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GROWTH AND GROWTH CONTROL EFFECTS ON AIR QUALITY IN BOULDER COUNTY, COLORADO

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ABSTRACT

Current literature is equivocal on the effects of such factors as growth control and dispersal of activity centers on environmental features such as air quality. An empirical study in the urban front range corridor of Colorado is reported. Both observed and modeled levels of carbon monoxide and total suspended particulate concentrations suggest that in a county of about 200,000 population, neither growth control policies in the largest city, nor general growth have a significant effect on air quality.

The effect of changing commuting patterns on various socio-economic and physical systems is of growing interest to urban planners. This study examines at a first level of approximation the effects of general growth and changing commuting patterns on air quality for part of Boulder County, Colorado. This is an interesting case because the City of Boulder has had in place since 1977 a growth control ordinance, and almost all of the surrounding cities have experienced rapid growth in the past decade. Whereas it is not possible to disentangle the two phenomenon of growth control in one place and rapid development in others, it is appropriate to examine some of the effects of the resulting overall decentralization in the county.

This paper looks first at the current literature concerning the effect of changing commuting patterns on air quality. The development of commuting in the Boulder commuting area is then examined. A review of observed air quality levels and the results of a simple air quality modeling procedure to project future air quality levels is then presented. Both the review and the

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projections suggest that in a county of about 200,000 population, neither growth control policies in the largest city nor general growth in a dispersed urban pattern have a significant effect on air quality.

PREVIOUS LITERATURE

Hagevik et al. has been among the leading proponents of the idea that air quality goals might be achievable in the long run by land use controls [1]. Among other things they point out that "there is an important need for state coordination of land use planning since land use controls affecting air quality may be inconsistent if not counterproductive unless they are coordinated carefully with land use controls having other objectives." One must make a distinction, however, between control of all kinds of land use which might include heavy industry for example, and land use or controls associated with commuting pattern change which is the focus of the present study.

Conflicting results are found in the literature concerning population distribution and pollution levels. Ingram and Pellechio conclude that a uniform decentralization of activities from an urban core to suburban areas will reduce emissions, and, by implication, pollutant concentrations, in central areas while having a minimal impact in suburban areas [2]; Robson reached a similar conclusion [3]. Dennis also found that dispersing people and automobiles over a greater area lowered the air pollution concentration levels [4].

In contrast, Naroff and Ostro [5] quote Domanski's [6] findings that the average concentration of air pollution for an entire region is greater with a dispersed pattern of population. Naroff and Ostro's own results concur with Robson in that population and employment dispersal will reduce trip patterns affecting the central city and reduce pollution at this location. However, they also find that the affect on pollution in the central city is small being in the order of a 2 per cent difference for NO_x. Part of the conflict in these studies arises because of the difficulty of relating pollution sources, pollutant dispersal and land use patterns [7].

Simulations of the effects of different degrees of dispersion on Denver metropolitan air quality sponsored by DRCOG also showed little effect even when extreme examples were taken [8]. This study concludes that predicted differences in air quality were less than the potential modeling error. Furthermore, the study found that large changes in population and employment produced small changes in ambient air quality. In arguing that land use changes *do* make a difference to air quality levels Yarborough has criticized the DRCOG study on several grounds [9]. These include:

1. the study period of only twenty-one years limited the amount of new urban land that could be considered;
2. VMT results are derived utilizing the same highway transportation plan despite major proposed changes of land use;

3. it is unsatisfactory to examine different land use scenarios without considering personal transport mode changes;
4. no account was made of increased trip lengths due to increased trip speeds resulting from highway engineering improvements; and
5. degradation and replacement of existing houses thus leading to further land use changes were not considered.

Despite these criticism however, it must be remembered that Denver is a large city. The results of other investigations quoted above also refer, for the most part, to large metropolitan areas. Therefore, if these studies are equivocal or show little change in air quality consequent upon widely different commuting patterns, intuitively, it might be expected that the even smaller commuting changes in Boulder County would not have a marked effect on air quality.

COMMUTING PATTERNS IN BOULDER COUNTY

Boulder county is located in the Front Range Urban Corridor about ten miles N.W. of Denver, Colorado (See Figure 1). The county population rose from 130,000 in 1970 to 187,000 in 1980 with the population of the largest city in the county, Boulder, rising from 78,000 to about 94,000 in the same period. Early in 1981 the University of Colorado, Colorado Center for Public Policy Research completed a study on the effect of the growth control policies of the City of Boulder, Colorado on the spatial relations between residence and workplace [10]. This study which will be referred to as the case study, concluded:

1. A larger percentage of employees working in Boulder live outside the Boulder Valley[1] in 1980 than in 1975.
2. The trend toward greater dispersion has been going on at least since 1970 and is not necessarily associated with a growth control ordinance for Boulder City which became effective in 1977.

The results of a concurrent study known at the CETA study[2] using a telephone survey of 1400 Boulder residents concluded:

1. The only change between 1978 and 1980 is an increase in people commuting to Boulder from the outlying small city complex of Louisville, Lafayette, Erie and Superior. This confirms the case studies on commuting patterns but further suggests that people are commuting both ways. New people moving in to Boulder are living and working in the city but some working in the city are moving out to the outlying small city complex.

[1] Boulder Valley is defined by the city planning department as an area slightly larger than the immediate city limits and including some of the major nearby subdivisions such as Gunbarrel Greens and Davidson Mesa.

[2] It is so-called because it was originally funded as a result of the federal Comprehensive Employment and Training Act.

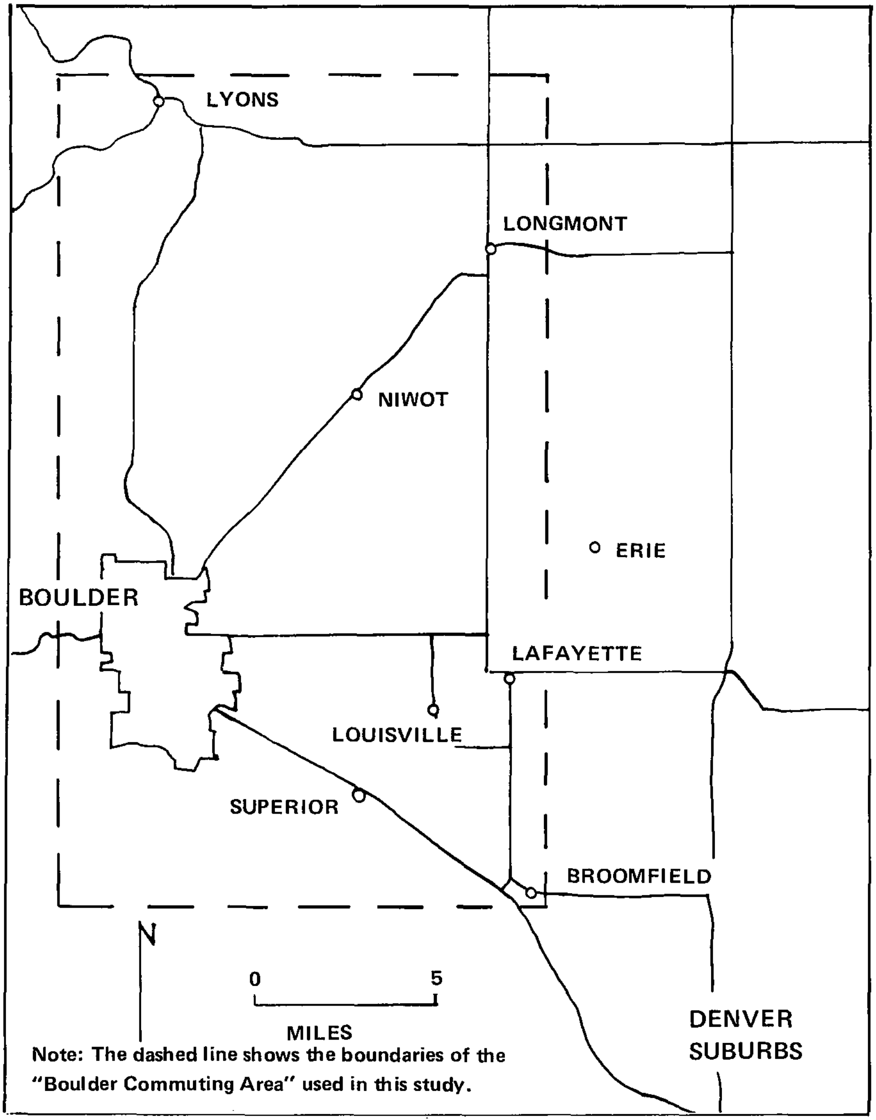

Figure 1. The study area.

2. The impact of Storage Technology Corporation, a large computer oriented employer near the town of Louisville, has had a greater impact on county commuting patterns than Boulder's growth policies.
3. "Commuting is occuring in all directions and although there is some increase in people moving out of Boulder and commuting into Boulder there are significant numbers of the county labor force commuting to Louisville/Lafayette/Erie/Superior and commuting out of Broomfield."[11]

One of the unanswered questions that the case study and the CETA study leave is what are the consequences of these commuting patterns and trends upon such factors as air quality? The present study attempts to answer this question although it must be made quite clear that the necessary data for a truly definitive answer are not available. Nevertheless, it may be possible to make some general conclusions at a very high level of approximation. This may be achieved by considering observed air quality levels over the 1970-80 decade and by modeling possible future air quality values. The latter procedure requires an estimate of vehicle miles traveled (VMT) in association with the changes in commuting.

There are no direct data on VMT for Boulder County. A combination of two sources were used in this study. The first is VMT data supplied by the Colorado State Department of Highways relating to a "Boulder Study Area" that is larger than the area encompassed by Boulder City limits [12]. Second, traffic volume data also from the Department of Highways were used to generate VMT for the major highways external to the "Boulder Study Area." The two data sets giving information from the beginning and end of the 1970-80 period were combined to give VMT for what is called in the present study the Boulder Commuting Area (see Figure 1). Details of the establishment of the data set are given by Greenland [13].

Two types of trends must be distinguished for the purposes of this study. The first is the trend in increased VMT over the 1970-1980 decade due to all sources of growth. The second trend is that amount of VMT increase due only to changing commuting patterns associated with changes in location of residences, work place or both. This section examines both kinds of trends and provides the important input data for the later air quality computation exercise.

Trends due to all growth sources are presented in Table 1. The accumulative approach used here was suggested by Dr. J. S. Fitch who computed the original table from population data, data from the CETA study, and the traffic volume data mentioned earlier. Following from these sources the table assumes intra-Boulder Valley travel to be 9.3 miles/day for both residents and for incommuters while they are in Boulder Valley, in 1970 and a value of 11.0 miles per day for 1980. Intra-Boulder Valley travel and the Boulder Commuting Area travel may be used for air quality computations and constitute what is listed in the table as Regional VMT.

Analysis of these data shows 60 per cent of the Total VMT to be due to commuting (the sum of lines, B, D, F, G, J, L and N) and 25 per cent of the total VMT is due to increased commuting between 1970 and 1980 (the sum of lines D, F, J and N). The value for Regional VMT is used for imput into the air quality model and the value for Total VMT was used for fuel/energy use computations elsewhere [13].

The value of 25 per cent of the total VMT being due to increased commuting is roughly in line with that most often obtained by using different subsets of the available data. For example, the same employers case study data shows an

Table 1. 1980 Boulder Commuting Area Automobile Traffic

Line	Types of Drivers	Numbers of Drivers	VMT	% Regional VMT	% Total VMT
	Intra - Boulder Valley Travel				
A	1970 BV Residents	78,401	729,832	34	28
B	1970 BV in Commuters	9,149	85,168	4	3
C	1980 Additional BV Residents	15,255	142,008	7	5
D	1980 Additional BV in Commuters	9,116	84,860	4	3
E	1970-80 Drivers Doing Additional 1.3 miles Residents		159,353	8	6
F	As in E but for In Commuters		31,079	2	1
	Sub Total		1,232,300	58	47
	Other Boulder Commuting Area Travel				
G	1970 In/Out Commuters	14,840	497,140	23	19
H	1980 Additional Commuters	12,574	421,229		
I	1970-80 Drivers driving decreased 1.0 miles		27,414		
J	Net 1970-80 increase (line I – line J)		393,815	19	15
	Sub Total (Lines G and J)		890,955	41	34
K	Total Regional VMT in Boulder Commuting Area (sum of two above subtotals)		2,123,255	100	80
	Boulder/Denver Commuting				
L	1970 Boulder/Denver Drivers	19,740	335,320		13
M	1980 Boulder/Denver Drivers	28,728	517,104		
N	1970-80 Additional Drivers	8,988	161,784		6
	Sub Total (lines L and N)		517,104		20
O	Total VMT		2,640,359		100

increase in the number of Boulder Valley workers living outside the Boulder Valley of only 11.6 per cent. If this were doubled to allow for the CETA study findings of two way commuting then a case could be made for taking the double value of 23.2 per cent of Total VMT as being due to increased commuting. A separate analysis using geocoded data for three of the sample employers showed the average straight line distance between employee and employer between 1975 and 1980 had increased by 23 per cent of the distance for the later year.

Air quality studies require VMT totals not only for the Boulder Commuting Area but also for some of the major transportation corridors and traffic concentrated areas within the larger area. For the present purposes it is more realistic to compute air quality values for these smaller areas than for the commuting area as a whole. Ingram and Pellechio advocated the need to perform the analysis of land use policies that focus on air quality improvements within a spatial rather than an aggregate framework [2]. Consequently, VMT values for major transportation corridors were computed from the traffic volume data for later input into the air quality modeling system.

There are two ways of estimating the effects of the commuting patterns just described on the air quality of the area. One is to examine the observed air quality as far as data availability permit. The second is to model air quality— an approach which allows for projections into the future. First, observed air quality will be considered.

OBSERVED AIR QUALITY

Several of the criteria (specified by the Clean Air Act) and some non-criteria pollutants have been measured periodically in Boulder County and City since 1963. The longest record for a single pollutant is that for Total Suspended Particulates (TSP) which are partly but not entirely automobile-related. A shorter and more broken record exists for carbon monoxide (CO) a pollutant very closely related to vehicular operation. Data on these two pollutants will be taken in this study as indices for Boulder air quality. TSP is taken because of its length of record and CO is considered because of its relation to traffic intensity.

Values for TSP for Boulder and Longmont since 1963 and 1969 indicate little in the way of any long term trends but clearly show Longmont to have many more particulates in the air than Boulder (See Table 2). The State Health Department suggests 30 ugm/m ^{3} as a natural background value for particulates for Boulder County. During the period 1971 and 1979 when the State Health Standard for TSP was at its present value of 75 ugm/m^3 Boulder reported an average value of 66 ugm/m^3 while Longmont reported an average of 98 ugm/m^3 and never met the standard for any individual year. Data for Broomfield for the period 1977 to 1979 showed that it has more particulates than Boulder and less than Longmont reported an average value for those three years of 73 ugm/m^3 which is just under the standard.

Table 2. TSP Values in ugm^{-3} for Boulder and Longmont

	Boulder		*Longmont*	
Year	*Mean*	*Highest*	*Mean*	*Highest*
1963	103			
1964	70			
1965	60	246		
1966	60		108	
1967	52		93	
1968	75		121	
1969	88	213	108	422
1970	70	177	106	354
1971	71	165	121	376
1972	72	225	108	284
1973	69	226	129	498
1974	61	151	94	563
1975	58	187	88	390
1976	59	136	91	286
1977	65	144	75	185
1978	72	197	84	563
1979	66	169	90	524
1980	69	216	105	382

Note: The state standard for the mean was 90 ug/m^3 before 1970, and 75 ug/m^3 thereafter. Arithmetic means are computer for 1970 and before and geometric means are computer after that. Boulder samples are taken at the Hall of Justice, 13th and Spruce Streets. Longmont samples are taken at Longmont City Hall, 4th and Kimbark Streets.
Source: Data supplied by Boulder County Department of Health.

Unfortunately, the record for CO is severly broken and is by no means as consistent as that for TSP. Table 3 summarizes the longest records available and these refer to Boulder City. None of the second highest readings exceed the state secondary standards during the period 1975 through 1980. Records from the County Health Department indicate that during this period there were only nine violations of the eight-hour primary standard. Eight of these occurred in the winter of 1975/76 and only one further violation has occurred and this took place in the winter of 1980. Some perspective on Boulder's air quality compared to that of Denver may be gained from the fact that during the same period when the eight violations occured in Boulder, 127 violations occurred in Denver at the corner of Colfax Avenue and Colorado Boulevard. The long period data for Boulder show that the arithmetic and geometric means are always well below the secondary standard and probably the primary standard of 9 ppm for eight-hours. However, the natural background value for CO used by the State is 0.18 ppm indicating that there is a significant amount of anthropogenic CO being put into the air of the county.

Table 3. Summaries of CO Values in ppm for Boulder City at 39th and Marine

Month	*Year*	*Number of Hourly Obs*	*Second Highest Reading*	*90th Percentile*	*Arith Mean*	*Geom. Mean*
12/9 - 12/31	1975	550	17.32	7.89	3.41	2.33
1/1 - 5/31	1976	3076	30.56	4.07	1.84	0.99
2/1 - 2/28	1977	658	18.00	3.40	1.15	0.51
3/20 - 5/31	1978	2691	11.50	2.00	0.94	0.54
6/1 - 10/31	1978[a]	2932	11.0	3.00	1.24	0.75
1/8 - 12/31	1979[a]	7371	20.0	3.50	1.60	1.12

[a]Data from new site at Broadway and University.

Source: Data supplied by Boulder County Department of Health.

In summary, present available data show, therefore, that for the latter part of the 1970's, TSP values for the county are near or exceed the state standards but CO levels are for the most part well below state and federal levels. In neither case is there any clearly marked temporal variation in these air quality indices.

MODELED AIR QUALITY

The air quality model used in this study is the simple version of the box model. This has been described in detail by Greenland [14]. Essentially this consists of an imaginary box of air whose sides are determined by the area under consideration and whose height is given by the mixing height. Pollutants are emitted into the box from its based and are considered to be instantaneously mixed through the box volume. Air can pass through the box in the form of wind and effectively increase the volume of the box. The concentration of pollutants in the box is given by dividing the emissions in a specified time by the volume of the box allowing for the action of the wind. Most commonly the concentrations are found for discrete sequential time periods. In the present case a single time period of the morning rush hour is considered when meteorological dispersal is likely to be minimal and air quality worst.

Under these circumstances the ending concentration of a pollutant in the box can be shown to be given as:

$$\chi = Q\,(1 - u/1)\,/\,V$$

where χ is the pollutant concentration ($gm.m^{-3}$), Q is the emission rate (gm. unit $time^{-1}$), u is the wind velocity (m. unit $time^{-1}$), 1 is the box length (m.) and V is the box volume (m^3). This formulation of the model has a couple of disadvantages. First, it does not allow for the memory of the box i.e.; pollutants left over from a previous time period. Second, it is inappropriate for cases when the wind covers a distance in the unit time used that exceeds the box length. In this case the box is completely flushed out but the model indicates physically impossible negative concentrations. Neither of these drawbacks are of great import in the present first order calculations.

Input data for this model were assembled from several sources. VMT were estimated as described earlier. Emission factors are those for high altitude provided by Dr. Robin Dennis, pers. comm., for CO [15]. These relate to an average traffic speed of 30 m.p.h. and are those used by NCAR's Denver Metropolitan study. An emission factor for TSP emissions was taken from EPA [16]. The factor of 0.58 gm. $mile^{-1}$, composed of exhaust and tire wear output, does not change over time. Unfortunately, no systematic way of including fugitive dust, thrown up by vehicles and important at times of road sanding in winter could be found. The areas of the boxes are given in Table 4. Areas for transportation corridors are derived by multiplying the length of the corridor by a one kilometer width. In some cases the boxes lie at an angle to the presumed westerly wind direction. This has the effect of shortening the length of the box so that its effective length is $L \cos \Theta$ where Θ is the angle between the box and the wind. This is incorporated into the model for boxes lying at an angle to the prevailing wind direction. Wind velocity and direction data were supplied for a site just east of Boulder by the National Oceanographic and Atmospheric Administration [17].

The air quality for carbon monoxide resulting from an application of the box model in the manner described is indicated in Table 5. The values in the table are referred to the secondary 1-hour federal and state standard rather than the primary eight-hour standard because only the morning rush hour is being considered.[3] The table demonstrates that in the county as a whole CO concentrations are far below federal and state standards and are likely to remain that way even if VMT were to continue at its growth rate for 1970-80. Computations were made for all the major transportation corridors into Boulder and the poorest air quality was found for the Broomfield/Denver corridor. However, Table 5 also indicates that projected carbon monoxide values here are also well below the standard. The main reason for this is that emission factors are projected to decrease in future years. If it is assumed that vehicle emissions do not improve above their 1980 value, CO concentrations become worse faster but the projected levels still do not give cause for concern.

It should not be assumed, however, that Boulder citizens are completely safe from episodes of poor air quality. The situation of the memory of the box where under zero or very low wind speeds and low mixing height pollutants from a previous time period are not flushed out, can fairly quickly lead to excessive

[3] Primary federal air quality standards are formulated using health criteria. Secondary standards relate to human welfare. Because of meteorological conditions in Boulder County it is rare for poor air quality to exist over an eight hour period.

Table 4. Areas of Boxes Used in the Study and the Angle of the Box to the Prevailing Wind

Location	*Area m^2*	*Area/Wind Angle*
Boulder Commuting Area	795,748,500	0
Longmont/Niwot Corridor	20,900,000	40
Broomfield/Denver Corridor	17,700,000	60

Table 5. Air Quality – Carbon Monoxide (Referred to Secondary 1 Hr. Standard – Morning Rush Hour)

Date	*Location*	*% Standard No Airflow*	*% Standard With Wind*
1970	Boulder Commuting Area	1.1	0.9
1980		1.5	1.2
1970-80		0.4	0.3
1990		1.2	0.9
2000		1.6	1.2
2010		2.7	2.1
2020		4.6	3.6
1970	Broomfield/Denver Corridor	5.6	3.2
1980		6.4	3.7
1990		4.2	2.2
2000		4.8	2.4
2010		6.8	3.5
2020		9.9	5.1
	With No Improvement in Emission Control Beyond 1980		
1990	Boulder Commuting Area	2.6	2.0
2000		4.5	3.5
1990	Broomfield/Denver Corridor	9.3	4.8
2000		13.6	7.0

Note: Calculations assume constant decadal growth rate in VMT as between 1970-80.

pollutant concentrations. If, for example, the 1980 airflow value for CO concentration (Table 5) is taken then if meteorological conditions did not change and if the emission rates remained the same[4] the secondary standard

[4]This is not very likely since it demands that traffic volume at 'rush hour' rates is continued throughout the day.

would be exceeded in 15.6 hours and the primary standard would be exceeded before that. It must also be remembered that vehicles are not the only source of pollutant emissions, and the effects of emissions from stationary sources and from sources outside the study area whose pollutants might be brought in, must also be considered.

An attempt was also made to examine the concentration values for total suspended particulates (TSP). The same approach was used with the exception that the rather high background concentration value of TSP for the area was added to all the computations. The effect of this is demonstrated in Table 6. Values of TSP associated with vehicle exhaust and tire wear increase only slowly through the year 2000. These values give a slightly false impression because they do not include the effect of fugitive dust thrown up by vehicles following winter sanding operations. However, on the other hand, it is quite possible that revisions to the TSP standard in the near future are likely to have the effect of relaxing the standard when the size of the particulates is taken into account. The main reason for the small effect of increased commuting on TSP values is that vehicle TSP emissions are only about 1/10 of the background levels.

The concentrations of CO and TSP listed in Tables 5 and 6 are low and refer to all commuting. If the high value of 25 per cent of all commuting is taken as that representative of commuting due to changing geographical patterns of commuting then the values show that the changing patterns have only a small effect on air quality.

The results of actual air quality observations and model projections illustrate a number of features. Both in the county as a whole and along its major transportation corridors, carbon monoxide concentrations have been far below federal and state standards. The effects of increased VMT between 1970 and 1980 and of changing commuting patterns (25% of total VMT) are noticeable but rather small in terms of increased carbon monoxide concentrations. Carbon monoxide pollution associated with vehicles involved in the changing commuting

Table 6. Air Quality - Total Suspended Particulates (Referred to Primary 24 Hr. Standard)

Date	*Location*	*% Standard No Airflow*
1970	Boulder Commuting Area	12.3
1980		12.7
1990		13.5
2000		14.7
1970	Broomfield/Denver Corridor	12.0
1980		12.4
1990		12.8
2000		13.4

patterns is negligible in the transportation corridors where it might be expected to be more marked. Assuming growth of VMT values at the 1970-1980 rate, commuting will not significantly contribute to a carbon monoxide problem in the foreseeable future. Computations of TSP levels through the end of the century also show that increased commuting has little effect. All these statements refer to average worse case meteorological conditions that might apply during a typical winter morning rush hour and not to atmospheric conditions of stagnation which could lead to air pollution episodes.

CONCLUSIONS

Overall it may be concluded that in a county of about 200,000 population, neither growth control policies in the largest city nor general growth in a dispersed urban pattern have a significant impact on air quality. This conclusion would support the earlier modeling studies that suggest land use changes leading to different commuting amounts and patterns have little effect on air quality. It must be remembered, however, that the earlier studies refer to a larger metropolitan area than is considered here. Nevertheless, the present results remain important within the planning context, at least in the present instance. They have, for example, been partly instrumental in a formal continuation of the Boulder City growth control ordinance. If more communities adopt growth control measures commuting patterns may not remain fixed over a longer period of time and more attention may have to be given to the effects of such changes on air quality and other environmental aspects.

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