# TECHNICAL SUPPORT DOCUMENT

## CARBON MONOXIDE REDESIGNATION REQUEST AND MAINTENANCE PLAN FOR THE DENVER METROPOLITAN AREA

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# 1. Introduction

This document presents the emissions and air quality modeling methodologies and results upon which the Denver carbon monoxide (CO) redesignation request and maintenance plan are based. It also presents a summary of carbon monoxide monitoring data for 1997, 1998, and 1999. It supports Colorado's request that EPA redesignate the Denver metropolitan area to attainment status for the National Ambient Air Quality Standards (NAAQS) for carbon monoxide. The Denver metropolitan area has been designated as a CO nonattainment area since the 1970s but has not violated the standard since 1995. Therefore, the area is now eligible for redesignation.

## 1.1. Background

### 1.1.1. National Ambient Air Quality Standards for Carbon Monoxide

The EPA has two standards for carbon monoxide, a rolling 8-hour average concentration of 9.0 parts per million (ppm) and a 1-hour concentration of 35 ppm. The national standard for carbon monoxide allows for no more than one exceedance of either standard in each calendar year. A violation occurs when two or more exceedances of the standard are recorded at the same monitoring site during a calendar year.

### 1.1.2. Health Effects of Carbon Monoxide

Carbon monoxide is a colorless, odorless, tasteless gas that enters the body through the lungs where it is absorbed by the bloodstream and then combines with hemoglobin in the red blood cells. Hemoglobin is the compound in the red blood cells that normally picks up oxygen from the lungs and carries it to the tissues. In the lungs, CO competes with oxygen for available hemoglobin. When CO binds with hemoglobin, it forms carboxyhemoglobin (COHb). Carbon monoxide attaches to hemoglobin much more readily than does oxygen. Once attached it does not disassociate from the hemoglobin as easily as oxygen. As a result, COHb levels can continue to increase in the bloodstream and the amount of oxygen being distributed throughout the body is reduced.

Blood containing CO can weaken heart contractions, lowering the blood volume being distributed through the body. Effects include fatigue, dizziness, headaches, loss of visual acuity, and mental confusion. Individuals with cardiovascular or chronic obstructive pulmonary disease, pregnant women, and children are at greatest risk from exposure to CO. Carbon monoxide also affects the central nervous system by depriving it of oxygen. Therefore, even healthy individuals can experience adverse effects from CO exposure, such as a reduced ability to concentrate. Carbon monoxide exposure in high altitude environments like the Denver area can present a greater risk because of the lower levels of oxygen present in the atmosphere.

### 1.1.3. Denver Carbon Monoxide Area Designation History

The Denver metropolitan area was originally designated as nonattainment for CO under provisions of the 1977 CAA Amendments. This designation was reaffirmed by the

1990 CAA Amendments when the Denver area was classified as a moderate CO nonattainment area with a design value greater than 12.7 ppm. The Denver metropolitan area was then reclassified as a "serious" nonattainment area by EPA in 1997 for failing to demonstrate attainment of the CO standard by the December 31, 1995 deadline for moderate areas.

The CO standard has not been violated in the metro area since 1995, making the area eligible to submit this request for redesignation to attainment status for the carbon monoxide standard.

### 1.1.4. Denver Metropolitan Attainment/Maintenance Area

The six-county Denver metro area is characterized by a broad valley along the South Platte River. The terrain to the east of the region is dominated by gently rolling plains while the Front Range foothills of the Rocky Mountains dominate the west. The elevation of downtown Denver is 5,280 feet above sea level, with somewhat higher elevations in some suburban areas.

The boundaries of the metro Denver nonattainment area are defined in Colorado's Ambient Air Quality Standards Regulation. Once redesignated, these will become the boundaries of the attainment/maintenance area. The area includes the entire City and County of Denver; those portions of Adams and Arapahoe counties west of Kiowa Creek, the portion of Douglas County below 6,000 feet, the portion of Jefferson County below 6,000 feet but including the US-6, I-70, and US-285 highway corridors; and the southeast portion of Boulder County below 6,000 feet (see Figure 1). The City of Longmont in Boulder County is a separate carbon monoxide nonattainment area and is the subject of a separate maintenance plan which has already been approved by EPA. The legal description of the area follows:

*Start at Colorado Highway 52 where it intersects the eastern boundary of Boulder County; Follow Highway 52 west until it intersects Colorado Highway 119; Follow northern boundary of Boulder city limits west to the 6000- ft. elevation line; Follow the 6000- ft. elevation line south through Boulder and Jefferson Counties to US 6 in Jefferson County; Follow US 6 west to the Jefferson County-Clear Creek County line; Follow the Jefferson County western boundary south for approximately 16.25 miles; Follow a line east for approximately 3.75 miles to South Turkey Creek; Follow South Turkey Creek northeast for approximately 3.5 miles; Follow a line southeast for approximately 2.0 miles to the junction of South Deer Creek Road and South Deer Creek Canyon Road; Follow South Deer Creek Canyon Road northeast for approximately 3.75 miles; Follow a line southeast for approximately five miles to the northern-most boundary of Pike National Forest where it intersects the Jefferson County-Douglas County line; Follow the Pike National Forest boundary southeast through Douglas County to the Douglas County-El Paso County line; Follow the southern boundary on Douglas County east to the Elbert County line; Follow the eastern boundary of Douglas County north to the Arapahoe County line; Follow the southern boundary of Arapahoe County east to Kiowa Creek; Follow Kiowa Creek northeast through Arapahoe and Adams Counties to the Adams-Weld County line; Follow the northern boundary of Adams County west to the Boulder County line; Follow the eastern boundary of Boulder County north to Highway 52.*

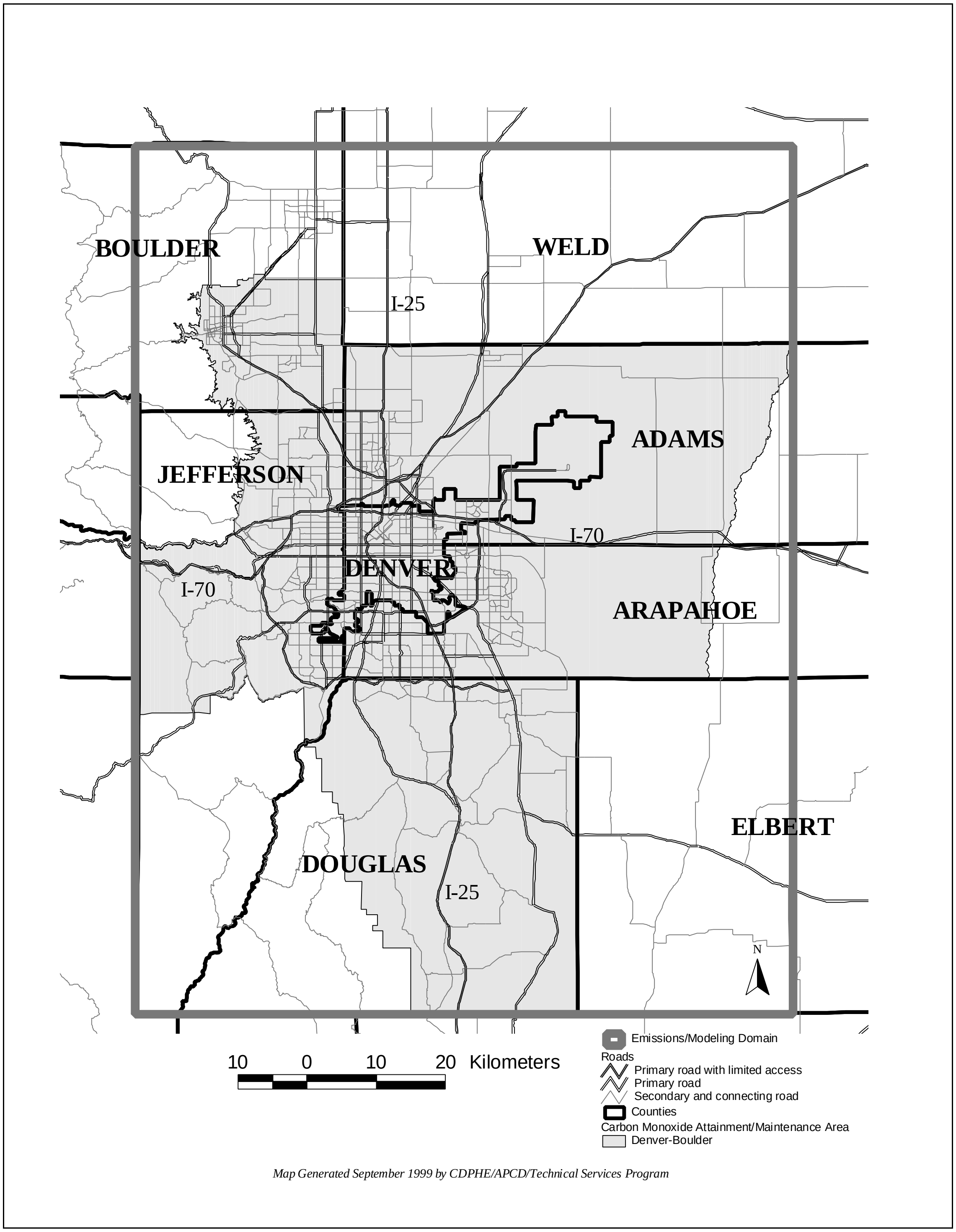


**Figure 1. Denver metropolitan area carbon monoxide (CO) Urban Airshed Model (UAM) domain and the Nonattainment Area (NAA) boundary. Once the NAA is redesignated for CO, the NAA is known as the Attainment/Maintenace Area. The State is not changing the boundaries, only the area's desgination.**

### 1.1.5. Topography, Climate, and Air Quality Meteorology

The climate of the Denver metropolitan area is strongly affected by local and regional topographic features. Denver is situated in the plains along the South Platte River Valley approximately 80 kilometers (50 miles) east of the Continental Divide. The Rocky Mountains rise to an elevation of about 3,200 to 4,300 meters (10,500 to 14,200 feet) just to the west of the city.

The meteorological site at Denver's closed Stapleton International Airport is at an elevation of about 1,611 meters (5,285 feet), the meteorological site at the new Denver International Airport is at an elevation of about 1,650 meters (5,412 feet). Greeley, which is north of Denver in the South Platte River Valley, is at an elevation of about 1,400 meters (4,600 feet). About 112 kilometers (70 miles) north of Denver is an east-west rise of land called the Cheyenne Ridge. It is roughly 1,800 –2,000 meters (6,000 to 6,500 feet) in elevation. About 25 miles to the south is another east-west running ridge called the Palmer Divide which rises to 1,800-2,300 meters (5,900 to 7,500 feet). These features form a three-sided basin and work in concert to influence airflow patterns and climate in the Denver metropolitan area, as shown in Figure 2.

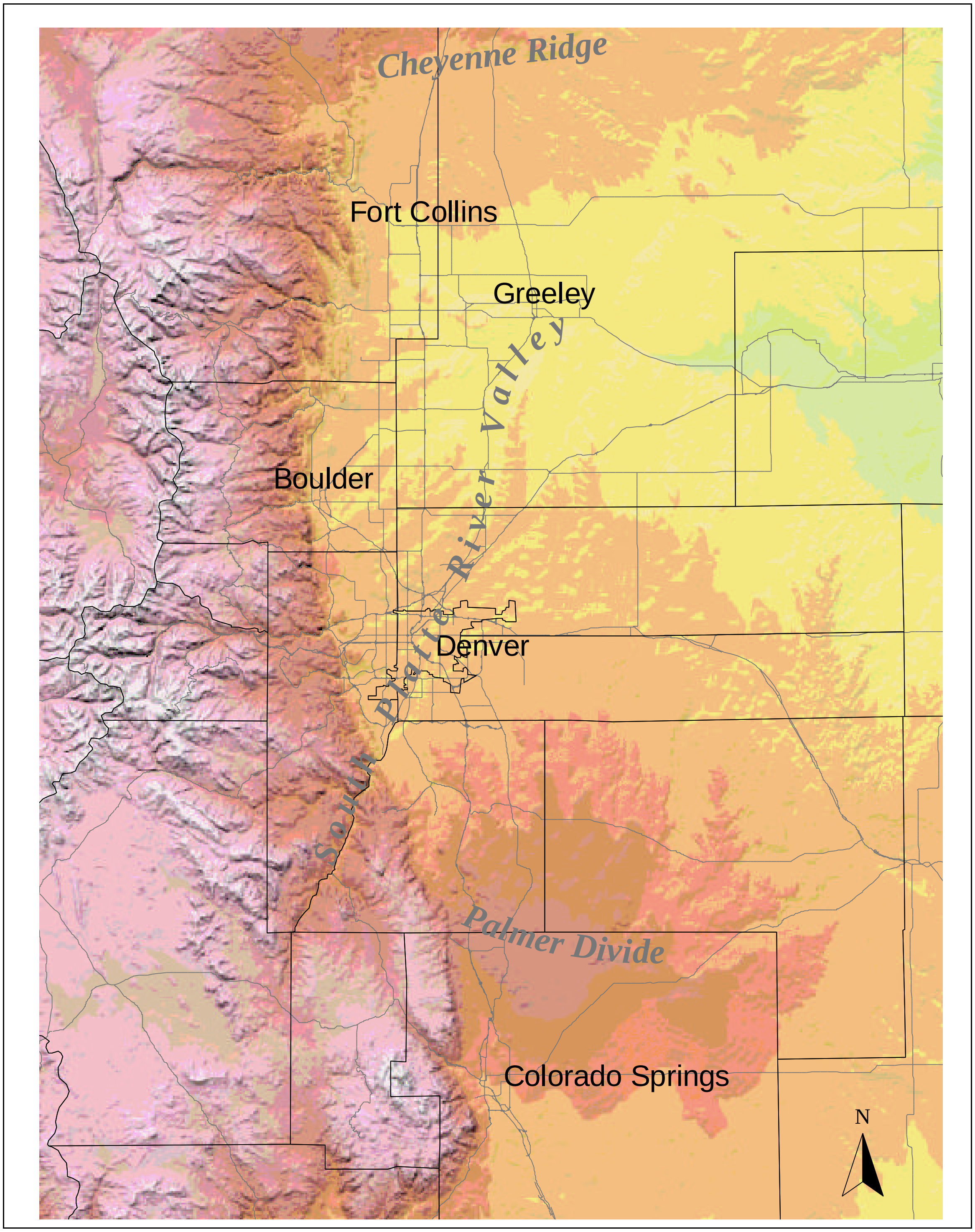


**Figure 2. Shaded relief map showing the topography in the Denver area.**

On average, Denver experiences low relative humidity, light precipitation, and abundant sunshine. Moisture from the Pacific must travel a long distance and over several high mountain barriers. Gulf moisture must be driven up-slope and against the prevailing westerly winds aloft.

From 8/1/1948 to 12/31/1998, Denver's annual average maximum temperature is 17.9EC (64.2EF), the annual average minimum is 2.6EC (36.6EF), and the normal daily mean temperature is 10.2EC (50.3EF). The city receives an average of 15.6 inches of total precipitation per year and an average total snowfall of 61.9 inches of snowfall. Denver receives an average of 70 percent of the possible sunshine during the year.

The prevailing wind direction in the South Platte River Valley is out of the south. The direction of the prevailing wind is a result of frequent evening, nighttime, and morning drainage wind off of the mountains and the Palmer Divide. These winds are channeled along the Platte River Valley. The other frequent wind direction is from the north. The relatively high frequency of winds from the north is the result of flow up-valley channeled along the Platte River Valley.

Local and regional topography greatly influences not only the climate, but also the dispersion of CO. In a paper written in 1989[1], W. D. Neff identified five flow regimes which impact the dispersion of the Denver "brown cloud." Of the five, stagnation is the main one associated with elevated concentrations of CO.

W. D. Neff suggests that "stagnation periods, those with relatively light and variable winds, usually occur following a period of upvalley flow of a cold air mass. In this cycle, large-scale pressure gradient forces cause a layer of cold air that has accumulated in the lowlands to move uphill towards the foothills. As this dense air mass follows the slope, an internal pressure force develops that begins to counteract the external one. For this reason the air mass may slow down as it approaches the mountains and a period of stagnation follows. When the forces involved are fairly weak, this process will be relatively gentle and the period of calm following the return flow may last many hours. However, in cases where the initial motion towards the foothills shows more vigor, the cold air will tend to overshoot and then flow back away from the foothills. In Denver, for example, one often observes a return flow carrying pollutants to the southwest through the city, a short period of relative calm, and then an outflow as the air moves back into the lowlands."[2]

The Air Pollution Control Division has forecast winter season high pollution events for more than a decade. This effort has been supported by significant field study and research by scientists with the National Oceanic and Atmospheric Administration (NOAA) Wave Propagation Laboratory. This research indicates that patterns of flow and their interaction in the region can be complex. Fortunately, these patterns have been well documented and provide a basis for understanding air quality climatology, thus assisting in formulating and evaluating air quality modeling efforts.

## 1.2. Requirements For Redesignation

Sections 107(d)(3)(D) and (E) of the CAA define the five required components of a redesignation request and maintenance plan. The five required components are addressed in detail in a separate document: "Carbon Monoxide Redesignation Request and Maintenance Plan for the Denver Metropolitan Area."

### 1.2.1. Attainment of the Standard

The State must show that the area has attained the national standards for carbon monoxide.

### 1.2.2. State Implementation Plan Approval

The State must have a fully approved carbon monoxide State Implementation Plan (SIP).

### 1.2.3. Improvement in Air Quality Due to Permanent and Enforceable Emissions Reductions

The State must demonstrate that the improvement in air quality leading to attainment of the standards is due to permanent and federally enforceable emissions reductions.

### 1.2.4. CAA Section 110 and Part D Requirements

The State must meet all requirements of Section 110 and Part D of the CAA. Section 110 describes general requirements for SIPs, while Part D pertains to general requirements applicable to all nonattainment areas. Refer to Appendix K – Section 110 of the Clean Air Act – for additional details.

### 1.2.5. Maintenance Plan

The State must have a fully approved CO maintenance plan that meets the requirements of CAA Section 175A, including a demonstration that the area will maintain the standard for a period of at least 10 years following redesignation by EPA. The plan must also contain contingency measures that could be implemented if a violation of the standard is monitored at any time during the maintenance period.

# 2. Emission Inventories

## 2.1. Emission Inventories Used in the Urban Airshed Model

Table 1 summarizes the inventories used in the approved CO SIP and in the 2006 and 2013 maintenance plan modeling. In the following table and elsewhere in this document, the precision of the results is not intended to imply a level of accuracy.

**Table 1. Emission inventories for the Denver carbon monoxide Urban Airshed Modeling.(1)**

| **Source Category** | 2001 Attainment SIP Inventory (tons per day) | 2006 Interim Year Inventory (tons per day) | 2013 Maintenance Year Inventory (tons per day) |
|---|---|---|---|
| Surface Point Sources(2) | 44.6 | 21.1 | 21.1 |
| Elevated Point Sources(3) | 25.6 | 25.6 | 25.6 |
| Woodburning | 50.6 | 32.8 | 25.8 |
| Natural Gas | 7.1 | 9.1 | 10.0 |
| Structural Fires | 3.9 | 5.0 | 5.5 |
| Agriculture Equip. | 0.3 | 0.3 | 0.3 |
| Airport - Aircraft | 16.3(4) | 22.3(4) | 24.4(4) |
| Airport Service Equip. | 7.6(4) | 7.2(4) | 7.7(4) |
| Construction Equip. | 9.9 | 7.9 | 8.1 |
| Industrial Equip. | 25.1 | 22.8 | 23.7 |
| Light Commercial Equip. | 136.6 | 125.9 | 131.3 |
| Helicopters | 0.4 | 0.4 | 0.4 |
| Railroads | 0.3 | 0.3 | 0.3 |
| On-Road Mobile | 875.2 | 844.7 | 867.2 |
| **TOTAL** | 1203.5 | 1125.4 | 1151.4 |

(1) The precision of the estimates is not intended to imply a level of accuracy.
(2) The point source emissions reduction from 2001 to 2006 is due to the use of actual instead of allowable emissions in 2006. Refer to section 2.6.1 for a discussion about point source growth in the future.
(3) Elevated points have been modeled with potential-to-emit, as done in the approved CO SIP (CDPHE, 1994).
(4) Revised Denver International Airport emissions for 2001, 2006, and 2013 are listed in section 2.5.1.

## 2.2. Demographic and Transportation Data

The Vehicle Mile Traveled (VMT) estimates are based on the Urban Transportation Planning System (UTPS) model run by the Denver Regional Council of Governments (DRCOG). Refer to Chapter 7 of the approved Denver CO SIP Technical Support Document (CDPHE, 1994) for a description of the travel demand forecasting process used in the 2001 estimates for approved CO SIP. For the maintenance period transportation modeling documentation, refer to Appendix N.[a]

In mid-1999, DRCOG updated growth projections for the region. The latest projections for population, households, and employment through 2020 are substantially higher than the previous estimate. At this time, updated transportation and demographic data sets incorporating these new projections are not available. In order to avoid understating the demographic and VMT numbers in this maintenance plan, the RAQC and the APCD were advised by DRCOG to use the current 2011 data sets as representative of 2006 and the current 2020 projections (plus 3.7%) as representative of 2013. The following table shows the 2006 and 2013 demographic and VMT data used to develop the maintenance plan emission inventories. It also presents current 2001 estimates along with the 2001 estimates made in the early 1990s for the CO SIP.

**Table 2. Demographic data used to develop emission inventories (modeling domain).**

| Period | Population | Households | Employment | Daily VMT |
|---|---|---|---|---|
| 2001 (SIP estimate) | 2,021,000 | 838,000 | 1,181,000 | 51,796,000 |
| 2001 (Current estimate) | 2,364,000 | 970,000 | 1,415,500 | 58,156,000 |
| 2006 | 2,616,000 | 1,097,000 | 1,568,000 | 66,760,000 |
| 2013 | 2,889,000 | 1,244,000 | 1,718,000 | 77,187,000 |

[a] No credit has been taken in DRCOG's transportation networks for the transportation control measure (TCM) contingency measures which are being removed from the approved Denver CO SIP.

## 2.3. Residential Woodburning

A survey of Denver metropolitan area woodburning devices and habits was conducted in 1988 by Community Response. Information from this survey was used to formulate an estimate of residential woodburning emissions for the UAM modeling for the Denver-Metro design day evaluation (December 5, 1988). Subsequent to the Community Response Survey, another survey of Denver metropolitan area woodburning devices and habits was conducted in 1991 by R. Bruce Hutton, Ph.D and Steven W. Hartley, Ph.D. This survey was the basis for the residential woodburning used in the 2001 UAM attainment demonstration as well as all other woodburning emission estimates subsequent to 1991. The following calculation of residential woodburning carbon monoxide emissions for 2006 and 2013 result directly from the Hutton survey as it was applied to the 1996 and 2001 inventories developed for the Colorado Carbon Monoxide State Implementation submission in 1994.

**Table 3. 2006/2013 Residential woodburning carbon monoxide emission inventory.**

| Source Type | Year | Emission Estimates | | |
|---|---|---|---|---|
| | | (Grams/season) | (tons/season) | (tons/design day) |
| Fireplaces | 2006 | 3097317779.4 | 3414.15 | 14.68 |
| Stoves | 2006 | 3811651428.5 | 4201.56 | 18.07 |
| Fireplaces | 2013 | 2007523881.9 | 2212.88 | 9.52 |
| Stoves | 2013 | 3428823840.7 | 3779.57 | 16.25 |

Note: tons/season to tons/design day factor = .0043. This factor is based on the fraction of the 1988-1989 heating season heating degree-days that occurred on December 5, 1988. This is documented in the Carbon Monoxide State Implementation Plan Technical Support Document (CDPHE, 1994). The precision of the estimates is not intended to imply a level of accuracy.

### 2.3.1. Fireplaces emissions calculations (grams/household)

#### 2.3.1.1. Variable Definition

Variables used in fireplace emission calculations follow:

fp_06 = number of fireplaces in region
fp_06-co = CO grams/HH rate of fireplace emissions
fp_13 = number of fireplaces in region
fp_13-co = CO grams/HH rate of fireplace emissions
fp-use = percent of devices in use
fp-cords = cords burned per year
kilograms of wood per cord = 1100
fireplace emission rate = 61.1 grams/KG of wood burned

#### 2.3.1.2. Number of Woodburning fireplaces

It is assumed that the population of conventional fireplaces is replaced with gas devices at the rate of 6% percent, compounded per year:

fp06 = (1996 fireplaces) * (0.54)

where 0.54 = 0.94^10 or 6% reduction, compounded per year

fp13 = 1996 fireplaces * .35

where 0.35 = .94^17 or 6% reduction, compounded per year

#### 2.3.1.3. Fireplace emissions

The equations used for the 2006 and 2013 fireplace emission calculations follow:

fp06-co = ( fp06 * fp-use * fp-cords * 61.1 * 1100. ) / hh06

fp13-co = ( fp13 * fp-use * fp-cords * 61.1 * 1100. ) / hh13

**Table 4. 2006 Fireplace emission rate variables/results.**

| Region | FP96 | FP06 | FP-USE | FP-CORDS | HH06 | FP06-CO (grams/HH-season) |
|---|---|---|---|---|---|---|
| 1 | 42,540 | 22,972 | 0.620 | 0.517 | 132,392.0 | 3,738 |
| 2 | 23,150 | 12,501 | 0.600 | 0.926 | 139,505.0 | 3,346 |
| 3 | 13,520 | 7,301 | 0.720 | 0.582 | 61,520.0 | 3,342 |
| 4 | 14,692 | 7,934 | 0.760 | 0.470 | 61,033.0 | 3,121 |
| 5 | 631 | 341 | 0.620 | 1.300 | 15,432.0 | 1,196 |
| 6 | 2,098 | 1,133 | 0.330 | 0.927 | 17,377.0 | 1,340 |
| 7 | 4,101 | 2,215 | 0.370 | 0.919 | 35,114.0 | 1,441 |
| 8 | 8,747 | 4,724 | 0.480 | 0.804 | 59,065.0 | 2,074 |
| 9 | 25,909 | 13,991 | 0.610 | 0.537 | 132,820.0 | 2,319 |
| 10 | 18,935 | 10,225 | 0.630 | 0.999 | 160,784.0 | 2,690 |
| 11 | 3,307 | 1,786 | 0.560 | 0.999 | 20,063.0 | 3,480 |
| 12 | 11,393 | 6,152 | 0.720 | 0.644 | 44,269.0 | 4,331 |
| 13 | 8,810 | 4,757 | 0.670 | 1.018 | 59,397.0 | 3,671 |
| 14 | 3,584 | 1,935 | 0.840 | 0.710 | 34,704.0 | 2,235 |
| 15 | 13,343 | 7,205 | 0.615 | 0.762 | 123,478.0 | 1,838 |

**Table 5. 2013 Fireplace emission rate variables/results.**

| Region | FP13 | FP-USE | FP-CORDS | HH13 | FP13-CO (grams/HH-season) |
|---|---|---|---|---|---|
| 1 | 14,889 | 0.620 | 0.517 | 143,172.40 | 2,240.4 |
| 2 | 8,102 | 0.600 | 0.926 | 160,082.70 | 1,890.0 |
| 3 | 4,732 | 0.720 | 0.582 | 65,183.75 | 2,044.5 |
| 4 | 5,142 | 0.760 | 0.470 | 65,510.40 | 1,884.4 |
| 5 | 221 | 0.620 | 1.300 | 18,121.57 | 660.0 |
| 6 | 734 | 0.330 | 0.927 | 18,832.96 | 801.5 |
| 7 | 1,435 | 0.370 | 0.919 | 47,308.98 | 693.4 |
| 8 | 3,062 | 0.480 | 0.804 | 63,503.80 | 1,250.5 |
| 9 | 9,068 | 0.610 | 0.537 | 140,626.50 | 1,419.7 |
| 10 | 6,627 | 0.630 | 0.999 | 188,682.20 | 1,485.7 |
| 11 | 1,157 | 0.560 | 1.039 | 22,338.02 | 2,026.1 |
| 12 | 3,987 | 0.720 | 0.644 | 46,628.70 | 2,664.9 |
| 13 | 3,083 | 0.670 | 1.018 | 68,564.37 | 2,061.5 |
| 14 | 1,254 | 0.840 | 0.710 | 42,407.08 | 1,185.7 |
| 15 | 4,670 | 0.615 | 0.762 | 152,896.30 | 962.0 |

## 2.3.2. 2006 and 2013 Stove Device Emission Calculations

### 2.3.2.1. Variable Definition

Variables used in the stove device emission calculations follow:

conv06, conv13 = 2006 and 2013 conventional stoves
ci06, ci13 = 2006 and 2013 phase I stoves
cii06, cii13 = 2006 and 2013 phase II stoves
ciii06, ciii13 = 2006 and 2013 phase III stoves
stv-var = percentage of the 1300 Phase III allocated to the region
stv-use = percentage of stove devices that are in use
Stv-cords = cords of wood burned each season
conv06-co, conv13-co = 2006, 2013 CO grams/HH rate of conventional stove emissions
ci06-co, ci13-co = 2006 and 2013 CO grams/HH rate of phase I stove emissions
cii06-co, cii13-co = 2006 and 2013 CO grams/HH rate of phase II stove emissions
ciii06-co, ciii13-co = 2006 and 2013 CO grams/HH rate of phase III stove emissions
conventional stove CO emission rate = 115.4 gram/Kg of wood burned
phase I stove CO emission rate = 58.8
phase II stove CO emission rate = 48.7
phase III stove CO emission rate = 49.7

### 2.3.2.2. Device Calculations

Phase III stoves are added to the stove population at the rate of 1,300 stoves per year. Eighty percent (80%) of these stoves replace the conventional stove population. Twenty percent (20%) of these phase III stoves are new to the population of phase III stoves. Eighty percent (80%) of new construction has a burning device; 95% of these devices are gas and 5% are Phase III devices. The variable 'stv-var' allocates the 1,300 Phase III stoves to the various regions based on information from the survey. The population of Phase I and Phase II stoves remains static at 1991 levels since sales of those devices ceased prior to 1991.

The equations used for the 2006 stove device calculations follow:

conv06 = conv91 - ( 2006 - 1991 ) * 1300 * stv-var * .8
ci06 = ci91
cii06 = cii91
ciii06 = ciii91 + ( 2006 - 1991 ) * 1300 * stv-var * .2 + ( hh06 - hh92 ) * .8 * .05

**Table 6. 2006 stove device calculations.**

| Region | CONV91 | CONV06 | CI06 | CII06 | CIII06 | STV-VAR |
|---|---|---|---|---|---|---|
| 1 | 4,398 | 2,933 | 330 | 660 | 2,909 | 0.0939 |
| 2 | 2,314 | 1,544 | 342 | 684 | 2,094 | 0.0494 |
| 3 | 1,517 | 1,012 | 152 | 303 | 1,199 | 0.0324 |
| 4 | 787 | 525 | 0 | 0 | 1,465 | 0.0168 |
| 5 | 433 | 289 | 0 | 0 | 362 | 0.0092 |
| 6 | 0 | 0 | 54 | 108 | 62 | 0.0000 |
| 7 | 2,447 | 1,632 | 0 | 0 | 1,177 | 0.0522 |
| 8 | 4,578 | 3,054 | 281 | 563 | 1,984 | 0.0977 |
| 9 | 9,079 | 6,056 | 681 | 1,362 | 4,860 | 0.1938 |
| 10 | 5,792 | 3,864 | 0 | 0 | 5,078 | 0.1236 |
| 11 | 972 | 648 | 44 | 87 | 688 | 0.0207 |
| 12 | 3,002 | 2,002 | 0 | 0 | 1,908 | 0.0641 |
| 13 | 5,514 | 3,678 | 144 | 288 | 2,818 | 0.1177 |
| 14 | 3,057 | 2,039 | 102 | 204 | 1,648 | 0.0653 |
| 15 | 2,965 | 1,978 | 185 | 370 | 4,032 | 0.0633 |

The equations used for the 2013 stove device calculations follow:

conv13 = conv91 - ( 2013 - 1991 ) * 1300 * stv-var * .8
conv13 = conv91 - ( 2013 - 1991 ) * 1300 * stv-var * .8
calc ci13 = ci91
calc cii13 = cii91
ciii13 = ciii91 + ( 2013 - 1991 ) * 1300 * stv-var * .2 + ( hh13 - hh92 ) * .8 * .05

**Table 7. 2013 stove device calculations.**

| Region | CONV91 | CONV13 | CI13 | CII13 | CIII13 | STV-VAR |
|---|---|---|---|---|---|---|
| 1 | 4,398 | 2,250 | 330 | 660 | 2,157 | 0.0939 |
| 2 | 2,314 | 1,184 | 342 | 684 | 2,351 | 0.0494 |
| 3 | 1,517 | 776 | 152 | 303 | 950 | 0.0324 |
| 4 | 787 | 403 | 0 | 0 | 1,413 | 0.0168 |
| 5 | 433 | 222 | 0 | 0 | 342 | 0.0092 |
| 6 | 0 | 0 | 54 | 108 | 139 | 0.0000 |
| 7 | 2,447 | 1,252 | 0 | 0 | 945 | 0.0522 |
| 8 | 4,578 | 2,342 | 281 | 563 | 909 | 0.0977 |
| 9 | 9,079 | 4,645 | 681 | 1,362 | 2,729 | 0.1938 |
| 10 | 5,792 | 2,964 | 0 | 0 | 4,490 | 0.1236 |
| 11 | 972 | 497 | 44 | 87 | 508 | 0.0207 |
| 12 | 3,002 | 1,536 | 0 | 0 | 1,119 | 0.0641 |
| 13 | 5,514 | 2,822 | 144 | 288 | 1,611 | 0.1177 |
| 14 | 3,057 | 1,564 | 102 | 204 | 1,091 | 0.0653 |
| 15 | 2,965 | 1,517 | 185 | 370 | 4,398 | 0.0633 |

### 2.3.2.3. Stove Emissions calculations

The equations used to estimate stove emissions for 2006 follow:

conv06-co = ( conv06 * stv-use * stv-cords * 1100. * 115.4 ) / hh06
ci06-co = ( ci06 * stv-use * stv-cords * 1100. * 58.8 ) / hh06
cii06-co = ( cii06 * stv-use * stv-cords * 1100. * 48.7 ) / hh06
ciii06-co = ( ciii06 * stv-use * stv-cords * 1100. * 49.7 ) / hh06

**Table 8. 2006 Stove emission calculation variables/results.**

| Region | STV-USE | STV-CORDS | CONV06-CO | CI06-CO | CII06-CO | CIII06-CO |
|---|---|---|---|---|---|---|
| 1 | 0.330 | 0.250 | 232 | 13 | 22 | 99 |
| 2 | 0.554 | 1.179 | 917 | 104 | 172 | 536 |
| 3 | 0.750 | 0.525 | 822 | 63 | 104 | 419 |
| 4 | 1.000 | 0.352 | 384 | 0 | 0 | 462 |
| 5 | 1.000 | 1.036 | 2,462 | 0 | 0 | 1,330 |
| 6 | 0.554 | 1.179 | 0 | 131 | 217 | 128 |
| 7 | 0.400 | 0.300 | 708 | 0 | 0 | 220 |
| 8 | 0.670 | 0.675 | 2,968 | 139 | 231 | 831 |
| 9 | 0.700 | 1.160 | 4,700 | 269 | 446 | 1,624 |
| 10 | 0.750 | 1.510 | 3,454 | 0 | 0 | 1,955 |
| 11 | 0.860 | 0.669 | 2,359 | 81 | 134 | 1,079 |
| 12 | 1.000 | 1.913 | 10,983 | 0 | 0 | 4,507 |
| 13 | 0.550 | 1.299 | 5,617 | 112 | 185 | 1,853 |
| 14 | 0.720 | 1.150 | 6,177 | 157 | 261 | 2,149 |
| 15 | 0.638 | 0.950 | 1,232 | 59 | 97 | 1,082 |

The equations used to estimate stove emissions for 2013 follow:

conv13-co = ( conv13 * stv-use * stv-cords * 1100. * 115.4 ) / hh13
ci13-co = ( ci13 * stv-use * stv-cords * 1100. * 58.8 ) / hh13
cii13-co = ( cii13 * stv-use * stv-cords * 1100. * 48.7 ) / hh13
ciii13-co = ( ciii13 * stv-use * stv-cords * 1100. * 49.7 ) / hh13

**Table 9. 2013 Stove emission calculation variables/results.**

| Region | STV-USE | STV-CORDS | CONV13-CO | CI13-CO | CII13-CO | CIII13-CO |
|---|---|---|---|---|---|---|
| 1 | 0.330 | 0.250 | 165 | 12.3 | 20.4 | 68.0 |
| 2 | 0.554 | 1.179 | 613 | 90.2 | 149.5 | 524.3 |
| 3 | 0.750 | 0.525 | 595 | 59.3 | 98.2 | 313.6 |
| 4 | 1.000 | 0.352 | 275 | 0.0 | 0.0 | 415.0 |
| 5 | 1.000 | 1.036 | 1,608 | 0.0 | 0.0 | 1,070.4 |
| 6 | 0.554 | 1.179 | 0 | 120.7 | 199.9 | 262.8 |
| 7 | 0.400 | 0.300 | 403 | 0.0 | 0.0 | 131.0 |
| 8 | 0.670 | 0.675 | 2,118 | 129.6 | 214.6 | 354.1 |
| 9 | 0.700 | 1.160 | 3,405 | 254.3 | 421.2 | 861.4 |
| 10 | 0.750 | 1.510 | 2,258 | 0.0 | 0.0 | 1,473.5 |
| 11 | 0.860 | 0.669 | 1,625 | 72.6 | 120.2 | 715.7 |
| 12 | 1.000 | 1.913 | 7,998 | 0.0 | 0.0 | 2,510.3 |
| 13 | 0.550 | 1.299 | 3,732 | 97.0 | 160.6 | 917.6 |
| 14 | 0.720 | 1.150 | 3,877 | 128.7 | 213.2 | 1,164.1 |
| 15 | 0.638 | 0.950 | 763 | 47.4 | 78.5 | 953.1 |

## 2.4. On-Road Mobile Sources

Estimates for carbon monoxide (CO) emissions from on-road mobile sources are based on the Environmental Protection Agency (EPA) Mobile Source Emissions Model – MOBILE5b.

### 2.4.1. Control Strategy Recommendations

Regional Air Quality Commission Mobile Source Carbon Monoxide Control Strategy Recommendation for 2006 and 2013:

- I/M 240 program with newest 4 model-year exemption
- 1.5% oxygenated fuel program for 2006; 1.7 % oxygenated fuel program for 2013
- 80% Remote Sensing Device (RSD) program

### 2.4.2. Vehicle Miles Traveled (VMT)

The DRCOG 1999-2004 Transportation Improvement Conformity networks were utilized as the basis for the vehicle miles traveled (VMT) estimates. DRCOG has revised population and household growth estimates since this TIP Conformity analysis was complete in August 1998. Incorporating the revised growth rates results in 2006 and 2013 VMT estimated as follows:

- 2006 magnitude and distribution of VMT in the Denver-Boulder NAA represented by 2011 DB Network 2020 AC
- 2013 magnitude and distribution of VMT in the Denver-Boulder NAA represented by 2020 AC Network multiplied by a factor on 1.037

The VMT totals are summarized in the following two tables.

**Table 10 . Daily VMT totals in the Denver-Boulder carbon monoxide Denver-Boulder Carbon Monoxide Nonattainment Area.**

| Year | AM Peak | PM Peak | Off-Peak | Total |
|---|---|---|---|---|
| 2006 | 9,441,436 | 21,234,530 | 31,012,298 | 61,688,264 |
| 2013 | 10,740,302 | 24,222,119 | 36,304,514 | 71,266,935 |

**Table 11 . VMT totals in the Denver-Boulder carbon monoxide Urban Airshed Modeling domain.**

| Year | AM Peak | PM Peak | Off-Peak | Total |
|---|---|---|---|---|
| 2006 | 10,179,724 | 22,873,759 | 33,706,082 | 66,759,564 |
| 2013 | 11,582,081 | 26,104,812 | 39,499,790 | 77,186,683 |

The tabular summaries of vehicle miles traveled by area type and functional classification and the ten peak periods are included in Appendix A.

### 2.4.3. Mobile5b Emission Factor Modeling

Elements of Mobile5b Emission Factor Modeling:

- I/M 240 program with newest four model years exempt
- 1.5% oxygenated fuel program in 2006; 1.7 % oxygenated fuel program in 2013
- 80% RSD program
- National Low Emitting Vehicle(NLEV) program commencing in 2001
- Mechanics training credit
- The most stringent cut-points available in Mobile5b for an I/M 240 program

2006 I/M 240 program on light duty gasoline powered vehicles is characterized as follows:

- Start year (January 1): 1982
- Pre-1981 MYR stringency rate: 20%
- First model year covered: 1982
- Last model year covered: 2002
- Waiver rate (pre-1981): 0%
- Waiver rate (1981 and newer): 0%
- Compliance Rate: 98%
- Inspection type: Test Only
- Inspection frequency: Biennial
- Vehicle types covered: LDGV LDGT1 LDGT2
- 1981 & later MYR test type: IM240 test
- Cutpoints: HC: 0.600 CO: 10.000 NOx: 1.500

2006 I/M 240 program on heavy duty gasoline powered vehicles is characterized as follows:

- Start year (January 1): 1982
- Pre-1981 MYR stringency rate: 20%
- First model year covered: 1982
- Last model year covered: 2002
- Waiver rate (pre-1981): 0%
- Waiver rate (1981 and newer): 0.%
- Compliance Rate: 98.%

- Inspection type Test Only
- Inspection frequency: Biennial
- Vehicle types covered: HDGV
- 1981 & later MYR test type: 2500 rpm / Idle
- Cutpoints: HC: 220.000 CO: 1.200 NOx: 999.000

Anti-tampering program in 2006 for all gasoline-powered vehicles is characterized as follows:

- Check: ATP
- Start Model Year: 1982
- Model Years Covered: 1975-2002
- Vehicle Classes Covered: LDGV LDGT1 LDGT2 HDGV
- Inspection Type: Test Only
- Frequency: Biennial
- Compliance Rate: 98.0%
- Air pump system disablement: Yes
- Catalyst removals: Yes
- Fuel inlet restrictor disablement: No
- Tailpipe lead deposit test: No
- EGR disablement: No
- Evaporative system disablement: No
- PCV system disablement: No
- Missing gas caps: Yes

2013 I/M Programs and Anti-tampering programs are characterized similarly.

### 2.4.4. NLEV Credit Estimate

The emission reduction affects of the National Low Emission Vehicle program on light-duty gas vehicles (LDGV) and light-duty truck 1 vehicles (LDGT1) was estimated for purposes of this analysis though two Mobile5b emission inventory runs. Mobile5b runs are made for high altitude as described above. In order to estimate the NLEV benefit on LDGV and LDGT1, a similar run was made for low altitude with the flags set to include the NLEV program starting in 2001. The emission factors for LDGV and LDGT1vehicles were taken from the low altitude mobile5b runs to replace the same emission factors from the high altitude runs. The composite (vehicle mix weighted) emission factor was then re-calculated. The FORTRAN algorithm used to accomplish these calculations is included in Appendix B.

### 2.4.5. RSD Program

RSD Modeling Inputs:

- RSD Fleet Coverage Option 2 (Commitment to vehicle coverage)
- Program type = 5 (Clean screening remote-sensing program)
- RSD cutpoint .5% CO, 200ppm HC
- RSD clean screening with I/M 240 final cutpoint effectiveness

- 2006 Vehicle Population of 2,459,748 (Based on 2 million vehicles in 1999 with 3% annual increase)
- Fleet subject to clean screen = 100%
- 80% Clean Screen (80% of vehicle population per vehicle age)
- Colorado's registration distribution

**Table 12. Input file in the EPA RSD model to generate the 80% credit file.**

```
000 Clean screen, vehicles projected 2006, 80% rsd
001         2 Commitment to vehicle coverage
002         5 Clean screening RSD
005 Imdata.d
007 Tech12.d
015 Im.d
017 Tech.d
034         2 ELIGIBLE CLEAN SCREEN PRE 75
035         2 ELIGIBLE CLEAN SCREEN 75-80
036         2 ELIGIBLE CLEAN SCREEN 81-85
037         2 ELIGIBLE CLEAN SCREEN 86-89
038         2 ELIGIBLE CLEAN SCREEN 90 +
039         4 RSD CUTPOINTS AND LEP VALUES (1=.5/200)
044         2 RSD FINAL CUTPOINT
000 NUMBER OF VEHICLES ELIGIBLE FOR CLEAN SCREEN
000 80% RSD
000 ----------- ----------
201      120734      96587 TOTAL VEHICLES, VEHICLES ELIGIBLE 0-1
202      140985     112788 TOTAL VEHICLES, VEHICLES ELIGIBLE 1-2
203      134224     107379 TOTAL VEHICLES, VEHICLES ELIGIBLE 2-3
204      146707     117365 TOTAL VEHICLES, VEHICLES ELIGIBLE 3-4
205      155424     124339 TOTAL VEHICLES, VEHICLES ELIGIBLE 4-5
206      186547     149238 TOTAL VEHICLES, VEHICLES ELIGIBLE 5-6
207      180287     144230 TOTAL VEHICLES, VEHICLES ELIGIBLE 6-7
208      153722     122978 TOTAL VEHICLES, VEHICLES ELIGIBLE 7-8
209      146709     117367 TOTAL VEHICLES, VEHICLES ELIGIBLE 8-9
210      100218      80174 TOTAL VEHICLES, VEHICLES ELIGIBLE 9-10
211      131124     104899 TOTAL VEHICLES, VEHICLES ELIGIBLE 10-11
212      125860     100688 TOTAL VEHICLES, VEHICLES ELIGIBLE 11-12
213      108005      86404 TOTAL VEHICLES, VEHICLES ELIGIBLE 12-13
214       78572      62857 TOTAL VEHICLES, VEHICLES ELIGIBLE 13-14
215       67328      53863 TOTAL VEHICLES, VEHICLES ELIGIBLE 14-15
216       60739      48591 TOTAL VEHICLES, VEHICLES ELIGIBLE 15-16
217       58171      46536 TOTAL VEHICLES, VEHICLES ELIGIBLE 16-17
218       55307      44246 TOTAL VEHICLES, VEHICLES ELIGIBLE 17-18
219       52444      41955 TOTAL VEHICLES, VEHICLES ELIGIBLE 18-19
220       30823      24658 TOTAL VEHICLES, VEHICLES ELIGIBLE 19-20
221       24506      19605 TOTAL VEHICLES, VEHICLES ELIGIBLE 20-21
222       18254      14603 TOTAL VEHICLES, VEHICLES ELIGIBLE 21-22
223       11937       9550 TOTAL VEHICLES, VEHICLES ELIGIBLE 22-23
224        4885       3908 TOTAL VEHICLES, VEHICLES ELIGIBLE 23-24
225        1432       1145 TOTAL VEHICLES, VEHICLES ELIGIBLE 24-25
```

## Table 13. Data used in model year calculations of eligible vehicles.

VEHICLE COUNT FOR 2006
BASED ON 3% INCREASE PER YEAR
1999 = 2,000,000

| 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2000000 | 2060000 | 2121800 | 2185454 | 2251018 | 2318548 | 2388105 | 2459748 | 2533540 | 2609546 | 2687833 | 2768468 | 2851522 |

VMT WEIGHTED AVERAGE VEHICLE MIX FOR 2006

| | | |
|---|---|---|
| LDGV | 0.582 | 1431573 |
| LDGT1 | 0.221 | 543604 |
| LDGT2 | 0.104 | 255814 |
| HDGV | 0.026 | 63953 |
| | TOTALS | 2294945 |

VEHICLE AGE

| | LDGV* | LDGV TOTALS | LDGT1* | LDGT1 TOTALS | LDGT2* | LDGT2 TOTALS | HDGV* | HDGV TOTALS | GRAND TOTALS |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.049 | 70147 | 0.058 | 31529 | 0.058 | 14837 | 0.066 | 4221 | 120734 |
| 2 | 0.065 | 93052 | 0.055 | 29898 | 0.055 | 14070 | 0.062 | 3965 | 140985 |
| 3 | 0.067 | 95915 | 0.044 | 23919 | 0.044 | 11256 | 0.049 | 3134 | 134224 |
| 4 | 0.074 | 105936 | 0.047 | 25549 | 0.047 | 12023 | 0.05 | 3198 | 146707 |
| 5 | 0.08 | 114526 | 0.047 | 25549 | 0.047 | 12023 | 0.052 | 3326 | 155424 |
| 6 | 0.083 | 118821 | 0.078 | 42401 | 0.078 | 19953 | 0.084 | 5372 | 186547 |
| 7 | 0.082 | 117389 | 0.071 | 38596 | 0.071 | 18163 | 0.096 | 6140 | 180287 |
| 8 | 0.068 | 97347 | 0.065 | 35334 | 0.065 | 16628 | 0.069 | 4413 | 153722 |
| 9 | 0.065 | 93052 | 0.062 | 33703 | 0.062 | 15860 | 0.064 | 4093 | 146709 |
| 10 | 0.043 | 61558 | 0.045 | 24462 | 0.045 | 11512 | 0.042 | 2686 | 100218 |
| 11 | 0.058 | 83031 | 0.056 | 30442 | 0.056 | 14326 | 0.052 | 3326 | 131124 |
| 12 | 0.052 | 74442 | 0.06 | 32616 | 0.06 | 15349 | 0.054 | 3453 | 125860 |
| 13 | 0.045 | 64421 | 0.051 | 27724 | 0.051 | 13047 | 0.044 | 2814 | 108005 |
| 14 | 0.034 | 48673 | 0.035 | 19026 | 0.035 | 8953 | 0.03 | 1919 | 78572 |
| 15 | 0.028 | 40084 | 0.032 | 17395 | 0.032 | 8186 | 0.026 | 1663 | 67328 |
| 16 | 0.024 | 34358 | 0.031 | 16852 | 0.031 | 7930 | 0.025 | 1599 | 60739 |
| 17 | 0.021 | 30063 | 0.033 | 17939 | 0.033 | 8442 | 0.027 | 1727 | 58171 |
| 18 | 0.019 | 27200 | 0.033 | 17939 | 0.033 | 8442 | 0.027 | 1727 | 55307 |
| 19 | 0.017 | 24337 | 0.033 | 17939 | 0.033 | 8442 | 0.027 | 1727 | 52444 |
| 20 | 0.009 | 12884 | 0.021 | 11416 | 0.021 | 5372 | 0.018 | 1151 | 30823 |
| 21 | 0.007 | 10021 | 0.017 | 9241 | 0.017 | 4349 | 0.014 | 895 | 24506 |
| 22 | 0.005 | 7158 | 0.013 | 7067 | 0.013 | 3326 | 0.011 | 703 | 18254 |
| 23 | 0.003 | 4295 | 0.009 | 4892 | 0.009 | 2302 | 0.007 | 448 | 11937 |
| 24 | 0.001 | 1432 | 0.004 | 2174 | 0.004 | 1023 | 0.004 | 256 | 4885 |
| 25 | 0.001 | 1432 | 0 | 0 | 0 | 0 | 0 | 0 | 1432 |
| | 1 | 1431573 | 1 | 543604 | 1 | 255814 | 1 | 63953 | 2294945 |

* REGISTRATION DISTRIBUTION

### 2.4.6. Oxygenated Fuel Program

The Mobile5b inputs through the LAP record reflect a 1.5% oxygenated fuel program in 2006 and a 1.7% oxygenated fuel program in 2013.

### 2.4.7. Mobile5b Scenario Inputs

The scenario section inputs reflect the same assumptions as were used for the Denver-Boulder Carbon Monoxide State Implementation Plan. The Mobile5b scenario section inputs for 2006 and 2013 are included in Appendix D as part on the Mobile5b input files. The vehicle speeds used as Mobile5b input result from the DRCOG Transportation Improvement Plan conformity analysis transportation network modeling. These speed are also included as part of the scenario section inputs.

### 2.4.8. Carbon Monoxide Emission Factors for 2006 and 2013

Appendix B includes the Mobile5b inputs and outputs for 2006 and 2013. Appendix C contains the resultant emission factors summarized by road class, area type and the ten peak periods.

### 2.4.9. Emission Inventory Calculations

The 2006 and 2013 carbon monoxide emission inventories in the Denver-Boulder Nonattainment area and in the Urban Airshed Modeling domain resultant from the emission factors and the VMT are summarized in the following tables. The 2006 and 2013 carbon monoxide emission inventories in the Carbon Monoxide Dispersion Modeling Domain and the Denver-Boulder Nonattainment Area are summarized by road class and area type in Appendix D.

**Table 14 . On-road mobile source emission estimates in tons per day (tpd) in the Denver-Boulder carbon monoxide Urban Airshed Modeling domain.**

| Year | AM Peak | PM Peak | Off-Peak | Total |
|---|---|---|---|---|
| 2006 | 189.23 | 275.80 | 379.62 | 844.65 |
| 2013 | 185.63 | 282.11 | 399.43 | 867.17 |

**Table 15 . On-road mobile source emission estimates in tons per day (tpd) in the Denver-Boulder Carbon Monoxide Nonattainment Area.**

| Year | AM Peak | PM Peak | Off-Peak | Total |
|---|---|---|---|---|
| 2006 | 178.22 | 259.01 | 346.41 | 783.64 |
| 2013 | 173.94 | 263.68 | 363.08 | 800.70 |

## 2.5. Non-Road Mobile Sources and Airports

The EPA NONROAD model (Draft updated to 6/15/99) was used to project the year 2000 gridded non-road emissions (which include ground support equipment emissions from airports) to 2006 and 2013. The model was run for these three years for the counties included in the inventory. A projection factor was calculated for each of the non-road source categories by dividing the county level emissions in the future year by the emissions in the year 2000. The factor was the same for each county within each source category. The non-road projection factor for each source category was then used to multiply the emissions in each grid cell in the year 2000 inventory to obtain the future year emissions by grid cell. See the "Denver Carbon Monoxide Maintenance Air Quality Modeling and Emission Inventory Protocol for Redesignation" document for more discussion.

Emissions from aircraft at airports were calculated using the same methodology as in the original SIP. Two methods are available for determining aircraft emissions.[3] As required by EPA guidance, the Federal Aviation Administration Aircraft Engine Database (FAEED) is used to determine emissions from large commercial airports and military bases. These types of facilities generally have the landing and take-off data by aircraft type (e.g., 330 Boeing 737 model 300 landing and take-offs (LTOs) occurred in 1996) necessary to run FAEED. At smaller airfields with general aviation or air taxi usage, the number of LTOs is categorized into broad aircraft types, not specific makes and models. For these facilities, a fleet average emissions factor is applied to each LTO based on the general type of aircraft (i.e., general aviation or air taxi). For instance, the emissions factor for general aviation is 12.014 LB of CO per LTO. Unfortunately, not all aircraft, nor aircraft engines are found in FAEED.[b] Therefore, neither all commercial, nor all military LTOs can be directly calculated using this application. The FAEED calculated emissions are increased in direct proportion to the ratio of total LTOs to FAEED calculated LTOs. In other words, the FAEED emissions are "scaled-up" to represent all aircraft emissions, even those not in the database. Projection of emissions for future years were based on the FAA Terminal Area Forecasts for Fiscal Years 1998 to 2015, October 1998.

### 2.5.1. Revised Emissions Estimates for Denver International Airport

Denver International Airport released the document 'Final Draft 1998 Emissions Inventory for Denver International Airport (DIA) and Carbon Monoxide Projections' on November 15, 1999. A summary of this document and projections of DIA emissions to 2006 and 2013 was transmitted to APCD on November 15, 1999. This transmittal is included in Appendix L.

The updated DIA inventories result in a 4.0 ton/day and 1.8 ton/day decrease in the aircraft operations emissions in the 2006 and 2013 inventories, respectively. The revised aircraft services inventories result in a 9.5 ton/day and 13.3 ton/day increases for 2006 and 2013, respectively. The cumulative aircraft and aircraft services DIA inventories increased 5.5 tons/day and 11.5 tons/day for 2006 and 2013, respectively.

[b] Generally older aircraft or more specialized aircraft are not found in FAEED. This is more of a problem for military, as opposed to commercial, aircraft.

The inventory prepared by DIA also includes point source, on-road mobile, construction, and industrial equipment categories. Since the point sources are permitted by APCD, they are included in the point source totals in Table 1 on page 8. The on-road mobile emission estimates account for vehicular travel on the airport property that is not included in the Denver Regional Council of Governments transportation modeling. Consequently, this on-road is not included in the On-Road Mobile category in Table 1. The construction and industrial equipment estimates are specific to DIA activities. If the on-road mobile, construction and industrial equipment emissions estimates are added to the aircraft and aircraft services the resultant inventory increase are 7.0 tons/day and 13.2 tons/day for 2006 and 2013, respectively. This represents a 33% and 56% increase in carbon monoxide emissions over the estimates that were used in the UAM modeling simulation for 2006 and 2013, respectively.

The Urban Airshed Modeling results in this document are based on airport emissions shown in Table 1 on page 17. These emission inventories, for all airports in the modeling domain, were developed as described in Section 2.5. The revised DIA emission estimates were not received until after the UAM modeling was complete. The Division has considered re-doing the UAM modeling with the revised DIA inventories, but concluded that the revised airport emissions would not change the maximum modeled 8-hour concentration estimates in downtown Denver. DIA is 30 kilometers away from the downtown Denver. Consequently, a substantial increase in emissions at DIA would not threaten the carbon monoxide standards in downtown Denver. In addition, meteorological conditions in the vicinity of DIA were not conducive to high carbon monoxide during the modeled episodes. Figure 14 and Figure 13 indicate that the modeled maximum 8-hour concentrations in the vicinity of DIA are below 2.0 ppm. Given the magnitudes of the emission increases with the updated DIA emission estimates (33% for 2006 and 56% for 2013), the CO NAAQS in the immediate vicinity of the airport would not be threatened.

The revised DIA emission inventories for 2001 are slightly higher than the emission inventories used in the development of the CO SIP 2001 attainment demonstration. The revised emission inventory, including construction and industrial equipment, is 21.88 tons/day. The inventory used in the 2001 attainment demonstration is 19.68 tons/day. This is a 11.2% increase over the emissions estimate for the 2001 attainment demonstration. For the reasons outlined in the previous paragraph, this small increase in the emissions estimate would not threaten the modeled CO NAAQS attainment demonstration in 2001.

Based on the preceding analysis, the Division has specifically identified and accounted for DIA emissions in the maintenance plan. Therefore, for the purposes of General Conformity demonstration DIA should use the emissions inventory from Table 16 on page 23 of this Technical Support Document.

**Table 16. Revised emission inventory for Denver International Airport.**

| | CO Emissions (tons/year) | | | |
|---|---|---|---|---|
| **Inventory Sub-category** | **1998** | **2001** | **2006** | **2013** |
| Aircraft | 2,164.20 | 2,727.01 | 3,674.95 | 5,057.65 |
| Ground Support Equipment | 3,537.45 | 4,542.35 | 6,109.60 | 7,701.33 |
| Rental Car Shuttles | 58.83 | 67.49 | 84.41 | 107.80 |
| Employee/Public Shuttle Buses | 25.59 | 29.36 | 36.72 | 46.89 |
| City Fleet & Plows | 233.36 | 265.92 | 319.31 | 380.67 |
| Central Plant Engines | 13.33 | 15.29 | 19.12 | 24.42 |
| Central Plant Boilers | 0.78 | 0.89 | 1.12 | 1.43 |
| Misc. NG sources | 6.98 | 8.01 | 10.01 | 12.79 |
| Diesel-fueled sources | 9.06 | 10.39 | 13.00 | 16.60 |
| Fire Fighter Training | N/A | 21.11 | 21.11 | 21.11 |
| Rental Car Refueling | ---- | ---- | ---- | ---- |
| Others – including paint booths and fuel tank farm | ---- | ---- | ---- | ---- |
| Oil & Gas Production | ---- | ---- | ---- | ---- |
| Oil & Gas Well Construction | 5.72 | 5.72 | 5.72 | 5.72 |
| Agricultural Operations | ---- | ---- | ---- | ---- |
| Construction Activities | 45.43 | 90.86 | 90.86 | 90.86 |
| **Total** | **6,100.73** | **7,784.40** | **10,385.93** | **13,467.28** |

| **Source Category** | **1998 DIA CO** | **2001 Forecast** | **2006 Forecast** | **2013 Forecast** |
|---|---|---|---|---|
| | **CO Emissions (tons/day)** | | | |
| Point Sources | 0.08 | 0.15 | 0.18 | 0.21 |
| Wood Burning | | | | |
| Natural Gas | | | | |
| Structural Fires | | | | |
| Agricultural Equipment | | | | |
| Airport-Aircraft | 5.93 | 7.47 | 10.07 | 13.86 |
| Airport Service Equipment | 9.69 | 12.44 | 16.74 | 21.10 |
| Construction Equipment | 0.12 | 0.25 | 0.25 | 0.25 |
| Industrial Equipment | 0.02 | 0.02 | 0.02 | 0.02 |
| Light Commercial Equipment | | | | |
| Helicopters | | | | |
| Railroads | | | | |
| On-Road Mobile | 0.87 | 0.99 | 1.21 | 1.47 |
| **Total** | **16.71** | **21.33** | **28.45** | **36.90** |

## 2.6. Point Sources

In the approved CO SIP, major sources were divided into area and elevated sources based on the effective plume height.[c] This is a requirement of the UAM model. The UAM has two emissions input files: (1) surface emissions and (2) elevated emissions. The value of 25 meters was used to determine if a source is a "surface" or "elevated" one. This height approximates the thickness of the lowest layer during the periods when CO concentrations are elevated. During periods with high ambient CO concentrations, vertical mixing is constrained, therefore limiting the ground-level impact of elevated sources of CO. Therefore, the cut-off height of 25 meters allows low level emissions to be retained in the surface inventory while appropriately limiting the impact of elevated sources.

Plume rise estimates in the CO SIP were based on the algorithm contained in the Emissions Preprocessor System PREPNT (i.e., preprocessor for point source emissions).[4] The procedures, methods, and assumptions used in the plume rise calculation are described in the attachments to the CO SIP.[5]

For the maintenance plan, the EPA Aerometric Information Retrieval System/AIRS Facility Subsystem (AIRS/AFS), which contains the currently updated and quality assured emission inventory for stationary sources, was queried during August 1999 to obtain the point source emissions. Actual emissions (AIRS field OAM at the plant and stack level) together with the UTM coordinates and stack parameters for certain sources were obtained for the latest year available for all of the CO sources in the inventory area. The OAM field represents the actual daily emissions rates for the winter season. These emissions were then summed for each grid cell in the inventory using geographical information system (GIS) database techniques. Elevated emissions from large sources were separated into a separate category using the stack parameter information. For the Urban Airshed Modeling, sources were also included from the portion of Weld County that is inside the modeling domain but outside the CO nonattainment area. The OAM field is not available for sources outside of nonattainment areas, so the EEA field (estimated actual emissions) was used instead.

In the approved CO SIP, it was assumed that no new major point sources were expected to be built in the modeling domain before 2000.[6] Since the CO SIP modeling was completed, several revisions were made to the major point source database.[7, 8, 9, 10] These changes have been made in the AIRS/AFS database and are reflected in the August 1999 AIRS retrieval used in the UAM modeling.

The actual emissions from all new CO point sources in the modeling domain have been included in the "surface" gridded inventory. That is, they have been modeled as gridded "area" sources so that the emissions are released into the lowest grid cell of the Urban Airshed Model. For those sources modeled as elevated point sources in UAM, the emissions have been removed from the surface gridded inventory to avoid double counting.

[c] Effective plume height is total of the plume rise and the stack height, and expressed in meters for this application.

### 2.6.1. Point Source Growth in 2006 and 2013

The same point source inventory has been used in the Urban Airshed Modeling for 2006 and 2013. Of the 47.1 tons per day (tpd) of carbon monoxide emitted from point sources in the modeling domain, 25.6 tpd are from elevated point sources and 21.1 tpd are from ground-level "area" point sources. As discussed below, the "elevated" point sources already account for reasonable future growth. The impacts from growth in "area" point sources are negligible in downtown Denver. Thus, the projection of point source emissions is not an issue with respect to the compliance demonstration.

For elevated point sources, the same inventory modeled in the CO SIP has been modeled for 2006 and 2013. Thus, the maximum short-term potential-to-emit was used instead of actual emissions, as was done in the CO SIP. [11] That is, the design capacity at each power plant has been modeled. This accounts for future growth in capacity factors at all existing power plants in the modeling domain.

From an attainment perspective, it important to realize that the plumes from the elevated point sources remain above the inversion during critical time periods for the episodes modeled. In other words, very little of the carbon monoxide emitted from elevated point sources actually reaches the ground during the critical hours of the episodes modeled. For example, for the "high" episode, the maximum 8-hour CO contribution from all modeled elevated point sources on ground-level carbon monoxide in the CAMP grid cell (23, 43) is only 0.01 ppm, according to a sensitivity test performed by the Division with the Urban Airshed Model. The maximum anywhere in the modeling domain at level 1 in the model (i.e., at the ground) is 0.16 ppm; however, this occurs late in the afternoon in grid cell (25,47), which is several miles from downtown. Therefore, for the maintenance demonstration, elevated point sources (e.g., power plants such as Cherokee) contribute only about 0.01 ppm to the overall maximum 8-hour concentration estimate. This suggests that even large increases in carbon monoxide emissions from elevated point sources will have virtually no effect on ground-level carbon monoxide concentrations in downtown Denver during a period where a strong statically stable air mass is trapping emissions near ground-level.

The plume rise from some of the large "area" point sources (as modeled in the Urban Airshed Model for this study) are actually elevated plumes from stacks that would also be above the ground-based inversion. Nevertheless, the Division did not model these sources as elevated point sources because of the time and resources necessary to prepare the necessary data for the elevated point source preprocessors required by the Urban Airshed Model. In any case, carbon monoxide emissions from "area" point sources are relatively small contributors to maximum carbon monoxide levels observed in downtown Denver, particularly during the stagnation episodes modeled in the approved CO SIP and in this maintenance plan.

While point source growth from "area" point sources can be anticipated, the location of new point sources is not known. Thus, it would be speculative to assume where new point source growth would occur.

In addition, the current "area" point source inventory near downtown is believed to overestimate actual ground level emissions of carbon monoxide from point sources. In particular, the Division decided to model a relatively large "elevated" point source (SCSE 080311318 – AT&T – NCC West) as a ground level "area" source. The reason is that it would have taken considerable resources to re-run the elevated point source processors for the Urban Airshed Model to include the source as an elevated one. If it had been modeled as an elevated source, it would have a negligible effect in downtown Denver. That is, the impact would be below 0.005 ppm. The Division performed a sensitivity test with the Urban Airshed Model to quantify the effect of including this source as an "area" source. As modeled, it emits 121 ton per year (0.33 tpd) of carbon monoxide. According to AIRS, the source is located in grid cell 2621, which is 2 miles east and 2 miles north of the CAMP grid cell (2501) in downtown Denver. The Urban Airshed Modeling showed that the source (modeled as a ground level "area" source in UAM) increased 8-hour CO by only about 0.01 ppm in downtown Denver. This suggests even a relatively large new source, even if modeled as a ground level source, has a relatively small effect on CO levels in downtown Denver provided that the source is located at least a mile or two away from downtown.

In summary, the Division concluded that the traditionally accepted methods for projecting stationary source emissions into the future would not change the outcome of the compliance demonstration or change the control strategy decisions in the maintenance plan. In addition, it's important to recognize that Colorado requires new point sources with CO emissions over 25 tons per year in a nonattainment area or 50 tons per year in an attainment area to demonstrate compliance with the CO ambient air standards before a permit can be issued. Thus, there is a regulatory mechanism to prevent new point sources from causing violations of ambient air standards.

## 2.7. Temporal Distribution of Daily Emissions

The UAM requires emissions for each hour of the episode. Thus, a set of 24 hourly factors was derived for each category to temporally distribute their emissions. For instance, the temporal factor for hour 0 applies to the hour from midnight to 1 A.M. These factors were used in all of the modeling inventories. Emissions from the following categories were evenly distributed throughout the day: structural fires, minor point sources, and major area point sources (i.e., non-elevated major point sources). Temporal allocation factors are the same as those used in the approved CO SIP for all source categories except for on-road mobile sources. For on-road mobile sources, the morning and afternoon rush hours are longer than assumed for 2001 in the CO SIP. Thus, the AM-peak, PM-peak, and off-peak scaling factors were replaced with factors developed in August 1999. Temporal allocation factors are applied uniformly throughout the domain. Refer to Appendix J for the factors used for each source category.

# 3. Air Quality Modeling Methodology

Model application is consistent with Appendix W of 40 CFR Part 51 - Guideline on Air Quality Models (*EPA Guideline*) and with methods approved in the Denver Carbon Monoxide State Implementation Plan (CDPHE, 1994; Federal Register, 1997). The Federal Register discussion on the CO SIP is in Appendix I.

## 3.1. Overview of Modeling Process

The 1990 federal Clean Air Act Amendments (CAAA) require a state implementation plan to demonstrate attainment of the carbon monoxide National Ambient Air Quality Standards (NAAQS) using U. S. EPA approved air quality models. The modeling analysis includes both areawide and hot spot analyses. An areawide analysis is performed to determine regional carbon monoxide (CO) concentrations. Hot spot analyses provide estimates of CO concentrations at specific roadway intersections. The concentration estimates from the areawide and hot spot analyses are combined. In the approved Denver Nonattainment Area CO SIP, the areawide model is the Urban Airshed Model (UAM). The hot spot modeling methodology is based on CAL3QHC.

UAM was applied in an inert mode with no chemical mechanisms activated.[d] Only carbon monoxide was modeled. The same approach has been used for the Denver metropolitan area maintenance plan modeling.

The overall modeling system, comprised of transportation, emission, wind, and air quality models, is initially used to replicate historic carbon monoxide high pollution episodes in order to establish base case simulations. Initially, air quality modeling is performed with a set of episode specific inputs for each historic episode. If the initial simulation fails to perform satisfactorily, input data are reviewed and refined, if appropriate.

## 3.2. Model Selection

The Diagnostic Wind Model version 1.1 level 900221 has been used to develop three-dimensional wind fields for the Urban Airshed Model.

The Urban Airshed Model (UAM) version 6.20 dated 920825 has been used. This is the same model and version as used in the approved Denver CO SIP. The Urban Airshed Model is a photochemical Eulerian-grid model, which simulates the atmospheric processes that affect pollutant concentrations. It simulates the emission, dispersion, advection and

[d] On a global scale, the chemical lifetime of CO with respect to OH and other reactive species is about 1 to 4 months or more (Seinfeld and Pandis, 1998; Finlayson-Pitts and Pitts, 1986). Longer lifetimes tend to occur in high latitudes during winter. On an urban scale shorter lifetimes could be expected. Nevertheless, for the time scales of CO high pollution events in Denver during the winter, atmospheric reactions involving CO are not considered to be significant enough to require explicit treatment with chemical mechanisms in the urban modeling process.

photochemical reactions of gaseous air pollutants. This application utilized a version of the UAM approved by the EPA for regulatory applications and compiled for the Microsoft Disk Operating System (DOS).[12] This model has primarily been applied to summertime ozone applications, but its ability to handle stagnation conditions also lends it modeling carbon monoxide episodes where Gaussian models perform poorly. Denver has been the site of three previous UAM applications. The first application was during the mid-seventies to determine if transportation plans were consistent with the SIP's ozone element;[13] it was also used in two draft CO SIP submittals to the EPA.[14, 15] While more recent versions of the Urban Airshed Model as well as more advanced grid models are now available, EPA Region VIII suggested that in this case, the originally approved modeling system from the approved SIP element may be used for the maintenance plan modeling.

The CAL3QHC line source dispersion model version 2.0 dated 95221 has been used. An earlier level (dated version) of version 2.0 was used in the approved CO SIP.

## 3.3. Flow Chart of Air Quality Modeling Process

The flow chart in Figure 3 illustrates the air quality modeling process. This diagram does not show the transportation and emission modeling processes.

A day specific CO emission inventory is first developed. The gridded inventory is then temporally allocated by the APCD’s FORTRAN code "PRCEMS11." This program also generates numerous graphic files. PRCEMS11 also generates the binary emissions files for input to the Urban Airshed Model.

Eleven other UAM input files are also used. These files define other aspects of the model, including initial and boundary conditions, meteorology, and other variables that control the simulation. The preprocessor files from the approved CO SIP modeling have been used in the maintenance plan modeling.

Roadway intersection modeling has been performed to assess impacts at intersections. Outputs from the UAM and CAL3QHC air quality models are combined during the post-processing phase. Hourly UAM and refined CAL3QHC concentration estimates are summed before 8-hour average concentration estimates are computed. In cases where screening-level worst-case CAL3QHC modeling has been performed, the 8-hour average CAL3QHC concentration estimates are directly added to the highest UAM estimate at each modeled intersection.

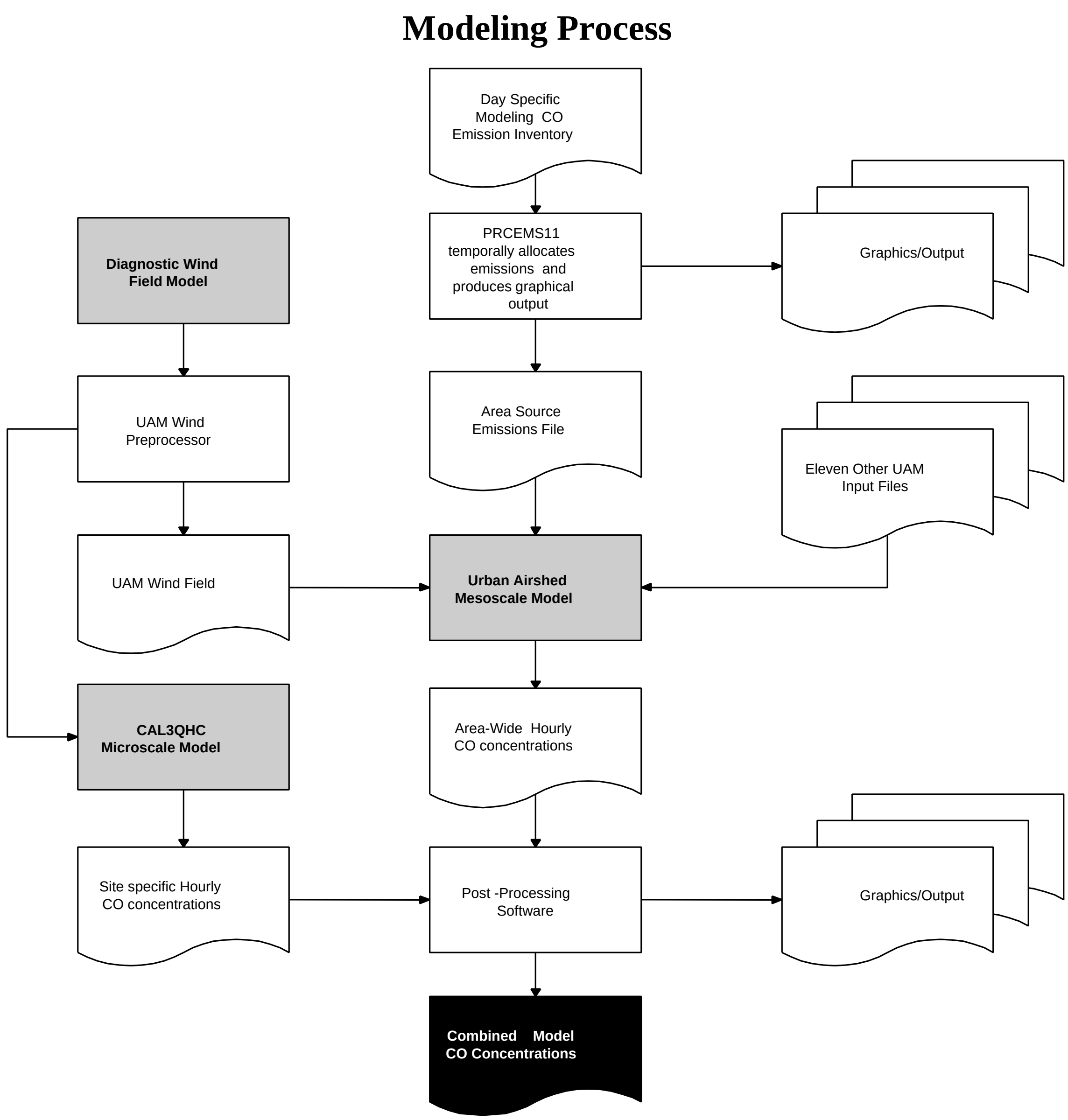


**Figure 3. Air quality modeling process. The meteorological files and preprocessor files from the CO SIP are the basis of the UAM maintenance plan modeling.**

## 3.4. Episode Selection

The modeling is based on the episodes used in the approved CO SIP (CDPHE, 1994). While emissions from vehicles have been reduced significantly since the late 1980s, meteorology is also an important factor. It's possible the climatology of the past few years has not included meteorological conditions that would cause high CO concentrations such as those modeled in the CO SIP. However, numerous stagnation episodes have occurred since 1995 which in the past have led to violations of the 8-hour CO standard. Since violations have not been monitored, it is safe to conclude monitored reductions are due to changes in emissions and in the transportation network and not due to a long period of favorable meteorology.

The episode selection process in the CO SIP is based on a review of the ten highest observed 8-hour average CO concentrations from the Denver nonattainment area for the period 1988 through 1991.[16] The top ten episodes are shown in Table 17. A review of meteorological data shows that insufficient data were available for the episodes ranked 3, 6, 7, 9, and 10. Therefore, the top episodes ranked 1, 2, and 4 were chosen as modeling candidates. In agreement with EPA Region VIII, modeling was conducted for the top two episodes. The third episode was held in reserve in case an additional simulation was necessary to confirm control strategy decisions.

Subsequent to selection of the episodes in early 1990, EPA issued guidance with specific requirements for selecting episodes.[17] In accordance with guidance, the episode selection process for the CO SIP was revisited.[18] The review process came to the same conclusions for the top two candidate episodes. The two selected episodes are referred to as the "high" and "second-high" episodes. It should be noted that each episode can be classified as a distinct meteorological regime.

**Table 17 . Ranking of Denver carbon monoxide episodes - 1988 through 1991 – as determined for the approved CO SIP.**

| Name of Monitor | Date | Ending Hour | Observed 8-hour Average CO Concentration | | Rank |
|---|---|---|---|---|---|
| | | | mg per m$^3$ | ppm | |
| CAMP (21st & Broadway) | 88/12/05 | 18 | 21.3 | 18.7 | 1[A] |
| CAMP | 88/01/15 | 19 | 18.5 | 16.2 | 2[B] |
| CAMP | 88/01/29 | 22 | 15.7 | 13.8 | 3 |
| CAMP | 91/01/31 | 21 | 14.7 | 12.9 | 4 |
| CARRIAGE (23rd & Julian) | 88/12/18 | 0 | 14.5 | 12.7 | 5 |
| CAMP | 88/01/28 | 20 | 14.3 | 12.5 | 6 |
| CAMP | 88/12/16 | 19 | 13.8 | 12.1 | 7 |
| CAMP | 90/03/08 | 21 | 13.8 | 12.1 | 8 |
| GRANDY'S (short-term study) | 88/12/17 | 0 | 13.7 | 12.0 | 9 |
| CARRIAGE | 88/01/28 | 23 | 13.5 | 11.8 | 10 |

[A] "High" Episode in Denver CO SIP
[B] "Second-High" Episode in Denver CO SIP

## 3.5. Meteorological Description of Modeling Episodes

Two meteorological episodes were initially simulated in the maintenance plan: the "high" episode - December 4-6, 1988 - and the "second-high" episode - January 14-16, 1988. The simulations for each episode span a three-day window. For the "high" episode, the simulation began late in the evening on December 4 and ended at noon on December 6. For the "second-high" episode, the simulation began early in the evening on January 14 and ended early in the morning on January 16.

### 3.5.1. Modeling Episode Selection for Maintenance Plan

For the maintenance plan modeling, both episodes were initially modeled with both 2006 and 2013 emissions scenarios. The modeling showed the “high” episode is clearly the controlling episode. For example, the “high” episode UAM maxima for 2006 and 2013 were 8.04 ppm and 8.42 ppm for some preliminary control strategy evaluations. In contrast, the “second-high” episode UAM maxima for 2006 and 2013 were 6.45 ppm and 6.82 ppm. The concentration maxima for the “second-high” episode were sufficiently low that all subsequent control strategy evaluations as well as the maintenance plan modeling are based on the "high" episode from the CO SIP.

### 3.5.2. Meteorological Conditions on December 5, 1988 - "High" Episode

For December 5, 1988 the National Weather Service, which at that time was located at Stapleton International Airport, reported clear skies, snow free ground, and temperatures that climbed from a low of 20°F to a high of 60°F. The morning sounding indicated a ground-based radiational inversion of 13°C over its 300 meters depth. Winds aloft were light (i.e., less than 15 knots up to 500 mb ) and westerly throughout this episode. Surface winds were light and southerly, indicative of drainage flow, and persisted throughout most of urban Denver until noon Mountain Standard Time. Then the winds reversed, becoming northerly, through 5 p.m. MST. During the early evening, when hourly CO levels reached 50.5 ppm at CAMP, winds were light, variable and interspersed with periods of calm. Gradually, the southerly drainage flow came to encompass the region, affecting downtown Denver last. By the next morning another radiational inversion had developed. On a broader synoptic scale, the upper-level 500 mb ridge was centered over western Kansas on the morning of the 5$^{th}$. By the next morning a weak upper-level low had moved over Colorado from the west coast. While at the surface, a great-basin high (over southern Idaho) and a low-pressure trough over western Kansas, resulted in a weak pressure gradient across Colorado. This weak gradient allowed mesoscale effects, such as drainage flows, to dominate the Denver wind field for this episode.

### 3.5.3. Meteorological Conditions on January 15, 1988 - "Second-High" Episode

While temperatures during the preceding two weeks averaged 19°F with lows less than 5°F on nine of those days, air flowing over the Rocky Mountains experienced down-slope warming which helped raise the temperature to 50°F on January 15, 1988. General snow cover existed. Broken to overcast cloud cover consisted of strato, alto, and cirrocumulus as well as rotor and lenticular clouds. While strong southwesterly to westerly winds existed aloft and at some surface sites, surface winds in the Platte valley near downtown Denver were typically less than 2 mph and occasionally from the northeast. Decoupled winds aloft generally flowed over a cold pool of air in the Platte valley; meanwhile, as the wind speed decreased at the surface, the cold ground enhanced cooling of the air immediately adjacent to it, thereby creating a stable boundary layer characterized by a shallow but strong temperature inversion which effectively trapped CO emissions[19]. On a synoptic-scale, a surface lee trough in eastern Colorado with a surface high pressure ridge to the west prevailed throughout the episode. A 500 mb ridge moved over the region with the axis over Kansas by 5 p.m. MST on January 15$^{th}$.

## 3.6. Modeling Domain

The UAM modeling domain was chosen to include the Denver and Longmont CO nonattainment areas, all current and future urbanized areas, point source emissions, air quality monitors, and hot spot intersections in the Denver metropolitan area for the two episodes. The UAM boundaries are sufficiently distant from the area of primary interest to minimize the effects of boundary conditions on calculated concentrations.

Figure 1 on page 3 depicts the UAM modeling domain and the Denver CO nonattainment area. The exact specifications for the modeling domain are listed in table below.

The Diagnostic Wind Model (DWM) domain is larger than the UAM domain. It is extended 20 miles to the west and 15 miles in the other cardinal directions. DWM grid cells have the same lateral dimensions as the UAM cells. Figure 4 shows the DWM and UAM domain along with the meteorological stations used in the modeling.

**Table 18. Denver metropolitan area Urban Airshed Modeling Domain.**

| | |
|---|---|
| UTM Origin (Easting) | 465,246 meters |
| UTM Origin (Northing) | 4,331,084 meters |
| UTM Zone | 13 |
| Cells in X-direction | 59 |
| Cells in Y-direction | 78 |
| Cells in Z-direction | 5 |
| Cell area | 1 $mile^2$ |
| Cell side dimension | 1 mile |

Once the modeling system has been evaluated and determined to perform within prescribed levels, the same meteorological inputs may be used along with a projected emission inventory to simulate the impact of future emission scenarios.

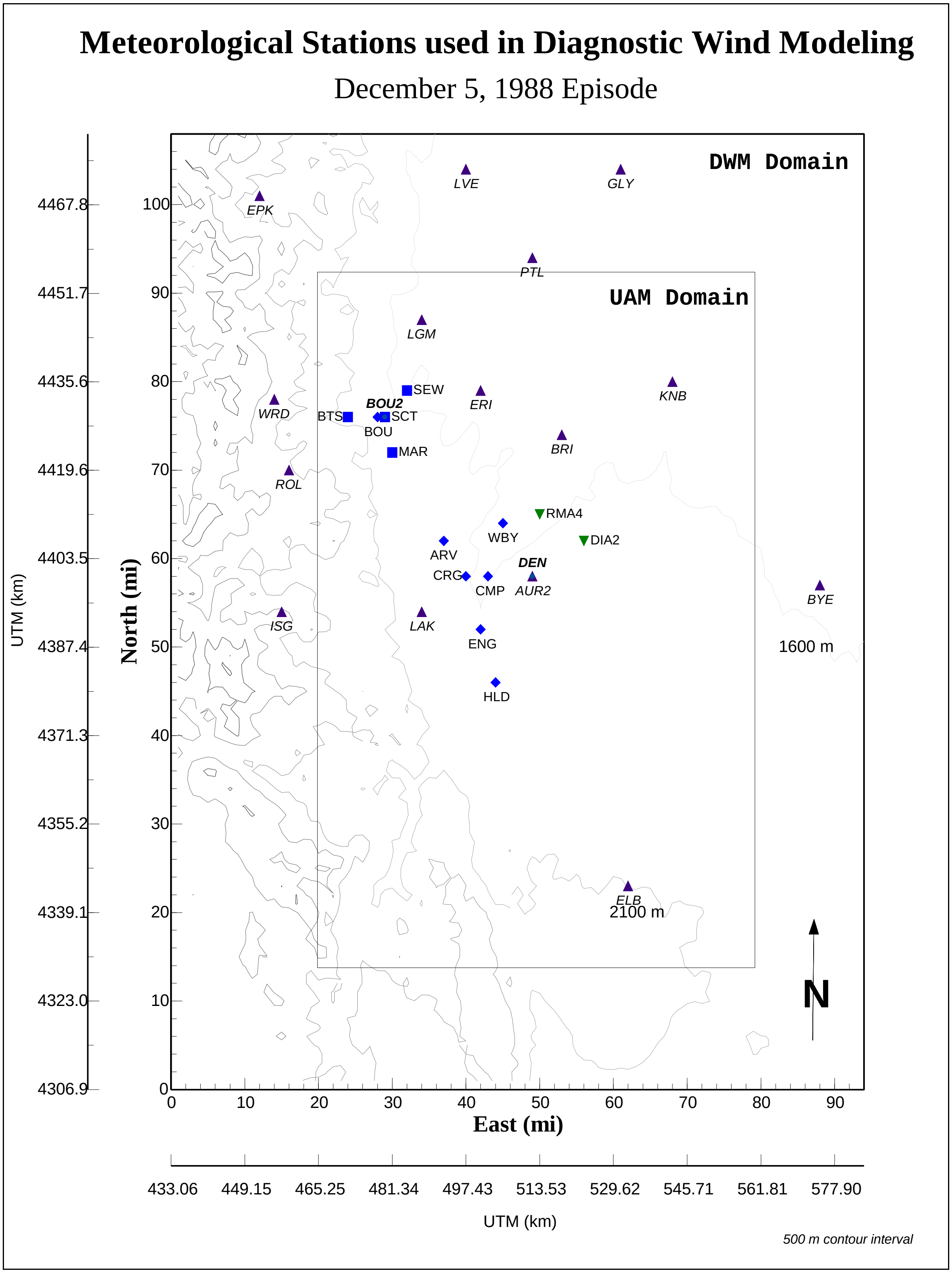


**Figure 4. Meteorological observation sites used in developing and evaluating the diagnostic wind model for the "high" episode used in the maintenance plan.**

## 3.7. Diagnostic Wind Model (DWM)

The Diagnostic Wind Model (DWM) was used to produce an hourly three-dimensional wind field. The DWM combines parameterized slope flows and observational data. Vertical velocities are minimized in the procedure. There are four principal steps in deriving a wind field for the UAM using the DWM:

1. A domain mean wind is defined and perturbations due to the effect of topography are added to it.
2. Surface and upper air observational data were interpolated with an inverse-distance-squared weighting method and combined with terrain influenced flow vectors.
3. The horizontal portion of the DWM domain, which represents the UAM domain, is extracted.
4. The DWM winds are vertically interpolated to match the UAM's vertical structure.

The DWM domain encompasses the smaller UAM domain, as recommended by guidance.[20] This allows for the effects of significant terrain outside the UAM domain, to influence the wind field within it. Therefore, the DWM domain used in this application extended 15 miles beyond the UAM domain boundaries, except to the west, where it was extended for 20 miles. It was composed of 1 mile square grid cells, with 94 cells from west to east, and 108 cells from south to north. In the vertical, the "high" episode used 12 layers of differing depth, extending to a combined thickness of 1,100 meters. The "second-high" episode was modeled using only 10 layers, but extending to the same height. Since Doppler sodar data was available for the "second-high" case, the layering scheme was adjusted to be consistent with it. The sodar data has constantly spaced data points, and the DWM layering scheme allowed for one data point per layer. Thus, the critical near-surface environment was well represented. Although, the top layer was quite large, extending from 400 to 1,000 meters above ground level (agl), the diffusion break is below this level throughout the entire episode.

The topographic relief in the domain is over 2,000 meters, from the continental divide at approximately 3500 meters, down to the Platte River valley at around 1,500 meters. Since the DWM uses terrain following coordinates, this did not present a problem to the model.

A full description of the DWM wind modeling can be found in the "CO SIP Technical Support Document" (CDPHE, 1994).

## 3.8. Urban Airshed Model (UAM) Setup and Application

The UAM is an air quality planning tool. To utilize it in a regulatory setting, the model needs to adequately reproduce the meteorology, emissions, and concentrations which occurred during selected historical episodes. The choice of episodes was discussed in a previous section. To determine if the model is getting the "right" results for the "right" reasons, the sensitivity of the model to critical input parameters is investigated. Statistical measures and graphic plots were used to interpret the results of these tests. Through this cyclical process the performance of the model is gradually improved until it accurately reflects the characteristics of the episodes and meets the EPA's performance criteria.

Inputs to the UAM must first be prepared by one of the UAM's 13 preprocessing programs. Input files and related discussions for all of the preprocessors can be found in the Technical Support Document for the CO SIP (CDPHE, 1994) or in this document. The Data Access Volume - Chapter 9 to the “CO SIP Technical Support Document” (CO SIP TSD) - and other chapters of the CO SIP TSD provide all the necessary files for the reader to duplicate the attached results for either episode.

The following sections and the CO SIP TSD describe the data sources, procedures, assumptions, and processing used in characterizing the meteorology and air quality of episodes modeled with the UAM. The procedures described below apply to both episodes unless otherwise noted. The primary guidance document for this modeling effort was Guideline for Regulatory Application of the Urban Airshed Model for Areawide Carbon Monoxide.[21] The detailed technical information on the model is contained in the Users Guide for the Urban Airshed Model which has five volumes.[22] The first three volumes are applicable to this application, neither Volumes IV nor V, which describe the Emissions Preprocessor System and the interface to the Regional Oxidant Model, were used.

### 3.8.1. Simulation Start and End Times (SIMCONTROL)

The start and end times for modeling episodes were chosen to test the model’s ability to replicate the onset and cessation of the elevated period of ambient CO concentrations. For the "high" (December 4-6, 1988) episode, the model was started at 10 PM Mountain Standard Time (MST) on December 4, 1988, and ended at 12 noon MST on December 6, 1988; the duration of the run was 38 hours. For the "second-high" (January 14-16, 1988) episode, the model was started at 6 PM MST on January 14, 1988, and ended at 6 am MST on January 16, 1988; the duration of the run was 36 hours. Graphs of hourly CO monitored and modeled concentrations found in the model performance section of the CO SIP TSD illustrate this point.

### 3.8.2. Initial Conditions (AIRQUALITY)

Setting the conditions at the beginning of a model run is referred to as "initializing" the model. The procedures, assumptions, and data sources used in this analysis are presented below and in the CO SIP TSD.

Initial air quality values were specified for the entire modeling domain, including all surface and upper level cells, for both base and future cases. These 1-hour CO concentrations represent ambient conditions at the beginning of an episode. Routine and special study monitors of the Colorado Department of Public Health and Environment were used as the source of CO observations. These values were input to the AIRQUALITY preprocessor, which utilized an inverse radius interpolation scheme to derive initial concentrations for the entire modeling domain. Since this method distributed high urban concentrations to rural areas, a series of "pseudo" monitoring stations were positioned in these remote areas and were assigned a "background" concentration value of 0.2 ppm.[23] The inputs to the AIRQUALITY preprocessor can be found in the attachments to the approved CO SIP TSD.

In determining future year initial conditions, it was assumed that all "pseudo" stations remained constant at "background" levels. This approach is based on the assumption that the background concentration accounts for ambient carbon monoxide that is either not accounted for in the emission inventory estimates or unaffected by emission controls. At actual monitors, it was assumed future year initial conditions would change in proportion to changes in the modeling emissions inventories (i.e., a linear "rollback" method was used).

Therefore, for future case UAM scenarios, the ratio of the 1988 modeling inventory to the future year modeling inventory was applied to all monitors specified in the AIRQUALITY input file. The equation follows:

$$C_{future} = (C_{1988} - C_b)(E_{future}/E_{1988})$$

where

$C_{future}$ = projected future year initial CO concentration
$C_{1988}$ = observed 1988 initial CO concentration
$C_b$ = background CO concentration
$E_{future}$ = total CO emissions in a future year
$E_{1988}$ = total CO emissions in 1988

If the projected future year initial CO concentration calculated from the above equation is negative, then the value was set equal to the background concentration of 0.2 ppm.

A comparison of domain-wide emissions totals for 2000-2001, as modeled in the CO SIP, and emissions for 2006 and 2013 indicate that changes in total CO emissions between 2001 and 2013 are relatively small. For example, the total CO emission rate from all source categories for 2001, as modeled in the CO SIP, is 1,203 tons per day. The estimates for 2006 and 2013 for the maintenance plan are 1,125 and 1,153 tons per day, respectively. Thus, the original initial conditions as used in the approved CO SIP are reasonable estimates for the maintenance plan years of 2006 and 2013. In fact, the CO SIP initial conditions for 2000-2001 may slightly overestimate initial conditions for 2006 and 2013.

If initial conditions were calculated using the above methods for 2006 and 2013, it would change the maximum CO concentration estimates by less than 0.01 ppm. This is based on UAM sensitivity tests that suggest the initial concentration levels observed at the start of the simulation are transported out of the modeling domain before the emissions occur which actually lead to the high pollution events. That is, the initial condition concentrations have essentially no effect on the maximum modeled concentrations in the attainment demonstration. Minimizing the effect of initial condition assumptions is, in fact, one of the criteria used to determine the day and hour to start the simulation for an episode.

### 3.8.3. Other UAM preprocessors

Discussions on the other UAM preprocessors are in the Chapter 6 of the CO SIP TSD (CDPHE, 1994). All other preprocessor files were identical to those used in the approved CO SIP.

## 3.9. CAL3QHC Model Setup and Application

CAL3QHC roadway intersection modeling is intended to estimate CO concentration levels in the vicinity of busy intersections where high concentration gradients can occur. According to EPA guidance, "in an urban area, sources of mobile emissions are especially widespread. Ambient concentrations of CO may be high near locations where vehicles tend to accumulate, slow down, and idle for a period of time (e.g., at an intersection). The extent of this problem is a direct function of the number of vehicles, their operating mode, their movement, and the length of delay. Thus, the CO distribution across an urban area is not only a function of the distribution of major urban development in the area, but also of individual intersection, street, and traffic characteristics."[24] In addition to the intersection geometry and vehicle operations, local meteorology and vehicle emission rates have a major impact on estimated CO concentrations.

Because of the time and resources necessary to model each individual intersection, EPA guidance suggests that hot spot modeling is necessary at only a select number of locations.

CAL3QHC analyses can be performed in either a conservative "screening" level mode or in a "refined" mode. Refined analyses are intended to provide more realistic concentration estimates than screening level analyses.

For the replication of the 1988 base case episodes, refined level modeling was conducted at both the CAMP and NJH monitoring sites.

For future year modeling, refined analyses were conducted as necessary to demonstrate attainment. If the combined UAM background estimate and the screening level CAL3QHC showed attainment with federal standards, refined level intersection modeling was not conducted.

For the maintenance plan modeling, the CAL3QHC model was applied to a total of five intersections to estimate the CO impacts from motor vehicles traveling at roadway intersections. The modeling approach and results are described and discussed in subsequent sections. CAL3QHC was applied in either a "refined" mode or in a "screening" level mode for future year scenarios, as appropriate.

Episode-specific CO concentration estimates for 1988 at the CAMP and NJH monitors are shown in the performance evaluation section of the CO SIP TSD. In general, the results show a rise in concentrations in the afternoon, peaking during the PM rush hour.

### 3.9.1. Intersection Selection

For the Denver maintenance plan, intersections were selected for modeling from the highest volume and most congested intersections in the Nonattainment Area based on information from the Denver Regional Council of Governments (DRCOG). The top three intersections in each of these two categories were selected for modeling. University

Boulevard and Hampden Avenue is first in congestion and second in volume, and while 28th St. and Colorado Avenue in Boulder is number 3 on the volume list, Foothills Parkway and Arapahoe Avenue in Boulder is number 4 in volume and number 2 in congestion; 28th St. and Colorado Avenue is also going to be reconstructed; thus, it was not selected for modeling. Thus, only five intersections were selected:

- University Boulevard and Hampden Avenue
- Foothills Parkway and Arapahoe Avenue
- University Boulevard and First Avenue (number 1 in volume)
- University Boulevard and Arapahoe Road (number 3 in congestion)
- Parker Road and Iliff Avenue (number 4 in congestion).

These intersections represent the top four intersections in congestion and three out of the top four in volume. One additional intersection from downtown Denver was modeled, even though this is not expressly required in EPA's intersection selection guidance. A downtown intersection was modeled during the Denver carbon monoxide SIP process in 1993 and 1994 because EPA requested the State "model an additional intersection in the central business district, to ensure that control strategies provide for attainment at hot spot locations in the urban core area, not just at suburban locations exposed to significantly lower background concentrations."[e]

The CAMP intersection at Broadway/Champa Avenue/21st Street (CAMP) was selected for use in the SIP attainment demonstration as the downtown intersection because on-site air quality and meteorological data were available at this location to validate the performance of the entire transportation, emissions, meteorological, CAL3QHC, and UAM modeling system. It was also the location of the maximum monitored CO levels in the Nonattainment Area for the episodes modeled. In addition, the CAMP monitor is close to several streets. The CO concentration measured at the CAMP site is a combination of the urban background concentration, which is predicted by the UAM model, and the impact of local streets, which is predicted by the CAL3QHC model.

A high level of uncertainty is associated with the results from the combined CAL3QHC/UAM modeling system at all downtown intersections[f] where basecase validation could not be done due to a lack of site-specific meteorological and air quality observations. The CAL3QHC model is not designed to simulate conditions in urban "canyons" and near large buildings that affect micrometeorology around the intersection. In the Federal Register (see Appendix I) it is stated that "micrometeorological effects of high-rise office buildings significantly increase modeling uncertainties at these intersections, where on-site meteorological data was not available."

Therefore, in order to include downtown intersections other than the CAMP intersection in the maintenance plan modeling, it would have been necessary to select and model new basecase episodes and to perform new model validation studies. Using EPA

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[e] Letter from EPA Region VIII to Tom Getz, APCD Director, dated March 23, 1995.
[f] This includes the intersection of Speer Blvd. and the Auraria Parkway. The Division is making every effort to improve the ability to model at this site. A carbon monoxide monitor has been located at this intersection since November 1993. A meteorological tower has been located near the intersection since March 1999.

episode selection guidance, episodes from the previous three years would have been reviewed to select episodes for modeling (i.e., 1996, 1997, 1998, and the first half of 1999). Since the climatology of the past few years did not include any episodes that threatened the federal standard[g], the Division concluded that the historic meteorological episodes from 1988 used in the approved CO SIP provided the appropriate "worst-case" meteorological regime on which to base future control strategies. Thus, since new basecase episodes were not modeled, it was not possible to model the Speer Blvd. and Auraria Parkway intersection in this plan.[h] The reasons for not performing CAL3QHC modeling at Speer and Auraria are discussed in the federal register notice in Appendix I.

On November 30, 1999, elevated carbon monoxide concentrations occurred in the Denver metro area. An exceedance of the federal standard occurred at the intersection of Speer and Auraria. The modeling for this maintenance plan was already complete at the time of the November 30 episode. Nevertheless, the episode provided confirmation that the "high episode" from the CO SIP was a good choice for selecting control strategies for the maintenance plan. The episode demonstrates that the CO standard can still be threatened or marginally exceeded in Denver. A marginal exceedance in 1999 is consistent with the approved CO SIP modeling results, which suggested that Denver would barely come into compliance with the federal standard at the end of the year 2000.

With respect to the downtown intersection selection process used in the approved CO SIP, the Federal Register states the following:

> *EPA concurs with the final modeling analysis submitted by the State. This decision is supported by the supplemental CO monitoring studies that have been performed in the downtown area. These studies support the continued use of CAMP as the maximum concentration downtown site….The reason the modeling results for the two intersections in the downtown area were dropped is that the CAL3QHC model could not be applied appropriately given the effects of nearby downtown buildings on wind flow and the lack of representative on-site data. Building effects were not an issue at the six suburban intersections modeled in the SIP.*

In the statement above, EPA refers to CAMP as the "maximum concentration downtown site." Based on a review of monitoring data through December 8, 1999, both the CAMP site and the site at Speer and Auraria are representative of the maximum concentration in Denver. Both sites are located in areas of the central business district where elevated CO concentrations can occur. While one data analysis approach might conclude that CAMP is the maximum site, another analysis method can support Speer and Auraria as the maximum site. For example:

- The maximum 2$^{nd}$-highs for 1997, 1998, and 1999 for Speer and Auraria are 6.4 ppm, 5.2 ppm, and 4.7 ppm, respectively. In comparison, for the same years, the maximum 2$^{nd}$-highs for CAMP are 5.5 ppm, 4.7 ppm, and 4.4 ppm.

[g] This statement does not include the episode on November 30, 1999 where a 9.5 ppm was observed at Speer and Auraria and a 9.1 was observed at CAMP.
[h] Downtown intersections like Speer and Auraria did not have monitoring data available in 1988, which is the year with the basecase episodes used in this plan.

- The maximum 8-hour CO in 1997 of 7.0 ppm was measured at the Carriage site west of downtown. The maximum in 1998 was 5.8 ppm measured at CAMP. The maximum in 1999 was 9.5 at the Speer and Auraria monitor.
- During the November 30th episode, hourly concentration levels at CAMP climbed sharply with respect to Speer and Auraria for the hourly periods at 5 p.m. and 6 p.m. (see Figure 5). For the hourly period at 7 p.m., the concentration at CAMP dropped dramatically while the concentration at Speer and Auraria continued to climb. If the concentration at CAMP had stayed elevated at around 11 ppm for the 7 p.m. period, the 8-hour average at CAMP and Speer and Auraria would have both been 9.5 ppm.
- From 1993, when a second downtown monitor was added at the corner of Speer and Auraria, through 1998, the CAMP monitor measured downtown Denver's maximum 1-hour carbon monoxide concentration every year. In 1999, three different sites have experienced about the same 1-hour maximum: 1) Arvada measured a 13.2 ppm on January 29th, 2) CAMP measured a 13.1 ppm on November 30th, 3) Speer and Auraria measured a 13.2 ppm on November 30th.
- Between 1993 and 1998, the CAMP monitor measured downtown Denver's maximum 8-hour concentration for three years while the monitor at Speer and Auraria measured the maximum 8-hour concentration twice. In one year (1993), the two downtown monitors both measured the same maximum eight-hour concentration of 10.4 ppm.
- A comparison of maximum 1-hour and 8-hour concentration data between 1993 and 1999 for the CAMP and Speer and Auraria sites are shown in Table 19, below.

**Table 19. Comparison of maximum 1-hour and 8-hour average carbon monoxide data at CAMP and Speer and Auraria between 1993 and 1999.**

| Year | Maximum 1-hour carbon monoxide concentration (ppm) | | Maximum 8-hour carbon monoxide concentration (ppm) | |
|---|---|---|---|---|
| | CAMP | Speer and Auraria | CAMP | Speer and Auraria |
| 1993 | 19.4 | 16.2 | 10.4 | 10.4 |
| 1994 | 20.4 | 13.8 | 9.9 | 9.0 |
| 1995 | 24.5 | 15.0 | 11.0 | 9.7 |
| 1996 | 21.6 | 15.7 | 9.0 | 9.2 |
| 1997 | 11.4 | 11.2 | 5.7 | 6.6 |
| 1998 | 11.6 | 10.1 | 5.8 | 5.6 |
| 1999 | 13.1 | 13.2 | 9.1 | 9.5 |

The fact is, in recent years, there are too few data points from episodes where the 8-hour average concentration exceeds 9.0 ppm to determine a single maximum site with certainty. In fact, the November 30, 1999 episode is the only episode with observed concentrations over 9 ppm in recent years.

Each episode has unique characteristics. The monitoring site with the highest concentration depends on the specific meteorology and emissions density during a given episode. Based on a review of current and historic data and on a conceptual understanding of the ingredients that lead to elevated CO levels in Denver, it's reasonable to believe that either the CAMP monitoring site or the Speer and Auraria site are capable of being the maximum site during a future high CO episode in Denver.[i]

It is reasonable to conclude that both monitoring stations are representative "maximum sites" for downtown Denver. Since a credible basecase validation exists only for the CAMP site, the maintenance plan modeling for Denver only includes intersection modeling for the CAMP intersection. In addition to being consistent with the approved CO SIP, the use of CAMP as the maximum modeling site (as opposed to using an unvalidated modeling system at Speer and Auraria) is reasonable for making control strategy decisions.

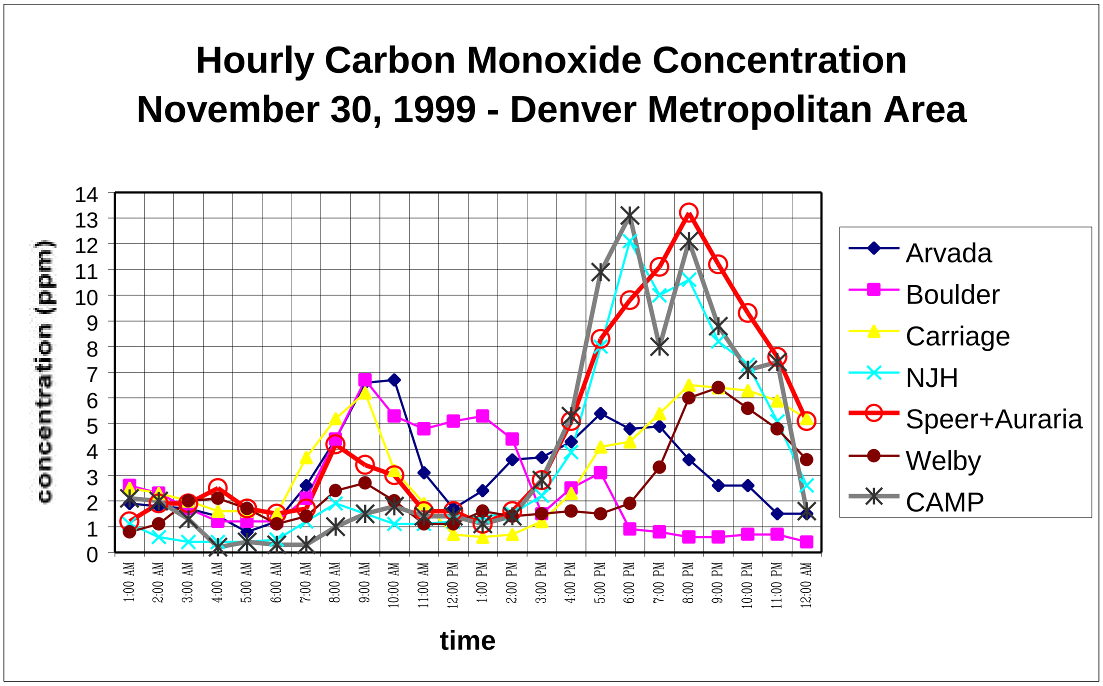


**Figure 5. Observed hourly concentration values on November 30, 1999.**

Finally, its important to emphasize that the air quality modeling system being used in the maintenance plan is based on the same model validation work and the same episodes that were used in the CO SIP. Since no new episodes have been modeled, a new basecase validation has not been performed.[j] Even though a meteorological tower and a CO monitor exist at Speer and Auraria, it is not possible to use the data in the modeling process used in this maintenance plan. Therefore, no downtown intersections besides the CAMP

[i] During the episode on 11/30/1999, a maximum 8-hr concentration of 9.5 ppm was observed at Speer and Auraria while 9.1 ppm was observed at CAMP. The 8-hr concentration maxima are very close. Slight changes in meteorology could have made CAMP the maximum concentration site during this episode. In any case, a comparsion of the hourly data in Figure 5 shows the magnitude of the hourly values are similar at the two sites.

[j] A basecase validation is only done for the historic episodes that have been modeled. Urban Airshed Modeling is based on the concept of developing a modeling system that can replicate the characteristics of a historic high pollution episode. Then, once the model performs in an acceptable manner, the emissions for the historic episode can be replaced with projected emissions for the future.

intersection have been modeled. If new basecase episodes were selected and modeled, the intersection of Speer and Auraria would be considered for inclusion in the modeling process. The intersection selection process for downtown Denver would depend on the characteristics of the episodes selected for modeling and upon the availability of data to support model development and evaluation. Even if UAM/CAL3QHC modeling were performed at a downtown intersection such as Speer and Auraria, the modeling results would only be recommended for use in control strategy determinations if the results from the modeling system performed within acceptable performance measures.

#### 3.9.1.1. Conclusions from the 1997/1998 CO Saturation Study at Speer and Auraria

The "Winter 1997/1998 CO Saturation Study" was conducted by the State to study CO concentration fields near Speer and Auraria. Nine CO samplers were placed near the intersection, two were placed near 7$^{th}$ and 9$^{th}$ Streets, three were sites in and around the Auraria campus to serve as general CO background monitors, and one was collocated with the permanent CO CAMP site. No episodes with CO concentration levels approaching the CO standard occurred during the study. Nevertheless, the data provide a better understanding of 8-hour average concentration gradients near the intersection. For example, on the day with the highest CO observations at the intersection, the samplers near the intersection had observations that varied from 2.6 to 4.8 ppm. The “background” samplers farther away from the intersection (but within the grid cell, as defined for Speer and Auraria in the CO SIP), had a range from 2.6 to 3.1 ppm on the same day. On the day with the next highest observations, the CO range at the intersection was 3.8 ppm to 4.7 ppm; the background samplers ranged from 3.0 to 3.9 ppm. On the third highest day, the CO range at the intersection was 3.6 ppm to 4.5 ppm; the background samplers ranged from 3.0 to 3.7 ppm. Thus, the data suggest there is a CO concentration gradient of up to 2 ppm near the intersection.

Insufficient ambient data exists to conclude that an 8-hour CO gradient at Speer and Auraria of up to 2 ppm exists under low, moderate, and high CO concentration levels. Nevertheless, based on theoretical arguments, it’s probably reasonable to assume that the 8-hour CO gradient near the intersection is about the same during both moderate and high concentration episodes. The primary difference between a moderate and high concentration episode would be changes in the “background” CO concentration. For example, during a stagnation event, CO would accumulate from one hour to another, thus raising the background, but the contribution from the intersection would remain about the same.

It would be speculative to add a 2 ppm intersection component for Speer and Auraria to the UAM-based background concentration for the 2006 and 2013 scenarios. Such an approach should only be used if appropriate basecase validation studies are performed to ensure that such an empirically-based approach performs within acceptable performance measures. The uncertainties associated with using an unvalidated analysis approach are unacceptably high for developing metropolitan-wide control strategies. Instead, monitoring will continue to be used to demonstrate compliance at Speer and Auraria until such time that new basecase episodes are modeled.

The saturation study provides further data to suggest that violations of CO standards did not occur at or near the intersection of Speer and Auraria during the study period. In addition, the study has provided a better understanding of concentration gradients near the intersection. From this, the Division has concluded that the current monitoring site inlet location is reasonably representative of worst-case concentration levels near the intersection. Nevertheless, based on the low CO concentrations observed during the study, it would be difficult to make conclusive statements about what the study means in terms of future compliance with federal standards. For example, on November 30, 1999, an 8-hour concentration of 9.5 ppm was measured at the intersection of Speer and Auraria. This is an exceedance of the federal standard. While this measurement causes concern about the potential for Denver to violate the federal 8-hour CO standard, this is the only measured exceedance since 1995. Thus, it is not considered to be a "violation" of the federal standards.

### 3.9.2. CAL3QHC Input data

CAL3QHC is a microscale air quality model and its accuracy depends on the accuracy of the input data. Therefore, high quality data have to be acquired. This section documents some of the CAL3QHC input data utilized in modeling all intersections.

In general, input data can be grouped into the following categories:

- Meteorological and site variables
- Roadway geometry
- Traffic variables
- Receptor locations
- Vehicular emission rates

### 3.9.3. Receptor Locations

The intent of EPA's guidance is to require receptors where "the maximum total project concentration is likely to occur and where the general public is likely to have access." As a rule, receptors should be located at a minimum of 3 meters (10 feet) from the outside lane of the traveled roadway to provide a buffer for the turbulence created by the moving vehicles.

Beyond these general rules, EPA suggests that receptors should be located at points where the public has access and is present on a more or less continuous basis for the model averaging time and where maximum pollutant concentrations are likely to occur. Typical receptor locations include sidewalks or building entrances or exits which are located outside the mixing zone of the free flow links of the intersection.

For this analysis, receptors were located according to EPA's guidance document at the beginning, middle, and end of each queue link for all intersection approaches. Each receptor was modeled at a conservative distance of 10 feet from the outside lane. Receptors were also placed at specific points 10 feet from the outside lane on each departure leg to determine contributions of vehicles exiting the intersection. All receptors were modeled six feet above the ground to reflect the breathing height of individuals.

### 3.9.4. Vehicle Emission Rates

EPA's MOBILE 5b emission factor model was used to generate composite running exhaust emission factors. MOBILE 4.1 was used to generate idling exhaust emission factors. Critical variables for MOBILE modeling include percentage cold start vehicles, idle emission factor, the vehicle type, average vehicle speed, and ambient temperature. The operating modes used for idle emissions were EPA default as was done in the approved SIP. Average vehicle speed (free flow speed) is the average speed of vehicles traveling through the intersection in the absence of delay caused by signals. Average free flow speeds were provided by DRCOG from field observations for all of the intersections except CAMP (which were based on information from the City of Denver).

Roadway geometry and traffic variables were obtained from DRCOG. Traffic counts from 1999 were used with growth factors developed from the DRCOG traffic models to develop traffic volumes.

### 3.9.5. Screening Procedures

Screening modeling is conducted because a full scale (i.e., refined) analysis of each of these intersections would be both time consuming and possibly unnecessary. Thus, it represents an alternative procedure that is intended to reduce the amount of time it takes to evaluate each intersection for its potential to violate the 8-hour NAAQS.

For screening level analyses, CAL3QHC is run for a single hour with worst case meteorology. A persistence factor of 0.7 is then applied to convert the 1-hour average estimate to an 8-hour value. Worst case meteorology includes wind speeds of 1 meter per second, a wind angle search of all angles from 5 to 360 degrees in 5 degree increments, “D stability” (neutral), and a mixing height of 1,000 meters. The PM-peak emission rates and traffic volumes were used.

The screening level procedures were sufficient to demonstrate attainment for all intersections except First and University and the CAMP intersection. For the First and University intersection, hourly meteorology from the UAM modeling was used with the PM-peak emission rates and traffic volumes with CAL3QHC-R to generate the 8-hour average concentration.

### 3.9.6. Refined Modeling Procedures

"Refined" CAL3QHC modeling is conducted when screening level modeling indicates that the NAAQS may be threatened. It is based on hourly traffic volumes, emissions, and meteorological data. Refined modeling was performed only at the CAMP intersection using the on-site meteorology from the original SIP. For the refined modeling, as was done in the original SIP, concentration estimates from the CAL3QHC model have been corrected to reference conditions as defined in the CFR for the CO standard (1013.2 mb and 298 K) by applying a correction factor of 15 percent (1.15) before the results are added to the UAM calculated background.

No altitude correction was made for the screening level modeling results because these results are already very conservative. It can also be argued that the persistence factor of 0.57 which was used for the screening level modeling in the original SIP is more appropriate than the more conservative persistence factor of 0.7 which was used for the screening level results in this analysis.

### 3.9.7. Treatment of Calms

According to EPA's "Guideline on Air Quality Models," (Appendix W to 40 CFR Part 51), "treatment of calm or light and variable wind poses a special problem in model applications since Gaussian models assume that concentration is inversely proportional to wind speed. Furthermore, concentrations become unrealistically large when wind speeds less than 1 $m \cdot s^{-1}$ are input to the model...." [25]

Therefore, EPA suggests that wind speeds less than 1 $m \cdot s^{-1}$ but higher than the response threshold of the instrument should be input to a Gaussian model as 1 $m \cdot s^{-1}$; the corresponding wind direction should also be input. Wind speeds less than the response threshold of the instrument are defined as "calm." That is, the wind is "indeterminate with regard to speed or direction."[26]

If the wind speed or direction is indeterminate, that particular hour should be treated as "missing" and short term averages should be calculated in accordance with EPA procedures.

EPA's CAL3QHC guidance document states that "a worst-case wind speed of 1 $m \cdot s^{-1}$ should be used in the CAL3QHC model for all analyses, except when urban areawide modeling using the Urban Airshed Model (UAM) is being performed in conjunction with the CAL3QHC intersection model. In such cases, each hour modeled in the UAM simulation should be modeled with CAL3QHC using the hourly wind speed (and direction) from the UAM grid square where the intersection is located."[27] However, the CAL3QHC Users guide states that the model has not been validated for wind speeds less than 1 $m \cdot s^{-1}$.

At CAMP, observed wind speeds are less than 1 $m \cdot s^{-1}$ for most hours of interest. According to the instrument specifications at the time of the "high" episode in 1988, the response threshold is less than 1.25 mph ($<0.6\ m \cdot s^{-1}$).

In this CAL3QHC application, all wind speeds less than 1 $m \cdot s^{-1}$ were input to the model as 1 $m \cdot s^{-1}$, regardless of the instrument threshold. This approach allowed the Division to compute hot spot concentration estimates for all hours and to compare the performance of the combined modeling system to observed values at CAMP. As can be seen in the approved CO SIP (CDPHE, 1994), model performance at CAMP was satisfactory with this approach. Therefore, the basecase validation supports the use of a similar methodology for treating calm winds for the maintenance plan. However, the impacts of not having on-site meteorology, or of substituting 1 $m \cdot s^{-1}$ wind speed during calm periods, are indeterminate at each intersection where on-site atmospheric measurements are lacking.

## 3.10. Model Performance Evaluation

The modeling performance evaluation presented here is the same as that performed for the approved Denver CO SIP. A new evaluation has not been performed. The performance evaluation is presented here for completeness.

According to California modeling guidance, "an underlying principle of the air quality modeling process is that there needs to be a technical foundation for judging the credibility of an air quality modeling simulation. A performance evaluation provides that technical foundation. A performance evaluation is the process of establishing that the model is working correctly and is accurately reproducing...observations."[28]

The model performance evaluation phase "is a process consisting of several thoughtful, orderly steps all structured around the intended application of the model....it is useful to distinguish between a 'regulatory' evaluation and a 'scientific' evaluation. In a regulatory evaluation, the focus is on the intended use of the model in public decision-making. Scientific evaluation has its focus on determining how well the model reproduces the observed behavior of atmospheric pollutants."[29] In this carbon monoxide application, both types of evaluation are considered to be essential.

The statistical measures suggested by EPA can be broadly classified as an "operational evaluation."[30] That is, they are an assessment of the models ability to estimate observed concentrations during the historic episodes being simulated. This type of evaluation does not necessarily address how well the simulation has replicated each applicable 'process.' That is, it does not explicitly address how well each individual module performed in the transportation, emission, and meteorological modeling process. Operational evaluations are certainly important, but additional tests are necessary to satisfactorily evaluate the modeling process.

EPA guidance encourages the use of operational, diagnostic,[k] and mechanistic[l] tests to evaluate model performance.

One of the basic questions with any simulation is whether or not the model is giving the correct results for the right reasons. In other words, are there compensating errors? For example, a simulation might underestimate carbon monoxide concentrations because the on-

[k] A *diagnostic evaluation* is "an assessment of a model's ability, when functioning as a whole, to simulate reliably processes or characteristics of the system occurring during...a(n) episode.... The events and tests are chosen to challenge the science in the model." (Tesche, et al, 1990)
[l] A *mechanistic evaluation* is "an assessment of an individual modules' ability to reproduce the observed salient features of the process it is intended to describe. When applied to all process modules that constitute the full model, mechanistic evaluation represents a test of the correctness of the underlying science." (Tesche, et al, 1990)

road mobile estimates from the transportation and emission models are too low. Subsequently, the meteorological modeler might lower the mixing depth to compensate for the low emissions. Thus, in such a case, the model might be giving the right result for the wrong reason. The implications of such compensating biases are difficult to assess and, in a worst-case scenario, incorrect control strategy decisions could be made.

Consequently, in the approved CO SIP from 1994, every attempt was made, within the time and resource constraints available, to conduct operational, diagnostic and mechanistic evaluations for the meteorological and air quality models.

EPA guidance recommends that three statistically based performance measures be calculated to assess the performance of the modeling system. These are described in the following section - "Statistical Performance Measures Required by EPA." A recommended goal is set for each of EPA's required measures.

In this application, six additional performance measures are applied; none of these are required by EPA. These are described in an upcoming section - "Additional Performance Measures." The State has not set performance goals for the additional measures; rather, they are used as tools to elucidate positive and negative aspects of the simulation so that biases in the model can be studied.

As inputs for each UAM preprocessor were developed, input and output data were reviewed to assess the performance of each module. Numerous sensitivity tests were conducted as diagnostic evaluations. Such tests allow one to study the behavior of the model over ranges of variation of inputs and parameters.[31]

A discussion of operational and mechanistic evaluations for specific modeling modules are in the CO SIP TSD and in subsequent sections of this document. A mechanistic evaluation is well suited for the emission and meteorological models. Chapter 6 in the CO SIP TSD presents a variety of tests conducted to evaluate meteorological aspects of the model.

### 3.10.1. Statistical Performance Measures Required by EPA

According to EPA guidance, "statistical measures provide a useful measure of model performance for spatially dense monitoring networks; however, for routine urban area CO monitoring networks, the typically sparse coverage may result in a statistically distorted view of model performance. However, on the basis of UAM applications in past areawide CO modeling, it is recommended that the following three statistical criteria be applied to all neighborhood-scale monitors (and, if applicable, roadway intersection monitors showing persistently high CO values during low traffic volumes)."[m]

While U.S. EPA guidance suggests that performance measures be applied to neighborhood-scale monitors, EPA Region VIII recommended that performance measures

[m] Carr, E. L., J. L. Fieber, R. C. Kessler, "Guideline for Regulatory Application of the Urban Airshed Model for Areawide Carbon Monoxide: Volume I. Technical Report," SYSAPP-92/045a, EPA Contract No. 68D00124, prepared for U.S. Environmental Protection Agency by Systems Applications International, 11 May 1992, page 44.

should also be calculated at microscale monitors.[n] This is accomplished by combining the UAM and CAL3QHC estimates. Calculation of performance measures at microscale sites is appropriate in only those instances where CAL3QHC intersection estimates are available.

Since inclusion of combined UAM and CAL3QHC results in the model performance measures is not explicitly addressed in EPA guidance, procedures were developed by CDPHE in consultation with Systems Applications International (SAI) and EPA.

For example, EPA's CAL3QHC guidance suggests that "the UAM modeled concentration from the grid cell where the intersection is located should be entered into the CAL3QHC model as the background concentration to determine the total impact for each hour. The results should then be averaged over 8-hours to determine the maximum 8-hour concentration."[o] While this procedure might produce a conservative summation of UAM and CAL3QHC estimates for future year estimates, it is not consistent with EPA's UAM guidance. That is, the issue of using a weighted average for the UAM "background" value is not addressed. To obtain a somewhat realistic UAM areawide concentration estimate, a weighted average from the four nearest UAM grid cells is desirable to account for strong concentration gradients from grid cell to grid cell in the areawide estimates.

Therefore, agreement was reached by CDPHE and EPA Region VIII to use a weighted average approach when computing "background" UAM estimates for use in CAL3QHC modeling.

There are several ways the CAL3QHC estimate at a given monitor could be computed. This is because, for Gaussian models in particular, "estimates of concentrations that occur at a specific time and site (i.e., receptor) are poorly correlated with actually observed concentrations...."[p]

EPA suggests that "poor correlations between paired concentrations at fixed stations may be due to 'reducible' uncertainties in knowledge of the precise plume location and to unquantified inherent uncertainties."[q]

In this application, a CAL3QHC receptor was placed near the probe inlet at each monitoring site. CAL3QHC estimates were generated only at those sites which might have a significant intersection component. Nevertheless, because CAL3QHC is a Gaussian model, some questions exist regarding exactly *how* the CAL3QHC component should be extracted from the matrix of potential receptor sites around a given monitor. Site specific intersection studies would be required to satisfactorily address this issue. This is

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[n] Golden, Kevin (U.S. Environmental Protection Agency - Region VIII), letter to Bob Graves (Colorado Department of Health, Air Pollution Control Division), 21 September 1992.
[o] U.S. Environmental Protection Agency, "Guideline for Modeling Carbon Monoxide from Roadway Intersections," EPA-454/R-92-005, Office of Air Quality Planning and Standards, November 1992, page 4-1.
[p] U. S. Environmental Protection Agency, "Guideline on Air Quality Models (Revised) - Appendix W of 40 CFR Part 51," EPA-450/2-78-027R, version with Supplement A (7/87) and Supplement B (2/93), Office of Air Quality Planning and Standards, July 1993, page 10-3.
[q] U.S. Environmental Protection Agency, EPA-450/2-78-027R, July 1993, page 10-3,4.

particularly true at both the CAMP and NJH sites because of the close proximity of buildings and structures that can influence the wind field.

Thus, the CAL3QHC 1-hour average estimates from a receptor located near the probe inlet of the monitor are combined with the weighted 1-hour average UAM estimates. Then the 8-hour average estimates are computed.

EPA recommends that, at a minimum, the following three formulations be applied as measures of model performance:

**<u>Performance Measure 1.</u> Unpaired (time or space) highest 8-hour estimation accuracy.**
This measure quantifies the difference between the highest observed 8-hour average concentration and the highest estimated 8-hour value over all hours and monitoring locations.

$$A_u = \frac{c_e(x,t) - c_o(x^{pk},t^{pk})}{c_o(x^{pk},t^{pk})}(100)$$

**Recommended Goal: " 30-35%**

where,
$A_u$= unpaired highest-estimated accuracy (quantifies the difference between the magnitude of the highest 8-hour observed value and the highest 8-hour estimated value)
$C_o(x^{pk},t^{pk})$= maximum 8-hour *observed* concentration over all hours and monitoring sites
$c_e(x,t)$= maximum 8-hour *estimated* concentration over all hours and surface grid squares
$x^{pk}$= peak monitoring station location
$t^{pk}$= time of the peak observation

In this application, the order of the top term in the above equation (i.e., $c_e$ - $c_o$) is reversed from the same term in EPA's measure (i.e., $c_o$ - $c_e$).[32] This is done so that the sign of the statistic will reflect whether the model is over- or under-estimating with respect to the observation. For example, for a model estimate that under-predicts by 20%, EPA's formulation would yield a value of +20%. We believe this could be misleading to some who are not familiar with the equation used. In the formulation used in this application, a model estimate that under-predicts by 20% would have a statistic of -20%.

**Performance Measure 2. Average absolute error in 8-hour *peak* estimation accuracy paired (time and space) values greater than 5.0 ppm.**

This measure quantifies the difference between the highest observed 8-hour average concentration and the highest estimated 8-hour value at the time and location of each observed maximum.

$$A_{pk} = \frac{1}{n}\sum_{i=1}^{n}\left| \frac{C_e(x_i,t_i) - C_o(x_i,t_i)}{C_o(x_i,t_i)} \right|(100)$$

**Recommended Goal: 25-30%**

where,

$A_{pk}$= mean paired *peak* prediction accuracy averaged over all monitoring stations with observed values >5.0 ppm

n = number of hourly estimate-observation pairs from all valid monitoring stations

$C_o$ $(x_i,t_i)$= *peak observed* value >5.0 ppm at station i for the period $t_i$

$C_e$ $(x_i,t_i)$= *estimated* concentration at station i for the period $t_i$

$t_i$= hour of the peak observed value at monitoring station i

**Performance Measure 3. Average absolute error in the estimated *time* of the 8-hour peak concentration, paired by station values greater than 5.0 ppm.**

This measure quantifies the difference between the time of the highest observed 8-hour average concentration and the time of the highest estimated 8-hour value at the location of each observed maximum within a window of time.

$$A_t = \frac{1}{n}\sum_{i=1}^{n}\left| t_o(i) - t_e(i) \right|$$

**Recommended Goal: 2 hours**

where,

$A_t$= mean absolute error in the estimated time of the *peak* concentration, paired by station (for all stations >5.0 ppm)

$t_o$ (i)= peak time of observed concentration >5.0 ppm at monitoring station i

$t_e$ (i)= peak time of estimated concentration at monitoring station i Graphical Performance Measures Required by EPA

Graphical displays can provide important information on qualitative relationships between predicted and observed concentrations. At a minimum, the following graphical displays should be developed for each meteorological episode: time series plots and ground-level isopleths.

Time series plots of estimated[r] and hourly carbon monoxide concentrations should be constructed for each simulation period for each monitoring station where data are available.[33]

Ground-level isopleths or tile maps of the spatial distribution of estimated concentrations should be constructed for selected hours. Also, ground-level isopleths or tile maps of the carbon monoxide maxima should be constructed.[34]

### 3.10.2. Additional Performance Measures

This section describes additional performance measures applied by the APCD that were not required by EPA. Specific acceptance or rejection criteria were not established for these measures. They are intended to provide additional information about the performance of the modeling system. In this application, these additional measures have been used to help identify additional areas for study.

**Performance Measure 4. Average absolute error in 8-hour estimation accuracy paired (time and space) values greater than 5.0 ppm.**

This measure quantifies the difference between all observed 8-hour average concentrations and the estimated 8-hour value at the time and location of each observed value. This test can sometimes provide a more realistic view of the overall performance of the model because, unlike the "average absolute error in 8-hour peak prediction accuracy," this statistical value is not influenced by a small shift in the timing of the observed and estimated peaks. This is because the observed and estimated values are compared for every hour in which the observed estimate is over 5 ppm; not just for those hours where the peak observation exceeds 5 ppm.

$$A = \frac{1}{n} \sum_{i=1}^{n} \left| \frac{c_e(x_i, t_i) - c_o(x_i, t_i)}{c_o(x_i, t_i)} \right| (100)$$

where,

A= mean paired estimated accuracy averaged over all stations with observed values >5.0 ppm
n = number of hourly estimate-observation pairs from all valid monitoring stations
$c_o(x_i,t_i)$= *observed* concentration >5.0 ppm at station i for the period $t_i$
$c_e(x_i,t_i)$= *estimated* concentration at station i for the period $t_i$
$t_i$= hour of each observed concentration at station i

[r] For this purpose, EPA recommends that "the predicted value is the weighted average of the predictions from the four grid cells nearest to the monitoring site. The four-cell weighted average is derived from bilinear interpolation." (SAI, SYSAPP-92/045a)

**<u>Performance Measure 5.</u> Mean normalized bias in 8-hour average prediction accuracy paired (time and space) for values greater than 5.0 ppm.**

This measure quantifies the degree to which simulated 8-hour average concentrations greater than 5 ppm are *over*- or *under*-predicting.

$$A = \frac{1}{n}\sum_{i=1}^{n}\frac{c_e(x_i,t_i) - c_o(x_i,t_i)}{c_o(x_i,t_i)}(100)$$

**<u>Performance Measure 6.</u> Average absolute error in 1-hour peak prediction accuracy paired (time and space) values greater than 5.0 ppm.**

This measure quantifies the difference between the highest observed 1-hour average concentration and the highest estimated 1-hour value at the time and location of each observed maximum.

$$A_{pk} = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{C_e(x_i,t_i) - C_o(x_i,t_i)}{C_o(x_i,t_i)}\right|(100)$$

**<u>Performance Measure 7.</u> Average absolute error in the estimated *time* of the 1-hour peak concentration, paired by station values greater than 5.0 ppm.**

This measure quantifies the difference between the highest observed 1-hour average concentration and the highest estimated 1-hour value at the location of each observed maximum within a window of time.

$$A_t = \frac{1}{n}\sum_{i=1}^{n}\left| t_o(i) - t_e(i) \right|$$

**<u>Performance Measure 8.</u> Average absolute error in 1-hour prediction accuracy paired (time and space) values greater than 5.0 ppm.**

This measure quantifies the difference between *all* observed 1-hour average concentrations and the estimated 1-hour value at the time and location of each observed value.

$$A = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{c_e(x_i,t_i) - c_o(x_i,t_i)}{c_o(x_i,t_i)}\right|(100)$$

**<u>Performance Measure 9.</u> Mean normalized bias in 1-hour average prediction accuracy paired (time and space) for values greater than 5.0 ppm.**

This measure quantifies the degree to which simulated 1-hour average concentrations greater than 5 ppm are *over*- or *under*-predicting.

$$A = \frac{1}{n}\sum_{i=1}^{n}\frac{c_e(x_i,t_i) - c_o(x_i,t_i)}{c_o(x_i,t_i)}(100)$$

### 3.10.3. Graphical Measures

In addition to the statistical measures above, color tile maps were generated for each episode. These maps show the overall maximum 8-hour concentration estimates for each UAM grid cell. This type of graphical analysis is useful for comparing the modeled estimates against emission estimates, meteorological variables, and conceptual models.

### 3.10.4. Selection of CO Monitors for Use in the Performance Evaluation Required by EPA

CO monitoring sites within the modeling domain form the basis of the performance evaluation. While most data are from CDPHE monitors, data from the Denver Brown Cloud Study (1987/88) and the Boulder Air Quality Study (1988/89) are also used. All monitoring data are based on EPA reference method monitors and have been quality assured. Table 20 shows the CO monitors used in this study. Although model performance was assessed at all monitors, final performance measures - as defined by EPA - have been computed for an appropriate subset of monitors.

A CDPHE FORTRAN code (P_STATS) logically selected all sites required by performance measures 2 - 9. Performance measure number 1 was calculated separately. P_STATS selected all sites with an observed 1-hour or 8-hour concentration greater than 5 ppm, regardless of whether or not the site should be included in computing measures for comparison against EPA's performance goals. Final performance measures for comparison with EPA's performance goals were computed for an appropriate subset of sites.

Computation of measures for only those hours where the observed concentration exceeded 5 ppm is done to focus the evaluation on only those hours where elevated CO concentrations existed. It prevents the statistics from being skewed by observed values in the low concentration range. Results from P_STATS can be found in the attachments to the CO SIP Technical Support Document (CDPHE, 1994).

Before final statistics were calculated for comparison with EPA's performance goals, the performance at each site was reviewed to study the appropriateness of including the site in the overall operational performance statistics. In some cases, it was appropriate to remove a site and recompute the measures. This does not imply that the results of the performance evaluation at certain sites were ignored, it means that a critical review was performed to decide if certain sites would skew the overall performance measures; that is, sites influenced by sub-grid scale phenomena that were outside the high emissions density area near downtown Denver were carefully reviewed. This approach is consistent with the intent of EPA's guidance. In addition, EPA Region VIII concurred with this approach. Subsequent sections describe the review process in detail.

For the "high" episode - December 4-6, 1988, the performance measures required by EPA were initially based on the following sites: CAMP, NJH, Welby, Carriage, Grandys, and Arvada; as determined by P_STATS. After reviewing each site, Grandys in Boulder and Arvada were eliminated as candidates for purposes of demonstrating that the model meets EPA's performance criteria. Both sites are outside the central business district where the controlling concentration levels are found.

Grandys was removed because it is a microscale site where CAL3QHC modeling was not conducted. As can be seen in the time series plots for the site (i.e., GRDS) in the attachments, UAM substantially under-estimated the CO concentration. Since it was a microscale monitor, it is not appropriate to compare the observations to UAM areawide estimates unless a CAL3QHC component is also included. Grandys was a special study site.

Unlike the Grandys site in Boulder, there was no obvious explanation for the poor model performance at the Arvada site. For the purpose of comparing the performance measures against EPA's goals, EPA Region VIII suggested that the Arvada monitor could be removed when the statistics were calculated. This decision was based in part on the fact that the highest CO levels existed in the greater downtown area during this episode and not in outlying areas such as Arvada. Also, it was recognized that poor performance at one site can strongly influence the overall statistics. However, EPA Region VIII indicated that the State would be required to submit an analysis as to why the model failed to perform well at the Arvada site. A detailed discussion about performance at the Arvada site can be found in later in this section.

For the "second-high" episode - January 14-16, 1988, the performance measures required by EPA were initially based on the following sites: CAMP, Tivoli, NJH, Welby, Carriage, and Arvada; as determined by P_STATS. As with the "high" episode, performance was poor at the Arvada site. Therefore, for consistency with procedures adopted for the "high" episode, the Arvada site was excluded from the list of final sites at which performance statistics were computed. As stated earlier, a detailed discussion about the Arvada monitor with respect to the air quality modeling can be found in a subsequent section.

**Table 20. Carbon monoxide monitoring sites used in the UAM and CAL3QHC modeling study for the Denver CO SIP.**

| Site Name | Abbreviation | Location | | | |
|---|---|---|---|---|---|
| | | UTM (meters) - Zone 13 | | UAM Grid Cell | |
| | | Easting | Northing | x | y |
| Tivoli (Special)[2] | TIV[A] | 499564 | 4399396 | 22 | 43 |
| CAMP[1, 2] | CMP | 501084 | 4399952 | 23 | 43 |
| Welby[1, 2] | WBY | 504364 | 4409703 | 25 | 49 |
| Carriage[1, 2] | CRG | 497360 | 4400000 | 20 | 43 |
| NJH-E[1, 2] | NJH | 505195 | 4398561 | 25 | 42 |
| Englewood[1] | ENG | 500161 | 4389516 | 22 | 37 |
| Arvada[1, 2] | ARV | 491500 | 4405400 | 17 | 47 |
| Boulder[1, 2] | BOU | 477219 | 4429024 | 8 | 61 |
| Boulder (Special)[1] | GRDS[B] | 478005 | 4429885 | 8 | 62 |
| Aurora[2] | AUR | 513595 | 4396144 | 31 | 41 |
| Aurora (Special)[1] | AURS[C] | 513183 | 4389716 | 30 | 37 |
| Palmer School (Special)[2] | PLM[D] | 506488 | 4397796 | 26 | 42 |
| Highland[1, 2] | HLD | 503673 | 4379691 | 24 | 31 |
| Brighton (Special)[2] | BTN[E] | 520018 | 4425877 | 35 | 59 |
| Federal Building (Sp.)[2] | FED[F] | 501100 | 4400000 | 23 | 43 |

[1] CO monitoring sites used in the "high" episode simulation of December 4-6, 1988
[2] CO monitoring sites used in the "second-high" episode simulation of January 14-16, 1988
[A] Special study site (Auraria Campus) during the Denver Brown Cloud Study
[B] Special study site (Grandys) near 28th between Walnut and Pearl St.
[C] Special study site (Dennys) near the intersection of I-225 and Parker Rd.
[D] Special study site at 10th and Grape; inlet located on top of two story building
[E] Special study site during the Denver Brown Cloud Study
[F] Special study site during Denver Brown Cloud Study; the inlet was located 72 m above ground level (i.e., on top of the Federal Building)

### 3.10.4.1. Basis for the Exclusion of the Arvada CO Monitor

The CDPHE Arvada CO monitor is located approximately 7 miles NW of downtown Denver in the suburb of Arvada.[s] The surrounding area is residential with commercial area to its north. This monitor is classified as a neighborhood scale monitor sited for determining population exposure.[35] Neighborhood scale CO monitors are representing an area of "relatively uniform land use with dimensions of in the 0.5 to 4.0 kilometer range." [36] The eight-hour CO NAAQS has not been violated at the site since 1986, yet its 8-hour second maxima remain high (i.e., 6.9 ppm in 1992).[37] Elevated levels of ambient CO are typically monitored during the morning rush hour and less frequently during the evening. When the wind speed was light and its direction was from west through north (i.e., out of the NW quadrant), the UAM model performed poorly at this site. The results of our investigation, concerning the UAM's poor performance at the Arvada monitor, are presented below.

**Monitoring Data at the Arvada Site -** The next figure contains wind roses and CO roses for the Arvada monitor. The CO rose shows the frequency of occurrence of CO concentrations greater than 3 ppm, as a function of wind speed and direction. A bidirectional pattern is evident with maxima in the NW and SE quadrants. Using the same data set with a higher cutoff value of 8 ppm, the CO rose has a more unidirectional distribution of CO occurrence. The Arvada monitor is on the edge the Denver metropolitan emissions locus with few sources to its NW.[t]

[s] The Arvada monitoring stations has an Aerometric Information Retrieval System - Air Quality Subsystem (AIRS/AQS) site number of 08-059-0002.
[t] The Arvada monitor is located in UAM grid cell 2731, which translates to X = 17, Y = 47 in the UAM domain coordinate set.

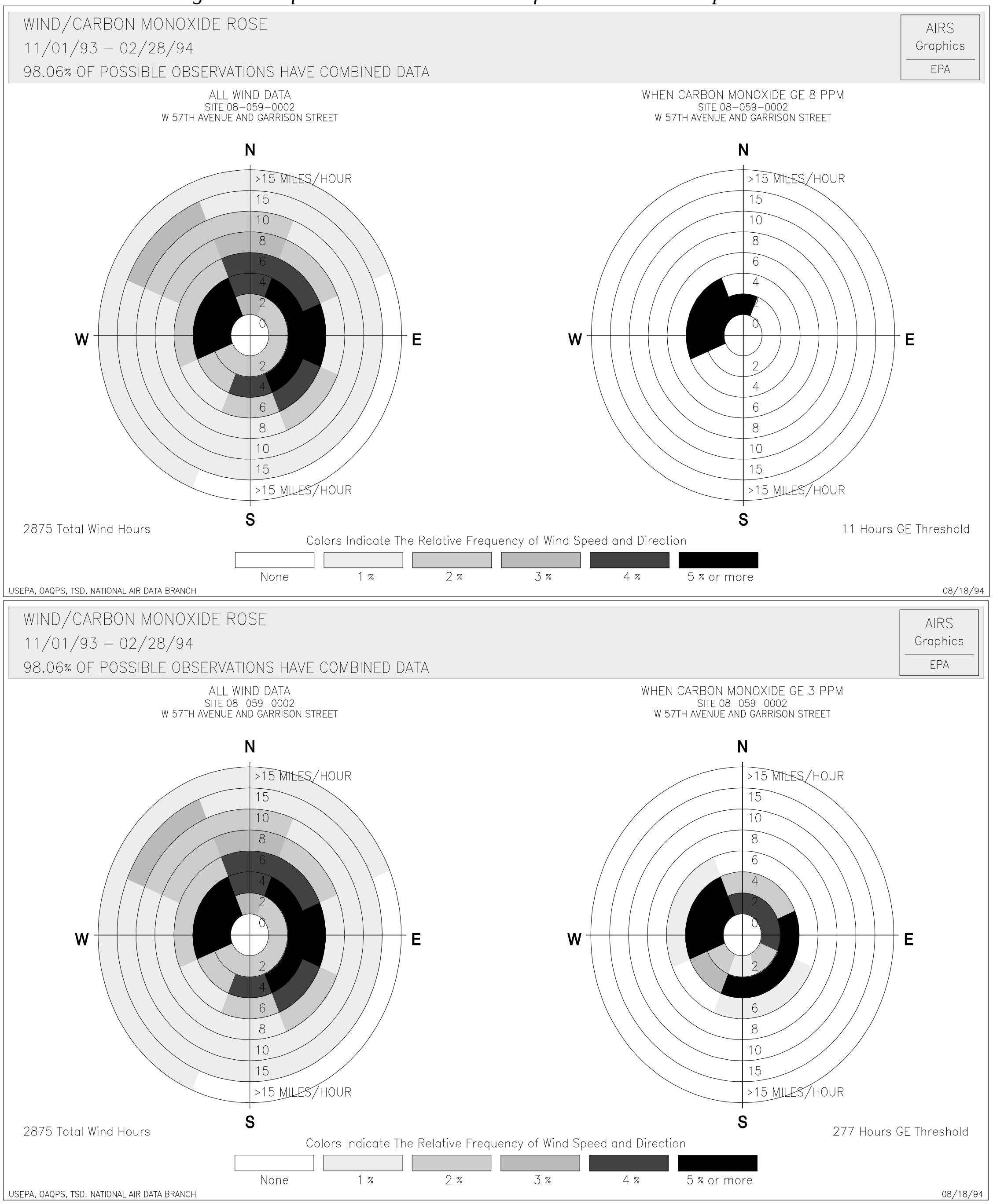



**Figure 6. Wind/Carbon Monoxide Roses at the Arvada Site. These show the frequency of occurrence of CO concentrations greater than 3 ppm or 8 ppm, as a function of wind speed and direction. High CO is largely constrained to the NW quadrant, with wind speeds of 4 mph or less.**

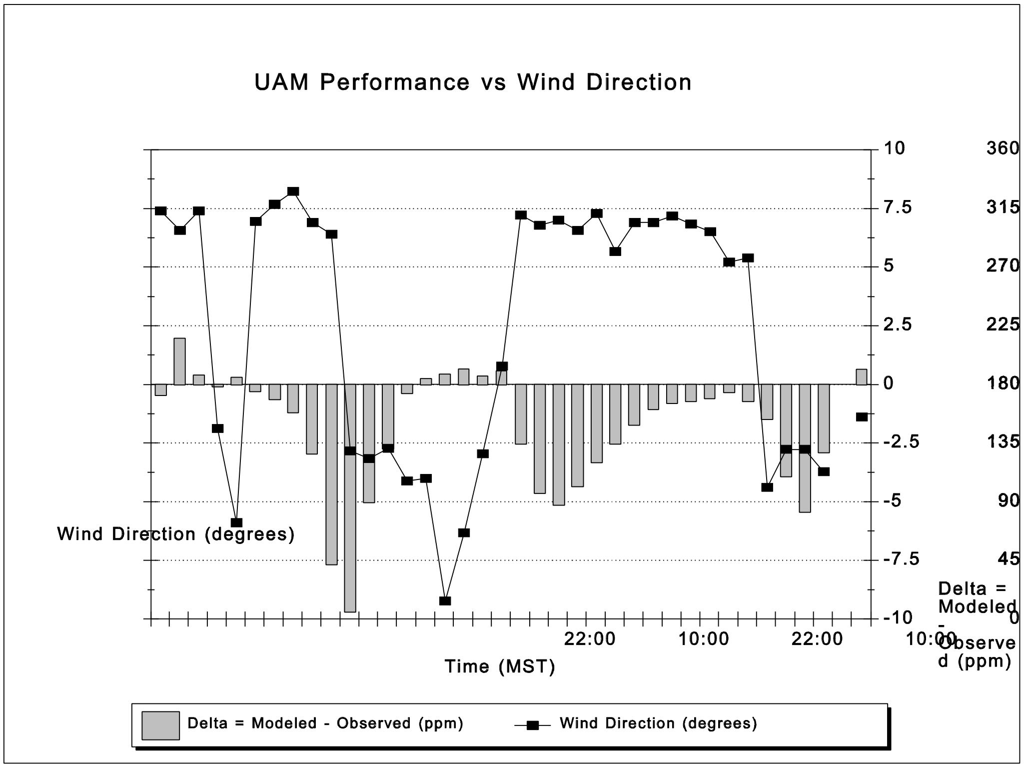



**Figure 7. Wind direction and UAM performance are displayed as a function of time for the "high" episode. Model performance is based on the difference between hourly monitored and modeled CO concentrations; a negative value means the model is under-predicting.**

**UAM Results at the Arvada Site -** The performance of the UAM, as described by the difference between modeled and monitored hourly CO concentrations, is presented for both modeling episodes in the following figures. In the following figure, wind direction is shown by a line with markers and references the left-hand y-axis. It represents the direction the wind is coming from. The bar in these plots is formed by subtracting the observed from modeled concentrations and represents how well the model is performing. It references the right-hand y-axis, which ranges from -10 to 10 ppm. The shorter the bar the better the model is replicating monitored values. If the model is under predicting, a negative value or "delta" is indicated, and over prediction is shown by positive values. It shows that UAM tends to under predict concentrations at this monitor, particularly when the wind is between 270 and 360 degrees (i.e., the NW quadrant).

The UAM concentrations for the Arvada monitor are bilinear interpolations of the four nearest grid cell values. These values are volume averages, each representing a 1 mile$^2$ area with depth varying according to mixing depth (i.e., DIFFBREAK). The bilinear weighting factor, which is applied to each of the hourly grid cell values, is inversely proportional to the distance center-of-the-cell to the interpolated point. These values are interpolated by the UAM postprocessor DPLOT written by Systems Applications International (SAI). Therefore, the CO concentrations calculated for a site by the DPLOT postprocessor represent four grid cells, not one.

**Site Specifics** - A CO emissions inventory, for the UAM grid cell containing the Arvada monitor and its eight neighboring cells, can be found in the appendix to Chapter 6 in the CO SIP Technical Support Document. In each of these cells, the on-road mobile source category is clearly the largest category. The on-road mobile source emissions were partitioned into the UAM grid cells by a geographic information system (GIS). The number of vehicle-miles-traveled (VMT) is the principal determinant of the quantity of on-road mobile emissions allocated to a given cell. The VMT data used by the inventory were produced by the Urban Transportation Planning System model run by the Denver Regional Council of Governments. To better understand the source of pollutants impacting the Arvada monitor from the NW, a detailed map was made for the area. This map can be found in the attachments to Chapter 6 of the CO SIP Technical Support Document (CDPHE, 1994). It shows:

- the location of the Arvada monitor,
- surrounding land uses,
- the DRCOG transportation network used in creating the inventory,
- the names of streets,
- The location of the UAM grid cell boundaries, and
- creeks, ponds and irrigation ditches.

The area surrounding the Arvada monitor is dominated by residential and commercial land uses. The principal drainage in the area is Ralston Creek. In the northwestern portion of the map, another "creek" is shown to cross Ralston Creek, this is an irrigation ditch. Since an irrigation ditch roughly follows a contour, the path it follows describes the shape of the Ralston Creek drainage. Ralston Creek flows to the SE, draining the nearby foothills and is a tributary of Clear Creek, which flows into the South Platte River. When atmospheric drainage flows develop, they will tend to follow this same drainage pattern. Notice the alignment of the Ralston Creek and Ralston Road, which are due NW from the Arvada monitor. Further, Ralston Road is a heavily traveled thoroughfare, as described by the DRCOG VMT estimates. At the intersection of Ralston Road and 58th Avenue, Ralston has an average daily traffic ( ADT) of approximately 26,000 and 58th has an ADT of about 21,000.

**Arvada Site Conclusions** - The CDPHE Arvada monitor is classified as neighborhood scale. Therefore, it is expected to be influenced by sources within a range of 0.5 to 4.0 kilometers. It is surrounded by an area dominated by residential and commercial land use, with no known major point sources of CO. The highest CO concentrations monitored at the site are experienced when flow is light and northwesterly. This wind regime has been described as a "drainage flow" of colder air that flows down slopes and valleys. The cooling of the surface allows for an inversion to form and the surface layer to decouple from the overlying atmosphere. A weak surface pressure gradient allows for drainage flows to develop. Generally, the drainage flow begins in the late afternoon and lasts through midmorning. The largest source category in the area is on-road mobile. Under drainage flow conditions, when the wind flowing down Ralston Creek will be picking up pollutants from the heavy traffic along Ralston Road, transport will be directly toward the Arvada monitor. Also upwind during drainage conditions is a busy intersection of Ralston Road and 58th Avenue that is only 1500 feet from the monitor. Therefore, under light northwesterly drainage flow conditions, the most likely source of the high hourly CO concentrations experienced by the Arvada monitor, are the heavily traveled intersections and streets found immediately upwind from the site.

Emissions for a grid cell are uniformly dispersed throughout its volume by the UAM. A localized source of emissions, smaller than a UAM grid cell, will have its emissions dispersed in the entire volume of the cell. This is called "artificial" dispersion, as it artificially reduces the concentrations attributed to it by the model. This under-prediction of CO concentrations by the UAM, under drainage flow conditions, is consistent with an upwind subgrid-cell sized emissions source that is close to the monitor. The intersection of 58th Avenue and Ralston Road, and the portion of Ralston Road that parallels the creek, are definitely of subgrid cell size. So, one could reasonably expect for these sources to effect the monitored CO concentrations, but not those calculated by the UAM. Therefore, the Arvada CO monitor should be excluded from the group of stations used in determining if the UAM is meeting the EPA's performance criteria.

### 3.10.5. "High" Episode Performance Measures

This section presents the performance statistics required by EPA guidance and additional data that summarize the modeling systems operational performance. A summary of EPA's statistical performance measures for the "high" episode are presented in Table 21. As discussed earlier, these statistics are based on the performance at four sites: CAMP, Welby, Carriage, and NJH. Although a range of goals are listed in some cases, the intent is that the calculated performance statistic should be within the limits of the upper bound of the range.

For the sites listed above, the simulation for the "high" episode meets the goals recommended by EPA.

As discussed earlier, all performance measures except the first are computed by the APCD's FORTRAN code P_STATS. The first measure quantifies the difference between the highest estimated 8-hour average CO concentration and the highest observed concentration anywhere in the modeling domain. In this episode, the maximum estimate is 17.51 ppm in the grid cell (i.e., X=22, Y=43), which includes the Auraria Campus. The highest observed 8-hour concentration occurred at the CAMP site, which is in an adjacent grid cell (i.e., X=23, Y=43). Note that, during this episode, a monitor was not located in the grid cell with the highest modeled concentration estimate. The "unpaired (time or space) highest 8-hour estimation accuracy" is -6.5%:

$$\frac{17.51ppm - 18.73ppm}{18.73ppm}(100) = -6.5\%$$

Graphical plots, site specific results, and results for the six other statistical measures can be found in the "CO SIP Technical Support Document" (CO SIP TSD) (CDPHE, 1994). Graphical plots can be found in the attachments. Note that the modeling results for the "high" episode (December 4-6, 1988) are referred to as simulation "A."

Table 22 shows the maximum modeled estimate and the corresponding observed 8-hour concentrations for all monitoring sites. Estimates and observations at each site are paired in time. Poor performance at the Grandys Special Study site occurred because microscale hot spot modeling (CAL3QHC) was not performed at nearby intersections. More discussion concerning the Grandys site is in the section named "Selection of CO Monitors for Use in the Performance Evaluation Required by EPA" in the CO SIP TSD.

Following are a series of figures showing 1-hour and 8-hour average time series plots for those sites used to generate the statistical measures required by EPA. Time series plots for other sites can be found in the attachments. Although 1-hour average concentration plots are presented, the reader should note that EPA's required statistical measures apply to 8-hour average estimates only.

Isopleths of the hour during which the highest estimated 1-hour and 8-hour averages occurred are presented in the following set of figures.

A review of the 1-hour average estimates at the CAMP site shows that the model:

- under-estimates the observed concentration of 45.0 ppm during hour 16 by about 55%;
- under-estimates the observed peak of 50.5 ppm during hour 17 by about 40%;
- slightly under-estimates the observed concentration of 30.0 ppm during hour 18 by about 1%;
- and over-estimates the observed concentration of 3.9 ppm during hour 19 by over 500%.

Thus, the model has difficulty simulating the rapid rise in the 1-hour average CO concentrations at the CAMP site. The model also has difficulty simulating the rapid decline in observed concentrations (i.e., 30 to 3.9 ppm in a 1-hour period). See Figure 8 for a graphical representation of the 1-hour average concentration estimates and observed 1-hour concentrations at CAMP.

There are several possible explanations for the behavior of the model at CAMP. A lack of sufficient site-specific data on spatial variability of the wind field, uncertainties surrounding the hourly mixing depths and other meteorological data, uncertainties surrounding the CAL3QHC estimates, and other factors - including uncertainties in both the transportation modeling and on-road mobile emission estimates - make it difficult to state a definitive reason.

Nevertheless, when 8-hour average concentration estimates are computed, the combination of over- and under-estimations from the 1-hour average estimates in the model produce an 8-hour estimate that satisfactorily replicates the observed behavior of 8-hour average concentrations. Although the 8-hour peak is shifted in time with respect to the observed peak, the magnitude of the maximum model estimate (i.e., 17.2 ppm) is close to the observed maximum of 18.7 ppm.

**Table 21. EPA's recommended statistical performance measures for the "high" episode.**

| Performance Measure | Performance Statistic | EPA's Performance Goal |
|---|---|---|
| **1.** Unpaired (time or space) highest 8-hour estimation accuracy, $A_u$. | -6.5% | ±30-35% |
| **2.** Average absolute error in 8-hour *peak* estimation accuracy paired (time and space) values >5.0 ppm, $A_{pk}$. | 21.2% | 25-30% |
| **3.** Average absolute error in the estimated *time* of the 8-hour peak concentration, paired by station values >5.0 ppm, $A_t$. | 2 hours | 2 hours |

**Table 22. Comparison of modeled vs. observed CO 8-hour average concentrations for the "high" episode (Run A) - December 5, 1988.**

| Monitor | Maximum MODELED 8-hour Average Concentration (ppm) | | | OBSERVED[1] 8-hr Average Concentration (ppm) |
|---|---|---|---|---|
| | UAM areawide | CAL3QHC hot spot | UAM + CAL3QHC | |
| CAMP – 2105 Broadway | 16.3 | 0.9 | 17.2 | 17.7 |
| National Jewish Hospital | 6.5 | 2.6 | 9.1 | 11.3 |
| Carriage – 23rd/Julian | 8.1 | NM[2] | NA[3] | 9.9 |
| Welby - 78th/Steel | 8.4 | NM | NA | 8.7 |
| Englewood - 3300 S. Huron | 2.9 | NM | NA | 3.4 |
| Boulder - 2320 Marine St | 1.6 | NM | NA | 2.1 |
| Boulder(Grandys) 28th/Pearl | 1.6 | NM | NA | 7.1 |
| Arvada – W.57th/Garrison | 2.8 | NM | NA | 3.2 |
| Highland - 8100 S. Univ. | 1.4 | NM | NA | 1.4 |
| Aurora(Dennys) Parker/Peoria | 4.7 | NM | NA | 4.2 |

[1] Estimated and Observed concentrations are paired in time (i.e., the monitored concentrations are for the same 8-hour averaging period as the modeled estimates).
[2] NM - Not Modeled with CAL3QHC.
[3] NA - Not Applicable.

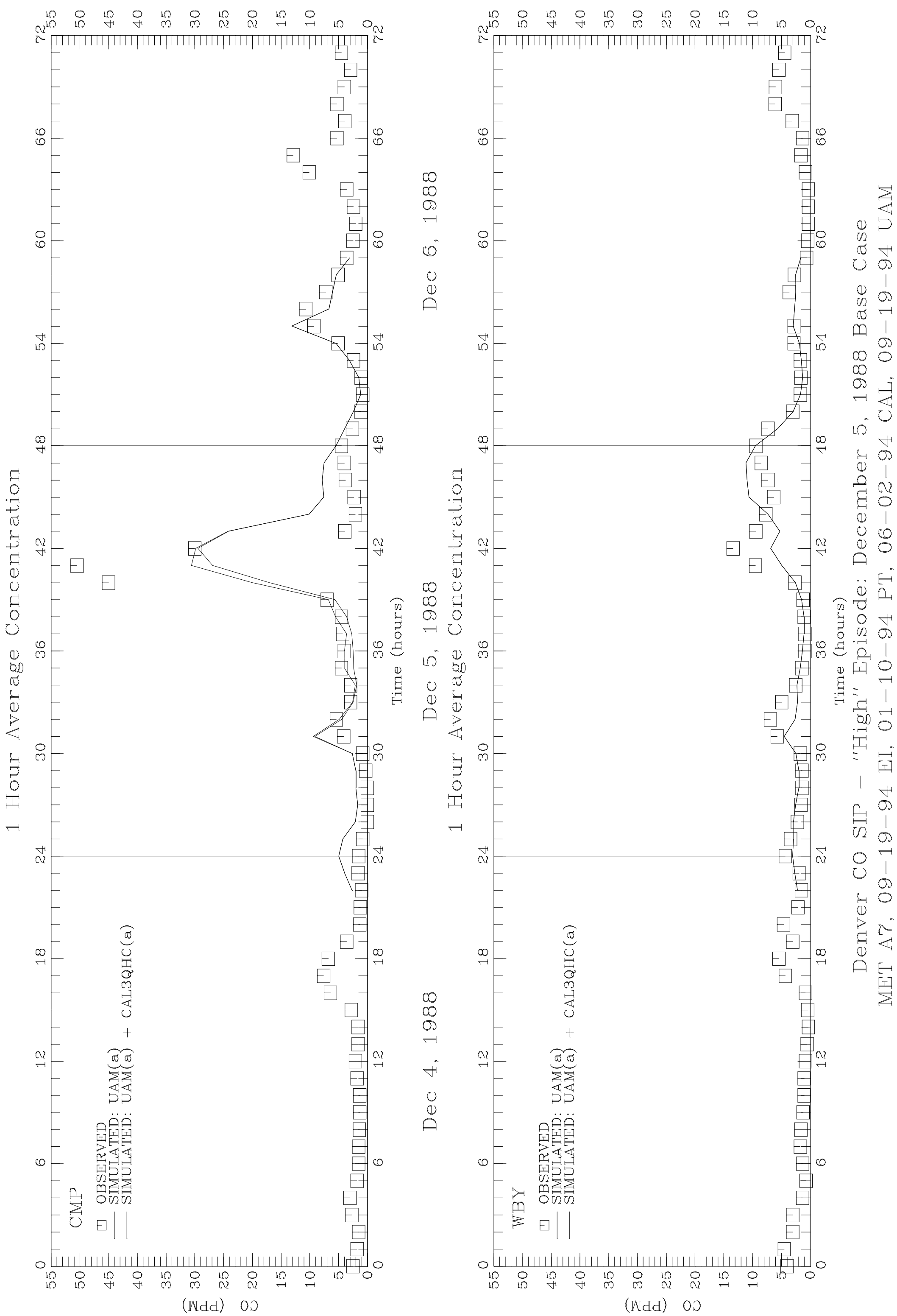



**Figure 8. One-hour (1-hr) time series plots showing observations (boxes) and model estimates (lines) at CAMP (CMP) and Welby (WBY).**

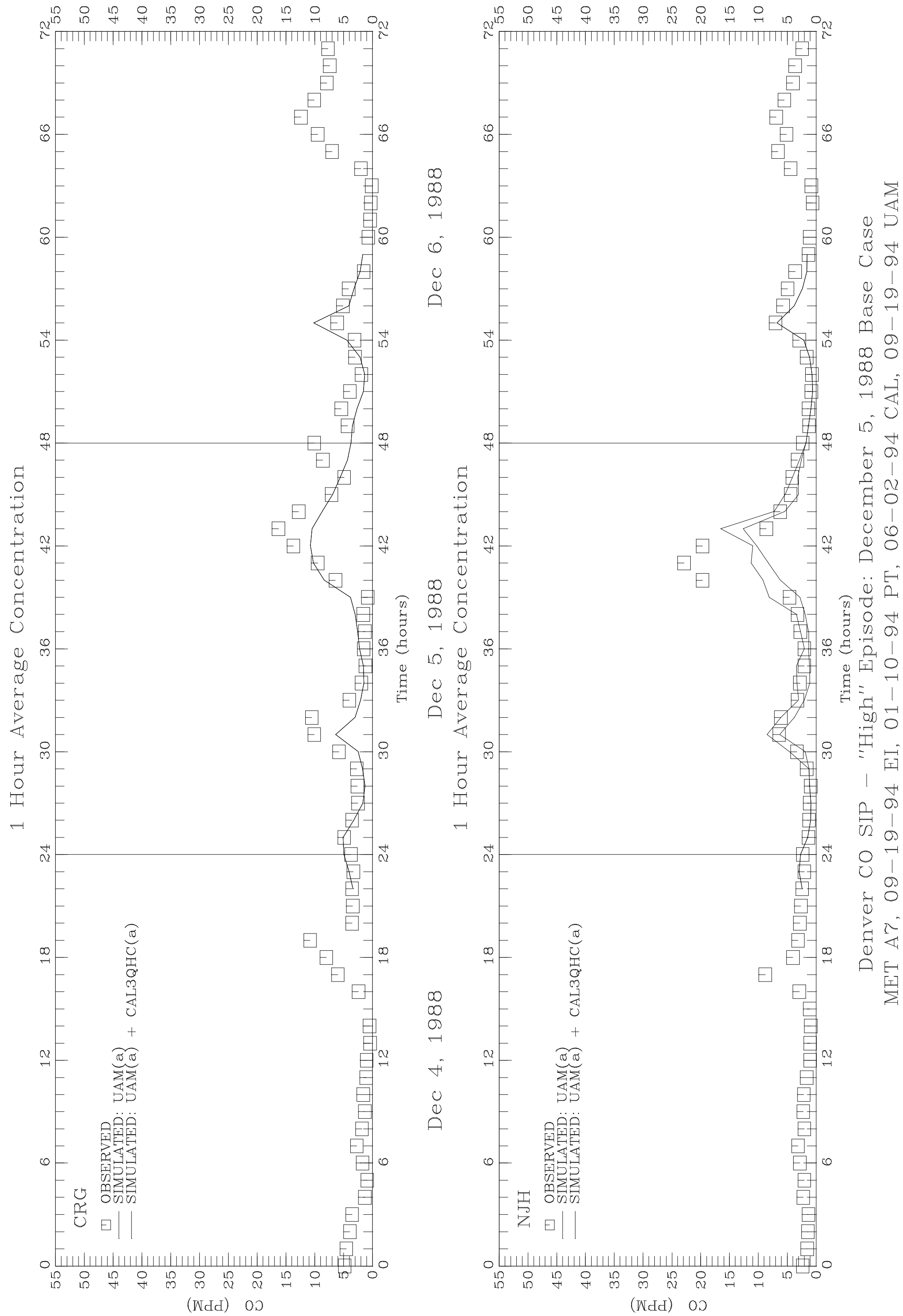



**Figure 9. One-hour (1-hr) time series plots showing observations (boxes) and model estimates (lines) at Carriage (CRG) and NJH.**

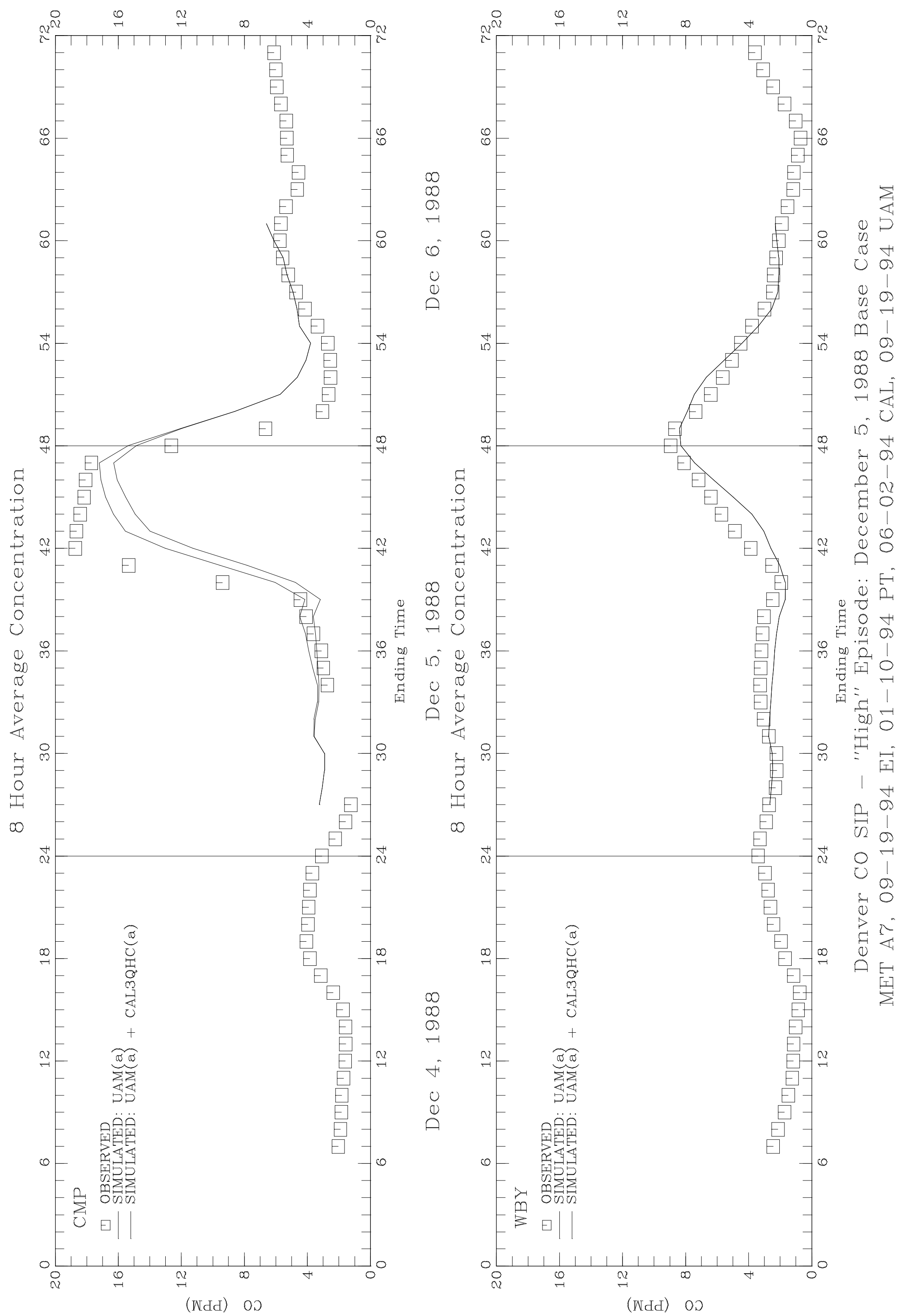



**Figure 10. Eight-hour (8-hr) time series plots showing observations (boxes) and model estimates (lines) at CAMP (CMP) and Welby (WBY).**

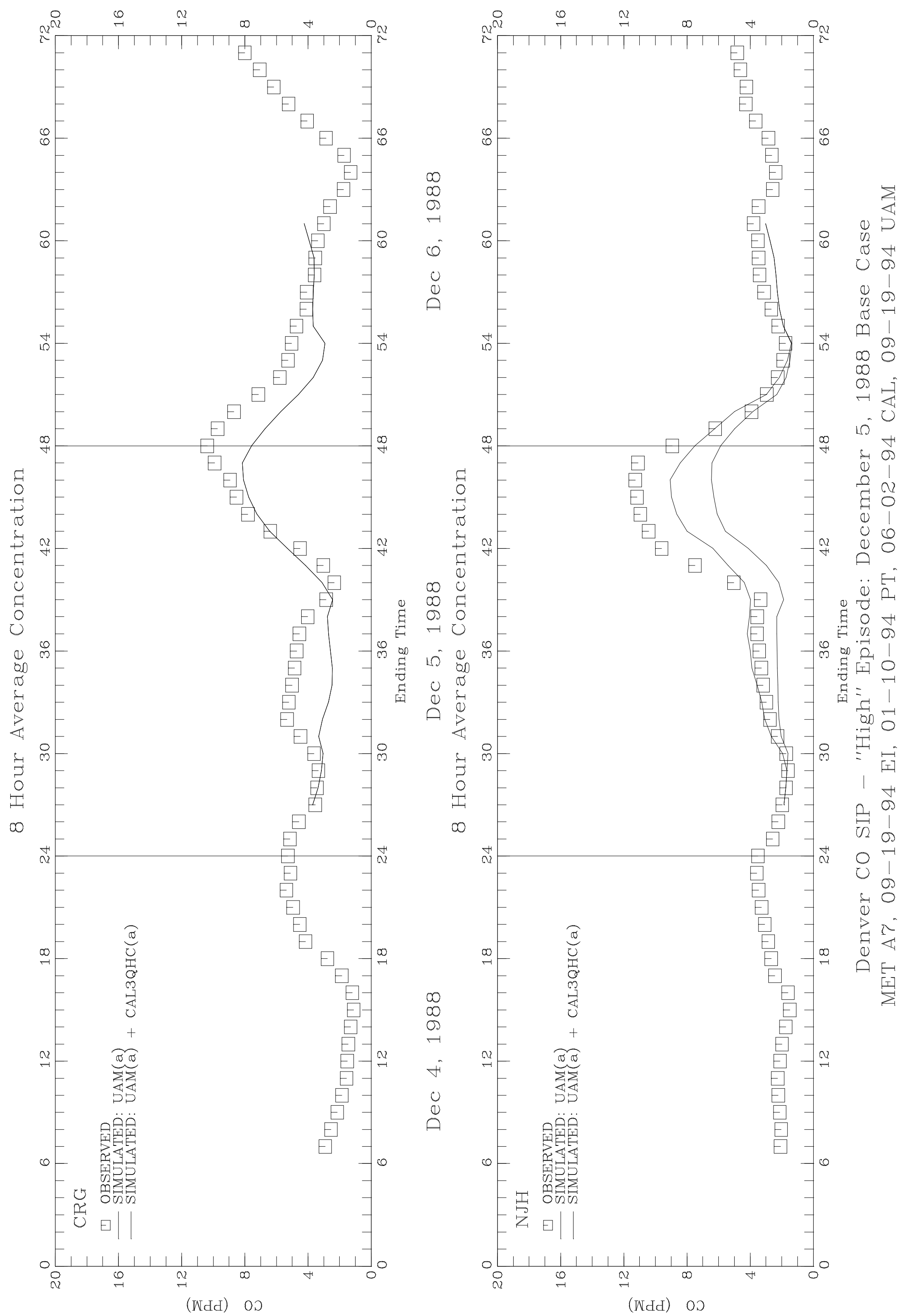



**Figure 11. Eight-hour (8-hr) time series plots showing observations (boxes) and model estimates (lines) at Carriage (CRG) and NJH.**

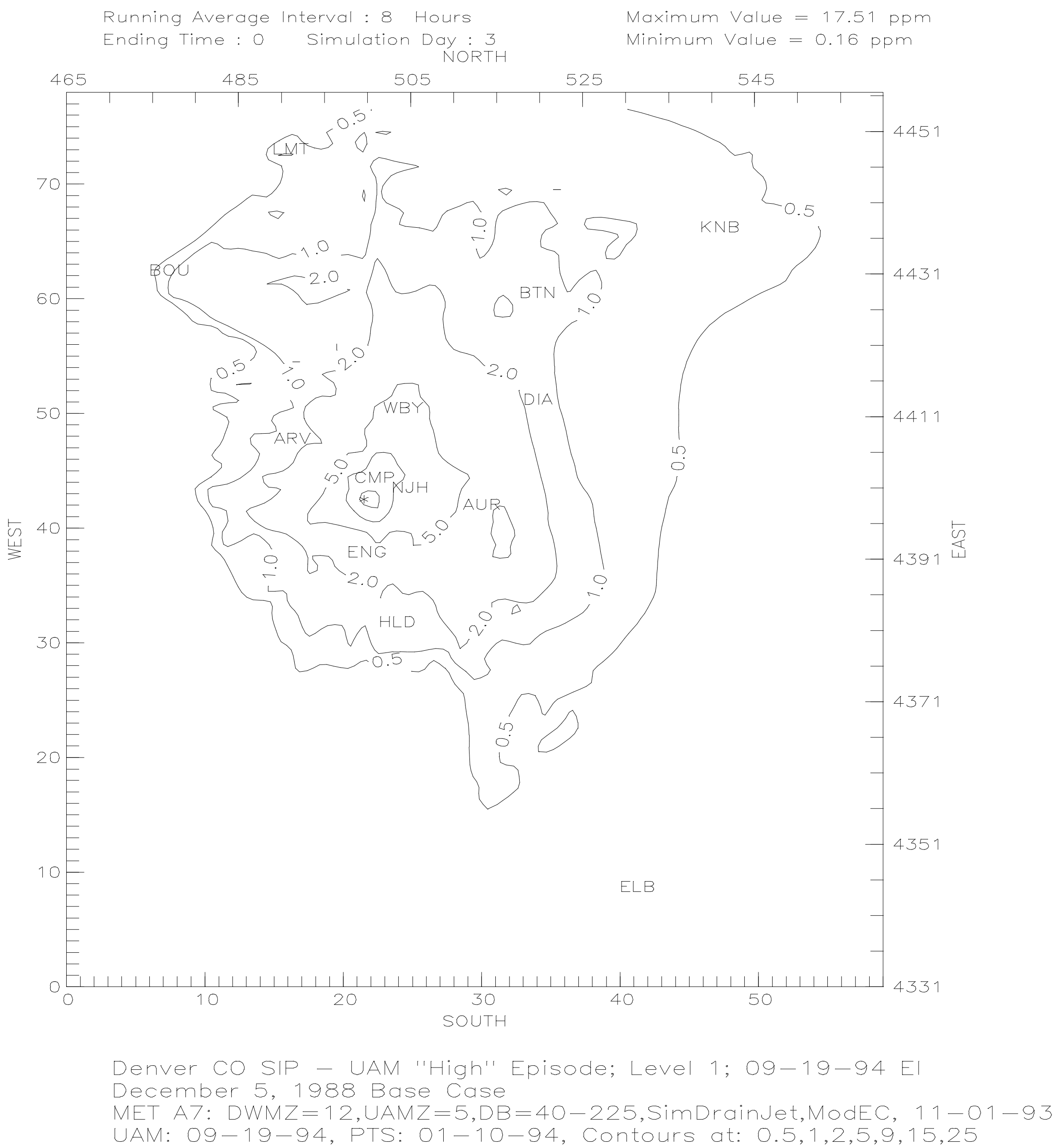



**Figure 12. UAM 8-hour CO concentration isopleths for the hour during which the maximum UAM predicted 8-hour concentration occurred during the "high" episode (December 5, 1988).**

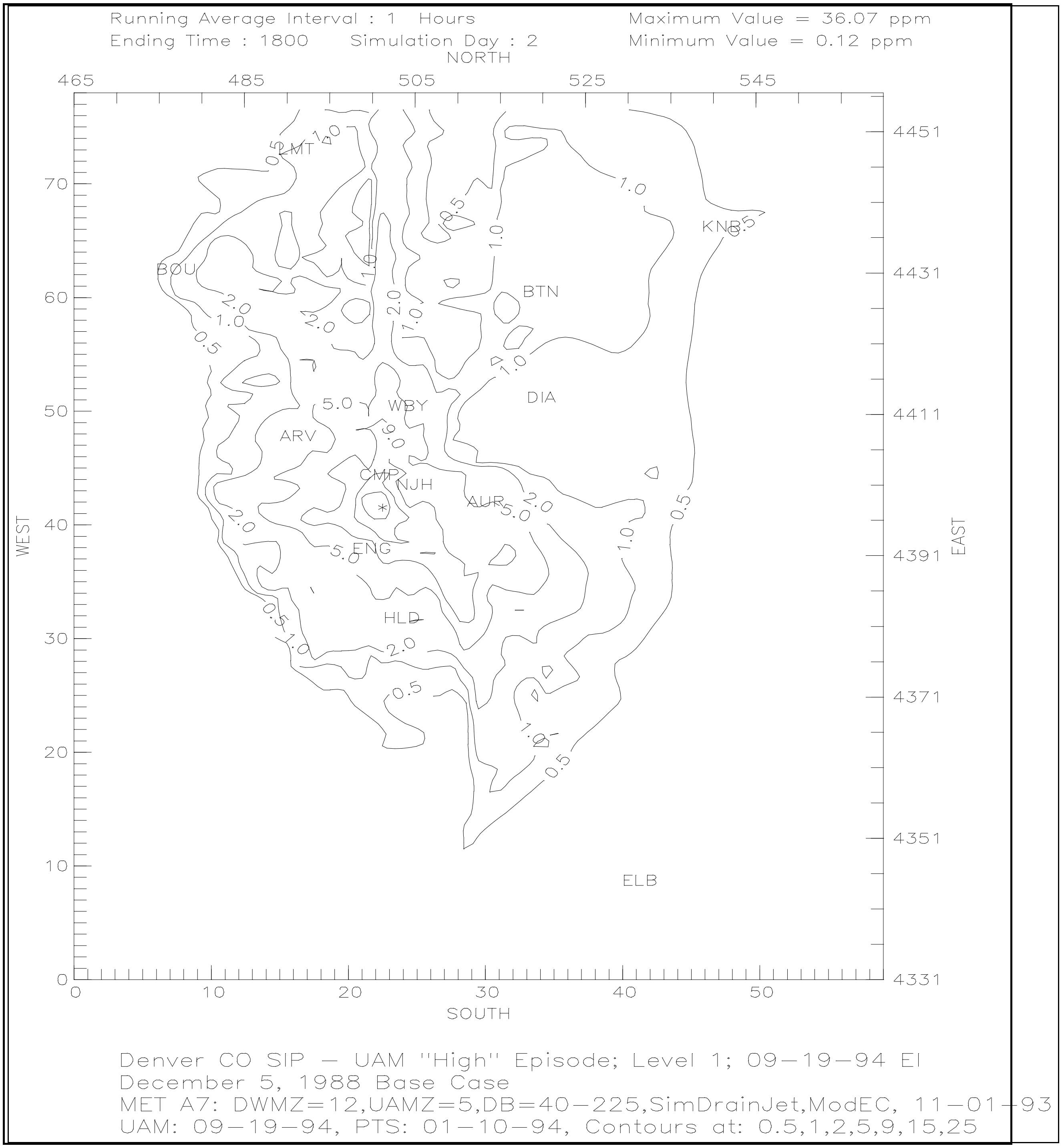



**Figure 13. UAM 1-hour CO concentration isopleths for the hour during which the maximum UAM predicted 1-hour concentration occurred during the "high" episode (December 5, 1988).**

# 4. Modeling-Based Maintenance Demonstration

## 4.1. Design Concentrations

The methodology used to demonstrate attainment in future years is the same as outlined in the approved CO SIP. The maintenance demonstrations are based on the "high" episode, which is the worst-case CO episode. Refer to Section 3.5.1 of this report for a discussion about why modeling results from "second-high" episode are not presented as part of the final maintenance plan.

The modeling approach demonstrates compliance on a typical weekday. Special events and weekend days have not been modeled.

As required by CAA Section 175A(a), each request for redesignation shall be accompanied by a SIP revision which provides for maintenance of the NAAQS for at least 10 years after redesignation. Following EPA guidance and policy which requires the same level of modeling for maintenance plans as that which was performed for the attainment demonstration, this maintenance demonstration is made through the use of areawide dispersion modeling, along with selected intersection hot spot modeling, for the years 2006 and 2013. The combined results of the dispersion and intersection modeling show no 8-hour maximum CO concentration greater than or equal to 9.0 ppm anywhere in the modeling domain with the implementation of the proposed control measures.

The 2006 (1.5% oxygenated fuels) and 2013 (1.7% oxygenated fuels) emission inventories were used as modeling inputs along with meteorological data from the CO SIP design day of December $5^{th}$, 1988. In addition, emissions estimates for the year 2012 (1.5% oxygenated fuels) were generated so that modeling could be done to verify that compliance with the standard could be demonstrated with 1.5% oxygenated fuels in 2012.

Consistent with EPA modeling guidance, intersections were selected for modeling based on the latest information from DRCOG regarding the highest volume and most congested intersections in the nonattainment area. These intersections differ in some cases from those modeled in the original attainment demonstration. As in the attainment demonstration, the CAMP intersection was modeled to provide a hot spot analysis for downtown, which is where the maximum CO concentrations in the region are measured.

The approach to demonstrating attainment in the CO SIP is explained below in an excerpt from the "CO SIP Technical Support Document" (CDPHE, 1994):

*The CAAA of 1990 require carbon monoxide (CO) nonattainment areas designated as "moderate" or "serious" to demonstrate attainment of the CO National Ambient Air Quality Standards (NAAQS) through air quality modeling or any other analytical method determined to* *be at least as effective. Denver's future-year attainment demonstration is based on CO estimates generated by the Urban Airshed Model (UAM) and the CAL3QHC roadway intersection model.*

*The Urban Airshed Model is a three-dimensional grid model designed to calculate the concentration of both inert and chemically reactive pollutants by simulating physical and chemical processes in the atmosphere that affect pollutant concentrations.[38] In this application, carbon monoxide has been modeled as an unreactive species.*

*CAL3QHC is a modeling methodology designed to predict the level of CO from motor vehicles traveling near roadway intersections. It is an extensively revised version of CAL3Q, which was a consolidation of two other models: the CALINE-3 line source dispersion model and an algorithm for estimating vehicular queue lengths at signalized intersections.[39]*

*In order to "demonstrate attainment of the carbon monoxide NAAQS, the combined results from the area wide and roadway intersection modeling should show no predicted 8-hour maximum carbon monoxide concentration greater than 9.0 ppm anywhere in the modeling domain for the episode modeled".[40] Furthermore, attainment demonstrations are required for each meteorological episode . EPA has required the Denver metropolitan area to submit future-year attainment demonstrations based on the meteorological conditions that occurred on December 5, 1988 ("high" episode) and January 15, 1988 ("second-high" episode). Episode selection procedures are discussed elsewhere.*

*The primary purpose for conducting UAM area wide and CAL3QHC roadway intersection modeling is to demonstrate the effectiveness of CO emission control strategies in attaining the 8-hour average NAAQS for carbon monoxide.[41] The attainment demonstration consists of four parts:*

- *Development of attainment-year base case emission inventories; this inventory reflects the net effect of federally mandated controls and growth projections for all source types;*
- *Development of future-year emission inventory with control strategies;*
- *Performing attainment year model simulations to assess inventories and control strategies;*
- *Use of modeling results to demonstrate attainment.*

*For the Urban Airshed Modeling, the estimated volume averaged CO concentrations from each of the 4,602 grid cells in the Denver modeling domain must show attainment of federal standards. For the UAM and CAL3QHC combined modeling system, the sum of the UAM area wide and CAL3QHC hot spot estimates must show attainment at each selected intersection.*

## 4.2. Control Strategy Assumptions

The metro Denver area will rely on the control programs listed below to demonstrate maintenance of the CO standards through 2013. No emission reduction credit has been taken in the maintenance demonstration for any other current State or local control programs and no other such programs, strategies, or regulations shall be incorporated or deemed as enforceable measures for the purposes of this maintenance demonstration. For a more detailed description of proposed control strategies and of the contingency plan, refer to the separately published "Proposed Carbon Monoxide Redesignation Request and Maintenance Plan for the Denver metropolitan area." The enforceable control measures for the maintenance plan are as follows:

a) Federal tailpipe standards and regulations, including those for small engines and non-road mobile sources. Credit is taken for these federal requirements but they are not part of the Colorado SIP.
b) Gasoline vehicle inspection and maintenance (I/M 240) program as modified and described in a separately published redesignation and maintenance plan documents.
c) Oxygenated gasoline program as modified and described in a separately published redesignation and maintenance plan documents.
d) Woodburning controls (AQCC Regulation No. 4).
e) Industrial source controls (AQCC Regulations No. 3 & 6 and Common Provisions). In accordance with State and federal regulations and policies, the State/federal nonattainment NSR requirements currently in effect for the Denver area will revert to the State/federal attainment PSD permitting requirements once EPA approves this redesignation request and maintenance plan.

In general, the maintenance plan modeling is based on 1.5% oxygenated fuels for 2006 and 1.7% oxygenated fuels for 2013. The I/M240 Program includes a four year exemption for new model vehicles. The remote sensing devices (RSD) program includes evaluation of up to 80% of the fleet.

## 4.3. UAM and CAL3QHC Results

The maximum 8-hour average carbon monoxide (CO) concentration estimates for 2006 and 2013 are located in the Urban Airshed Model grid cell (23,43). This is the grid cell that includes most of the tall buildings in downtown Denver; it also includes the CAMP monitoring site where the highest CO concentration levels have been observed historically.

In the approved CO SIP, the maximum grid cell at the end of the year 2000 is the cell where the intersection of Speer Blvd. and the Auraria Parkway exists; it is directly west of the CAMP grid cell (which is the maximum grid cell for the 2006 and 2013 modeling). Since the meteorology in the Urban Airshed Modeling is identical in both cases, the shift in the maximum grid cell is due to changes in the spatial and temporal distributions of emissions.[u] In any case, the Urban Airshed Modeling suggests that the maximum 8-hour carbon monoxide concentration estimates in the "CAMP" grid cell (23,43) and in the "Speer and Auraria" grid cell (22, 43) are similar. Both cells are in the central business district.

The maximum concentration estimate for 2006 is 8.71 ppm. It is based on combined UAM and CAL3QHC estimates at the intersection of Broadway/Champa/21$^{st}$ (i.e., the CAMP intersection).

The maximum concentration estimate for 2012 is 8.98 ppm. It is based on combined UAM and CAL3QHC estimates at the intersection of Broadway/Champa/21$^{st}$ (i.e., the CAMP intersection). The concentration maximum for 2012 is slightly higher than 2013 because the modeling is based on 1.5% oxygenated fuels instead of the 1.7% used for 2013.

The maximum concentration estimate for 2013 is 8.96 ppm. It is based on combined UAM and CAL3QHC estimates at the intersection of Broadway/Champa/21$^{st}$ (i.e., the CAMP intersection).

Finally, its important to note that the air quality modeling system being used in the maintenance plan is based on the same model validation work and the same episodes as were used in the CO SIP. Since no new episodes have been modeled, a new basecase validation has not been performed. Thus, no downtown intersections besides the CAMP intersection have been modeled. If new basecase episodes were selected and modeled, the intersection of Speer and Auraria could be included in the modeling process. In any case, based on observed CO data from 1997, 1998, and 1999, it's clear that modeling based on any episode in the 1997-99 period would result in compliance in 2006 and 2013 with the

[u] There are many reasons why the spatial and temporal distribution of future emissions have changed. For example, the description of links that represent the transportation network for future years have been significantly improved. This is due in part to the use of Geographical Information Systems (GIS) that allow more accurate placement of links in the modeling systems. This has resulted in portions of some links moving from one grid cell to another. For example, the links for the year 2000 in current transportation models provide a better representation of the road network than the historic year 2000 links that were used in the approved CO SIP. In addition, the transportation modeling process now uses ten time periods instead of three. Thus, there is better temporal resolution of mobile source emissions than in the past.

control packages presented in the proposed redesignation plan. Of course, the situation is less clear since a 9.5 ppm was measured at Speer and Auraria on November 30, 1999. Since only the second exceedance at a site constitutes a violation, the exceedance on November $30^{th}$ is not a violation of the federal standard. In fact, a marginal exceedance in 1999 is consistent with the approved CO SIP modeling results, which suggested that Denver would barely come into compliance with the federal standard at the end of the year 2000.

By design, the compliance demonstration is based on the minimum set of control strategies necessary to demonstrate compliance with federal standards in 2006 and 2013. For example, the 2012 modeled maximum 8-hour CO concentration is 8.98 ppm, just two-hundredths of a ppm below the federal standard of 9.0 ppm. While this appears to leave little room for error in the modeling analysis, it's important to note that monitored compliance with the federal 8-hour standard is based on 9.5 ppm, not 9.0 ppm. Thus, EPA's monitoring-based compliance process, by design, provides an adequate safety margin between the modeled 8.98 ppm value and the monitoring-based compliance goal of 9.5 ppm. In any case, in the unexpected event that monitored violations of federal standards occurred in the future, additional control strategies could be implemented to reduce emissions accordingly.

## 4.4. 2006 and 2013 Budget Related Emission Inventories

The Colorado Air Quality Control Commission has adopted budgets for $PM_{10}$, Nitrogen Oxides and Volatile Organic Compounds as a result of the State Implementation Plan for $PM_{10}$ and a Maintenance Plan and Redesignation Request for the Denver Ozone Nonattainment Area. Emission inventories for these pollutants for 2006 and 2013 were calculated to estimate the affects of the strategies proposed in this maintenance plan and redesignation request. Table 23 summarizes the results of this analysis.

**Table 23. Comparison of approved emission budgets with emissions estimates that would result from the Denver carbon monoxide maintenance plan.**

| Pollutant | SIP Budget (tons per day) | Carbon Monoxide Maintenance Plan Emissions Inventory | |
|---|---|---|---|
| | | 2006 (tons per day) | 2013 (tons per day) |
| PM10 Precursors: Nitrogen Oxides | 119.4 | 110.17 | 108.70 |
| $PM_{10}$ | 60 | 47.1 | 46.7 |
| Carbon Monoxide | 825 | 783.64 | 800.00 |
| Ozone Precursors: NOx (in 2006) | 139 | 123.3 | 125.9 |
| Ozone Precursors: NOx (in 2013) | 135 | | |
| Ozone Precursors: VOCs | 124 | 88.25 | 77.13 |

#### 4.4.1.1. UAM Results for 2006 (UAM simulation "H")

**Table 24. Combined UAM and CAL3QHC estimates for "high" episode - Run H: Enhanced Inspection/Maintenance 240 with new vehicles exempted for their first four years; 1.5% oxygenated gasoline; evaluation of up to 80% of the fleet with Remote Sensing Devices (80% RSD).**

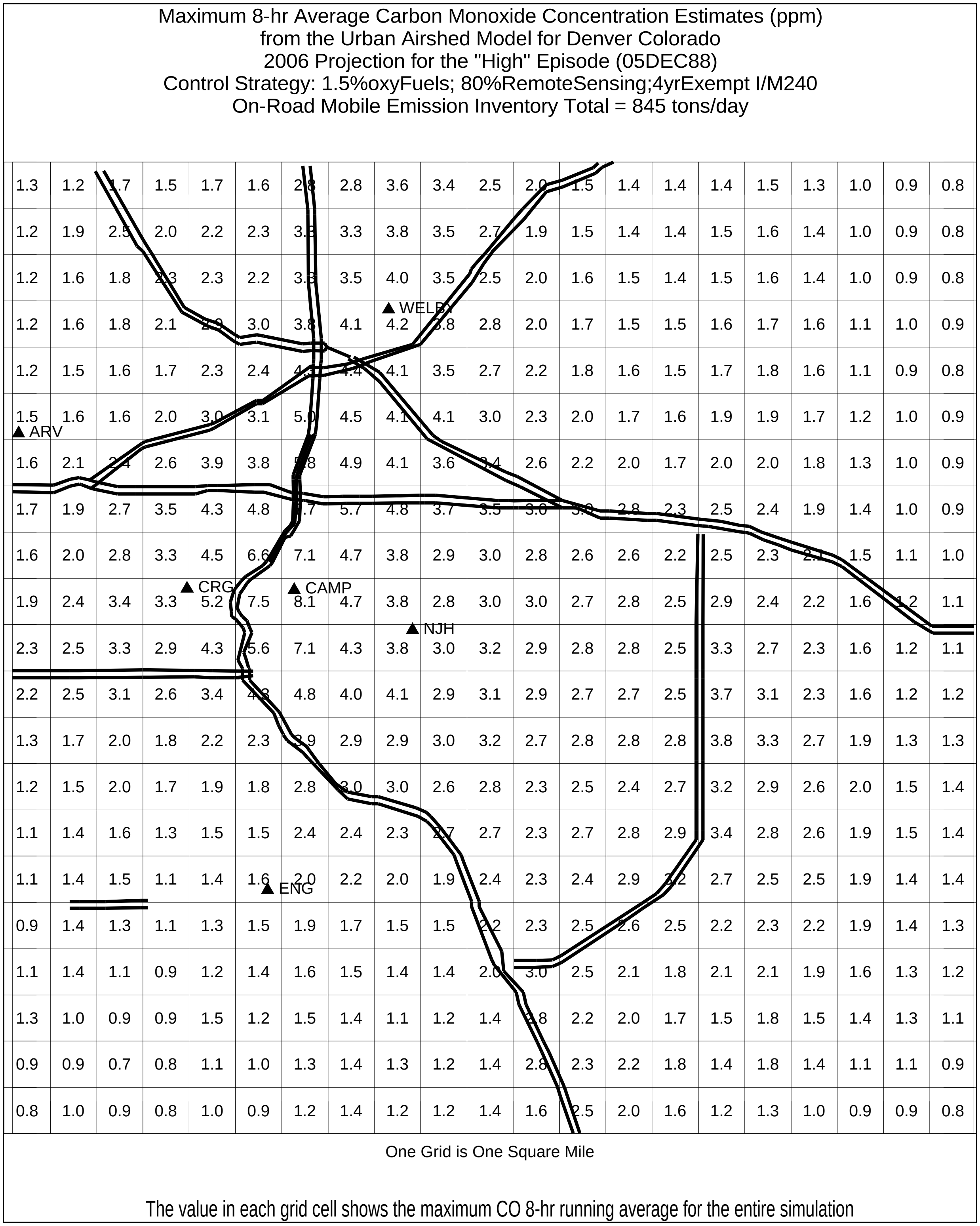
| Location | Maximum 8-hour Average CO Concentration Estimates for the Year 2006 | | |
|---|---|---|---|
| | CAL3QHC | UAM | UAM + CAL3QHC |
| Maximum UAM cell (23,43) | NA | **8.08** ppm (1) | NA |
| Broadway & Champa St. (i.e., CAMP intersection) | **1.12** ppm (2) | **7.59** ppm (3) | **8.71** ppm (2,3) |
| Foothills & Arapahoe | *0.9 ppm (4)* | *0.9 ppm (5)* | *5.7 ppm (4,5)* |
| 1st and University | *4.0 ppm (4)* | *4.0 ppm (5)* | *8.3 ppm (4,5)* |
| Hampden & University | *1.9 ppm (4)* | *1.9 ppm (5)* | *5.5 ppm (4,5)* |
| Parker & Iliff | *2.7 ppm (4)* | *2.7 ppm (5)* | *5.8 ppm (4,5)* |
| Arapahoe & University | *1.3 ppm (4)* | *1.3 ppm (5)* | *5.0 ppm (4,5)* |

NA = Not Applicable (Note: This value is the maximum from the UAM simulation. There is no CAL3QHC component because UAM and CAL3QHC are separate models.)

NOTES:

- Modeling results at intersections where conservative CAL3QHC screening-level modeling has been performed at shown in *italics*; in addition, only one decimal place of precision is included.
- The precision of the results is not intended to imply a level of accuracy.
- The estimate at "Broadway & Champa St. (i.e., CAMP intersection)" is from the maximum hot spot receptor at the intersection near the CAMP monitor.

1) UAM maximum grid cell estimate
2) Refined CAL3QHC estimate
3) Weighted UAM average
4) Screening- level CAL3QHC estimate
5) Maximum weighted UAM average




| | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1.3 | 1.2 | 1.7 | 1.5 | 1.7 | 1.6 | 2.8 | 2.8 | 3.6 | 3.4 | 2.5 | 2.0 | 1.5 | 1.4 | 1.4 | 1.4 | 1.5 | 1.3 | 1.0 | 0.9 | 0.8 |
| 1.2 | 1.9 | 2.5 | 2.0 | 2.2 | 2.3 | 3.3 | 3.3 | 3.8 | 3.5 | 2.7 | 1.9 | 1.5 | 1.4 | 1.4 | 1.5 | 1.6 | 1.4 | 1.0 | 0.9 | 0.8 |
| 1.2 | 1.6 | 1.8 | 2.3 | 2.3 | 2.2 | 3.3 | 3.5 | 4.0 | 3.5 | 2.5 | 2.0 | 1.6 | 1.5 | 1.4 | 1.5 | 1.6 | 1.4 | 1.0 | 0.9 | 0.8 |
| 1.2 | 1.6 | 1.8 | 2.1 | 2.9 | 3.0 | 3.8 | 4.1 | 4.2 | 3.8 | 2.8 | 2.0 | 1.7 | 1.5 | 1.5 | 1.6 | 1.7 | 1.6 | 1.1 | 1.0 | 0.9 |
| 1.2 | 1.5 | 1.6 | 1.7 | 2.3 | 2.4 | 4.3 | 4.4 | 4.1 | 3.5 | 2.7 | 2.2 | 1.8 | 1.6 | 1.5 | 1.7 | 1.8 | 1.6 | 1.1 | 0.9 | 0.8 |
| 1.5 | 1.6 | 1.6 | 2.0 | 3.0 | 3.1 | 5.0 | 4.5 | 4.1 | 4.1 | 3.0 | 2.3 | 2.0 | 1.7 | 1.6 | 1.9 | 1.9 | 1.7 | 1.2 | 1.0 | 0.9 |
| 1.6 | 2.1 | 2.4 | 2.6 | 3.9 | 3.8 | 5.8 | 4.9 | 4.1 | 3.6 | 3.4 | 2.6 | 2.2 | 2.0 | 1.7 | 2.0 | 2.0 | 1.8 | 1.3 | 1.0 | 0.9 |
| 1.7 | 1.9 | 2.7 | 3.5 | 4.3 | 4.8 | [illegible] | 5.7 | 4.8 | 3.7 | 3.5 | 3.0 | 3.0 | 2.8 | 2.3 | 2.5 | 2.4 | 1.9 | 1.4 | 1.0 | 0.9 |
| 1.6 | 2.0 | 2.8 | 3.3 | 4.5 | 6.6 | 7.1 | 4.7 | 3.8 | 2.9 | 3.0 | 2.8 | 2.6 | 2.6 | 2.2 | 2.5 | 2.3 | 2.1 | 1.5 | 1.1 | 1.0 |
| 1.9 | 2.4 | 3.4 | 3.3 | 5.2 | 7.5 | 8.1 | 4.7 | 3.8 | 2.8 | 3.0 | 3.0 | 2.7 | 2.8 | 2.5 | 2.9 | 2.4 | 2.2 | 1.6 | 1.2 | 1.1 |
| 2.3 | 2.5 | 3.3 | 2.9 | 4.3 | 5.6 | 7.1 | 4.3 | 3.8 | 3.0 | 3.2 | 2.9 | 2.8 | 2.8 | 2.5 | 3.3 | 2.7 | 2.3 | 1.6 | 1.2 | 1.1 |
| 2.2 | 2.5 | 3.1 | 2.6 | 3.4 | 4.3 | 4.8 | 4.0 | 4.1 | 2.9 | 3.1 | 2.9 | 2.7 | 2.7 | 2.5 | 3.7 | 3.1 | 2.3 | 1.6 | 1.2 | 1.2 |
| 1.3 | 1.7 | 2.0 | 1.8 | 2.2 | 2.3 | 3.9 | 2.9 | 2.9 | 3.0 | 3.2 | 2.7 | 2.8 | 2.8 | 2.8 | 3.8 | 3.3 | 2.7 | 1.9 | 1.3 | 1.3 |
| 1.2 | 1.5 | 2.0 | 1.7 | 1.9 | 1.8 | 2.8 | 3.0 | 3.0 | 2.6 | 2.8 | 2.3 | 2.5 | 2.4 | 2.7 | 3.2 | 2.9 | 2.6 | 2.0 | 1.5 | 1.4 |
| 1.1 | 1.4 | 1.6 | 1.3 | 1.5 | 1.5 | 2.4 | 2.4 | 2.3 | 2.7 | 2.7 | 2.3 | 2.7 | 2.8 | 2.9 | 3.4 | 2.8 | 2.6 | 1.9 | 1.5 | 1.4 |
| 1.1 | 1.4 | 1.5 | 1.1 | 1.4 | 1.6 | 2.0 | 2.2 | 2.0 | 1.9 | 2.4 | 2.3 | 2.4 | 2.9 | 3.2 | 2.7 | 2.5 | 2.5 | 1.9 | 1.4 | 1.4 |
| 0.9 | 1.4 | 1.3 | 1.1 | 1.3 | 1.5 | 1.9 | 1.7 | 1.5 | 1.5 | 2.2 | 2.3 | 2.5 | 2.6 | 2.5 | 2.2 | 2.3 | 2.2 | 1.9 | 1.4 | 1.3 |
| 1.1 | 1.4 | 1.1 | 0.9 | 1.2 | 1.4 | 1.6 | 1.5 | 1.4 | 1.4 | 2.0 | 3.0 | 2.5 | 2.1 | 1.8 | 2.1 | 2.1 | 1.9 | 1.6 | 1.3 | 1.2 |
| 1.3 | 1.0 | 0.9 | 0.9 | 1.5 | 1.2 | 1.5 | 1.4 | 1.1 | 1.2 | 1.4 | 2.8 | 2.2 | 2.0 | 1.7 | 1.5 | 1.8 | 1.5 | 1.4 | 1.3 | 1.1 |
| 0.9 | 0.9 | 0.7 | 0.8 | 1.1 | 1.0 | 1.3 | 1.4 | 1.3 | 1.2 | 1.4 | 2.8 | 2.3 | 2.2 | 1.8 | 1.4 | 1.8 | 1.4 | 1.1 | 1.1 | 0.9 |
| 0.8 | 1.0 | 0.9 | 0.8 | 1.0 | 0.9 | 1.2 | 1.4 | 1.2 | 1.2 | 1.4 | 1.6 | 2.5 | 2.0 | 1.6 | 1.2 | 1.3 | 1.0 | 0.9 | 0.9 | 0.8 |

**Figure 14. Urban Airshed Model Results for 2006 (simulation "H").**

#### 4.4.1.2. UAM Results for 2012 (UAM simulation "L")

**Table 25. Combined UAM and CAL3QHC estimates for "high" episode - Run L: Enhanced Inspection/Maintenance 240 with new vehicles exempted for their first four years; 1.5% oxygenated gasoline; evaluation of up to 80% of the fleet with Remote Sensing Devices (80% RSD).**

| Location | Maximum 8-hour Average CO Concentration Estimates for the Year 2012 | | |
|---|---|---|---|
| | CAL3QHC | UAM | UAM + CAL3QHC |
| Maximum UAM cell (23,43) | NA | **8.34** ppm (1) | NA |
| Broadway & Champa St. (i.e., CAMP intersection) | **1.09** ppm (2) | **7.89** ppm (3) | **8.98** ppm (2,3) |

NA = Not Applicable (Note: This value is the maximum from the UAM simulation. There is no CAL3QHC component because UAM and CAL3QHC are separate models.)

NOTES:

- The precision of the results is not intended to imply a level of accuracy.
- The estimate at "Broadway & Champa St. (i.e., CAMP intersection)" is from the maximum hot spot receptor at the intersection near the CAMP monitor.

1) UAM maximum grid cell estimate
2) Refined CAL3QHC estimate
3) Weighted UAM average

Maximum 8-hr Average Carbon Monoxide Concentration Estimates (ppm)
from the Urban Airshed Model for Denver Colorado
2012 Projection for the "High" Episode (05DEC88)
Control Strategy: 1.5%oxyFuels; 80%RemoteSensing;4yrExempt I/M240
On-Road Mobile Emission Inventory Total = 869 tons/day

| | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1.3 | 1.2 | 1.7 | 1.5 | 1.7 | 1.6 | 2.7 | 2.8 | 3.6 | 3.4 | 2.6 | 2.0 | 1.5 | 1.4 | 1.4 | 1.5 | 1.5 | 1.4 | 1.0 | 1.0 | 0.8 |
| 1.1 | 1.9 | 2.5 | 1.9 | 2.1 | 2.2 | 3.2 | 3.2 | 3.9 | 3.6 | 2.7 | 1.9 | 1.5 | 1.4 | 1.4 | 1.5 | 1.6 | 1.4 | 1.0 | 1.0 | 0.9 |
| 1.2 | 1.6 | 1.7 | 2.2 | 2.2 | 2.1 | 3.2 | 3.5 | 4.1 | 3.6 | 2.6 | 2.0 | 1.6 | 1.4 | 1.4 | 1.5 | 1.7 | 1.5 | 1.1 | 0.9 | 0.9 |
| 1.2 | 1.6 | 1.7 | 2.0 | 2.8 | 2.8 | 3.8 | 4.1 | ▲ WELBY 4.3 | 3.9 | 2.8 | 2.0 | 1.7 | 1.5 | 1.4 | 1.6 | 1.7 | 1.7 | 1.2 | 1.1 | 1.0 |
| 1.2 | 1.5 | 1.5 | 1.7 | 2.2 | 2.3 | 4.3 | 4.5 | 4.2 | 3.6 | 2.8 | 2.1 | 1.8 | 1.6 | 1.5 | 1.6 | 1.8 | 1.7 | 1.2 | 1.0 | 0.9 |
| 1.4 ▲ ARV | 1.6 | 1.6 | 2.0 | 3.0 | 3.1 | 5.0 | 4.5 | 4.1 | 4.2 | 3.1 | 2.3 | 2.1 | 1.7 | 1.6 | 1.9 | 1.9 | 1.8 | 1.3 | 1.0 | 1.0 |
| 1.6 | 2.2 | 2.3 | 2.6 | 3.8 | 3.8 | 5.7 | 4.9 | 4.1 | 3.7 | 3.4 | 2.7 | 2.3 | 1.9 | 1.7 | 2.0 | 2.0 | 1.8 | 1.3 | 1.0 | 1.0 |
| 1.7 | 2.0 | 2.7 | 3.5 | 4.2 | 4.8 | [illegible] | 5.7 | 4.8 | 3.7 | 3.5 | 3.0 | 3.1 | 2.8 | 2.3 | 2.5 | 2.4 | 1.9 | 1.4 | 1.1 | 1.0 |
| 1.6 | 2.0 | 2.8 | 3.3 | 4.3 | 7.0 | 7.4 | 4.8 | 3.8 | 2.9 | 3.0 | 2.8 | 2.7 | 2.5 | 2.2 | 2.4 | 2.3 | 2.1 | 1.5 | 1.1 | 1.1 |
| 1.8 | 2.4 | 3.3 | 3.2 | ▲ CRG 5.1 | 7.9 | ▲ CAMP 8.3 | 4.6 | 3.7 | 2.7 | 3.0 | 2.9 | 2.6 | 2.7 | 2.5 | 2.8 | 2.5 | 2.1 | 1.6 | 1.2 | 1.2 |
| 2.3 | 2.6 | 3.3 | 2.9 | 4.1 | 5.7 | 7.1 | 4.2 | 3.6 | ▲ NJH 2.9 | 3.2 | 2.8 | 2.8 | 2.7 | 2.4 | 3.1 | 2.7 | 2.2 | 1.7 | 1.2 | 1.2 |
| 2.1 | 2.6 | 3.0 | 2.6 | 3.3 | 4.3 | 4.6 | 3.8 | 4.0 | 2.8 | 3.1 | 2.9 | 2.6 | 2.6 | 2.4 | 3.4 | 3.1 | 2.3 | 1.7 | 1.2 | 1.3 |
| 1.3 | 1.8 | 1.9 | 1.8 | 2.1 | 2.3 | 3.8 | 2.8 | 2.9 | 2.8 | 3.1 | 2.6 | 2.8 | 2.7 | 2.7 | 3.5 | 3.2 | 2.6 | 1.9 | 1.3 | 1.4 |
| 1.1 | 1.6 | 1.9 | 1.6 | 1.8 | 1.8 | 2.7 | 2.8 | 2.9 | 2.5 | 2.7 | 2.3 | 2.5 | 2.3 | 2.7 | 2.9 | 2.8 | 2.5 | 2.0 | 1.5 | 1.5 |
| 1.0 | 1.5 | 1.5 | 1.3 | 1.5 | 1.5 | 2.3 | 2.3 | 2.2 | 2.6 | 2.6 | 2.2 | 2.6 | 2.6 | 2.8 | 3.0 | 2.6 | 2.5 | 1.9 | 1.5 | 1.5 |
| 1.0 | 1.4 | 1.5 | 1.1 | 1.3 | 1.6 | ▲ ENG 2.0 | 2.1 | 2.0 | 1.9 | 2.3 | 2.3 | 2.4 | 2.8 | 3.2 | 2.5 | 2.4 | 2.4 | 1.9 | 1.4 | 1.4 |
| 0.8 | 1.4 | 1.3 | 1.1 | 1.2 | 1.5 | 1.8 | 1.7 | 1.5 | 1.4 | 2.1 | 2.3 | 2.4 | 2.4 | 2.6 | 2.2 | 2.3 | 2.2 | 1.8 | 1.4 | 1.3 |
| 1.0 | 1.5 | 1.1 | 0.9 | 1.1 | 1.4 | 1.6 | 1.5 | 1.4 | 1.3 | 2.0 | 2.9 | 2.4 | 2.1 | 1.9 | 2.1 | 2.2 | 1.9 | 1.6 | 1.3 | 1.2 |
| 1.3 | 1.0 | 0.9 | 0.9 | 1.4 | 1.2 | 1.5 | 1.4 | 1.1 | 1.1 | 1.4 | 2.7 | 2.1 | 1.9 | 1.7 | 1.7 | 2.0 | 1.6 | 1.5 | 1.3 | 1.1 |
| 1.0 | 0.8 | 0.7 | 0.8 | 1.1 | 1.0 | 1.3 | 1.4 | 1.3 | 1.3 | 1.5 | 2.8 | 2.4 | 2.3 | 2.0 | 1.7 | 2.3 | 1.6 | 1.2 | 1.2 | 1.0 |
| 0.8 | 1.0 | 0.9 | 0.8 | 1.1 | 0.9 | 1.2 | 1.4 | 1.2 | 1.1 | 1.3 | 1.5 | 2.5 | 2.1 | 1.8 | 1.4 | 1.4 | 1.1 | 1.0 | 1.0 | 0.9 |

One Grid is One Square Mile

The value in each grid cell shows the maximum CO 8-hr running average for the entire simulation

**Figure 15. Urban Airshed Model Results for 2012 (simulation "L").**

#### 4.4.1.3. UAM Results for 2013 (UAM simulation "O")

**Table 26. Combined UAM and CAL3QHC estimates for "high" episode - Run O: Enhanced Inspection/Maintenance 240 with new vehicles exempted for their first four years; 1.7% oxygenated gasoline; evaluation of up to 80% of the fleet with Remote Sensing Devices (80% RSD).**

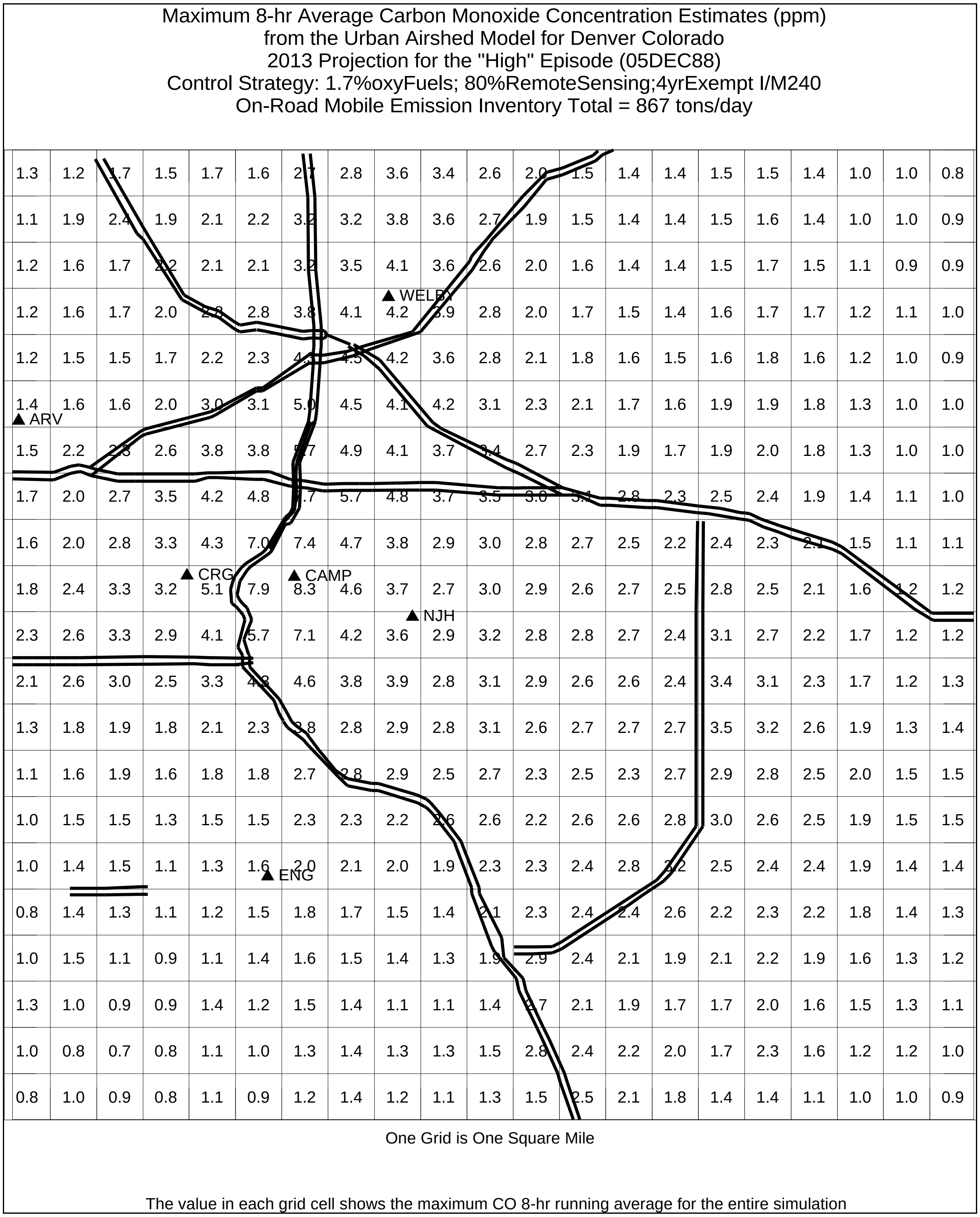
| Location | Maximum 8-hour Average CO Concentration Estimates for the Year 2013 | | |
|---|---|---|---|
| | CAL3QHC | UAM | UAM + CAL3QHC |
| Maximum UAM cell (23,43) | NA | **8.32** ppm (1) | NA |
| Broadway & Champa St. (i.e., CAMP intersection) | **1.08** ppm (2) | **7.88** ppm (3) | **8.96** ppm (2,3) |
| Foothills & Arapahoe | *4.7 ppm (4)* | *0.9 ppm (5)* | *5.6 ppm (4,5)* |
| 1st and University | *4.2 ppm (4)* | *3.9 ppm (5)* | *8.0 ppm (4,5)* |
| Hampden & University | *4.3 ppm (4)* | *1.9 ppm (5)* | *6.2 ppm (4,5)* |
| Parker & Iliff | *3.0 ppm (4)* | *2.6 ppm (5)* | *5.6 ppm (4,5)* |
| Arapahoe & University | *3.9 ppm (4)* | *1.3 ppm (5)* | *5.3 ppm (4,5)* |

NA = Not Applicable (Note: This value is the maximum from the UAM simulation. There is no CAL3QHC component because UAM and CAL3QHC are separate models.)

NOTES:

- Modeling results at intersections where conservative CAL3QHC screening-level modeling has been performed at shown in *italics*; in addition, only one decimal place of precision is included.
- The precision of the results is not intended to imply a level of accuracy.
- The estimate at "Broadway & Champa St. (i.e., CAMP intersection)" is from the maximum hot spot receptor at the intersection near the CAMP monitor.

1) UAM maximum grid cell estimate
2) Refined CAL3QHC estimate
3) Weighted UAM average
4) Screening- level CAL3QHC estimate
5) Maximum weighted UAM average




| | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1.3 | 1.2 | 1.7 | 1.5 | 1.7 | 1.6 | 2.7 | 2.8 | 3.6 | 3.4 | 2.6 | 2.0 | 1.5 | 1.4 | 1.4 | 1.5 | 1.5 | 1.4 | 1.0 | 1.0 | 0.8 |
| 1.1 | 1.9 | 2.4 | 1.9 | 2.1 | 2.2 | 3.2 | 3.2 | 3.8 | 3.6 | 2.7 | 1.9 | 1.5 | 1.4 | 1.4 | 1.5 | 1.6 | 1.4 | 1.0 | 1.0 | 0.9 |
| 1.2 | 1.6 | 1.7 | 2.2 | 2.1 | 2.1 | 3.2 | 3.5 | 4.1 | 3.6 | 2.6 | 2.0 | 1.6 | 1.4 | 1.4 | 1.5 | 1.7 | 1.5 | 1.1 | 0.9 | 0.9 |
| 1.2 | 1.6 | 1.7 | 2.0 | 2.8 | 2.8 | 3.8 | 4.1 | 4.2 | 3.9 | 2.8 | 2.0 | 1.7 | 1.5 | 1.4 | 1.6 | 1.7 | 1.7 | 1.2 | 1.1 | 1.0 |
| 1.2 | 1.5 | 1.5 | 1.7 | 2.2 | 2.3 | 4.3 | 4.5 | 4.2 | 3.6 | 2.8 | 2.1 | 1.8 | 1.6 | 1.5 | 1.6 | 1.8 | 1.6 | 1.2 | 1.0 | 0.9 |
| 1.4 | 1.6 | 1.6 | 2.0 | 3.0 | 3.1 | 5.0 | 4.5 | 4.1 | 4.2 | 3.1 | 2.3 | 2.1 | 1.7 | 1.6 | 1.9 | 1.9 | 1.8 | 1.3 | 1.0 | 1.0 |
| 1.5 | 2.2 | 2.3 | 2.6 | 3.8 | 3.8 | 5.7 | 4.9 | 4.1 | 3.7 | 3.4 | 2.7 | 2.3 | 1.9 | 1.7 | 1.9 | 2.0 | 1.8 | 1.3 | 1.0 | 1.0 |
| 1.7 | 2.0 | 2.7 | 3.5 | 4.2 | 4.8 | [illegible] | 5.7 | 4.8 | 3.7 | 3.5 | 3.0 | 3.1 | 2.8 | 2.3 | 2.5 | 2.4 | 1.9 | 1.4 | 1.1 | 1.0 |
| 1.6 | 2.0 | 2.8 | 3.3 | 4.3 | 7.0 | 7.4 | 4.7 | 3.8 | 2.9 | 3.0 | 2.8 | 2.7 | 2.5 | 2.2 | 2.4 | 2.3 | 2.1 | 1.5 | 1.1 | 1.1 |
| 1.8 | 2.4 | 3.3 | 3.2 | 5.1 | 7.9 | 8.3 | 4.6 | 3.7 | 2.7 | 3.0 | 2.9 | 2.6 | 2.7 | 2.5 | 2.8 | 2.5 | 2.1 | 1.6 | 1.2 | 1.2 |
| 2.3 | 2.6 | 3.3 | 2.9 | 4.1 | 5.7 | 7.1 | 4.2 | 3.6 | 2.9 | 3.2 | 2.8 | 2.8 | 2.7 | 2.4 | 3.1 | 2.7 | 2.2 | 1.7 | 1.2 | 1.2 |
| 2.1 | 2.6 | 3.0 | 2.5 | 3.3 | 4.8 | 4.6 | 3.8 | 3.9 | 2.8 | 3.1 | 2.9 | 2.6 | 2.6 | 2.4 | 3.4 | 3.1 | 2.3 | 1.7 | 1.2 | 1.3 |
| 1.3 | 1.8 | 1.9 | 1.8 | 2.1 | 2.3 | 3.8 | 2.8 | 2.9 | 2.8 | 3.1 | 2.6 | 2.7 | 2.7 | 2.7 | 3.5 | 3.2 | 2.6 | 1.9 | 1.3 | 1.4 |
| 1.1 | 1.6 | 1.9 | 1.6 | 1.8 | 1.8 | 2.7 | 2.8 | 2.9 | 2.5 | 2.7 | 2.3 | 2.5 | 2.3 | 2.7 | 2.9 | 2.8 | 2.5 | 2.0 | 1.5 | 1.5 |
| 1.0 | 1.5 | 1.5 | 1.3 | 1.5 | 1.5 | 2.3 | 2.3 | 2.2 | 2.6 | 2.6 | 2.2 | 2.6 | 2.6 | 2.8 | 3.0 | 2.6 | 2.5 | 1.9 | 1.5 | 1.5 |
| 1.0 | 1.4 | 1.5 | 1.1 | 1.3 | 1.6 | 2.0 | 2.1 | 2.0 | 1.9 | 2.3 | 2.3 | 2.4 | 2.8 | 3.2 | 2.5 | 2.4 | 2.4 | 1.9 | 1.4 | 1.4 |
| 0.8 | 1.4 | 1.3 | 1.1 | 1.2 | 1.5 | 1.8 | 1.7 | 1.5 | 1.4 | 2.1 | 2.3 | 2.4 | 2.4 | 2.6 | 2.2 | 2.3 | 2.2 | 1.8 | 1.4 | 1.3 |
| 1.0 | 1.5 | 1.1 | 0.9 | 1.1 | 1.4 | 1.6 | 1.5 | 1.4 | 1.3 | 1.9 | 2.9 | 2.4 | 2.1 | 1.9 | 2.1 | 2.2 | 1.9 | 1.6 | 1.3 | 1.2 |
| 1.3 | 1.0 | 0.9 | 0.9 | 1.4 | 1.2 | 1.5 | 1.4 | 1.1 | 1.1 | 1.4 | 2.7 | 2.1 | 1.9 | 1.7 | 1.7 | 2.0 | 1.6 | 1.5 | 1.3 | 1.1 |
| 1.0 | 0.8 | 0.7 | 0.8 | 1.1 | 1.0 | 1.3 | 1.4 | 1.3 | 1.3 | 1.5 | 2.8 | 2.4 | 2.2 | 2.0 | 1.7 | 2.3 | 1.6 | 1.2 | 1.2 | 1.0 |
| 0.8 | 1.0 | 0.9 | 0.8 | 1.1 | 0.9 | 1.2 | 1.4 | 1.2 | 1.1 | 1.3 | 1.5 | 2.5 | 2.1 | 1.8 | 1.4 | 1.4 | 1.1 | 1.0 | 1.0 | 0.9 |

**Figure 16. Urban Airshed Model Results for 2013 (simulation "O").**

# 5. Monitoring-Based Attainment Demonstration

Attainment of the national standard for carbon monoxide is demonstrated when two consecutive years of monitoring data for each site show no more than one exceedance per year of the 8-hour (9 ppm) and 1-hour (35 ppm) standards. The following information demonstrates, as required by Section 107(d)(3)(E) of the CAA, that the Denver metropolitan area has attained the national standard for carbon monoxide. This is based on quality assured monitoring data representative of the location of expected maximum concentrations of CO in the area (downtown Denver).

## 5.1. Denver Area Historical Perspective

Historically, the CO standards were exceeded frequently throughout the Denver metropolitan area. With the implementation of emission control programs aimed at reducing automobile, truck, and woodburning emissions, CO concentrations began to decrease substantially. The last recorded violation of the 8-hour standard occurred in 1995. The last violation of the 1-hour standard occurred in 1990.

## 5.2. Carbon Monoxide Monitoring Network

The current CO ambient air monitoring network in the Denver area consists of one National Air Monitoring Station (NAMS) and seven State and Local Air Monitoring Stations (SLAMS) operated by the APCD. The monitoring sites are listed, along with summary data from 1997, 1998 and 1999, in the tables that follow. The following map shows the location of CO monitors active between 1997 and 1999. The Marine Street monitor in Boulder was shut down on December 31, 1998.

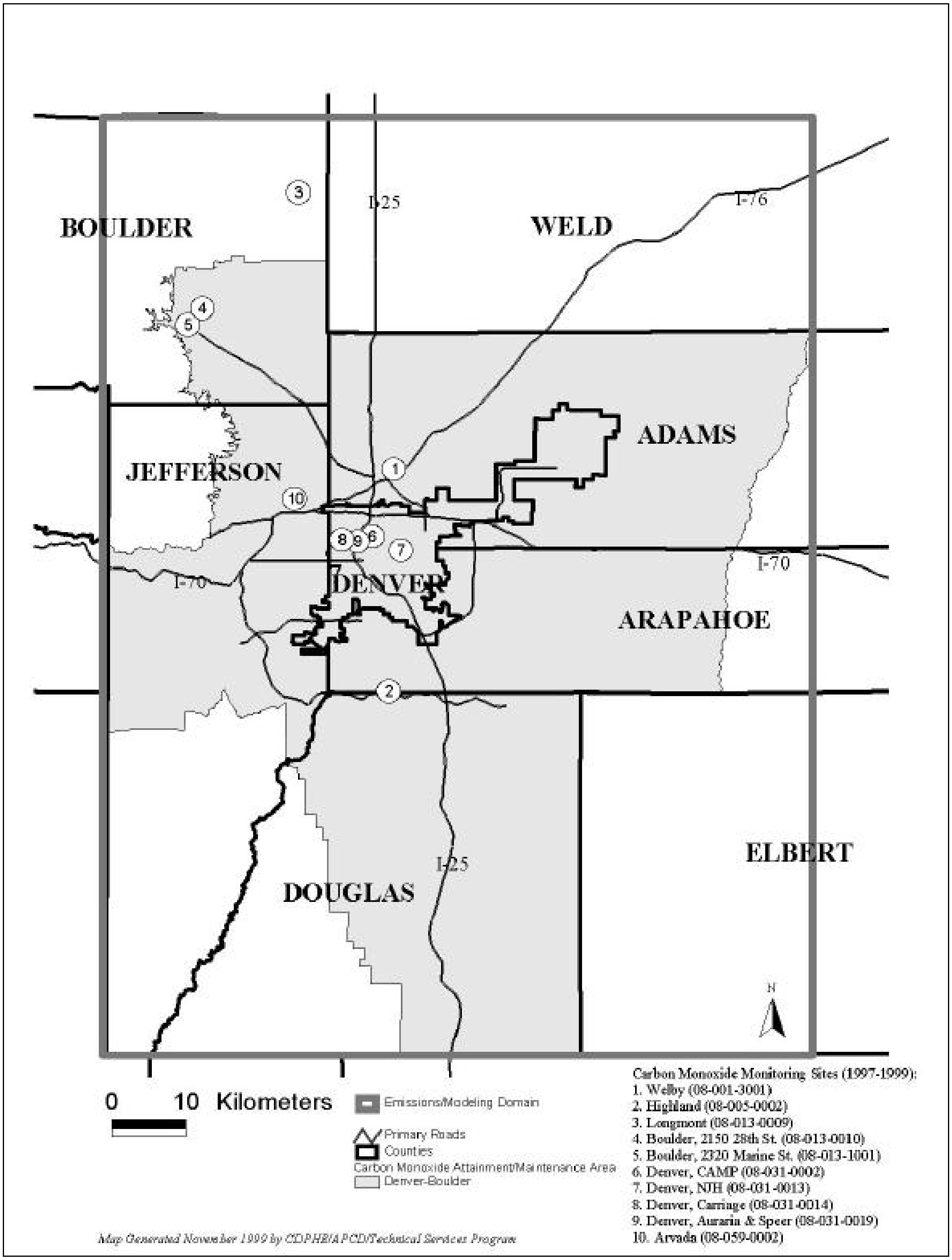



**Figure 17. Active carbon monoxide monitoring sites in the Denver metropolitan area from 1997-1999.**

## 5.3. Monitoring-Based Attainment Demonstration

The monitoring data presented in Table 27, Table 28, and Table 29 verify that the Denver area has been in attainment with the national standard for carbon monoxide for the most recent complete two year period (1997-98)[v], in accordance with the federal requirements of 40 CFR 50.8. In fact, the area has been in attainment with the standard since 1996. Data through December 31, 1999 continues to support the fact that Denver has not violated the carbon monoxide standard since 1995.

Only one exceedance of the standard has been measured since the exceedance on December 1, 1995; it occurred on November 30, 1999 when an 8-hour average concentration value of 9.5 ppm was observed at the monitoring site near the intersection of Speer Blvd. and the Auraria Parkway. During the November 30th episode, a 9.1 ppm was measured at CAMP and an 8.2 ppm was measured at NJH. Since only the second exceedance at a site constitutes a violation, the exceedance on November 30th is not a violation. Concentration data from the three highest monitoring sites for the November 30th episode are shown in Table 30 on page 90. Figure 5 on page 43 shows the hourly concentration data from all CO monitoring sites in the metropolitan area during the exceedance on November 30, 1999.

Data recovery rates for the monitors exceed the seventy-five percent (75%) completeness requirements for all years with the exception of 54% data capture at the CAMP monitor in 1999. The low data capture at CAMP occurred because the monitor was out of service from June 10 through November 19, 1999 for a scheduled reconstruction of the monitoring site.

All State and federal quality assurance procedures have been complied with, further substantiating the validity of the monitoring data as indicators of ambient CO levels in the Denver metropolitan area. Figure 18, Figure 19, Figure 20, Figure 21, and Figure 22 on pages 91 - 95 present the long-term record for each monitor in the network.

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[v] Although this report includes carbon monoxide measurements through the December 31, 1999, it should be noted that the December 1999 data were considered to be “preliminary” at the time this report was written.

**Table 27. 1997 Carbon monoxide data summary for the Denver Metropolitan Area.**

| Site Name | Data Capture (%) | 1-Hour [CO] (ppm) | | 8-Hour [CO] (ppm) | |
|---|---|---|---|---|---|
| | | Maximum | 2nd Maximum | Maximum | 2nd Maximum |
| Welby, 78th Ave & Steele St. | 99% | 8.3 | 6.6 | 5.0 | 4.3 |
| Highland, 8100 S. University Blvd.[w] | 97% | 4.3 | 4.0 | 3.0 | 2.0 |
| Boulder, 2150 28th St | 99% | 9.0 | 8.2 | 5.5 | 3.9 |
| Boulder, 2320 Marine St. | 97% | 7.1 | 6.9 | 5.1 | 3.3 |
| Denver CAMP, 2105 Broadway | 99% | 11.4 | 10.0 | 5.7 | 5.5 |
| Denver, NJH, 14th Ave. & Albion St. | 99% | **11.6** | 10.6 | 4.8 | 4.7 |
| Denver Carriage, 23rd Ave & Julian St. | 99% | 9.5 | 8.4 | **7.0** | 6.2 |
| Speer & Auraria, Firehouse #6 | 95% | 11.2 | **11.2** | 6.6 | **6.4** |
| Arvada, 57th Ave. & Garrison St. | 99% | 9.2 | 7.7 | 5.1 | 4.9 |

Standards: 1-hour: 35 ppm*; 8-hour: 9-ppm**
* Due to mathematical rounding, a value of 35.5 ppm or greater is necessary to exceed the standard.
** Due to mathematical rounding, a value or 9.5 ppm or greater is necessary to exceed the standard.

**Table 28. 1998 Carbon monoxide data summary for the Denver Metropolitan Area.**

| Site Name | Data Capture (%) | 1-Hour [CO] (ppm) | | 8-Hour [CO] (ppm) | |
|---|---|---|---|---|---|
| | | Maximum | 2nd Maximum | Maximum | 2nd Maximum |
| Welby, 78th Ave & Steele St. | 99% | 6.6 | 6.1 | 3.7 | 3.5 |
| Boulder, 2150 28th St | 99% | 11.1 | **10.6** | 5.1 | 4.8 |
| Boulder, 2320 Marine St. | 98% | 5.2 | 4.1 | 2.5 | 2.1 |
| Denver CAMP, 2105 Broadway | 97% | **11.6** | 9.9 | **5.8** | 4.7 |
| Denver, NJH, 14th Ave. & Albion St. | 99% | 8.5 | 8.1 | 4.3 | 4.3 |
| Denver Carriage, 23rd Ave & Julian St. | 99% | 8.3 | 8.1 | 5.0 | 4.4 |
| Speer & Auraria, Firehouse #6 | 96% | 10.1 | 10.1 | 5.6 | **5.2** |
| Arvada, 57th Ave. & Garrison St. | 99% | 7.2 | 6.6 | 3.7 | 3.6 |

Standards: 1-hour: 35 ppm*; 8-hour: 9-ppm**
* Due to mathematical rounding, a value of 35.5 ppm or greater is necessary to exceed the standard.
** Due to mathematical rounding, a value or 9.5 ppm or greater is necessary to exceed the standard.

[w] Carbon Monoxide monitoring at Highland was discontinued at the end of 1997 due to historically low concentration levels.

**Table 29. 1999 Carbon monoxide data summary for the Denver Metropolitan Area**

| Site Name | Data Capture (%) | 1-Hour [CO] (ppm) | | 8-Hour [CO] (ppm) | |
|---|---|---|---|---|---|
| | | Maximum | 2nd Maximum | Maximum | 2nd Maximum |
| Welby, 78th Ave & Steele St. | 97% | 6.4 | 6.0 | 4.3 | 3.6 |
| Boulder, 2150 28th St | 99% | 7.1 | 7.0 | 4.8 | 3.7 |
| Denver CAMP, 2105 Broadway | 54% | 13.1 | **12.1** | 9.1 | 4.4 |
| Denver, NJH, 14th Ave. & Albion St. | 99% | 12.1 | 10.6 | 8.2 | **7.5** |
| Denver Carriage, 23rd Ave & Julian St. | 99% | 6.5 | 6.5 | 5.5 | 4.2 |
| Speer & Auraria, Firehouse #6 | 99% | **13.2** | 11.2 | **9.5** | 4.7 |
| Arvada, 57th Ave. & Garrison St. | 99% | **13.2** | 8.0 | 4.9 | 4.1 |

Standards: 1-hour: 35 ppm*; 8-hour: 9-ppm**
* Due to mathematical rounding, a value of 35.5 ppm or greater is necessary to exceed the standard.
** Due to mathematical rounding, a value or 9.5 ppm or greater is necessary to exceed the standard.
Notes:

- Data from December 1999 are preliminary.
- The Denver CAMP monitor was out of service from June 10 through November 19, 1999 due to a scheduled reconstruction of the monitoring site.

**Table 30. Carbon monoxide data during the episode on November 30, 1999.**

| | 1-hour Carbon Monoxide Concentration (ppm) | | |
|---|---|---|---|
| **Hour** | Denver CAMP<br>2105 Broadway | Denver, NJH<br>14th Ave. & Albion | Speer & Auraria<br>Firehouse #6 |
| 12 | 1.1 | 1.4 | 1.1 |
| 13 | 1.4 | 1.5 | 1.6 |
| 14 | 2.8 | 2.2 | 2.8 |
| **15** | **5.3** | **3.9** | **5.1** |
| **16** | **10.9** | **8.0** | **8.3** |
| **17** | **13.1** | **12.1** | **9.8** |
| **18** | **8.0** | **10.0** | **11.1** |
| **19** | **12.1** | **10.6** | **13.2** |
| **20** | **8.8** | **8.2** | **11.2** |
| **21** | **7.1** | **7.3** | **9.3** |
| **22** | **7.4** | **5.1** | **7.6** |
| 23 | 1.6 | 2.6 | 5.1 |
| | | | |
| Maximum 8-hour Average | 9.09 | 8.15 | 9.45 |

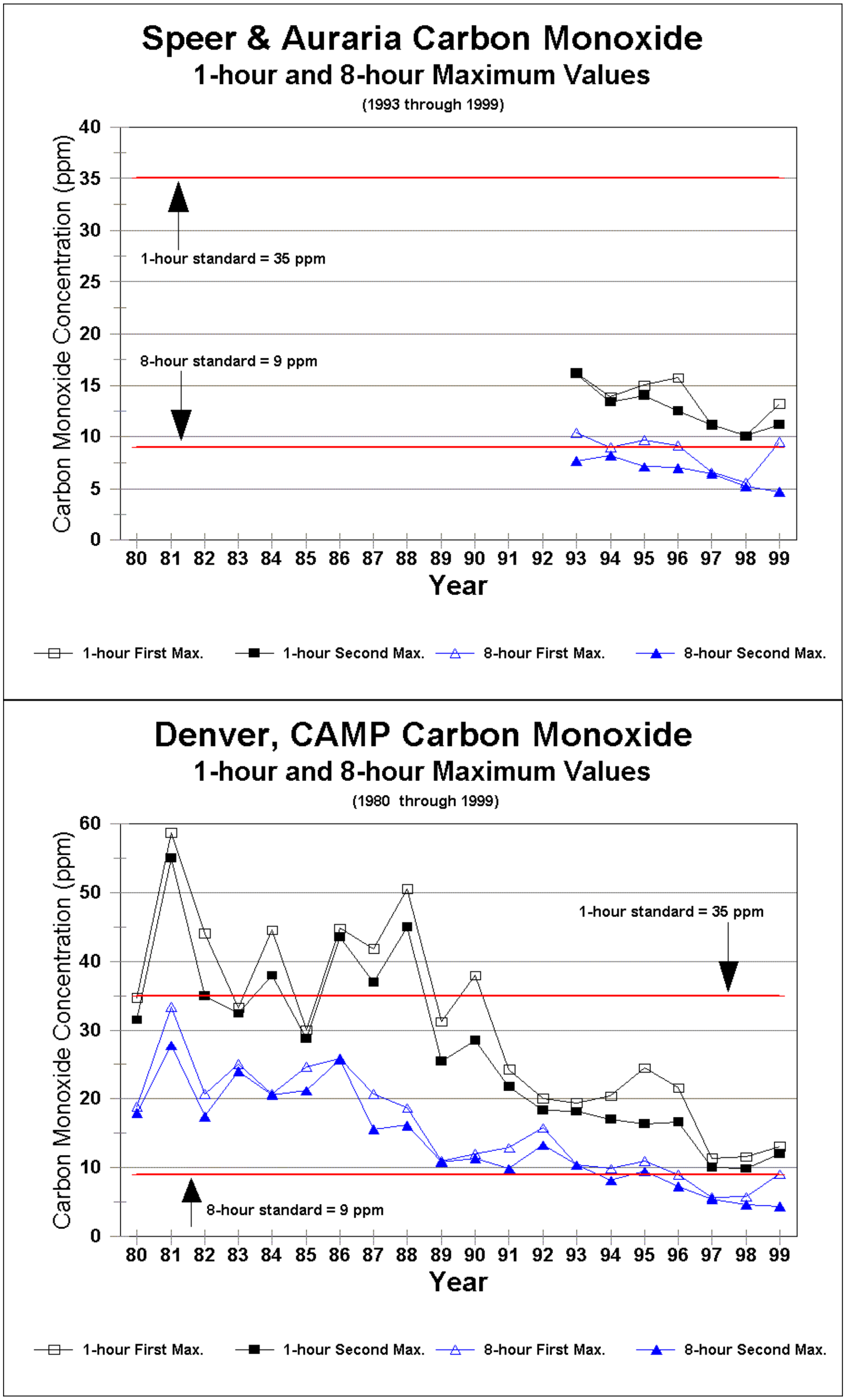



**Figure 18. Historic trends in ambient CO concentrations at CAMP and Speer and Auraria in downtown Denver.**

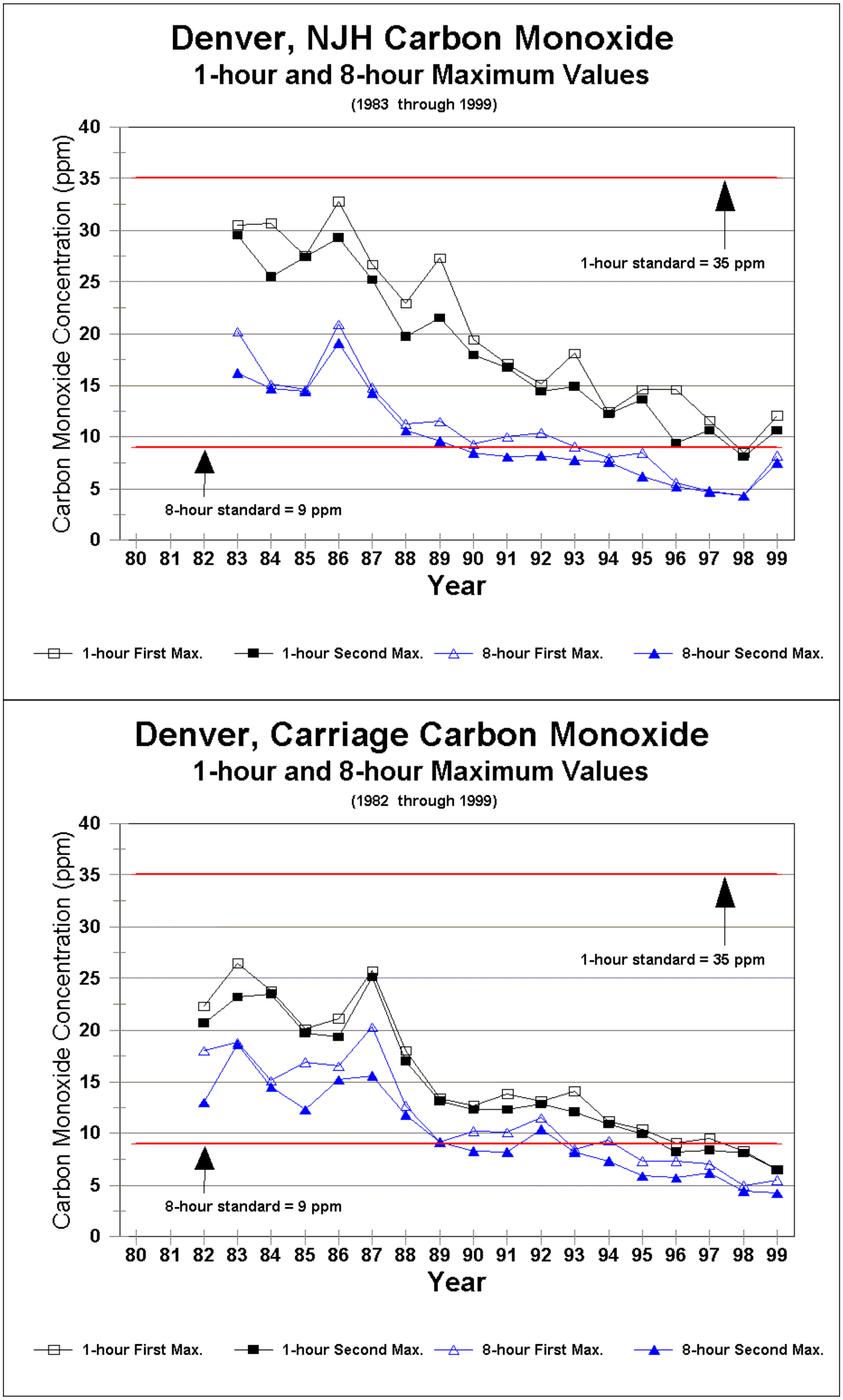



**Figure 19. Historic trends in ambient CO concentration at Carriage and NJH in Denver.**

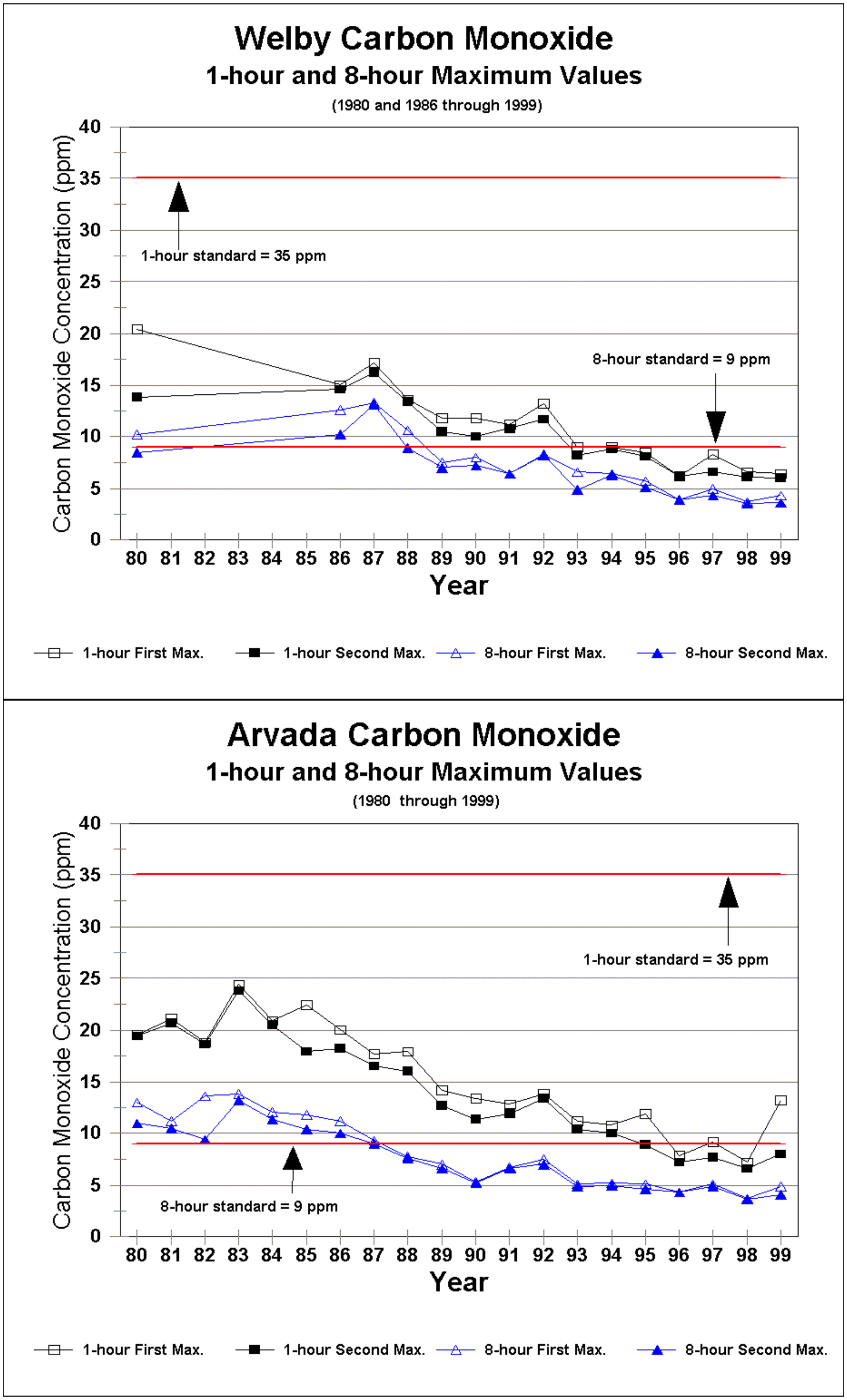
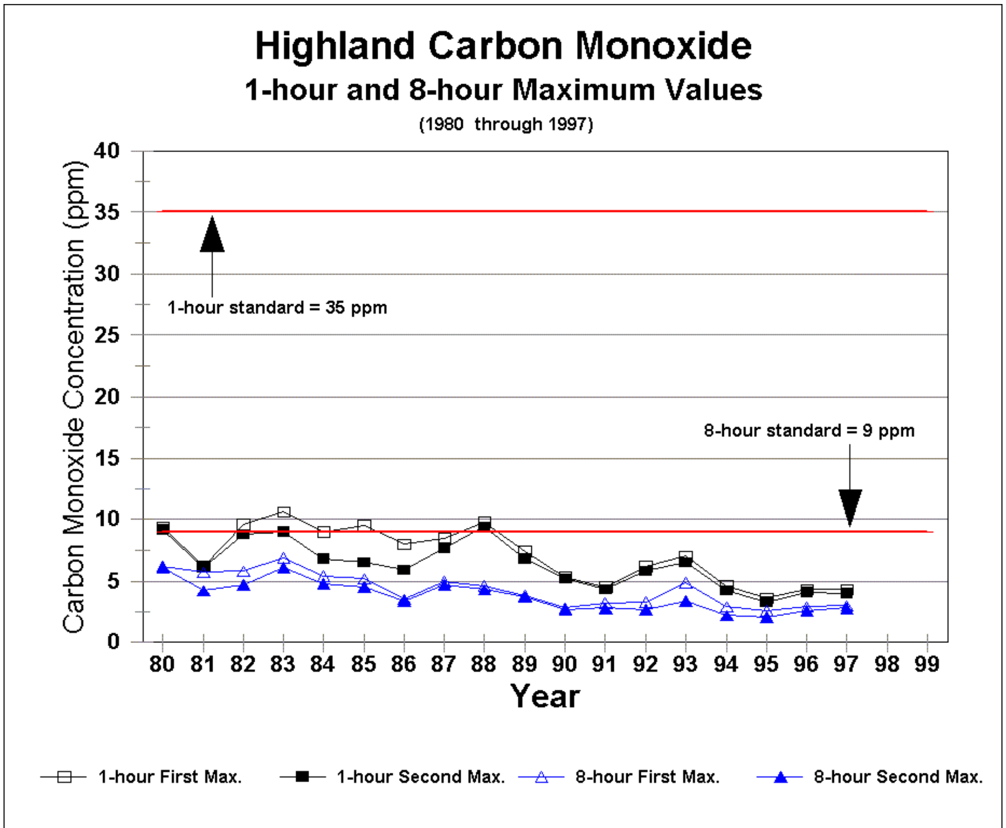



**Figure 20. Historic trends in the ambient CO concentration at Welby and Arvada.**



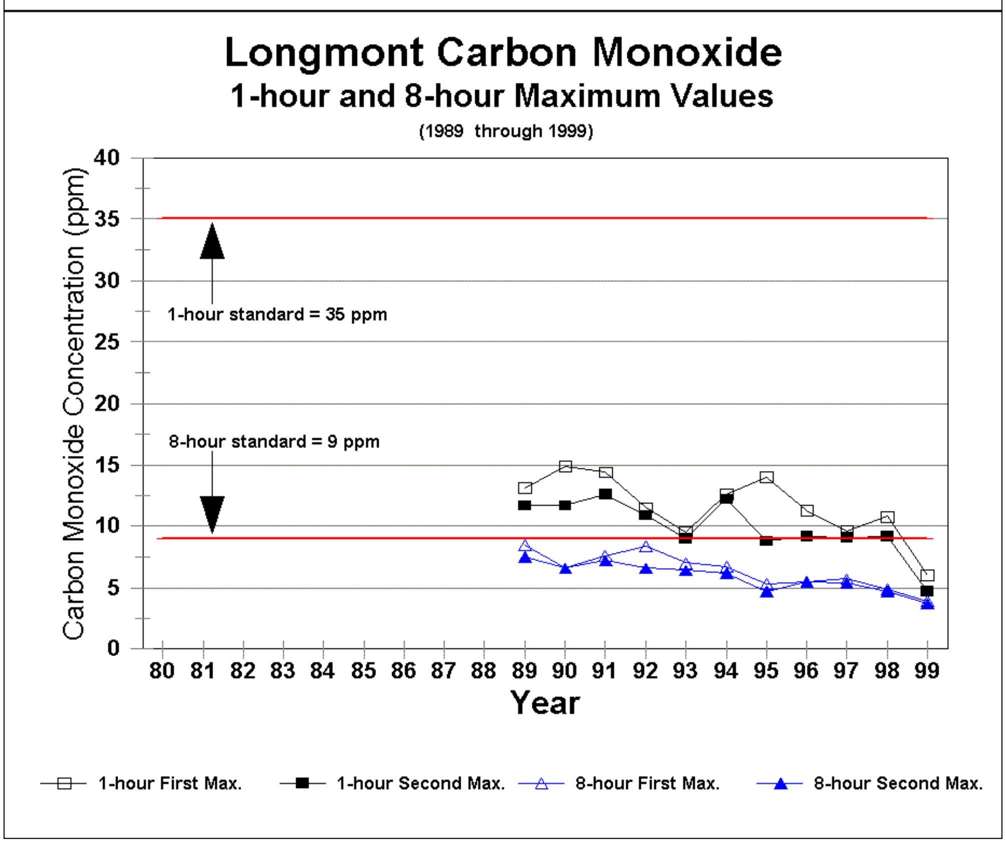
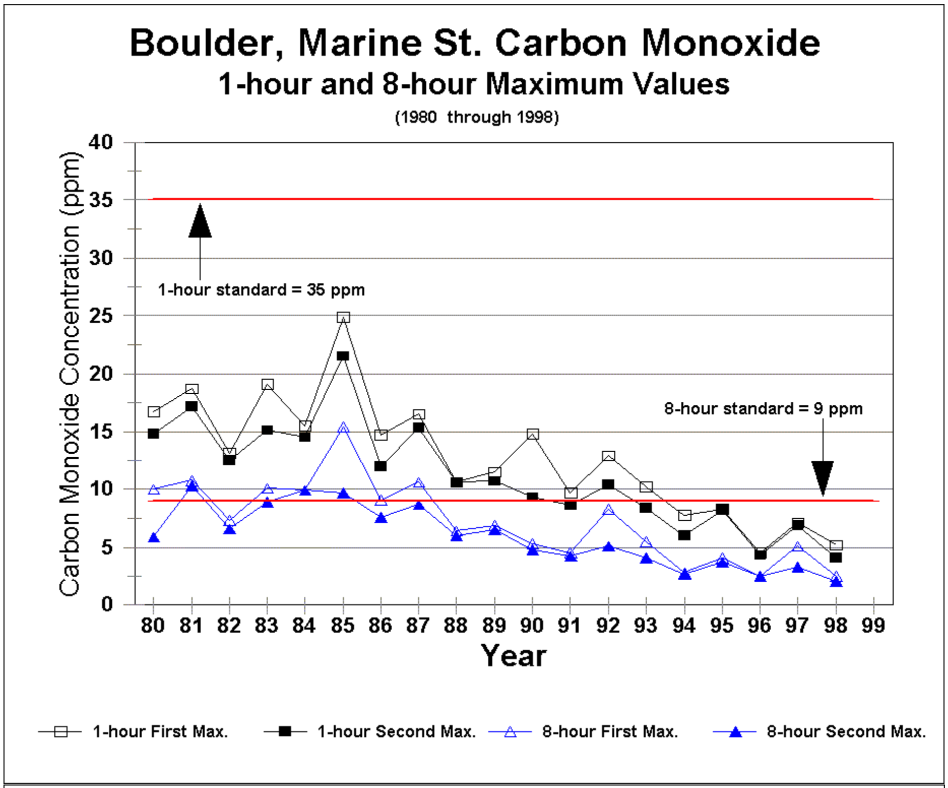




**Figure 21. Historic trends in the ambient CO concentration at Highland and Longmont.**



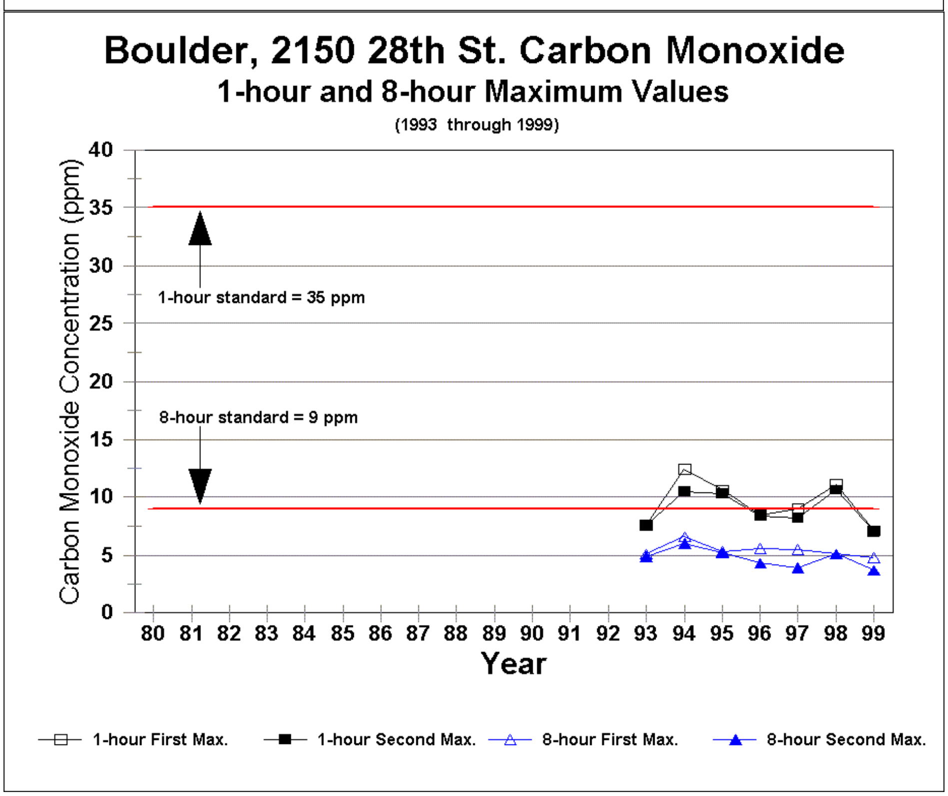




**Figure 22. Historic trends in the ambient CO concentration in Boulder at 2320 Marine Street and 2150 28$^{th}$ Street .**

## 5.4. Quality Assurance Program

The Air Pollution Control Division (APCD) is required to develop and implement a quality assurance program for continuous carbon monoxide monitoring. The program must encompass policies, procedures, specifications and standards, and must provide the documentation necessary to: (1) yield data of adequate quality to meet monitoring objectives, and (2) minimize the loss of air quality data due to sampler malfunctions or out-of-control situations.

Minimum quality assurance requirements for State and Local Air Monitoring stations (SLAMS) as well as for National Air Monitoring stations (NAMS) are specified in 40 CFR, Part 58, Appendix A. These requirements are implemented through the EPA guidance document *Quality Assurance Handbook for Air Pollution Measurement Systems, Volume II: Part 1 - Ambient Air Quality Monitoring Program Quality System Development*, and the APCD's *Standard Operating Procedures Manual*.

### 5.4.1. Internal Quality Assurance Programs

The APCD's routine quality assurance program provides operational procedures for the following topic areas:

- **Selection of methods, analyzers or samplers**: The analyzers used at the Denver metropolitan area sites have been designated as reference methods for carbon monoxide by EPA.
- **Operator training**: The APCD has an on-going operator training program under the direction of the Continuous Monitoring and Data Systems Support Unit of the APCD Technical Services Program. This training is detailed in the APCD Standard Operating Procedures Manual.
- **Selection and control of calibration standards**: Carbon monoxide calibration standards are directly traceable to gaseous standard reference materials produced by the National Institute of Standards and Technology. Determination of carbon monoxide cylinder concentrations is made by the gas vendor in accordance with the Revised EPA Protocol for Assay and Certification of Compressed Gas Calibration Standards.
- **Calibrations**: Continuous carbon monoxide samplers operated by the APCD are calibrated at least once per calendar quarter. More frequent calibrations are conducted in response to audit failures, instrument replacement or major maintenance.
- **Control checks and their frequency**: Station operators perform weekly site visits to ensure that analyzers are operating within the instrument manufacturers specifications.
- **Zero/span checks and their frequency**: Continuous carbon monoxide analyzers operated by the APCD are subjected to daily zero and span checks that are automatically initiated near midnight. During these checks, the analyzer samples scrubbed ambient air to obtain a zero concentration value and is followed by a

span, or upscale test, where the analyzer samples bottled carbon monoxide gas with a concentration of about 35 – 40 ppm.

- **Control limits for zero/span checks and corrective actions**: The APCD has established acceptance limits for zero and span response from continuous carbon monoxide analyzers. The daily zero and span values for each analyzer are plotted and are evaluated with respect to these acceptance limits. The limits are detailed in the APCD Standard Operating Procedures Manual and provide a means to quickly identify malfunctions or out-of-control situations. In the event of analyzer performance outside the acceptance limits, corrective actions will occur and may include instrument maintenance, repair or replacement, and possibly re-calibration.
- **Preventive and remedial maintenance**: The APCD Continuous Monitoring and Data Systems Support Unit follows a weekly, monthly, quarterly and semi-annual preventive maintenance program for continuous carbon monoxide analyzers. Details on these procedures are provided in the APCD Standard Operating Procedures Manual.
- **Recording and validating data**: The output of continuous analyzers operated by the APCD are recorded by a data acquisition system and transmitted either hourly or daily to the APCD central computer. An electronic strip chart recorder on each analyzer serves as a backup/secondary data logger. The raw data are routinely reviewed for anomalous results by the Continuous Monitoring and Data Systems Support Unit as detailed in the APCD Standard Operating Procedures Manual before submission to the EPA Aerometric Information Retrieval System (AIRS). In addition, data may be deleted in response to failed audits, malfunctions or out-of-control situations which are identified through routine quality control checks.
- **Data quality assessment (precision and accuracy)**: The APCD is required to perform a biweekly precision test on each continuous carbon monoxide analyzer. This test involves introducing an analyte gas of known concentration (~ 8-10 ppm CO) and determining the analyzer response. To meet EPA protocol, these tests must be performed manually on a random basis, either during site visits or initiated remotely. Additionally, they are automatically initiated once per week by the data logger to ensure meeting the EPA minimum requirement of once every two weeks. The precision test is designed to assess the ability of an analyzer to repeatedly measure a known analyte gas at a lower level than the full scale range of the analyzer and is typically near the level of the National Ambient Air Quality Standard. The results of these precision tests are submitted to AIRS within 90 days of the end of each calendar quarter. The accuracy audit involves challenging a continuous analyzer with analyte gases of known concentrations. These accuracy audits are required to be performed at least annually using personnel and equipment independent of those used for the analyzer calibration. Carbon monoxide analyzers are challenged with analyte gases in three concentration ranges; Level 1 (3-8 ppm CO), Level 2 (15-20 ppm CO) and Level3 (35-45 ppm CO). The results of these accuracy audits are also submitted to AIRS within 90 days of the end of each calendar quarter.

- **Quality control procedures documentation**: Detailed information about the quality control procedures discussed above are provided in the APCD Standard Operating Procedures Manual. The APCD also prepares an annual Quality Assurance Report which provides detailed information on the results of precision and accuracy testing, and of data validation conducted by the APCD's Continuous Monitoring and Data Systems Support Unit.

### 5.4.2. External Quality Assurance Programs

In addition to the routine quality assurance procedures discussed above, the APCD participates in two other independent quality assurance programs, the EPA inter-laboratory comparison studies and external field audits. These are described below:

- **EPA inter-laboratory comparison program**: This program is operated by EPA contractors under the aegis of the EPA National Performance Audit Program (NPAP). The inter-laboratory comparison studies involve challenging the APCD carbon monoxide analyzers with audit concentrations generated with EPA equipment and gases. These audit concentrations are unknown to APCD personnel conducting the assessment. The inter-laboratory results are conducted annually on at least 25% of APCD carbon monoxide analyzers with the results being transmitted by NPAP to APCD and to the EPA Regional Office. The results of these inter-laboratory comparisons are documented in the annual APCD Quality Assurance Report.
- **External field audits**: Audits of the APCD continuous carbon monoxide monitoring system are periodically conducted by EPA Regional Office staff or by EPA contractors under the aegis of the EPA National Performance Audit Program (NPAP). These external field audits provide an independent assessment of the quality of the APCD monitoring network. These results are documented in the annual APCD Quality Assurance Report.

### 5.4.3. Results of the Denver Metropolitan Area Precision and Accuracy Program

The precision and accuracy data submitted to AIRS are used to calculate precision probability limits as well as accuracy probability limits at the three levels. The results of these tests conducted at the Denver metropolitan area carbon monoxide sites in 1997 and 1998 are presented in the table below. The upper and lower 95 percent probability limits indicate the range of percent difference from the "actual value" that would include 95 percent of the "indicated values". About five percent of the results of precision or accuracy tests on an analyzer would exceed these limits. Ideally, the probability ranges are very small and are centered around zero, indicating that the ambient data collected by the analyzer are both precise and accurate.

A review of the precision data for the Denver metropolitan area sites for 1997 and 1998 indicate that almost all the annual probability limit data are within a range of " 10 percent of the actual value. The accuracy audit data show more variability mainly due to the small number of audits that are required to be performed each year. However, the majority of the accuracy audit probability limit data are also within a range of " 10 percent of the actual value.

**Table 31. Denver metropolitan area carbon monoxide precision and accuracy probability limits (% difference): Welby, Highland.**

| | | | Accuracy Audit Level | | |
|---|---|---|---|---|---|
| | **# of Prec. Tests** | **Precision** | **Level 1** | **Level 2** | **Level 3** |
| **Welby**<br>**78th Ave & Steele St.**<br>**08-001-3001** | | | | | |
| 1997 | 46 | -02, +03 | -02, -02 | +02, +05 | +01, +06 |
| 1997 Qtr. 1 | 13 | -02, +03 | APCD accuracy audits:<br>30 January 1997<br>10 July 1997 | | |
| 1997 Qtr. 2 | 13 | +00, +02 | | | |
| 1997 Qtr. 3 | 13 | +00, +02 | | | |
| 1997 Qtr. 4 | 7 | -06, +07 | | | |
| 1998 | 26 | -04, +05 | +01, +23 | +04, +10 | -01, +08 |
| 1998 Qtr. 1 | 7 | +00, +04 | APCD accuracy audits:<br>17 June 1998<br>14 December 1998 | | |
| 1998 Qtr. 2 | 6 | -05, +07 | | | |
| 1998 Qtr. 3 | 6 | -06, +01 | | | |
| 1998 Qtr. 4 | 7 | +00, +02 | | | |
| **Highland**<br>**8100 S. University Blvd.**<br>**08-005-0002** | | | | | |
| 1997 | 44 | -05, +04 | -02, +04 | -01, +09 | -02, +10 |
| 1997 Qtr. 1 | 11 | -03, +05 | APCD accuracy audits:<br>21 January 1997<br>03 July 1997 | | |
| 1997 Qtr. 2 | 13 | -02, +03 | | | |
| 1997 Qtr. 3 | 13 | -05, -02 | | | |
| 1997 Qtr. 4 | 7 | -02, +01 | | | |
| 1998 | n/a | n/a | n/a | n/a | n/a |
| 1998 Qtr. 1 | n/a | n/a | (Analyzer removed from service) | | |
| 1998 Qtr. 2 | n/a | n/a | | | |
| 1998 Qtr. 3 | n/a | n/a | | | |
| 1998 Qtr. 4 | n/a | n/a | | | |
| * Unable to calculate probability limits. Only one audit is available. | | | | | |

**Table 32. Denver metropolitan area carbon monoxide precision and accuracy probability limits (% difference): Longmont, Boulder2 - YMCA.**

| | | | Accuracy Audit Level | | |
|---|---|---|---|---|---|
| | **# of Prec. Tests** | **Precision** | **Level 1** | **Level 2** | **Level 3** |
| **Longmont<br>440 Main St.<br>08-013-0009** | | | | | |
| 1997 | 46 | -04, +02 | +00, * | +00, * | +04, * |
| 1997 Qtr. 1 | 13 | -02, +02 | APCD accuracy audits:<br>22 December 1997 | | |
| 1997 Qtr. 2 | 12 | -03, +02 | | | |
| 1997 Qtr. 3 | 13 | -04, +00 | | | |
| 1997 Qtr. 4 | 8 | -03, +00 | | | |
| 1998 | 26 | -05, +04 | -02, * | +02, * | +02, * |
| 1998 Qtr. 1 | 7 | -06, +03 | APCD accuracy audits:<br>17 February 1998 | | |
| 1998 Qtr. 2 | 6 | -04, +02 | | | |
| 1998 Qtr. 3 | 6 | -02, +05 | | | |
| 1998 Qtr. 4 | 7 | -04, +03 | | | |
| **Boulder2 - YMCA<br>2150 28th St.<br>08-013-0010** | | | | | |
| 1997 | 45 | -09, +06 | -03, -00 | -01, +05 | +01, +04 |
| 1997 Qtr. 1 | 13 | -08, +01 | APCD accuracy audits:<br>12 February 1997<br>16 December 1997 | | |
| 1997 Qtr. 2 | 13 | -09, +03 | | | |
| 1997 Qtr. 3 | 12 | +00, +05 | | | |
| 1997 Qtr. 4 | 7 | -09, +06 | | | |
| 1998 | 26 | -02, +04 | -02, * | +01, * | +01, * |
| 1998 Qtr. 1 | 6 | -05, +05 | APCD accuracy audits:<br>17 February 1998 | | |
| 1998 Qtr. 2 | 7 | +00, +03 | | | |
| 1998 Qtr. 3 | 6 | -03, +06 | | | |
| 1998 Qtr. 4 | 7 | -01, +02 | | | |
| * Unable to calculate probability limits. Only one audit is available. | | | | | |

**Table 33. Denver metropolitan area carbon monoxide precision and accuracy probability limits (% difference): Boulder Marine St., Denver CAMP.**

| | | | **Accuracy Audit Level** | | |
|---|---|---|---|---|---|
| | **# of Prec. Tests** | **Precision** | **Level 1** | **Level 2** | **Level 3** |
| **Boulder 2320 Marine St. 08-013-1001** | | | | | |
| 1997 | 42 | -05, +04 | +00, +00 | +03, +05 | +04, +05 |
| 1997 Qtr. 1 | 12 | -07, +06 | APCD accuracy audits: 13 February 1997 23 September 1997 | | |
| 1997 Qtr. 2 | 12 | -03, +01 | | | |
| 1997 Qtr. 3 | 12 | -03, +00 | | | |
| 1997 Qtr. 4 | 6 | -03, +05 | | | |
| 1998 | 26 | -04, +03 | +00, * | +02, * | +03, |
| 1998 Qtr. 1 | 6 | -05, +03 | APCD accuracy audits: 25 September 1998 | | |
| 1998 Qtr. 2 | 7 | -02, +03 | | | |
| 1998 Qtr. 3 | 6 | -03, +01 | | | |
| 1998 Qtr. 4 | 7 | -06, +02 | | | |
| **CAMP 2105 Broadway 08-031-0002** | | | | | |
| 1997 | 48 | -03, +02 | -07, +10 | +02, +05 | +01, +07 |
| 1997 Qtr. 1 | 13 | -02, +04 | APCD accuracy audits: 27 January 1997 13 June 1997 | | |
| 1997 Qtr. 2 | 13 | -02, +01 | | | |
| 1997 Qtr. 3 | 13 | -02, +01 | | | |
| 1997 Qtr. 4 | 9 | -03, +00 | | | |
| 1998 | 26 | -10, +04 | -22, +17 | -11, +12 | -09, +10 |
| 1998 Qtr. 1 | 7 | -02, +02 | APCD accuracy audits: 17 March 1998 04 December 1998 | | |
| 1998 Qtr. 2 | 6 | -05, +05 | | | |
| 1998 Qtr. 3 | 6 | -11, +00 | | | |
| 1998 Qtr. 4 | 7 | -11, -02 | | | |
| * Unable to calculate probability limits. Only one audit is available. | | | | | |

**Table 34. Denver metropolitan area carbon monoxide precision and accuracy probability limits (% difference): Denver NJH, Denver Carriage.**

| | | | Accuracy Audit Level | | |
|---|---|---|---|---|---|
| | # of Prec. Tests | Precision | Level 1 | Level 2 | Level 3 |
| **NJH<br>14th Ave. & Albion St.<br>08-031-0013** | | | | | |
| 1997 | 46 | -02, +04 | +00, +00 | +03, +05 | +04, +04 |
| 1997 Qtr. 1 | 13 | -01, +04 | APCD accuracy audits:<br>11 February 1997<br>21 April 1997 | | |
| 1997 Qtr. 2 | 13 | -02, +05 | | | |
| 1997 Qtr. 3 | 12 | -04, +05 | | | |
| 1997 Qtr. 4 | 8 | -03, +03 | | | |
| 1998 | 26 | -04, +04 | +05, +05 | +01, +09 | -01, +11 |
| 1998 Qtr. 1 | 6 | -02, +05 | APCD accuracy audits:<br>28 September 1998<br>10 December 1998 | | |
| 1998 Qtr. 2 | 7 | -05, +04 | | | |
| 1998 Qtr. 3 | 6 | -05, +06 | | | |
| 1998 Qtr. 4 | 7 | -03, +03 | | | |
| **Carriage<br>23rd Ave. & Julian St.<br>08-031-0014** | | | | | |
| 1997 | 45 | -02, +02 | -04, +02 | -01, +04 | -02, +06 |
| 1997 Qtr. 1 | 12 | -02, +01 | APCD accuracy audits:<br>22 January 1997<br>18 July 1997 | | |
| 1997 Qtr. 2 | 13 | -03, +04 | | | |
| 1997 Qtr. 3 | 13 | -02, +03 | | | |
| 1997 Qtr. 4 | 7 | -01, +01 | | | |
| 1998 | 25 | -03, +05 | -05, +12 | +01, +08 | +02, +06 |
| 1998 Qtr. 1 | 7 | -02, +04 | APCD accuracy audits:<br>31 March 1998<br>25 September 1998 | | |
| 1998 Qtr. 2 | 6 | -04, +08 | | | |
| 1998 Qtr. 3 | 5 | -01, +01 | | | |
| 1998 Qtr. 4 | 7 | -03, +03 | | | |
| * Unable to calculate probability limits. Only one audit is available. | | | | | |

**Table 35. Denver metropolitan area carbon monoxide precision and accuracy probability limits (% difference): Denver Speer & Auraria, Arvada.**

| | | | Accuracy Audit Level | | |
|---|---|---|---|---|---|
| | **# of Prec. Tests** | **Precision** | **Level 1** | **Level 2** | **Level 3** |
| **Auraria Fire Speer & Auraria Pkwy. 08-031-0019** | | | | | |
| 1997 | 48 | -07, +08 | -02, +10 | +01, +16 | -03, +20 |
| 1997 Qtr. 1 | 12 | -11, +10 | APCD accuracy audits: 11 February 1997 03 April 1997 | | |
| 1997 Qtr. 2 | 13 | -04, +06 | | | |
| 1997 Qtr. 3 | 13 | -04, +01 | | | |
| 1997 Qtr. 4 | 10 | +00, +09 | | | |
| 1998 | 26 | -04, +03 | +03, * | +03, * | +03, * |
| 1998 Qtr. 1 | 6 | -04, +02 | APCD accuracy audits: 19 June 1998 | | |
| 1998 Qtr. 2 | 7 | -06, +04 | | | |
| 1998 Qtr. 3 | 6 | -01, +03 | | | |
| 1998 Qtr. 4 | 7 | -03, +03 | | | |
| **Arvada 57th Ave. & Garrison St. 08-059-0002** | | | | | |
| 1997 | 48 | -07, +06 | +00, +00 | +01, +04 | -01, +06 |
| 1997 Qtr. 1 | 13 | -05, +00 | APCD accuracy audits: 03 June 1997 31 December 1997 | | |
| 1997 Qtr. 2 | 13 | -02, +00 | | | |
| 1997 Qtr. 3 | 13 | -09, +11 | | | |
| 1997 Qtr. 4 | 9 | -05, +07 | | | |
| 1998 | 26 | -04, +06 | +05, * | +05, * | +06, * |
| 1998 Qtr. 1 | 7 | -02, +05 | APCD accuracy audits: 24 September 1998 | | |
| 1998 Qtr. 2 | 6 | -05, +09 | | | |
| 1998 Qtr. 3 | 6 | +00, +02 | | | |
| 1998 Qtr. 4 | 7 | -05, +02 | | | |
| * Unable to calculate probability limits. Only one audit is available. | | | | | |

# 6. Data Access

When requested, key modeling input and output files and this report will be made available on the Internet at:

http://apcd.state.co.us

Files that are prohibitively large will not be available for download. To obtain data or information not published on the Internet, contact the Division directly.

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