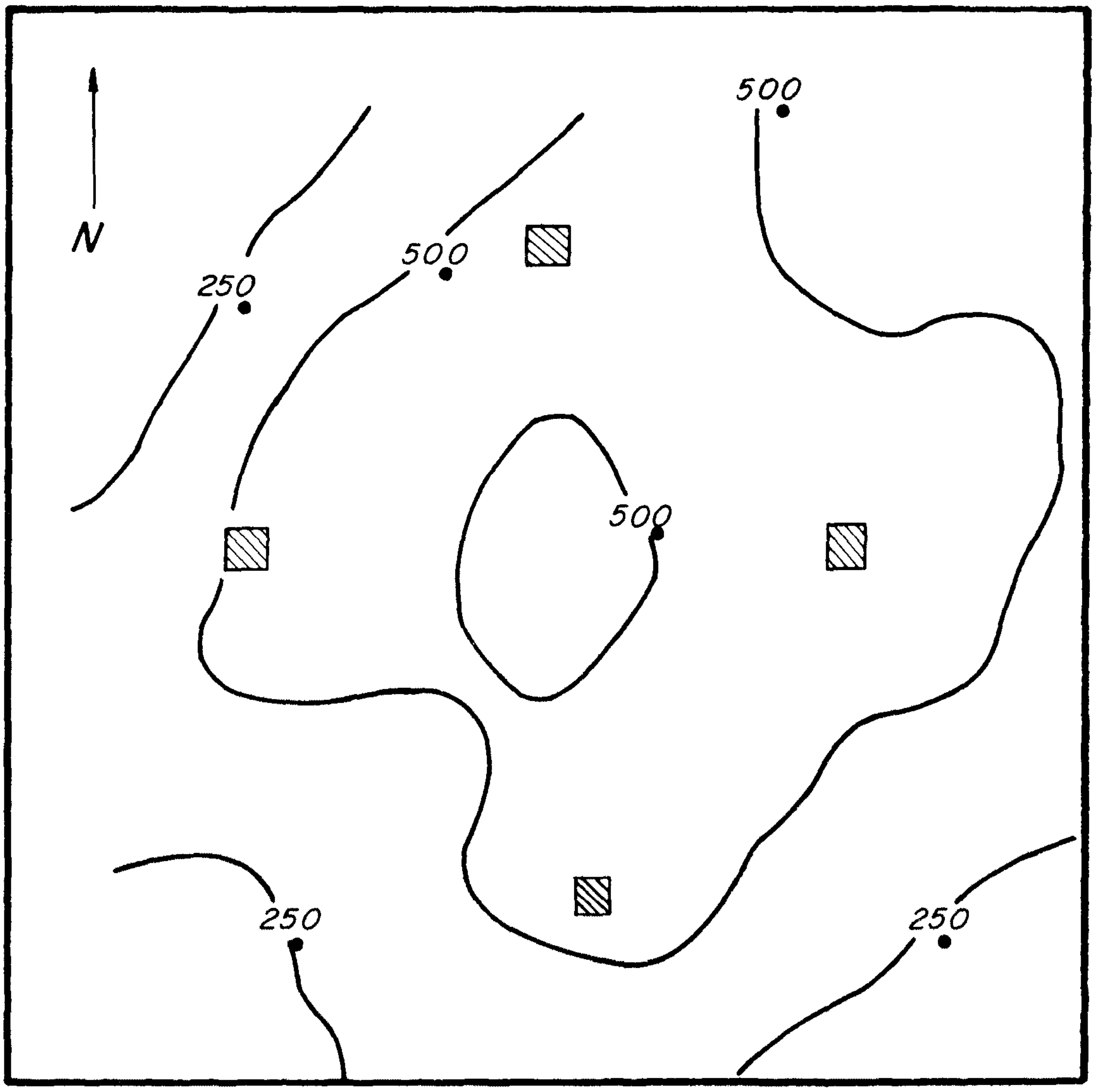


Note: Total source strength = 4000.0 ($\frac{grams}{sec}$)

Maximum concentration: 2123

Minimum concentration: 80

Figure 13 Annual average pollutant concentrations ($\mu g/m^3$) for a single area source



Note: Total source strength = 4000.0 $(\frac{\text{grams}}{\text{sec}})$

Maximum concentration: 870
Minimum concentration: 142

Figure 14 Annual mean pollutant concentrations (μg/m^3) for dispersed area sources

2) Dispersion of industry greatly increases the lowest annual mean pollutant concentrations (those observed away from the sources) compared to concentrating the same emissions sources. This effect comes about because fewer receptors can be great distances away from any source when industry is dispersed.

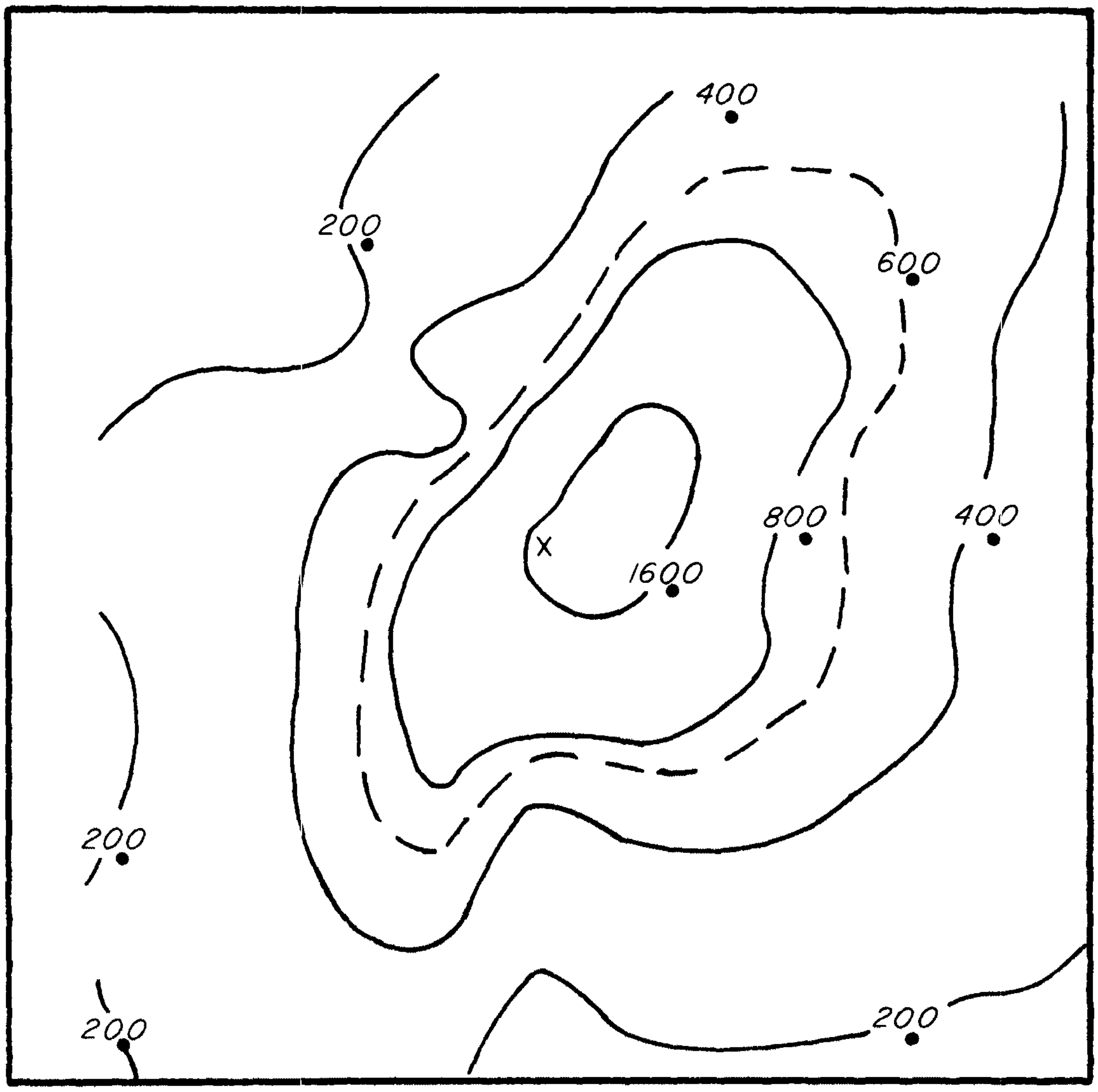
The spatial analysis shown above in Figures 13 and 14 shows clear differences between the clustered and dispersed alternatives that should be considered in light of the other constraints and options that are available. Several tradeoffs are apparent for this case study. Sensitive receptors fare best when carefully placed within a region with clustered emission sources. On the other hand, if annual mean concentrations predicted by a box model are close to ambient air-quality standards, then a dispersed configuration of major sources may be the only way to keep maximum concentrations low enough to meet standards. In addition, concentrations very far away from a source are often sufficiently low so that even a doubling would not cause them to approach the approximate threshold of adverse effects for even the most sensitive receptors.

Case Study No. 2

The second case study is aimed at investigating the relative effects on air quality of clustered versus dispersed configurations of point sources. This relates to the problem of deciding from an air quality standpoint whether a region would better be served by one large incinerator or by several smaller facilities.

Figure 15 shows contours of equal annual-average pollutant concentration resulting from a single large point source. It is interesting to note that the concentration profiles indicated in the figure differ somewhat from those for an area source of equal strength (refer to Figure 13). Since the same meteorological conditions were used for both studies, the differences are solely attributed to differences in source geometry (i.e., area as opposed to point source). In particular, an area source inherently implies a dispersion of emissions over the area of the source. Consequently, one would expect an area source to exhibit lower ground level pollutant concentrations than a point source having the same total emissions. However, the height at which pollutants are released has a strong effect on pollutant dispersion in the vertical direction. Because a point source is generally a single stack (or group of stacks), its emissions generally occur at significant heights above ground level. Ground level pollutant concentrations near the base of the stack are not always indicative of maximum values. In most cases, maximum ground level concentrations occur immediately adjacent to ground level sources and at some downwind distance from elevated sources. Furthermore, for the same total emissions, an elevated source will most often exhibit lower maximum ground level concentrations than will a ground level source, although its impact will usually be felt over a larger area.

Figure 16 shows the concentrations resulting from four dispersed point sources that together have the same total emission rate as the point source in Figure 15. The effects on air quality of dispersing point sources are identical with those of dispersing area sources so that the comments and conclusions of the previous study are equally valid here. This represents a steady state meteorological condition (fixed wind speed, direction and, stability class). Depending on individual source configuration, steady state conditions will occur within an hour, given an hour of persistent meteorological conditions. Concentrations may be taken to be representative of 1-hour maximum concentrations under steady state conditions.



Note: Total source strength = 4000 ($\frac{\text{grams}}{\text{sec}}$)

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Figure 15 Annual mean pollutant concentrations ($\mu g/m^3$) for a single point source

Note: Total Source Strength = 4000.0 $(\frac{\text{grams}}{\text{sec}})$

Figure 16 Annual mean pollutant concentrations ($\mu g/m^3$) for dispersed point sources

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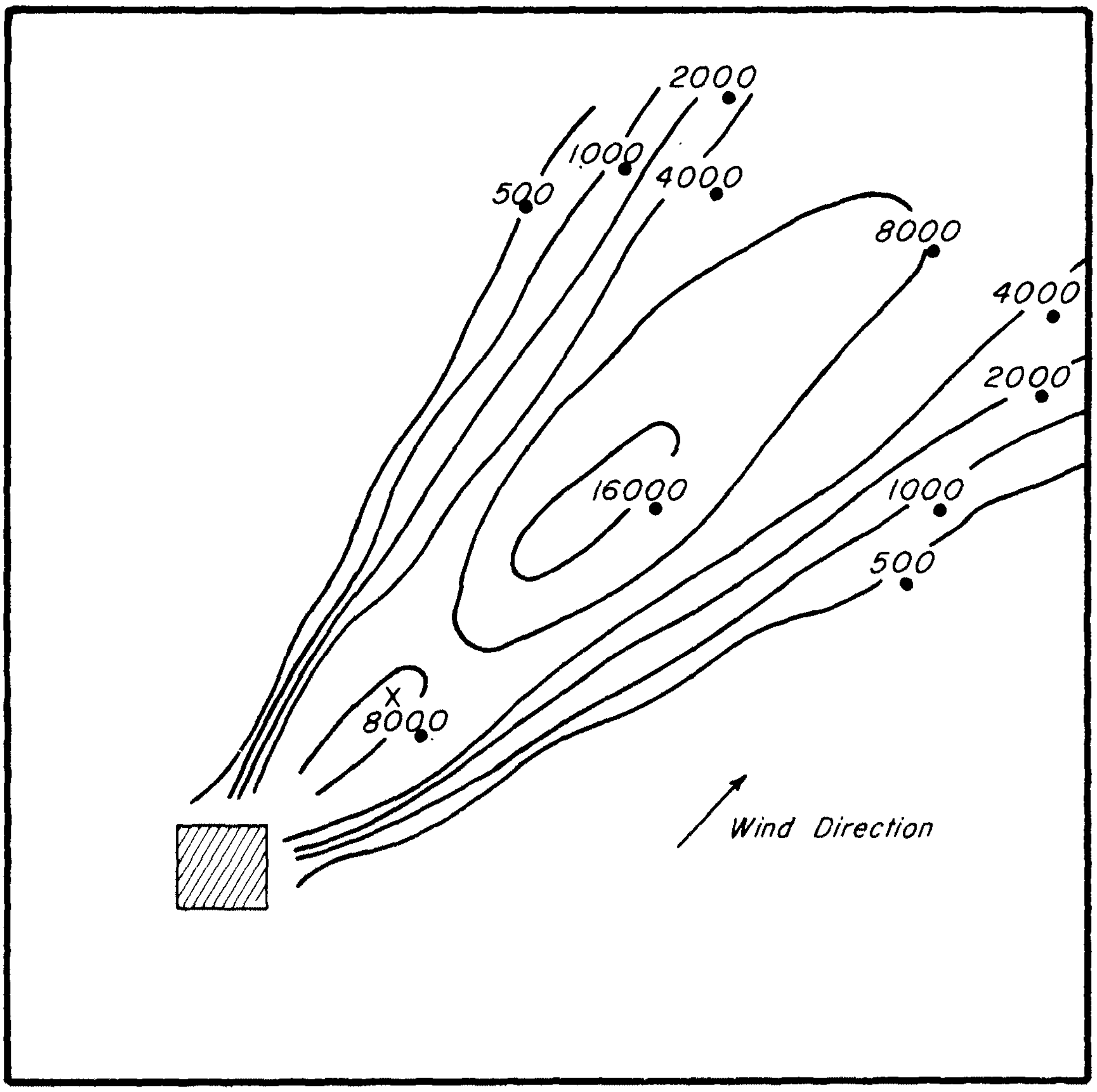
Case Study No. 3

The third case study is aimed at investigating the relative effects on air quality of clustered versus dispersed sources in a worst-case situation. In this case, the wind direction chosen was southwest, with a stable atmosphere. Figure 17 shows the concentrations resulting from two sources, an area source and a point source. Southwest was chosen as the worst-case wind direction, because the downwind effects of the two sources are superimposed most strongly for a southwest wind. Each contour, moving toward a maximum, represents a doubling of pollutant concentrations. Largest concentrations are observed somewhat downwind of the sources. With this single wind direction, the model predicts negligible contributions to areas outside a rather narrow downwind sector. As shown in Figure 17, the gradient of pollutant concentration is quite strong for this worst-case situation.

This sensitivity study was purposely complicated with the inclusion of two sources, in order to illustrate the complexities of a situation only slightly more realistic than that shown in the first two studies. Figure 18 shows an alternate land use plan, where the area source is dispersed into four smaller area sources. The point source remains. The wind direction is southwest, as in Figure 17. In Figure 18, the point source is clearly the dominant influence on the pattern of pollutant concentration, as the highest grid-point value of concentration is located directly downwind of it.

A comparison of the two land use alternatives shows that measurable concentrations for this worst-case situation are predicted for a few more grid points with the dispersed area sources than for the single area source. In compensation, the maximum grid-point concentration value (16483) for the dispersed plan is smaller by a factor of 1.4 than the maximum grid-point concentration value (22601) for the plan with the area sources consolidated. In practice, sensitive receptors can be positioned slightly more freely for the case shown in Figure 17 than for the configuration shown in Figure 18. However, when the maximum concentration of a pollutant is close to standards, source dispersion is a useful technique for keeping worst-case concentrations to a lower level for the same amount of emitted pollutant.

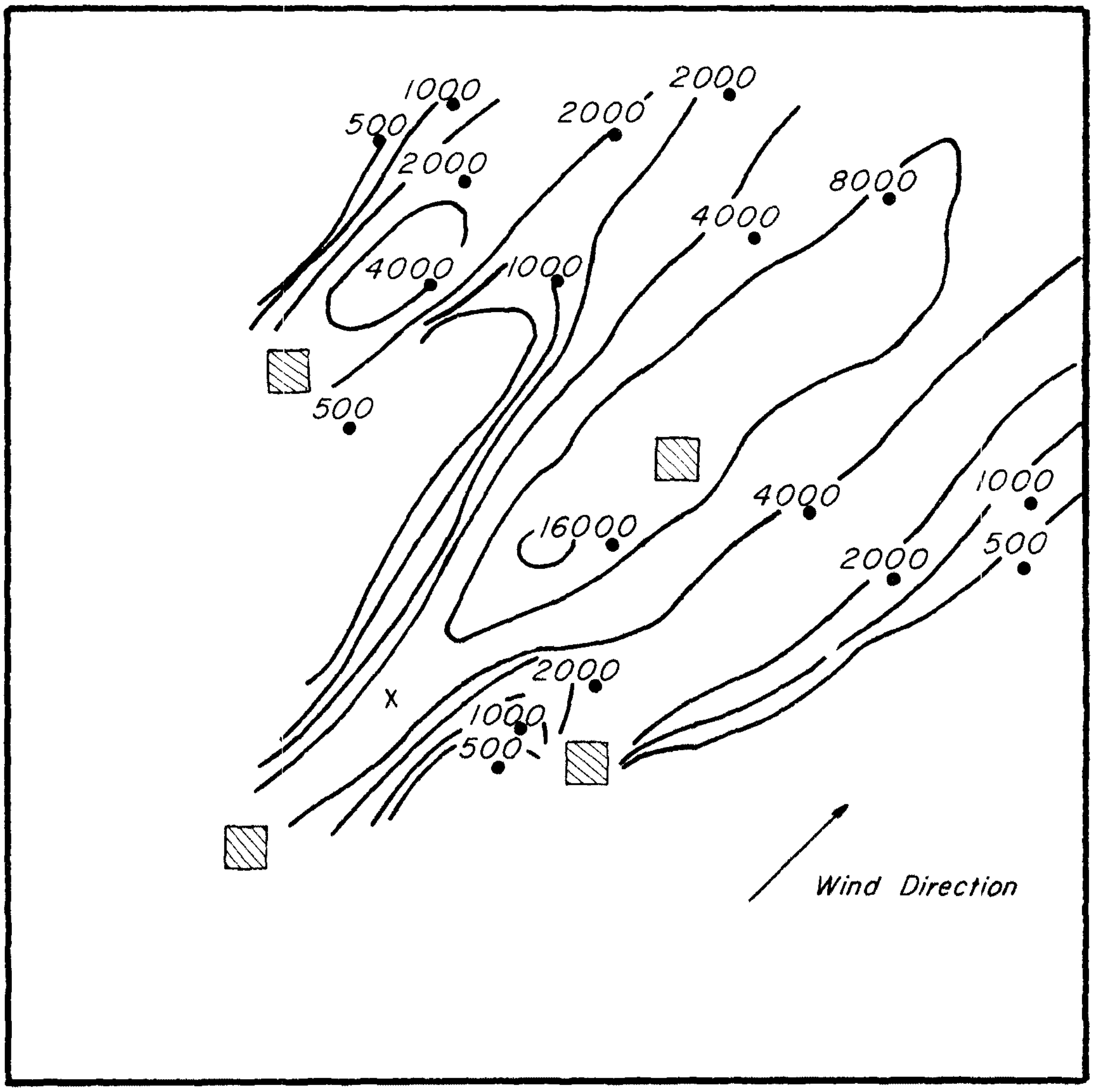


Note: Total source strength = 9000 ($\frac{\text{grams}}{\text{seconds}}$)

Point source strength = 5000 ($\frac{\text{grams}}{\text{seconds}}$)

Area source strength = 4000 ($\frac{\text{grams}}{\text{seconds}}$)
Maximum concentration: 22601
Minimum concentration: 0

Figure 17 Worst case pollutant concentrations ($\mu g/m^3$) for a single point and area source



Note: Total source strength = 9000 $(\frac{\text{grams}}{\text{seconds}})$

Point source strength = 5000 $(\frac{\text{grams}}{\text{seconds}})$

Area source strength = (4x1000) = 4000 $(\frac{\text{grams}}{\text{seconds}})$

Maximum concentration: 16483
Minimum concentration: 0

Figure 18 Worst case pollutant concentrations ($\mu g/m^3$) for a single point source and dispersed area sources

Summary of the Three Sensitivity Studies

The above sensitivity studies have illustrated several important planning guidelines:

1) Meteorological conditions in an area strongly affect pollutant concentrations, for both annual mean and worst-case situations.

2) When the sources are dispersed to several smaller, more widely spaced sources, minimum concentrations increase markedly for the same total emissions. Thus, the most sensitive receptors in a region might benefit from the concentration of large sources if the receptors are located far from the sources.

3) When large sources are dispersed to several smaller, more widely spaced sources, maximum concentrations decrease markedly for the same total emissions. Thus, it may be useful in a planning region to disperse large sources like industry, power generation, and incineration, rather than to cluster them, in order to meet ambient air-quality standards.

4) Very sensitive receptors fare best in the concentrated land use plan, when they are placed far from the source. On the other hand, because the maximum concentrations are higher in the clustered case, only a limited area is available for the sensitive receptors. For less sensitive receptors, the dispersed land use plan rates higher for regional air quality on an annual average. The highest concentrations are markedly reduced. When questions exist as to whether a region will be able to meet air quality standards, disperson of sources should be seriously considered as a means of reducing maximum concentrations.

7.2 Highway Sources

The dispersion patterns of pollutants emitted from highway sources are dependent on three sets of variables: meteorological conditions, highway geometry, and traffic characteristics. In terms of specifying highway configurations which are consistent with air quality considerations, the planner can exercise some degree of control over two of these sets (highway geometry and traffic characteristics) and must be aware of the implications of the third.

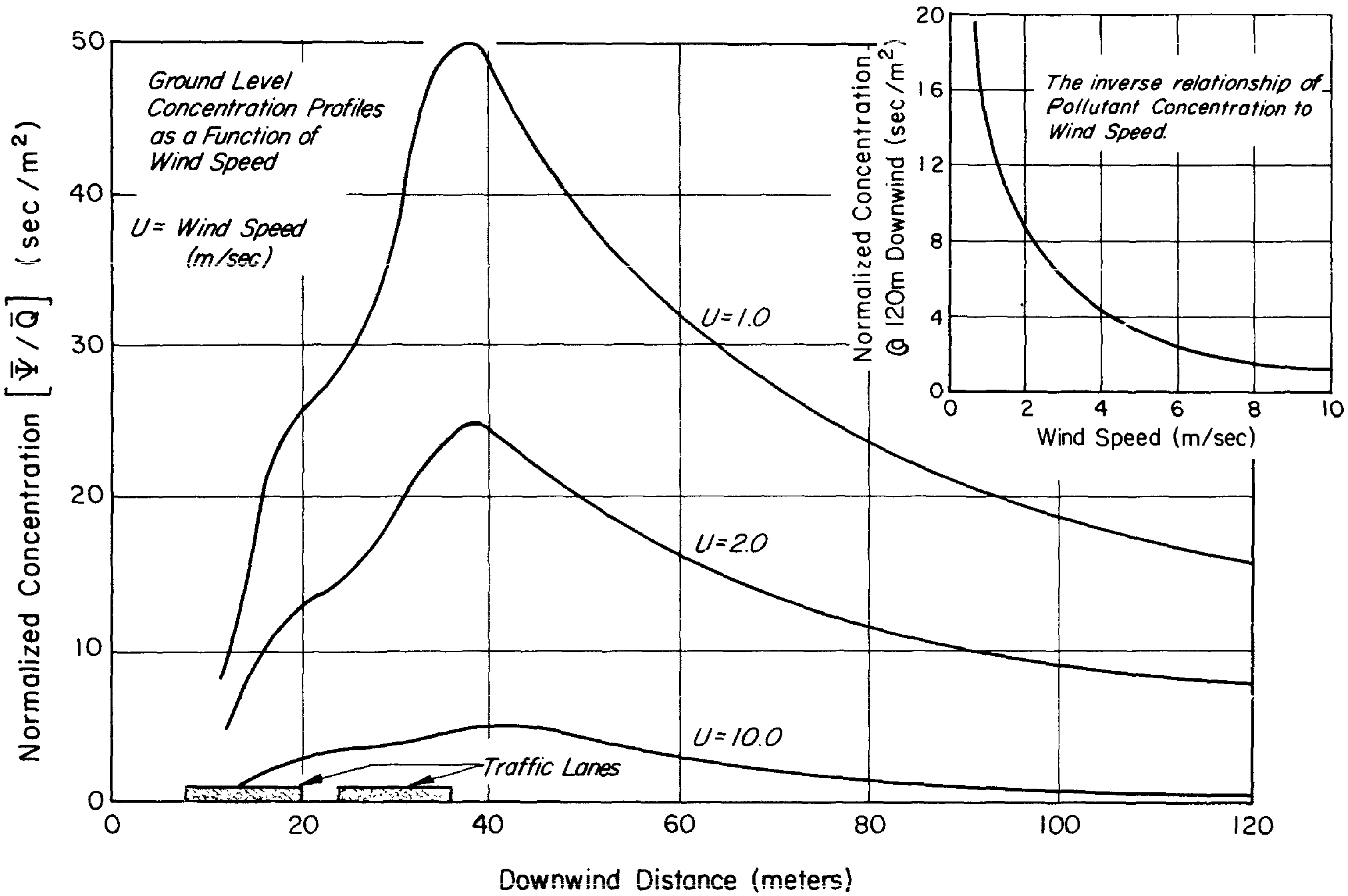


Figure 19 The relationship of pollutant concentration to wind speed at a height of six (6) meters above the ground

In order to quantify the relative sensitivity of air quality to each of the three sets of variables, a numerical simulation model, EGAMA, was put through a series of computer runs specifically designed to determine the effect of each on the pollutant concentration field. Great care was taken in the execution of this analysis to ensure that neither the operational capability of the model nor the myriad constraints of physical reality were exceeded. Consequently, the sensitivity of model results to variations of the parameters considered is consistent with observable phys.´·al behavior.

Meteorology

Atmospheric dispersion processes are influenced to a large degree by meteorological conditions. General comments relative to meteorological concerns in the air quality planning process, as discussed in previous sections, are equally valid in considering highway impact, and so will not be repeated here. However, a graphic presentation of the effects of micrometeorology on pollutant dispersion may serve to illustrate the utility of this information in locating highway and other land uses relative to one another.

Figure 19 shows the ground level concentration profiles for a typical at-grade, six-lane highway configuration as a function of wind speed. Concentration values are independent of pollutant and are normalized by the pollutant emission rate (in grams/meter-second) so that application of the curve to determining the concentration patterns of specific highways (of the geometry shown) may be accomplished simply by multiplying the ordinate scale by the appropriate emission rate. It is noted that the relationship of wind speed to the reciprocal of pollutant concentration at a given downwind point is linear, so that the joint frequency of occurrence of average and worst-case wind speed and traffic conditions can be used in conjunction with Figure 19 to perform approximate microscale evaluations of anticipated air quality levels. Specifically, estimates of emissions for the highway, under various assumptions of vehicular use, may be made using Table 8. Application of these estimates to the normalized concentrations will provide "actual" concentration profiles for the wind speeds shown. Wind speed values considered to be representative of worst-case and annual average conditions can then be used in adjusting these

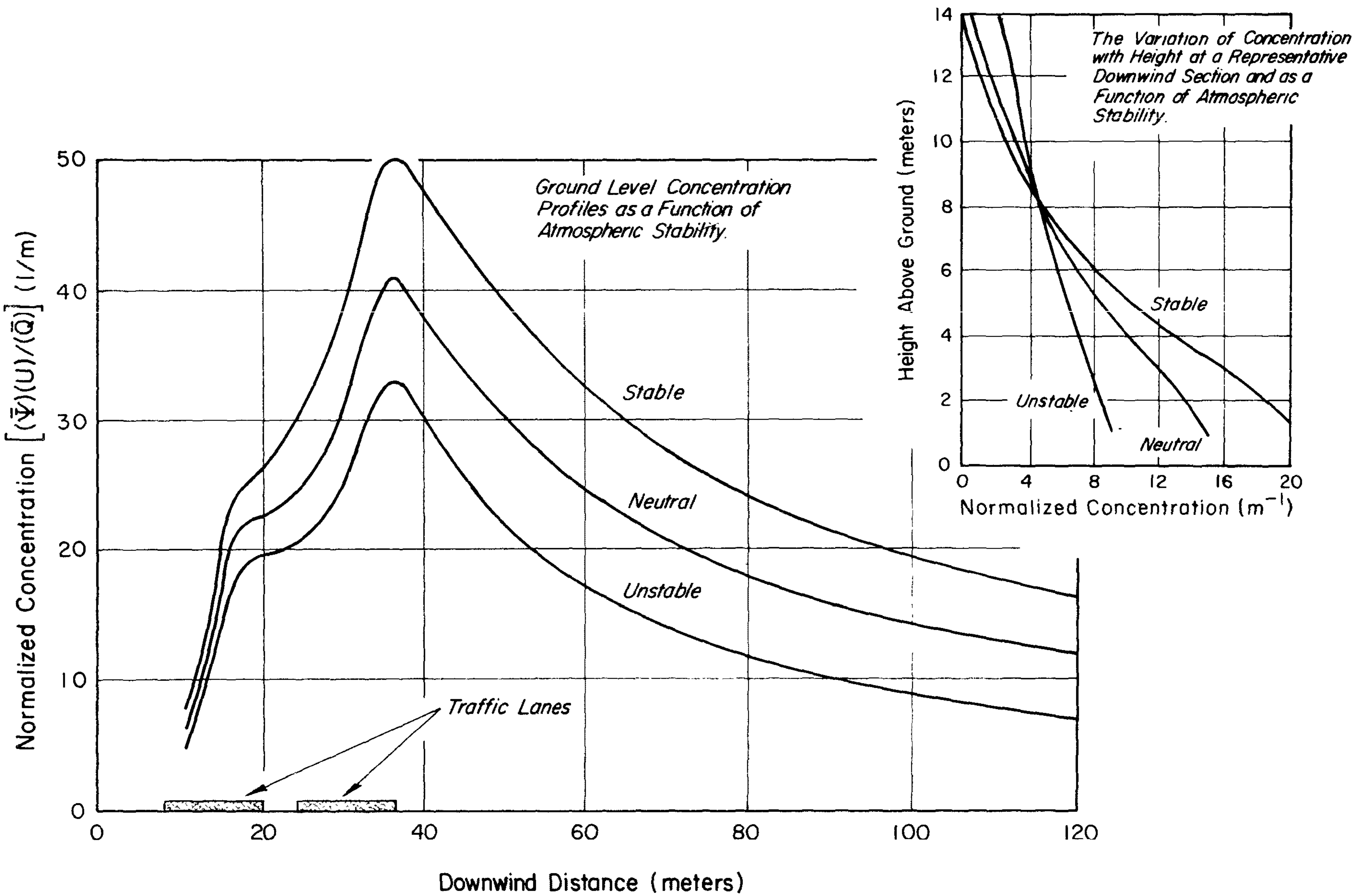


Figure 20 Relationship of pollutant concentration to atmospheric stability

profiles to present both annual average and worst-case air pollutant concentrations. The planner can then determine how close to the highway various land use categories may be specified without causing undue exposure to undesirable air quality levels. Conversely, where a proposed highway is to be built through densely populated areas, these profiles can be used as guides in routing the highway to minimize impact according to receptor type.

It should be cautioned here that Figure 19 does not show the effects of atmospheric stability on the concentration profiles. (The curves shown are for the stable condition.) Where the planner has data on atmospheric stability available, adjustments to the profiles generated from Figure 19 may be made to more accurately define worst-case as well as annual average conditions. Concentration profiles shown in Figure 20 are normalized by the ratio of emission rate ($\overline{Q}$) to wind speed (U) so that 'actual' values may be obtained by multiplying the ordinate scale by this ratio for a specific highway. Applications of Figure 20 to the planning process are identical with those discussed for Figure 19.

Highway Geometry

The cross sectional geometry of a highway influences pollutant dispersion by altering natural ventilation flows. Because highway geometry is the only parameter which can be independently specified, it represents a possible means of controlling very local air quality levels.

EGAMA recognizes three general highway cross sections: at-grade, elevated, and depressed. The ground-level concentration profiles for each will depend strongly upon the combined effects of relative location of traffic lanes to regions of circulating flows or flow stagnation, the depression or elevation dimensions, and meteorological parameters. Thus, the effects of highway geometry on air quality levels cannot be simply graphically condensed. (Indeed, this is a prime reason for use of high-speed computer facilities for these studies.) The following generalizations may be made, however, regarding the gross effects of highway configuration. In the very near field of the road, concentration values for all pollutants are predicted to be highest for the depressed geometry and lowest for the elevated. This is consistent with the ventilation velocities (local wind fields) associated with each geometry and is compatible with observable

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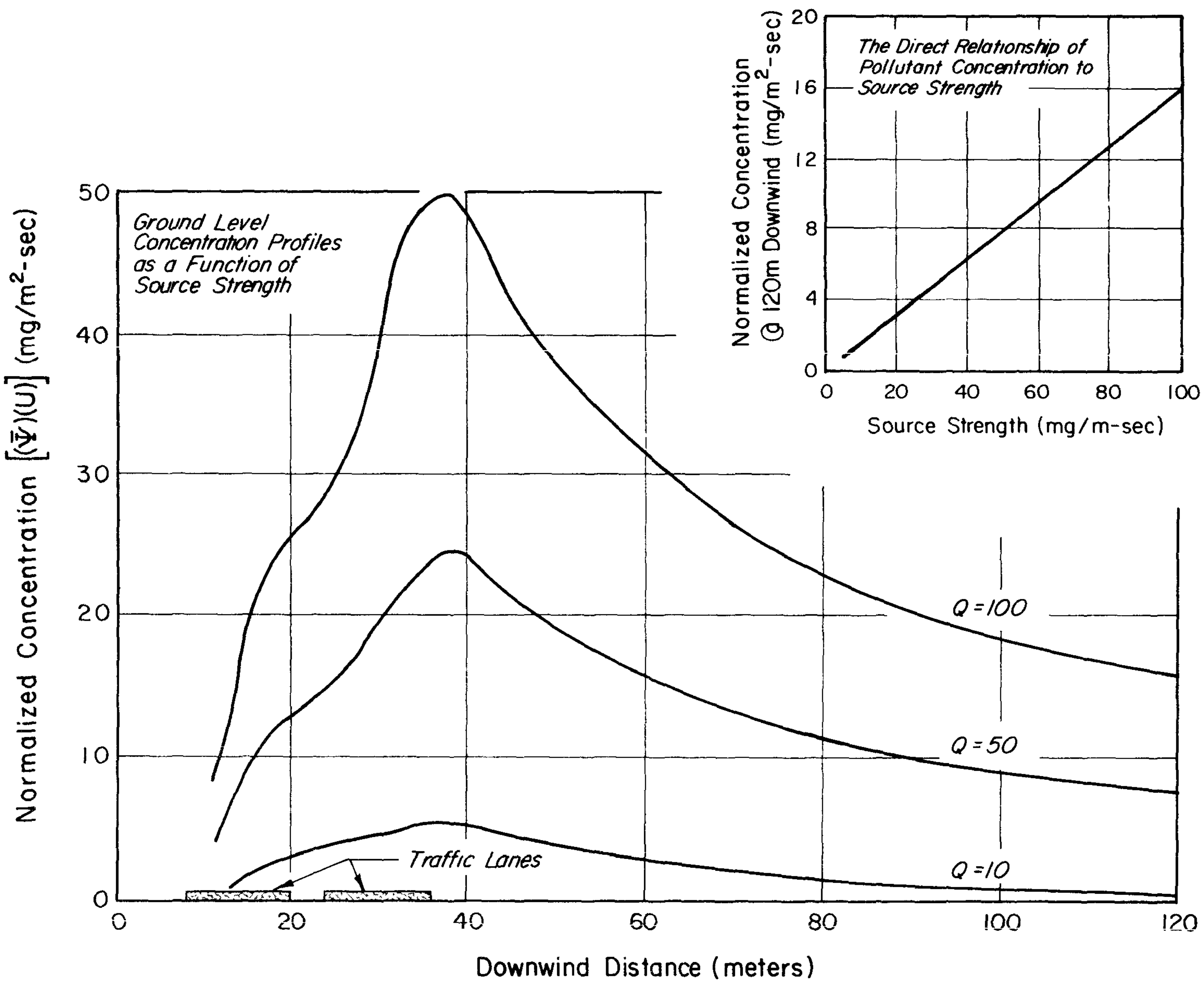

Figure 21 Relationship of pollutant concentration to source strength

physical phenomena. At larger distances from the road, differences in the ground level concentrations caused by design configuration become smaller and air quality levels depend primarily on the basic emissions and meteorological factors. Peak ground-level concentrations for an elevated highway section will occur at some distance downwind of the roadway. The peaks will always be lower than those expected for either an at-grade or depressed highway section. Measures taken to prevent noise pollution may have an adverse effect on pollution dispersion because of noise barrier that prevent ventilation flow.

Traffic Characteristics

Traffic characteristics are critically important to air quality predictions in the neighborhood of a highway because they determine the strength and spatial distribution of pollutant emissions. Traffic volume, speed distribution, and vehicle year and design mix determine source strength. Traffic distribution by lane determines the spatial source distribution.

Source strength is the direct measure of the total amount of a given pollutant assumed to be emitted per unit time and unit roadway length by the vehicular traffic being modeled. As expected, the concentration values downwind of the highway vary directly with source strength. In other words, at a given downwind point a two-fold increase in concentration would result from a two-fold increase in source strength. Figure 21 demonstrates this relationship for a typical highway configuration. The concentrations indicated in the figure are normalized by the reciprocal of wind speed, so that 'actual' concentration values may be obtained by dividing the ordinate scale by the appropriate value of wind speed. Because of the linear nature of the effect of source strength on concentration contributions, the sensitivity of model outputs to factors such as vehicle speed can be directly deduced from the emissions factor data presented in Section 5.

Source distribution is the spatial distribution of the total source strength within a given highway configuration. For a given total source strength, varying the lane-by-lane source distribution will yield a significant variation in the near road concentration values but has only a small effect on concentrations further from the immediate roadway vicinity.

Because the effect of source distribution on the concentration field is also a function of the combined effects of highway geometry and meteorology, a simply condensed graphical presentation of the sensitivity of local air quality to source distribution is not possible.

Summary

1) The pollutant concentration field resulting from dispersion of highway emissions is most strongly a function of wind speed and source strength. Concentration levels will vary directly with source strength and inversely with wind speed so that the characteristic profiles indicated in Figure 21 may be used to estimate spatial patterns of highway pollutant concentrations for both worst-case and annual average conditions. Furthermore, because source strength may be defined in terms of traffic volumes and speed distribution, the design of individual highways will be a major factor influencing air quality in the microscale highway environment.

2) Generally, ground level pollutant concentrations for all pollutants are highest in those areas immediately adjacent to the highway, fall off rapidly within about 80 meters (to approximately 30% of the maximum value), and then decrease more gradually with downwind distance. Consequently, highway rights-of-way should be maintained as limited-access areas wherever possible. In particular, the practice of specifying land use adjacent to major roadways for recreational purposes (public parks, pedestrian walkways, bicycle paths, etc.) is especially bad air quality impact planning.

3) While highway configurations are generally postulated to satisfy the transportation demand of a given land use configuration, there may be several viable alternative roadway networks which can accomplish this. The general comments addressing regional clustering versus dispersion of pollutant sources presented in the previous section are valid for highway sources where adjustments for emissions due to variations in speed distribution are made.

8. AQUIP - AN EVALUATIVE TOOL FOR RANKING 'FINAL' PLANS

Having determined the desired mix and intensity of land use (step 3) and distributed the industrial/transportation design(s) within the planning area (step 4) with regard to location-sensitivity, the final step is the evaluation of the plan(s) which have been formulated. Until quite recently, a major constraint to the consideration of air pollution within the planning process had been the lack of established procedures and analytical tools which could be applied to the evaluation of land use plans.

In a study sponsored jointly by the Environmental Protection Agency and the State of New Jersey, a methodology was developed which permits planners to evaluate planning proposals to determine the effect on air quality. This methodology, which has been designated as the AQUIP System (Air Quality for Urban and Industrial Planning), is a computer-oriented set of procedures involving the planner in an iterative cycle of plan evaluation and modification consisting of the basic steps illustrated schematically in Figure 22. The AQUIP System does not provide for the evaluation of plans and revisions to plans in regard to other community planning goals and constraints, such as population growth, future income levels, efficient circulation systems, and so forth.

Components of the AQUIP System include techniques for projecting future emissions based on land use and transportation planning input data, a gaussian plume atmospheric dispersion model for projecting pollutant concentration patterns over the planning region, data management and computation routines for calculating quantitative measures of air pollution impact, and computer-graphics programs for displaying land use and air quality data for plan evaluation.

The use of a system like AQUIP is generally beyond the operational capabilities of most planning agencies in terms of computer facilities and data requirements. The AQUIP system has been fully documented elsewhere in a series of reports and users manuals and the reader is referenced to these reports for more information on the system and the methodologies.[8]

THE AQUIP SYSTEM

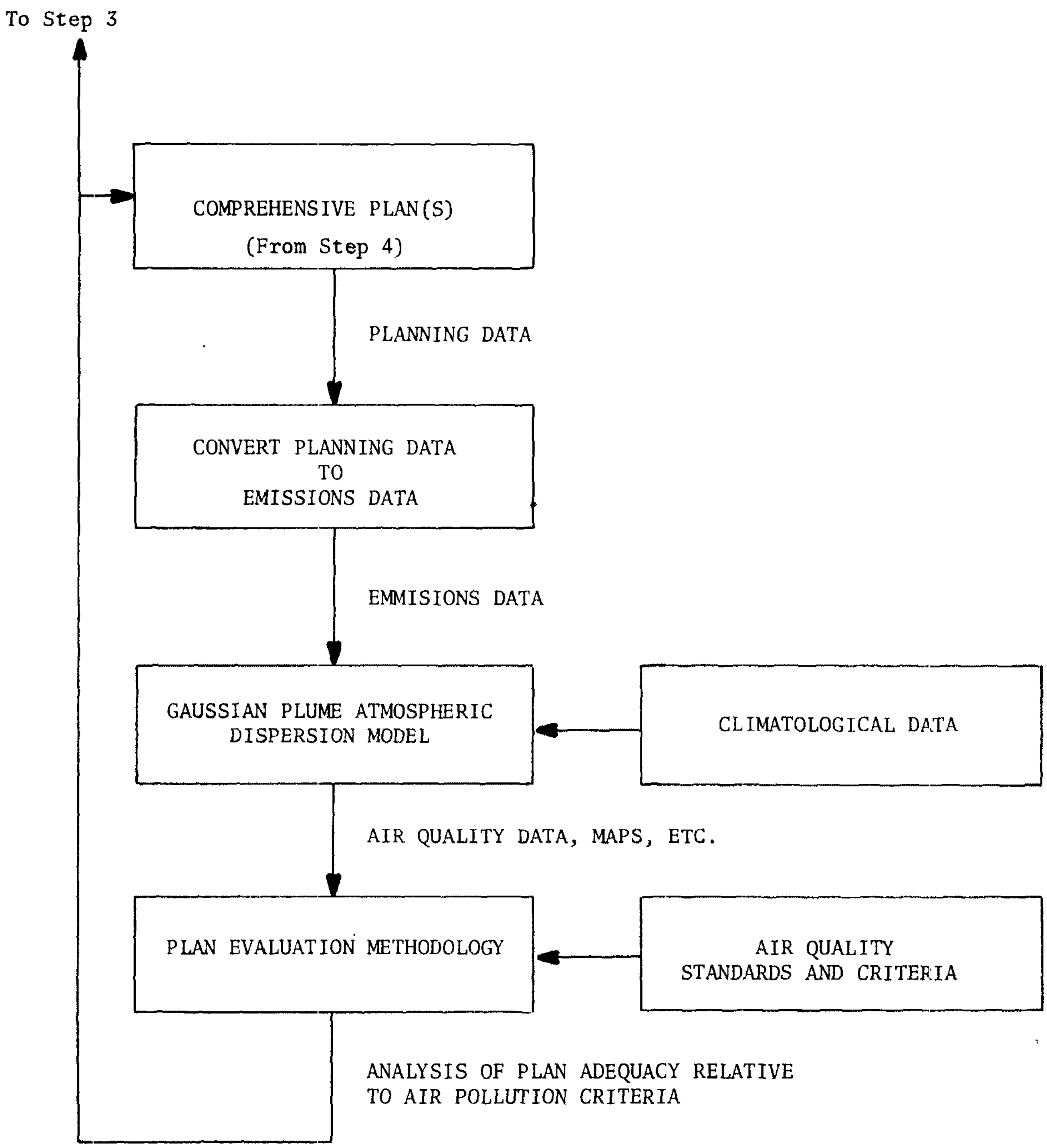

Figure 22 Steps in the air quality impact-land use planning process; evaluating the air quality impact of 'final' plans

9. SUMMARY AND CONCLUSIONS

In terms of defining an effective and meaningful policy of air resource management, the specification of land use categories and intensities offers the most fundamental level of air pollution control. In particular, specification of the types and amounts of industrial and transportation activity which are consistent with air quality criteria forms the basis for generating urban configurations which are compatible with acceptable levels of air quality. The methodology, analytical procedures, and generalized emissions data presented in this document provide the planner with a set of guidelines for incorporating the consideration of air quality into the formulation of comprehensive land use plans.

Section 2 presented basic information regarding planning air quality parameters and their relative impact on the planning process.

Section 3 presented an overview of the air quality impact-land use planning process, including a 5-step procedure for its implementation.

Within the procedural framework presented, applications of air quality criteria to planning decisions were defined at various levels of detail. A 'final' land use configuration which represented a synthesis of these procedures was postulated. This design was the result of avoiding potential air quality problems as they might occur within the sequence of design decisions defining plan development.

Prior to developing the land use plan, those parameters and factors influencing air quality in planning were discussed. Specifically, air quality design criteria, source categories of air pollution, and natural physical phenomena affecting the dispersion of pollutant emissions constitute considerations in air quality planning in the implementation of the air quality impact-land use planning process.

Sections 4 and 5 provided the basis for translating air quality planning criteria to preliminary plan designs in terms of industrial land use and transportation activity. Section 4 presented a procedural scheme for implementing step 2, Section 5 for implementing step 3. Together these steps comprised a cycle of preliminary planning decisions and air quality evaluations to provide for a quick estimate of the compatibility of anticipated or postulated industrial and transportation mixes and densities with acceptable air quality. Section 6 provided illustrative examples in order to clarify the procedures involved in emissions calculations and postulating an industrial mix, along with traffic constraints needed to implement the air quality impact-land use planning process.

Section 7 presented information relative to the dispersion patterns of various major source configurations so that the placement of comprehensive land uses associated with preliminary designs generated in step 3 would not be incompatible with local air quality considerations. Incorporation of this information within the planning process occurred in step 4.

Finally, Section 8 discussed a methodology which provided for the air quality impact evaluation of complete urban designs. The methodology, designated as the AQUIP System, is completely operational and has been used in the evaluation of alternative land use plans for the Hackensack Meadowlands of New Jersey. A document describing AQUIP is available from the EPA.

This guide has been designed as a resonable first estimate of the procedures planners can use to determine air quality implications of plan design decisions. It has been based upon current data for regions previously studied; accordingly, the specific quantitative guidelines may not translate well to certain geographic areas or long-term planning decisions. It is expected that further studies will continue to expand upon and improve the various data bases and specific procedures involved in the process. In this way separate guides can be prepared for different scales of planning decision and for varying time periods.

Limitations of Air Quality Impact - Land Use Planning Procedure

The application and interpretation of these procedures are subject to many conditions which limit their accuracy and general applicability. A primary limitation is due to the fact that the emissions estimation factors presented in Sections 4 and 5 are generalized values derived from specific current data sets, and thus cannot reasonably be expected to coincide with assumptions involved in other regional planning situations and for long-term future planning periods. A second limitation is that the box model analysis presented in Section 4.3 is a very crude approximation to atmosheric dispersion processes in general, and, as presented, does not allow for regional variations in meteorological parameters. A third basic limitation is that these procedures give no indication of the resultant pollutant concentration spatial patterns. A final major limitation is the accuracy of the emission estimation factors themselves. The emission rates presented represent averages over very broadly defined land use categories; a detailed examination would indicate that specific emission rates for different types of industrial developments may vary by factors ranging from 10 to 1000. Thus, the listed emission rates for each land use category can only be regarded as gross estimation factors.

Despite such limiting factors, these simplified procedures can be useful to the planner since: (1) they provide a means for rapid estimation of the air pollution potential of preliminary inventories (or lists) of industrial/transportation land use, (2) they are relatively easy to apply, and do not require a computer, and (3) they reduce the susceptibility of 'final' designs to major changes in land use required by compliance with the air quality standards.

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16. ABSTRACT

A Guide for Considering Air Quality in Urban Planning presents analytical procedures and generalized emissions data needed to generate urban configurations which are compatible with acceptable levels of air quality. Procedures are outlined for establishing a planning area's air quality baseline and for defining the tolerance of a planning area toward receiving additional pollutant emissions as a function of air quality standards, existing air quality, and air quality maintenance policies. Methods are presented for determining acceptable industrial and transportation activities as a function of pollutant tolerance and generalized emission rates and for distributing land uses within comprehensive plans.

17. KEY WORDS AND DOCUMENT ANALYSIS

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