REPORT FOR CONSULTATION ON THE

METROPOLITAN DENVER

AIR QUALITY CONTROL REGION

. U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Consumer Protection and Environmental Health Service
National Air Pollution Control Administration

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PREFACE

The Secretary, Department of Health, Education, and Welfare, is directed by the Air Quality Act of 1967 to designate "air quality control regions" to provide a basis for the establishment of air quality standards and the implementation of air quality control programs. In addition to listing the major factors to be considered in the development of region boundaries, the Act stipulates that the designation of a region shall be preceded by consultation with appropriate State and local authorities.

The National Air Pollution Control Administration, DHEW, has conducted a study of the Metropolitan Denver Area, the results of which are presented in this report. The Region* boundaries proposed in this report reflect consideration of all available and pertinent data; however, the boundaries remain subject to revisions suggested during consultation with State and local authorities. Formal designation of a Region will follow the consultation meeting. This report is intended to serve as background material for the consultation.

The Administration appreciates assistance received either directly during the course of this study or indirectly during previous activities in the Denver Metropolitan Area from the official air pollution agencies, The Denver Regional Council of Governments, the Colorado State Planning Office and Larimer County Planning Commission.

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*For the purposes of this report, the word region, when capitalized, will refer to the Metropolitan Denver Air Quality Control Region. When not capitalized, unless otherwise noted, it will refer to air quality control regions in general.

INTRODUCTION

> "For the purpose of establishing ambient air quality standards pursuant to section 108, and for administrative and other purposes, the Secretary, after consultation with appropriate State and local authories shall, to the extent feasible, within 18 months after the date of enactment of the Air Quality Act of 1967 designate air quality control regions based on jurisdictional boundaries, urban-industrial concentrations, and other factors including atmospheric areas necessary to provide adequate implementation of air quality standards. The Secretary may from time to time thereafter, as he determines necessary to protect the public health and welfare and after consultation with appropriate State and local authorities, revise the designation of such regions and designate additional air quality control regions. The Secretary shall immediately notify the Governor or Governors of the affected State or States of such designation."
>
> Section 107 (a) (2), Air Quality Act of 1967

THE AIR QUALITY ACT

Air pollution in most of the Nation's urban areas is a regional problem. Consistent with the problem, the solution demands coordinated regional planning and regional effort. Yet, with few exceptions, such coordinated efforts are notable by their absence in the Nation's urban complexes.

Beginning with the Section quoted above, in which the Secretary is required to designate air quality control regions, the Air Quality Act presents an approach to air pollution control involving closely coordinated efforts by Federal, State, and local governments, as shown in Figure 1. After the Secretary has (1) designated regions, (2) published air quality criteria, and (3) published corresponding documents on

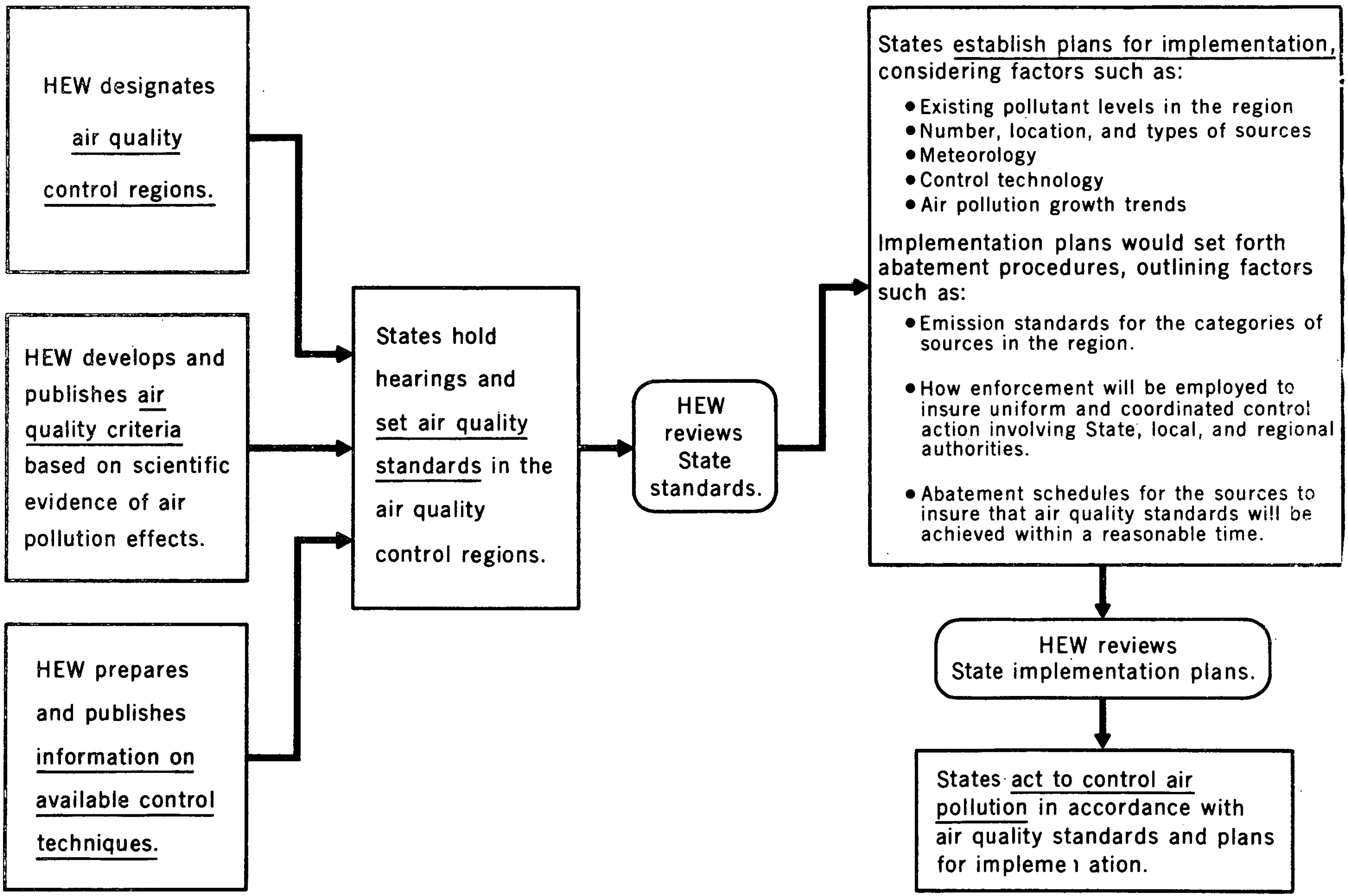


Figure 1. Flow diagram for State action to control air pollution on a regional basis.

control technology and associated costs, the Governor(s) of the State(s) must file with the Secretary within 90 days a letter of intent, indicating that the State(s) will adopt within 180 days ambient air quality standards for the pollutants covered by the published criteria and control technology documents and adopt within an additional 180 days plans for the implementation, maintenance, and enforcement of those standards in the designated air quality control regions.

The new Federal legislation provides for a regional attack on air pollution and, at the same time, allows latitude in the form which regional efforts may take. While the Secretary reserves approval authority, the State(s) involved in a designated region assumes the responsibility for developing standards and an implementation plan which includes administrative procedures for abatement and control. Informal cooperative arrangements with proper safeguards may be adequate in some regions, whereas in others, more formal arrangements, such as interstate compacts, may be selected. The objective in each instance will be to provide effective mechanisms for control on a regional basis.

PROCEDURE FOR DESIGNATION OF REGIONS

Figure 2 illustrates the procedures used by the National Air Pollution Control Administration for designating air quality control regions.

A preliminary delineation of the region is developed by bringing together two essentially separate studies --the "Evaluation of

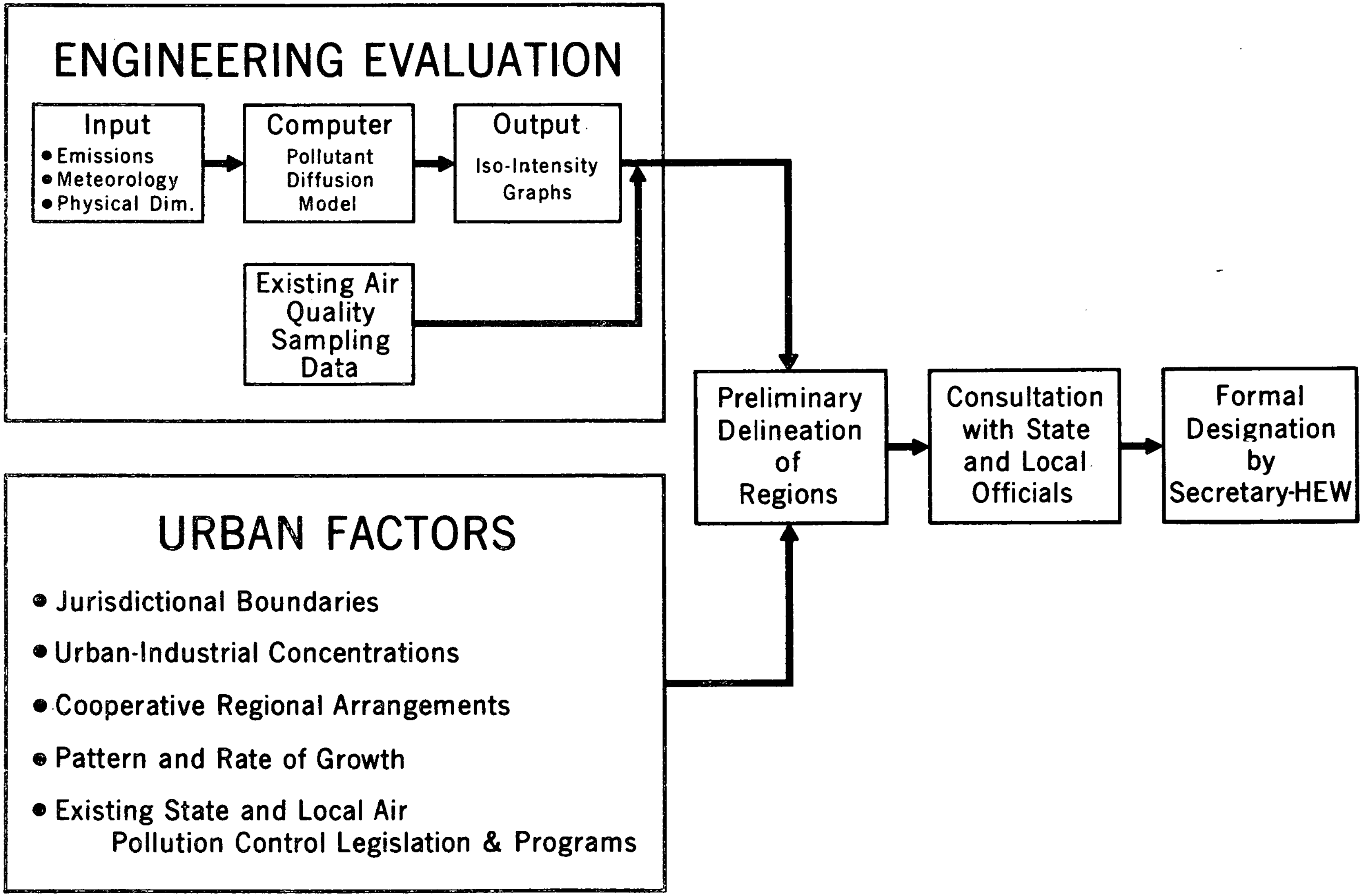


Figure 2. Flow diagram for the designation of air quality control regions.

Engineering Factors," and the "Evaluation of Urban Factors."

The study of "Engineering Factors" indicates the location of pollution sources and the geographic extent of serious pollutant concentrations in the ambient air. Pollution sources are located by an inventory of emissions from automobiles, industrial activities, space heating, waste disposal, and other pollution generators. Pollution concentrations in the ambient air are estimated from air quality sampling data and from a theoretical diffusion model. When it exists, air quality sampling data is more reliable than the theoretical diffusion model results since the data is directly recorded by pollution measuring instruments. Unfortunately, in many cases air quality sampling data is available for only one or two pollutants measured at an insufficient number of locations. The theoretical model is used to supplement inadequate air quality sampling data.

The box labeled "Input" in Figure 2 describes the information required to apply the diffusion model. This information consists of data on the type, quantity, and location of pollution emissions, the average depth of air available for mixing and dilution, the frequency of various wind velocities (direction and speed), and the physical dimensions of the urban area under study. Calculations are made with this information in the next step, labeled "Computer." The result, or "Output," of the diffusion model estimates the geographic pattern of air pollution caused by pollution sources within the study area, and serves as a guide to the appropriate size of the air quality control region. As a whole, the engineering study indicates how large the air quality control region must be in order to encompass most pollution sources and most people and property affected by those sources.

The study of "Urban Factors" encompasses all non-engineering considerations. It reviews existing governmental jurisdications, current air pollution control programs, present concentrations of population and industry, and expected patterns of urban growth. Other non-engineering factors are discussed when they are relevant. As a whole, the study of urban factors indicates how large an air quality control region must be in order to encompass expected growth of pollution sources in the future. It also considers which group of governmental jurisdictions will most effectively administer a strong regional air quality control program.

The conclusions of the engineering study are combined with the results of the urban factors study to form the basis of an initial proposal for an air quality control region. As shown in figure 2, the proposal is then submitted for consultation with State and local officials. After reviewing the suggestions raised during the consultation, the Secretary formally designates the region with a notice in the Federal Register and notifies the governors of the States affected by the designation.

The body of this report contains a proposal for the boundaries of the Metropolitan Denver Air Quality Control Region and supporting studies on engineering and urban factors. The report itself is intended to serve as the background document for the formal consultation with appropriate State and local authorities.

THE PROPOSED REGION

PROPOSAL

Subject to the scheduled consultation, the Secretary, Department of Health, Education and Welfare, proposes to designate an air quality control region for the metropolitan Denver area, consisting of the following jurisdictions:

> All lands lying within the counties of Boulder and Jefferson, and in addition thereto, the following described area lying adjacent thereto, commencing at the Northwest corner of Section 6, Township 1 South, Range 68 West; thence East along the section lines approximately 18 miles to the Northeast corner of section 1, Township 1 South, Range 66 West; thence South along the section lines approximately 36 miles to the Southeast corner of Section 36, Township 6 South, Range 66 West; thence West along the section lines approximately 22 miles to the Jefferson County line.

The boundaries of the proposed Region are illustrated in Figure 3. Figure 4 locates the Region in relation to the rest of Colorado and surrounding states.

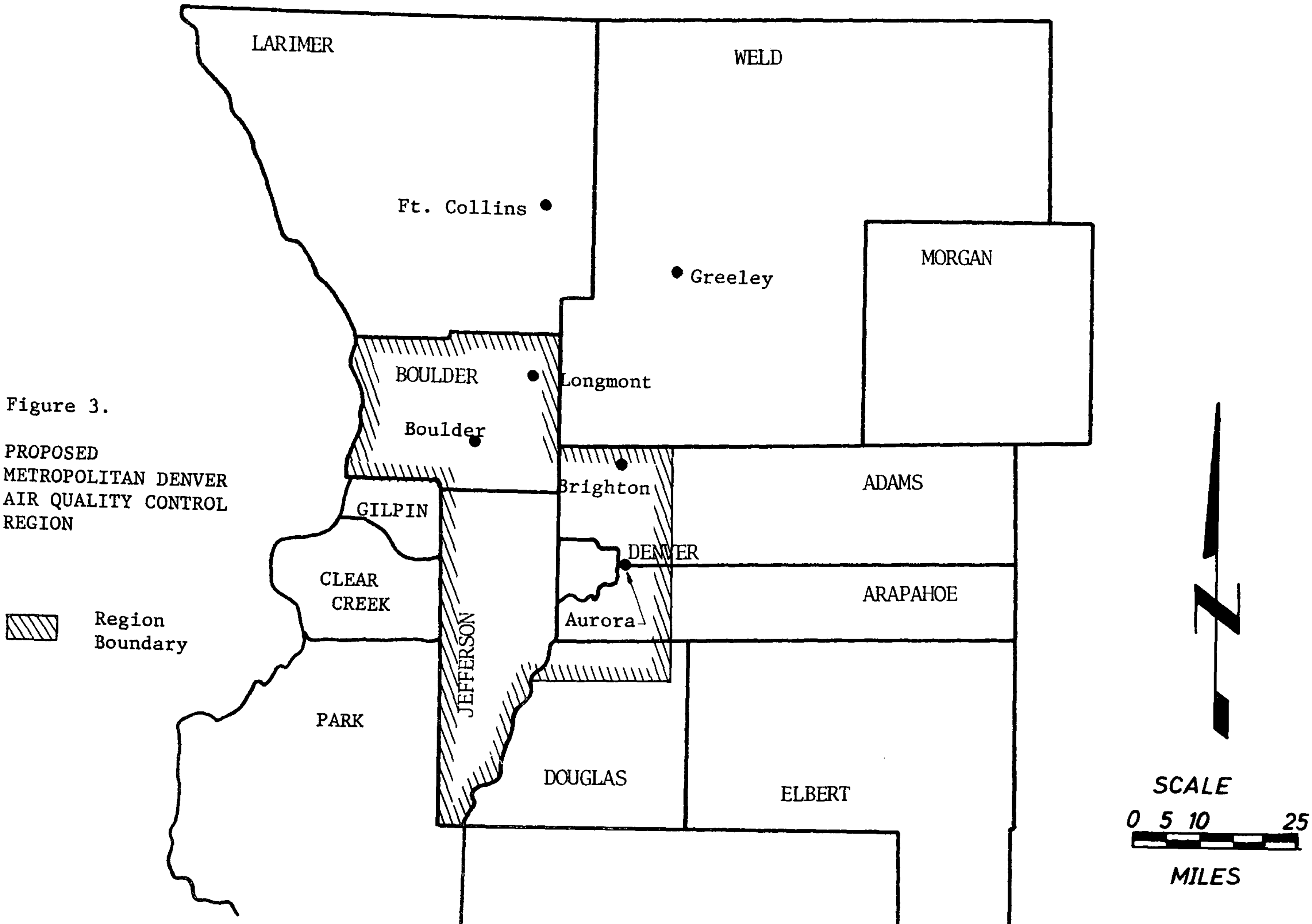


Figure 3.

PROPOSED
METROPOLITAN DENVER
AIR QUALITY CONTROL
REGION

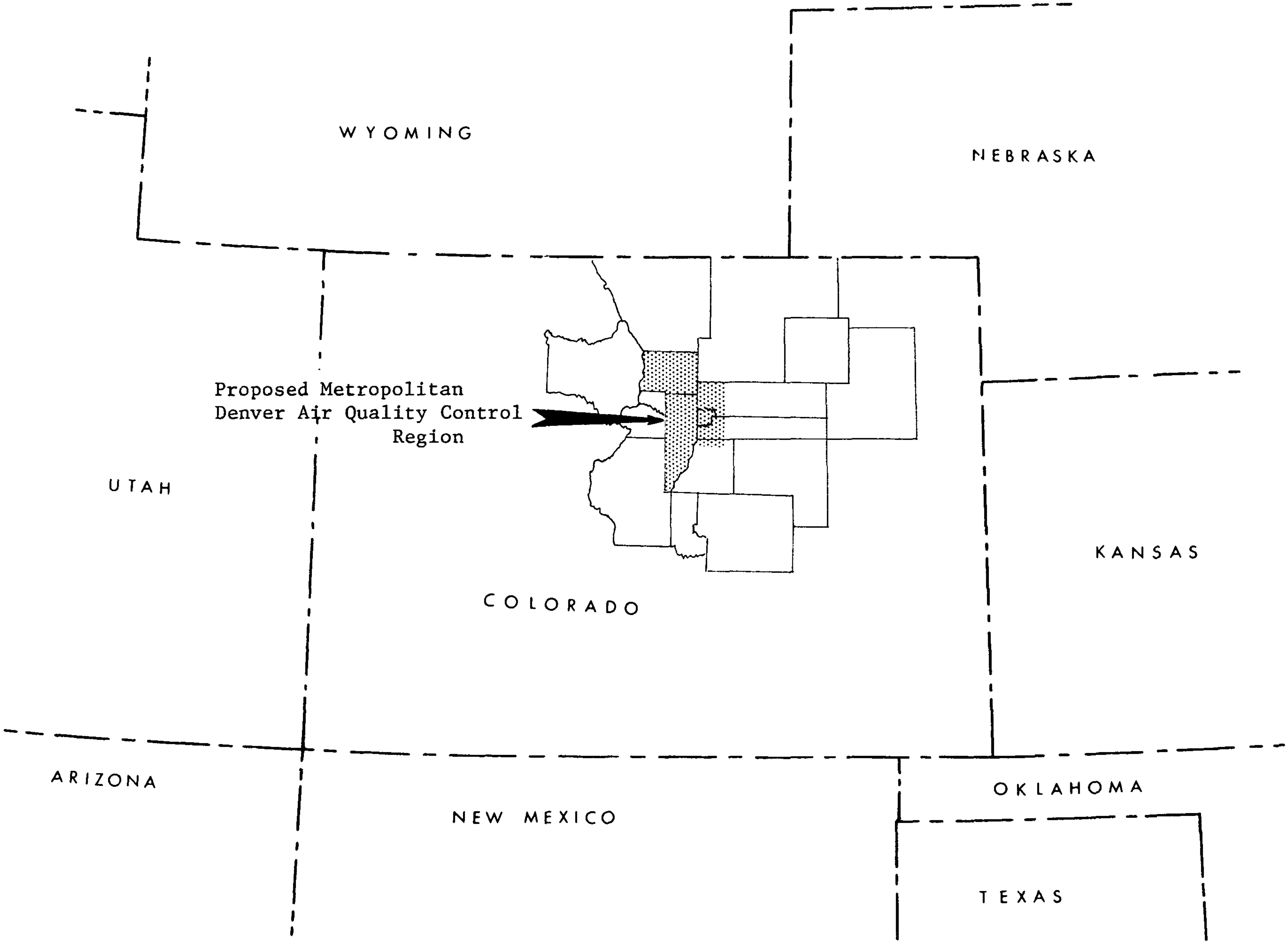


Figure 4. Relationship of Proposed Metropolitan Denver Air Quality Control Region to surrounding areas.

DISCUSSION OF PROPOSAL

Introduction:

To be successful, an air quality control region should meet three basic conditions. First, its boundaries should encompass most pollution sources as well as most people and property affected by those sources. Second, the boundaries should encompass those locations where industrial and residential development will create significant air pollution problems in the near future. Third, the boundaries should be chosen in a way which is compatible with and even fosters unified and cooperative governmental administration of the air resource throughout the region. The proposed boundaries of the Metropolitan Denver Air Quality Control Region were designed to satisfy these three requirements.

As proposed, the Region boundaries coincide with the Denver Air Basin boundaries established by the State of Colorado during May, 1967. In general, state-defined air basins do not automatically qualify as air quality control regions. However, the Air Quality Act of 1967 requires region boundaries to take into account existing jurisdictions, among other factors. Clearly, a state-designated basin is an important jurisdictional consideration. Therefore, this study of the geographic extent of the air pollution problem indirectly evaluates the suitability of the state-designated basin as a geographic basis of attack on the problem. As discussed below, the Denver Air Basin satisfies the three requirements for air quality control region boundaries, although certain marginal areas on the outer periphery of the

Basin should be re-examined periodically and included in the Region if warrented by future population and industrial growth.

The Core Area:

The core area of the proposed Region centers on the City of Denver. Nearly 50 percent of the residents of the metropolitan area live in the City, the heaviest concentrations of industry and automobile traffic are in the City, and the largest air pollution program in the area is operated by the City. Suburban communities located in eastern portions of Jefferson County and western portions of Adams and Arapahoe Counties are also part of the core area. In these communities, automobiles emit significant amounts of carbon monoxide, while various point sources are major emitters of particulates. The analysis of air quality indicates that the suburban residents, more than 400,000 people, are subjected to air pollutant concentrations significantly above the background level. Furthermore, industry and population in these areas are expected to grow rapidly during the next decade. Thus, Denver City and surrounding suburban areas represent the core area of the metropolitan air pollution problem, and clearly should be included in the Metropolitan Denver Air Quality Control Region.

Areas on the Periphery:

Some communities outside the core area are still linked to the metropolitan air pollution problem. The emission inventory reveals important pollutant sources in Boulder County. The air quality analysis shows that the southeast portion of Boulder County experiences carbon monoxide and particulate concentrations which are above the background level and affect a large majority of the 117,000 residents in the County. The western portions of Boulder and Jefferson Counties are mountainous areas, have only a small population, and are essentially unaffected by air pollution from the Metropolitan areas. Douglas County, on the southern periphery of the core area, contains less than 7,000 residents, but experiences pollutant concentrations slightly higher than background levels, and has a few emission sources. The City of Aurora marks the eastern edge of the core area. Emission sources, pollutant concentrations and population density decline sharply to the east of Aurora. The southwest tip of Weld County contains less than 10,000 residents and only a few emission sources. But the prevailing southerly wind carries air pollution from the core area down the South Platte valley and into this portion of Weld County. The pollutant concentrations are about the same as those in the southeast portion of Boulder County, and taper off to background levels long before reaching Greeley, 45 miles northeast of downtown Denver. Greeley contains less than 40,000 residents. Although significant sources of carbon monoxide and particulates are located in Greeley, the air pollution problem which they create is presently separate and independent of the Denver problem. A twenty mile buffer zone lies between the Denver core area and Greeley. In addition, Greeley is not closely linked to Denver on an economic or political level. Particulate emission sources extend north from Boulder County into Larimer County, but the air quality analysis did not reveal the presence of air pollutant concentrations significantly above the background level in Larimer. The only major population concentration in Larimer County is Fort Collins, which has fewer than 40,000 residents and is located about twenty miles north of Boulder County. The mountainous portions of Boulder and Jefferson, the southern portion of Douglas, the eastern portions of Adams and Arapahoe, and most of Weld and Larimer Counties are essentially unaffected by air pollution from the core area.

Growth:

Growth in the Denver area is predicted to expand along a north-south corridor. The foothills, extending north and south along the edge of the Rocky Mountains, are attractive residential areas. Convenient north-south transportation arteries will influence growth patterns of industrial development. During the next decade, the bulk of residential expansion is expected to occur in the suburban areas and in Boulder. Population concentrations are likely to reach into northern Douglas County and into the southwestern tip of Weld County. Thus, time will tend to alter the rural character of Douglas County and to bridge the buffer zone separating Denver from Fort Collins and Greeley. Although the majority of growth is expected to occur along the north-south axis, some expansion eastward from Aurora is also likely.

Governmental Jurisdictions:

During 1966 the State of Colorado first designated an air basin for the Denver area. The original Denver Air Basin included Denver County and parts of Boulder, Jefferson, Douglas, Adams, and Arapahoe Counties. In 1967 the Basin was extended to include all of Jefferson and Boulder Counties, in order to facilitate the administration of air pollution programs throughout those counties. However, with support from the county governments of Douglas, Adams, and Arapahoe, the Denver Air Basin continued to include only parts of these three counties. Colorado State law provides the State Department of Public Health with authority to enforce emission standards in the Air Basin, but this authority has been redelegated to local enforcement agencies. Representatives of the local enforcement agencies have formed the Regional Air Pollution Control Agency in order to promote uniform emission standards and enforcement procedures throughout the Basin. An amendment to the State law also promotes regional cooperation and coordination through a provision requiring air pollution control agencies to review periodically each other's programs and plans.

Summary:

In sum, the evidence seems to indicate that the Denver Air Basin satisfies the three conditions for establishing air quality control regions. It contains the important emission sources as well as the people and property affected by those sources. By including part of Douglas County it allows room for growth of industry and population towards the south. Finally, governmental jurisdictions within the Air Basin have taken initial steps towards developing a unified and coordinated administration of air pollution control. However, expected growth patterns suggest that the southern portions of Weld and Larimer Counties will become more strongly connected to the metropolitan Denver air pollution problem with the passage of time. In addition, growth eastward from Aurora may carry the pollution problem past the present eastern boundary of the Denver Air Basin. Therefore, the boundaries of the Metropolitan Denver Air Quality Control Region should be re-examined periodically to determine if they are keeping pace with growth in these directions.

Previous proposals for air quality control regions have avoided splitting county jurisdictions in order to promote ease of administration of air pollution control. However, when a county is large and when only a small part of it is involved in an air pollution problem, ease of administration may dictate the splitting of the county. Since State and especially local governments will be responsible for administering air pollution control in the Region, they should be given an important voice in determining whether splitting or not splitting a county is beneficial to overall administration of a regional program. The existing boundaries of the Denver Air Basin seem to indicate that program administration is not hampered by the cutting of Adams, Arapahoe, and Douglas Counties.

When air quality control region boundaries have been designated, a situation may develop involving a source of pollution on one side of the region boundary which affects in some real way air quality on the other side of the boundary. If adjustment of the boundary is not a practical way to aleviate the situation, relief should be found in the control implementation plan which follows the designation. The plan should contain provisions for the control of sources located close to but beyond the region boundaries. The level of control for such sources should depend, in part, upon the degree to which emissions from the source cause air quality levels to exceed the standards chosen for application within the region.

The Metropolitan Denver Air Quality Control Region proposed herein is considered on the whole to be the most cohesive and yet inclusive area within which an effective regional effort can be mounted to prevent and control air pollution in the urban area surrounding Denver. The remaining two sections of this report describe the initial evaluation of urban and engineering factors.

EVALUATION OF URBAN FACTORS

INTRODUCTION

A number of urban factors are relevant to the problem of defining air quality control region boundaries. First, the location of population is an important consideration, since human activity is the ultimate source of air pollution, and humans are the ultimate victims. The population growth pattern is another important consideration, since an air quality control region should be designed not only for the present but also for the future. For similar reasons, the location of industrial activity and the industrial growth pattern are relevant considerations. Political and jurisdictional factors are also important, since the 1967 Air Quality Act envisions air pollution programs based on cooperative efforts among many political jurisdictions. In many urban areas cooperative arrangements among cities and counties have been developed for planning and other regional programs. An air quality control region should take note of existing regional cooperation among governmental units and should avoid a combination of jurisdictions which would irritate local political relationships. It should consider also the strength of regional cooperation among existing local air pollution programs. The following discussion of urban factors will present these considerations as they apply to the Denver area.

POPULATION

Figure 5 displays present population concentrations in the Denver metropolitan area. About 500,000 people, who represent nearly 50% of the metropolitan population, reside within the City of Denver. Most of the remainder reside in adjacent suburban areas in Jefferson, Adams, and Arapahoe Counties. Population outside of the immediate Denver area spreads generally northward, with concentrations in Boulder, Fort Collins, Greeley, Brighton, Longmont, and Loveland. Collectively, these areas contain less than 150,000 residents.

Figure 6 shows expected population growth in the Denver metropolitan area. Table 1 gives county-wide population projections. Population growth is expected to occur in the suburbs immediately south and west of the City of Denver, in the foothills around Boulder, and north of Denver towards Fort Collins and Greeley. Expansion eastward from Denver along interstate highway 70 will probably be less rapid than expansion north and south along interstate highway 25. Douglas County will probably remain sparsely populated for at least 10 years except in its northern portion.

INDUSTRY

Figure 7 displays the present location of industrial activity in the Denver area, according to land use maps. Table 2 indicates land use by various industrial categories for four counties. Heavy industry is most densely located in the City of Denver. Jefferson County is the site of major industrial establishments also. Concentrations of light

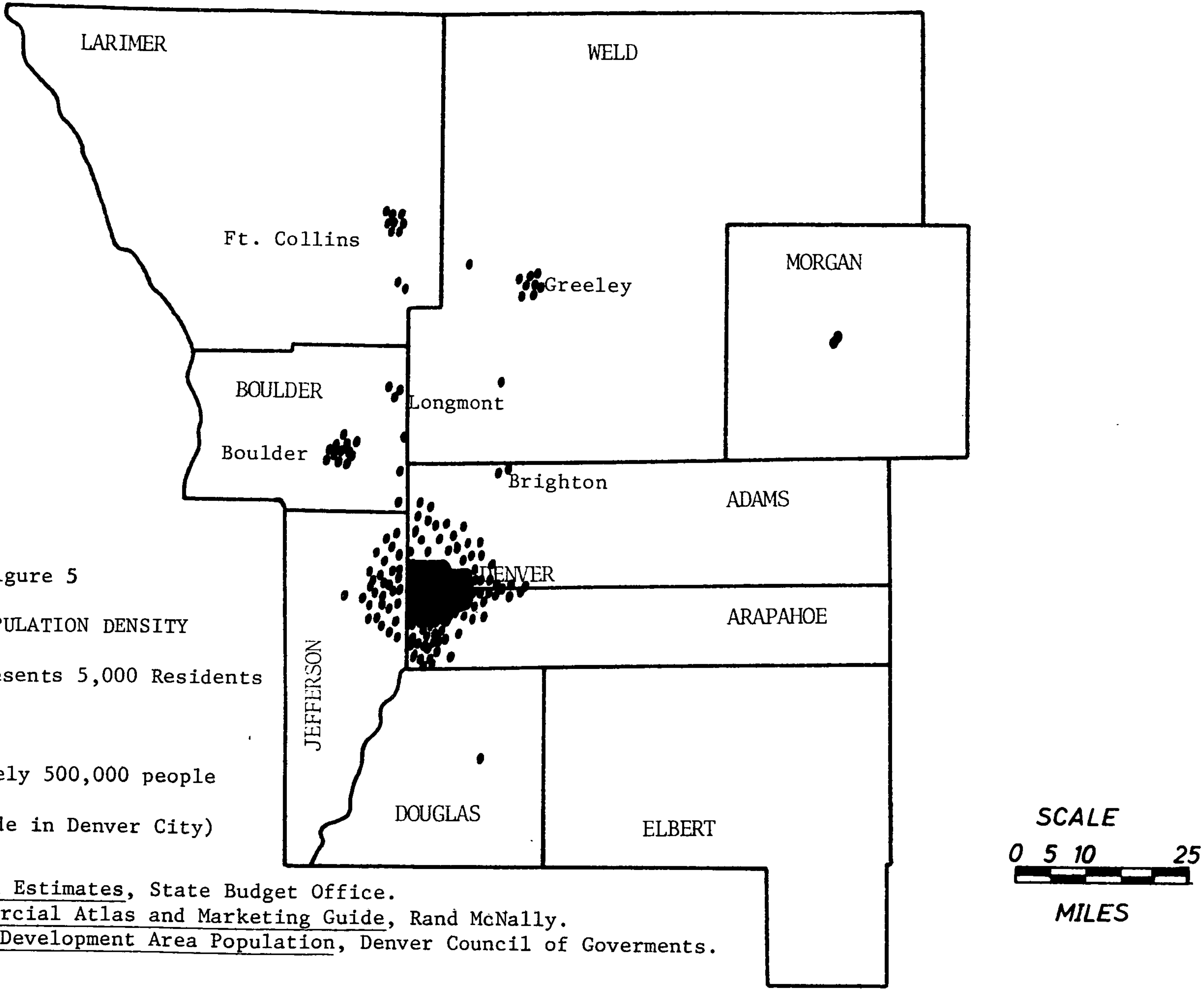


Figure 5

1968 POPULATION DENSITY

Each Dot Represents 5,000 Residents

(approximately 500,000 people

reside in Denver City)

Sources: Population Estimates, State Budget Office.
1968 Commercial Atlas and Marketing Guide, Rand McNally.
Community Development Area Population, Denver Council of Goverments.

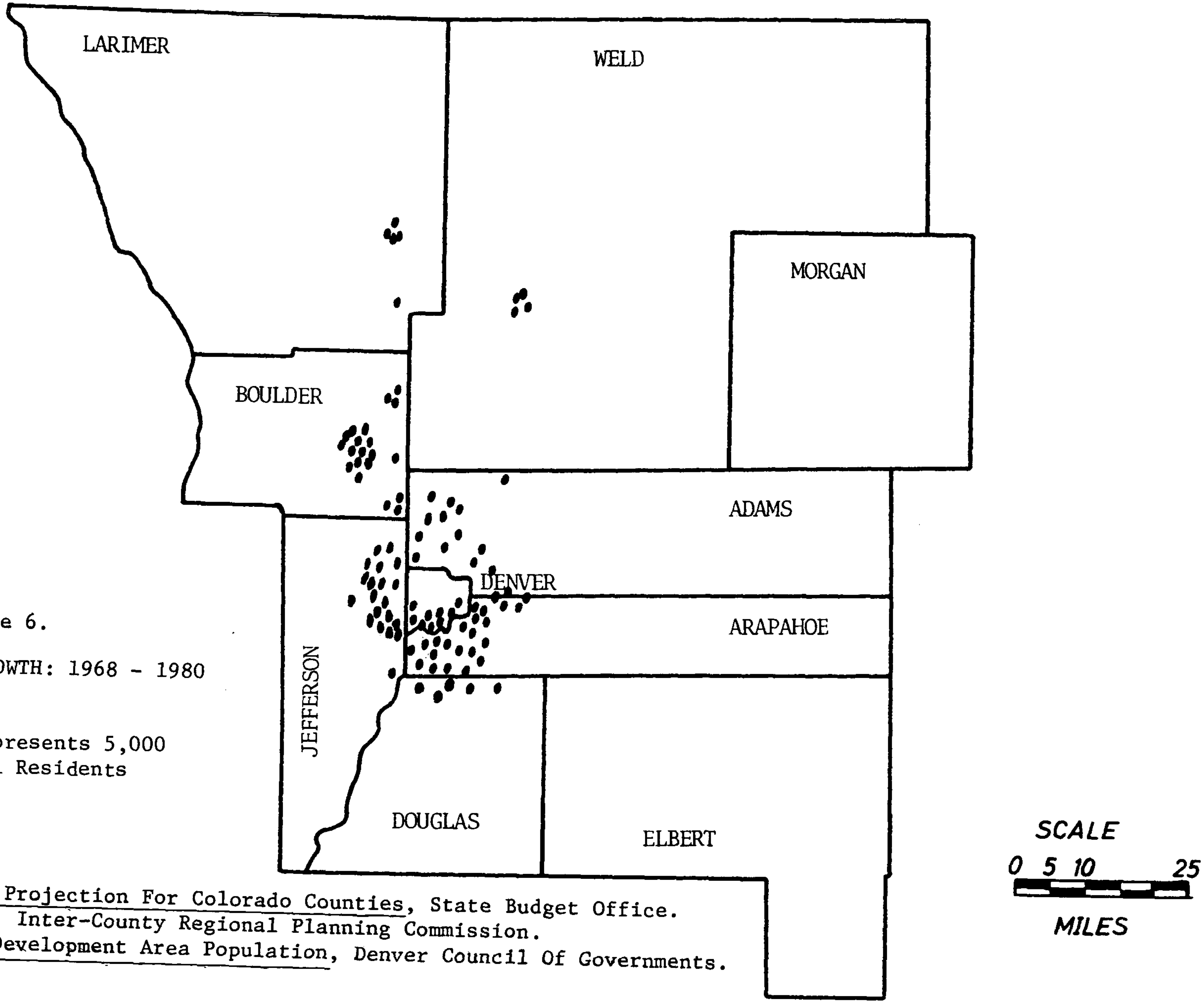


Figure 6.

POPULATION GROWTH: 1968 - 1980

Each Dot Represents 5,000 Additional Residents

Sources: Population Projection For Colorado Counties, State Budget Office.
Population, Inter-County Regional Planning Commission.
Community Development Area Population, Denver Council Of Governments.

Table 1.

Denver SMSA Population Projections by County

Year	County					Denver SMSA
	Adams	Arapahoe	Boulder	Denver	Jefferson	
1900	4,100	6,200	21,544	140,500	9,306	181,650
1910	8,892	10,263	30,330	213,381	14,231	277,097
1920	14,430	13,766	31,861	256,491	14,400	330,948
1930	20,245	22,647	32,456	287,861	21,810	385,019
1940	22,481	32,150	37,438	322,412	30,725	445,206
1950	40,234	52,125	48,296	415,786	55,687	612,128
1960	120,296	113,426	74,254	493,887	127,520	929,383
1965	156,000	138,000	95,000	505,000	180,000	1,074,000
1970*	175,000	150,000	125,000	525,000	225,000	1,200,000
1975	233,000	193,000	160,000	551,000	275,000	1,412,000
1980	270,000	225,000	200,000	570,000	325,000	1,590,000
1985	325,000	260,000	238,000	595,000	388,000	1,806,000
1990	380,000	295,000	275,000	620,000	450,000	2,020,000
1995	425,000	327,000	313,000	630,000	525,000	2,220,000
2000	470,000	360,000	350,000	640,000	600,000	2,420,000

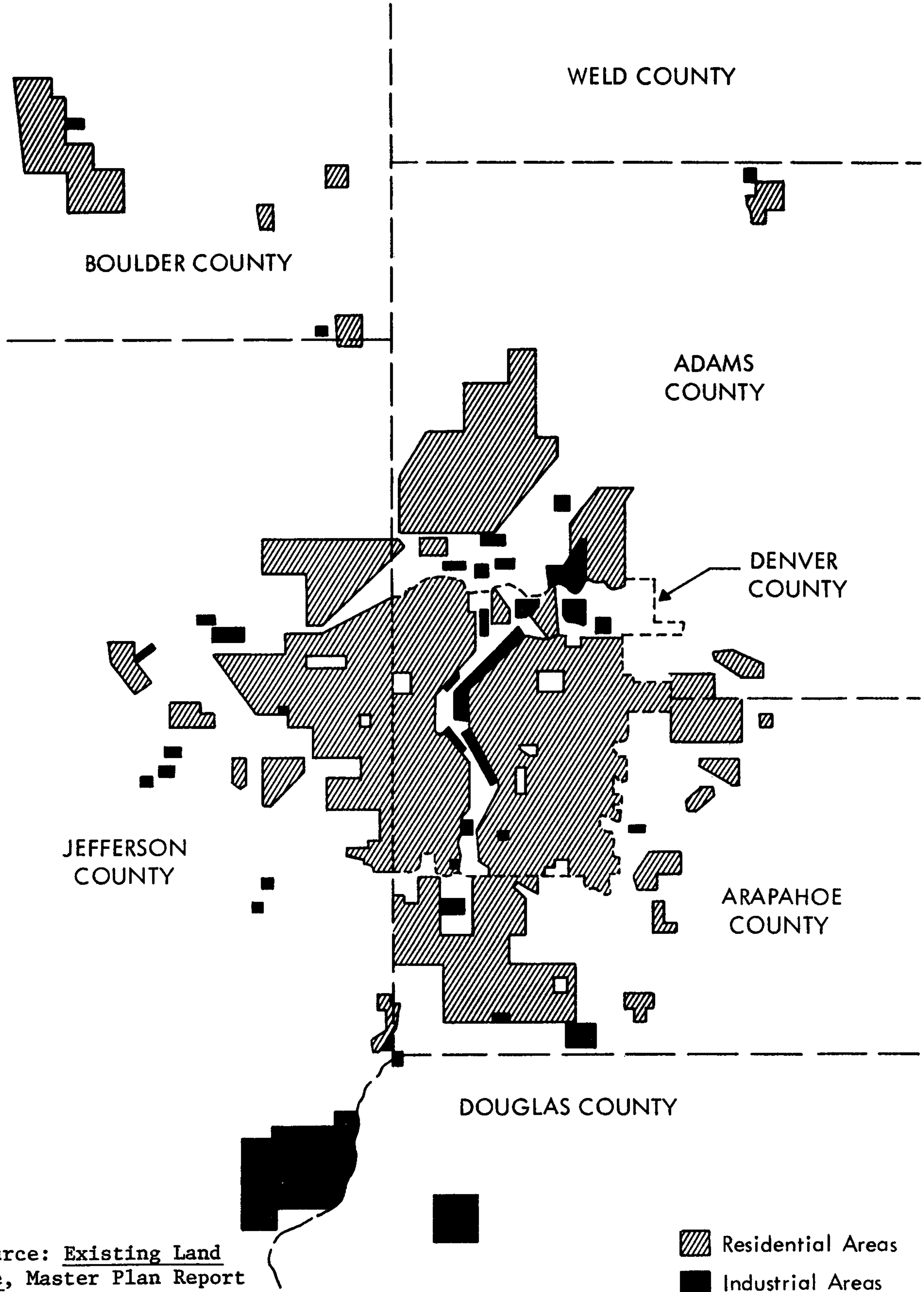
ICRPC projections based on revised growth rates for the 1965-1970 period.

Sources: U. S. Census figures for 1900-1960 as of April 1; ICRPC estimates and projections for 1965-2000 as of January 1.

Table 2. Industrial Land Use (Acres)

	Adams	Arapahoe	Denver	Jefferson	Total
Manufacturing.......	366.5	123.0	1,386.0	381.0	2,256.5
Storage, Research...	268.5	136.5	1,827.5	149.0	2,381.5
Air Transportation..	57.0	-----	2,182.0	185.0	2,424.0
Rail Yards..........	54.0	-----	824.5	-----	878.5
Truck Terminals.....	29.5	-----	552.0	-----	581.5
Public Utilities....	194.0	95.5	114.0	297.5	701.0

Survey of 1962 Generalized Land Use in the Denver Metropolitan Region, Master Plan Report No. 21, ICRPC, Denver, Colorado, December, 1962.



Source: Existing Land Use, Master Plan Report D. 28, Inter-County Regional Planning Commission, October 1968.

Figure 7. Present Industrial Land Use

industry and warehouse storage are located in Denver and in Commerce City, just north of Denver in Adams County. Boulder City contains light, research-oriented industry. Greeley, Longmont, and Brighton contain industrial activity oriented towards agricultural processing.

Figure 8 shows planned industrial parks and areas zoned for industrial land use but partially undeveloped. Thus, it indicates areas where industrial growth is likely to occur. Figure 9 indicates the major expressway arteries in the Denver metropolitan area. Significant industrial expansion is likely to occur both within the City of Denver and also in outlying areas. Industrial growth located within the urban center will strengthen present commuting patterns between the suburbs and the center city. Counteracting this trend will be the attraction which outlying areas offer to large developments of light industry, storage warehouses, and research firms. These developments will be economically linked to the Denver urban center but will be located outside it. In a similar category is the power plant project which is expected to locate in Platteville.

Figures 5-9 show that present concentrations and expected growth of population and industry are contained in an area bounded by the mountains on the west, Fort Collins and Greeley on the north, Brighton and Aurora on the east, and the northern portion of Douglas County on the south. Presently there are large open spaces between the Denver urban center and the two northern communities, Fort Collins and Greeley. Fort Collins and Greeley have approximately 35,000 to 40,000 residents each. They are located about 45 miles north of down-

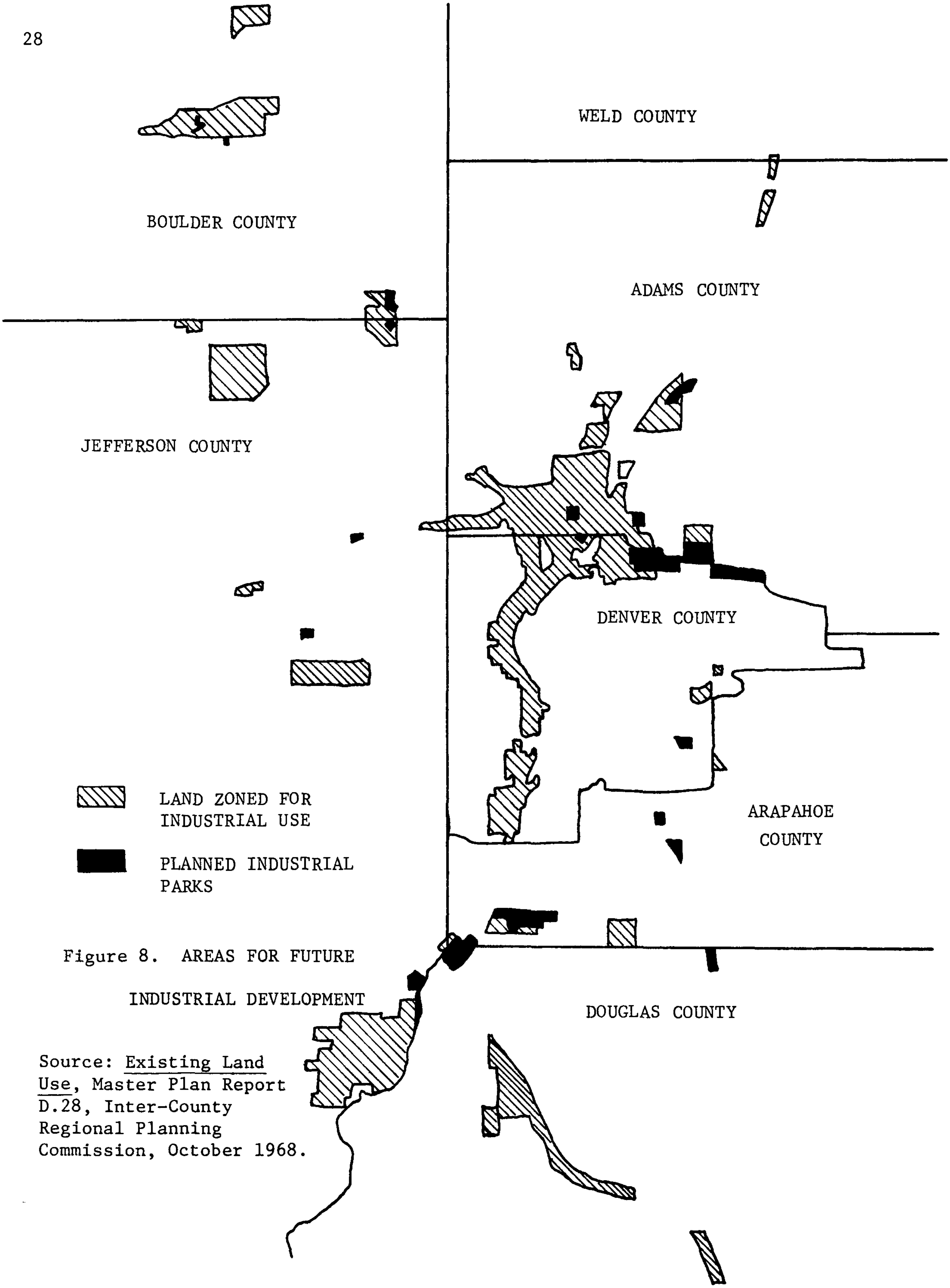


Figure 8. AREAS FOR FUTURE INDUSTRIAL DEVELOPMENT

Source: Existing Land Use, Master Plan Report D.28, Inter-County Regional Planning Commission, October 1968.

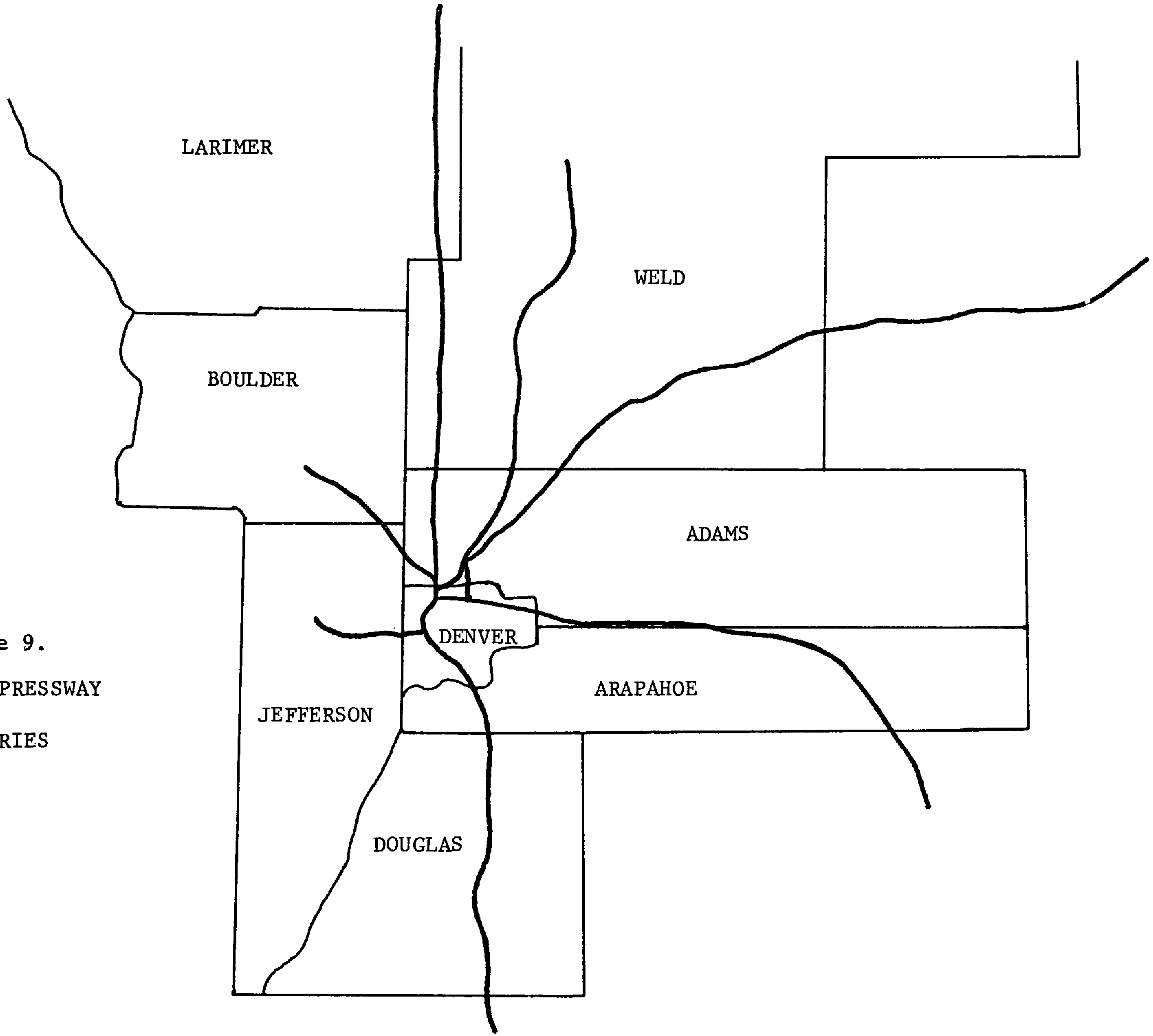


Figure 9.

MAJOR EXPRESSWAY

ARTERIES

town Denver, and at the present time their economic links with Denver are not strong. For example, the 1959 traffic study conducted by the Colorado State Highway Department revealed that on an average day less than 6,000 motor vehicles (cars and trucks) traveled from the whole of Larimer and Weld Counties into Denver. Residents of Fort Collins and Greeley do not generally consider themselves to be part of the Denver metropolitan population. In sum, many indications reveal that Fort Collins and Greeley are separate from Denver. Growth of population, industry, and traffic along interstate highway 25 will tend in the future to bridge existing open spaces. But for the next ten years, Fort Collins and Greeley will probably retain independence from the Denver urban center.

EXISTING AIR POLLUTION PROGRAMS

Colorado State law requires the State Department of Public Health to designate air basins wherever the ambient air exceeds air quality standards set by the State legislature. The State law further specifies emission standards which apply only within air basins and authorizes the State Department of Public Health to enforce those emission standards. The Department has re-delegated this enforcement responsibility to those county and local air pollution programs which have jurisdiction in the air basins. The local programs enforce State emission standards except in counties which have adopted emission standards more stringent than the State standards, where the counties enforce their own standards.

During 1966 the State Department of Public Health designated the Denver Air Basin. It encompassed Denver County, those portions of Jefferson and Boulder Counties east of the Rocky Mountains, those portions of Adams and Arapahoe counties west of range 65 west, and those portions of Douglas County west of range 65 west and north of township 7 south. The boundaries of this basin were based on topographical and meteorological considerations. During 1967, this basin was enlarged to include all of Jefferson and Boulder Counties, in accordance with the desires of county enforcement officials. Figure 10 shows the present boundaries. Figure 10 also shows the boundaries of the Larimer Weld Air Basin, designated by the State in 1967.

Although the State Department of Public Health has re-delegated enforcement authority to county and local agencies, it retains legal authority to enforce State emission standards in any area where local enforcement is considered inadequate. For the most part, the Department has left enforcement activities in the hands of local agencies. In the Denver Air Basin, the local enforcement agencies are the Denver Building Department and the Denver Department of Health and Hospitals for Denver County; the Tri-county Health Department for Adams, Arapahoe, and Douglas; the Boulder Health Department for Boulder County; and the Jefferson Health Department for Jefferson. The Larimer Weld Air Basin falls under the jurisdiction of the Larimer and Weld County health departments.

Table 3 shows the approximate total and per-capita budgets of these local air pollution control programs for 1969. The City of Denver has

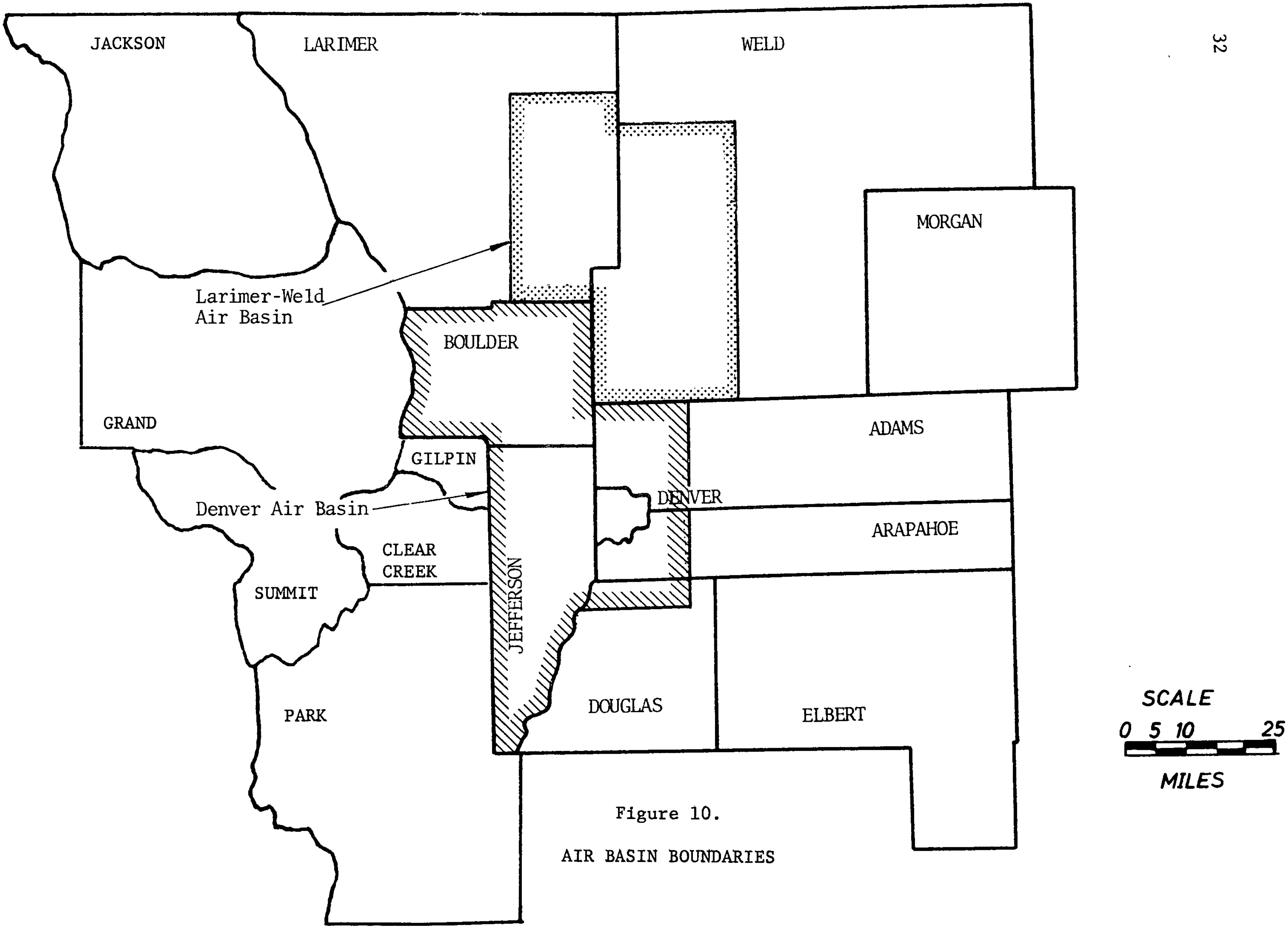


Figure 10.

AIR BASIN BOUNDARIES

Table 3. Budgets of Air Pollution Control Programs

County	Total Annual Budget 1969 (approximate)	Percapita Annual Budget 1969 (approximate)
Denver	$ 302,000	$ 0.59
Boulder	14,000	0.12
Jefferson	38,000	0.18
Tri-County	97,000	0.30

by far the largest per-capita annual budget, at $0.59 per resident. The programs in the surrounding counties have annual budgets on the order of $0.20 per resident. These differences reflect variations in the severity of air pollution and in the density of sources among the counties.

So far, regional cooperation among the local control programs has been fostered by two actions. First, the Regional Air Pollution Control Agency (RAPCA), a subcommittee of the Denver Regional Council of Governments, was established to coordinate standards and enforcement among member agencies. RAPCA serves as an advisory committee to its members; its resolutions do not have any binding force. Nonetheless, all of the member agencies except one have adopted the model air pollution control code developed by RAPCA. Second, a recent amendment to the Colorado law requires the State Department of Public Health and local air pollution control agencies to review periodically each other's programs and plans, and to coordinate air pollution control efforts on the basis of those reviews. These initial two methods of strengthening regional cooperation indicate a promising trend towards coordination of air pollution control efforts within the Denver Air Basin. This trend is moving towards the goal of the Air Quality Act of 1967, which calls for state and local administration of regional air quality control programs. An air quality control region which coincides with the existing Denver Air Basin would take full advantage of these hopeful developments towards regional air pollution control.

SUMMARY

At the present time the Denver Air Basin designated by the State of Colorado contains all significant population and industrial concentrations in the Denver area. Fort Collins and Greeley lie outside of the Denver Air Basin, but they are independent of the Denver urban center. Air pollution control agencies have been established to enforce emission standards throughout the Denver Air Basin. These agencies concur with the present location of the Basin boundaries. They have taken initial steps to promote regional cooperation and uniformity. On the basis of these considerations, it appears that the boundary of the Metropolitan Denver Air Quality Control Region should coincide with the existing boundary of the Denver Air Basin. As growth in the Denver area spreads north and south along the existing transportation arteries, the boundaries of the Air Qulaity Control Region should be reconsidered and perhaps extended to include the southwest tip of Weld County or even the whole Larimer Weld Air Basin, and a larger portion of Douglas County.

EVALUATION OF ENGINEERING FACTORS

The engineering evaluation for the Denver area was based on a study of pollutant emissions, meteorology, topography, estimated air quality levels and available ambient air quality data. The emission inventory indicated the location of point and area sources, the quantity of pollutants emitted from these sources, and the resulting emission densities. These data were subsequently used in a diffusion model[6] to estimate air quality levels in the Denver area.

EMISSION INVENTORY

The National Air Pollution Control Administration* conducted an inventory of air pollutant emissions for the Denver area.** Three major pollutants--sulfur oxides, carbon monoxide, and suspended particulates--have been considered in previous studies by NAPCA to aid in designating air quality control regions. Since sulfur oxides emissions in the Denver area are low,*** only carbon monoxide and suspended particulates are treated as significant pollutants in this study, and they provide a measure of the general geographic extent of the overall problem. Carbon monoxide pollutant levels

*The Air Quality and Emissions Data Program of NAPCA
**For a more detailed treatise, see Appendix A.
***Kansas City's seven county metropolitan area (includes Johnson, Leavenworth, and Wyandott Counties in Kansas, and Cass, Clay, Jackson, and Platte counties in Missouri) with a population of 1,288,600 compared to 1,235,000 in the Denver study area, has an annual SO_X emission rate of over 4 times that of the Denver area.

provide the best indication of the impact of gasoline-powered motor vehicles on the regional air pollution pattern since over 94% of all carbon monoxide emitted in the Denver area comes from motor vehicles. Particulate emission data provide an indication of the combined effect of all source categories since emissions of this pollutant are more evenly distributed among the possible source categories (no single source category accounts for more than 27% of the total). Results of the emission inventory are tabulated in Table A-3 in Appendix A.

The Denver study included emissions estimates for the counties of Denver, Adams, Arapahoe, Boulder, Jefferson, Larimer, Weld, and part of Douglas. This area was divided into the grid coordinate system shown in Figure A-1, Appendix A. The estimated annual emissions of each of the three pollutants by grid zone were converted to average daily emissions for three different time periods--annual, winter, and summer[1] (Table A-4).

Average annual emission densities for each of the three pollutants in tons/square mile/day were determined by relating the total quantity of pollutants emitted in each of the grid zones to the land area of each zone. The resulting emission densities are shown graphically in Figures A-3, A-4, and A-5. The general pattern of emission densities for each of the three pollutants is closely related to the pattern of urbanization in the central part of the Denver study area. The highest emission densities occur in or close to the Denver City area, but the density patterns extend into all of the remaining counties in the study area.

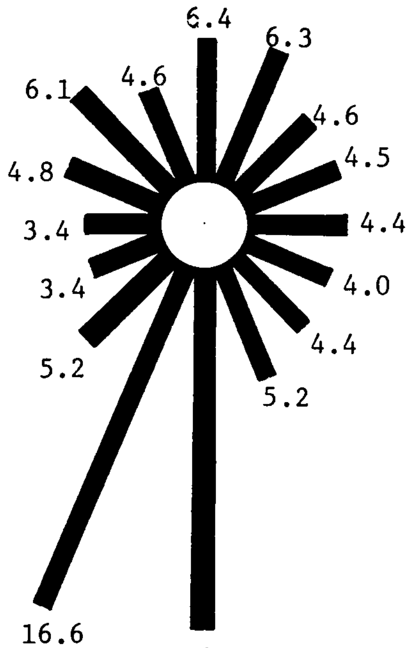
Major point sources contributing to the Denver air pollution problem are shown in Figure A-2 in Appendix A.

AIR QUALITY ANALYSIS

The geographical distribution of pollutant sources illustrates the core of the problem area. It does not, however, elucidate the extent of the influence of pollution sources on the people and property located outside the highly urbanized portion of the Denver metropolitan area. A study of air quality levels known or estimated to occur is useful in determining the area affected by the pollution sources and thus subject to inclusion in the air quality control region. Such analysis can be based directly on air quality sampling data in those instances where the sampling program covers a large-enough area and has been in existence long enough to provide reliable patterns of air quality throughout the region under study. Since such air quality data rarely exists, it becomes necessary to develop estimates of prevailing air quality. Diffusion modeling is a technique by which such estimates can be made based on the location and quantity of pollutant emissions and on meteorological conditions. The influence of topography on ambient air quality levels is reflected in the results of the model, but only to the extent that it influences meteorological conditions. The diffusion model results become invalid in the Rocky Mountain Range west of Denver. The concentration contours presented in this section, therefore, are dotted in the mountainous area. The diffusion model used in this study and the results obtained are covered in detail in Appendix B.

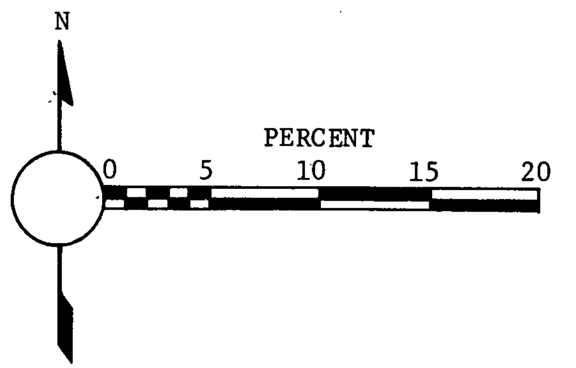
The diffusion model was applied for each of the three pollutants for three different time periods--annual, winter, and summer. Figure 11 and Tables B-1 and B-2 show the meteorological data required to apply the model for each of the three time periods. Figure 11 shows the percent frequency of occurrence of wind direction from 1951 through 1960 in Denver for summer, winter, and annual conditions. The wind speed and direction data used in the diffusion model were considered representative of the prevailing wind patterns throughout the general Denver area. Since the Martin-Tikvart model[6] used in this study attempts to show long-term rather than episodic air quality conditions, only average emissions and long-term average meteorology are considered. If episodic data (i.e., data with very low frequency of occurrence) were used to aid in delineating a region boundary, the region would be unnecessarily large. Even the "smaller" region defined on the basis of mean conditions would undoubtedly encompass the area of maximum concentration upon which a reduction plan is to be developed. Some studies[2,3,4,5] have reported a pronounced diurnal variation in wind direction with south to southwest winds prevailing in the morning and evening and an opposing afternoon flow. The wind rose data (Figure 11) show that the south to southwest winds predominate but that winds from remaining directions show little variation in frequency. Pollutant concentration contours based on mean conditions for the Denver area show a general SSW-NNE elongation thus reflecting the predominate wind directions.

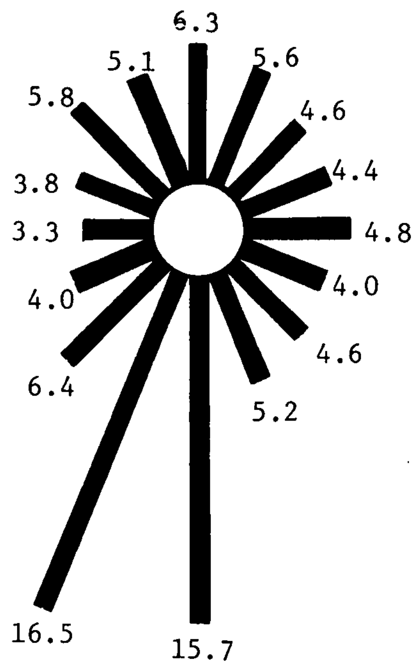
The mixing depths for the time periods are an average of the mean morning and afternoon values as shown in Table B-2 in Appendix B;



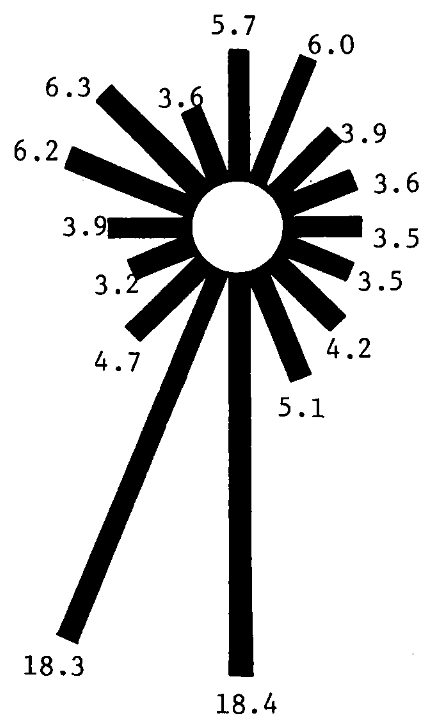
ANNUAL

Figure 11. Percent frequency of wind direction for various averaging times, based on 1951-1960 data.





SUMMER
(June, July, August)



WINTER
(December, January, February)

these data were obtained from the National Weather Records Center (ESSA). Combined with wind data, these data are used in the diffusion model to assess the spatial distribution of pollution concentrations.

The pollutant concentrations estimated by the diffusion model process are in addition to "background" levels since the model was not supplied with information on sources located outside the area initially surveyed. The results are presented in Figures B-1 through B-9 in Appendix B as theoretical concentrations and are discussed in greater detail below.

Sulfur Oxides

Sulfur oxides pollution in the Denver area is not considered a serious problem. Emissions are low due to the extensive use of natural gas and low sulfur coals. As a result the diffusion model contour lines for SO_X, shown in Figures A-1 through A-3 in Appendix A, indicate relatively low values. Figure 12, representing winter (December, January, and February) conditions, was chosen for discussion since, of the three conditions winter averages were the most extensive.

Comparison of the diffusion model results with air quality data shows no significant variation near the core of the study area. SO_X data from the CAMP station located in downtown Denver gives a winter SO_X average of 0.017 ppm (December, 1965, January and February, 1966) and 0.007 ppm for December, 1967. This station lies within the 0.01 ppm contour line produced by the model. Another 0.01 ppm contour line is located in the Boulder area. Despite

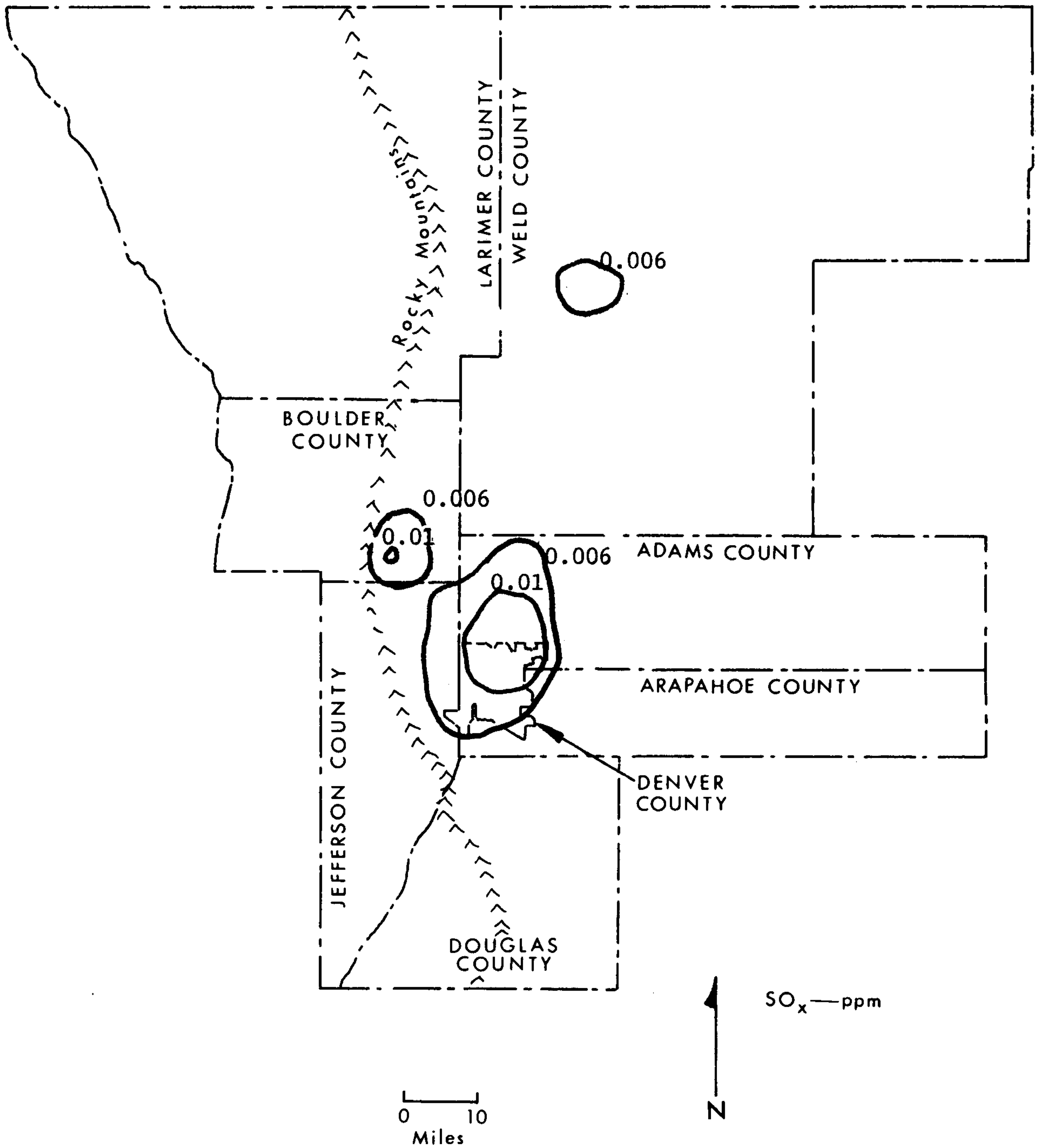


Figure 12. Theoretical SO_X concentration, winter average, above background.

relatively low SO_X values, the diffusion model contours illustrate the SSW-NNE orientation of the diffusion pattern.

Carbon Monoxide

The results of the theoretical model estimates of carbon monoxide concentrations for the three seasonal conditions are presented in Figures B-4 through B-6 in Appendix B. The results for and average summer day are discussed here since, of the three conditions considered, summer day isopleths showed the highest concentrations. Air quality data from Denver's CAMP station indicate that the model underestimates concentrations by a factor of about 10.* For the purpose of showing relative distribution of CO levels, the model estimates are adequate; but they are less adequate for the purpose of assessing the extent of serious CO concentrations because of the discrepancy between measured and theoretical values. The diffusion model does not reflect the built-up nature of the area in which most of the CO is emitted and thus assumes that the pollutant has more immediate space and volume within which to disperse. This fact is assumed to cause much of the discrepancy between estimated and measured concentrations.

Based on this difference, a factor of 10 was applied to the theoretical diffusion model estimates to give "adjusted" CO concentrations. In so doing, the relative distribution of CO levels calculated by the model is preserved, while the absolute values

* CAMP Station results for June, July, and August, 1966, give an average CO concentration of 6.9 ppm. The station is located very near the 6 ppm contour line given by the "adjusted" model results for CO in Figure 13.

assigned to the contours are brought more in line with actual sampling results. The resulting CO level estimate is shown in Figure 13. Theoretical contours have been plotted for 6, 2, and 1 ppm of the pollutant. 1 ppm is assumed to be close to the background level in most highly urbanized areas; this value at the outskirts of an area, then, might be used as a starting point in defining the area affected by sources within the region.

Suspended Particulates

Figures B-7 through B-9 in Appendix B show the diffusion model results for suspended particulates. Winter (December, January, and February) concentration contours give the highest results of the three time periods considered and will be discussed in this section. Table 4 shows a comparison of diffusion model estimates and measured suspended particulate data* from 14 sampling stations in the Denver core area. Measured values were an average of 3.85 times greater than diffusion model estimates. In adjusting the model contour lines by this multiplier, the theoretical isopleths become comparable to measured values while the relative concentrations are not disturbed. Figure 14 shows the "adjusted" theoretical concentration contours for the Denver area.

Two Hi-Vol samplers are located in Greeley. The winter averages (1964-1968 for Central Fire Station and 1966-1968 for fire station at 23rd and Reservoir Rd.) reported by the stations are 96 $\mu g/m^3$ and 72 $\mu g/m^3$. Using a factor of 3.85 to adjust the two isopleths surrounding Greeley, the values of the contours become more consistant with actual

* Data provided by the Colorado Department of Public Health

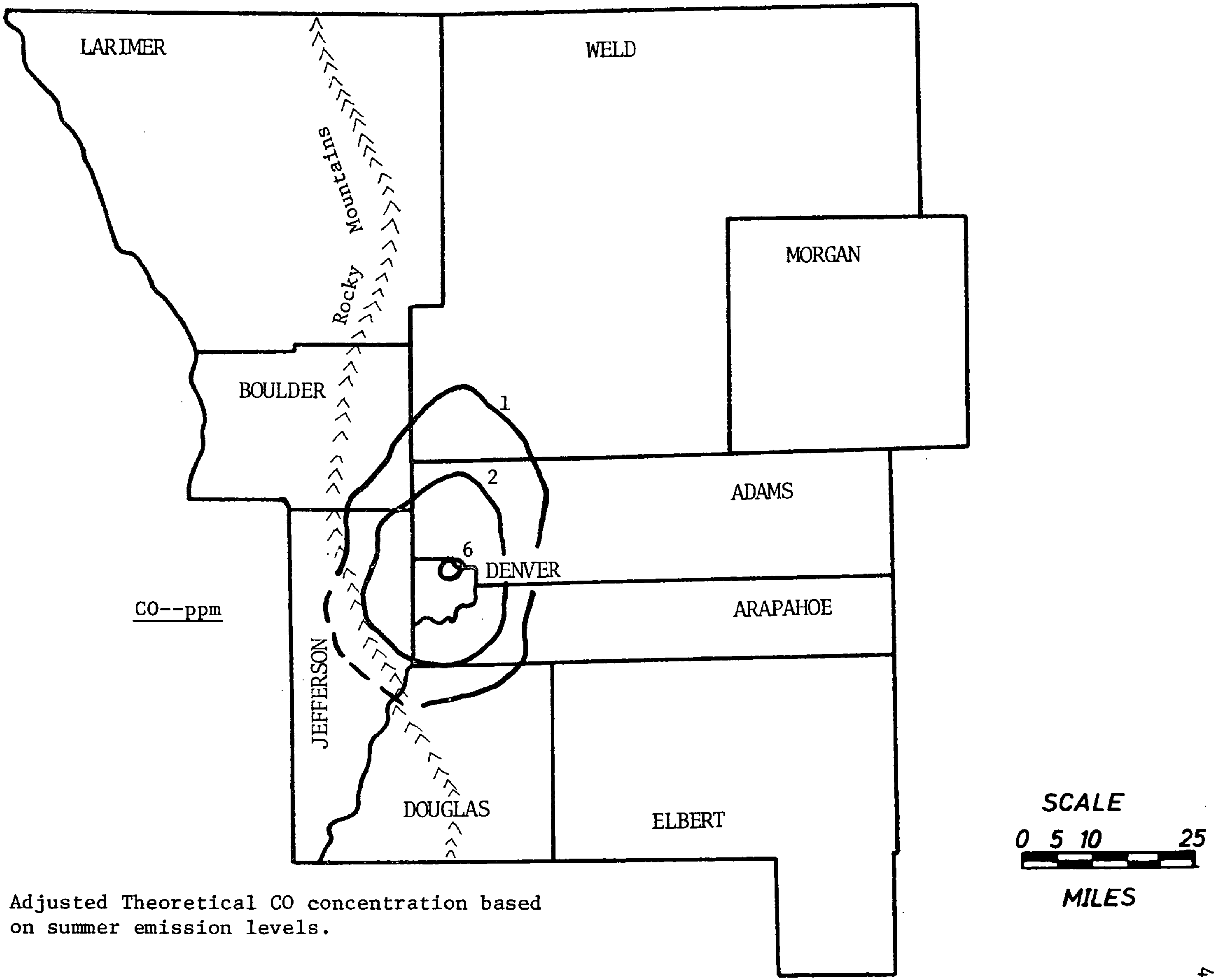


Figure 13. Adjusted Theoretical CO concentration based on summer emission levels.

Table 4. Relationship of Diffusion Model Results to Aerometric Data for Suspended Particulates

County	Station	Measured M	Estimated E	Ratio M/E
Denver	Hull Photo[a]	87	38	2.29
	State Health Bldg.[a]	86	39	2.20
	Shwayder Bros.[a]	146	32	4.56
	Sewer Plant[a]	179	39	4.59
	School Adm.[a]	153	39	3.92
	North High[a]	114	37	3.08
Adams	Aurora[b]	89	32	2.78
	Adams City[a]	156	32	4.87
Arapahoe	Englewood[a]	131	28	4.32
	Cherry Creek Dam[c]	41	16	2.56
Jefferson	Lakewood[d]	73.5	33	2.23
	Arvada[e]	135	30	4.50
	Golden[e]	92	20	4.60
Boulder	Boulder[a]	74.5	10	7.45
				53.95

Average ratio--- $\frac{53.95}{14} = 3.85$

Averaged over the time periods listed below:

[a] December, January, February, 1963-1968
[b] December, January, February, 1963-1964 and 1966-1968
[c] December, January, February, 1967-1968
[d] December, January, February, 1963-1965 and 1966-1968 plus a reading for January, 1966
[e] February 1967 and December, January, February, 1967-1968

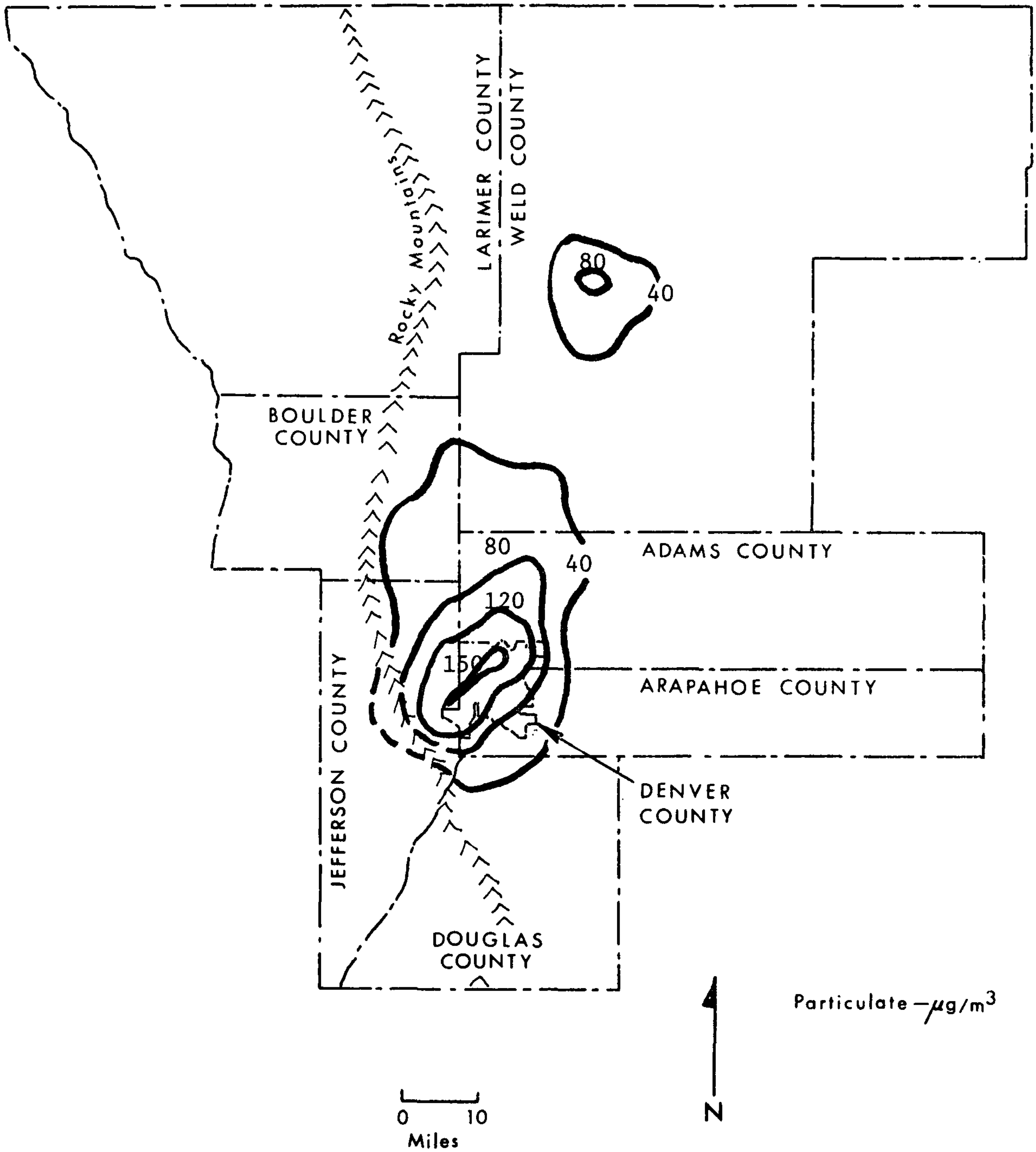


Figure 14. Adjusted theoretical suspended particulate concentration, winter average.

measurements (Figure 14).

The Hi-Vol sampler at Cherry Creek Reservoir gives the lowest winter average suspended particulate values of all stations in the Denver area. For winter, 1967-1968 the average suspended particulate level was 41 $\mu g/m^3$ which is considered very close to background level in the non-urban area surrounding Denver. The region enclosed by this "background level" isopleth might be considered the area most affected by particulate emissions in the Denver area.

SUMMARY

The 1 ppm CO contour line encloses the whole of Denver City-County, the western portions of Adams and Arapahoe Counties, the southeast corner of Boulder County, the eastern half of Jefferson County, and the northwest corner of Douglas County.

The 40 $\mu g/m^3$ suspended particulate concentration line includes essentially the same area as the 1 ppm CO contour; also included is a portion of west-central Weld County in the Greeley vicinity.

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2. "Report on Graphic Climatology Related to Air Pollution, Denver, Colorado," Wayne H. May, Air Pollution Control Section, Colorado Department of Health, Denver, Colorado, July 1, 1968.

3. "Air Pollution in the Denver Area," Loren W. Crow, Certified Consulting Meteorologist, Denver, Colorado.

4. "Airflow Related to Denver Air Pollution," Loren W. Crow, Consulting Meteorologist, Denver, Colorado (presented at the 56th Annual Meeting of APCA, Sheraton-Cadillac Hotel, June 9-13, 1963, Detroit, Michigan).

5. "Further Studies of Denver Air Pollution," N. Djordevic, W. Ehrman, G. Swanson, Elmar R. Reiter (principal investigator), Atmospheric Science Paper No. 105, Department of Atmospheric Science, Colorado State University, Fort Collins, Colorado.

6. "General Atmospheric Diffusion Model for Estimating the Effects on Air Quality of One or More Sources," Martin, D. and Tikvart, J., Paper No. 68-148, 61st Annual Meeting, APCA, St. Paul, Minnesota, June, 1968.

APPENDICES

APPENDIX A. EMISSION INVENTORY

The emission inventory used in this study resulted from a rapid emission inventory of air pollutant sources in the Denver Metropolitan area. The objectives of the inventory were to determine the total quantities of various air pollutants emitted, using appropriate emission factors[2], and to estimate the geographical and seasonal variation in air pollutant emissions. To accomplish this task, the study area was divided into a grid coordinate system and the emission quantities were reported in terms of tons of pollutant per grid on an average annual day, average summer day, and average winter day.

The pollutants considered in this survey are sulfur oxides, particulates, and carbon monoxide. Data presented herein are representative of 1967 and were mainly gathered by State and local agencies.

The study area, as presented in Figure A-1, consists of the City and County of Denver, and the Counties of Adams, Arapahoe, Boulder, Jefferson, Larimer, Weld, and part of Douglas. For the purposes of this survey, the study area was divided into 81 grids based on latitude and longitude. Five grid sizes of 2 minute, 4 minute, 16 minute, and 32 minute grids were utilized depending upon the extent of urbanization of the area. Figure A-1 indicates the grid system used for reporting the emissions. In those cases where sections of outlying counties are omitted, the air pollutant emissions are considered negligible.

The air pollutant emissions by political jurisdiction are given in Table A-1. Table A-2 lists the breakdown of pollutant emissions by source category in the study area. The following is a brief summary of pollutant emissions and sources:

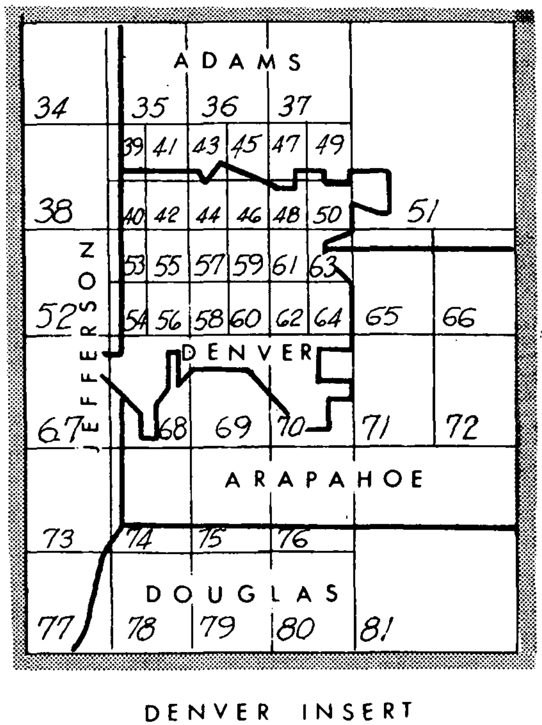
(1) Of the 31,400 tons of SO_X, emitted annually, 67% originate from fuel combustion sources, 28% from industrial process losses, and 5% from mobile sources. The contribution from solid waste disposal is negligible. The combustion of coal, mainly in steam electric power plants, produces 62% of the total sulfur oxides in the area.

(2) Particulate emissions from fuel combustion contributes 54%, solid waste disposal 4%, industrial process losses 27%, and mobile sources 15% of the 33,400 tons of particulates emitted in the study area. The combustion of coal produces 50% of the total particulate emissions.

(3) Mobile sources contribute 94% of the 616,000 tons of CO emitted per year. Other sources are the combustion of fuels in stationary sources which contribute less than 1%, solid waste disposal 1%, and industrial process losses, 4%.

For the purpose of modeling the air pollutant emissions in the study area, the emissions are apportioned on the grid coordinate system. Sixteen point sources of SO_X, 15 point sources of particulates, and 2 point sources of CO are identified individually with respect to location and emissions. The emissions for SO_X, particulates, and CO are presented in Tables A-4 and A-5 as average summer day, average winter day, and average annual day estimates. Figures A-2 through A-5 illustrate the point source locations and the maximum emission densities of the three time periods.

The daily emission rates were obtained by dividing yearly totals by appropriate operating day values. Fuel combustion was divided into space heating and constant emissions. Space heating was apportioned on the basis of degree day variations. Unless specific data were obtained from individual sources, industrial, commercial, and institutional sources were assumed to operate from 250 to 310 days per year. Mobile sources and solid waste disposal sources were assumed to be spread throughout the year. The seasonal variations in motor vehicle emissions were based on average daily traffic factors.



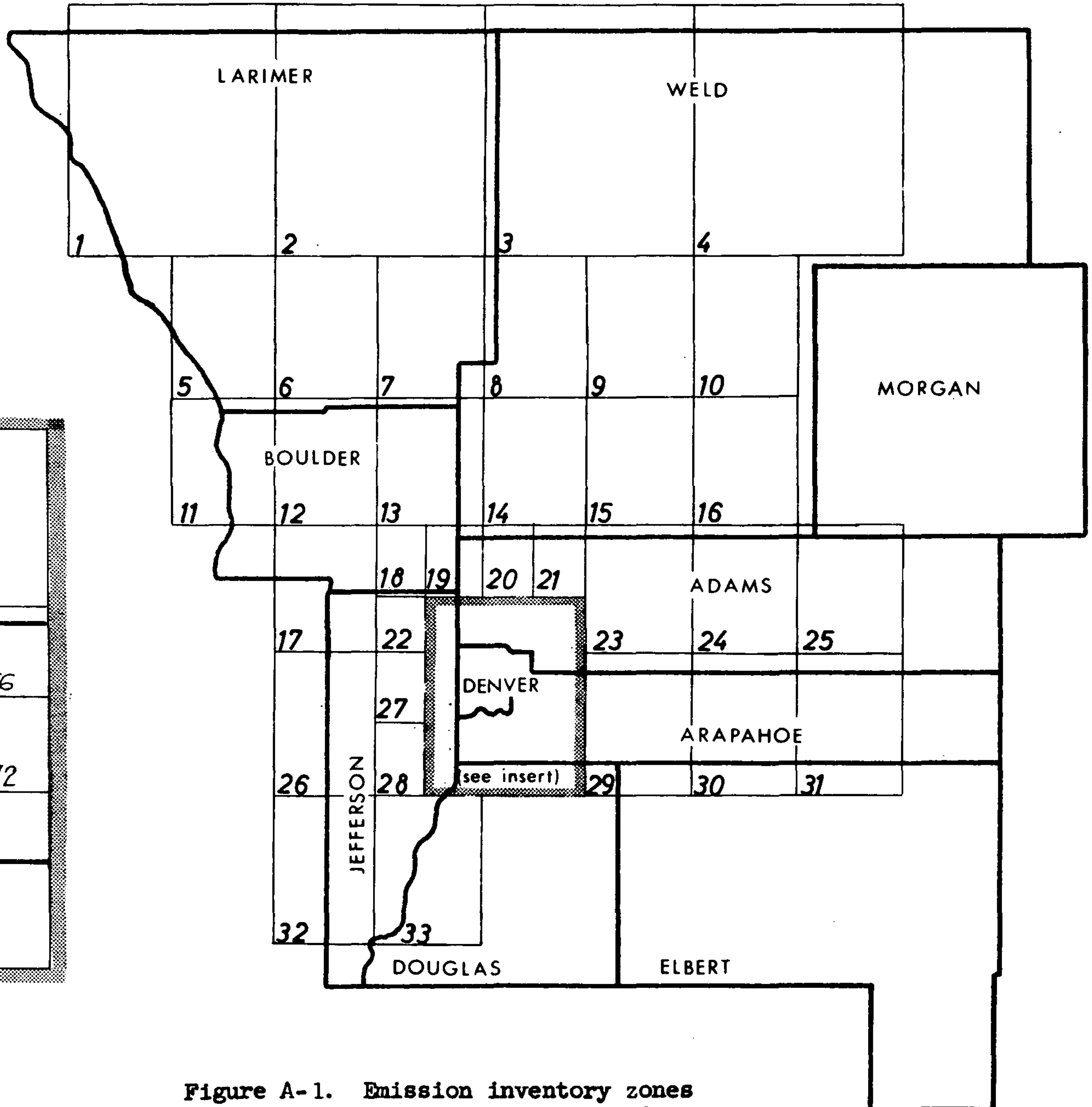


Figure A-1. Emission inventory zones for Denver area study.

Table A-1. Emissions By Political Jurisdiction
tons/year

County	SO_x	Particulate	CO
Adams	15,100	8,980	94,300
Arapahoe	320	1,180	81,700
Boulder	5,630	4,550	33,600
Denver	6,950	9,370	241,600
Jefferson	1,350	4,670	115,700
Larimer	910	2,000	22,200
Weld	1,070	2,600	26,400
Study Area Total	31,330	33,350	615,500

Table A-2. Emissions By Source Category In Study Area, 1967

tons/year

Source Category	SO_x	Particulate	CO
Fuel combustion (Stationary sources)			
Coal	19,300	16,700	4,400
Oil	1,000	300	100
Gas	570*	1,200	n
Total	20,870	18,200	4,500
Solid waste disposal			
Open burning	n	100	970
Incineration	n	n	n
On-site			
Backyard	13	550	6,600
Incineration	39	650	2,200
Total	52	1,300	9,770
Industrial process	8,800	8,900	24,700
Mobile sources			
Gasoline combustion	1,000	2,300	563,900
Diesel combustion	500	1,300	800
Railroads	100	300	200
Aircraft	n	1,100	11,500
Total	1,600	5,000	576,000

n = negligible
*500 tons/year due to burning of mustard gas.

Table A-3. Pollutant Emissions by Source Category and Political Jurisdiction in the Denver Study Area.

Pollutant	County	Fuel Combustion Sources: Ind.	Com. & Inst.	Res.	Power Plants	Total Fuel	Ind. Process	Trans.	Refuse Disposal	Total
Particulate	Adams	1070	130	90	2820	4110	4200	580	80	8980
	Arapahoe	210	140	60	----	410	90	680	n	1180
	Boulder	1140	520	140	1520	3320	940	300	n	4550
	Denver	680	1570	360	1120	3730	2900	2130	590	9370
	Jefferson	1500	2140	110	----	3750	230	690	20	4670
	Larimer	510	120	300	470	1400	250	230	120	2000
	Weld	1000	150	280	----	1430	230	460	480	2600
	Total	6110	4770	1340	5930	----	8840	5070	1290	33350
	% of Total	18.4	14.3	4.0	17.8	----	26.4	15.2	3.9	100
Sulfur Oxides	Adams	440	600	40	7860	8940	6000	n	240	15100
	Arapahoe	80	40	20	----	140	n	190	n	320
	Boulder	880	210	80	4240	5410	n	120	n	5630
	Denver	210	380	120	2860	3570	2800	520	30	6950
	Jefferson	500	540	40	----	1080	n	270	n	1350
	Larimer	500	30	190	100	820	n	90	n	910
	Weld	670	40	180	----	890	n	170	10	1070
	Total	3280	1840	670	15060	----	8800	1360	280	31330
	% of Total	10.5	5.9	2.1	48.0	----	28.1	4.5	0.9	100
Carbon Monoxide	Adams	70	40	50	----	160	24300	69700	240	94300
	Arapahoe	30	70	10	----	110	60	81400	10	81700
	Boulder	130	290	120	110	650	190	32700	60	33600
	Denver	50	800	190	90	1130	80	237800	1970	241600
	Jefferson	60	1060	20	----	1140	n	114300	220	115700
	Larimer	80	70	340	n	490	n	20800	980	22200
	Weld	90	90	320	----	500	n	19600	6350	26400
	Total	510	2420	1050	200	----	24630	576300	9830	615500
	% of Total	neg.	0.4	neg.	neg.	----	4.0	94.0	1.6	100

n = not available

Table A-4. Summary of Emissions From Area Sources By Season
ton/day

Grid	Area	SO_x			Particulate			CO		
	Sq. Km.	S	W	A	S	W	A	S	W	A
1	2,741	.0	.0	.0	.01	.01	.01	.69	.57	.61
2	2,741	.47	1.23	.85	2.03	3.88	2.96	44.74	36.56	39.24
3	2,741	.16	.42	.29	.63	.89	.76	12.28	10.52	11.10
4	2,741	.01	.03	.02	.16	.20	.18	3.61	3.03	3.22
5	171.4	.0	.02	.01	.08	.12	.10	1.36	1.11	1.19
6	171.4	.0	.0	.0	.02	.02	.02	1.31	1.06	1.14
7	171.4	.10	.40	.24	.45	1.32	.89	21.27	17.49	18.73
8	171.4	.39	.65	.52	.47	.77	.62	8.25	7.08	7.46
9	171.4	.48	1.33	.91	2.09	4.04	3.07	39.37	33.51	35.43
10	171.4	.08	.08	.08	.08	.08	.08	1.25	1.01	1.09
11	171.4	.0	.02	.01	.04	.08	.06	4.11	3.32	3.58
12	171.4	.47	1.44	.96	1.40	4.38	2.90	51.50	41.67	44.89
13	171.4	.49	1.11	.80	2.23	4.10	3.17	22.11	18.17	19.46
14	171.4	.08	.20	.14	.41	.69	.55	8.57	7.40	7.78
15	171.4	.05	.07	.06	.16	.20	.18	2.67	2.31	2.43
16	171.4	.0	.0	.0	.19	.19	.19	2.24	2.00	2.08
17	171.4	.0	.0	.0	.04	.04	.04	5.31	4.29	4.62
18	42.84	.82	1.24	1.03	1.14	1.38	1.26	29.64	23.97	25.83
19	42.84	.21	.43	.32	.55	1.17	.86	29.75	24.47	26.20
20	42.84	.04	.04	.04	.10	.10	.10	5.77	4.67	5.03
21	42.84	.07	.07	.07	.27	.27	.27	12.68	10.25	11.05
22	42.84	.27	.63	.45	.73	1.92	1.33	49.43	40.06	43.13
23	171.4	.0	.0	.0	.04	.04	.04	.78	.65	.69
24	171.4	.0	.0	.0	.11	.11	.11	1.25	1.12	1.16
25	171.4	.0	.0	.0	.0	.0	.0	.46	.37	.40
26	171.4	.07	.07	.07	.15	.15	.15	23.64	19.09	20.58
27	42.84	.36	.60	.48	.71	1.58	1.15	61.09	49.34	53.19
28	42.84	.04	.04	.04	.08	.08	.08	16.20	13.08	14.10
29	171.4	.0	.0	.0	.04	.04	.04	5.74	4.64	5.00
30	171.4	.0	.0	.0	.04	.04	.04	5.74	4.64	5.00
31	171.4	.0	.0	.0	.05	.05	.05	5.77	4.67	5.03
32	171.4	.01	.01	.01	.04	.04	.04	4.08	3.29	3.55
33	171.4	.0	.0	.0	.01	.01	.01	1.63	1.32	1.42
34	42.84	.05	.05	.05	.10	.10	.10	19.02	15.36	16.56
35	42.84	.12	.16	.14	.27	.43	.35	38.10	30.78	33.18
36	42.84	.14	.18	.16	.95	1.03	.99	44.59	36.01	38.82
37	42.84	.20	.26	.23	.83	.97	.90	33.69	27.27	29.37
38	42.84	.16	.50	.33	.28	1.43	.86	40.37	32.68	35.20
39	10.71	.05	.53	.29	.62	.94	.78	13.58	10.98	11.83
40	10.71	.07	.65	.36	.16	2.17	1.17	20.99	17.01	18.31
41	10.71	.10	.20	.15	.20	.28	.24	12.19	9.85	10.62
42	10.71	.12	.26	.19	.36	.80	.58	59.76	48.31	52.06
43	10.71	.09	.15	.12	1.27	1.41	1.34	15.09	12.19	13.14
44	10.71	.29	.43	.36	3.30	3.66	3.48	50.43	38.98	42.73
45	10.71	.11	.17	.14	1.63	1.77	1.70	15.67	12.77	13.72
46	10.71	.15	.41	.28	3.08	3.91	3.50	59.80	48.35	52.10

(Continuation of Table A-4)

Grid	Area Sq. Km.	SO_x S	SO_x W	SO_x A	Particulate S	Particulate W	Particulate A	CO S	CO W	CO A
47	10.71	.08	.16	.12	.79	1.03	.91	20.70	16.73	18.03
48	10.71	.15	.21	.18	.48	.68	.58	23.94	19.37	20.87
49	10.71	.02	.02	.02	.02	.02	.02	3.73	3.01	3.25
50	10.71	.01	.01	.01	2.45	2.45	2.45	32.06	30.93	31.30
51	171.4	.12	.20	.16	.40	.64	.52	26.12	21.11	22.75
52	42.84	.18	.92	.55	.19	3.15	1.68	33.58	27.27	29.34
53	10.71	.10	.70	.40	.20	2.49	1.35	28.16	22.79	24.55
54	10.71	.05	.23	.14	.10	.64	.37	19.07	15.41	16.61
55	10.71	.09	.31	.20	1.02	1.66	1.34	60.28	48.83	52.58
56	10.71	.08	.20	.14	1.39	1.79	1.59	36.88	29.83	32.14
57	10.71	.31	1.09	.70	.81	3.28	2.05	111.57	90.19	97.19
58	10.71	.21	.39	.30	1.76	2.28	2.02	59.83	48.38	52.13
59	10.71	.13	.55	.34	.33	1.78	1.06	59.77	48.32	52.07
60	10.71	.06	.18	.12	.20	.60	.40	31.90	25.82	27.81
61	10.71	.09	.29	.19	.23	.99	.61	36.89	29.84	32.15
62	10.71	.04	.06	.05	.06	.22	.14	15.79	12.75	13.75
63	10.71	.32	64	.48	.09	.53	.31	19.72	15.94	17.18
64	10.71	.04	.04	.04	.01	.01	.01	3.91	3.15	3.40
65	42.84	.22	.40	.31	.19	.67	.43	37.37	30.19	32.54
66	42.84	.01	.01	.01	.72	.72	.72	23.31	19.44	20.71
67	42.84	.07	.07	.07	.10	.16	.13	16.29	13.16	14.19
68	42.84	.27	.35	.31	.74	1.06	.90	41.77	33.81	36.42
69	42.84	.38	.60	.49	.97	2.02	1.50	53.43	43.18	46.54
70	42.84	.15	.15	.15	.45	.55	.50	31.96	26.63	28.38
71	42.84	.05	.05	.05	.05	.05	.05	13.21	10.67	11.50
72	42.84	.0	.0	.0	.01	.01	.01	2.87	2.32	2.50
73	42.84	.05	.05	.05	.08	.08	.08	16.20	13.08	14.10
74	42.84	.13	.15	.14	.27	.39	.33	19.28	15.57	16.79
75	42.84	.08	.08	.08	.10	.16	.13	16.40	13.25	14.38
76	42.84	.04	.04	.04	.04	.06	.05	9.17	7.40	7.98
77	42.84	.02	.02	.02	.05	.05	.05	4.08	3.29	3.55
78	42.84	na	na	na	na	na	na	na	na	na
79	42.84	na	na	na	na	na	na	na	na	na
80	42.84	na	na	na	na	na	na	na	na	na
81	171.4	.04	.04	.04	.08	.08	.08	14.91	12.04	12.98

na = not available (Douglas County)

S = Average summer day

W = Average winter day

A = Average day

Table A-5

Summary of Emissions From Point Sources By Season
ton/day

Type of Plant	Grid	SO_x			Particulate			CO		
		S	W	A	S	W	A	S	W	A
Chemical Plant	56	4.49	4.49	4.49	-	-	-	-	-	-
Chemical Plant	58	3.60	3.60	3.60	-	-	-	-	-	-
Industry	22	0.81	1.20	1.01	4.14	5.70	4.90	-	-	-
Grain Elevator	41	-	-	-	7.70	7.70	7.70	-	-	-
Grain Elevator	47	-	-	-	2.42	2.42	2.42	-	-	-
Industry	13	1.94	2.88	2.41	1.81	2.46	2.18	-	-	-
Industry	21	neg.	4.00	1.43	neg.	10.00	3.60	-	-	-
Industry	9	neg.	2.44	0.89	neg.	6.45	2.32	-	-	-
Federal Facility	51	2.20	2.20	2.20	-	-	-	-	-	-
Federal Facility	63	-	-	-	2.11	6.30	4.18	-	-	-
Industry	7	neg.	4.45	1.59	neg.	3.06	1.10	-	-	-
Industry	9	neg.	2.67	0.97	neg.	3.78	1.36	-	-	-
Federal Facility	52	0.05	1.59	0.80	0.19	7.53	3.78	-	-	-
Power Plant	55	1.10	6.20	2.95	0.55	2.15	1.15	-	-	-
Power Plant	68	0.53	8.92	4.88	0.55	3.23	1.95	-	-	-
Power Plant	45	16.80	23.20	21.50	6.03	8.35	7.73	-	-	-
Power Plant	13	11.85	13.50	11.60	4.28	4.88	4.18	-	-	-
Power Plant	2	-	-	-	1.30	1.30	1.30	-	-	-
Refinery	45	16.91	16.91	16.91	-	-	-	27.20	27.20	27.20
Refinery	45	1.80	1.80	1.80	-	-	-	37.00	37.00	37.00

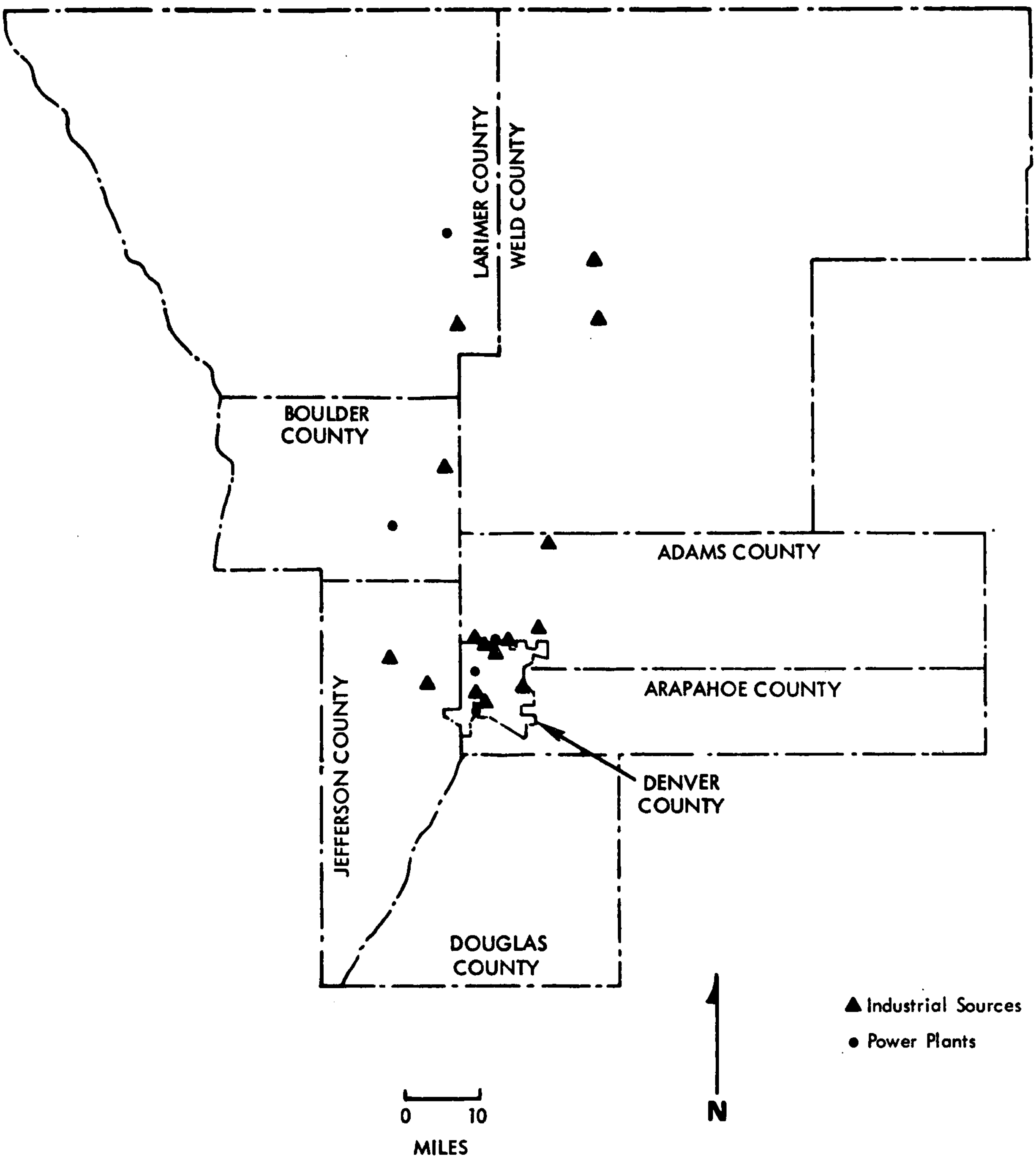


Figure A-2. Major Point Sources

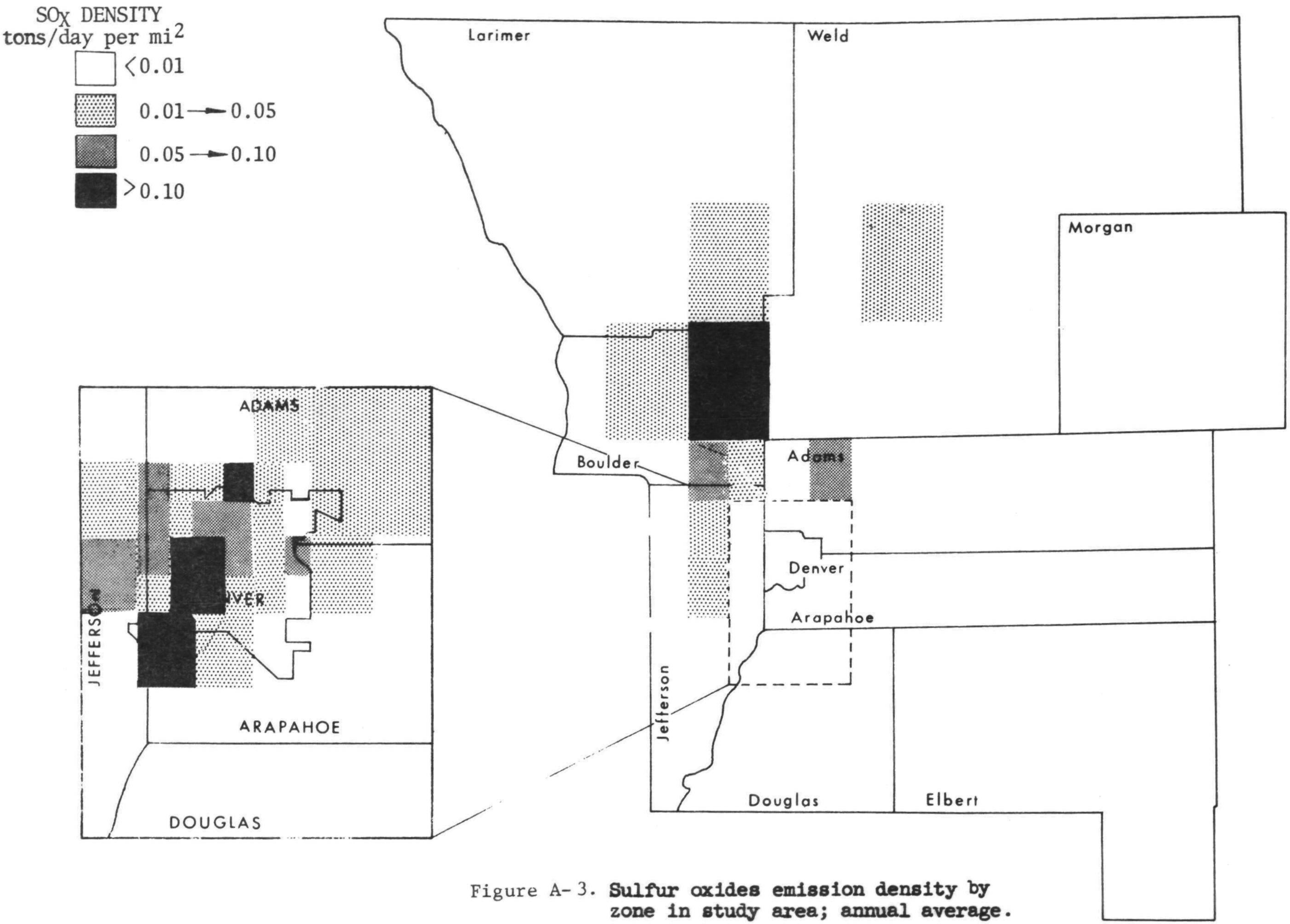


Figure A-3. **Sulfur oxides emission density by zone in study area; annual average.**

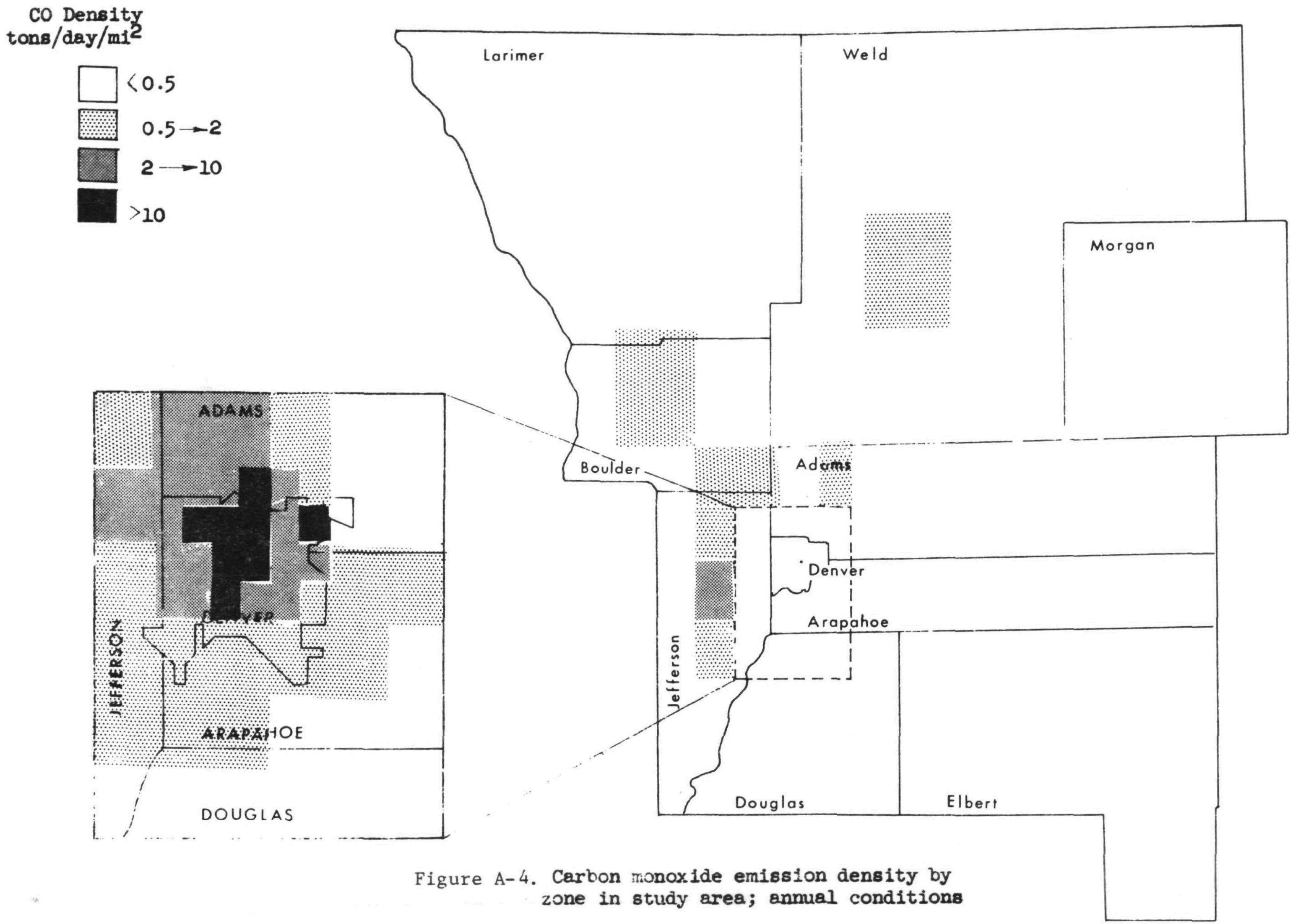


Figure A-4. Carbon monoxide emission density by zone in study area; annual conditions

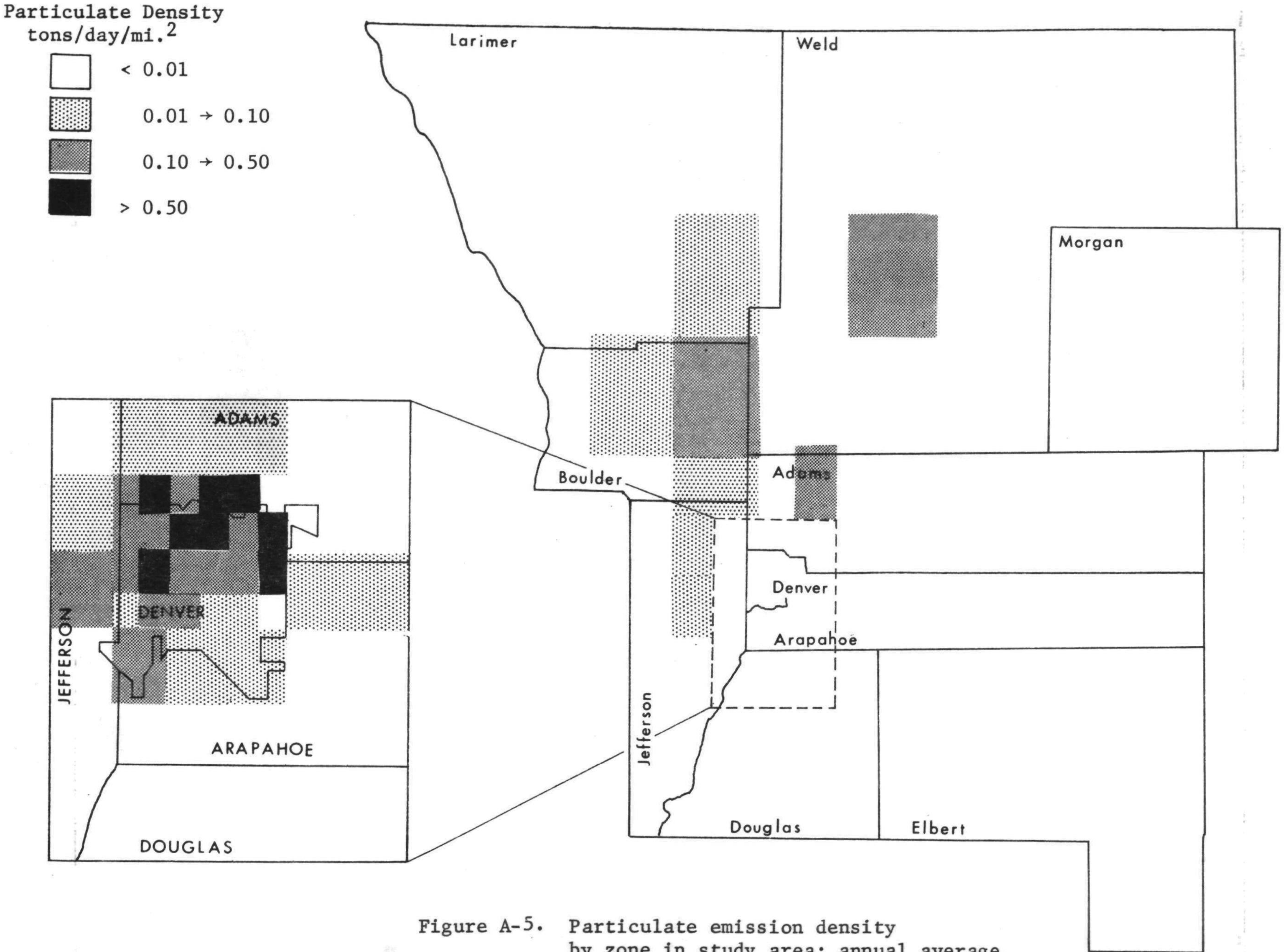


Figure A-5. Particulate emission density by zone in study area; annual average.

References for Appendix A

1. "Rapid Survey Technique for Estimating Community Air Pollution Emissions," PHS, Publication No. 999-AP-29, Environmental Health Series, USDHEW, NCAPC, Cincinnati, Ohio, October 1966.

2. Duprey, R. L., "A Compilation of Air Pollution Emission Factors," USDHEW, PHS, BDPEC, NCAPC, Durham, North Carolina, 1968.

APPENDIX B. DIFFUSION MODEL DESCRIPTION AND RESULTS

Title I, Section 107 (a) (2) of the Air Quality Act of 1967 (Public Law 90-148, dated November 21, 1967), calls for the designation of air quality control regions, based on a number of factors, including "atmospheric conditions," interpreted to mean that the boundaries of air quality control regions should reflect the technical aspects of air pollution and its dispersion. Within this guideline, however, the position has been taken that region boundaries cannot be based on an extreme set of circumstances which might have a theoretical chance of occurrence. Hence, the analysis of a region's atmospheric dilution potential is largely based on mean annual values, although summer and winter mean values are analyzed with respect to reviewing seasonal variations in meteorology and pollutant emissions.

With the realization that the meteorological analysis would help define tentative boundaries only and that final boundaries would be developed subsequently to reflect local government aspects, it was decided that the meteorological assessment should be as unpretentious as possible. Accordingly, the widely accepted long-term Gaussian diffusion equation, described by Pasquill[1] and Turner[2], has been applied with a few modifications to accommodate certain requirements inherent to the delineation of air quality control regions. In summary, the Gaussian diffusion equation is utilized to provide a theoretical estimate of the geographical distribution of long-period mean ground-level concentrations of SO_X, CO, and suspended particulates. The model used has the necessary flexibility to utilize information on emissions from both point and area-wide sources.

To maintain simplicity, all pollutant sources were assumed to be at ground level; for CO this assumption is realistic. The same assumption is used for major point sources of SO_X and particulates, since the distances of interest are sufficiently great to obviate the source-height effect for most receptors. Also, since there is no agreement on an appropriate half-life and deposition rate for SO_X and particulates, respectively, these factors were not applied to the computations of ground-level pollutant concentrations during the initial diffusion model analysis.

METHODOLOGY

The diffusion model used is based on the Gaussian diffusion equation[1,2], as modified by Martin[3]. Essentially, the model sums the effects (ground-level concentration) of a number of sources (area and point) for a specified number of receptors, averaged over a season or a year. For this study, 97 receptor points were used (20, 30, 40, 50, 70, and 100 kilometers from an assumed center, at each of 16 compass points).

The meteorological data input to the model is screened to determine the representiveness of the data. Appropriate surface wind rose data are selected from U.S. Weather Bureau records; if necessary, special wind data tabulutions are obtained from the National Weather Records Center (NWRC). Table B-1 presents the wind data in the form utilized by the diffusion model. The data are given in terms of a ratio of the relative frequency (F) with which a particular wind direction occurs to the effective wind speed (u) for the respective direction. The mean mixing depth for each region, for each respective time period (seasonal and average), is determined on the basis of computed mixing depths documented by Holzworth[4,5], and recent tabulations furnished the Meteorology Program by the National Weather Records Center (ESSA). Table B-2 gives the mixing depth values utilized by the model for computing theoretical ground level concentrations in the Denver area. Figures B-1 through B-9 present unmodified theoretical ground level concentrations of SO_X, CO, and suspended particulates during the three time periods, annual, summer, and winter.

Table B-1. Denver Region Wind Rose Data

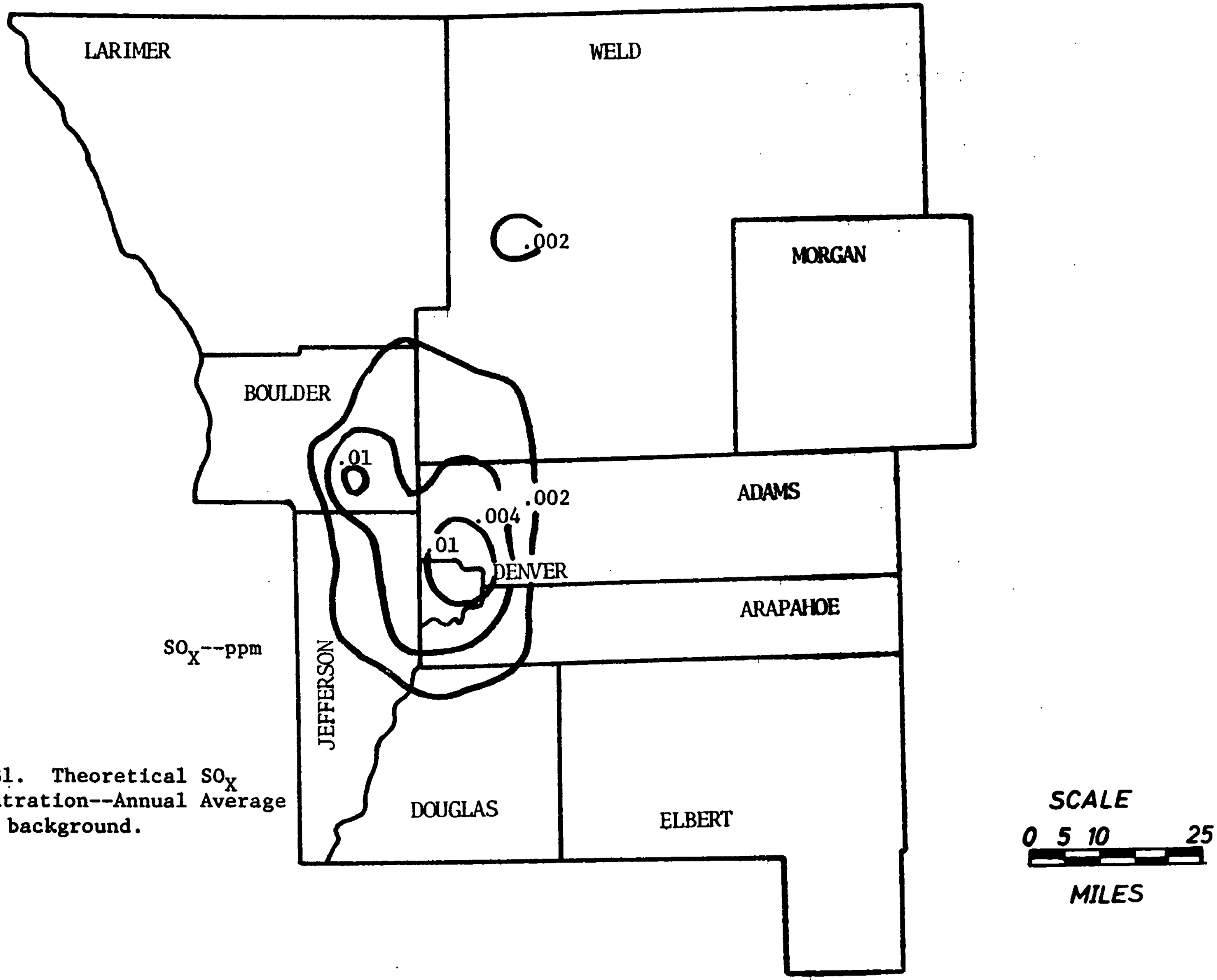
F/U

SEASON	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
WINTER (Dec., Jan., Feb.)	2.06	2.26	1.85	1.75	1.42	1.54	2.01	2.19	5.65	5.57	2.05	1.32	1.25	1.93	2.18	1.5
SUMMER (June, July, Aug.)	2.16	2.11	1.87	1.92	1.83	1.62	1.93	2.12	5.19	5.72	2.95	2.27	1.75	1.86	2.53	2.19
ANNUAL	2.15	2.31	1.96	1.90	1.75	1.73	1.95	2.21	5.26	5.34	2.30	1.68	1.39	1.77	2.37	1.93

F = Relative frequency of occurrence of wind direction.
U = Effective Wind speed (meters/second).

Table B-2. Average Mixing Depths
for Denver Area by Season

Season	Mixing Depths, meters		
	Morning Average	Afternoon Average	Average, morning and afternoon
Winter (Dec., Jan., Feb.)	178	1357	768
Summer (June, July, August)	243	3358	1800
Annual (4 seasons)	236	2438	1337



SO_X--ppm

Figure B1. Theoretical SO_X Concentration--Annual Average Above background.

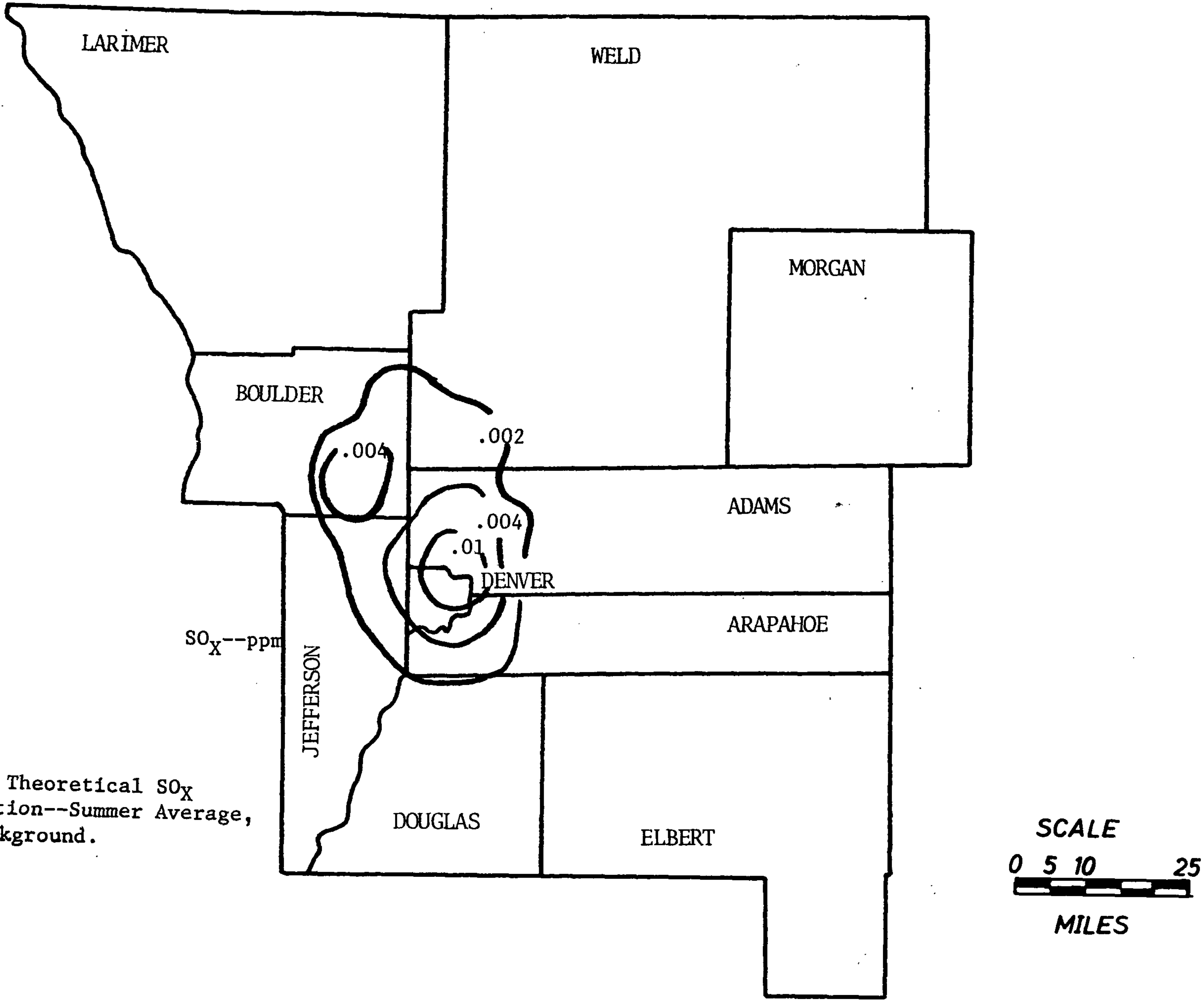


Figure B2. Theoretical SO_X Concentration--Summer Average, Above background.

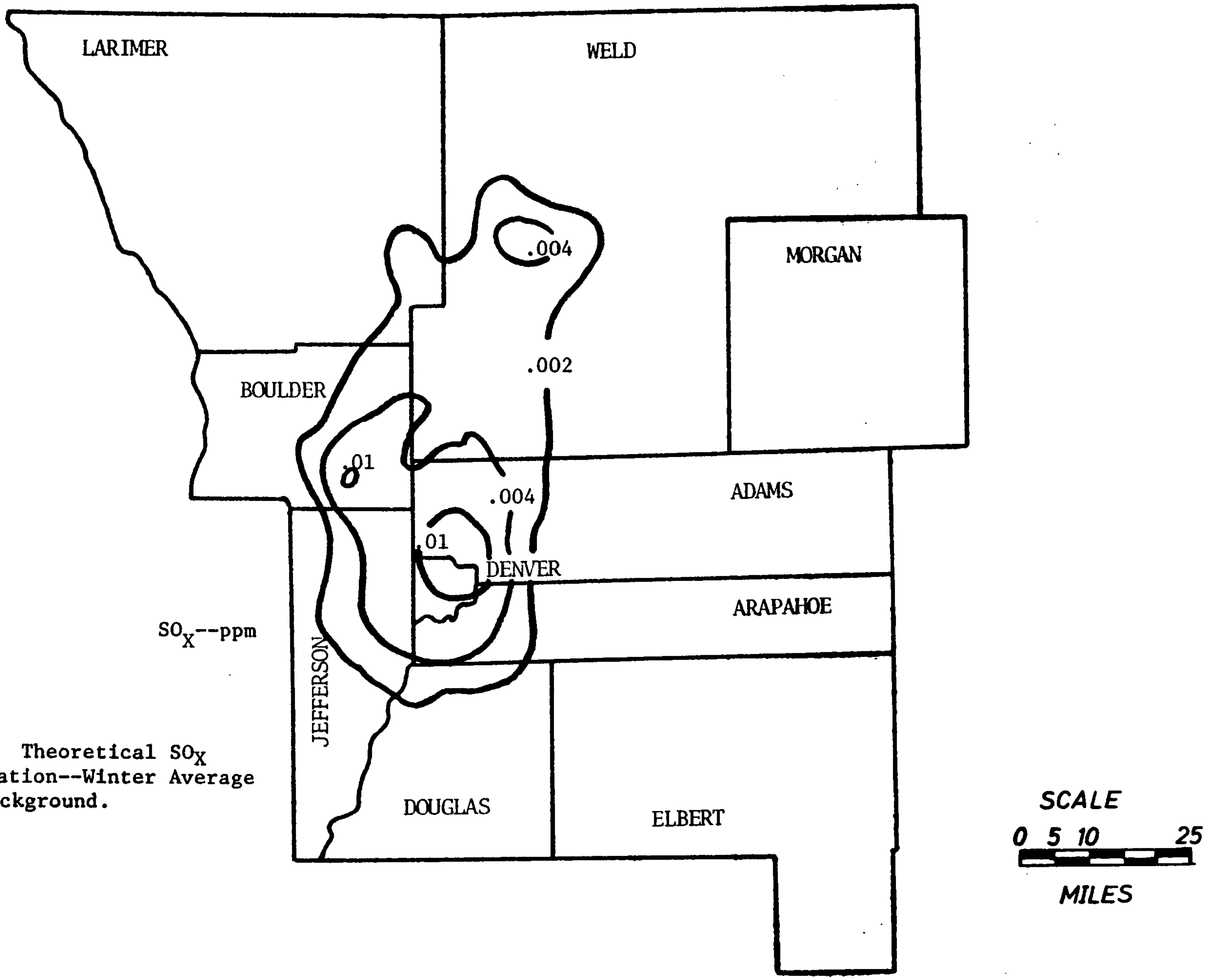


Figure B3. Theoretical SO$_X$ Concentration--Winter Average Above background.

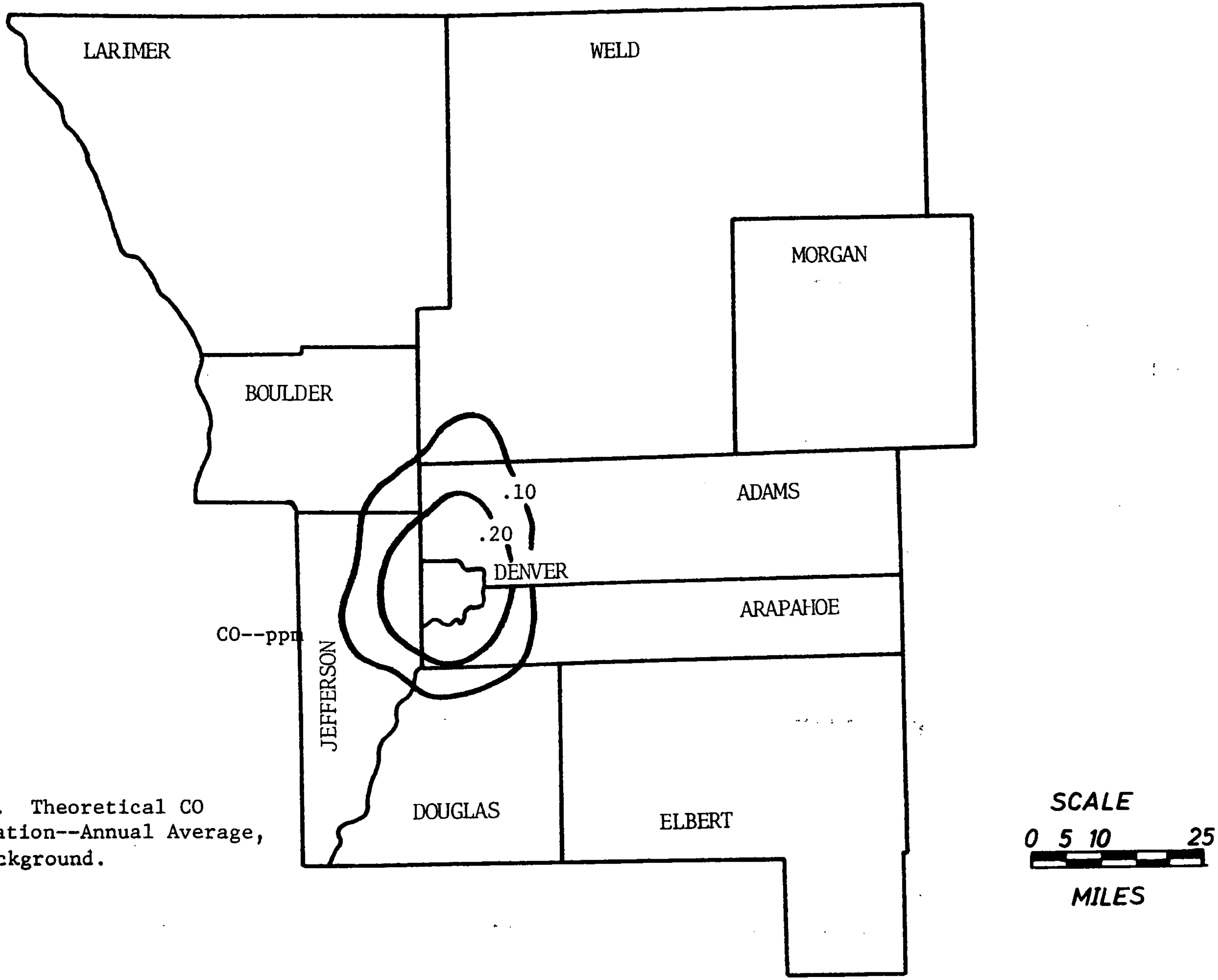


Figure B-4. Theoretical CO Concentration--Annual Average, Above background.

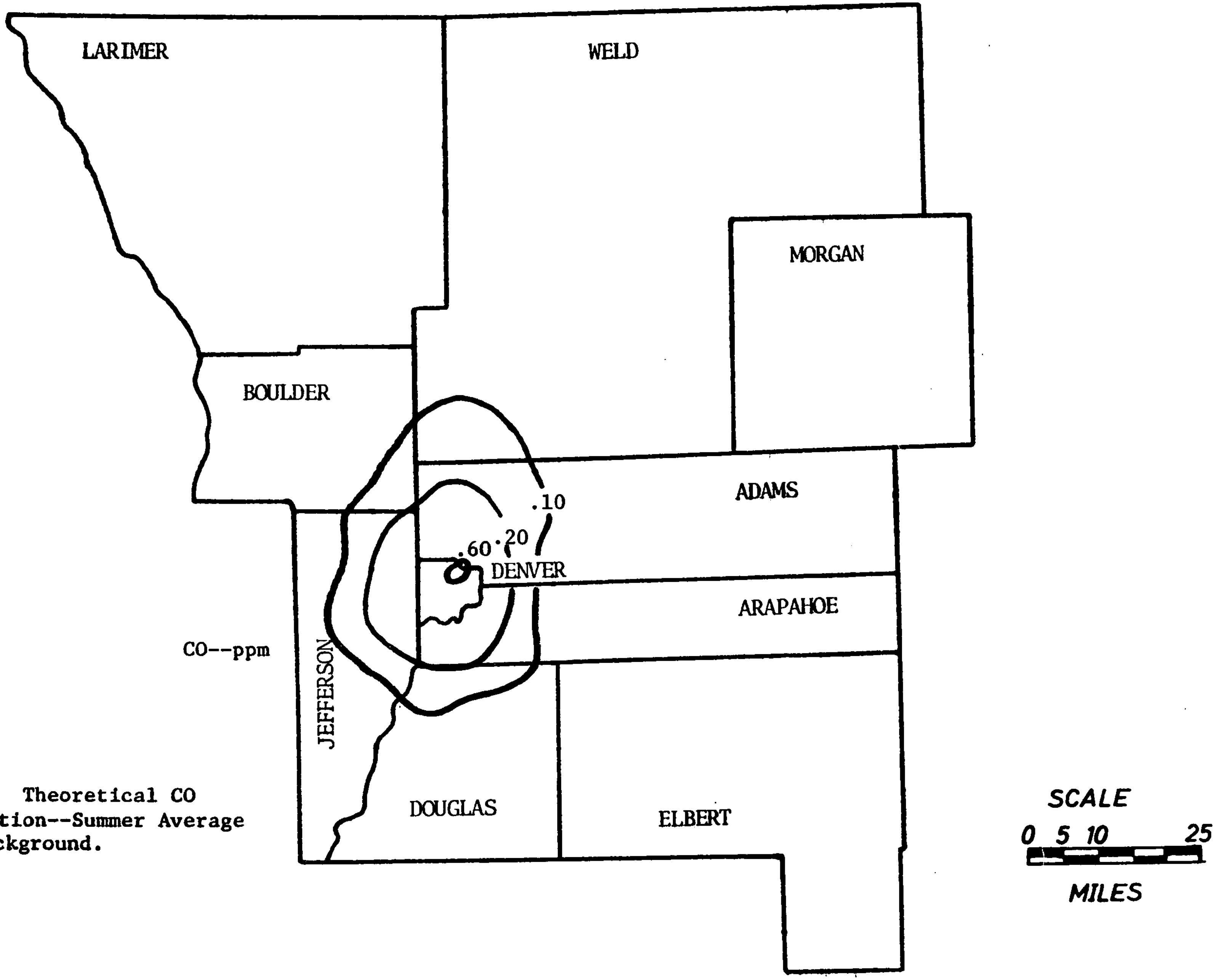


Figure B-5. Theoretical CO Concentration--Summer Average Above background.

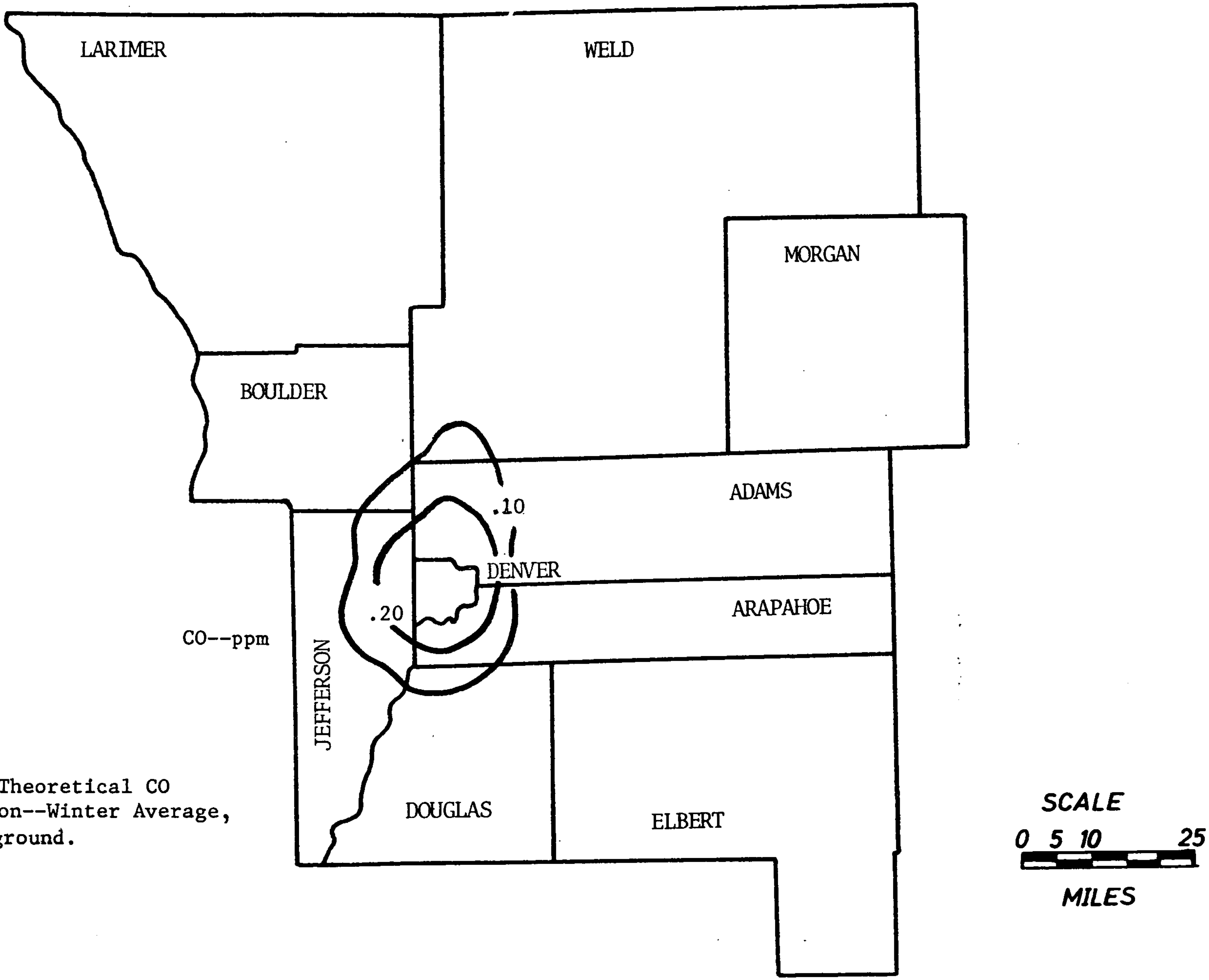


Figure B-6. Theoretical CO Concentration--Winter Average, Above background.

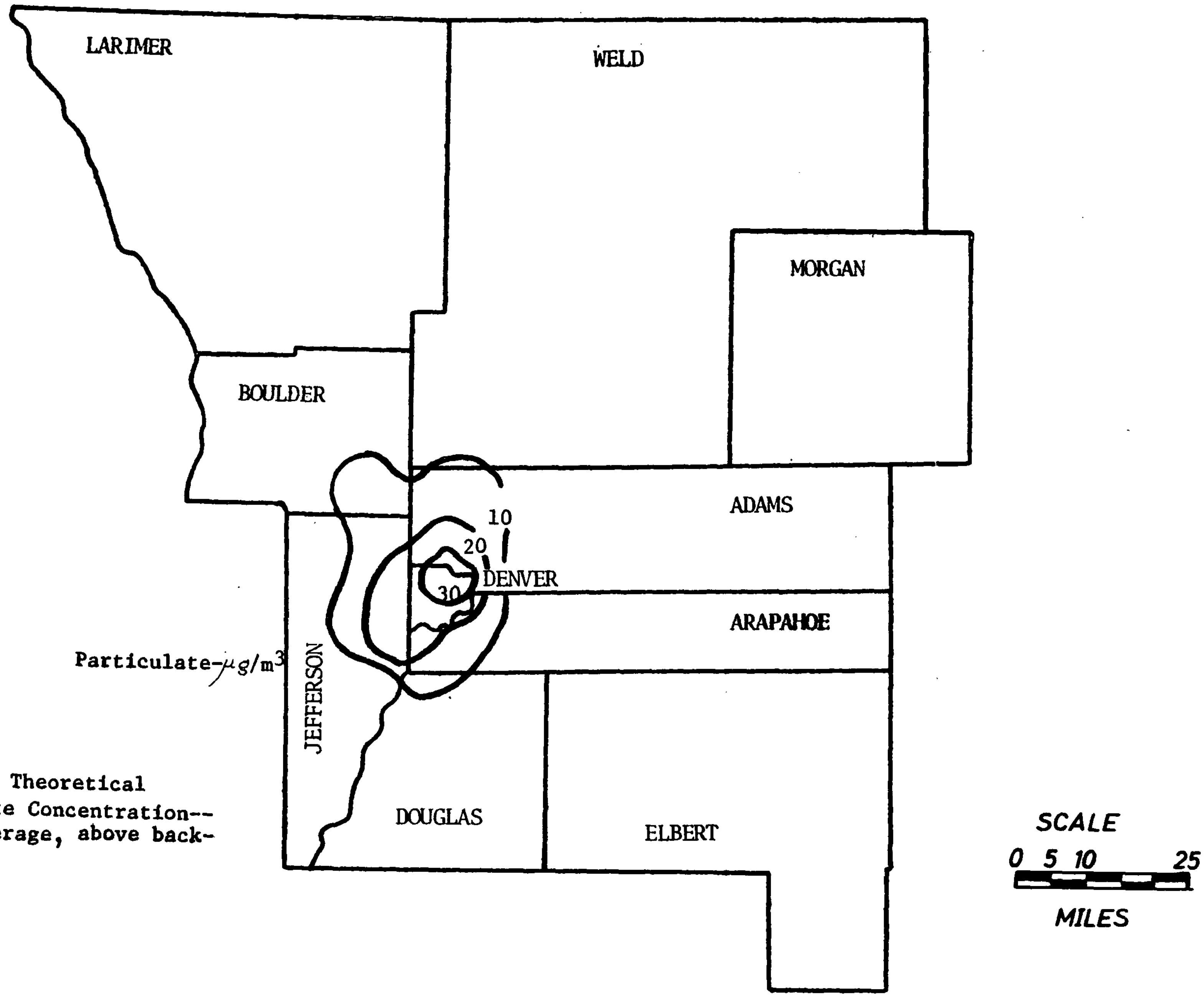


Figure B-7. Theoretical Particulate Concentration--Annual Average, above background.

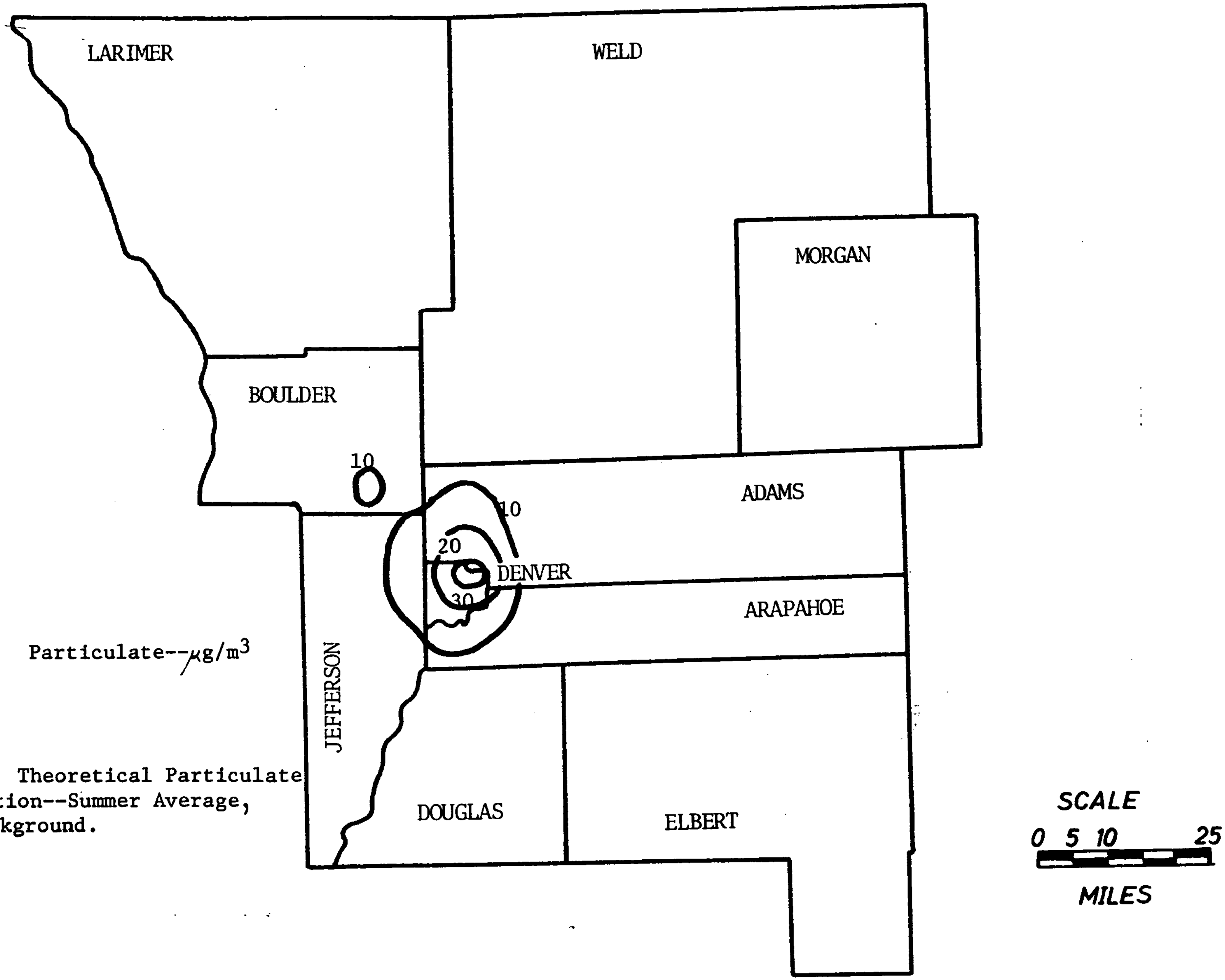


Figure B-8. Theoretical Particulate Concentration--Summer Average, Above Background.

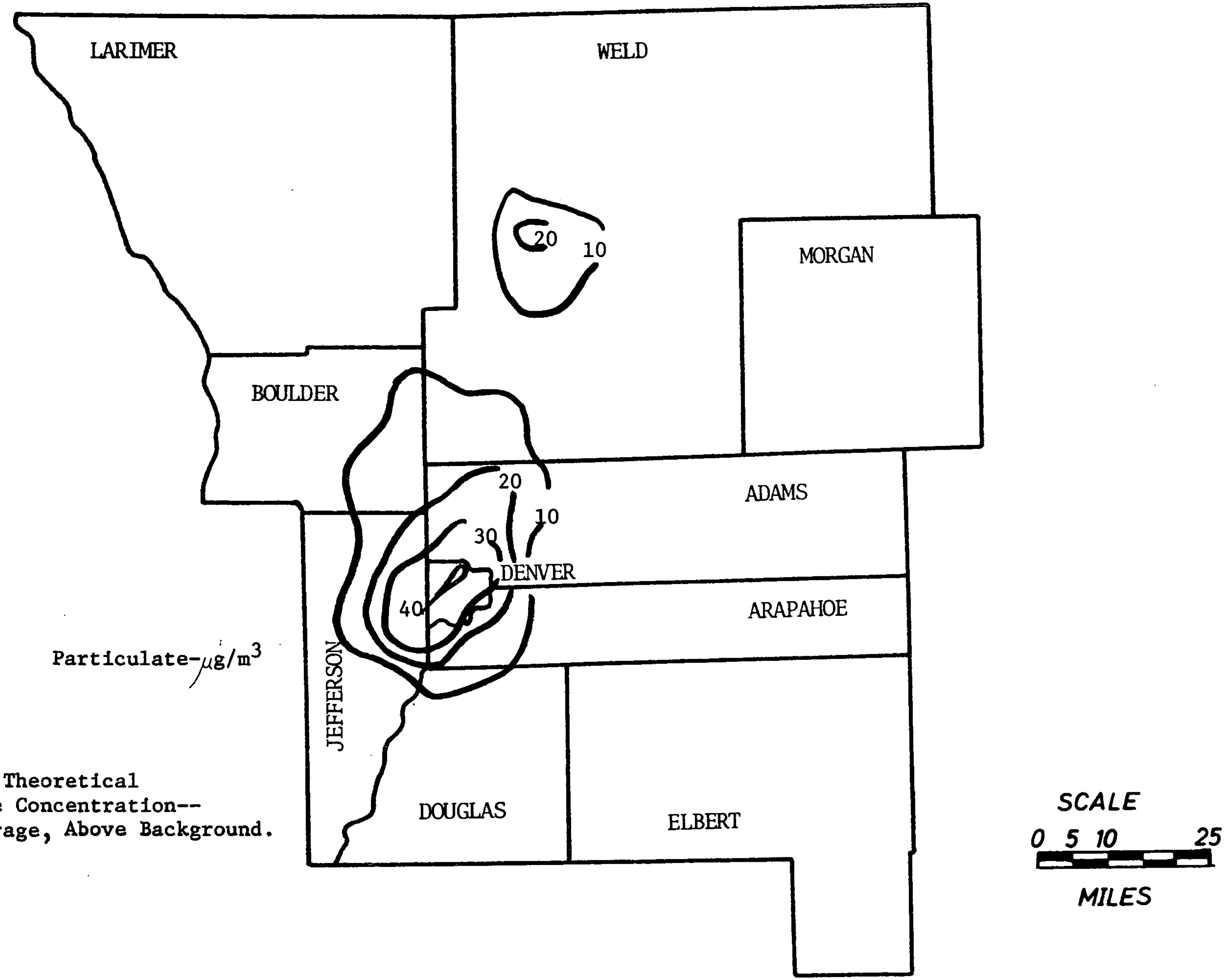


Figure B-9. Theoretical Particulate Concentration--Winter Average, Above Background.

References for Appendix B

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4. Holzworth, G. C., "Mixing Depths, Wind Speeds and Air Pollution Potential for Selected Locations in the United States," J. Appl. Meteor., No. 6, December, 1967, pp. 1039-1044.

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