Colorado

2011 Air Quality Data Report

Air Pollution Control Division

1876

Colorado Department
of Public Health
and Environment

Cover photograph – Hilltop mine between Mt. Sherman and Mt. Sheridan

COLORADO
AIR QUALITY
DATA REPORT

2011

**Colorado Department
of Public Health
and Environment**

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1. PURPOSE OF THE ANNUAL DATA REPORT

The Colorado Department of Public Health and Environment, Air Pollution Control Division (APCD) publishes the Colorado Air Quality Data Report as a companion document to the Colorado Air Quality Control Commission Report to the Public. The Air Quality Data Report addresses changes in ambient air quality measured by APCD monitors. The Report to the Public discusses the policies and programs designed to improve and protect Colorado's air quality.

1.1. Symbols and Abbreviations

The following symbols and abbreviations have been used throughout this report:

APCD	Air Pollution Control Division
CDPHE	Colorado Department of Public Health and Environment
CO	Carbon monoxide
EPA	U.S. Environmental Protection Agency
Met	Meteorological measurements which typically include wind speed, wind direction, temperature, relative humidity and standard deviation of horizontal wind direction
NAAQS	National Ambient Air Quality Standard
NO	Nitric oxide
NO_2	Nitrogen dioxide
NO_X	Oxides of nitrogen
NOy	Reactive oxides of nitrogen
O_3	Ozone
PM_{10}	Particulate matter less than 10 microns in aerometric diameter
$PM_{2.5}$	Particulate matter less than 2.5 microns in aerometric diameter
Pb	Lead
ppb	parts per billion – used with gaseous pollutants
ppm	parts per million – used with gaseous pollutants
SO_2	Sulfur dioxide
SO_X	Oxides of sulfur
TSP	Total suspended particulates
$\mu g/m^3$	micrograms per cubic meter

1.2. Description of Monitoring Areas in Colorado

The state has been divided into five multi-county areas that are generally based on topography. The areas are: The Eastern Plains, The Northern Front Range, The Southern Front Range, The Mountains, and The Western Counties. These divisions are a somewhat arbitrary grouping of monitoring sites that have similar characteristics. Table 1 and 2 list the locations of the pollutant monitors by area.

The Eastern Plains consist of those counties that are located east of the urbanized I-25 corridor to the eastern border of Colorado and extending from the northern to the southern border. These counties consist mostly of rolling agricultural plains below the elevation of 6,000 feet.

The Front Range counties are generally those along the I-25 corridor from the northern border of Colorado to the southern border. They are split into two areas, north, and south, with the Palmer Ridge as the dividing area. While the northern counties all have a direct association with I-25, that association is not as well defined in the southern counties. Teller, Fremont, Custer, Alamosa, and Costilla counties are included with the Southern Front Range counties because they have more in common meteorologically with that group than they do with the other Mountain counties.

The Mountain counties are generally those higher altitude counties located along the Continental Divide. The Western counties are those adjacent to the Utah border.

Other analyses have made different divisions to fit other needs, but these five divisions are appropriate for this report. Figure 1 shows the approximate boundaries of these areas. Counties with monitors are colored yellow, and the pin symbols on the map mark the approximate locations of the monitors in that county.

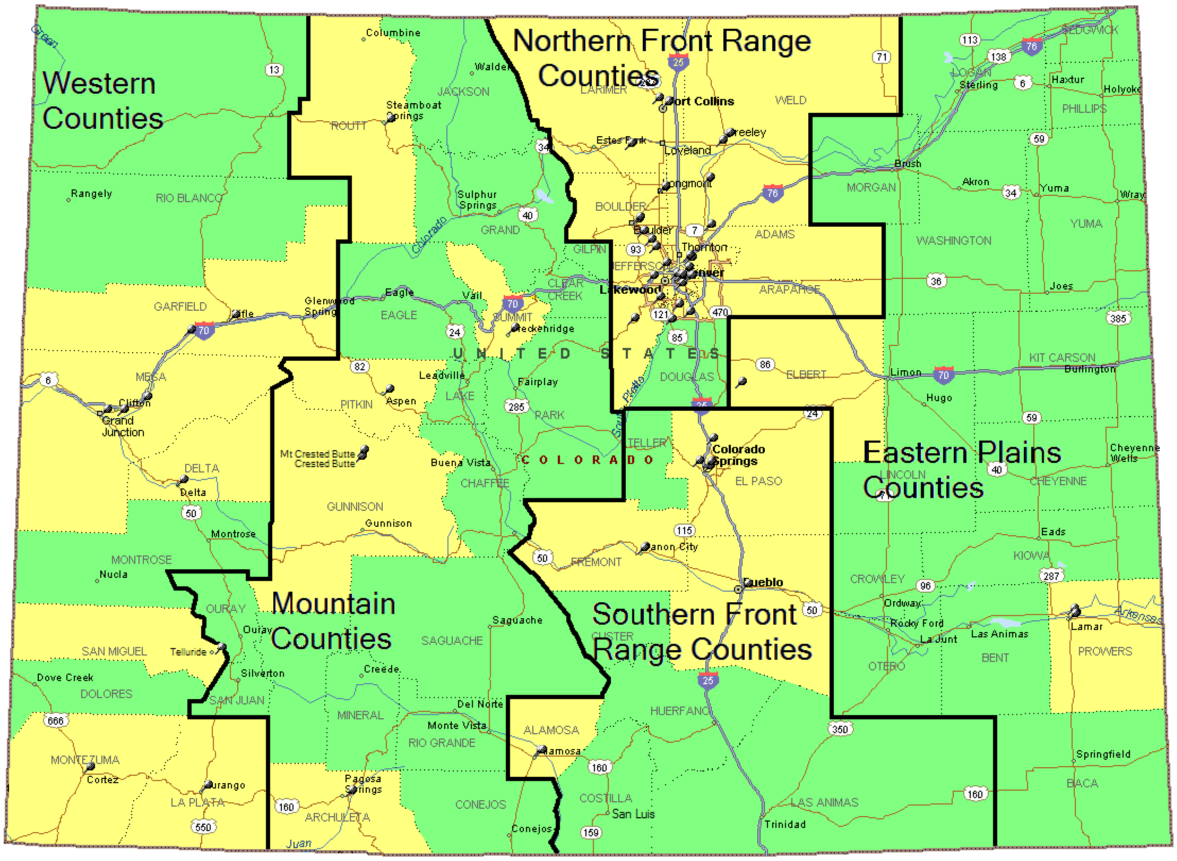

Figure 1. Monitoring Areas in Colorado[1]

1.2.1 Eastern Plains Counties

The Eastern Plains Counties are those located east of the urbanized I-25 corridor. Historically, there have been a number of communities that were monitored for particulates and meteorology but not for any of the gaseous pollutants. In the northeast along the I-76 corridor, the communities of Sterling, Brush, and Fort Morgan have been monitored for total suspended particulates (TSP). Along the I-70 corridor only the community of Limon has been monitored for TSP. Along the US-50/Arkansas River corridor the Division has monitored for TSP in the communities of La Junta, Rocky Ford, and Trinidad. These monitors were all discontinued in the late 1970's and early 1980's after a review showed that the concentrations were well below the standard and trending downward. Currently, there are two PM_{10} monitoring sites and a meteorology station in Lamar, but no gaseous pollutant monitors in the area. The Elbert County monitor was located on the Palmer Divide and operated as a background $PM_{2.5}$ monitor until April of 2011. For over ten years, this monitor provided background $PM_{2.5}$ readings as it was located away from urban sources of manmade particulates. The background $PM_{2.5}$ monitor will be moved to Castlewood Canyon State Park in 2012.

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[1] Counties shown in yellow contain at least one monitor, and the pin symbols on the map show the approximate location of the monitors within the county. Counties in green do not contain a monitoring site.

1.2.2 Northern Front Range Counties

The Northern Front Range Counties are those along the urbanized I-25 corridor from the Colorado/Wyoming border to just south of the city of Castle Rock. Most of the larger cities in the state are in these counties. The majority of monitors are located in the Denver metropolitan area and the rest are located in or near Boulder, Fort Collins, Greeley, Longmont, and Platteville. Currently, there are 26 gaseous pollutant monitors, 24 particulate monitors (including 2 TSP/lead monitors), and 15 meteorological monitors in the Northern Front Range area. There are seven CO, 16 O_3, two NO_2, and three SO_2 monitors. At the beginning of 2011, additional CO, NOy and SO_2 trace gas monitors were installed at the Denver Municipal Animal Shelter site. There are nine PM_{10}, 13 $PM_{2.5}$, and two TSP/lead monitoring sites.

1.2.3 Southern Front Range Counties

The Southern Front Range Counties are those along the urbanized I-25 corridor from south of the city of Castle Rock to the southern Colorado border. The cities with monitoring in the area are Colorado Springs, Pueblo, Cañon City, and Alamosa. These last two cities are not strictly in the Front Range I-25 corridor but meteorologically fit better with those cities than they do the Mountain Counties. Colorado Springs is the only city in the area that is monitored for CO and O_3 by the APCD. The other cities are only monitored for particulates. In the past the APCD has conducted TSP monitoring in both Walsenburg and Trinidad but that monitoring was discontinued in 1979 and 1985 respectively, due to low concentrations. Currently, there are three gaseous pollutant monitors and seven particulate monitors in the Southern Front Range area. There are one CO and two O_3 monitors in the Colorado Springs area. There are five PM_{10} and two $PM_{2.5}$ monitoring sites in the region.

1.2.4 Mountain Counties

The Mountain Counties are generally those located on or near the Continental Divide. They consist of mostly small towns located in tight mountain valleys. Their primary monitoring concern is with particulate pollution from wood burning and road sanding. These communities range from Steamboat Springs in the north to Breckenridge near the I-70 corridor, as well as Aspen, Crested Butte and Mt. Crested Butte in the central mountains and Pagosa Springs in the south. Currently, there are no gaseous and six particulate monitoring sites (PM_{10}) operated by the APCD in the Mountain Counties region.

1.2.5 Western Counties

The Western Counties are generally smaller towns, usually located in fairly broad river valleys. Grand Junction is the only large city in the area, and the only location that monitors for CO and air toxics on the western slope. In 2008, Rifle, Palisade, and Cortez began monitoring for ozone. The other Western County locations monitor only for particulates. They are located in Cortez, Delta, Durango, Parachute, and Telluride. Currently, there are four gaseous pollutant monitors and 11 particulate monitors in the Western Counties area. There are one CO, three O_3, eight PM_{10}, and three $PM_{2.5}$ monitoring sites.

Table 1. Statewide Gaseous and Meteorological Monitors in Operation for 2011

County	***Site Name***	***Location***	***CO***	***SO_2***	***NO_X***	***O_3***	***Met***
Eastern Plains Counties							
Prowers	Lamar - POE	7100 Hwy 50					**X**
Northern Front Range Counties							
Adams	Commerce City	7101 Birch St.					**X**
	Welby	3174 E. 78th Ave.	**X**	**X**	**X**	**X**	**X**
Arapahoe	Aurora East	36001 E. Quincy Ave.				**X**	**X**
	Highland Res.	8100 S. University Blvd.				**X**	**X**
Boulder	South Boulder Creek	1405½ S. Foothills Pkwy.				**X**	
	Longmont	440 Main St.	**X**				
Denver	Denver CAMP	2105 Broadway	**X**	**X**	**X**		**X**
	Denver Carriage	2325 Irving St.				**X**	**X**
	DESCI Building	1901 E. 13th Ave. (Visibility)					
	Firehouse #6	1300 Blake St.	**X**				
	Denver Animal Shelter	678 S. Jason St	**A**	**A**	**A***	**X**	**X**
Douglas	Chatfield State Park	11500 N. Roxborough Pk. Rd.				**X**	**X**
Jefferson	Arvada	9101 W. 57th Ave.				**X**	**X**
	Aspen Park	26137 Conifer Rd.				**X**	**X**
	NREL	2054 Quaker St.				**X**	
	Rocky Flats - N	16600 W. Hwy. 128				**X**	**X**
	Rocky Flats - SE	9901 Indiana St.					**X**
	Welch	12400 W. Hwy. 285				**X**	**X**
Larimer	Fort Collins - Mason	708 S. Mason St.	**X**			**X**	**X**
	Rist Canyon	11835 Rist Canyon Rd.				**X**	**X**
	Fort Collins - Viz	300 Remington St. (Visibility)					
	Fort Collins - West	3416 Laporte Ave.				**X**	
Weld	Greeley – West Annex	905 10th Ave.	**X**				
	Greeley – County Tower	3101 35th Ave.				**X**	
Southern Front Range Counties							
El Paso	U.S. Air Force Academy	USAFA Rd. 640				**X**	
	CO Springs Hwy. 24	690 W. Hwy. 24	**X**				
	Manitou Springs	101 Banks Pl.				**X**	
Western Counties							
Garfield	Rifle – Health Dept	195 W. 14th Ave.				**X**	
Moffat	Lay Peak	17820 CR 17				**A**	**A**
Mesa	Grand Junction – Pitkin	645¼ Pitkin Ave.	**X**				**X**
	Palisade Water Treatment	865 Rapid Creek Rd.				**X**	**X**
Montezuma	Cortez – Health Dept	106 W. North Ave.				**X**	

(X) – Continued, (A) – Added, (D) – Discontinued, *NOy

Table 2. Statewide Particulate Monitors in Operation for 2011

County	***Site Name***	***Location***	***TSP***	***Pb***	PM_{10}	$PM_{2.5}$
Eastern Plains Counties						
Elbert	Elbert	24950 Ben Kelly Rd				**X6**
Prowers	Lamar - Power Plant	100 N. 2nd St.			**X1**	
	Lamar - Municipal	104 E. Parmenter St.			**X1**	
Northern Front Range Counties						
Adams	Commerce City	7101 Birch St.			**X1**	**X3/H/S6**
	Welby	3174 E. 78th Ave.			**X6/H**	
Arapahoe	Arapahoe Comm. College	6190 S. Santa Fe Dr.				**X3**
	Centennial Airport	7800 S. Peoria St.	**X6**	**X6**		
Boulder	Longmont – Municipal Bldg.	350 Kimbark St.			**X6**	**X3/H**
	Boulder - Chamber	2440 Pearl St.			**X6**	**X3**
	Boulder – CU – Athens	2102 Athens St.				**H**
Denver	Denver CAMP	2105 Broadway			**X6/H**	**X1/H**
	Denver NJH	14th Ave. & Albion St.				**H**
	Denver Visitor Center	225 W. Colfax Ave.			**X1**	
	Denver Animal Shelter	678 S. Jason St.	**X6**	**X6**	**X3/H**	**X3/H/S3**
	Swansea Elementary Sch.	4650 Columbine St.				**X1**
Douglas	Chatfield Reservoir	11500 N. Roxborough Park Rd.				**X3/H**
Larimer	Fort Collins – CSU - Edison	251 Edison Dr.			**X3/H**	**X3/H**
Weld	Greeley – Hospital	1516 Hospital Rd.			**X3**	**X3/H**
	Platteville Middle School	1004 Main St.				**X3/S6**
Southern Front Range Counties						
Alamosa	Alamosa - ASU	208 Edgemont Blvd.			**X1**	
	Alamosa- Municipal Bldg.	425 4th St.			**X1**	
El Paso	Colorado College	130 W. Cache La Poudre			**X6**	**X3/H**
Fremont	Cañon City – City Hall	128 Main St.			**X6**	
Pueblo	Pueblo – Fountain School	925 N. Glendale Ave.			**X3**	**X3**
Mountain Counties						
Archuleta	Pagosa Springs School	309 Lewis St.			**X1**	
Gunnison	Crested Butte	603 6th St.			**X3**	
	Mt. Crested Butte	19 Emmons Rd.			**X1**	
Montezuma	Cortez – Health Department	106 W. North St				**X6**
Pitkin	Aspen – Library	120 Mill St.			**X3**	
Routt	Steamboat Springs	136 6th St.			**X1**	
Summit	Breckenridge	501 N. Park Ave.			**X1**	
Western Counties						
Delta	Delta – Health Dept	560 Dodge St.			**X3**	
Garfield	Parachute – 2nd St.	100 E. 2nd St.			**X3**	
	Rifle - Henry Building	144 E. 3rd St.			**X3/H**	**H**
La Plata	Durango - River City Hall	1235 Camino del Rio			**X3**	
Mesa	Grand Junction - Powell	650 South Ave.			**X3**	**X3/H**
	Clifton	Hwy. 141 & D Rd.			**X3**	
Montezuma	Cortez – Health Dept.	106 W. North St.				**X6**
San Miguel	Telluride	333 W. Colorado Ave.			**X3**	

(Xn) – Filter Sample Continued; n=frequency in days, (A) – Added, (D) – Discontinued, (H) – Hourly particulate monitor, (S) – Chemical Speciation

2. CRITERIA POLLUTANTS

Criteria pollutants are those for which the federal government has established ambient air quality standards in the Federal Clean Air Act and its amendments. There are six criteria pollutants. They are carbon monoxide (CO), ozone (O_3), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), lead (Pb), and particulate matter which is currently split into two size fractions. The standards for criteria pollutants are established to protect the most sensitive members of society. These are usually defined as those with heart and / or respiratory problems, the very young, and the elderly. The standards for each of the criteria pollutants are discussed in the following sections. A summary of these levels is presented in Table 3 (United States Environmental Protection Agency 2010). Nitrogen dioxide and sulfur dioxide have new one-hour standards beginning in 2010. The 1.5 μg/m^3 quarterly average standard for lead was changed in 2010, and replaced with a new standard of 0.15 μg/m^3 over a three month rolling average. The primary standards are set to protect human health. The secondary standards are set to protect public welfare, and take into consideration such factors as crop damage, architectural damage, damage to ecosystems, and visibility in scenic areas.

Table 3. National Ambient Air Quality Standards

Pollutant		Primary / Secondary	Averaging Time	Level	Form
CO		Primary	8-hour	9 ppm	Not to be exceeded more than once per year
			1-hour	35 ppm	
Pb		Primary and secondary	Rolling 3-Month Average	0.15 μg/m^3 (2)	Not to be exceeded
NO_2		Primary	1-hour	100 ppb	98th percentile, averaged over 3 years
		Primary and secondary	Annual	53 ppb (3)	Annual mean
O_3		Primary and secondary	8-hour	0.075 ppm (4)	Annual fourth-highest daily maximum 8-hour concentration, averaged over 3 years
Particle	$PM_{2.5}$	Primary and secondary	Annual	15 μg/m^3	Annual mean, averaged over 3 years
			24-hour	35 μg/m^3	98th percentile, averaged over 3 years
	PM_{10}	Primary and secondary	24-hour	150 μg/m^3	Not to be exceeded more than once per year on average over 3 years
SO_2		Primary	1-hour	75 ppb (5)	99th percentile of 1-hour daily maximum concentrations, averaged over 3 years
		Secondary	3-hour	0.5 ppm	Not to be exceeded more than once per year

2.1. Exceedance Summary Table

Table 4 is a summary of the sites with exceedances of the ambient air quality standards for Colorado, with the number of days in exceedance listed. Exceedances in this table are for single-year equivalents, though violation is determined over multi-year periods. The right-most column of the table illustrates sites in violation. These exceedances contain exceptional event data, see Section 2.2.5.1. Standards are discussed in Section 2.2 below.

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2 Final rule signed October 15, 2008.

3 The official level of the annual NO2 standard is 0.053 ppm, which is shown here for the purpose of clearer comparison to the 1-hour standard.

4 Final rule signed March 12, 2008. The 1997 ozone standard (0.089 ppm, annual fourth-highest daily maximum 8-hour concentration, averaged over 3 years) and related implementation rules remain in place.

5 Final rule signed June 2, 2010. The 1971 annual and 24-hour SO2 standards were revoked in that same rule making. However, these standards remain in effect until one year after an area is designated for the 2012 standard, except in areas designated nonattainment for the 1971 standards, where the 1971 standards remain in effect until implementation plans to attain or maintain the 2010 standards are approved.

Table 4. Exceedance Summary Table[6]

AQS ID	**Location**	**2010**			**2011**			**Violation**
		O_3	**PM_{10}**	**$PM_{2.5}$**	**O_3**	**PM_{10}**	**$PM_{2.5}$**	**O_3**
08 001 0006	Commerce City						1	
08 001 3001	Welby				3			
08 003 0001	Alamosa – Adams State Coll.		*4*			*2*		
08 003 0003	Alamosa – Municipal Building		*3*			*2*		
08 005 0002	Highlands Reservoir	3			5			
08 005 0006	Aurora – East				4			
08 007 0001	Pagosa Springs School		*5*					
08 013 0011	South Boulder Creek	1			4			
08 013 0012	Boulder Chamber of Commerce			*1*				
08 031 0014	Carriage				2			
08 035 0004	Chatfield State Park	8 (*1*)			9			X
08 041 0013	U.S. Air Force Academy	*1*			3			
08 041 0016	Manitou Springs	*2*			2			
08 051 0004	Crested Butte		*1*					
08 051 0007	Mt. Crested Butte – Realty		*1*					
08 059 0002	Arvada	2			6			
08 059 0005	Welch	1			6			
08 059 0006	Rocky Flats – N	4			8			X
08 059 0011	NREL	3			10			
08 059 0013	Aspen Park	2 (*1*)			1			
08 067 0004	Durango – River City Hall		*2*					
08 067 7001	*Weminuche Wilderness Area*	2			1			
08 067 7003	*7571 Hwy. 5505, La Plata County*				1			
08 069 0007	*Rocky Mountain NP*	6			8			
08 069 0011	Fort Collins – West	1			8			X
08 069 0012	Rist Canyon				1			
08 077 0017	Grand Junction – Powell Bldg		*1*	3				
08 077 0018	Grand Junction – Pitkin		1					
08 077 0019	Clifton – Sanitation		*1*					
08 083 0006	Cortez – Health Dept	1						
08 083 0101	*Mesa Verde NP*	1			1			
08 099 0001	Lamar Power Plant					*2*		
08 103 0006	Rangely Golf Course				3			
08 113 0004	Telluride		*1*					
08 123 0009	Greeley – County Tower	2 (*1*)			6			

2.2. General Statistics for Criteria Pollutants

The EPA produces a National Emissions Inventory every three years. The latest complete inventory is for 2008. The CDPHE anticipates that the next scheduled inventory, for 2011, will be completed sometime this year, but is not yet available. Because of this, the emissions trends graphs and tables reflect only data through 2008. Additionally, the EPA's monitor ranking report has not been published since 2008. Monitors across the nation have been ranked

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[6] *Underlined numbers to the right or in parentheses* are exceedance events (or subsets) that the Division is documenting as exceptional events. None of the exceptional events have obtained EPA concurrence as of April 2012. Station names in italics are stations reported to the EPA Air Quality System in Colorado that are not considered part of the State of Colorado network.

in the following sections by the CDPHE, based on maximum relevant concentrations found in the respective references. Should a conflict occur between this report and a future publication of the EPA's monitor ranking, it should be considered that the EPA is correct.

Finally, in this section NAAQS are used in the analyses. This comparison is for reference only because the NAAQS apply to one station and not an average of all concentrations across the state. Section 4 below discusses concentrations in a manner directly relatable to the NAAQS.

2.2.1 Carbon Monoxide

CO is a colorless and odorless gas, formed when carbon compounds in fuel are not burned completely. It is a component of motor vehicle exhaust, which contributes about 50 percent of all CO emissions nationwide. Non-road vehicles account for the remaining CO emissions from transportation sources. High concentrations of CO generally occur in areas with heavy traffic congestion. In cities, as much as 85 percent of all CO emissions may come from automobile exhaust. Peak CO concentrations typically occur during the colder months of the year when CO automotive emissions are greater, and nighttime temperature inversions (conditions where air pollutants are trapped near the ground beneath a layer of warm air) are more frequent (United States Environmental Protection Agency 2009).

2.2.1.1 Carbon Monoxide - Standards

The EPA has developed two national standards for CO. They are 35 ppm averaged over a 1-hour period and 9 ppm averaged over an 8-hour period. These values are not to be exceeded more than once in a year at the same location. A site will violate the standard with a second exceedance of either the 1-hour or 8-hour standard in the same calendar year. The EPA directive states that comparison with the CO standards will be made in integers. Fractions of 0.5 or greater are rounded up, thus, actual concentrations of 9.5 ppm and 35.5 ppm or greater are necessary to exceed the 8-hour and 1-hour standards, respectively (United States Environmental Protection Agency 2009).

2.2.1.2 Carbon Monoxide - Health Effects

CO affects the central nervous system by depriving the body of oxygen. It enters the body through the lungs, where it combines with hemoglobin in the red blood cells, forming carboxyhemoglobin. Normally, hemoglobin carries oxygen from the lungs to the cells. The oxygen attached to the hemoglobin is exchanged for the carbon dioxide generated by the cell's metabolism. The carbon dioxide is then carried back to the lungs where it is exhaled from the body. Hemoglobin binds approximately 240 times more readily with CO than with oxygen. How quickly the carboxyhemoglobin builds up is a factor of the concentration of the gas being inhaled (measured in ppm) and the duration of the exposure. Compounding the effects of the exposure is the long half-life of approximately 5 hours of carboxyhemoglobin in the blood. Half-life is a measure of how quickly levels return to normal. This means that for a given exposure level, it will take about 5 hours for the level of carboxyhemoglobin in the blood to drop to half its current level after the exposure is terminated.

The health effects of CO vary with concentration. At low concentrations, effects include fatigue in healthy people and chest pain in people with heart disease. At moderate concentrations, angina, impaired vision, and reduced brain function may result. At higher concentrations, effects include impaired vision and coordination, headaches, dizziness, confusion, and nausea. It can cause flu-like symptoms that clear up after leaving the polluted area. CO is fatal at very high concentrations. The EPA has concluded that the following groups may be particularly sensitive to CO exposures: angina patients, individuals with other types of cardiovascular disease, persons with chronic obstructive pulmonary disease, anemic individuals, fetuses, and pregnant women. Concern also exists for healthy children because of increased oxygen requirements that result from their higher metabolic rate (Occupational Health and Safety Administration 2007).

2.2.1.3 Carbon Monoxide – Emissions and Sources

The 2008 National Emissions Inventory estimates that 50 percent of CO emissions are from highway vehicle sources. They also estimate that off-highway sources contribute an additional 23 percent of emissions. Table 5 gives a breakdown of CO emissions by source for 2008 (United States Environmental Protection Agency 2009). Figure 2 illustrates the downward trend of national CO emissions from 1970 through 2008.

Table 5. Carbon Monoxide National Emissions for 2008

Description	National	
	Thousand-Tons/Year	Percent
Fuel Combustion – Electrical Utilities	699	0.9
Fuel Combustion - Industrial	1,216	1.6
Fuel Combustion - Other	3,369	4.3
Chemical Processing/Mfg	265	0.3
Metal Processing	947	1.2
Petroleum Processing	355	1.5
Other Industrial Processes	500	0.6
Solvent Utilization	2	0.0
Storage & Transportation	115	0.2
Waste Disposal & Recycling	1,584	2.0
Highway Vehicles	38,866	50.0
Off- Highway	18,036	23.2
Miscellaneous	11,731	15.1
Total	***77,685***	***100.0***

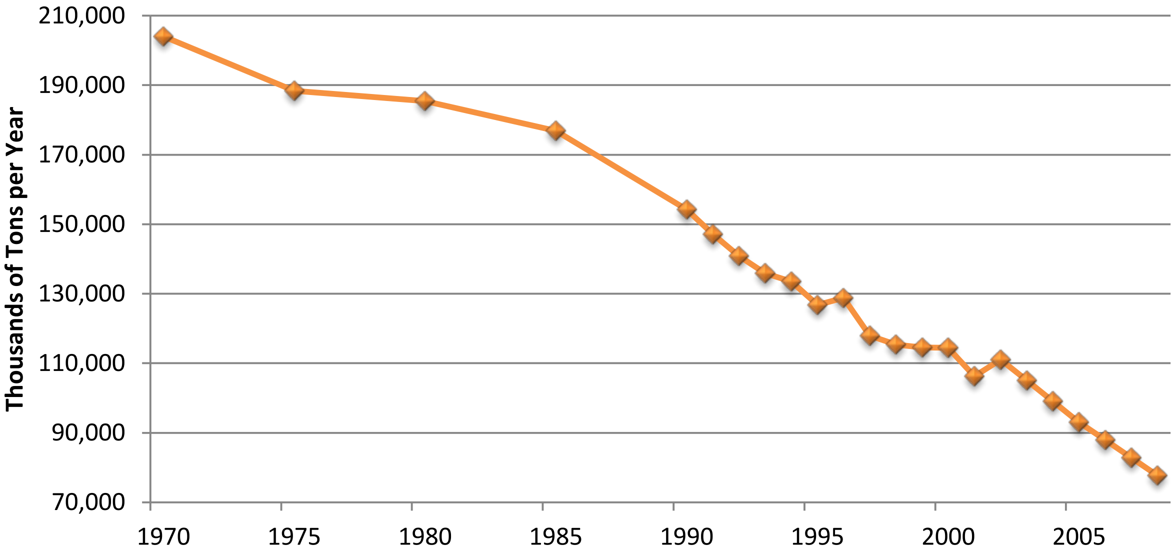

Figure 2. Changes in National Carbon Monoxide Emissions from 1970 to 2008

2.2.1.4 Carbon Monoxide – Statewide Summaries

CO concentrations have dropped dramatically from the early 1970s. This change can be seen in both the concentrations measured and the number of monitors that exceeded the level of the 8-hour standard. In 1975, 9 of the 11 (81%) state-operated monitors exceeded the 8-hour standard. In 1980, 13 of the 17 (77%) state-operated monitors exceeded the 8-hour standard. Since 1996 none of the state-operated monitors have recorded a violation of the 8-hour standard. In 2011 the highest statewide 2nd maximum 8-hour concentration was 2.1 ppm recorded at the Longmont monitor.

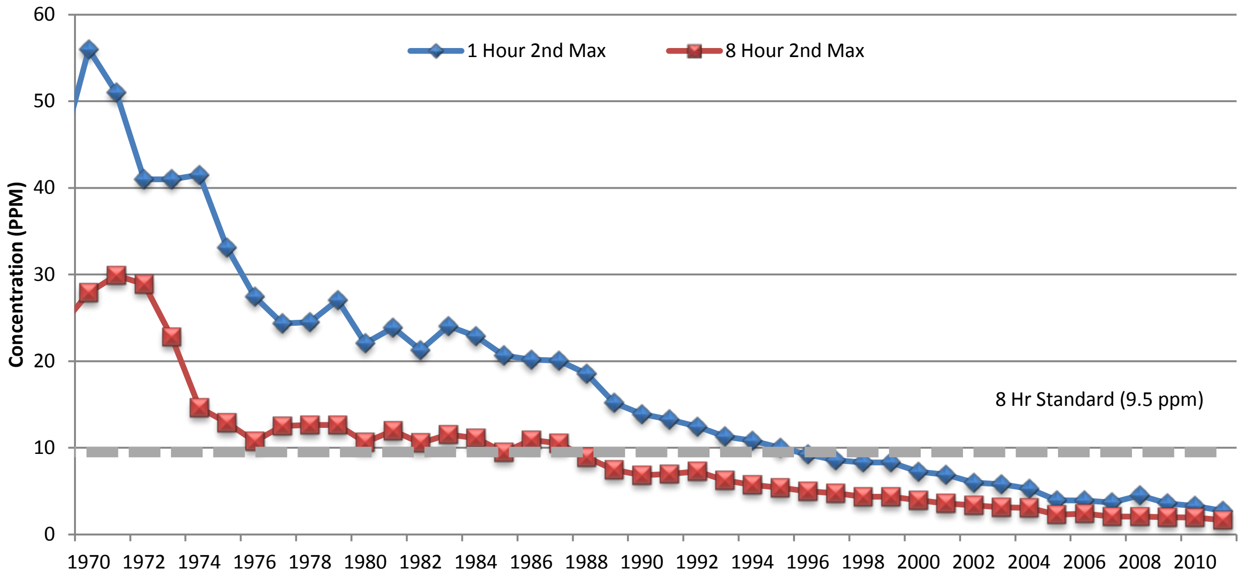

Figure 3. Statewide Ambient Trends for Carbon Monoxide

Figure 3 shows the trend of the statewide average for the second maximum 1-hour and 8-hour concentrations for CO between 1970 and 2011 by averaging sites state-wide. There are two important notes. First, before 1989 the average 2nd maximum 8-hour concentration for all state-operated CO monitors was greater than the 8-hour standard of 9.5 ppm. Second, for the last several years the downward trend in concentrations has continued, but at a slower rate. The statewide average 8-hour concentration is now less than half of the standard.

The trend in the second maximum1-hour average CO concentrations statewide has fallen more dramatically than the 8-hour concentrations. The maximum 1-hour concentration ever recorded at any of the state-operated monitors was a 79.0 ppm recorded at the Denver CAMP monitor in 1968. In 2011, the maximum 1-hour concentration recorded was 4.3 ppm recorded at the Longmont monitor. The 1-hour annual maximum concentrations have declined from more than twice the standard in the late 1960s to about one quarter of the standard. Table 6 presents the historical maximum values (United States Environmental Protection Agency 2010).

Table 6. Historical Maximum 1-Hour and 8-Hour Carbon Monoxide Concentrations

1-Hour (ppm)	Location	Date	Number of Annual Exceedances	8-Hour (ppm)	Location	Date	Number of Annual Exceedances
79.0	CAMP	11-20-68	13	48.1	CAMP	12-21-73	133
70.0	CAMP	11-21-74	15	33.9	CAMP	12-28-65	197
67.0	CAMP	12-21-73	21	33.4	CAMP	12-04-81	42
65.0	CAMP	12-21-73	21	33.2	CAMP	12-23-71	188
64.9	NJH-W	11-16-79	15	33.1	CAMP	11-20-68	98
2011 Maximum Carbon Monoxide Concentration							
4.3	Longmont	07-30-11	0	2.1	Longmont	07-31-11	0

2.2.1.5 Carbon Monoxide – National Comparisons

According to the EPA's emissions trends report, between 1980 and 2008, national average ambient CO concentrations decreased 79 percent (United States Environmental Protection Agency 2009). As recently as 1998, the National Ranking of CO monitors showed that the top sixteen monitors recorded at least one exceedance of the 8-hour CO standard with nine monitors reporting two or more exceedances (United States Environmental Protection Agency 2008). In 2011, one monitor reported an exceedance of the level of the 1-hour standard. This data is illustrated in Table 7 below (United States Environmental Protection Agency 2010).

Table 7. 2011 National Ranking of Carbon Monoxide Monitors by 8-hour Concentrations in ppm

Nationwide (351 monitors)					Colorado (9 Monitors)				
National Rank	**City/Area**	**Max**	**2^{nd} Max**	**# ≥9.5**	**National Rank**	**City/Area**	**Max**	**2^{nd} Max**	**# ≥9.5**
1	El Centro, CA	9	7.5	1	45	Longmont	2.6	2.1	0
2	Evansville, IN	6.4	5.8	0	105	Greeley Annex	2	1.5	0
3	Calexico, CA	6.1	5.5	0	106	Welby	2	1.6	0
4	Birmingham, AL	5.7	5.5	0	110	CAMP	1.9	1.8	0
5	Compton, CA	4.7	3.8	0	124	Firehouse	1.8	1.7	0

2.2.2 Ozone

Ozone (O_3) is a gas composed of three oxygen atoms. It is not usually emitted directly into the air, but at ground-level is created by a chemical reaction between oxides of nitrogen (NO_X) and volatile organic compounds (VOC) in the presence of sunlight. Ozone has the same chemical structure whether it occurs miles above the earth or at ground-level and can be beneficial or detrimental, depending on its location in the atmosphere.

In the earth's lower atmosphere, ground-level ozone is of concern to human health. Motor vehicle exhaust and industrial emissions, gasoline vapors, and chemical solvents as well as natural sources emit NO_X and VOCs that help form ozone. Ground-level ozone is the primary constituent of smog. Sunlight and hot weather cause ground-level ozone to form in harmful concentrations in the air. As a result, it is known as a summertime air pollutant. Many urban areas tend to have high levels of ozone, but even rural areas are also subject to increased ozone levels because wind carries ozone and pollutants that form it hundreds of miles away from their original sources.

Ozone may be a wintertime pollutant in some areas. Emerging science is indicating that mountain valleys may be subject to higher ozone concentrations under the appropriate conditions. Low mixing boundaries (inversions) combined with high albedo snow cover can create and maintain high ozone concentrations within the valley. This is thought to occur because the stable atmospheric conditions allow for a build-up of precursor chemicals and the reflectivity of the snow cover increases the ultraviolet reactions during the day creating high ozone concentrations. The ozone, and its precursors, is then held in place by the inversion. The Upper Green River Basin in Wyoming has been studied to model such effects (Wyoming Department of Environmental Quality 2010).

In the stratosphere the beneficial ozone layer extends upward from about 6 to 30 miles and protects life on Earth from the sun's harmful ultraviolet (UV) rays. This natural shield had been gradually depleted by man-made chemicals like chlorofluorocarbons (CFCs), though evidence suggests that the total ozone column has not decreased since 1998 (Elizabeth C. Weatherhead 2006). A depleted ozone shield allows more UV from the sun to reach the ground, leading to more cases of skin cancer, cataracts, and other health problems." (United States Environmental Protection Agency 2009)

2.2.2.1 Ozone - Standards

In May 2008, the EPA established a new ozone standard. The reasons for these changes were: "*Based on its review of the air quality criteria for ozone (O_3) and related photochemical oxidants and national ambient air quality standards (NAAQS) for O_3, EPA is making revisions to the primary and secondary NAAQS for O_3 to provide requisite protection of public health and welfare, respectively. With regard to the primary standard for O_3, EPA is revising the level of the 8-hour standard to 0.075 parts per million (ppm), expressed to three decimal places. With regard to the secondary standard for O_3, EPA is revising the current 8-hour standard by making it identical to the revised primary standard.*" (Federal Register 2008) The O_3 standard will be revised with the on-going 5-year review, with scheduled implementation in 2013, and is expected to fall between 0.060 and 0.070 ppm as an eight-hour average. For more details, see http://www.epa.gov/ozonepollution/actions.html.

2.2.2.2 Ozone - Health Effects

Exposure to ozone has been linked to a number of health effects, including significant decreases in lung function, inflammation of the airways, and increased respiratory symptoms, such as cough and pain when taking a deep breath. Exposure can also aggravate lung diseases such as asthma, leading to increased medication use and increased hospital admissions and emergency room visits. Active children are the group at highest risk from ozone exposure because they often spend a large part of the summer playing outdoors. Children are also more likely to have asthma, which may be aggravated by ozone exposure. Other at-risk groups include adults who are active outdoors (e.g., some outdoor workers) and individuals with lung diseases such as asthma and chronic obstructive pulmonary disease. In addition, long-term exposure to moderate levels of ozone may cause permanent changes in lung structure, leading to premature aging of the lungs and worsening of chronic lung disease.

Ozone also affects vegetation and ecosystems, leading to reductions in agricultural crop and commercial forest yields, reduced growth and survivability of tree seedlings, and increased plant susceptibility to disease, pests, and other environmental stresses (e.g., harsh weather). In long-lived species, these effects may become evident only after several years or even decades and may result in long-term effects on forest ecosystems. Ground level ozone injury to trees and plants can lead to a decrease in the natural beauty of our national parks and recreation areas (United States Environmental Protection Agency 2009).

2.2.2.3 Ozone – Emissions and Sources

Ozone is not emitted directly from a source, as are other pollutants, but forms as a secondary pollutant. Its precursors are certain reactive hydrocarbons and oxides of nitrogen, which react chemically in sunlight to form ozone. The main sources for these reactive hydrocarbons are automobile exhaust, gasoline, oil storage and transfer facilities, industrial paint solvents, degreasing agents, cleaning fluids, and ink solvents. Vegetation can also emit reactive hydrocarbons such as terpenes from pine trees (United States Environmental Protection Agency 2009). High temperature combustion combines nitrogen and oxygen in the air to form oxides of nitrogen.

Although some ozone is produced all year, the highest concentrations usually occur in the summer. The stagnant air and intense sunlight on hot, bright summer days provide the conditions for the precursor chemicals to react and form ozone. The ozone produced under these stagnant summer conditions remains as a coherent air mass and can be transported many miles from its point of origin. The way to reduce ozone in the atmosphere is to reduce the compounds that react to form it. Table 8 and Figure 4 are included in the ozone section because of the importance of volatile organic compounds (VOC's) in the formation of ozone. Emissions of VOCs are shown in Table 8 (United States Environmental Protection Agency 2009) and Figure 4.

Table 8. VOC National Emissions for 2008

Description	**National**	
	Thousand-Tons/Year	**Percent**
Fuel Combustion – Electrical Utilities	50	0.3
Fuel Combustion - Industrial	130	0.8
Fuel Combustion - Other	1,269	8.0
Chemical Processing/Mfg	228	1.4
Metal Processing	46	0.3
Petroleum Processing	561	3.5
Other Industrial Processes	404	2.5
Solvent Utilization	4,226	26.5
Storage & Transportation	1,303	8.2
Waste Disposal & Recycling	374	2.3
Highway Vehicles	3,418	21.5
Off- Highway	2,586	16.2
Miscellaneous	1,332	8.4
Total	***15,927***	***100.0***

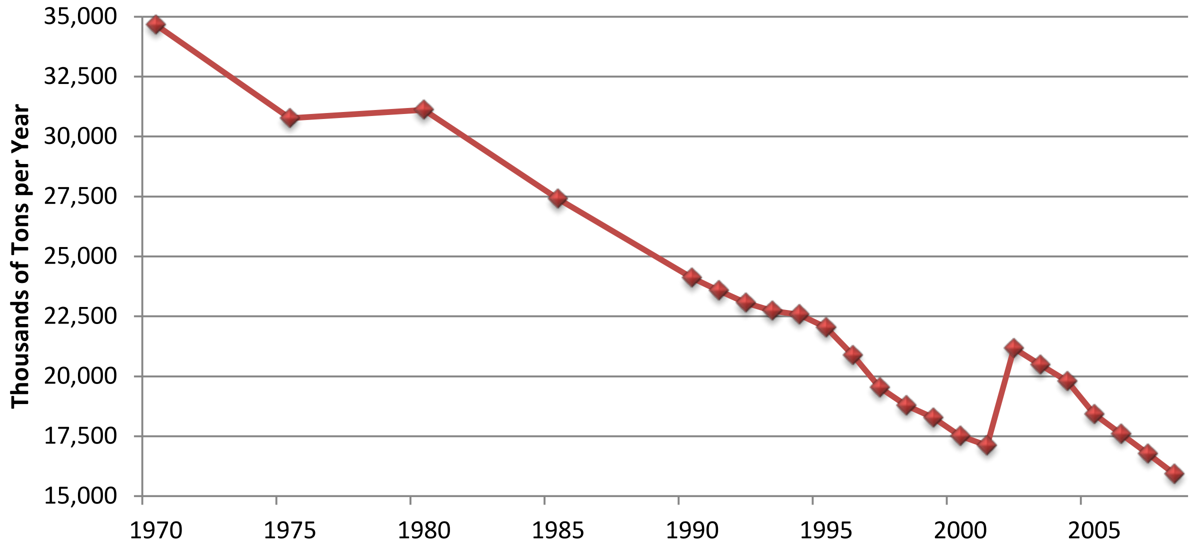

Figure 4. Changes in National VOC Emissions from 1970 to 2008

2.2.2.4 Ozone – Statewide Summaries

As illustrated in Figure 5, an average of sites state-wide, O_3 averages have fluctuated around the standard. In recent years, the trend has been downward, but the averages seem to fluctuate within the amount of variance seen for the last several years.

Ozone monitoring began in 1972 at the Denver CAMP station, and eight exceedances of the then-applicable 1-hour standard were recorded that year. Table 9 lists the 5 highest 8-hour ozone concentrations recorded in Colorado (United States Environmental Protection Agency 2010). Note that four of the top five were within the first two years of ozone monitoring.

Table 9. 2011 Historical Maximum 8-Hour Ozone Concentrations

8-Hour ppm	Monitor	Date
0.310	Denver CAMP	1972
0.264	Denver CAMP	1973
0.198	Arvada	1973
0.194	Denver Carriage (recorded at nearby CARIH)	1973
0.146	Denver CAMP	1980
2011 Maximum Ozone Concentration		
0.083	NREL	2011

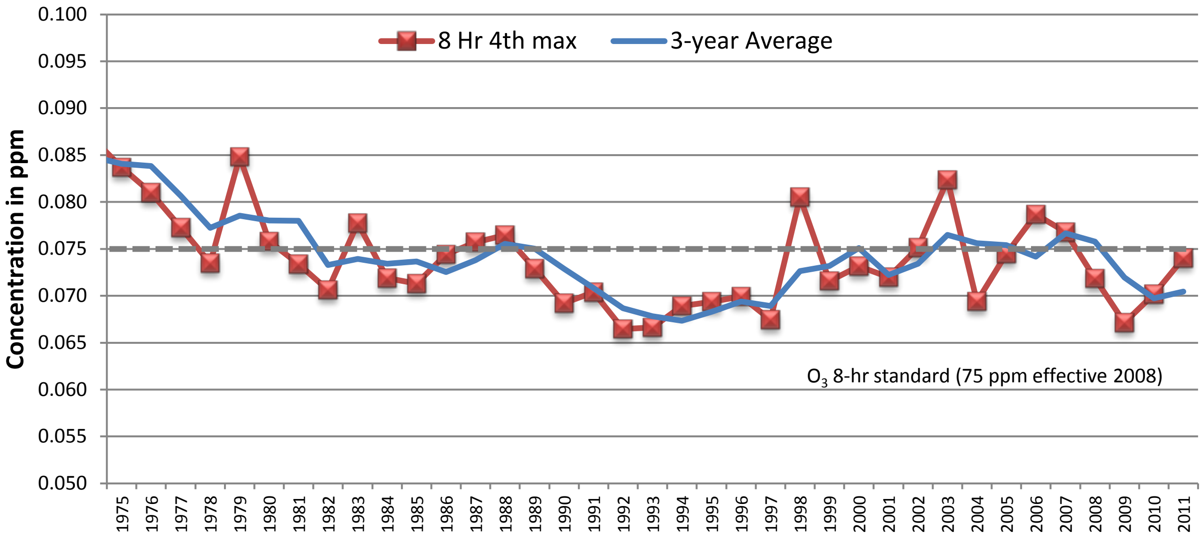

Figure 5. Statewide Ambient Trends for Ozone

2.2.2.5 Ozone – National Comparisons

Between 1990 and 2007, NO_X and VOC emissions have declined 33 percent and 35 percent respectively. These are two of the primary factors in ozone production. This decline has been accomplished in spite of increases in energy consumption (up 20 percent), population (up 21 percent), vehicle miles traveled (up 45 percent) and gross national product (up 63 percent) (United States Environmental Protection Agency 2008). Table 10 lists the five highest ranked ozone monitors nationwide and in Colorado, by the number of days over the standard (United States Environmental Protection Agency 2010).

Table 10. 2010 National Ranking of Ozone Monitors by 8-hour Concentration in ppm

Nationwide (2,668 Monitors)					**Colorado (30 Monitors)**[7]				
National Rank	**City/Area**	**Max**	**2nd Max**	**Days >0.075**	**National Rank**	**City/Area**	**Max**	**2nd Max**	**Days >0.075**
1	Sequoia NP, CA	0.103	0.101	87	114	NREL	0.096	0.086	10
2	Crestline, CA	0.136	0.110	84	136	Chatfield Res	0.099	0.084	9
3	Redlands, CA	0.133	0.120	80	154	Rocky Flats North	0.104	0.083	8
4	Rubidoux, CA	0.115	0.111	67	179	Ft Collins West	0.086	0.081	8
5	Hesperia, CA	0.113	0.102	67	240	Arvada	0.100	0.083	6

2.2.3 Sulfur Dioxide

Sulfur dioxide (SO_2) belongs to the family of sulfur oxide gases. These gases dissolve easily in water. Sulfur is prevalent in all raw materials, including crude oil, coal, and ore that contains common metals like aluminum, copper, zinc, lead, and iron. Sulfur dioxide gases are formed when fuel containing sulfur, such as coal and oil, is burned, when gasoline is extracted from oil, or metals are extracted from ore. Sulfur dioxide dissolves in water

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[7] Some recorded maximum 8-hour concentrations in 2011 in Colorado were due to a stratospheric inversion, in which air from the stratosphere comes down to the troposphere and is detected by ground-level monitors. This kind of event is similar to the exceptional event concept for particulates and is being documented as such with the EPA.

vapor to form acid, and interacts with other gases and particles in the air to form sulfates and other products that can be harmful to people and their environment (United States Environmental Protection Agency 2007).

2.2.3.1 Sulfur Dioxide - Standards

There are three primary standards for sulfur dioxide. The first is a long-term, one year arithmetic average not to exceed 30 ppb. The second is a short-term, 24-hour average where concentrations are not to exceed 140 ppb more than once per year. Beginning on June 22, 2010, a third standard for sulfur dioxide was introduced as a 3-year average of the 99th percentile of the daily maximum 1-hour average not to exceed 75 ppb. The first two standards are revoked as of the final rule on the 75 ppb standard. The secondary standard is a 3-hour average not to exceed 500 ppb more than once per year (National Primary and Secondary Ambient Air Quality Standards for Sulfer Dioxide 2010). Note that Table 3 only lists current EPA standards.

2.2.3.2 Sulfur Dioxide - Health Effects

High concentrations of sulfur dioxide can result in temporary breathing impairment for asthmatic children and adults who are active outdoors. Short-term exposures of asthmatic individuals to elevated sulfur dioxide levels during moderate activity may result in breathing difficulties that can be accompanied by symptoms such as wheezing, chest tightness, or shortness of breath. Other effects that have been associated with longer-term exposures to high concentrations of sulfur dioxide, in conjunction with high levels of particulate matter, include aggravation of existing cardiovascular disease, respiratory illness, and alterations in the lungs' defenses. The subgroups of the population that may be affected under these conditions include individuals with heart or lung disease, as well as the elderly and children (United States Environmental Protection Agency 2006). Sulfur dioxide also is a major precursor to $PM_{2.5}$, which is a significant health concern, and a main contributor to poor visibility (AirNow 2003).

2.2.3.3 Sulfur Dioxide – Emissions and Sources

Nationwide, over 66 percent of sulfur dioxide released to the air, or more than 7 million tons per year, comes from electric utilities, especially those that burn coal. Other sources of sulfur dioxide are industrial facilities that derive their products from raw materials like metallic ore, coal, and crude oil, or that burn coal or oil to produce process heat. Examples are petroleum refineries, cement manufacturing, and metal processing facilities. Also, locomotives, large ships, and some non-road diesel equipment currently burn high sulfur fuel and release sulfur dioxide emissions to the air in large quantities (United States Environmental Protection Agency 2007). Table 11 (United States Environmental Protection Agency 2009) and Figure 6 illustrate the national emissions quantities and trends for sulfur dioxide.

Table 11. Sulfur Dioxide National Emissions For 2008

Description	National	
	Thousand-Tons/Year	**Percent**
Fuel Combustion – Electrical Utilities	7,552	66.1
Fuel Combustion - Industrial	1,670	14.6
Fuel Combustion - Other	578	5.1
Chemical Processing/Mfg	255	2.2
Metal Processing	203	1.8
Petroleum Processing	206	1.8
Other Industrial Processes	329	2.9
Solvent Utilization	0	0.0
Storage & Transportation	4	0.0
Waste Disposal & Recycling	27	0.2
Highway Vehicles	64	0.6
Off- Highway	456	4.0
Miscellaneous	85	0.7
Total	***11,472***	***100.0***

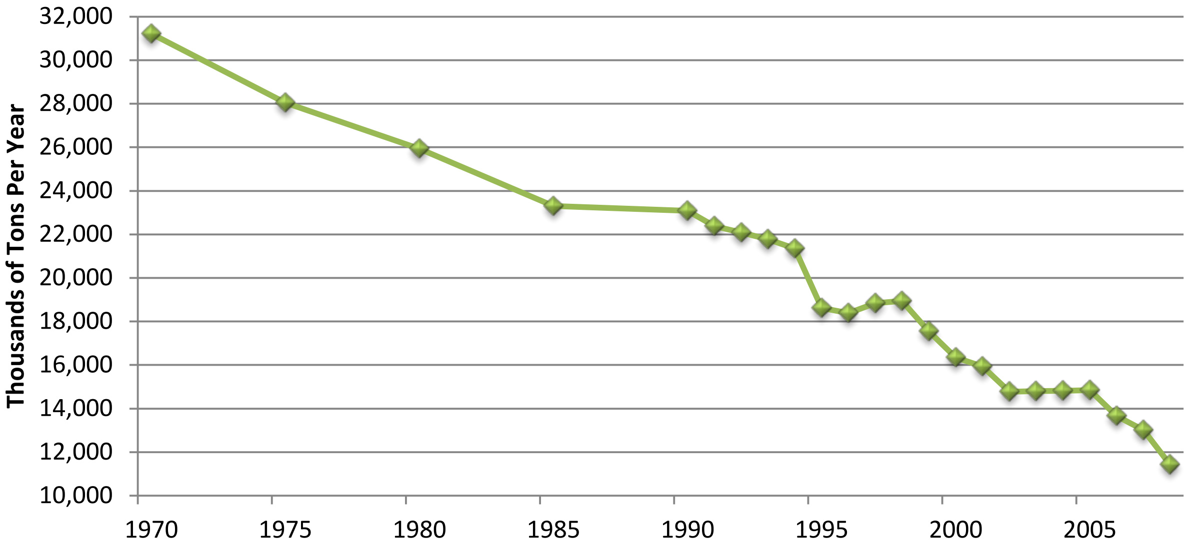

Figure 6. Changes in National Sulfur Dioxide Emissions from 1970 to 2008

2.2.3.4 Sulfur Dioxide – Statewide Summaries

The concentrations of sulfur dioxide in Colorado have never been a major health concern since we have few industries that burn large amounts of coal and coal in this area is naturally low in sulfur. The concern in Colorado with sulfur dioxide has been associated with acid deposition and its effects on the mountain lakes and streams, as well as the formation of fine aerosols. Historically the maximum annual concentration recorded by APCD monitors was 18 ppb in 1979 at the Denver CAMP monitor compared to a current annual standard of 30 ppb. Since 1990, the annual average at the Denver CAMP monitor has declined from a high in 1992 of 10 ppb to 2 in 2011.

Table 12 (United States Environmental Protection Agency 2010) and Figure 7 show both the declining trend in sulfur dioxide readings, as well as the generally low concentrations of sulfur dioxide recorded at the APCD's monitors. This same trend is evident, although not as pronounced, in the 3-hour and 24-hour averages as well.

Table 12. Historical Maximum Annual Average Sulfur Dioxide Concentrations

Annual Average (ppb)	Monitor	Date
18	CAMP	1979
13	CAMP	1981
13	CAMP	1983
13	CAMP	1980
11	CAMP	1984
2011 Maximum Sulfur Dioxide Concentration		
2	CAMP, DMAS	2011

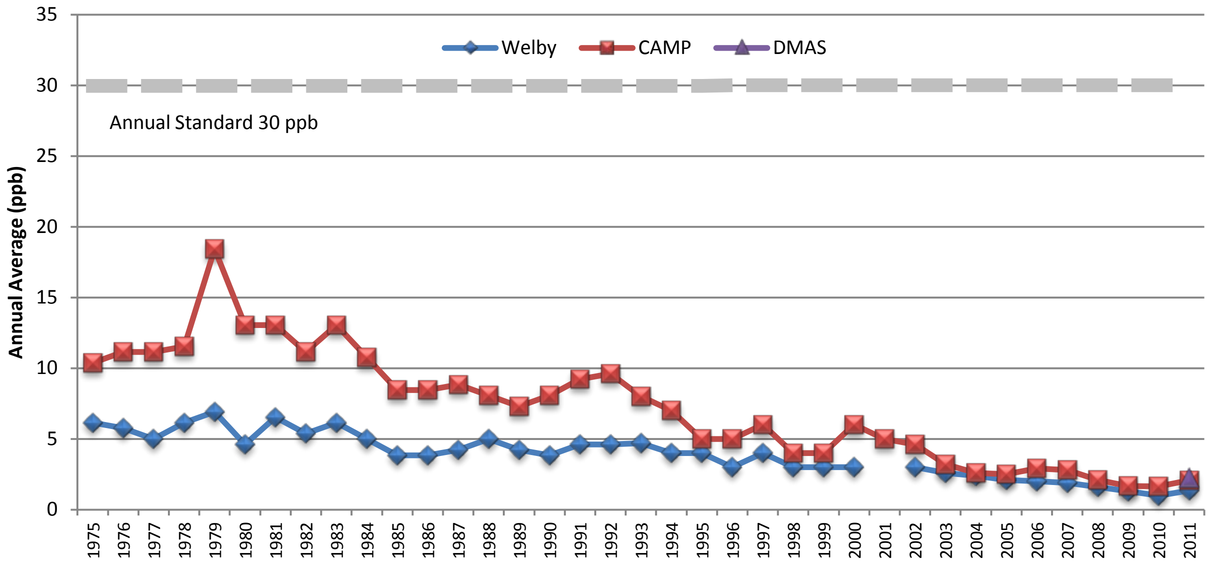

Figure 7. Statewide Ambient Trends for Sulfur Dioxide

2.2.3.5 Sulfur Dioxide – National Comparisons

“Nationally, average sulfur dioxide ambient concentrations have decreased 71 percent from 1980 to 2008 and 37 percent over the more recent 10-year period of 1999 to 2008. Reductions in sulfur dioxide concentrations and emissions since 1990 are due, in large part, to controls implemented under EPA’s Acid Rain Program beginning in 1995.” (United States Environmental Protection Agency 2006) Table 13 lists the national ranking of sulfur dioxide monitors by 24-hour concentration nationwide, and for the State of Colorado. (United States Environmental Protection Agency 2010)

Table 13. 2010 National Ranking of Sulfur Dioxide Monitors by 24-hour Concentration in ppb

Nationwide (472 Monitors)					Colorado (3 Monitors)				
National Rank	City/Area	Max	2nd Max	#>140	National Rank	City/Area	Max	2nd Max	#>140
1	Volcanoes National Park, HI[8]	271	187	4	206	CAMP	10	7	0
2	Liberty, PA	134	94	0	269	DMAS	6.9	5.5	0
3	Rhinelander, WI	134	94	0	329	Welby	5	5	0
4	Suncook, NH	100	87	0					
5	Muscatine, IA	100	88	0					

2.2.4 Nitrogen Dioxide

In its pure state, NO_2 is a reddish brown gas with a characteristic pungent odor. It is corrosive and a strong oxidizing agent. As a pollutant in ambient air, however, it is virtually colorless and odorless. NO_2 can be an irritant to the eyes and throat. Oxides of nitrogen (nitric oxide and NO_2) are formed when the nitrogen and oxygen in the air are combined in high temperature combustion.

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[8] For this ranking, the state of Hawaii was grouped as one site. Individually considering each site, Hawaii claims four of the top five ranks.

2.2.4.1 Nitrogen Dioxide – Standards

The standard for NO_2 was first established by the EPA in 1971. Both the primary standard, to protect public health, and the secondary standard, to protect public welfare, were set as an annual average of 53 ppb. On June 26, 2009, EPA proposed to strengthen the primary National Ambient Air Quality Standards for nitrogen dioxide. The proposed changes would protect public health, especially the health of sensitive populations, people with asthma, children, and the elderly.

On January 22, 2010, EPA established a new 1-hour nitrogen dioxide standard at 100 ppb, over a 3-year average of the 98th percentile of the annual distribution of daily 1-hour maximum nitrogen dioxide concentrations. This new standard does not alter the existing standard of 53 ppb annual average (United States Environmental Protection Agency 2010).

2.2.4.2 Nitrogen Dioxide – Health Effects

Elevated concentrations of nitrogen dioxide cause respiratory distress, degradation of vegetation, clothing, and visibility, and increased acid deposition. Nitrate aerosols, which result from nitric oxide and nitrogen dioxide combining with water vapor in the air, have been consistently linked to Denver's visibility problems. Nitrogen dioxide also causes concern with the formation of fine aerosols.

2.2.4.3 Nitrogen Dioxide – Emissions and Sources

Nationally, about 58 percent of the oxides of nitrogen emissions come from on and off-road vehicles and about 36 percent come from industrial sources (United States Environmental Protection Agency 2009). In Denver, about 26 percent of the emissions of nitrogen dioxide come from large combustion sources such as power plants, 14 percent comes from oil and gas point and area sources, 36 percent comes from motor vehicles, 7 percent from aircraft and railroad, and 18 percent from miscellaneous off-road vehicles. Minor sources include fireplaces and woodstoves and high temperature combustion processes used in industrial work (Air Pollution Control Division 2010). Table 14 (United States Environmental Protection Agency 2009) and Figure 8 illustrate the oxides of nitrogen emissions values and trends.

Table 14. Oxides of Nitrogen National Emissions for 2008

Description	**National**	
	Thousand-Tons/Year	**Percent**
Fuel Combustion – Electrical Utilities	3,006	18.4
Fuel Combustion - Industrial	1,838	11.2
Fuel Combustion - Other	727	4.4
Chemical Processing/Mfg	67	0.4
Metal Processing	68	0.4
Petroleum Processing	350	2.1
Other Industrial Processes	418	2.6
Solvent Utilization	6	0.0
Storage & Transportation	18	0.1
Waste Disposal & Recycling	120	0.7
Highway Vehicles	5,206	31.9
Off- Highway	4,255	26.0
Miscellaneous	260	1.6
Total	***16,339***	***100.0***

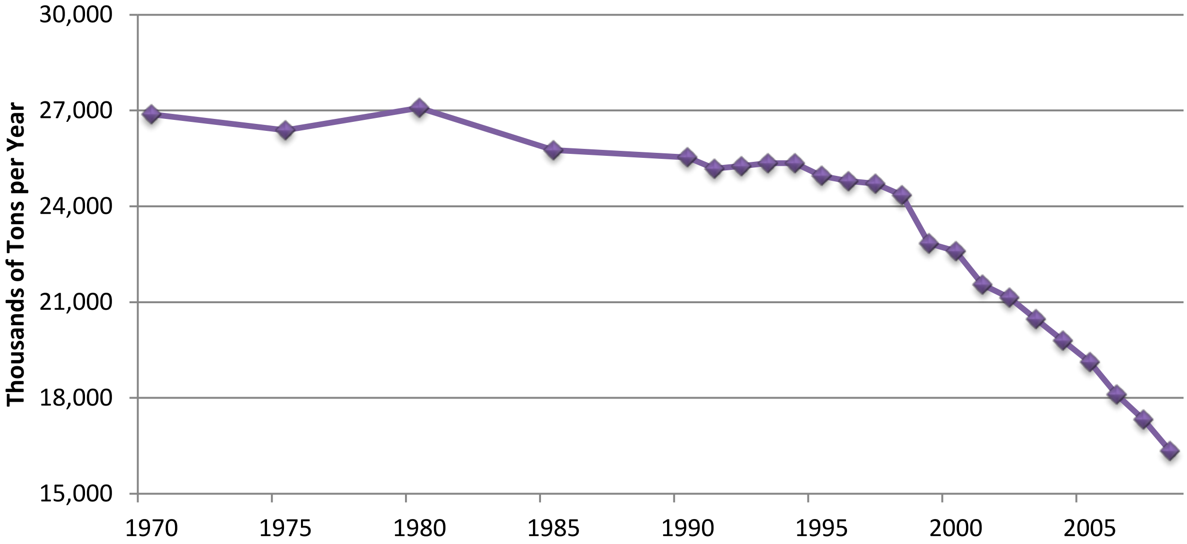

Figure 8. Changes in National Oxides of Nitrogen Emissions from 1970 to 2008

2.2.4.4 Nitrogen Dioxide – Statewide Summaries

Colorado exceeded the NO_2 standard in 1977 at the Denver CAMP monitor. Concentrations have shown a gradual decline for the past 20 years. However, the trend of annual averages for the past ten years has been nearly flat. Figure 9 shows that levels have declined at the Welby monitor over the past ten years while the annual average at the Denver CAMP monitor has shown little to no change at all. The cause of this is most likely due to an increase in the number of vehicles and increased power generation associated with the increases in population in the Denver-metro area. Table 15 (United States Environmental Protection Agency 2010) and Figure 9 illustrate the NO_2 trends for the State of Colorado.

Table 15. Historical Maximum Annual Average Nitrogen Dioxide Concentrations

Annual Average (ppb)	Monitor	Date
54	CAMP	1977
52	CAMP	1983
52	CAMP	1979
52	CAMP	1975
52	CAMP	1976
2011 Maximum Nitrogen Dioxide Concentration		
24	CAMP	2011

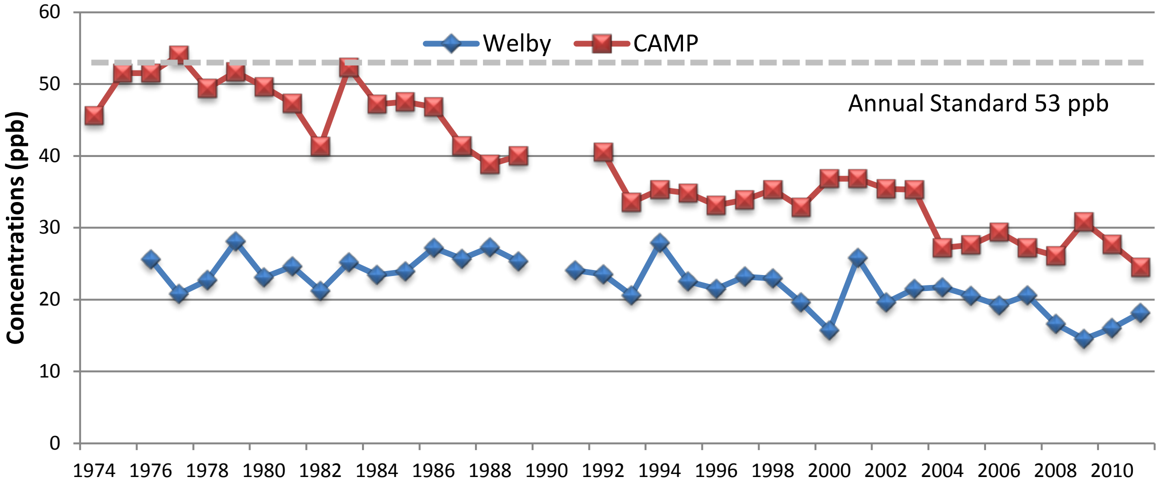

Figure 9. Statewide Ambient Trends for Nitrogen Dioxide

2.2.4.5 Nitrogen Dioxide – National Comparisons

"Since 1983, monitored levels of nitrogen dioxide have decreased 21 percent. These downward trends in national nitrogen dioxide levels are reflected in all regions of the country. Nationally, average nitrogen dioxide concentrations are well below the NAAQS and are currently at the lowest levels recorded in the past 20 years. All areas of the country that once violated the NAAQS for nitrogen dioxide now meet that standard. Over the past 20 years, national emissions of oxides of nitrogen have declined by almost 15 percent. While overall oxides of nitrogen emissions are declining, emissions from some sources such as nonroad engines have actually increased since 1983. These increases are of concern given the significant role oxides of nitrogen emissions play in the formation of ground-level ozone (smog) as well as other environmental problems like acid rain and nitrogen loadings to water bodies described above. In response, EPA has proposed regulations that will significantly control oxides of nitrogen emissions from nonroad diesel engines" (United States Environmental Protection Agency 2008) including construction and mining vehicles as well as power generators. Table 16 shows national and state ranking for nitrogen dioxide monitors (United States Environmental Protection Agency 2010). The annual mean for all Colorado sites is well below the annual NAAQS of 53 ppb.

Table 16. 2010 National Ranking of Nitrogen Dioxide Monitors by 1-hour Concentration in ppm

Nationwide (408 Monitors)					Colorado (7 Monitors)				
National Rank	**City/Area**	**1-hr Max**	**2nd Max**	**Annual Mean**	**National Rank**	**City/Area**	**1-hr Max**	**2nd Max**	**Annual Mean**
1	Calexico, CA	130	111	14.5	18	CAMP	94	93	24.4
2	El Centro, CA	117	62	8.5	39	Welby	78	75	18.1
3	Hogansburg, NY	116	96	3.8					
4	Phoenix, AZ	115	59	16.8					
5	Los Angeles, CA	110	98	23					

2.2.5 PM_{10}

Particle pollution is a mixture of microscopic solids and liquid droplets suspended in air. This pollution, also known as particulate matter, is made up of a number of components, including acidic aerosols (such as nitrates and sulfates), organic chemicals, metals, soil or dust particles, and allergens (such as fragments of pollen or mold spores). Some of these particles are carcinogenic and others have health effects due to their size, morphology, and composition.

The size of particles is directly linked to their potential for causing health problems. Small particles, less than 10 micrometers (microns) in diameter, pose the greatest problems. Since PM_{10} contains all particles smaller than 10 microns, $PM_{2.5}$ and ultrafine particles which are <0.1 microns are included in the PM_{10} measurement. The smallest particles, like $PM_{2.5}$, can get deep into the lungs, and some, like ultrafine particles, can penetrate all the way into the bloodstream. Exposure to such particles can affect the lungs, the heart, and the cardiovascular system. Larger particles are of less concern, although they can irritate the eyes, nose, and throat (AirNow 2003), and cause serious harm due to inflammation in the airways of people with respiratory diseases such as asthma, chronic obstructive pulmonary disease, and pneumonia (Weinmayr, et al. 2010).

2.2.5.1 An Explanation of Exceptional Events

Sometimes air pollution comes from natural sources that are not preventable and cannot be reasonably controlled by humans. These include things like volcanic eruptions, large regional dust storms, and wildfires. If an exceedance of the NAAQS, or PM_{10} concentrations greater than 155 $\mu g/m^3$ in attainment areas and ≥ 98 $\mu g/m^3$ in PM_{10} non-attainment areas, can be shown to have resulted from a natural event and can be documented with scientific evidence, the event can be excluded from NAAQS calculations. For example, one such event was the large wind and dust storm that occurred on March 31, 1999 when monitors from Steamboat Springs to Telluride reported high PM_{10} concentrations. Similar exceptional events have been documented in Lamar and Alamosa. These events are not included in NAAQS determinations, not because they are without any health risk but because they are natural events that cannot be reasonably controlled. The EPA must concur on events that the Division flags and documents as exceptional in the EPA's AQS database. The Exceptional Events Rule was revised on March 22, 2007, with an effective date of May 21, 2007. The EPA has been much more restrictive on concurring natural events since the revision. Table 4 indicates the number of these exceptional events, and more detail can be obtained from the APCD. Concentrations between 98 and 155 $\mu g/m^3$ that are located in SIP maintenance areas are also allowed by the Exceptional Events Rule to be flagged and documented as exceptional events.

2.2.5.2 PM_{10} - Standards

The nation's air quality standards for particulate matter were first established in 1971 as total suspended particulates and were not significantly revised until 1987, when EPA changed the indicator of the standards to regulate inhalable particles smaller than, or equal to, 10 micrometers in diameter (about 1/4 the size of a single grain of table salt). In 1997 the EPA revised the particulate matter standards, setting separate standards for fine particles ($PM_{2.5}$) and for PM_{10}. The health data showed that particles in the $PM_{2.5}$ range were linked to more serious health problems ranging from increased symptoms, hospital admissions and emergency room visits to premature death in people with heart or lung disease. They decided to retain the existing 24-hour PM_{10} standard of 150 $\mu g/m^3$. The EPA revoked the annual PM_{10} standard, because available evidence did not suggest a link between long-term exposure to the coarse fraction of PM_{10} and health problems. The $PM_{2.5}$ standard covers the non-coarse fraction of PM_{10}, and is discussed in Section 2.2.6 below.

2.2.5.3 PM_{10} - Health Effects

Since PM_{10} includes $PM_{2.5}$ and ultrafine particles, health effects associated with $PM_{2.5}$ are also PM_{10} health effects. "…With regard to $PM_{2.5}$, various toxicological and physiological considerations suggest that fine particles may play the largest role in effecting human health. For example, they may be more toxic because they include sulfates, nitrates, acids, metals, and particles with various chemicals adsorbed onto their surfaces. Furthermore, relative to larger particles, particles indicated by $PM_{2.5}$ can be breathed more deeply into the lungs, remain suspended for longer periods of time, penetrate more readily into indoor environments, and are transported over much longer distances. PM_{10}, an indicator for inhalable particles that can penetrate the thoracic region of the lung, consists of particles with an aerodynamic diameter less than or equal to a 10-µm cut point and includes fine particles and a subset of coarse particles. $PM_{10-2.5}$ consists of the PM_{10} coarse fraction defined as the difference between PM_{10} and $PM_{2.5}$ mass concentrations and, for regulatory purposes, serves as an indicator for thoracic coarse particles."(C. A. Pope 2006)

The welfare effects of particulate exposure may be the most widespread of all the pollutants. No place on earth has been spared from the particulate pollution generated by urban and rural sources. This is due to the potential for extremely long-range transport of fine particles and chemical reactions that occur from gasses in the atmosphere to create secondary particulate matter in the form of tiny liquid droplets. The effects of particulates range from visibility degradation to climate changes and vegetation damage. General soiling, commonly thought to be just a nuisance, can have long-term adverse effects on building paints and other materials. Acid deposition as particulates can be detected in the most remote areas of the world.

2.2.5.4 PM_{10} – Emissions and Sources

The majority of PM_{10} pollution is from miscellaneous sources, which are mainly fugitive dust sources rather than stack emissions or internal engine combustion sources. Fugitive emissions are those not caught by a capture system and are often due to equipment leaks, earth moving, equipment and vehicles, and windblown disturbances. While the amount of miscellaneous emissions isn't broken down specifically, the miscellaneous category contains sources such as agricultural crops, agricultural livestock, paved road re-suspension, unpaved roads, construction activities, and mining and quarrying (United States Environmental Protection Agency 1999). Table 17 (United States Environmental Protection Agency 2009) shows a breakdown of PM_{10} emissions on a national scale in 2008. Figure 10 illustrates the national emissions trends for PM_{10} which has been steadily declining since 1990.

Table 17. PM_{10} National Emissions for 2008

Description	National	
	Thousand-Tons/Year	Percent
Fuel Combustion – Electrical Utilities	5.34	3.6
Fuel Combustion – Industrial	330	2.2
Fuel Combustion – Other	466	3.1
Chemical Processing/Mfg	39	0.3
Metal Processing	78	0.5
Petroleum Processing	24	0.2
Other Industrial Processes	967	6.5
Solvent Utilization	8	0.1
Storage & Transportation	57	0.4
Waste Disposal & Recycling	288	1.9
Highway Vehicles	171	1.2
Off- Highway	304	2.1
Miscellaneous	11,540	77.9
Total	***14,806***	***100.0***

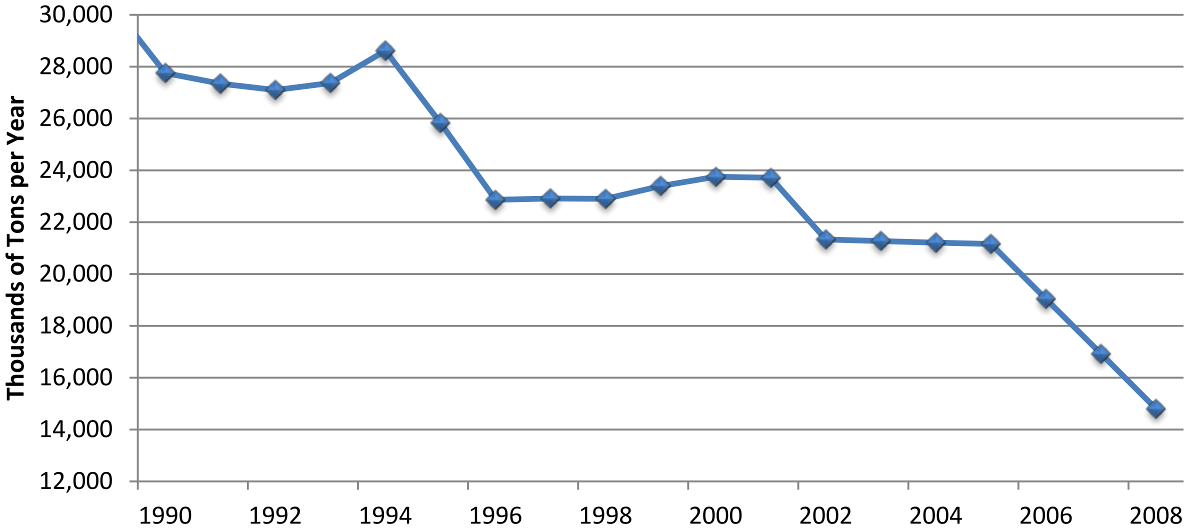

Figure 10. Changes in National PM_{10} Emissions from 1990 to 2008

2.2.5.5 PM_{10} – Statewide Summaries

PM_{10} data have been collected in Colorado since 1985. The samplers were modified in 1987 to conform to the requirements of the new standard when it was established in July of 1987. Therefore, annual trends are only valid back to July 1987. Since 1988, the state has had at least one monitor exceed the level of the 24-hour PM_{10} standard (150 $\mu g/m^3$) every year except 2004. By contrast, no monitor with at least 75 percent data recovery per calendar quarter, which is required for NAAQS comparisons, has exceeded the level of the former standard (50 $\mu g/m^3$).

In cases other than exceptional events, and more so than other pollutants, PM_{10} is a localized pollutant where concentrations vary considerably. Thus, local averages and maximum concentrations of PM_{10} are more meaningful than averages covering large regions or the entire state. The APCD has concluded that it is inappropriate to display a state-wide average graph for PM_{10}. Regional averages for all pollutants are discussed in more detail in Section 4 below.

The data contained in Table 18 include those concentrations that are the result of exceptional events (United States Environmental Protection Agency 2010). See Section 2.2.5.1. There have been several of these events documented in Colorado since PM_{10} monitoring began in 1988.

Table 18. Historical Maximum 24-Hour PM_{10} Concentrations

24-Hour Maximum ($\mu g/m^3$)	Monitor	Date
494	Alamosa - Municipal	2007
473	Alamosa - Adams State College (ASC)	2007
424	Alamosa - ASC	2006
412	Alamosa - ASC	1991
367	Lamar, Power Plant	2008
2011 Maximum PM_{10} Concentration		
635	Alamosa – Municipal	2011

2.2.5.6 PM_{10} – National Comparisons

In the past several years the top five locations on the list have generally included Keeler, CA; Olancha, CA; the sites around Owens Lake, CA; and sites around Mono Lake, CA. The last two years have seen rankings from Casa

Grande in Arizona. All of these levels are associated with hot dry winds. The levels around Owens Lake are associated with the high winds that blow across the large dry lake bed. In the past several years monitors in that area have recorded levels in excess of 20,000 μg/m^3 as a 24-hour average. Exceedances in Colorado are mainly due to large regional dust storms that usually begin in desert areas to the south and west of the state. These are natural or exceptional events for which the Division is currently analyzing the scientific data and documenting as high wind/blown dust exceptional events. The nationwide and statewide ranking of PM$_{10}$ monitors can be seen in Table 19 (United States Environmental Protection Agency 2010).

Table 19. National Ranking of PM$_{10}$ Monitors by 24-hour Maximum Concentration in μg/m^3

Nationwide (1,034 Monitors)					**Colorado (39 Monitors)**				
National Rank	**City/Area**	**1st Max**	**2nd Max**	**Annual Mean**	**National Rank**	**City/Area**	**1st Max**	**2nd Max**	**Annual Mean**
1	Mono Lake, CA	4,886	3,393	69.5	16	Alamosa Municipal	635	372	38.0
2	Owens Lake, CA	3,444	462	30.7	28	Alamosa ASC	440	295	25.3
3	Keeler, CA	2,994	524	35	87	Lamar Power Plant	192	169	27.5
4	Casa Grande, AZ	2,040	1,161	76.9	141	Steamboat	135	79	20.6
5	Owens Lake, CA	937	484	28.4	170	Denver Visitor Center	123	84	25.2

2.2.6 PM$_{2.5}$

EPA generally defines PM$_{2.5}$ as particulate matter with an aerodynamic diameter less than or equal to 2.5 microns in size. According to the Environmental Protection Agency's Our Nation's Air – Status and Trends through 2008:

"The chemical composition of PM$_{2.5}$ is characterized in terms of five major components that generally comprise the mass of PM$_{2.5}$: sulfate, nitrate, organic carbon (OC), elemental carbon (also called black carbon, BC), and crustal material.

…On average, sulfate is the largest component by mass in the eastern U.S. Generally, the largest source of sulfate in the eastern U.S. are electric utilities and industrial boilers. OC is the next largest component in the East. The primary sources of OC are highway vehicles, non-road mobile, waste burning, wildfires, and vegetation. Next is nitrate; the largest sources of nitrate originate from highway vehicles, non-road mobile, electric utilities, and industrial boilers. Elemental carbon is a small component of the overall PM$_{2.5}$ composition (typically 5-10 percent in U.S. cities). Elemental carbon is directly emitted from incomplete combustion processes such as fossil fuel and biomass burning. Crustal material is typically a small fraction of PM$_{2.5}$ mass, although two cities show higher than average values (Birmingham, AL and Detroit, MI). Crustal materials come from suspended soil and metallurgical operations.

In the West, OC is generally the largest estimated component of PM$_{2.5}$ by mass. Fireplaces and woodstoves are important contributors to OC in the West. On an annual average basis, nitrate, sulfate, and crustal material can also represent substantial components of PM$_{2.5}$ for the western U.S. The composition varies from city to city and may vary by geography. For example, in southern California and port cities in the Northwest, emissions from marine vessels also likely contribute a significant portion of PM$_{2.5}$ sulfate."

2.2.6.1 PM$_{2.5}$ - Standards

In 1997, the EPA added 24-hour and annual fine particle standards, PM$_{2.5}$, to the existing PM$_{10}$ standards. EPA added an annual PM$_{2.5}$ standard set at a concentration of 15 μg/m^3 and a 24-hour PM$_{2.5}$ standard set at 65 μg/m^3. The annual component of the standard was set to provide protection against typical day-to-day exposures as well as longer-term exposures, while the daily component protects against more extreme short-term events. EPA revised the air quality standards for particle pollution in 2006 to be more protective of human health since recent data showed significant health impacts below the 1997 standards. The 2006 standards tightened the 24-hour fine particle standard from 65 µg/m^3 to 35 µg/m^3, and retained the current annual fine particle standard at 15 µg/m^3. The NAAQS for $PM_{2.5}$ are currently under review.

2.2.6.2 $PM_{2.5}$ - Health Effects

The health effects of $PM_{2.5}$ are not just a function of their size, with the largest fine particles measuring about 1/20th the width of an average human hair, which allows them to be breathed deeply into the alveoli of the lungs. It is also a function of their composition. These tiny particles can remain in the lungs for a long time and cause a great deal of damage to lung tissue. They can reduce lung function as well as cause or aggravate respiratory problems. They can increase the long-term risk of lung cancer or lung diseases such as emphysema or pulmonary fibrosis. The smallest range of $PM_{2.5}$ particles, also called ultrafine particles (those with a diameter <0.1 µm) can be transported from the lungs into the blood stream and affect the heart and cardiovascular system. (Cardiovascular Toxicology 2006) Once in the blood stream, ultrafine particles can be transported anywhere in the body. Some of these ultrafine particles are carcinogenic.

2.2.6.3 $PM_{2.5}$ – Emissions and Sources

Figure 11 shows the nationwide changes in emissions of $PM_{2.5}$ particulates from 1990 through 2008. Table 20 lists the national $PM_{2.5}$ emissions for 2008. (United States Environmental Protection Agency 2009) The primary source of fine particles emitted directly into the air is carbonaceous material from combustion sources such as cars, trucks, and industrial boilers. Secondary particles are another large source of “fine” particulates. Secondary particles are those that are created in the atmosphere by chemical reactions of gaseous pollutants and water vapor to form tiny liquid droplets or semi-solid particle. Efficient light scattering and absorption mean that fine particles are the major contributor to visibility problems. As with PM_{10}, the majority of emissions come from the miscellaneous category which includes sources such as agricultural crops, agricultural livestock, paved road re-entrained dust, unpaved roads, construction activities, and mining and quarrying. (United States Environmental Protection Agency 1999)

Table 20. $PM_{2.5}$ National Emissions for 2008

Description	National	
	Thousand-Tons/Year	Percent
Fuel Combustion – Electrical Utilities	410	8.4
Fuel Combustion - Industrial	175	3.6
Fuel Combustion - Other	421	8.6
Chemical Processing/Mfg	29	0.6
Metal Processing	52	1.1
Petroleum Processing	11	0.3
Other Industrial Processes	355	7.3
Solvent Utilization	7	0.1
Storage & Transportation	22	0.1
Waste Disposal & Recycling	267	5.5
Highway Vehicles	110	2.2
Off- Highway	283	5.8
Miscellaneous	2,742	56.1
Total	***4,890***	***100.0***

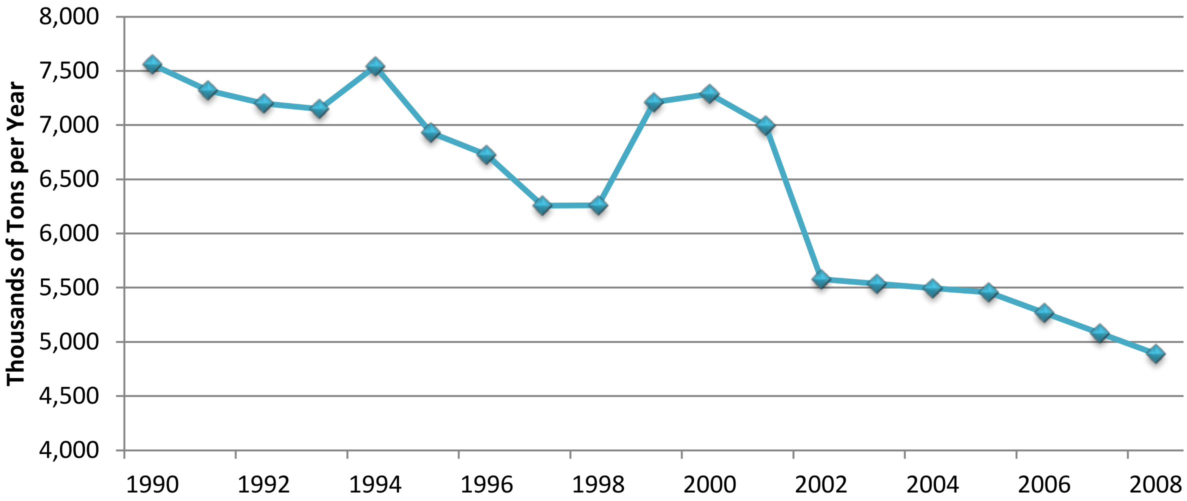

Figure 11. Changes in National $PM_{2.5}$ Emissions from 1990 to 2008

2.2.6.4 $PM_{2.5}$ – Statewide Summaries

Monitoring for $PM_{2.5}$ in Colorado began with the establishment of sites in Denver, Grand Junction, Steamboat Springs, Colorado Springs, Greeley, Fort Collins, Platteville, Boulder, Longmont, and Elbert County in 1999. Additional sites were established nearly every month until full implementation of the base network was achieved in July of 1999. In 2004, there were 20 $PM_{2.5}$ monitoring sites in Colorado. Thirteen of the 20 sites were selected based on the population of the metropolitan statistical areas. This is a federal selection criterion that was developed to protect the public health in the highest population centers. In addition, there were seven special-purpose-monitoring (SPM) sites. These sites were selected due to historically elevated concentrations of PM_{10} or because citizens or local governments had concerns of possible high $PM_{2.5}$ concentrations in their communities. All SPM sites were removed as of December 31, 2006 due to low concentrations and a lack of funding.

Table 21 shows the historical maximum readings for $PM_{2.5}$. (United States Environmental Protection Agency 2010) Though data has only been collected for the past nine years, the levels of $PM_{2.5}$ appear to be essentially flat. Figure 12 shows the three-year average of the top 98th percentile, and the 3-year average of the annual mean. There is an apparent upward trend for the 98th percentile, but there are too few data points to draw any definitive conclusions. Since the standard is based on a three-year average of the top 98th percentile of samples, the 24-hour standard has not been violated at any site[9]. Neither has the three-year average annual standard of 15 $\mu g/m^3$.

Table 21. Historical Maximum $PM_{2.5}$ Concentrations

24-Hour Maximum ($\mu g/m^3$)	Monitor	Date
68.4	Denver CAMP	2001
68.0	Denver CAMP	2001
60.5	Denver CAMP	2007
60.2	Arapahoe Community College	2007
57.3	Commerce City	2001
2011 Maximum $PM_{2.5}$ Concentration		
41.9	Commerce City	2011

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[9] In 2001, before the current standard went into effect (in 2006), the Adams City monitor showed a three-year 98th percentile average of 35.1 $\mu g/m^3$. Due to rounding conventions, 35.5 $\mu g/m^3$ is needed to violate the 24-hour NAAQS. Data collection at this site began in 1999.

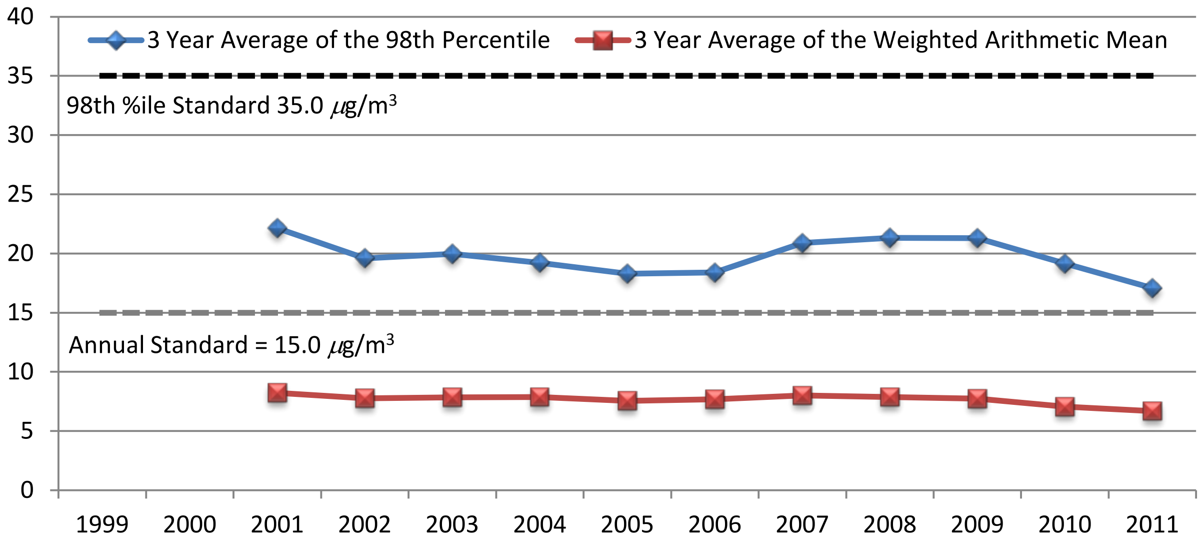

Figure 12. Statewide Ambient Trends for $PM_{2.5}$

2.2.6.5 $PM_{2.5}$ – National Comparisons

Five of the top five highest annual arithmetic mean concentrations (and indeed the top 31 monitors) were in California, shown in Table 22. (United States Environmental Protection Agency 2010) . The highest 24-hour $PM_{2.5}$ concentrations were in California, Texas, and Arizona. Even though California continues to show improvement, they remain the state with the highest concentrations.

Some sites had high 24-hour $PM_{2.5}$ concentrations but low annual $PM_{2.5}$ concentrations, and vice versa. Sites that have high 24-hour concentrations but low or moderate annual concentrations exhibit substantial variability from season to season. (United States Environmental Protection Agency 2009)

Table 22. National Ranking of $PM_{2.5}$ Monitors by Annual Mean Concentrations in μg/m^3

Nationwide (1,290 Monitors)					Colorado (22 Monitors)				
National Rank	City/Area	1st Max	2nd Max	Annual Mean	National Rank	City/Area	1st Max	2nd Max	Annual Mean
1	Fresno, CA	79	76	76	196	Greeley Hospital	29	27	22.5
2	Clovis, CA	76	76	69	379	Grand Junction – Powell	24	23	22.2
3	Hanford, CA	79	75	65	565	Swansea	34	30	19.7
4	Fresno, CA	78	68	60	580	Commerce City	41.9	20	19.5
5	Madera, CA	71	70	59	678	CAMP	32	28	19.4

2.2.7 Lead

Lead is a metal found naturally in the environment as well as in manufactured products. The major sources of ambient air lead emissions have historically been motor vehicles (such as cars and trucks) and industrial sources (such as lead smelters). Due to the phase out of leaded gasoline for automobiles, piston engine aircraft and metals processing are now the major source of lead emissions to the air today. The highest levels of lead in air are generally found near lead smelters and general aviation airports. Other stationary sources are waste incinerators, utilities, and lead-acid battery manufacturers. (United States Environmental Protection Agency 2007)

2.2.7.1 Lead - Standards

The Clean Air Act requires EPA to review the latest scientific information and standards every five years. Before new standards are established, policy decisions undergo rigorous review by the scientific community, industry, public interest groups, the general public, and the Clean Air Scientific Advisory Committee (CASAC) (http://yosemite.epa.gov/sab/sabpeople.nsf/WebCommittees/CASAC).

On October 15, 2008, EPA strengthened the National Ambient Air Quality Standards for lead. The level for the previous lead standard was 1.5 $\mu g/m^3$, not to be exceeded as an average for a calendar quarter, based on an indicator of lead in total suspended particles (TSP). The new standard, measured in either TSP or low-volume PM_{10} samples, has a level of 0.15 $\mu g/m^3$, not to be exceeded as an average for any rolling three-month period within three years. On December 30, 2009 (effective January 26, 2011), EPA revised the requirements for monitoring for lead (74 FR 69050). In addition to requiring lead monitoring at NCore sites, and removing the CBSA-based monitoring requirement, the EPA lowered the emissions threshold from 1 ton per year to 0.5 ton per year for industrial lead sources, and in urban areas with a population equal to or greater than half a million people. Airports maintain an emission threshold of 1 ton per year, and the EPA is studying the potential need for monitoring at less than 1 ton per year. On December 14, 2010, EPA made final revisions to the ambient monitoring requirements for measuring lead in the air. These amendments expand the nation's lead monitoring network to better assess compliance with the 2008 National Ambient Air Quality Standards for lead. (United States Environmental Protection Agency 2010)

2.2.7.2 Lead - Health Effects

Exposure to lead occurs mainly through inhalation of air and ingestion of lead in food, water, soil, or dust. It accumulates in the blood, bones, and soft tissues and can adversely affect the kidneys, liver, nervous system, and other organs. Excessive exposure to lead may cause neurological impairments such as seizures, intellectual disability[10], and behavioral disorders. Even at low doses, lead exposure is associated with damage to the nervous systems of fetuses and young children, resulting in learning deficits and lowered IQ. Recent studies also show that lead may be a factor in high blood pressure and subsequent heart disease. Lead can also be deposited on the leaves of plants, presenting a hazard to grazing animals and humans through ingestion. (United States Environmental Protection Agency 2009)

2.2.7.3 Lead – Emissions and Sources

"Because industrial processes are now responsible for all violations of the lead NAAQS, the lead monitoring strategy currently focuses on emissions from these point sources." (United States Environmental Protection Agency 2009) Since leaded fuel is still used in piston-engine aircraft, airports with general aviation are another significant source of lead emissions. Figure 13 shows the decline in lead emissions between 1975 and 2005. Table 23 shows the emission sources for 2005. (T. G. Pope 2009)

Table 23. Lead National Emissions for 2005

Description	National	
	Tons/Year	**Percent**
Aviation Gasoline	561	45
Metallurgical Industries	283	23
Manufacturing	171	14
Incineration	94	8
Boilers	70	6
Miscellaneous smaller categories	57	5
Total	***1236***	***100***

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[10] Referenced material from 2009 contains antiquated terminology, see http://www.opencongress.org/bill/111-s2781/show

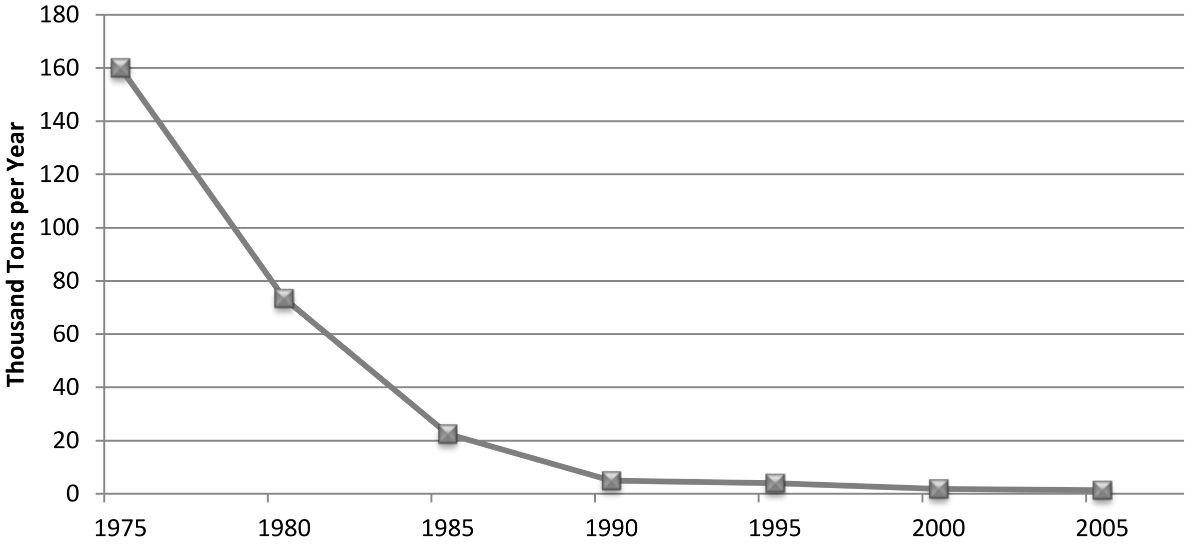

Figure 13. Changes in National Lead Emissions from 1975 to 2005

2.2.7.4 Lead – Statewide Summaries

In Colorado the last violation of the previous 1.5 µg/m^3 lead standard occurred in the first quarter of 1980 at the Denver CAMP monitor. Since then, the concentrations recorded at all monitors showed a steady decline. This decline is the direct result of the use of unleaded gasoline and replacement of older cars with newer ones that do not require leaded gasoline. The reduction in atmospheric lead shows what pollution control strategies can accomplish. In 2006, monitoring for lead by the APCD was reduced from six locations to one. In 2007, that lead monitor was moved from the Denver CAMP location to the Denver Municipal Animal Shelter NCore site at 678 S. Jason St.

The EPA established a new level for the lead standard on October 15, 2008. A more complete discussion of the new standard is covered in Section 2.2.7.1 above. Colorado currently operates two lead monitors. Table 24 (United States Environmental Protection Agency 2010) and Figure 14 illustrate the historic statewide lead trends.

Table 24. Historical Maximum Quarterly Lead Concentrations

Quarterly Maximum (µg/m^3)	Monitor	Date
3.47	Denver CAMP, 2105 Broadway	1st Qtr 1979
3.40	Denver, 414 14th St.	4th Qtr 1969
3.03	Denver, 414 14th St.	1st Qtr 1973
3.03	Denver CAMP, 2105 Broadway	4th Qtr 1978
3.02	Denver, 414 14th St.	4th Qtr 1972
2011 Maximum Quarterly Lead Concentration		
0.020	Centennial Airport	August to October

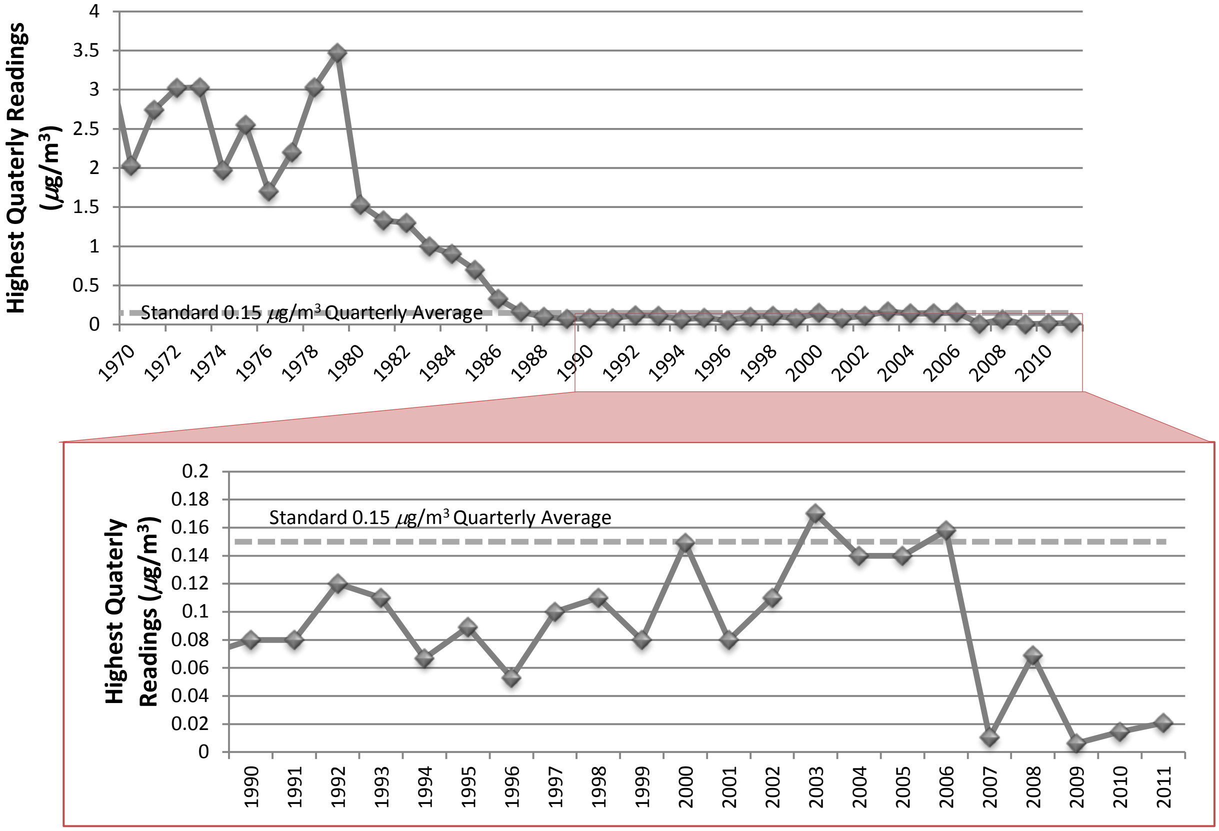

Figure 14. Statewide Ambient Trends for Lead

2.2.7.5 Lead – National Comparisons

"On October 15, 2008, EPA strengthened the National Ambient Air Quality Standards for lead. The level for the previous lead standards was 1.5 µg/m^3, not to be exceeded as an average for a calendar quarter, based on an indicator of lead in total suspended particles (TSP). The new standards, also in terms of lead in TSP, have a level of 0.15 µg/m^3, not to be exceeded as an average for any three-month period within three years." (United States Environmental Protection Agency 2008) Table 25 lists the nationwide comparisons of lead concentrations. (United States Environmental Protection Agency 2010)[11]

Table 25. National Ranking of Lead Monitors by 24-hour Maximum Concentration in µg/m^3

Nationwide (260 Monitors)				Colorado (2 Monitors)			
National Rank	**City/Area**	**24-hr Max**	**Highest Quarterly Mean**	**National Rank**	**City/Area**	**24-hr Max**	**Highest Quarterly Mean**
1	Herculaneum, MO	10.0	5.4	156	Centennial	0.02	0.02
2	Troy, AL	6.2	4.3	198	DMAS	0.01	0.01
3	Vernon, CA	4.0	4.5				
4	Tampa, FL	3.6	3.4				
5	Frisco, TX	3.5	1.8				

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[11] Herculaneum, MO sites near the Doe Run lead smelter, constituting 10 of the top 15 concentrations, were collected as one site for this comparison.

3. NON-CRITERIA POLLUTANTS

Non-criteria pollutants are those pollutants for which there are no current national ambient air quality standards. These include but are not limited to the pollutants that impair visibility, certain oxides of nitrogen species, total suspended particulates, and air toxics. Meteorological measurements of wind speed, wind direction, temperature, and humidity are also included in this group, as is chemical speciation of $PM_{2.5}$ analyses.

3.1. Visibility

Visibility is unique among air pollution effects in that it involves human perception and judgment. It has been described as the maximum distance that an object can be perceived against the background sky. Visibility also refers to the clarity with which the form and texture of distant, middle and near details can be seen as well as the sense of the trueness of their apparent coloration. As a result, measures of visibility serve as surrogates of human perception. There are several ways to measure visibility but none of them tell the whole story or completely measure visibility as we experience it.

3.1.1 Visibility - Standards

The Colorado Air Quality Control Commission established a visibility standard in 1990 for the Front Range cities from Fort Collins to Colorado Springs. The standard, an atmospheric extinction of 0.076 per inverse kilometer, was based on the public's definition of unacceptable amounts of haze as judged from slides of different haze levels taken in the Denver area. At the standard, 7.6 percent of the light in a kilometer of air is blocked. The standard applies from 8 A.M. to 4 P.M. each day, during those hours when the relative humidity is less than 70 percent. Visibility, along with meteorology and concentrations of other pollutants for which National Ambient Air Quality Standards exist, is used to determine the need for mandatory wood burning and voluntary driving restrictions.

There is no quantitative visibility standard for Colorado's pristine and scenic rural areas. However, in the 1977 amendments to the Federal Clean Air Act, Congress added Section 169a (Clean Air Act as ammended in 1977, Section 169a 1977) and established a national visibility goal that created a qualitative standard of “the prevention of any future and the remedying of any existing, impairment of visibility in mandatory Class I federal areas which impairment results from manmade air pollution.” The implementation of Section 169a has led to federal requirements to protect visual air quality in large national parks and wilderness areas (Visibility Protection for Federal Class 1 Areas n.d.). Colorado has 12 of these Class I areas. Federal and state law prohibits visibility impairment in national parks and wildernesses due to large stationary sources of air pollution.

3.1.1 Visibility - Health Effects

Visual air quality is an element of public welfare. Specifically, it is an important aesthetic, natural, and economic resource of the State of Colorado. EPA, the US Forest Service, and the US National Park Service have conducted studies that show that good visibility is something that people undeniably value. They have also shown that impaired visibility affects the enjoyment of a recreational visit to a scenic mountain area.

The APCD believes although the worth of visibility is difficult to measure, people prefer to have clear views from their homes and offices. These concerns are reflected in residential property values and office rents. Any loss in visual air quality may contribute to corresponding losses in tourism and usually make an area less attractive to residents, potential newcomers, and industry. Researchers have found this link strongest with concentrations of fine particles, which also contribute to visibility impairment. In July 1997, the EPA developed a NAAQS for $PM_{2.5}$ (more detail is in Section 2.2.6). Any control strategies to lower ambient concentrations of fine particulate matter for health reasons will also improve visibility.

3.1.2 Visibility - Sources

The cause of visibility impairment in Colorado is most often fine particles in the 0.1 to 2.5 micrometer size range. Light passing from a vista to an observer is either scattered away from the sight path or absorbed by the atmospheric fine particulates. Sunlight entering the pollution cloud may be scattered into the sight path adding brightness to the view and making it difficult to see elements of the vista. Sulfate, nitrate, elemental carbon, and organic carbon are the types of particulate matter most effective at scattering and/or absorbing light. The man-made sources of these particulates include wood burning, electric power generation, industrial combustion of coal or oil, and emissions from cars, trucks, and buses.

Visibility conditions vary considerably across the state. Usually, visibility in Colorado is among the best in the country. Our prized western vistas exist due to unique combinations of topography and scenic features. Air in much of the West contains low humidity and minimal levels of visibility-degrading pollution. Nevertheless, visibility problems occur periodically throughout the state. Wood burning haze is a concern in several mountain communities each winter. Denver has its "Brown Cloud." Even the national parks, monuments, and wilderness areas show pollution related visibility impairment on occasion due to regional haze, the interstate or even regional-scale transport of visibility-degrading pollution. The visibility problems across the state have raised public concern and spurred research. The goal of Colorado's visibility program is to protect visual air quality where it is presently good and improve visibility where it is degraded.

3.1.3 Visibility - Class I Areas in Colorado

Phase 1 of the visibility program, also known as Reasonably Attributable Visibility Impairment (RAVI), addresses impacts in Class I areas by establishing a process to evaluate source specific visibility impacts, or *plume blight*, from individual sources or small groups of sources. Figure 15 illustrates these areas in Colorado.

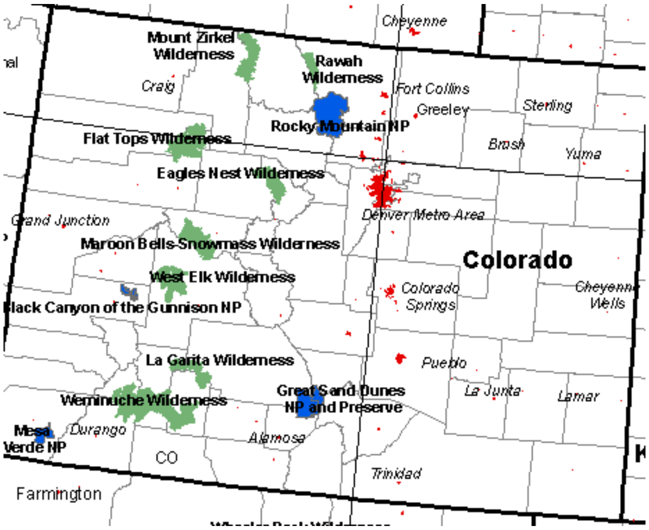

Figure 15. Class I areas in Colorado

Section 169B was added to the Clean Air Act Amendments of 1990 to address Regional Haze. Since Regional Haze and visibility problems do not respect state and tribal boundaries, the amendments authorized EPA to establish visibility transport regions as a way to combat regional haze.

Phase 2 of the visibility program addresses Regional Haze. This form of visibility impairment focuses on overall decreases in visual range, clarity, color, and ability to discern texture and details in Class I areas. The responsible air pollutants can be generated in the local vicinity or carried by the wind often many hundreds or even thousands of miles from where they originated.

The APCD developed a Regional Haze State Implementation Plan (SIP) in 2010 illustrating how Colorado intends to meet the requirements of EPA's Regional rules for the period ending in 2018 (the first planning period in the rule), while also establishing enforceable controls that will help address the long term national visibility goals targeted to be achieved by the year 2064.

Colorado's Regional Haze SIP was approved by the Colorado Air Quality Control Commission on January 7, 2011. This plan will lead to less haze and improved visibility in some of Colorado's most treasured and scenic areas, including Rocky Mountain National Park, Mesa Verde, Maroon Bells, and the Great Sand Dunes. By 2018, the plan will result in more than 70,000 tons of pollutant reductions annually, including 35,000 tons of nitrogen oxides, which leads to ground-level ozone formation. In total, the plan covers 30 industrial emitters at 16 facilities throughout Colorado, including coal-fired power plants and cement kilns.

3.1.4 Visibility - Monitoring

There are several ways to measure visibility. The APCD uses camera systems to provide qualitative visual documentation of a view. Transmissometers and nephelometers are used to measure the atmosphere's ability to attenuate light quantitatively.

A visibility site was installed in Denver in late 1990 using a long-path transmissometer. Visibility in the downtown area is monitored using a receiver located near Cheesman Park at 1901 E. 13th Avenue, and a transmitter located on the roof of the Federal Building at 1929 Stout Street (Figure 16). Renovations at the Federal Building forced the transmissometer to temporarily move to 1255 19th Street in 2010, and quality control measurements showed no meaningful difference between old and new locations. This instrument directly measures light extinction, which is proportional to the ability of atmospheric particles and gases to attenuate image-forming light as it travels from an object to an observer. The visibility standard is stated in units of atmospheric extinction. Days when the visibility is affected by rain, snow, or relative humidity above 70% are termed "excluded" (as shown in Figure 28) and are not counted as violations of the visibility standard.

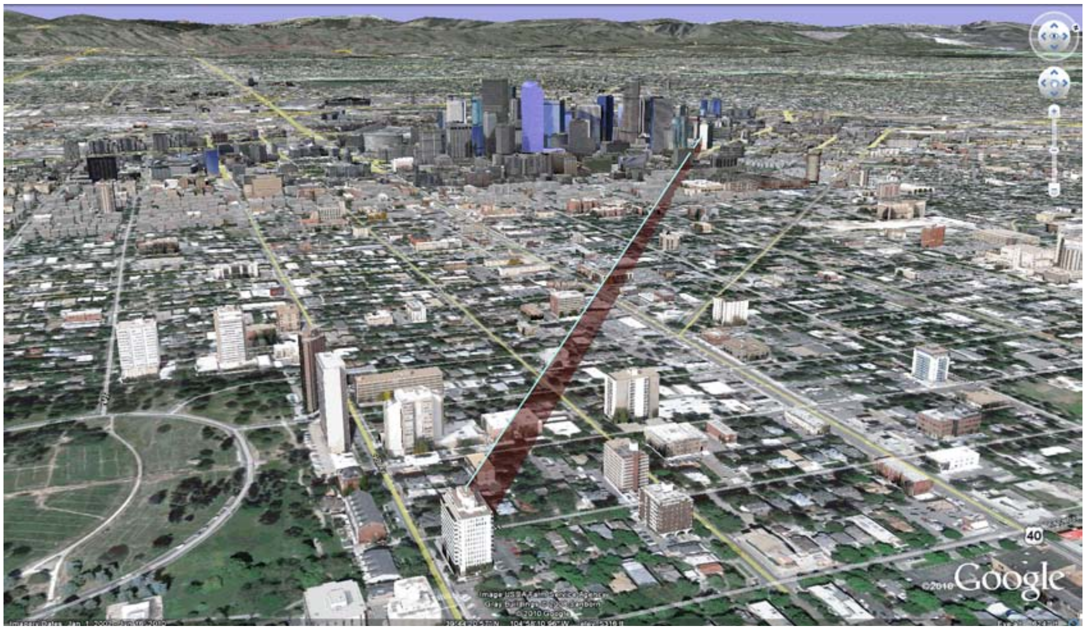

Figure 16. Transmissometer Path (Illustration Purposes Only)

In September 1993, a transmissometer and nephelometer were purchased by the city of Fort Collins to monitor visibility. Elsewhere in Colorado, several agencies of the federal government, in cooperation with regional and nationwide state air pollution organizations, also monitor visibility in a number of national parks and wilderness Class I areas, either individually or jointly through the Interagency Monitoring of Protected Visual Environments (IMPROVE) program. The goals of the monitoring programs are to establish background visibility levels, identify trends of deterioration or improvement, identify suspected sources of visibility impairment, and to track regional haze. Visibility and the atmospheric constituents that cause visibility degradation are characterized with camera systems, transmissometers, and extensive fine particle chemical composition measurements by the monitoring network. There are currently monitoring IMPROVE sites in Rocky Mountain National Park, Mesa Verde National Park, Weminuche Wilderness, Mount Zirkel Wilderness, Great Sand Dunes National Monument, and White River National Forest. These data are not contained in this report, but are available at: http://vista.cira.colostate.edu/improve/

3.1.5 Visibility - Denver Camera

The APCD operates a web-based camera that can be viewed on the Live Image of Denver icon on the bottom left side of the screen at the APCD web site http://www.colorado.gov/airquality. There is a great deal of other information available from this site in addition to the image from the visibility camera, including the Front Range Air Quality Forecast, Air Quality Advisory, Monitoring Reports, this report, and Open Burning Forecast.

The images in Figure 17 show the visibility on one of the best and worst days for the year. The best visibility day was November 24, 2011. The worst visibility day was December 13, 2011.

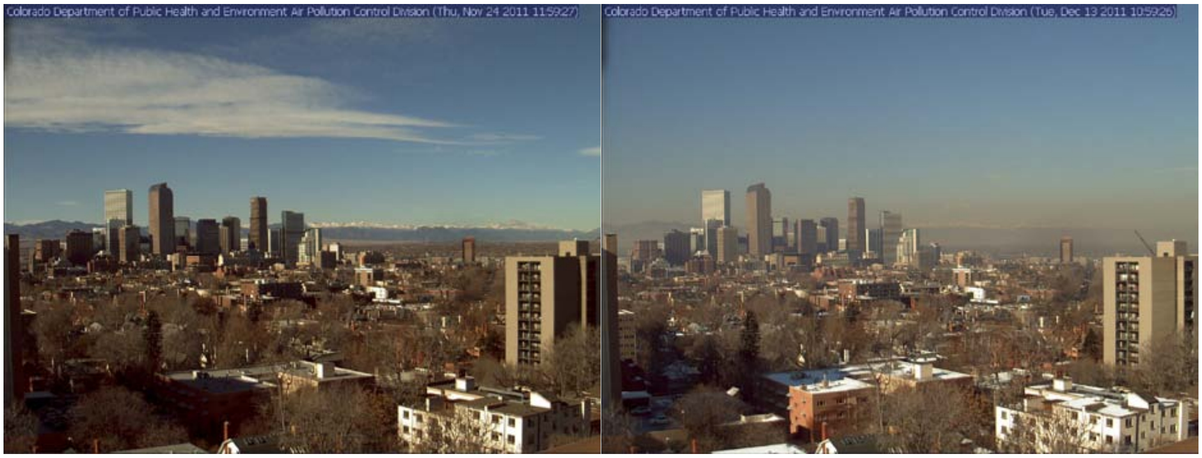

Figure 17. Best (left) and Worst (right) Visibility Days in Denver

These two pictures are images made by the web camera at the visibility monitor located at 1901 E. 13th Avenue in Denver, and are centered on the Federal Building at 1929 Stout Street (see Figure 16, the camera follows the transmissometer path). The difference in these two pictures is not just the brightness but the detail that can be seen between the two images. On the best day, buildings can be clearly resolved, and the Front Range is visible. On the worst day, however, contrast between buildings is lower, and the Front Range is almost entirely obscured.

3.2. Nitric Oxide

Nitric oxide is the most abundant of the oxides of nitrogen emitted from combustion sources. There are no known adverse health effects at normal ambient concentrations. However, nitric oxide is a precursor to nitrogen dioxide, nitric acid, particulate nitrates, and ozone, all of which have demonstrated adverse health effects. (United States Environmental Protection Agency 1982) There are no federal or state standards for nitric oxide.

Table 26. Nitric Oxide Summary

Site	1st Maximum Value (PPB)	Annual Arithmetic Mean (PPB)
CAMP	448	20.8
Welby	319	17.6
DMAS	234	11.7

Nitric oxide was sampled simultaneously with NO_2 at Welby, CAMP, and DMAS. Table 26 shows the maximum and average NO concentrations in Colorado. Without national standards with which to compare these numbers, they are only here for informational purposes, and are considered by the APCD to be consistent with recent historical nitric oxide concentrations. The annual mean fell slightly at CAMP and Welby.

3.3. Total Suspended Particulates

Total suspended particulates (TSP) were first monitored in Colorado in 1960 at 414 14th Street in Denver. This location monitored TSP until 1988. The Adams City and Gates TSP monitors began operation in 1964 and the Denver CAMP monitor at 2105 Broadway began operating in 1965. Either the EPA or the City of Denver operated these monitors until the mid-1970s, when daily operation was taken over by the Colorado Department of Public Health and Environment. None of these monitors are in operation today.

Particulate monitoring expanded to more than 70 locations around the state by the early 1980s. The primary standards for total suspended particulates were 260 $\mu g/m^3$ as a 24-hour sample and 75 $\mu g/m^3$ as an annual geometric mean. On July 1, 1987, with the promulgation of the PM_{10} standards, the old particulate standards were eliminated. Until December 2006 the Division operated six TSP samplers to measure lead. On January 1, 2007 the number of lead monitoring sites was reduced to one, at the Denver Municipal Animal Shelter located at 678 S. Jason Street. The reason for the change in the number of TSP monitors is that the ambient concentrations of lead have been reduced dramatically.

In October of 2008 the lead standard changed again. With this change, a TSP sampler was installed near the Centennial Airport in Arapahoe County. The location was selected to more closely monitor lead from small aircraft that still use leaded fuel. The maximum TSP concentration recorded in 2011 was 110 $\mu g/m^3$ at DMAS, and the maximum TSP recorded in 2011 at the Centennial Airport was 124 $\mu g/m^3$. A more detailed explanation of the lead standard and measurements can be found in Section 2.2.7 and 4.2 respectively.

3.4. Air Toxics

Toxic air pollutants, or air toxics, are those pollutants that cause or may cause cancer or other serious health effects, such as reproductive effects or birth defects. Air toxics may also cause adverse environmental and ecological effects. EPA is required to reduce air emissions of 188 air toxics listed in the Clean Air Act. Examples of air toxics include benzene (found in gasoline), perchloroethylene (emitted from some dry cleaning facilities), and methylene chloride (used as a solvent by a number of industries). Most air toxics originate from man-made sources, including mobile sources like cars, trucks, and construction equipment, and stationary sources like factories, refineries, and power plants, as well as indoor sources (some building materials and cleaning solvents). Some air toxics are also released from natural sources such as volcanic eruptions and forest fires. (United States Environmental Protection Agency 2009)

People exposed to air toxics at sufficient concentrations may experience various health effects including cancer and damage to the immune system, as well as neurological, reproductive (including reduced fertility), developmental, respiratory, and other health problems. In addition to exposure from breathing air toxics, risks are also associated with the deposition of toxic pollutants onto soils or surface waters, where they are taken up by plants and ingested by animals and eventually magnified up through the food chain. Like humans, animals may experience health problems due to air toxics exposure.

The APCD currently monitors for air toxics in Grand Junction as part of EPA's National Air Toxics Trend Stations project. Monitoring for air toxics also began at CAMP and Platteville in December of 2011. The data from the Grand Junction study are available in a separate report, available at http://www.colorado.gov/airquality/tech.aspx#misc.

3.5. Meteorology

The APCD takes a limited set of meteorological measurements at 18 locations around the state. These measurements include wind speed, wind direction, temperature, standard deviation of horizontal wind direction, and select monitoring of relative humidity. Relative humidity measurements are also taken in conjunction with the two visibility monitors. The humidity data are not summarized in this report since they are used primarily to validate the visibility measurements taken at the specific locations. The Division does not collect precipitation measurements. The wind speed, wind direction, and temperature measurements are collected primarily for air quality forecasting and air quality modeling. These instruments are installed on ten-meter towers and the data are collected as hourly averages and sent along with other air quality data to be stored on the EPA's Air Quality Systems database. The wind speed and wind direction data are shown as wind roses at the end of each monitoring area in Section 4 below.

The wind roses displayed in this report are placed on a background map that shows the approximate location of the meteorological site. The wind roses are based on the direction that the wind is blowing from. Another way of visualizing a wind rose is to picture you standing in the center of the plot and facing into the wind. The wind direction is divided into the 16 cardinal directions (ESE, for example). The wind speed is divided into six ranges. The roses in Section 4 below use 1-3 mph, 4-5 mph, 7-11 mph, 12-14 mph, 15-38 mph, and greater than 38 mph.

The length of each arm of the wind rose represents the percentage of time the wind was blowing from that direction at that speed. The longer the arm, the greater the percentage of time the wind is blowing from that direction.

3.6. $PM_{2.5}$ Chemical Speciation

Numerous health effects studies have correlated negative health effects to the total mass concentration of $PM_{2.5}$ in ambient air. (AirNow 2003) However, it has not yet been completely determined if the health correlation is to total mass concentration, or to concentrations of specific chemical species in the $PM_{2.5}$ mix. When the EPA promulgated the NAAQS for $PM_{2.5}$ in 1997, a compliance monitoring network based on total $PM_{2.5}$ mass was established. Mass concentrations from the compliance network are used to determine attainment of the NAAQS. EPA soon supplemented the $PM_{2.5}$ network with the Speciation Trends Network (STN) monitoring to provide information on the chemical composition of $PM_{2.5}$. The main purpose of the STN is to identify sources, develop implementation plans to reduce $PM_{2.5}$ pollution, and support health effects research.

Colorado began chemical speciation monitoring at the Commerce City site in February 2001 at the state’s only STN site. Four other chemical speciation sites were established in 2001 in Colorado Springs, Durango, Grand Junction, and Platteville. The Durango site was closed in September 2003. The Colorado Springs site was closed in December, 2006. These sites were eliminated when concentrations were found to trend low and when funding was reduced for the project. The Grand Junction site was closed in December 2009 and moved to DMAS NCore where it began sampling in January of 2010 to comply with the requirement from EPA to monitor $PM_{2.5}$ speciation at NCore sites.

Chemical speciation monitoring is conducted for 47 elemental metals, five ionic species, and elemental and organic carbon. Selected filters can also be analyzed for semi-volatile organics and microscopic analyses. The results of these samples can be obtained from the APCD upon request. Some of these chemical species and compounds can cause serious health effects, premature deaths, visibility degradation, and regional haze. The chemical speciation data for $PM_{2.5}$ is used in many ways, such as to determine which general source categories are likely responsible for the $PM_{2.5}$ pollution at a given monitoring site on a given day, and how much pollution comes from each source category. There are two broad categories of $PM_{2.5}$ – primary and secondary particles. Primary $PM_{2.5}$ particles include those emitted directly to the air from carbonaceous particles from incomplete combustion of internal combustion engines, wood burning, waste burning, and crushed geologic materials. Secondary $PM_{2.5}$ is formed from gases that combine in the atmosphere through chemical processes and form liquid aerosol droplets. Ammonium nitrates and ammonium sulfates are generally the two largest types of secondary $PM_{2.5}$ in Colorado. If $PM_{2.5}$ pollution needs to be controlled, it is important to know the composition of $PM_{2.5}$ particles so that the appropriate sources can be targeted for control (see Section 2.2.6.3 above for more information on $PM_{2.5}$ sources).

4. MONITORING RESULTS BY AREA IN COLORADO

Please refer to section 1.2 for a brief description of the monitoring areas below.

4.1. Eastern Plains Counties

Currently, there are two PM_{10} monitoring sites and one meteorological site in Lamar and a background $PM_{2.5}$ monitor in Elbert County. The Lamar monitors have recorded exceedances of the 24-hour PM_{10} standard in the past three years. These have been associated with high winds and blowing dust from large regional dust storms and dry conditions. Table 27 lists the 2011 concentration values for the Eastern Plains particulate monitors, while Figure 18 is an illustration of the wind rose overlain on a map of the monitoring site.

Table 27. Eastern Plains Particulate Values

Site Name	**PM_{10} (µg/m^3)**			**$PM_{2.5}$ (µg/m^3)**	
	Annual Average	**24-hour Max**	**3-Year Avg. Exceedance**	**3-Year Weighted Average**	**3-Year Average of 98th %ile**
Elbert					
Elbert				4.0	8.9
Prowers					
Lamar Power Plant	28	192	1.3		
Lamar Municipal	21	122	0.7		

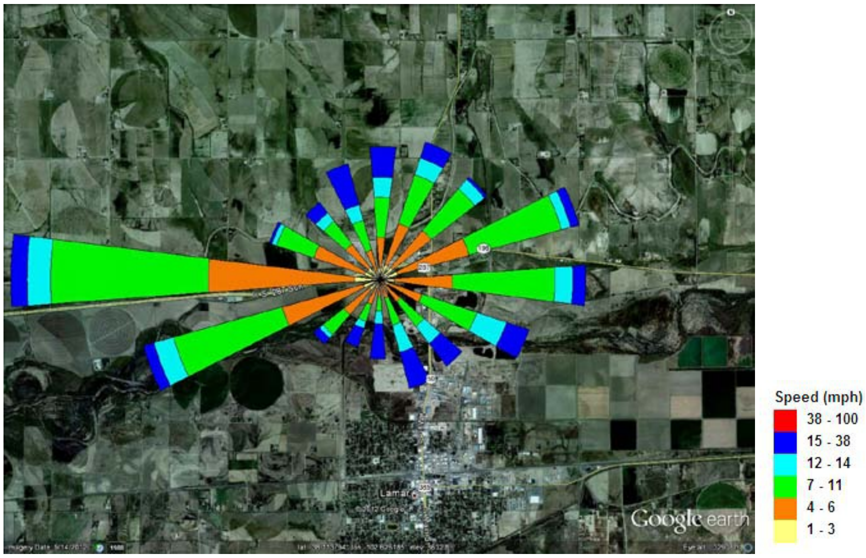

Figure 18. Eastern Plains Wind Rose, Lamar Port of Entry, 7100 US Hwy 50

The Lamar Power Plant station has had an average of 1.3 exceedances per year over the last 3 years (3, 0, and 1 exceedances for 2009, 2010, and 2011 respectively), which is in violation of the annual average primary standard, if exceptional events are not excluded (United States Environmental Protection Agency 2010). See Section 2.2.5.1. However, the Lamar Power Plant site is inappropriately sited and does not represent ambient air exposure. It is located on the roof of the old power plant near an obstructing wall which may bias the results. APCD has sent a request to EPA that the site be closed.

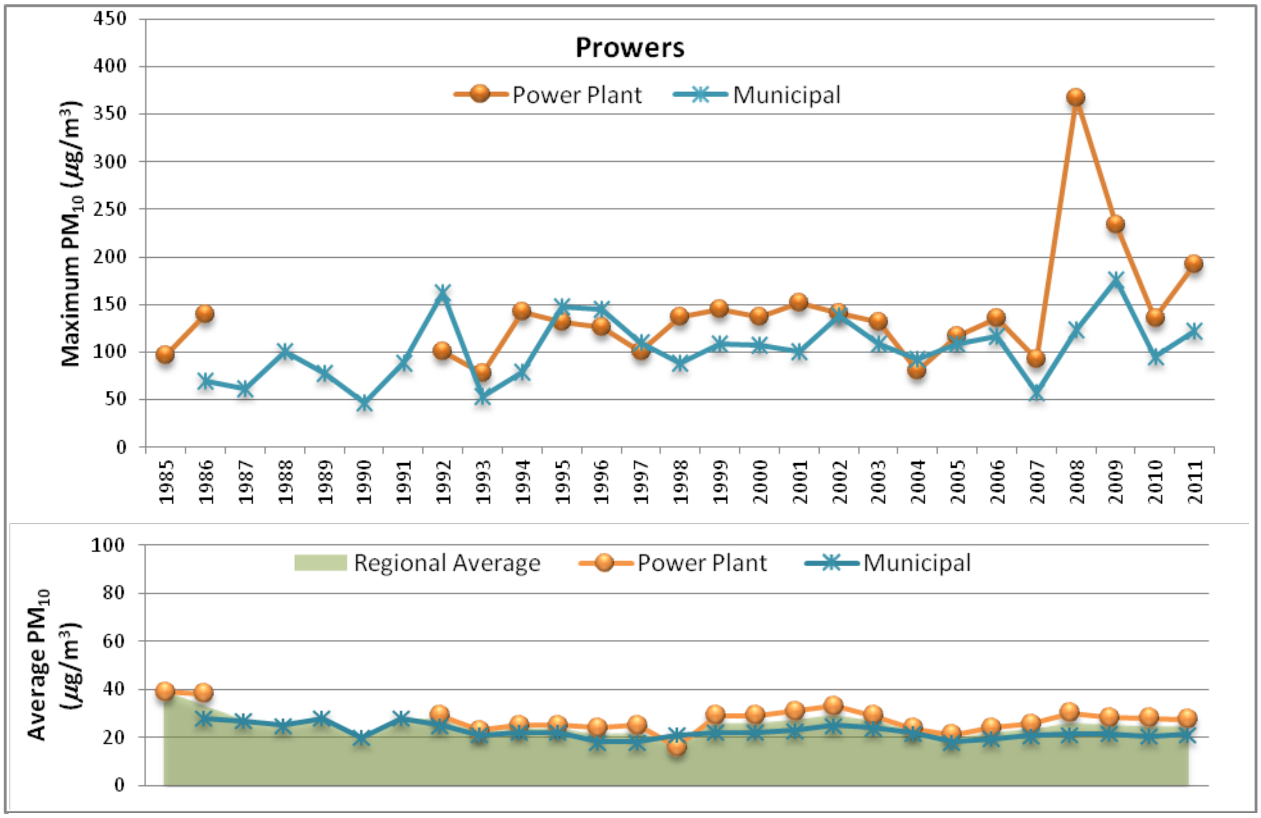

Figure 19. Average and Maximum PM_{10} Concentrations for the Eastern Plains Counties

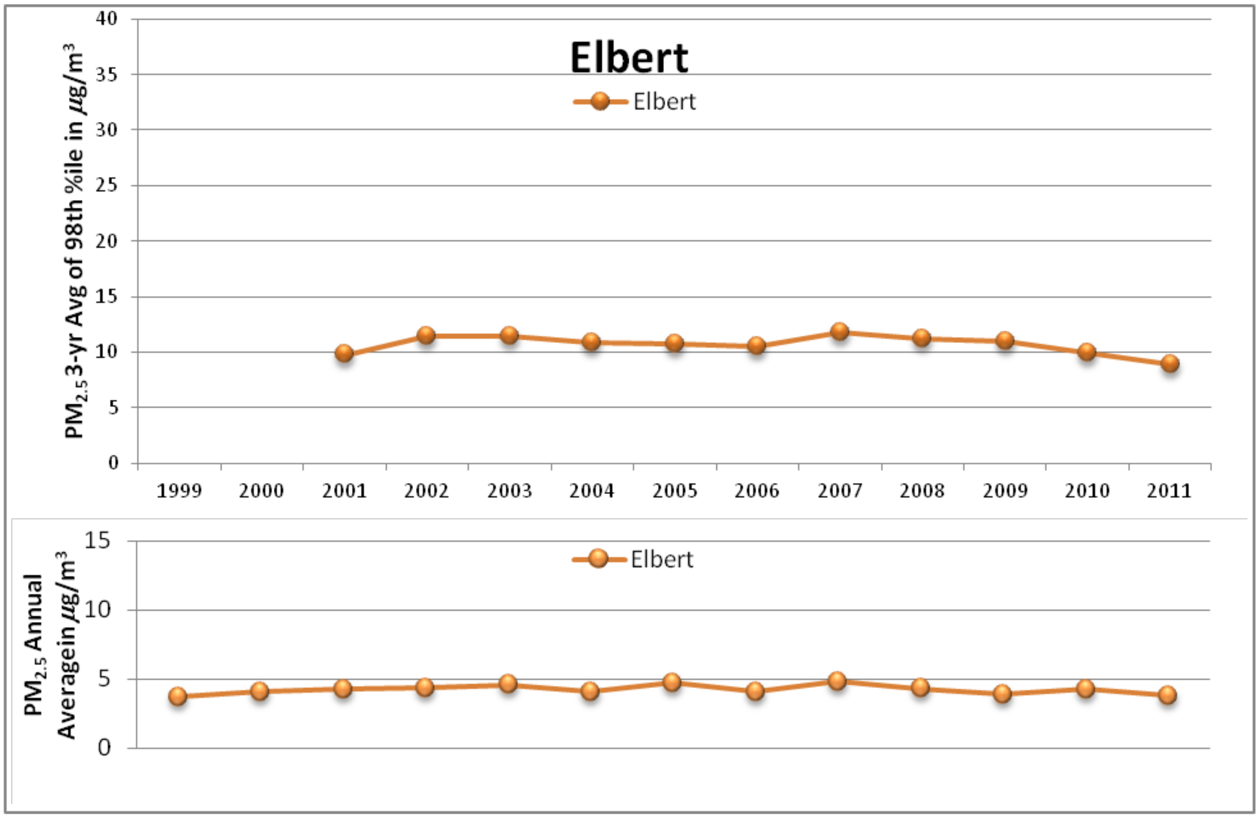

Figure 20. 3-Year 98th Percentile and Weighted Averages for $PM_{2.5}$ for Eastern Plains Counties

4.2. Northern Front Range Counties

Table 28 shows there were no violations of the $PM_{2.5}$ or PM_{10} NAAQS in the northern Front Range counties. Data below may include exceptional events. See Section 2.2.5.1.

Table 28. Northern Front Range Particulate Values[12]

Site Name	**PM_{10} (µg/m^3)**			**$PM_{2.5}$ (µg/m^3)**	
	Annual Average	**24-hour Maximum**	**3-Year Average Exceedance**	**3-Year Weighted Average**	**3-Year Average of 98th %ile**
Adams					
Commerce City	24.6	82	0	8.1	21.1
Welby (Continuous)	28.4	67	0		
	23.5	80			
Arapahoe					
Arapahoe Com. College				6.3	14.5
Boulder					
Longmont	19.8	36	0	6.9	20.3
Boulder, 2440 Pearl St.	19.1	35	0	6.5	18.7
Denver					
Denver CAMP (Continuous)	32.9	109	0	7.6	18.8
	30.1	96			
Visitor Center	25.2	123	0		
Swansea School				7.5	18.6
DMAS (Continuous)	22.3	47	0	7.3	17.6
	23.5	63			
Douglas					
Chatfield Res				5.7	15.6
Larimer					
Fort Collins - Edison (Continuous)	17.3	53	0	6.3	17.7
	16.9	45			
Weld					
Greeley	19.9	46	0	7.3	22.9
Platteville				7.6	20.1

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[12] Continuous monitors report hourly averages of particulate matter 365 days of the year. Other monitors sample particulate matter on filters on a fixed but non-continuous schedule.

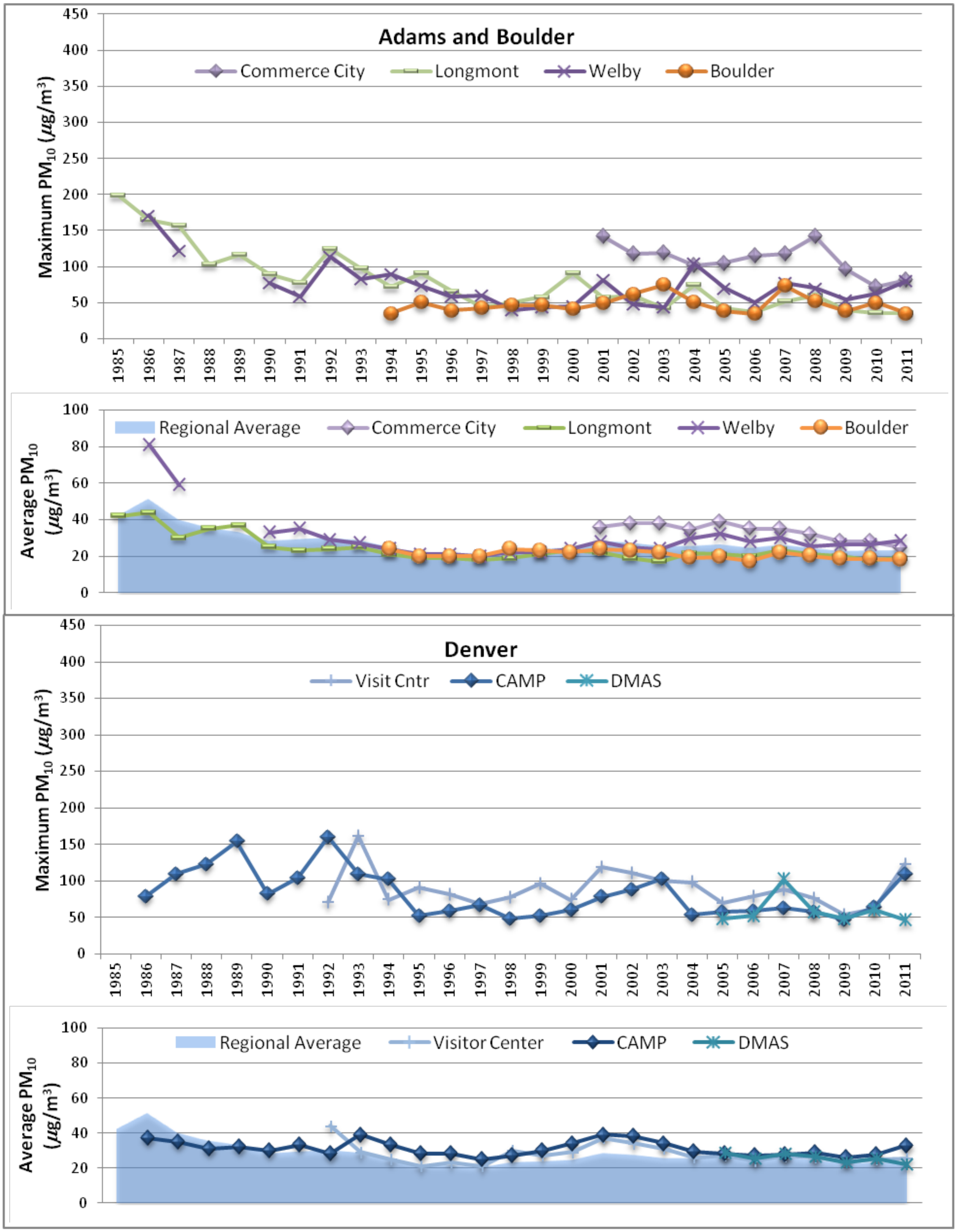


Figure 21. Average and Maximum PM_{10} Concentrations for the Northern Front Range Counties

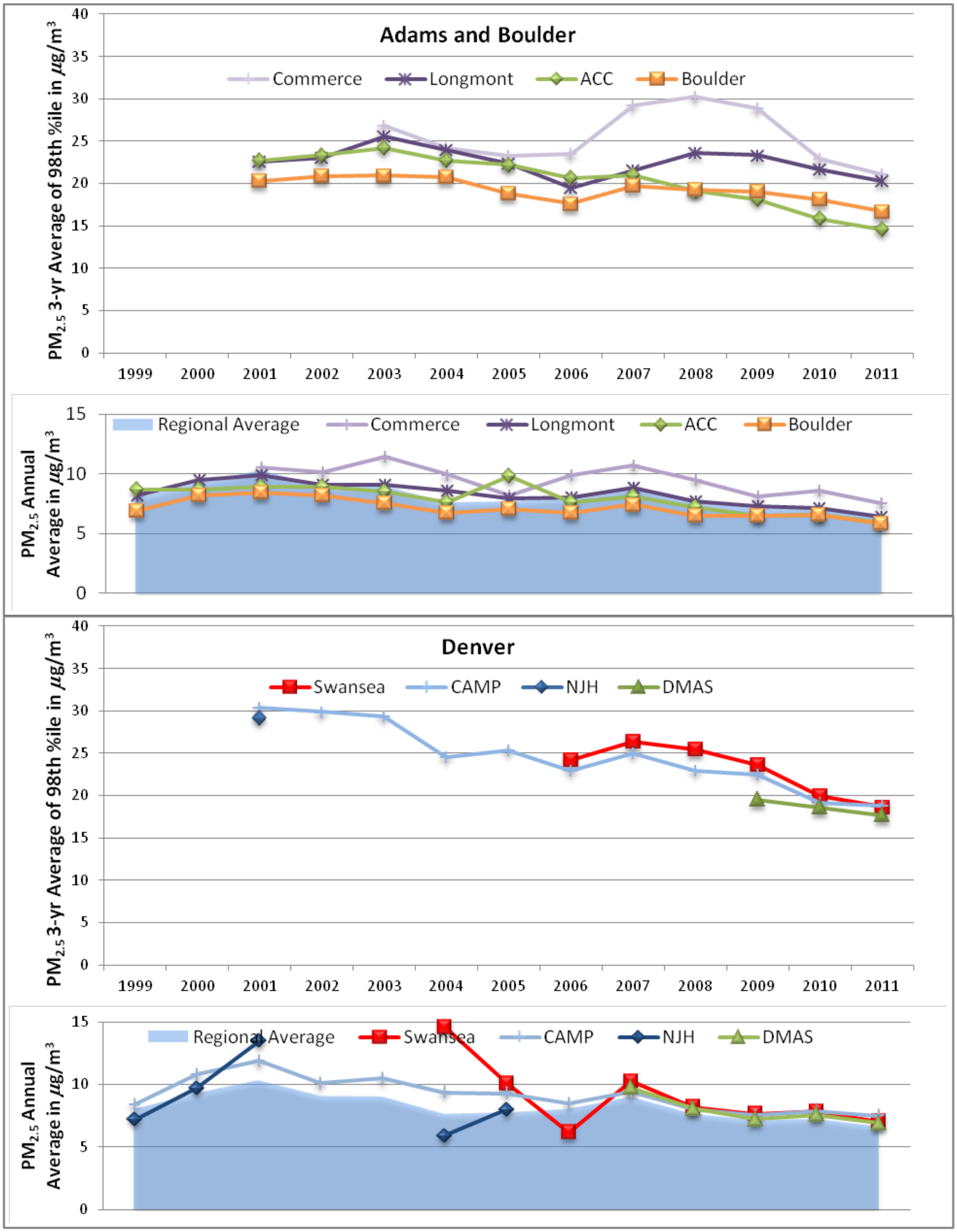


Figure 22. 3-Year 98th Percentile and Weighted Averages for $PM_{2.5}$ for the Northern Front Range Counties

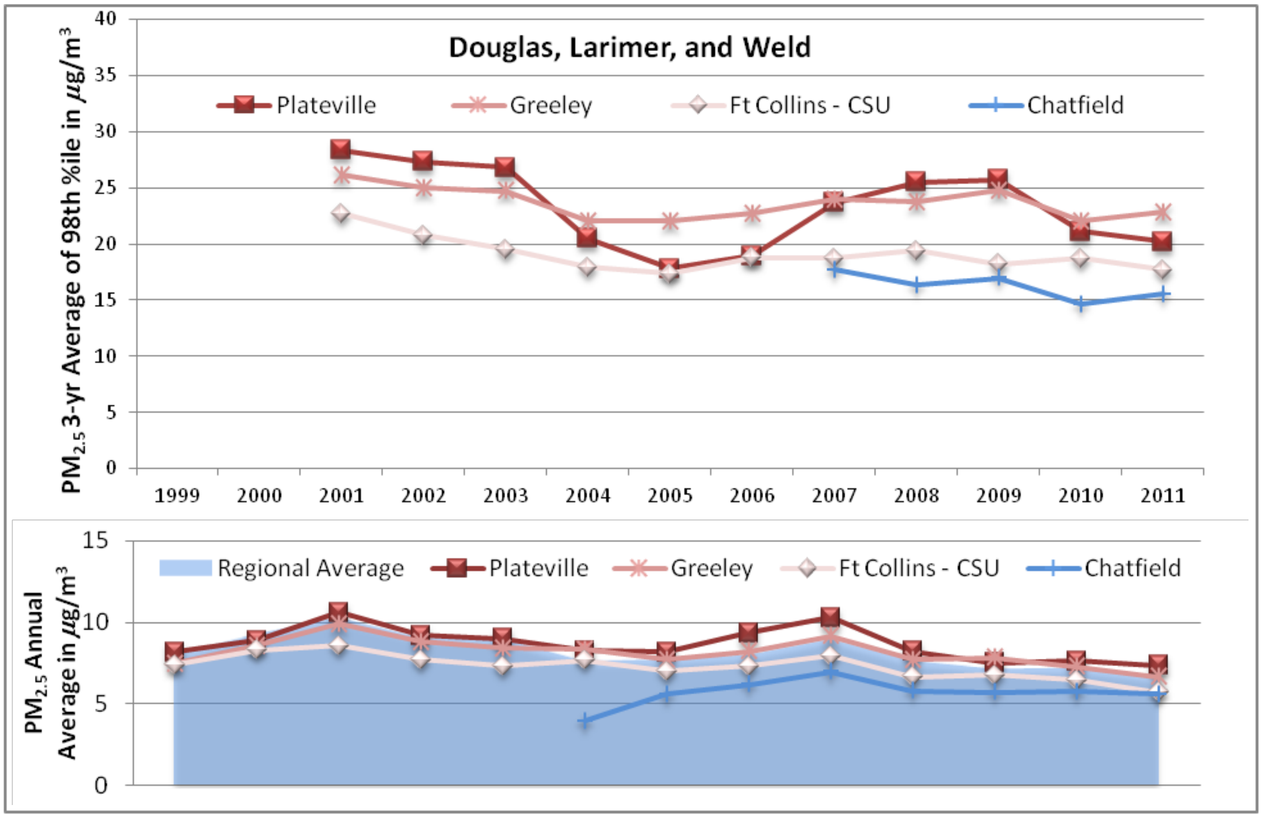


Figure 22. 3-Year 98th Percentile and Weighted Averages for $PM_{2.5}$ for the Northern Front Range Counties

Table 29. Northern Front Range TSP and Lead Values

Site Name	TSP (µg/m^3)		Lead (µg/m^3)	
	Annual Mean	**24-hour Maximum**	**Maximum Quarter**	**24-hour Maximum**
Denver				
DMAS	50.4	139	0.0147	0.018
Centennial	28.6	124	0.0370	0.060

() indicates less than 75 percent data for one or more quarters.

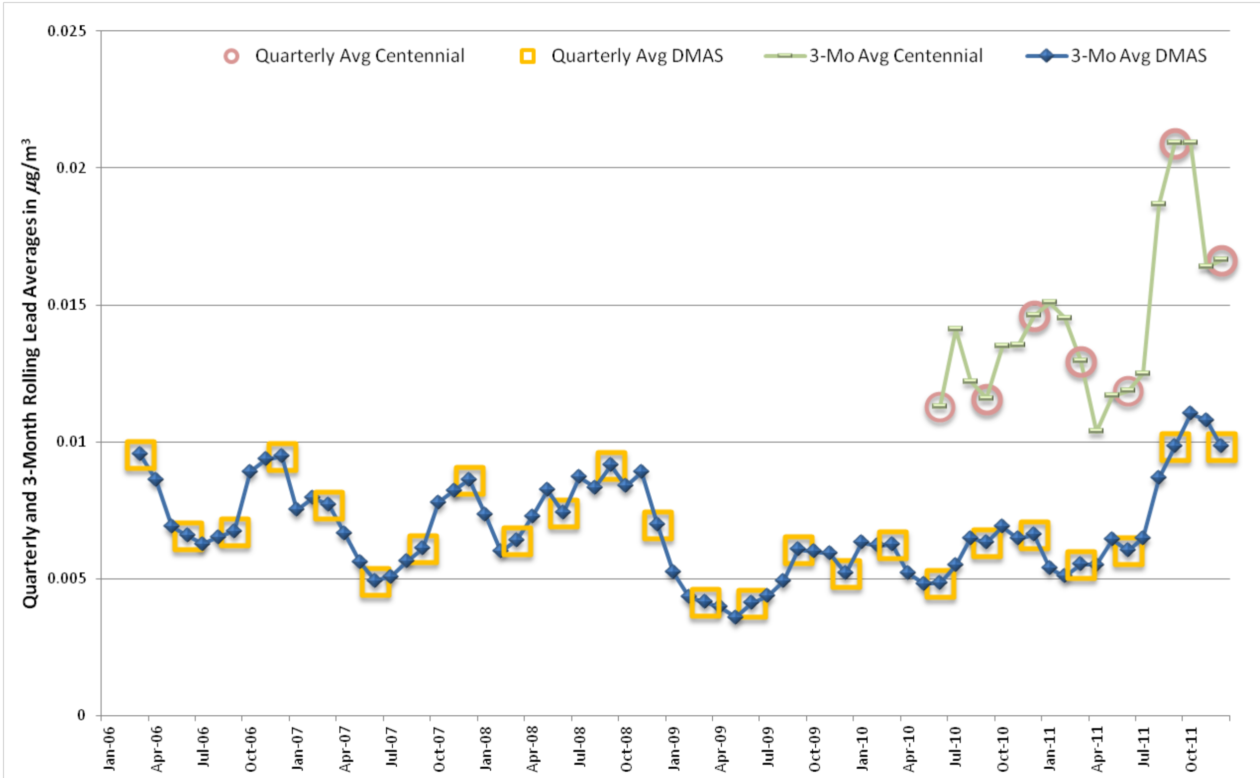


Figure 23. Quarterly Lead Averages for the Northern Front Range Counties

Table 30. Northern Front Range Carbon Monoxide Values

Site Name	Location	CO 1-hour Avg. (ppm)		CO 8-hour Avg. (ppm)	
		1st Maximum	**2nd Maximum**	**1st Maximum**	**2nd Maximum**
Adams					
Welby	3174 E. 78th Ave.	2.4	2.4	2.0	1.6
Boulder					
Longmont	440 Main St.	8.6	4.3	2.6	2.1
Denver					
Denver-CAMP	2105 Broadway	3.5	3.1	1.9	1.8
Firehouse #6	1300 Blake St.	2.7	2.7	1.8	1.9
DMAS	678 S. Jason St	2.5	2.4	1.5	1.5
Larimer					
Fort Collins	708 S. Mason St	2.8	2.5	1.5	1.3
Weld					
Greeley	905 10th Ave.	2.7	2.5	2.0	1.5

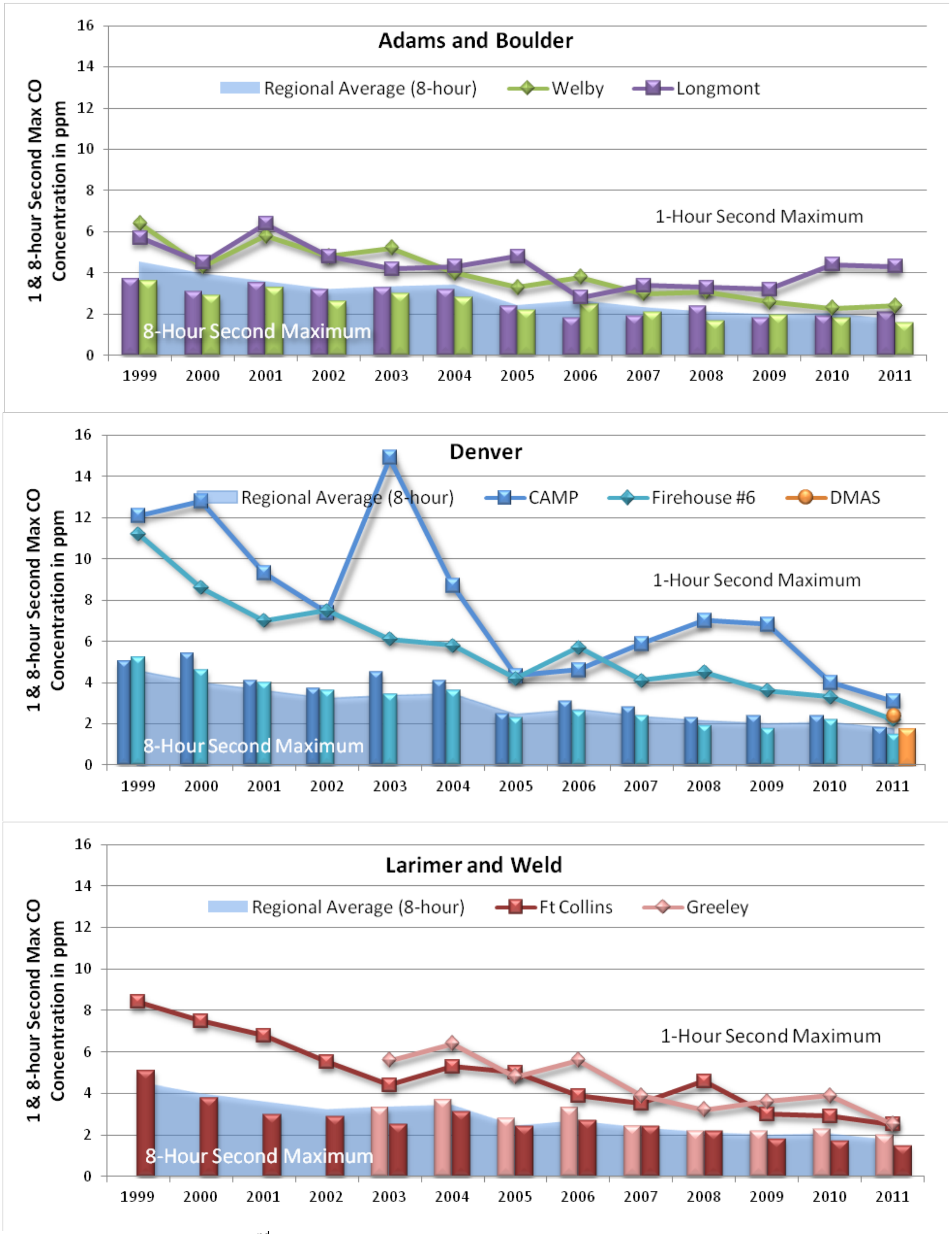


Figure 24. 1-hour and 8-hour 2nd Maximum Carbon Monoxide Averages for the Northern Front Range Counties

Table 31.	Northern Front Range Ozone Values

Site Name	**Location**	**Ozone 8-hour Avg. (ppm)**		
		1st Maximum	**4th Maximum**	**3-year Average of 4th Maximum**
Adams				
Welby	3174 E. 78th Ave.	0.089	0.075	0.070
Arapahoe				
Highland Reservoir	8100 S. University Blvd	0.087	0.078	0.074
Aurora East	36001 E. Quincy Ave.	0.089	0.073	0.071
Boulder				
Boulder	1405½ Foothills Parkway	0.082	0.076	0.074
Denver				
Denver Carriage	2325 Irving St.	0.073	0.074	0.069
DMAS	678 S. Jason St.	0.075	0.070	0.065
Douglas				
Chatfield Reservoir	11500 N. Roxborough Park Rd.	0.099	0.081	0.077
Jefferson				
Arvada	9101 W. 57th Ave.	0.100	0.079	0.075
Welch	12400 W. Hwy 285	0.087	0.077	0.073
Rocky Flats-N	16600 W. Colorado 128	0.104	0.081	0.079
NREL	2054 Quaker St.	0.096	0.083	0.075
Aspen Park	26137 Conifer Rd.	0.078	0.071	0.071
Larimer				
Fort Collins-W	3416 La Porte Ave.	0.086	0.080	0.076
Rist Canyon	11835 Rist Canyon Rd.	0.080	0.073	0.071
Fort Collins-Mason	708 S. Mason St.	0.071	0.068	0.066
Weld				
Weld County Tower	3101 35th Ave.	0.081	0.077	0.072

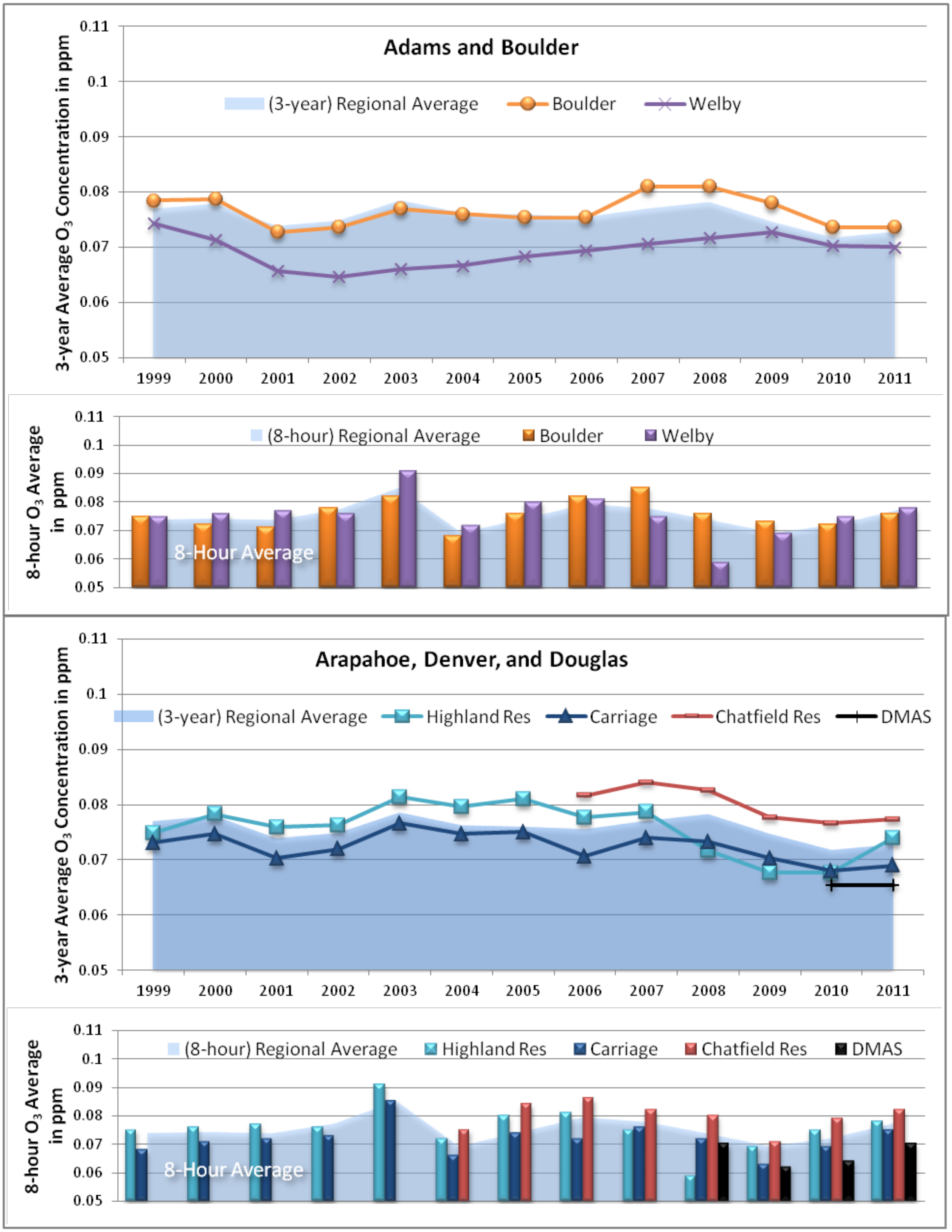


Figure 25. 3-year 4th Maximum Average and 8-hour 4th Maximum Ozone Concentrations for the Northern Front Range Counties

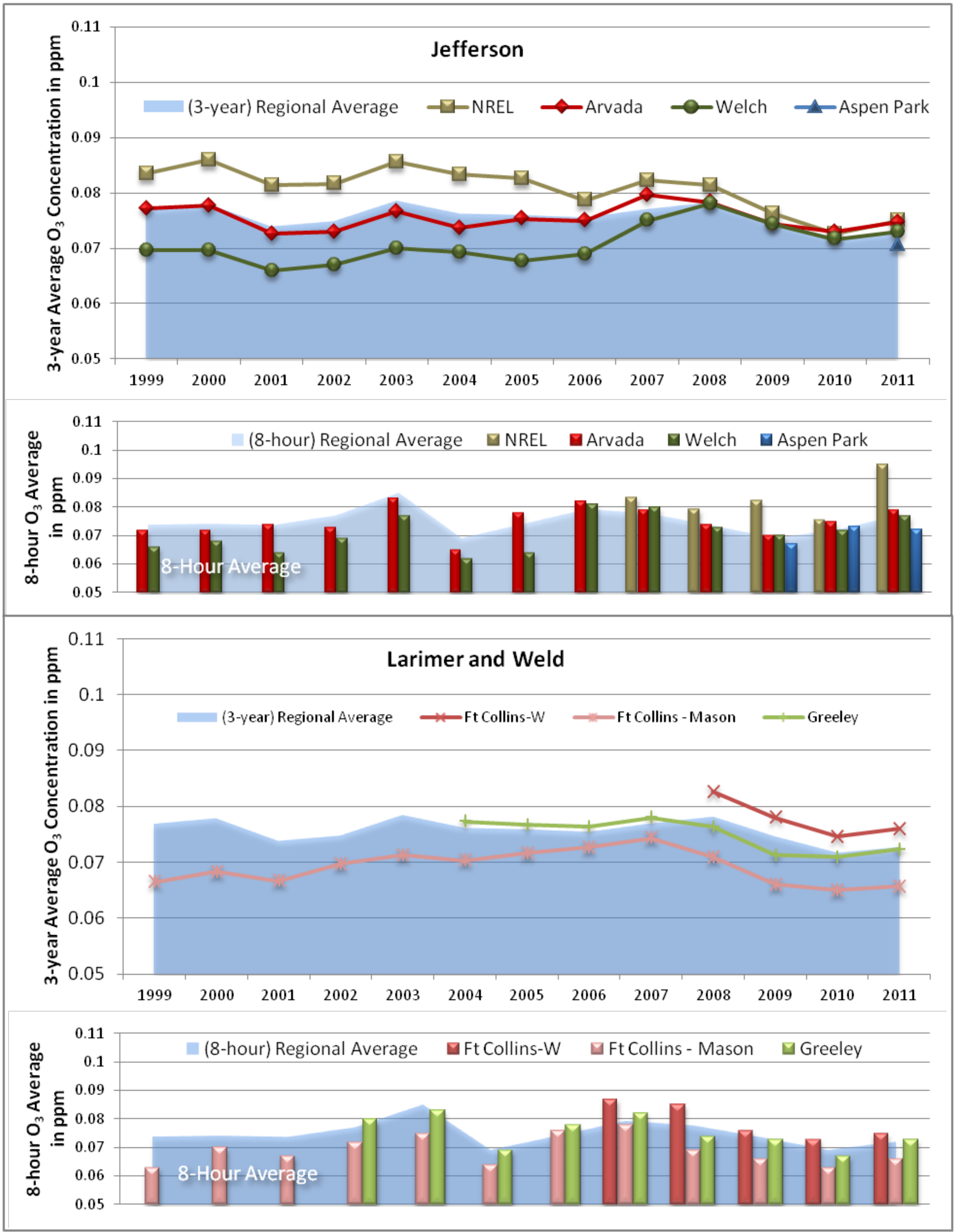
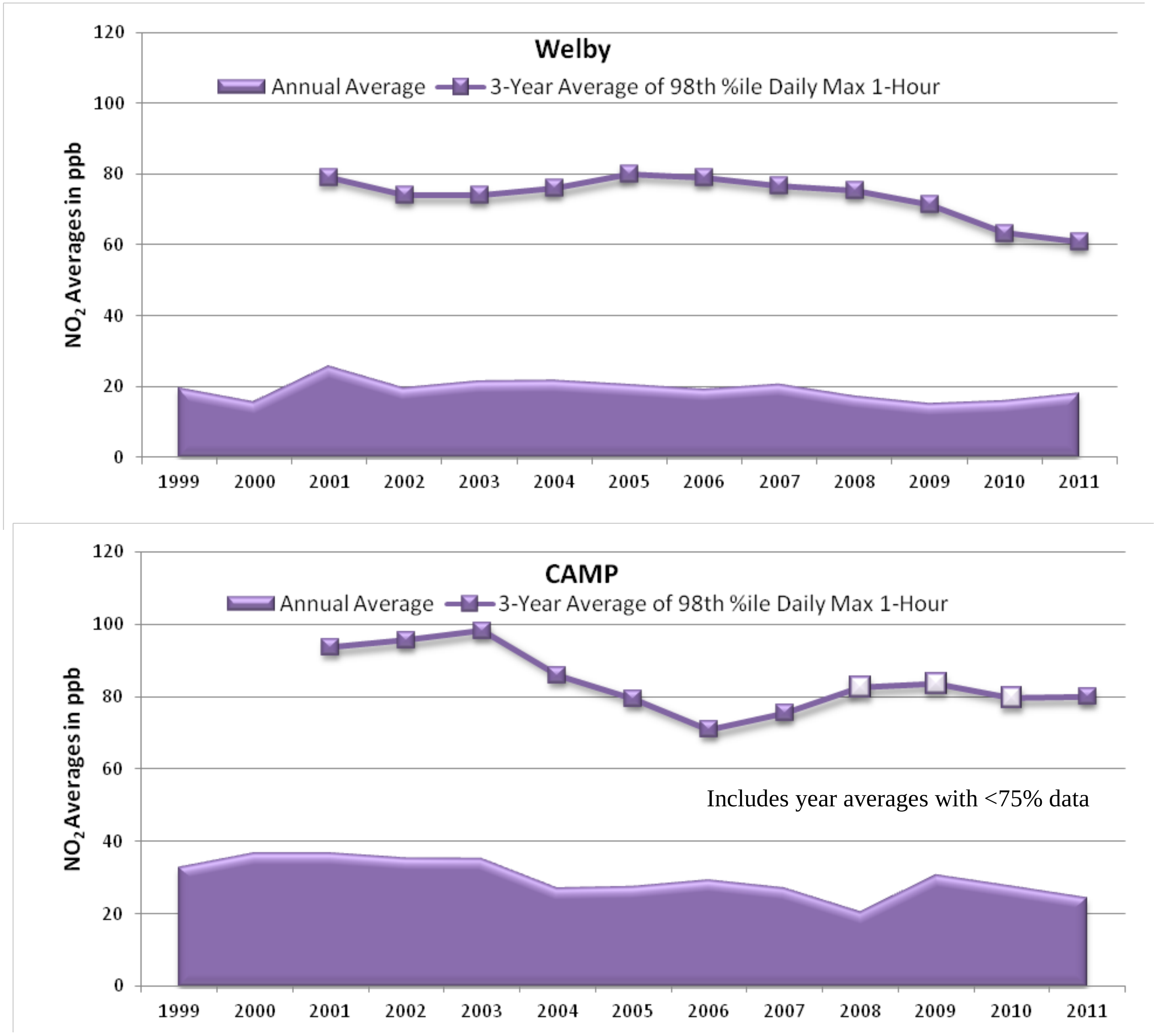


Figure 25. 3-year 4th Maximum Average and 8-hour 4th Maximum Ozone Concentrations for the Northern Front Range Counties

Table 32. Northern Front Range Oxides of Nitrogen and Sulfur Dioxide Values

Site Name	**Nitrogen Dioxide (ppb)**		**Sulfur Dioxide (ppb)**			
	Annual Mean	**3-year Avg 2nd 1-hr Max**	**3-hour 2nd Max**	**24-hour 2nd Max**	**Annual Mean**	**3-year Avg**
Welby	18.1	70	19	4.7	1.36	39
CAMP	24.5	88	26	7.3	2.07	41
DMAS			19	5.5	2.2	<3 Years

() indicates <75% data recovery



Includes year averages with <75% data

Figure 26. Annual and 3-year Average Nitrogen Dioxide Concentrations for Northern Front Range Counties

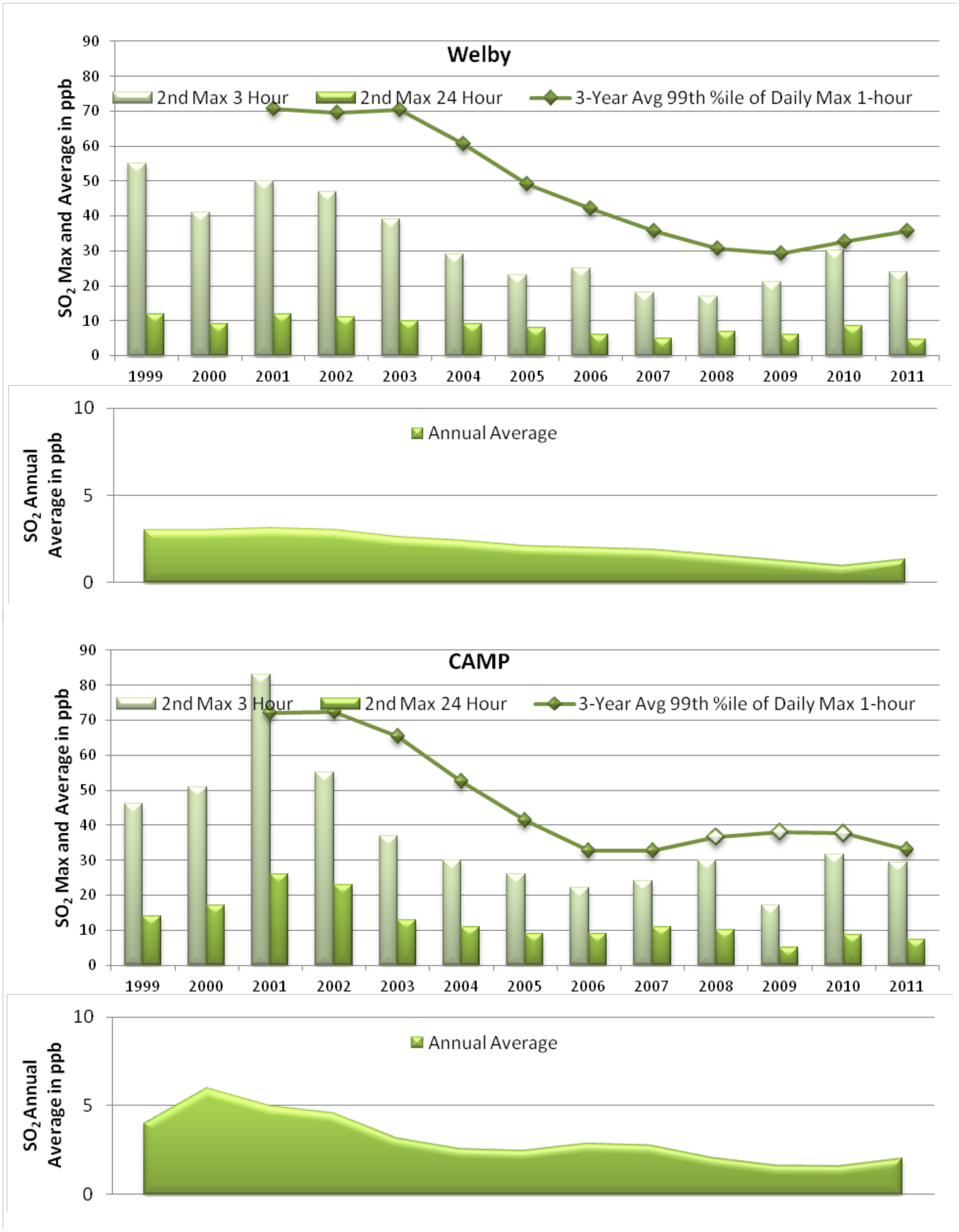


Figure 27. Sulfur Dioxide Maximums and Averages for Northern Front Range Counties

Table 33. Denver Visibility Standard Exceedance Days (Transmissometer Data)

Month	Days	EX POOR	POOR	FAIR	GOOD	Missing	(>70% RH)
January	31	1	4	12	11		3
February	28		4	13	6	2	3
March	31		2	19	8		2
April	30		4	10	12	3	1
May	31		6	14	5		6
June	30	1	4	11	1	13	
July	31		3	18	10		
August	31		1	24	6		
September	30			26	1		3
October	31		2	20	7		2
November	30	3	1	14	9	2	1
December	31	1	7	18	1		4
Totals							
	365	6	38	199	77	20	25

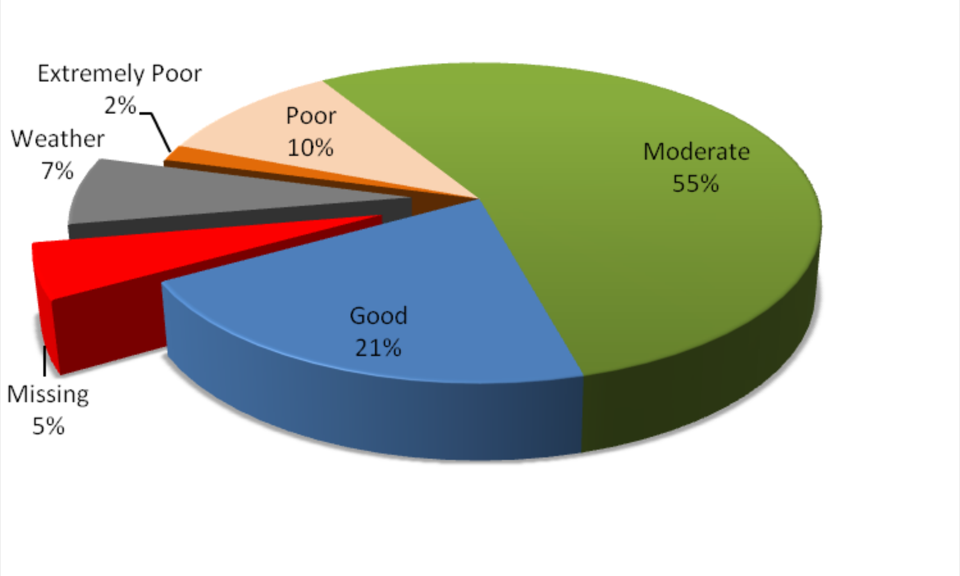


Figure 28. Denver Visibility Data

In Figure 29 and 30, days above the standard are shown as positive numbers and days below the standard are shown as negative numbers. In addition, error bars in the positive direction indicate the number of days where data is missing, and error bars in the negative direction indicate the number of days with data excluded for weather (only tracked at Ft. Collins since 2009).

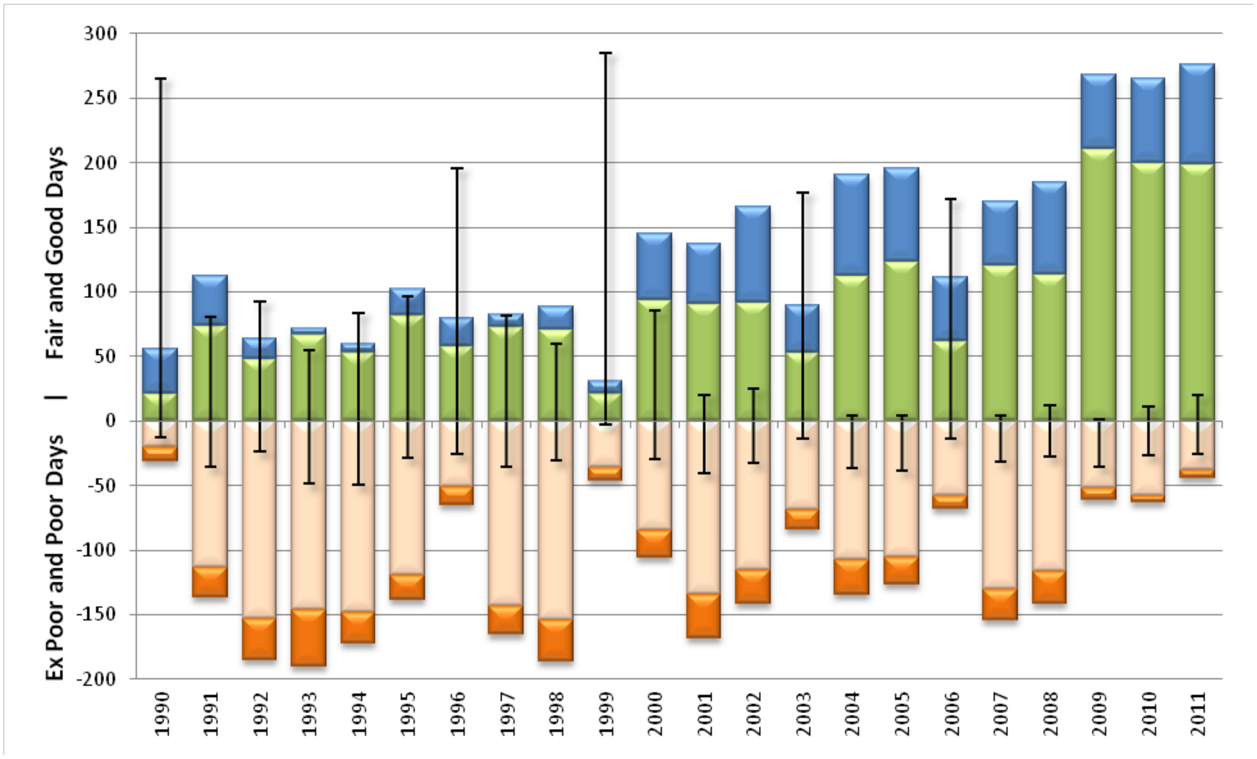


Figure 29. Annual Comparison of Visibility Data in Denver Between 1990 and 2011

Table 34. Fort Collins Visibility Standard Exceedance Days (Transmissometer Data)

Month	Days	EX POOR	POOR	FAIR	GOOD	Missing	(>70% RH)
January	31		3	5	11	9	3
February	28			4	14	9	1
March	31		2	10	15	3	1
April	30		4	11	11	4	
May	31		4	7	11	9	
June	30		6	5	12	6	
July	31		3	14	13	1	
August	31		5	17	7	2	
September	30			1	3	26	
October	31		4	11	12	4	
November	30		1	6	16	7	
December	31			3	7	16	5
Totals							
	365	0	32	94	132	96	10

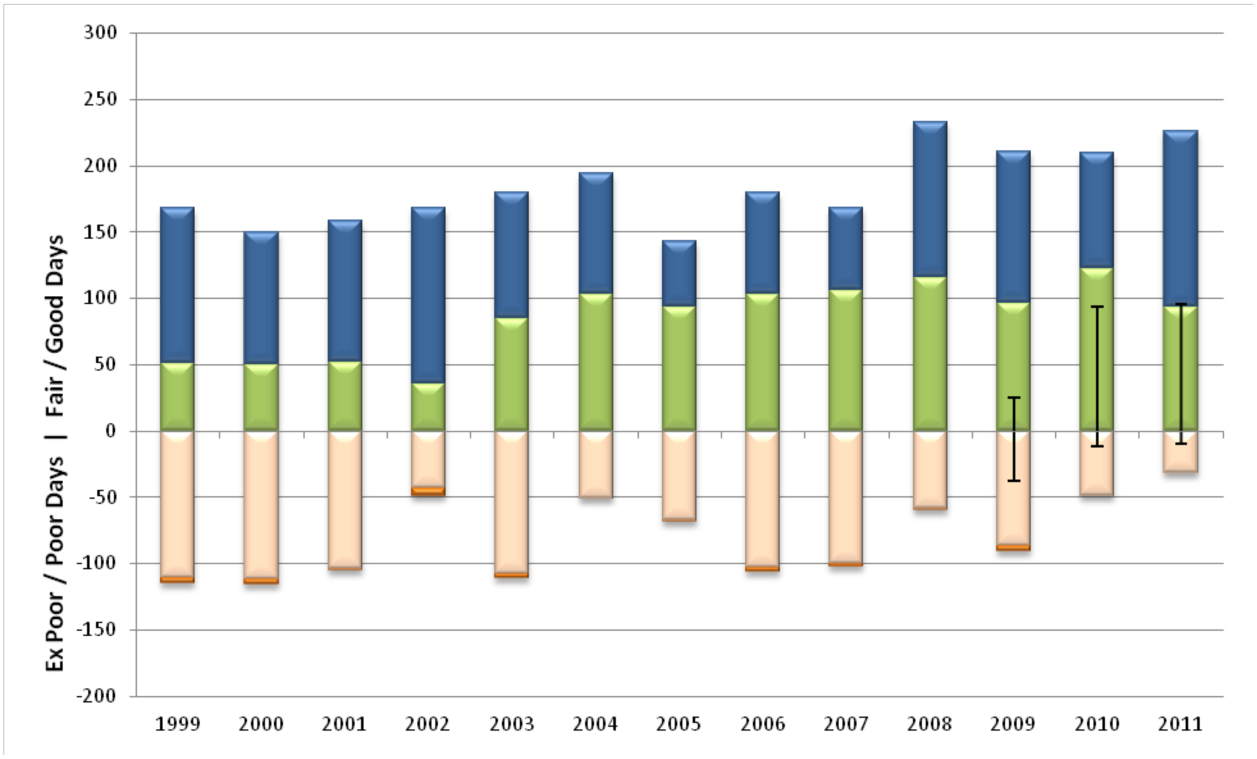


Figure 30. Annual Comparison of Visibility Data in Ft. Collins between 1999 and 2011

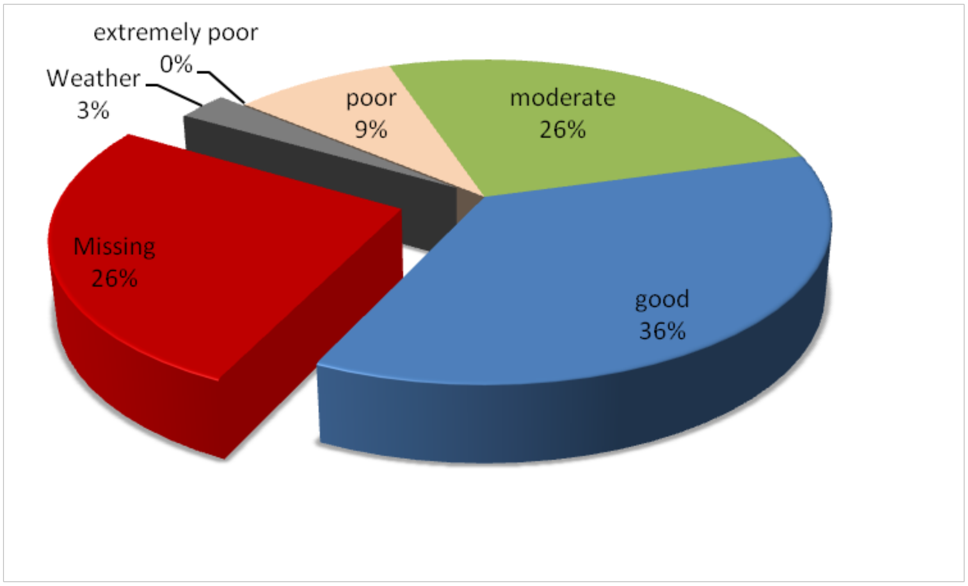
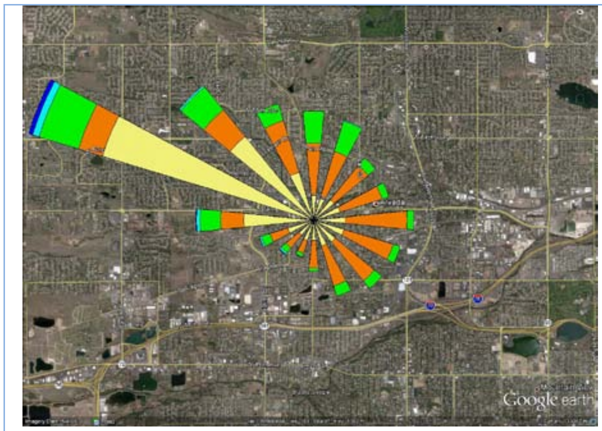
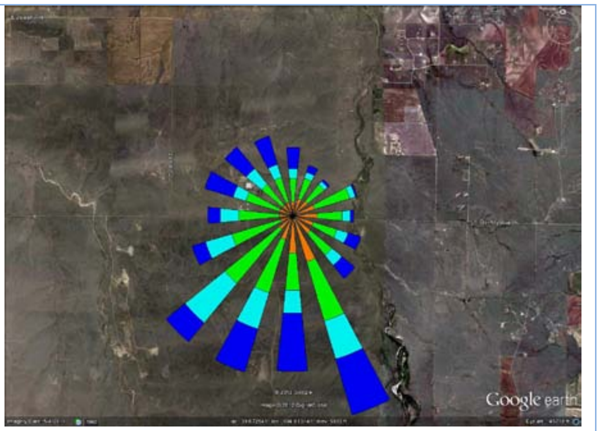


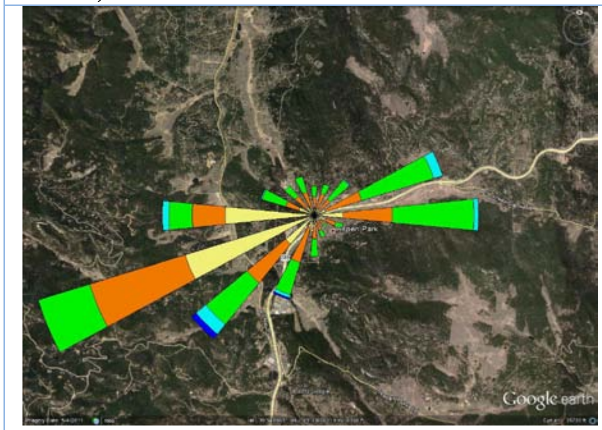
Figure 31. Ft. Collins Visibility Data

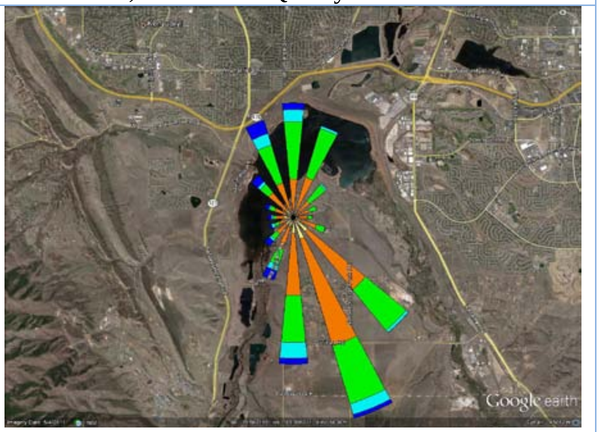
Figure 29 shows that since 1999, Fort Collins has averaged 89 days per year where the visibility was either “Fair” or “Good” and only 44 days where the visibility was either “Poor” or “Ex Poor.” The missing days are lost due to either high relative humidity (greater than 70 percent) or machine maintenance.

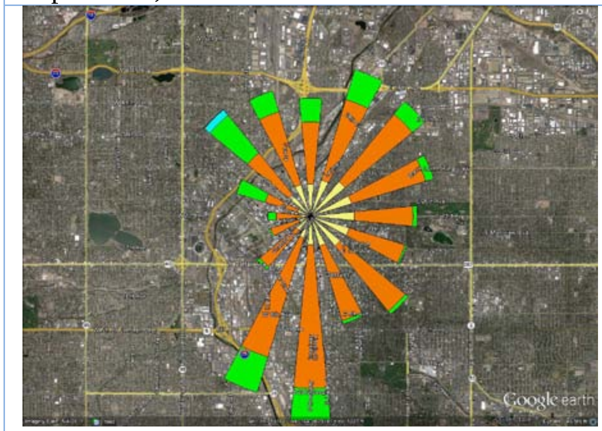
Figure 32. Northern Front Range Wind Roses (Pages 53-55)

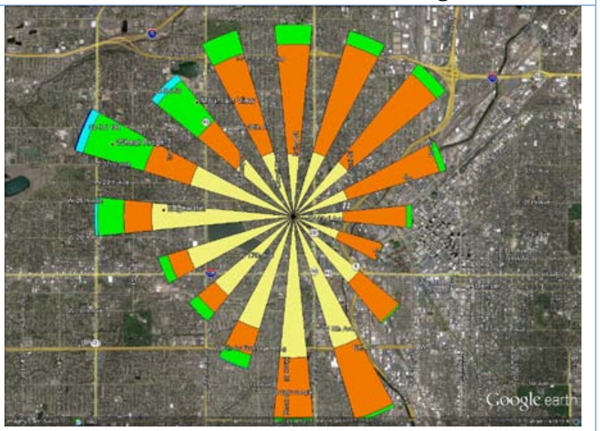

Arvada, 9101 W. 57th Ave.


Aurora East, 36001 East Quincy Ave.


Aspen Park, 26137 Conifer Rd.


Chatfield Reservoir, 11500 N. Roxborough Pk. Rd.

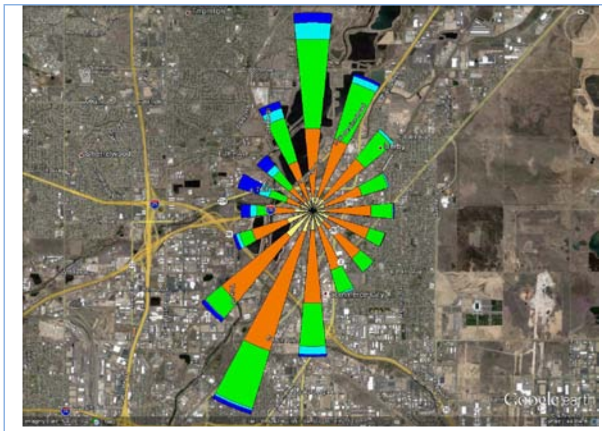

Denver CAMP, 2105 Broadway


Denver Carriage, 2325 Irving St.

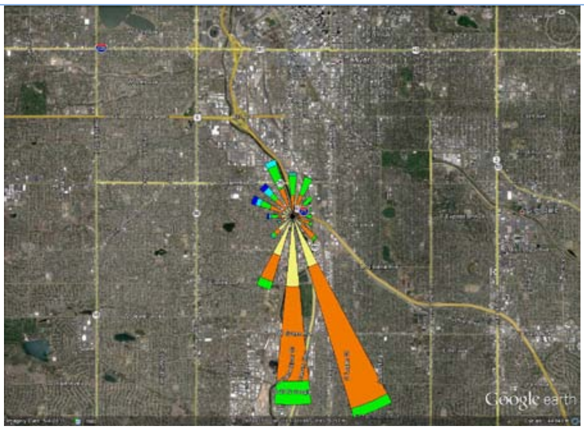
Speed (mph)

🟥 38 - 100
🟦 15 - 38
🟦 12 - 14
🟩 7 - 11
🟧 4 - 6
🟨 1 - 3

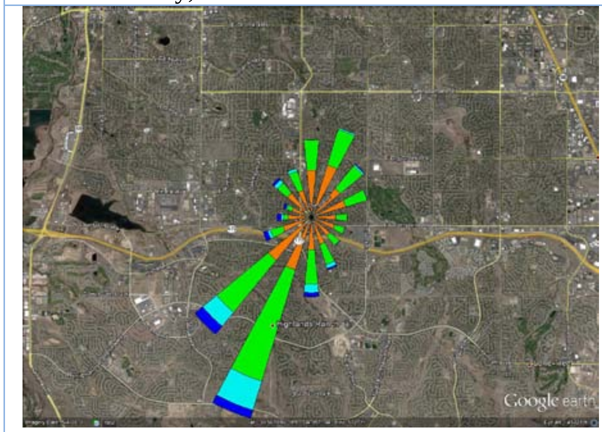
Figure 32. Northern Front Range Wind Roses (Pages 53-55) (Continued)



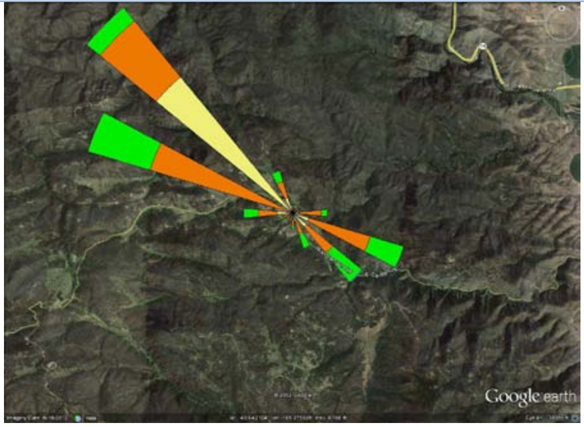
Commerce City, 7101 Birch St.



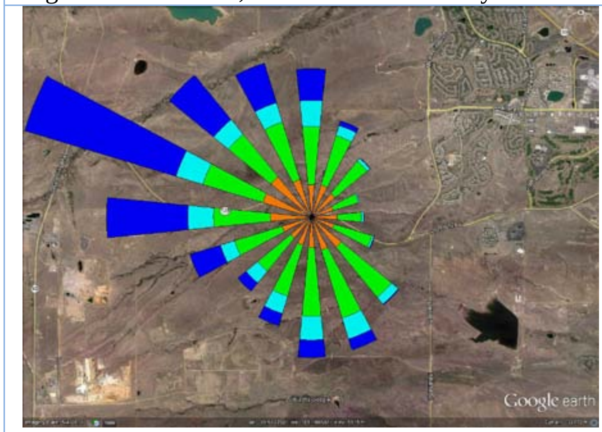
Denver Municipal Animal Shelter, 678 S. Jason St.



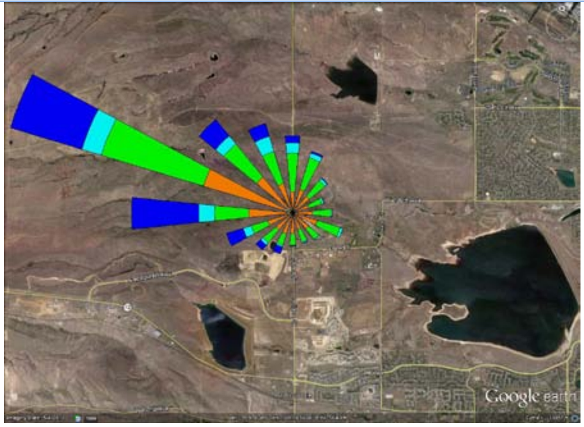
Highlands Reservoir, 8100 South University Blvd.



Rist Canyon and 708 S. Mason St.



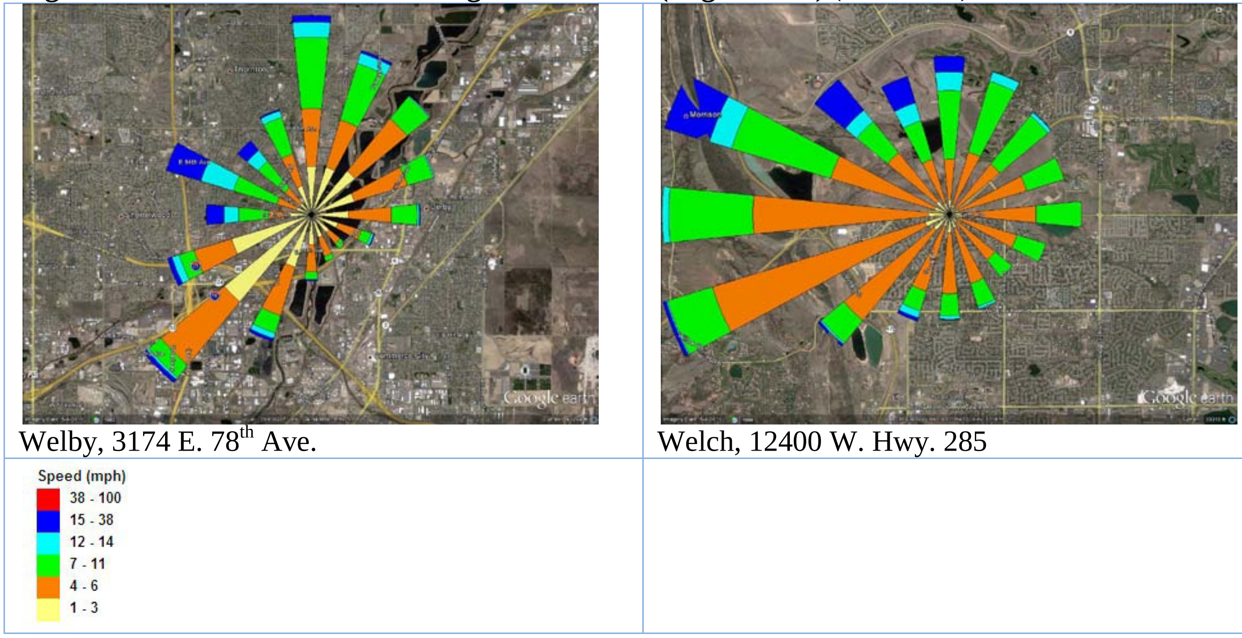
Rocky Flats-N, 16600 W. Hwy. 128



Rocky Flats- SE, 9901 Indiana St.

Speed (mph)
🟥 38 - 100
🟦 15 - 38
🟦 12 - 14
🟩 7 - 11
🟧 4 - 6
🟨 1 - 3

Figure 32. Northern Front Range Wind Roses (Pages 53-55) (Continued)


Welby, 3174 E. 78th Ave.

Welch, 12400 W. Hwy. 285

4.3. Southern Front Range Counties

Data below may include exceptional events. See Section 2.2.5.1.

Table 35. Southern Front Range Particulate Values

Site Name	Location	PM_{10} (µg/m^3)			$PM_{2.5}$ (µg/m^3)	
		Annual Avg.	24-hour Max	3-Year Avg. Exceedance	3-Year Weighted Avg.	3-Year Average of 98th %ile
Alamosa						
ASC	208 Edgemont Blvd. (ASC)	25.3	440	3.3		
Alamosa Municipal	425 4th St. (Municipal)	38.0	635	2.6		
El Paso						
Colorado Springs	130 W. Cache la Poudre	19.0	63	0	5.9	13.7
Fremont						
Cañon City	128 Main St.	18.8	71	0		
Pueblo						
Fountain Magnet	925 N. Glendale Ave.	20.6	117	<3 Years Data	<3 Years Data	<3 Years Data

The Alamosa Municipal station has had an average of 3 exceedances per year over the last 3 years (1, 3, and 4 exceedances for 2009, 2010, and 2011 respectively), and the ASC site had an average of 3 exceedances (1, 4, and 5 respectively), which is in violation of the annual average primary standard. Not including exceptional events awaiting EPA concurrence, neither site is in violation of this standard (United States Environmental Protection Agency 2010). In 2009, the Pueblo site was moved to the Fountain Magnet school, which has not yet collected three complete years of data.

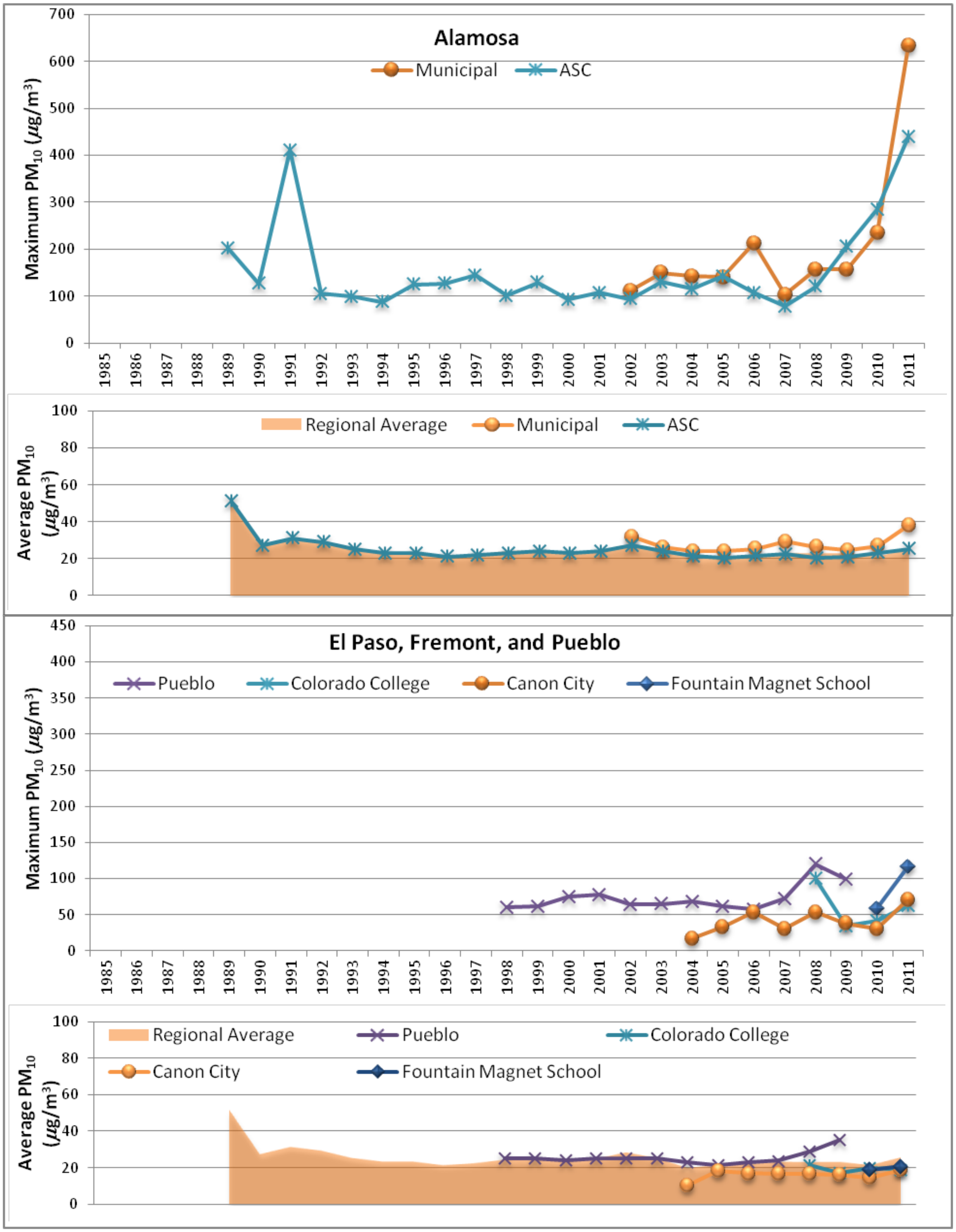


Figure 33. Average and Maximum PM10 Concentrations for Southern Front Range Counties

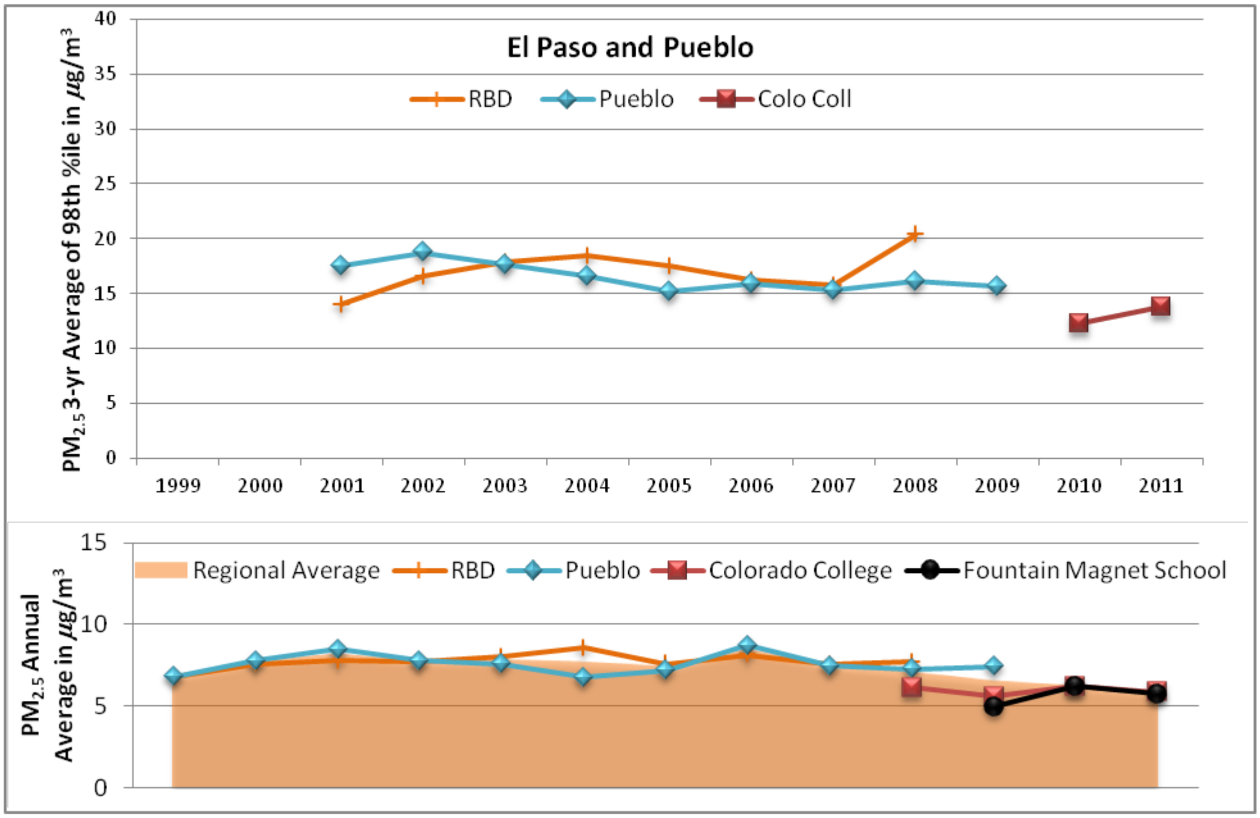


Figure 34. 3-Year 98th Percentile and Weighted Averages for $PM_{2.5}$ for the Southern Front Range Counties

Table 36. Southern Front Range Carbon Monoxide Values

Site Name	**Location**	**CO 1-hour Avg. (ppm)**		**CO 8-hour Avg. (ppm)**	
		1st Maximum	**2nd Maximum**	**1st Maximum**	**2nd Maximum**
El Paso					
Colorado Springs	690 W. Hwy 24	3.0	2.7	1.7	1.5

Table 37. Southern Front Range Ozone Values

Site Name	**Location**	**Ozone 8-hour Avg. (ppm)**		
		1st Maximum	**4th Maximum**	**3-year Average of 4th Maximum**
El Paso				
USAFA	USAFA Rd 640	0.083	0.074	0.067
Manitou Springs	101 Banks Pl.	0.080	0.075	0.070

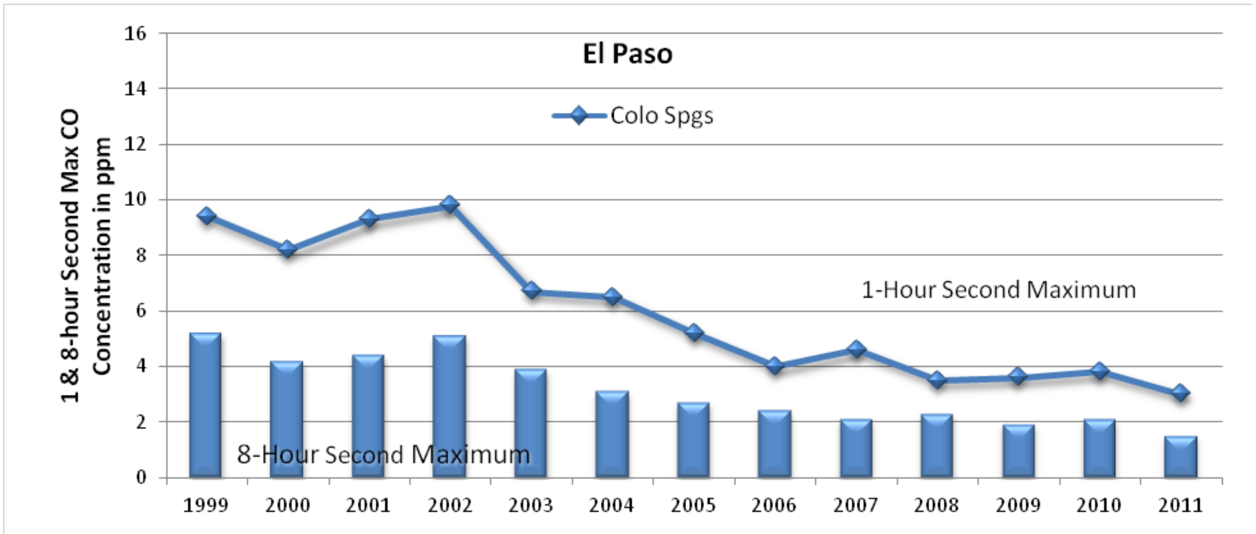


Figure 35. 1-hour and 8-hour 2nd Maximum Carbon Monoxide Averages for the Southern Front Range Counties

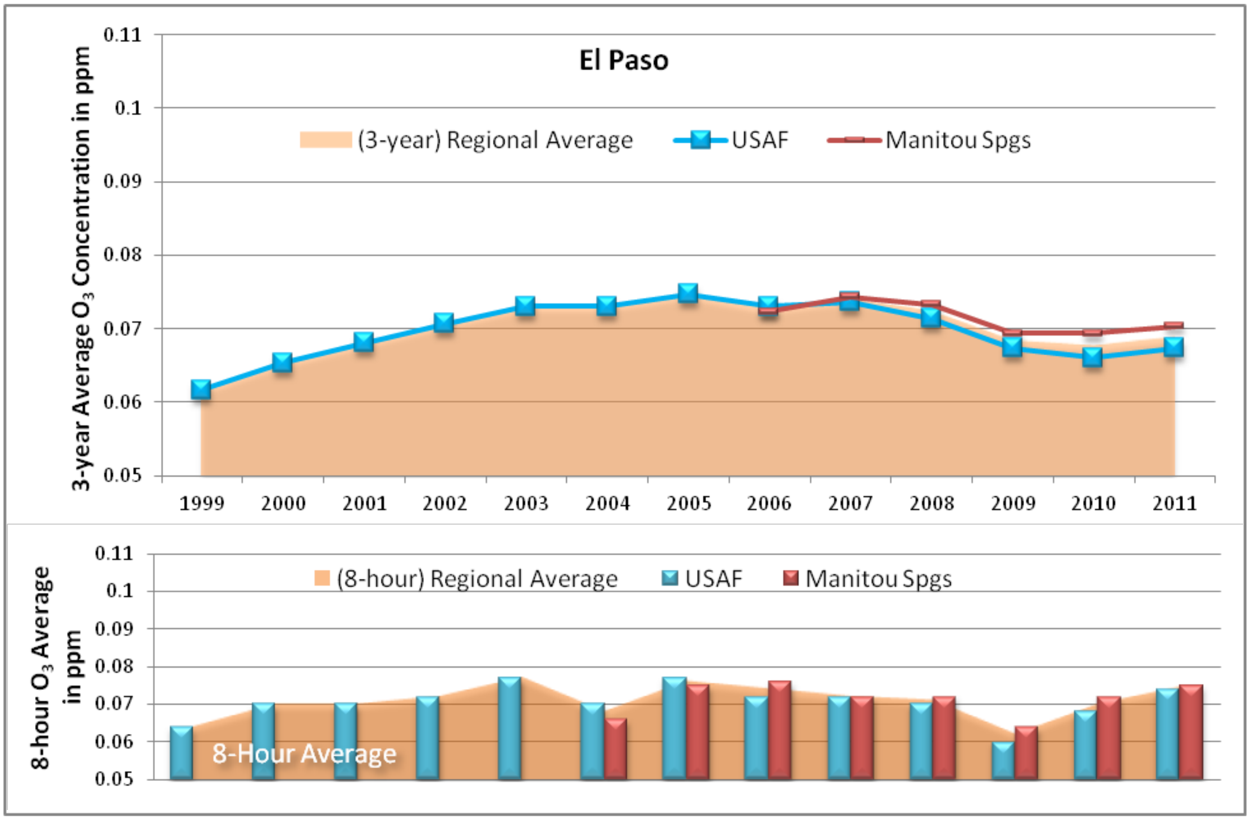


Figure 36. 3-year 4th Maximum Average and 8-hour 4th Maximum Ozone Concentrations for the Southern Front Range Counties

4.4. Mountain Counties

The data below may include exceptional events. See Section 2.2.5.1.

Table 38. Mountain Counties Particulate Values

Site Name	Location	PM_{10} (μg/m^3)		
		Annual Avg.	24-Hr Max	3-Year Avg. Exceedances
Archuleta				
Pagosa Springs	309 Lewis St.	20.5	109	3
Gunnison				
Crested Butte	603 6th St.	23.1	74	0
Mt. Crested Butte	19 Emmons Loop	15.1	65	0
Pitkin				
Aspen	120 Mill St.	15.3	51	0
Routt				
Steamboat Springs	136 6th St.	20.6	135	0
Summit				
Breckenridge	501 N. Park Ave.	15.3	86	0

The Pagosa Springs station has an average of 3 exceedances per year over the last 3 years (4, 5, and 0 exceedances for 2009, 2010, and 2011 respectively), which is in violation of the annual average primary standard. Not including exceptional events awaiting EPA concurrence, the station is not in violation of this standard (United States Environmental Protection Agency 2010).

The city of Aspen operates an ozone monitor. In the past data from that monitor has been included in this report (for calendar year 2010). Quality Assurance concerns have led to the monitor being excluded from this report for 2011.

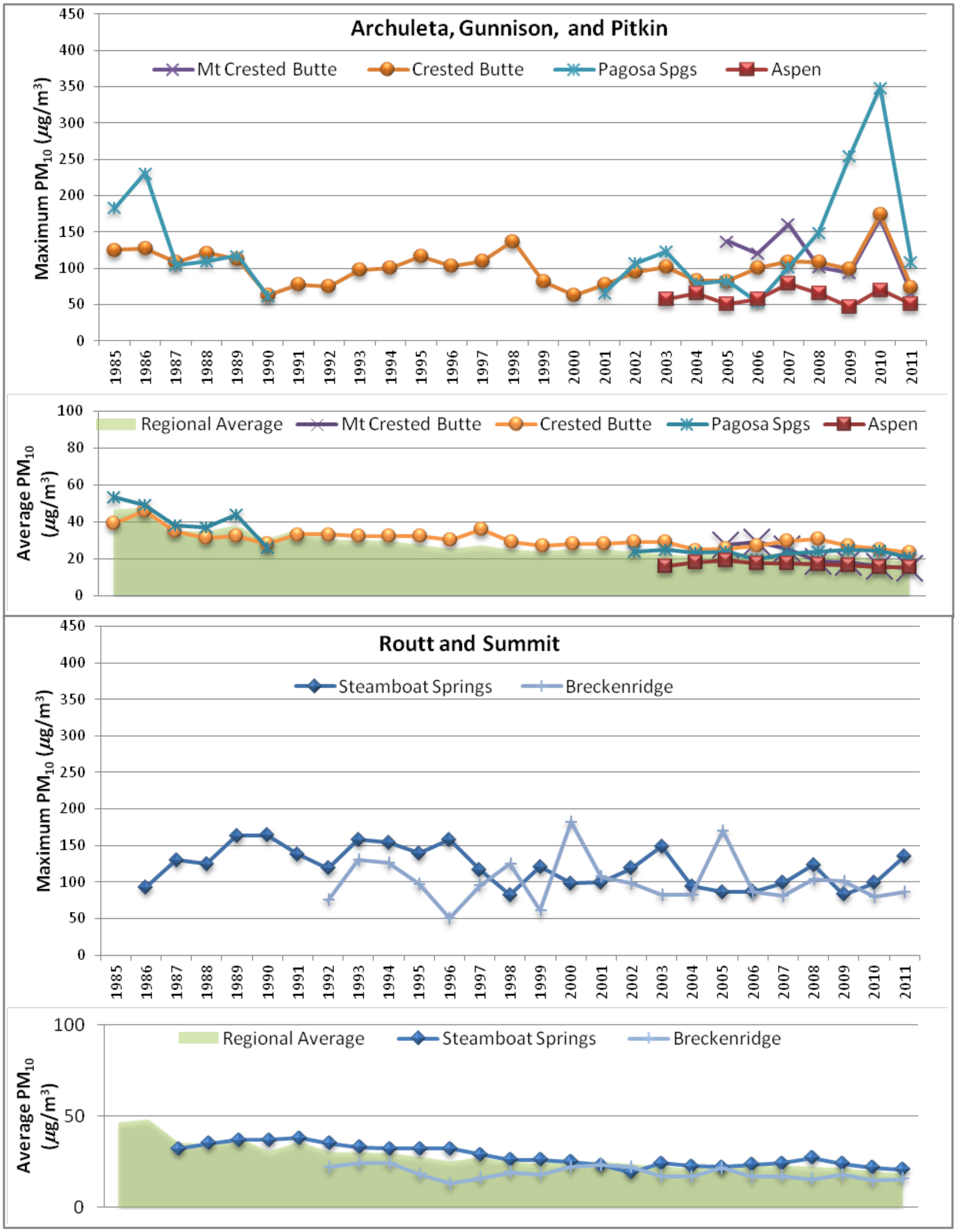


Figure 37. Average and Maximum PM_{10} Concentrations for the Mountain Counties

4.5. Western Counties

The data below may include exceptional events. See Section 2.2.5.1. Rifle, Palisade, and Cortez started monitoring in 2008, so prior years' data are not available.

Table 39. Western Counties Particulate Values

Site Name	Location	PM_{10} (µg/m^3)			$PM_{2.5}$ (µg/m^3)	
		Annual Avg.	24-hour Max	3-Year Avg. Exceedances	3-Year Weighted Avg.	3-Year Average of 98th %ile
Delta						
Delta	560 Dodge St.	21.4	51	0		
Garfield						
Parachute	100 E. 2nd Ave.	21.3	96	0		
Rifle	144 E. 3rd Ave.	20.5	54	0		
La Plata						
Durango	1235 Camino Del Rio	18.1	51	1.3		
Mesa						
Grand Junction	650 South Ave.	18.6	41	0	8.6	33.5
Pitkin (Continuous)	645 ¼ Pitkin Ave.	23.0	90	0		
Clifton	141 & D St.	19.9	60	1		
Montezuma						
Cortez	106 W. North St.				6.3	14.4
San Miguel						
Telluride	333 W. Colorado Ave.	16.4	68	3.1		

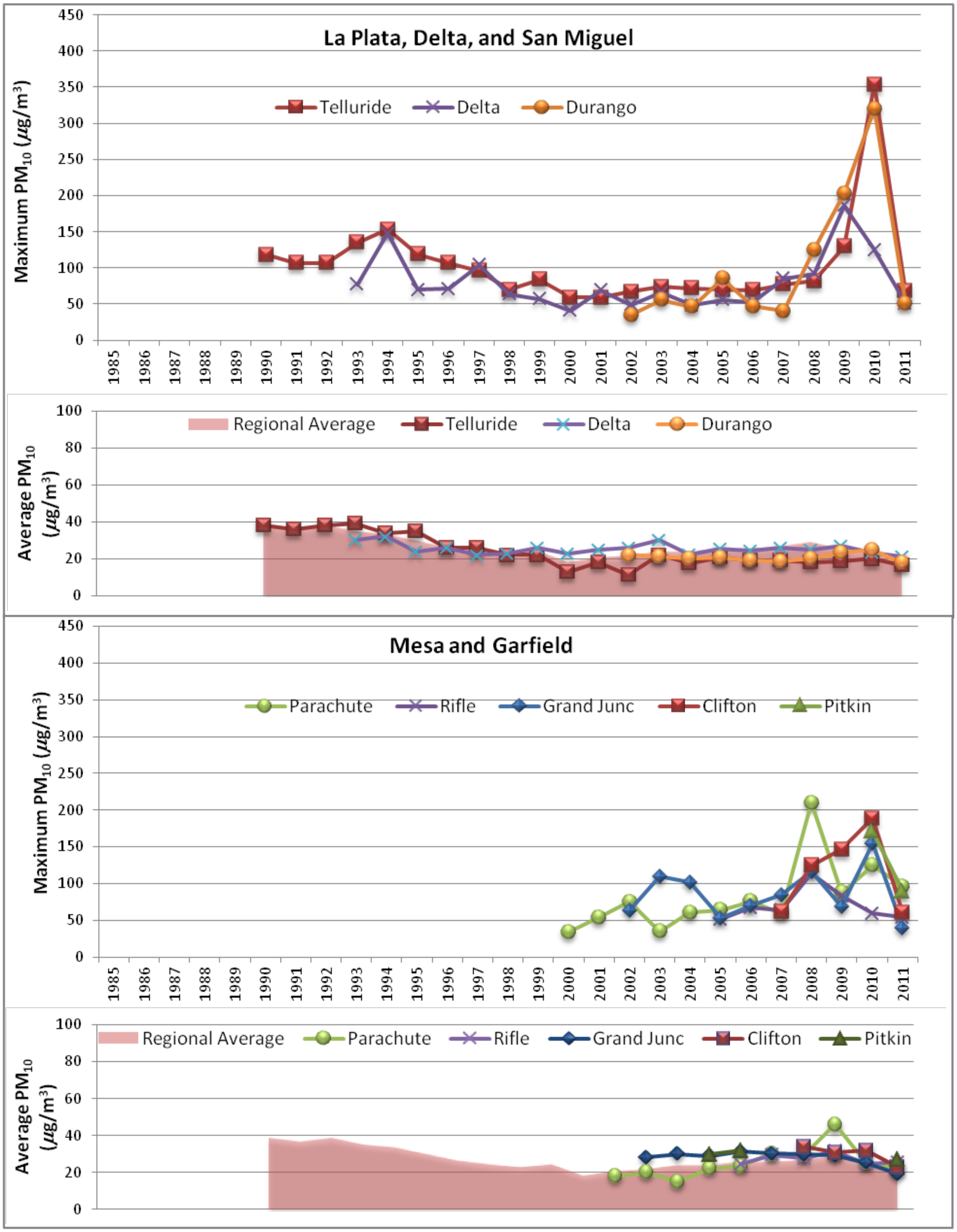


Figure 38. Average and Maximum PM$_{10}$ Concentrations for Western Counties

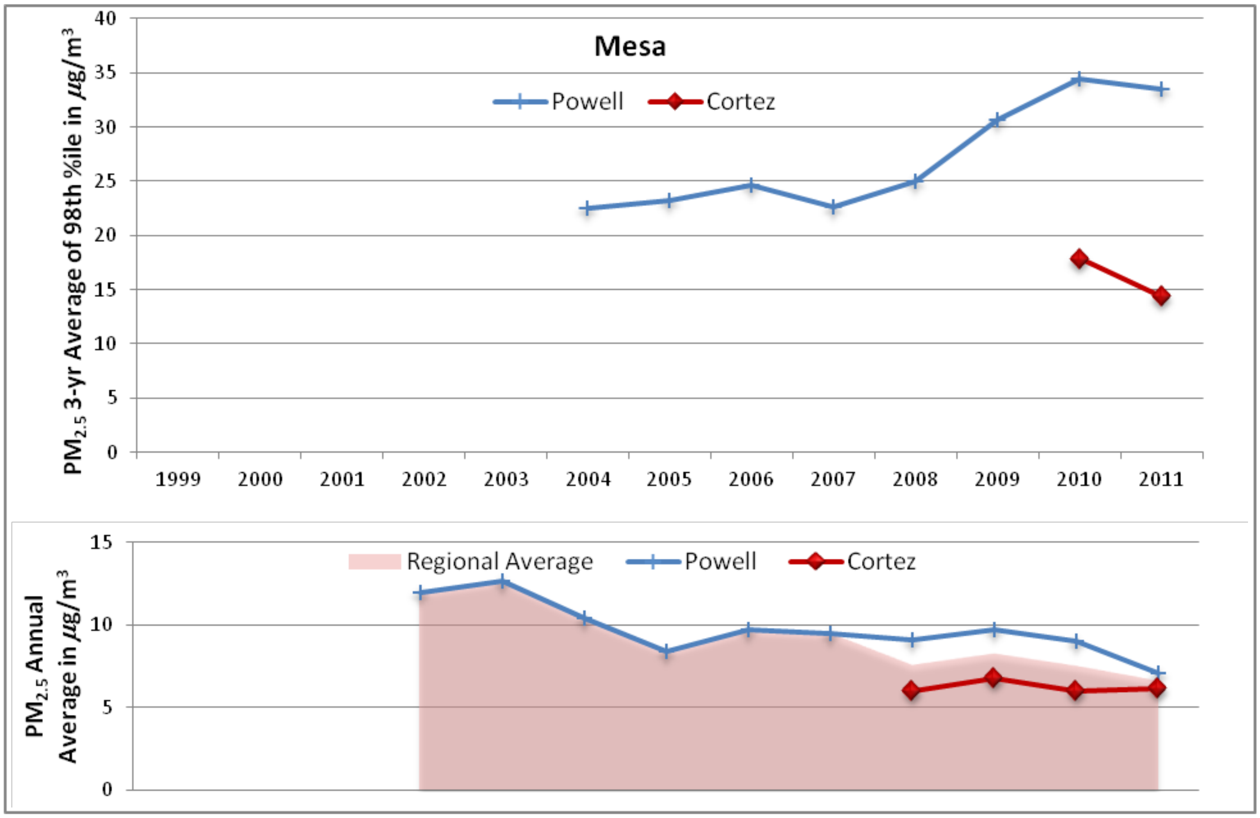


Figure 39. 3-Year 98th Percentile and Weighted Averages for $PM_{2.5}$ for the Western Counties

Table 40. Western Counties Carbon Monoxide Values

Site Name	Location	CO 1-hour Avg. (ppm)		CO 8-hour Avg. (ppm)	
		1st Maximum	2nd Maximum	1st Maximum	2nd Maximum
Mesa					
Grand Junction	645 ½ Pitkin Ave.	1.8	1.8	1.1	1.1

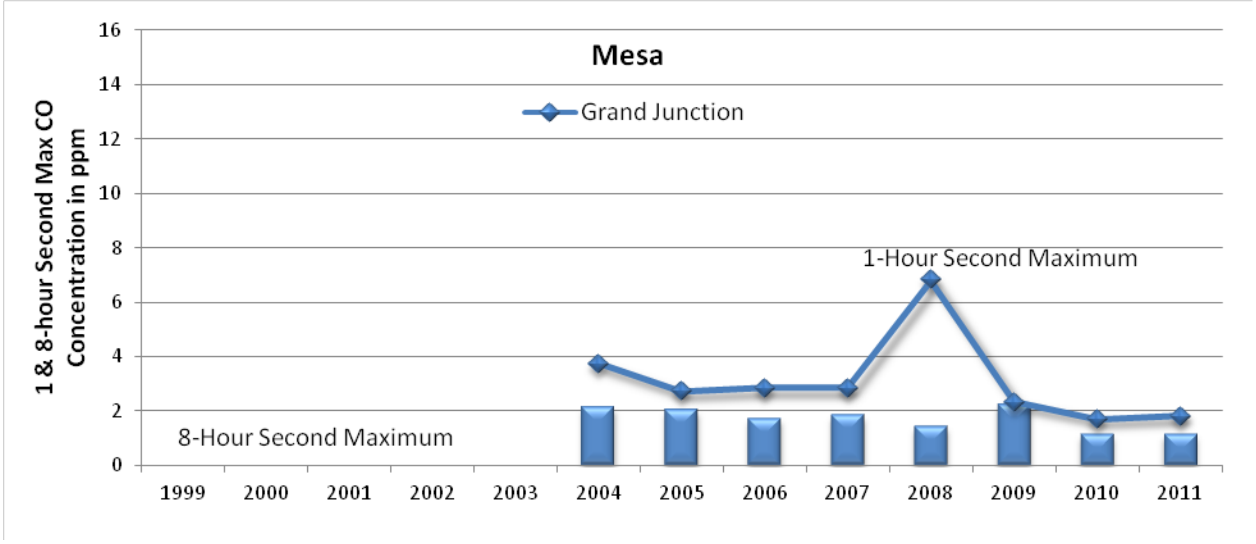


Figure 40. 1-hour and 8-hour 2nd Maximum Carbon Monoxide Averages for the Western Counties

Table 41. Western Counties Ozone Values

Site Name	Location	Ozone 8-hour Avg. (ppm)		
		1st Maximum	4th Maximum	3-year Average of 4th Maximum
Garfield				
Rifle	195 W. 14th St.	0.068	0.066	0.064
Mesa				
Palisade Water Treatment Plant	865 Rapid Creek Dr.	0.069	0.066	0.066
Montezuma				
Cortez	106 W. North Ave.	0.073	0.071	0.066
Moffat				
Lay Peak	17820 CR 17	0.065	0.060	<3 years data

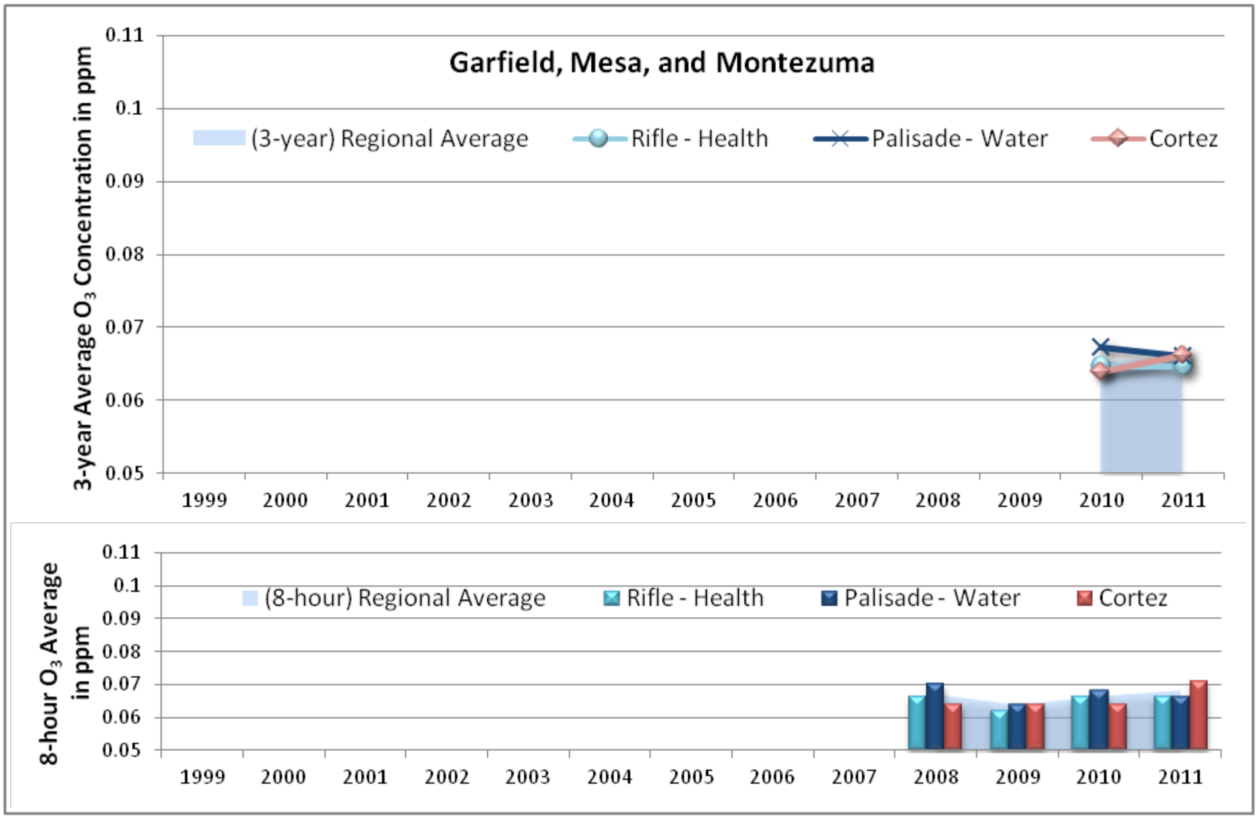
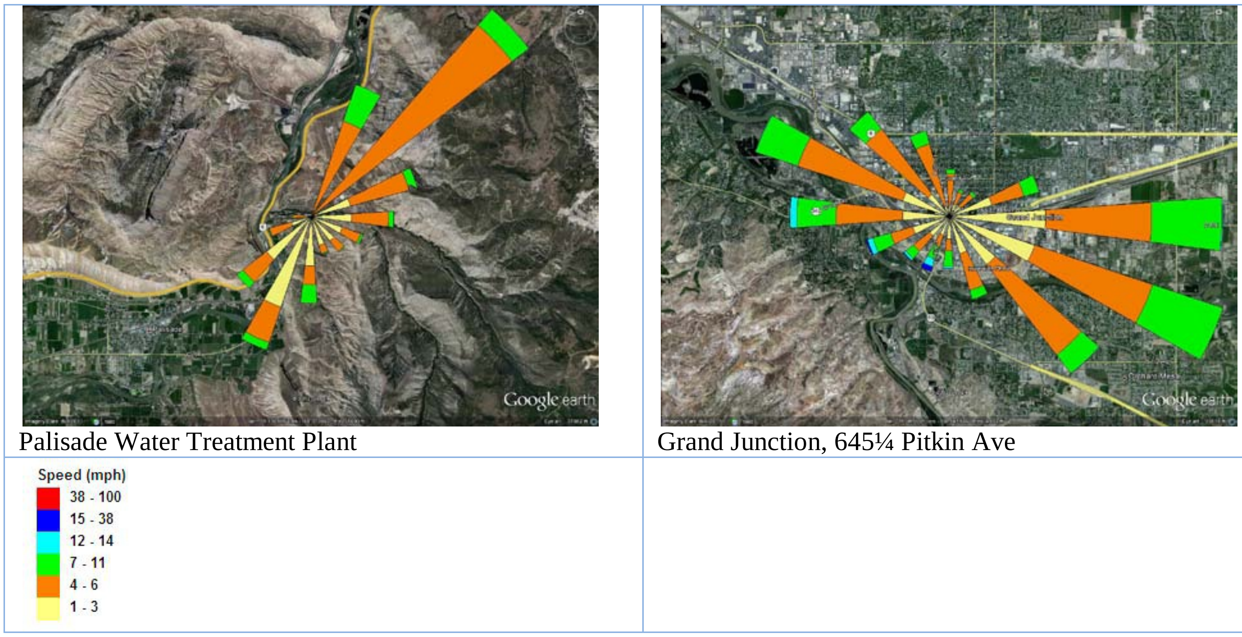


Figure 41. Ozone 8-hour 4th Maximum Concentrations for the Western Counties

Figure 42. Western Counties Wind Roses



Palisade Water Treatment Plant

Grand Junction, 645¼ Pitkin Ave

5. RESULTS THROUGH THE YEAR

In the previous sections, summary data has been presented to give an overall picture of the progress of air quality through the years and to compare measured concentrations against NAAQS, in Sections 0 and 4 respectively. However, the APCD collects data on hourly averages (which are themselves the result of even more brief intervals being averaged together) for select criteria pollutants at each site. In this section, monthly averages will be presented, and compared against the state-wide range of averages at each site.

In some sense, there is little interpretation to be done concerning the air quality information presented in this section. It is not intended to compare Colorado's air quality against the standards, other states, or past air quality. This section is only to suggest a more detailed picture of the air quality in our state throughout the year.

In all of the graphs in this section, the minimum and maximum average ranges are illustrated as blue shading in the background. This is the range for the entire state. The sites are not grouped in a geographic fashion, rather they are presented in order of their Air Quality Site ID, which is an EPA designated code derived from the state and county where the site is located, along with a unique site number. Each graph has been limited in the number of sites it presents for clarity sake, but for each pollutant set, the minimum and maximum state-wide range is the same. Data in the graphs below may include exceptional events, see Section 2.2.5.1.

5.1. Carbon Monoxide

CO can generally be considered an indicator of overall air quality. High CO concentrations indicate poor air quality, and low concentrations mean generally good air quality (except for O_3). CO is normally higher in the winter months and lower in the summer, for reasons discussed in Section 2. This notion of low summer concentrations and higher winter concentrations holds true throughout Colorado. Figure 43 shows the monthly average concentrations for CO across the state.

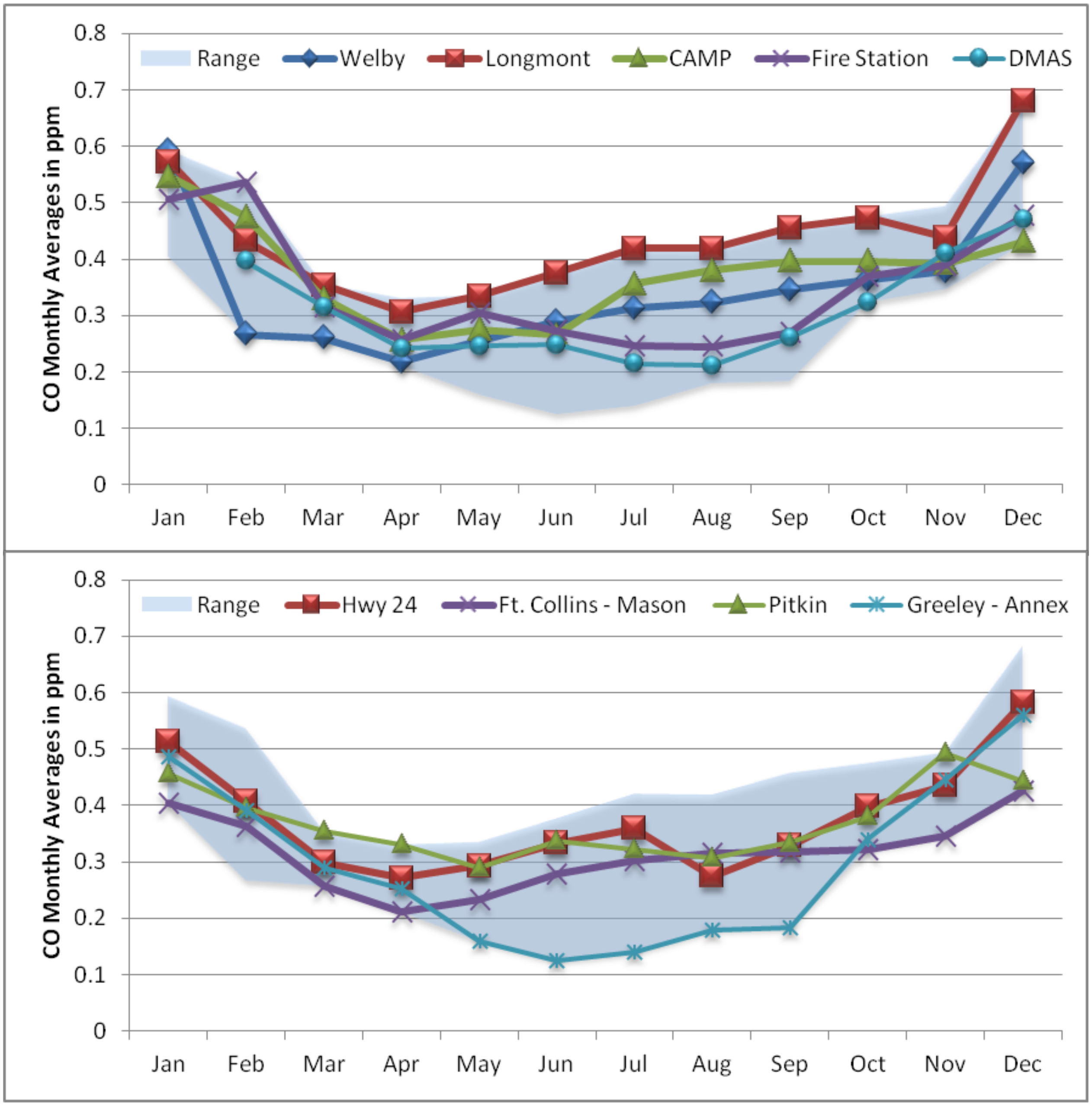


Figure 43. Monthly Carbon Monoxide Averages

5.2. Ozone

Ozone follows an opposite pattern than that of CO. The summer months see high ozone and the winter shows lower levels in part because of the length of daytime and the angle of the sun relative to the ground. Remember that ozone may be indicative of ground-level smog or the “Denver Brown Cloud”. Generally speaking, sites in the Northern Front Range counties fared worse than other areas (especially sites directly west of, and at higher elevation than, metro Denver), though sites outside the Front Range occasionally had the highest averages.

Recent studies are finding that high ozone concentrations within mountain valleys may occur during the winter (see Section 2.2.2). Atmospheric inversions combined with snow cover in mountain valleys may lead to more ozone being created and retained within the valley. This condition has not been observed within Colorado by the APCD.

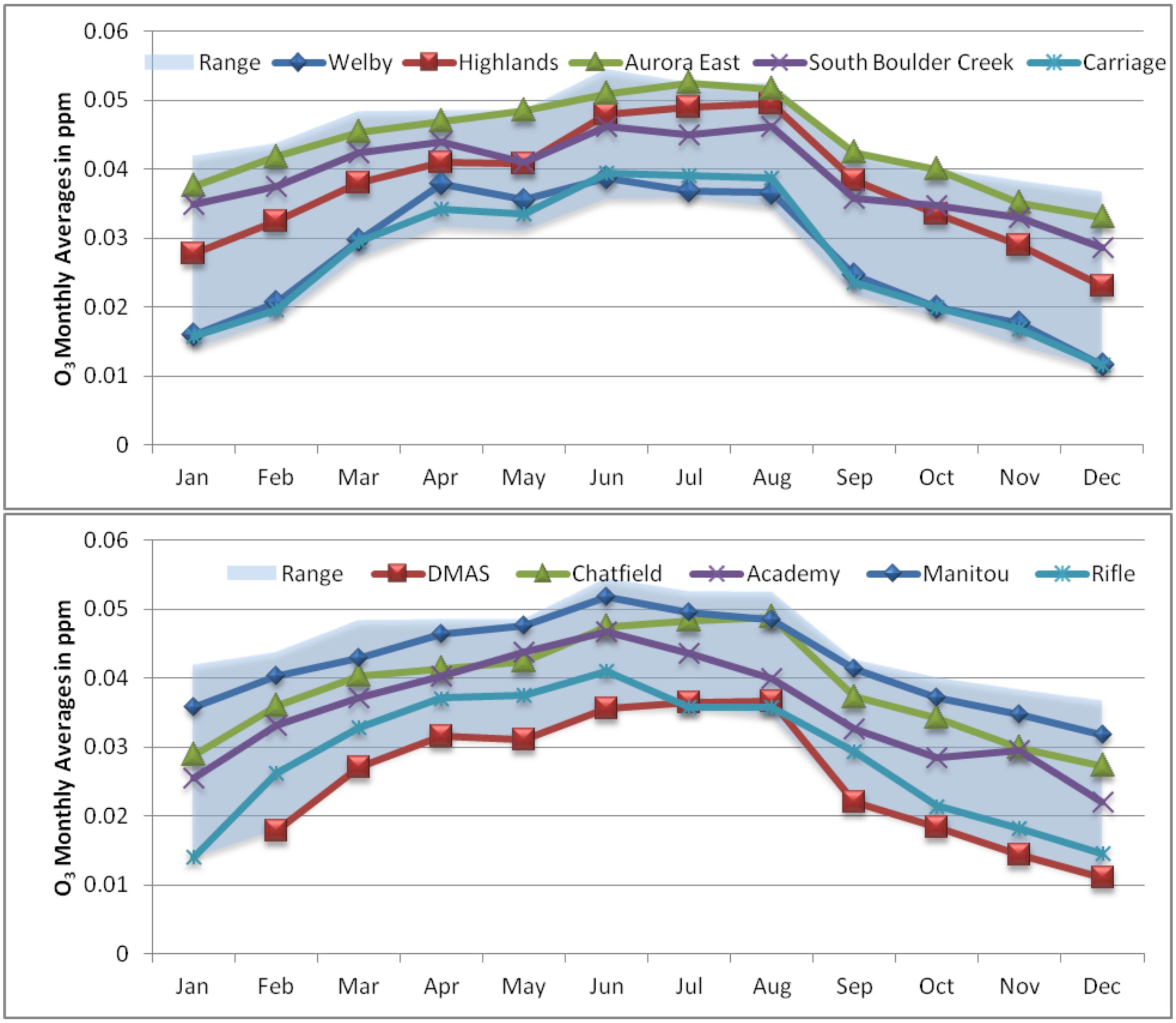


Figure 44. Monthly Ozone Averages

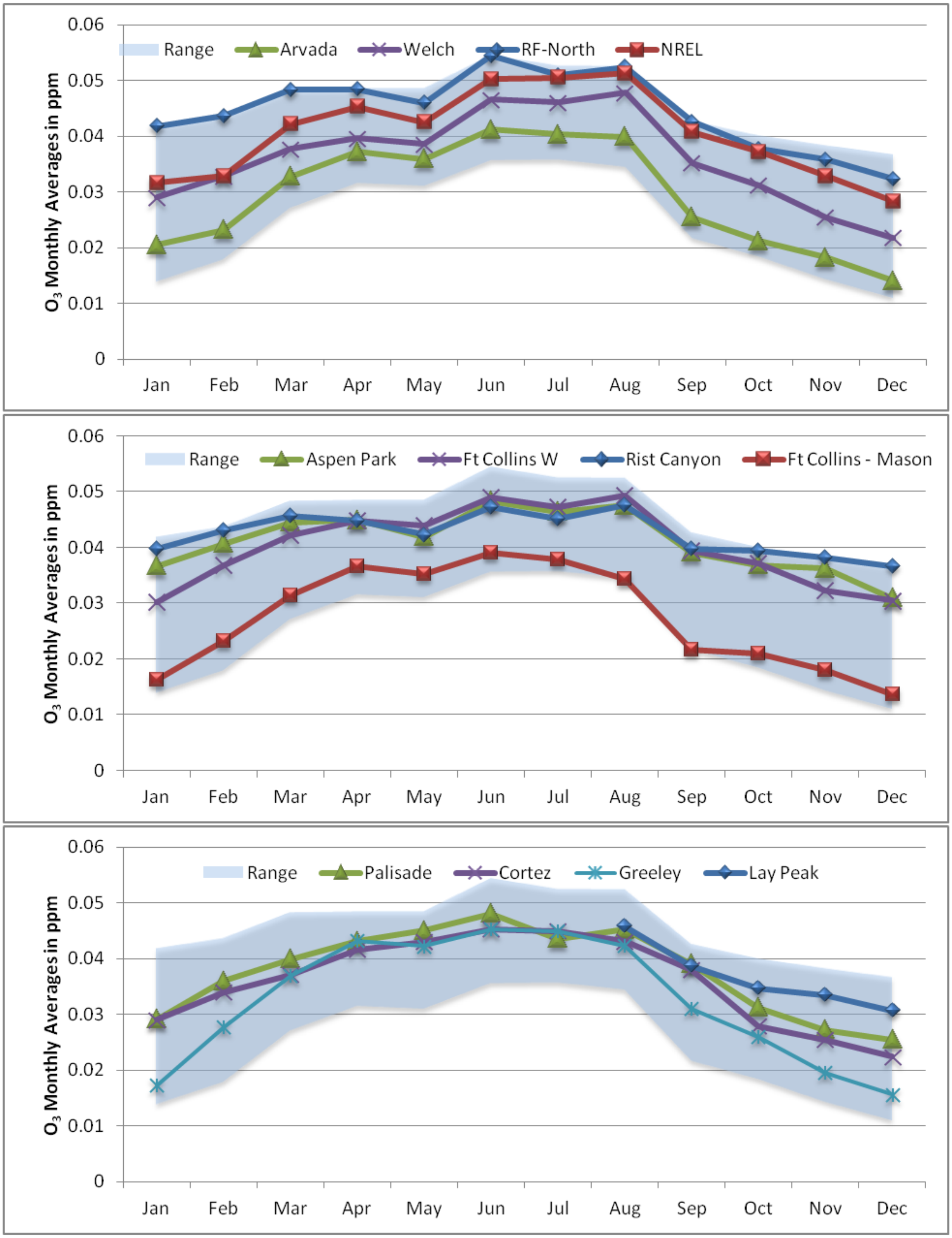


Figure 44. Monthly Ozone Averages (Continued)

5.3. Sulfur Dioxide

Sulfur dioxide is measured at three stations in Colorado: Welby, DMAS, and CAMP, in the metro Denver area. Concentrations between the stations appear to track well with each other. That is to say that when one site reads higher measurements the other sites also reads higher measurements. DMAS data was only valid from September to the end of the year.

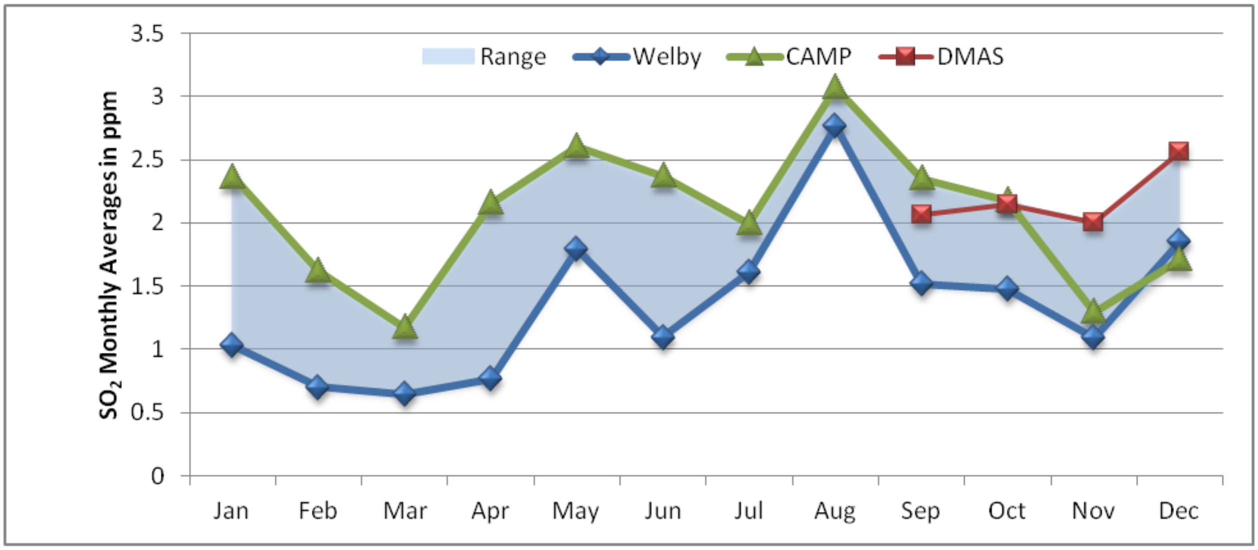


Figure 45. Monthly Sulfur Dioxide Averages

5.4. Nitrogen Dioxide

Nitrogen dioxide seems to follow the same pattern of CO, generally lower concentrations in the warmer months and higher in the colder months. As with SO2, NO2 at sites in fairly close proximity appear to track with each other well.

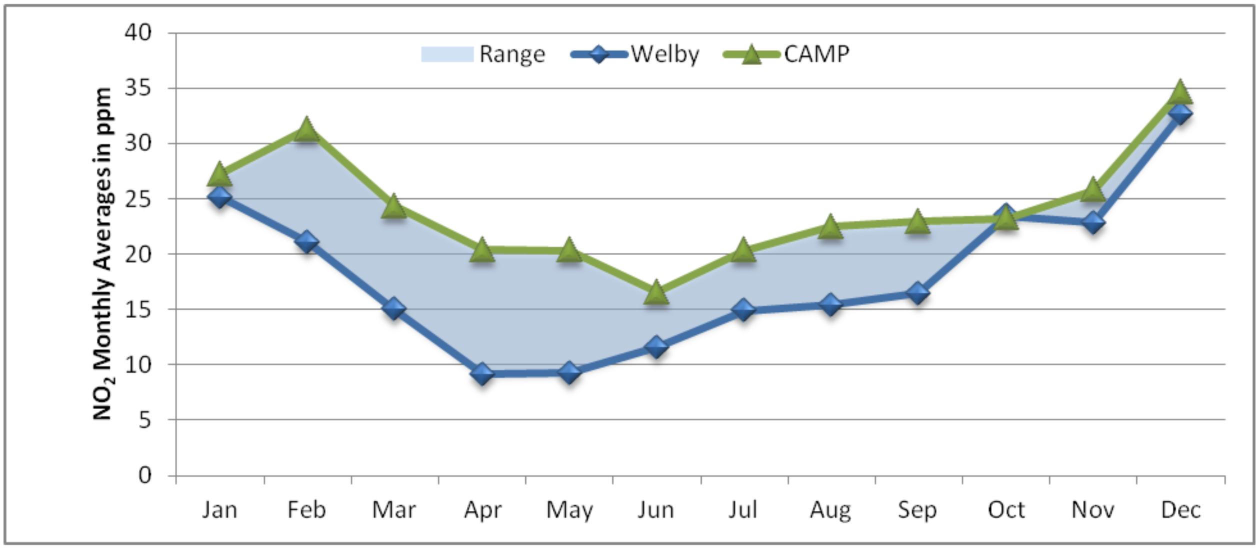


Figure 46. Monthly Nitrogen Dioxide Averages

5.5. Particulate Matter – PM_{10}

PM_{10} can be high for a variety of reasons including anthropogenic and natural occurrences. Higher PM_{10} concentrations might be expected during dry months, since the soil has a chance to dry out and be picked up by the winds. This can be somewhat seen in the range of PM_{10} concentrations found in the following graphs, but the peaks in concentrations are often due to single-point high-concentration events. The data below may contain exceptional events. See Section 2.2.5.1.

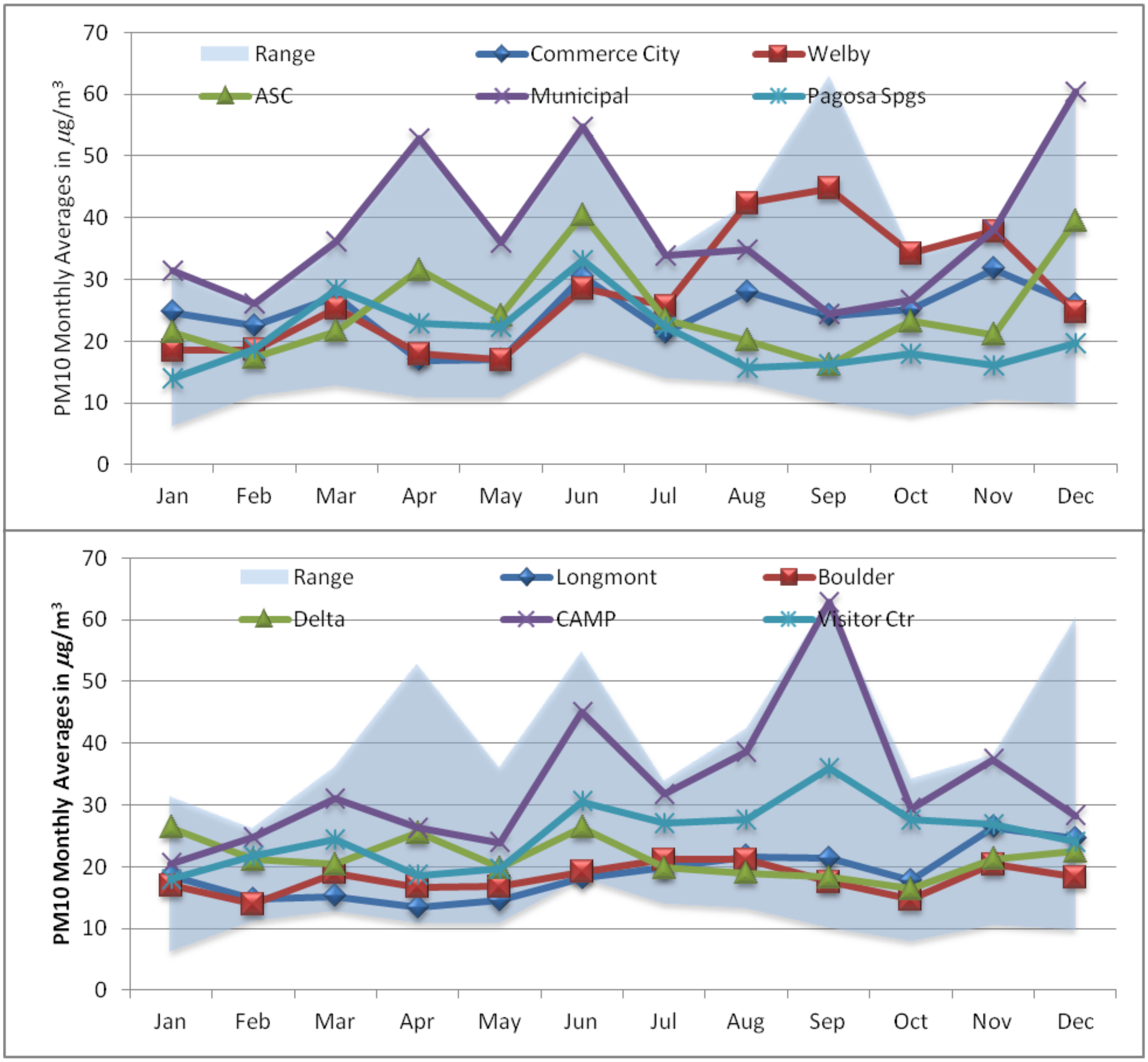


Figure 47. Monthly PM_{10} Averages

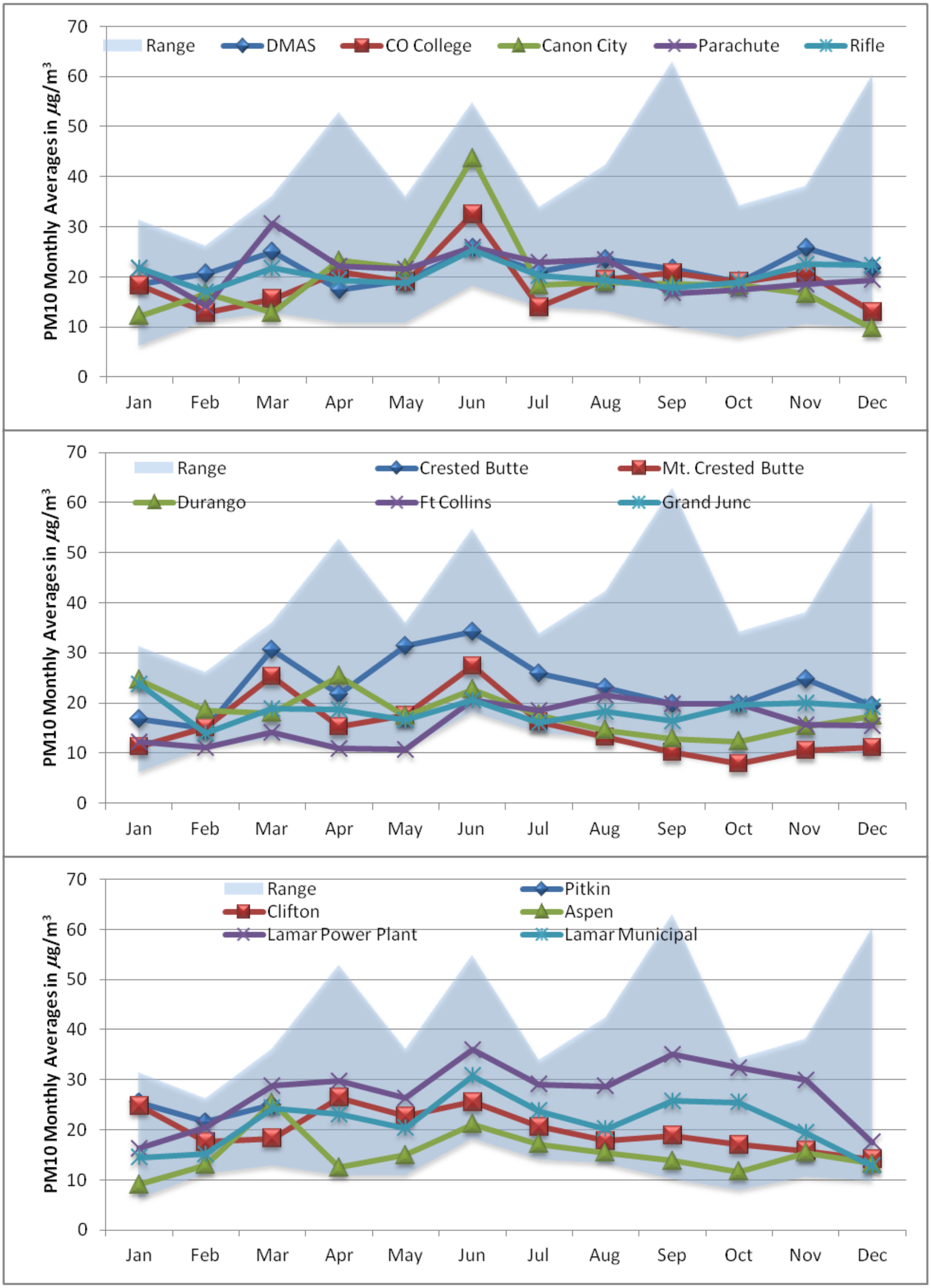


Figure 47. **Monthly PM$_{10}$ Averages (Continued)**

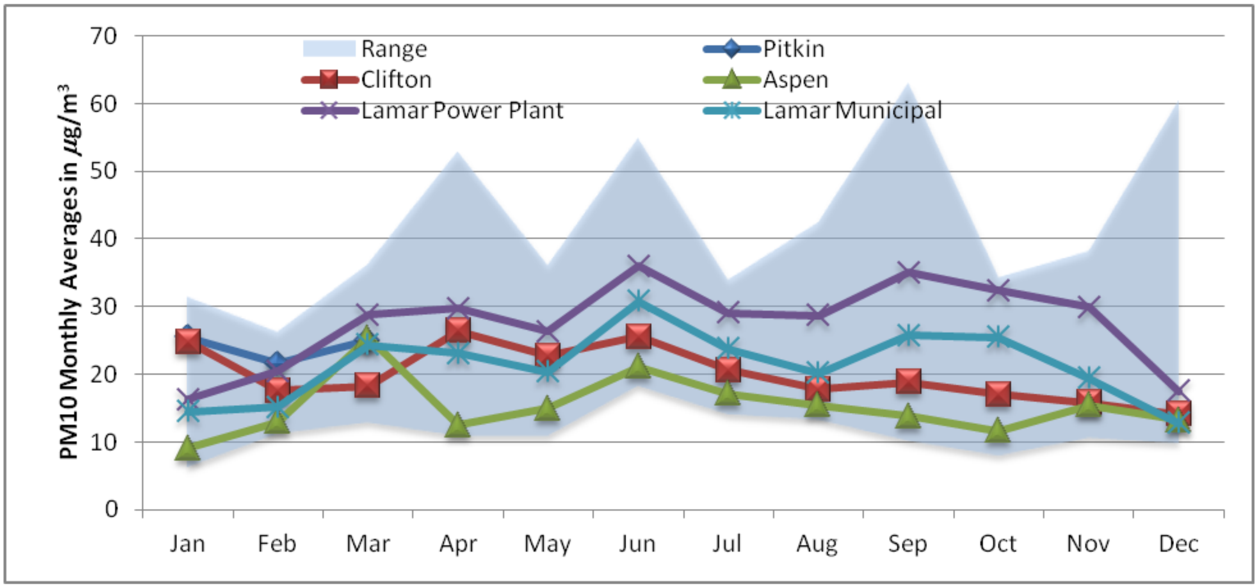


Figure 47. Monthly PM_{10} Averages (Continued)

5.6. Particulate Matter – $PM_{2.5}$

$PM_{2.5}$ concentrations are stable throughout much of the year, with a higher period in the winter caused by temperature inversions, and relatively similar at sites across the state. Platteville, Longmont, and Greeley saw high concentrations in December, and most other sites had their highest concentrations in January. The graphs here include exceptional event data.

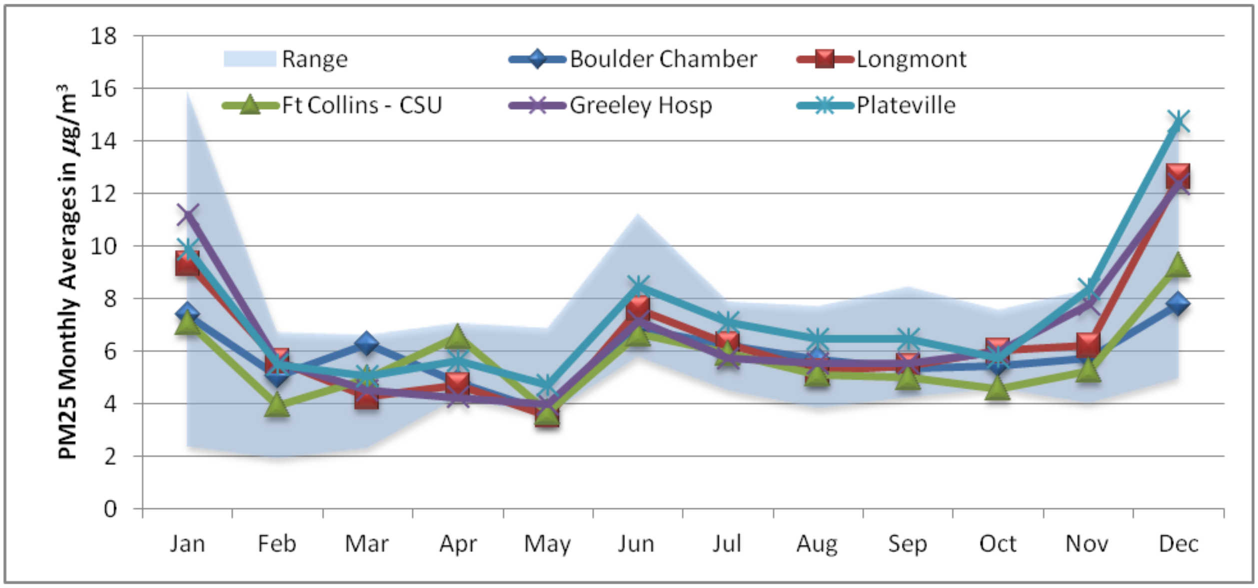


Figure 48. Monthly $PM_{2.5}$ Averages

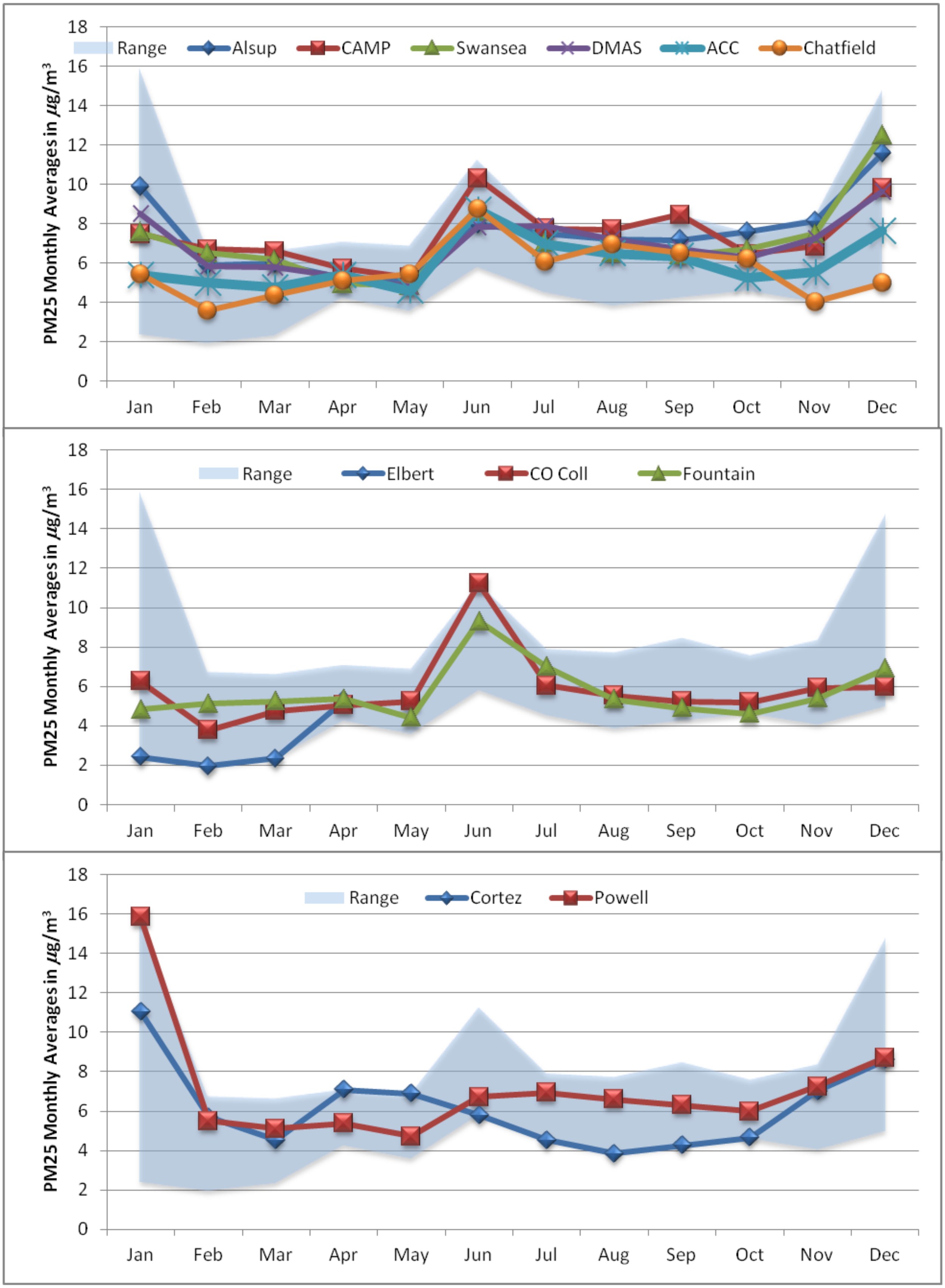


Figure 48. **Monthly $PM_{2.5}$ Averages (Continued)**

5.7. Lead

Lead is sampled once every 6 days, and each sample covers a 24-hour period. Lead concentrations are approximately flat throughout the year at DMAS, and well below the standard even at Centennial. The variability of lead concentrations at Centennial is certainly higher than that at DMAS, indicating the airport is likely responsible for the higher lead levels, rather than a more general urban source. As Centennial is a source-oriented monitor, this is to be expected.

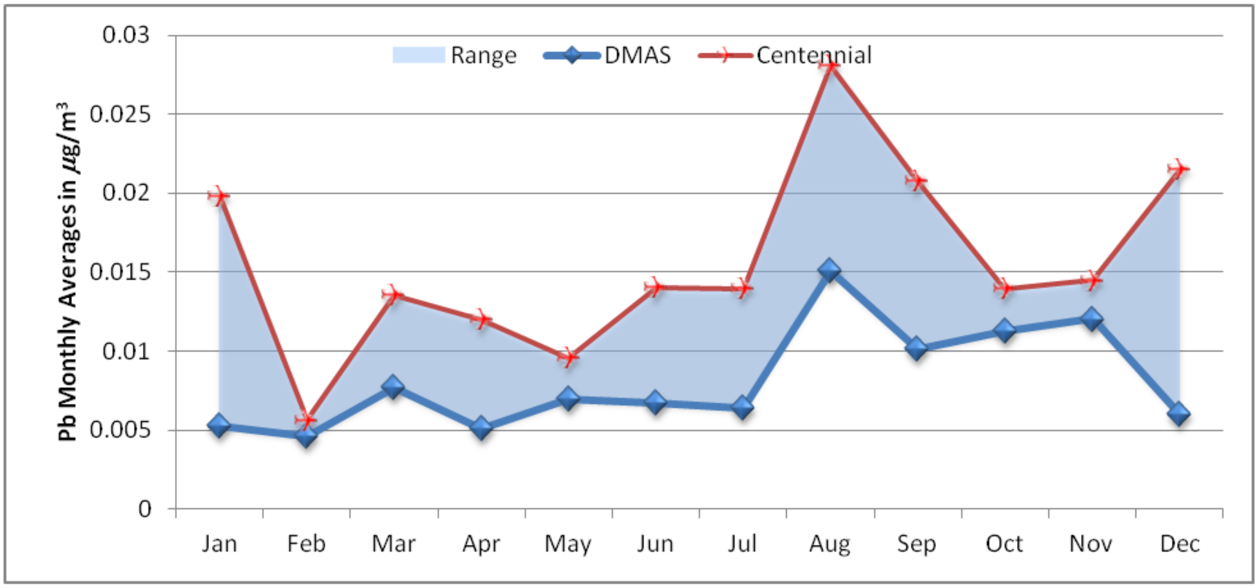


Figure 49. Monthly Lead Averages

6. DATA QUALITY ASSURANCE / QUALITY CONTROL

This section describes the APCD Technical Services Program's success in meeting its data quality objectives for ambient air pollution monitoring data of priority pollutants. This section is laid out in accordance with 40CFR Part 58 Appendix A requirements. APCD's attainment of quantitative objectives, such as completeness, precision, and bias, are shown in Table 42, below.

Table 42. Attainment of Quantitative Quality Objectives for Ambient Air Monitoring Data

Measurement	Program met objectives for: (CDPHE goals / EPA requirements)			
	Completeness	**Precision**	**Bias**	**Accuracy**
CO	Yes	Yes	Yes	Yes
NO_2	No/Yes	Yes	Yes	Yes
O_3	Yes	Yes	Yes	Yes
SO_2	Yes	Yes	Yes	Yes
Time Integrated PM_{10}	Yes	Yes	n/a	Yes
Time Integrated $PM_{2.5}$	Yes	Yes	Yes	Yes
Continuous PM_{10}	No/Yes	Yes	Yes	Yes
Continuous $PM_{2.5}$	No/Yes	Yes	Yes	Yes
Pb	Yes	Yes	n/a	n/a
TSP	Yes	No	Yes	Yes

Other quality objectives were assessed via laboratory and site system audits. The results of these audits indicate compliance with APCD's standard operating procedures and EPA acceptance criteria, with the exception of bias based on the Performance Evaluation Program (PEP) audits for PM2.5 filter-based monitoring[13]. The 2012 PEP audits have not yet been made available by EPA. Copies of the APCD laboratory audits may be obtained from the Quality Assurance Unit within the APCD.

Other audits were performed and can be made available for review, for National Air Toxic Trends Stations (NATTS), Speciation Trends Network (STN), Colorado based Ozone sites that are operated by other organizations, and CDPHE meteorological networks. These results are not included in this report because other agencies perform the data assessments for the NATTS and STN networks. Meteorological data is not considered a priority pollutant and so a statistical assessment of this data is not provided.

6.1. Data Quality

Data quality is related to the needs of the end users of the data, and should be of sufficient quality to aid in decision making. Each user specifies their required level of data quality in the form of their data quality objectives (DQOs). Quality objectives for measurement data are designed to ensure that the user's DQOs are met. Measurement quality objectives are concerned with both quantitative objectives (such as representativeness, completeness, accuracy, precision, and detection level) and qualitative objectives (such as site placement, operator training, and sample handling techniques).

6.2. Quality Assurance Procedures

Quality assurance is a general term for the procedures used to ensure that a particular measurement meets the quality requirements for its intended use. In addition to performing tests to determine bias and precision, additional quality indicators (such as sensitivity, representativeness, completeness, timeliness, documentation quality, and sample custody control) are also evaluated. Quality assurance procedures fall under two categories:

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[13] For criteria, see http://www.epa.gov/ttnamti1/files/ambient/pm25/qa/pepadequacy.pdf

- Quality Control (QC) - procedures built into the daily sampling and analysis methodologies to ensure data quality, and

- Quality Assessment (QA) - periodic independent evaluations of data quality.

Some ambient air monitoring is performed by automated equipment located at field sites, while other measurements are made by taking samples from the field to the laboratory for analysis. For this reason, we will divide quality assurance procedures into two parts – field and laboratory quality assurance.

6.2.1 Field Quality Assurance

Quality control of automated analyzers and samplers consists of calibration and precision checks. The overall precision of filter based sampling methods is measured using collocated samplers. Quality assurance is evaluated by periodic performance and system audits.

Automated analyzers (except O_3) are calibrated by comparing the instrument's response when sampling a cylinder gas standard of a known concentration level. The analyzer is then adjusted to produce the correct response. O_3 analyzers are calibrated by on-site generation of O_3 whose concentration is determined by a separate analyzer with an EPA-traceable calibration. The site's analyzer is then adjusted to produce the same measured concentration as the traceable analyzer. Manual samplers are calibrated by comparing their volumetric flow rate at one or more levels to the flow measured by a flow rate transfer standard. Calibrations are performed when an instrument is first installed and at assigned intervals thereafter depending on the analyzer type. Calibrations are also performed after instrument repairs or when quality control charts indicate a drift in response to quality control check standards.

Precision is a measure of the variability of an instrument. The precision of automated analyzers is evaluated by comparing a sample of a known concentration against the instrument's response. The precision of manual samplers is determined by collocated sampling – the simultaneous operation of two identical samplers placed side by side. The difference in the results of the two samplers is used to estimate the precision of the entire measurement process (i.e., both field and laboratory precision).

The bias of automated methods is assessed through field performance audits (also called accuracy audits). Performance audits are conducted by sampling a blind sample (i.e., a sample whose concentration is known, but not to the operator). Bias is evaluated by comparing the measured response to the known value. Typically, performance evaluations are performed biannually using samples of several different concentrations.

System audits indicate how well a sampling site conforms to the standard operating procedures as well as how well the site is located with respect to its mission (e.g., urban or rural sampling, special purpose sampling site, etc.). System audits involve sending a trained observer (QA Auditor) to the site to review the site compliance with standard operating procedures. Some areas reviewed include: site location (possible obstruction, presence of nearby pollutant sources), site security, site characteristics (urban versus suburban or rural), site maintenance, physical facilities (maintenance, type and operational quality of equipment, buildings, etc.), recordkeeping, sample handling, storage and transport.

6.2.2 Laboratory Technical Systems Audit

Laboratory quality control includes calibration of analytical instrumentation, analysis of blank samples to check for contamination, and analysis of duplicate samples to evaluate precision. Quality assurance is accomplished through laboratory performance and system audits.

Laboratory analytical instruments are calibrated by comparing the instrument's response with sampling standards of a known concentration level. The differences between the measured and known concentrations are then used to adjust the instrument to produce the correct response.

A blank sample is one that has intentionally not been exposed to the pollutant of interest. Analysis of blank samples reveals possible contamination in the laboratory or during field handling or transportation.

Duplicate analyses of the same sample are performed to monitor the precision of the analytical method.

A regular sample is spiked with a known concentration to determine if the sample matrix is interfering with detection capabilities of the instrumentation.

Regular performance audits are conducted by having the laboratory analyze samples whose physical or chemical properties have been certified by an external laboratory or standards organization. The difference between the laboratory's reported value and the certified values is used to evaluate the analytical method's accuracy.

System audits indicate how well the laboratory conforms to its standard operating procedures. System audits involve sending a QA Auditor to the laboratory to review compliance with standard operating conditions. Areas examined include: record keeping, sample custody, equipment maintenance, personnel training and qualifications, and a general review of facilities and equipment.

The CDPHE Laboratory Services Division (LSD) performs the gravimetric analysis for the filter based particulates. APCD conducted a full Laboratory Technical Systems Audit of the High-Volume (High-Vol), Low-Volume (Low-Vol) Particulate Matter Gravimetric Laboratories and the Chemistry Metals Laboratories Dec. 6th – Dec. 8th of 2011. Results from these audits are available upon request from the APCD Quality Assurance Unit.

6.3. Gaseous Criteria Pollutants

6.3.1 Quality Objectives for Measurement Data

The Quality Objectives for the APCD’s ambient air monitoring of gaseous criteria pollutants are shown in Table 43, below.

Table 43. Data Quality Objectives for Gaseous Criteria Pollutants

Data Quality Indicator	APCD Goal	EPA Requirement
Precision for O_3	7%	7%
Precision for CO, SO_2, NO_2	10%	10%
Precision Completeness	90%	75%
Bias for O_3	7%	7%
Bias for CO, SO_2, NO_2	10%	10%
Accuracy for O_3	10%	10%
Accuracy for CO, SO_2, NO_2	10%	15%
Accuracy Audits (Performance Evaluations) Completeness	2 audits per analyzer per year	25% of analyzers quarterly
90% Probability Intervals	Meet EPA requirement	95% of audit values
NPAP TTP audits for O_3	Meet EPA requirement	10%
NPAP TTP audits CO, SO_2, NO_2	Meet EPA requirement	15%
Overall Data Completeness	90%	75%

6.3.2 Gaseous Data Quality Assessment

6.3.2.1 Summary

Assessment of the data for APCD gaseous criteria pollutants showed that all gaseous analyzers met the minimum EPA criteria and most monitoring sites met APCD goals for precision, bias, accuracy, national performance evaluations, and completeness. There were a number of notable problems in the gaseous network during 2011 that include the following:

1) Welby had two failed NO_2 precisions in 2011, one in early June and one in early Dec. Both were found to be malfunctions of the calibrator generating the calibration gas. The June 2011 precision did not appear to be representative during the analysis and therefore no data was invalidated for this time period at this site. The failed December precision was a result of the calibrator not generating GPT, after a back up calibrator

was installed the instrument passed precisions. No data was invalidated for this site during this time period but precisions for both these time periods were not loaded to AQS.

2) CAMP failed a precision for NO_2 in early June. The data for that time period was invalidated, effecting data completeness.

3) The DMAS site was not fully operational until February 2011. Therefore no data was reported to AQS for the month of January 2011.

4) DMAS NO_y data was invalidated for most of the month of Aug. 2011 due to the analyzer failing precisions. Data was validated from 8/11/2011 through 8/22/2011 due to a passing precision on 8/15/2011. The NO_y analyzer at DMAS was taken offline and shipped back to the factory for repairs Nov. 20th, 2011 and reinstalled Dec. 26th, 2011. No data was loaded to AQS for that time period.

5) No SO_2 precision data were loaded to AQS for Jan. 2011 at Welby due to the calibrator that was delivering the calibration gas malfunctioning. The ambient data was compared to the Denver CAMP site and compared well, which led to no ambient SO_2 data being invalidated for Jan. 2011 at the Welby site.

6) An SO_2 precision in early Dec. failed at the Welby site, which led to the invalidation of the ambient SO_2 data for Dec. 1st through Dec. 13th 2011 at Welby.

7) DMAS SO_2 data from start up through Sept. 15th, 2011 was invalidated due to multiple analyzer problems resulting in low confidence in the validity of the data produced by the start-up analyzer. A new analyzer was installed on September 16th, 2011, and the ambient data was validated from that time through the end of 2011.

8) The Arvada ozone site failed a precision in early February. The precision record for this time period was not loaded to AQS which affected precision completeness. The ambient data associated with this time period compared well to the NREL site so no data was invalidated for this time period.

6.3.2.2 Precision (Coefficient of Variation)

At least once every two weeks, precision is determined by sampling a gas of known concentration for every gaseous analyzer. Table 44 summarizes the number of precision checks that were performed (precision count) as well as the percent completeness of these precision checks and an annual summary by organization of the percent of precision checks that fell within the acceptance criteria of +/-10% (+/-7% for O_3). Table 44 also summarizes the statistical data quality assessment of these precision checks for all gaseous criteria pollutants. The Coefficient of Variation (CV) for the precision checks is summarized annually by site, quarterly by organization, and annually by organization. The equations used to calculate precision, bias, and upper and lower probability limits for the 90% probability intervals using the bi-weekly precision checks can be found in 40CFR58 Appendix A part 4.1.

6.3.2.3 Bias

For gaseous pollutants the bias is also calculated using the bi-weekly precision checks. The Bias is summarized in Table 44 (by the same groupings as the CV). Additionally a plus or minus bias was assigned to the annual “by site” and “by organization” groupings based on an evaluation of where the 25th and 75th percentiles of percent differences of the precision data fell. If both percentiles fell below zero then the bias was assigned a minus sign, and if both percentiles fell above zero, then the bias was assigned a plus sign. If one bias was positive and one bias was negative (i.e. straddling zero) there is no sign associated with the bias. Organizationally CO showed a negative 2% bias for the year. SO_2 showed an approximate 4% negative bias at both the CAMP and DMAS monitoring sites for the year as well as for the organization in 2011. There was no sign associated with the calculated bias (4.8%) for the NO_2 precision checks, at the 25th and 75th percentiles, for the organization as a whole, but the probability interval is fairly large (-10.42% to 9.2%).

6.3.2.4 Performance Evaluations (Accuracy Audits)

Audits were performed at least twice on every gaseous analyzer within the APCD network during the 2011 calendar year. The primary goal of these audits is to evaluate the analyzer performance and calibration. Other factors are also noted during these audits such as operator performance, station operational criteria, record keeping, site upkeep issues, and general safety problems.

All Performance Evaluations (accuracy audits) performed for all gaseous analyzers during 2011 passed both the APCD objectives and EPA requirements with the following exceptions:

1) The NO_2 audit at the Welby monitoring station for 2^{rd} quarter of 2011 fell within the warning range. Only the low level fell within the warning range of 11%, still passing the established EPA criteria but falling outside the CDPHE DQO limit of 10%.

Figure 50 shows the percent differences from all the accuracy audits for all sites within the gaseous network for 2011. A large trace level CO value was removed from the graph due to a large percent difference between the results, 0.6 ppm (audit value) and 0.8 ppm (analyzer response), a 33% difference. This audit difference was assessed based on an absolute value difference and not a percent difference.

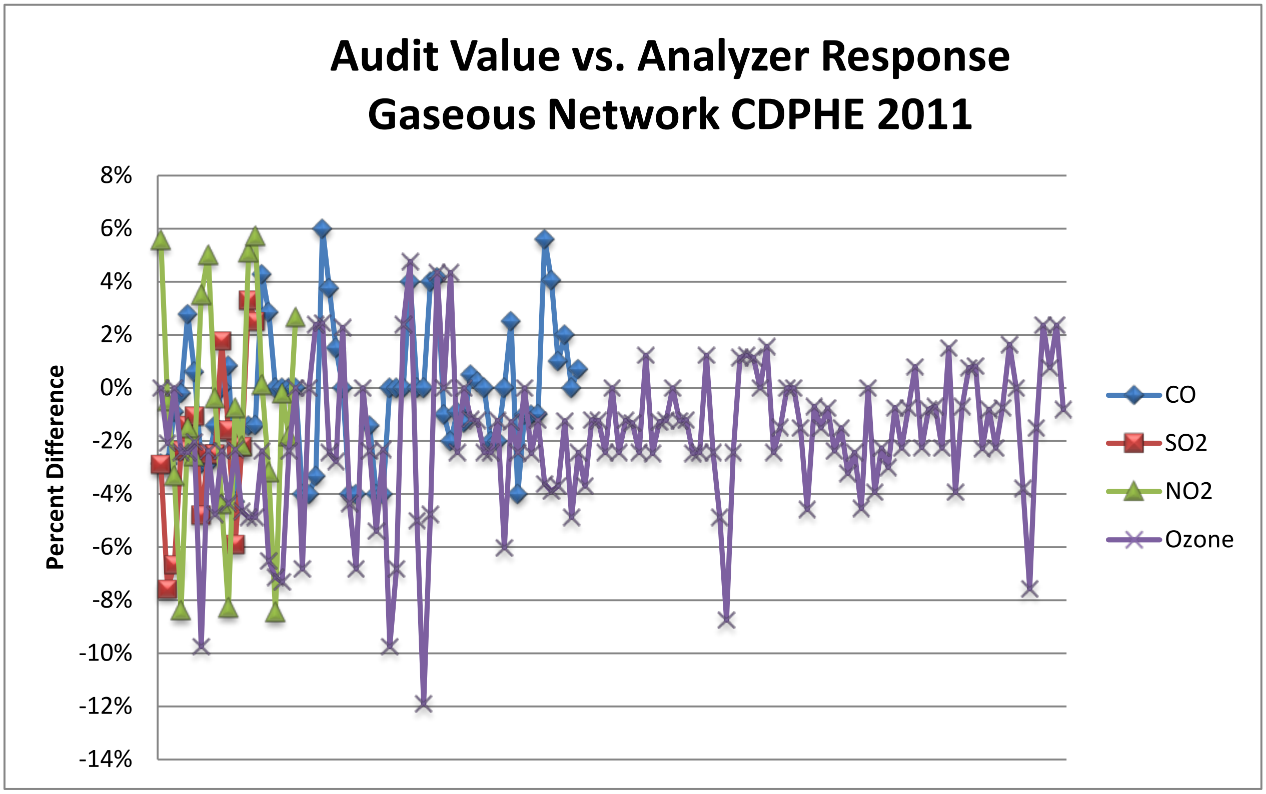

Figure 50. 2011 CDPHE Accuracy Audit percent differences for the gaseous network

6.3.2.5 Probability Intervals (Upper and Lower Probability Limits)

Probability Intervals (upper and lower probability limits) are calculated per 40CFR58 Appendix A part 4, by using the percent differences retrieved from station precision checks. The EPA has established that 95% of the independent audit points taken for a given year should fall within this calculated probability interval to validate the bias calculated from the precision checks. The percent differences between the audit concentrations and the indicated concentrations taken in 2011for CO were compared to the probability intervals. Only one concentration taken for CO failed to fall between the probability intervals because of the low concentration used (0.6 ppm audit vs.

0.8 ppm indicated). This means that out of the 63 audit concentration points taken, 98.4% fall between the probability intervals. There were 135 audit concentration points taken during 2011 for ozone. Of those 135 ozone audit points, 6 fall outside the probability intervals. This means that 95.6% of the audit points for ozone fall between the probability intervals in 2011. Out of the 21 audit points taken in 2011 for NO_2, 100% fall between the probability limits. Out of the 15 audit points taken for SO_2 in 2011, 100% fall between the probability limits.

Figure 51 below shows the 2011 upper and lower probability limits for the 4 gaseous networks.

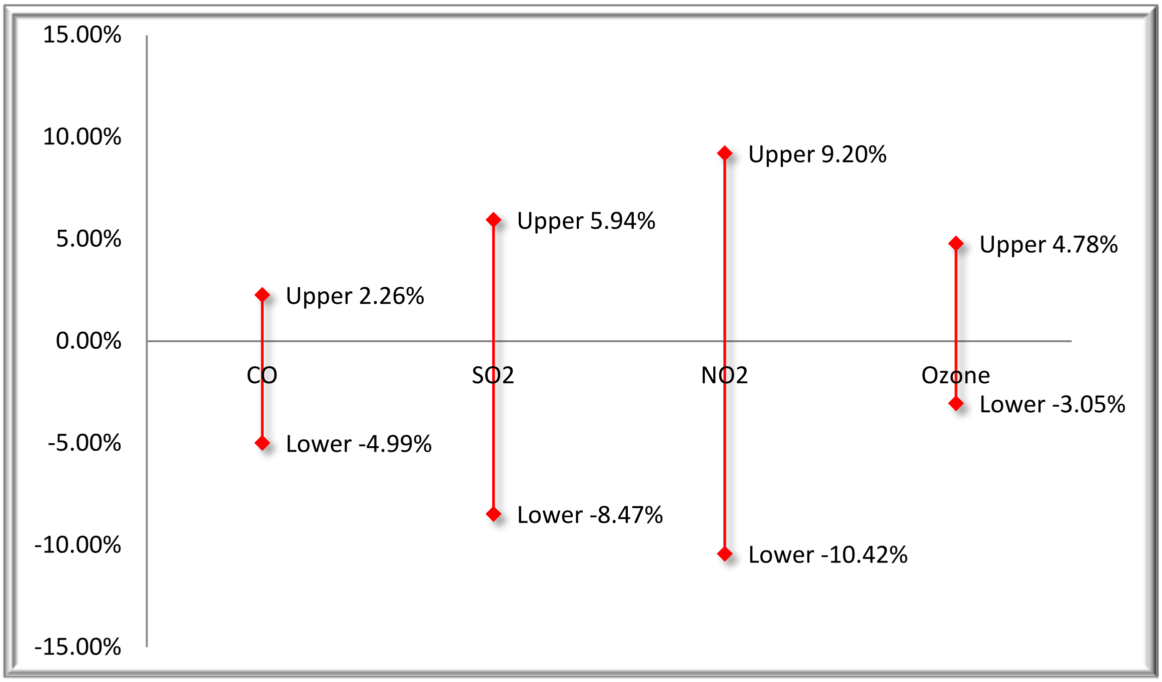

Figure 51. Gaseous Probability limits

6.3.2.6 Completeness

Data Completeness for the year is shown by site in Table 44. Precision Completeness is shown as the number of precision checks that were performed and submitted to AQS for the year. Precision completeness is evaluated against the number of checks that should have been performed at each site during the year. Completeness for accuracy audits in 2011 met or exceeded APCD DQO goals for every gaseous analyzer, with a minimum of two audits performed on every analyzer.

6.3.2.7 NPAP TTP Gaseous Audits

During Aug. of 2011, the EPA performed National Performance Audit Program (NPAP) audits on five CDPHE O_3 analyzers (Aurora East, Cortez Health Dept., DMAS, Palisade Water Treatment and Rifle) and one CO (Grand Junction Pitkin) analyzer. Four of the ozone audits and the CO audit were conducted Through the Probe (TTP) and one ozone audit (Palisade water treatment plant) was conducted through the Back of the Analyzer (BOA). Each evaluation consisted of three audit concentration levels. All six audits passed the NPAP criteria for all concentration levels (+or- 10% for ozone and +or- 15% for CO). One of the ozone audits fell into the warning range (+or- 7%) for all concentration levels (Cortez Health Dept.). The CO audit (Grand Junction Pitkin) also fell into the warning range (+or- 10%) for one concentration point, level 3 (the highest level). Copies of these audits are available upon request.

Table 44 summarizes the statistical evaluations for all gaseous precision, accuracy, bias, and completeness data. The basis for these calculations can be found in 40CFR58 Appendix A part 4.1.

Table 44. Summary of Precision, Accuracy, Bias, and Completeness Data for Gaseous Monitoring

Site or Organization	Analyte	Quarter or Year	Precision Count	Precision Completeness (%)	% In DQO Limits	CV (%)	BIAS (%)	+/- on Bias	(90% Probability Interval) Probability Limits		% in Probability Limits	Data Completeness (%)
									Lower	Upper		
Welby	CO	2011	27	100		1.7	3.3	-	-5.49	-0.03		93
Longmont	CO	2011	26	100		1.5	1.3	-	-3.0	1.81		98
CAMP	CO	2011	25	96		2.6	2.1		-4.77	3.37		97
Auraria	CO	2011	25	96		1.7	3.0	-	-5.26	0.24		100
Co. Springs Hwy 29	CO	2011	26	100		2.0	1.9	-	-4.26	2.07		99
Ft. Collins CSU	CO	2011	28	100		0.1	1.2	-	-2.46	0.65		99
Grand Junction Pitkin	CO	2011	26	100		1.9	1.8	-	-4.07	2.11		96
Greeley Annex	CO	2011	26	100		2.1	1.6		-3.58	3.07		98
DMAS trace	CO	2011	25	96		3.1	3.4	-	-7.49	2.45		86
CDPHE	CO	1	52			1.8	1.6	-	-3.84	2.44		
CDPHE	CO	2	60			1.7	1.9	-	-4.35	1.45		
CDPHE	CO	3	63			1.7	2.0	-	-4.41	1.43		
CDPHE	CO	4	59			2.9	2.6	-	-6.61	3.22		
CDPHE	CO	2011	234	97	100	2.0	1.9	-	-4.99	2.26	100	95
Welby	SO_2	2011	24	92		6.1	4.9		-9.78	9.31		91
CAMP	SO_2	2011	26	100		3.0	3.4	-	-7.24	2.2		98
DMAS trace	SO_2	2011	9	35		2.4	1.8	-	-3.44	2.66		28
CDPHE	SO_2	1	10			3.6	4.9	-	-8.37	1.15		
CDPHE	SO_2	2	14			2.5	4.1	-	-6.83	0.51		
CDPHE	SO_2	3	14			4.8	4.1	+	-4.99	8.94		
CDPHE	SO_2	4	21			4.6	3.6	-	-8.2	6.11		
CDPHE	SO_2	2011	59	96	97	4.2	3.5	-	-8.47	5.94	N/A	93
Welby	NO_2	2011	25	96		6.6	5.8		-12.4	8.45		89
CAMP	NO_2	2011	24	92		5.4	4.3		-7.7	9.24		83
DMAS	NO	2011	19	58		4.5	6.2	-	-11.5	2.23		60
CDPHE	NO_2	1	12			7.7	6.3		-12.46	9.1		
CDPHE	NO_2	2	12			5.7	4.4		-8.51	7.28		
CDPHE	NO_2	3	13			7.3	6.4		-13.04	7.62		
CDPHE	NO_2	4	12			5.3	5.0		-4.65	10.0		
CDPHE	NO_2	2011	49	94	98	5.8	4.8		-10.42	9.2	N/A	86
Welby	O_3	2011	28	100		2.9	2.4		-3.86	5.4		99
Highland	O_3	2011	27	100		2.1	1.5		-3.52	3.11		91
Aurora East	O_3	2011	26	100		2.9	2.2		-4.44	4.71		93
S. Boulder	O_3	2011	27	100		1.5	1.8	+	-1.08	3.79		99

Site or Organization	Analyte	Quarter or Year	Precision Count	Precision Completeness (%)	% In DQO Limits	CV (%)	BIAS (%)	+/- on Bias	(90% Probability Interval) Probability Limits		% in Probability Limits	Data Completeness (%)
Crk.												
Carriage	O_3	2011	26	100		1.8	1.4	+	-2.51	3.05		94
DMAS	O_3	2011	23	89		4.1	3.5		-7.45	5.44		95
Chatfield	O_3	2011	26	100		1.8	1.7	+	-2.13	3.63		99
Co. Spgs. Academy	O_3	2011	26	100		2.9	3.5	+	-2.14	7.08		94
Co. Spgs. Manitou	O_3	2011	26	100		1.6	1.4	+	-1.81	3.26		99
Rifle	O_3	2011	29	100		4.0	3.6	+	-4.93	7.85		99
Arvada	O_3	2011	26	100		1.5	1.4	+	-1.77	3.06		99
Welch	O_3	2011	27	100		1.6	1.9	+	-1.23	3.96		99
Rocky Flats North	O_3	2011	26	100		1.9	1.7	+	-2.14	3.89		98
NREL	O_3	2011	25	96		3.0	2.5	+	-3.87	5.72		99
Aspen Park	O_3	2011	26	100		2.4	2.0		-3.37	4.39		94
Ft. Collins West	O_3	2011	26	100		1.3	1.6	+	-0.85	3.26		99
Rist Canyon	O_3	2011	26	100		1.5	2.4	+	-0.55	4.35		99
Ft. Collins CSU	O_3	2011	26	100		2.9	2.8	+	-2.77	6.37		97
Palisade	O_3	2011	27	100		4.0	4.3	+	-3.35	9.36		100
Cortez	O_3	2011	28	100		4.9	4.1		-7.56	8.27		99
Lay Peak	O_3	2011	13	100		3.9	3.0		-5.0	5.94		93
Greeley Tower	O_3	2011	26	100		3.3	2.6	+	-4.55	5.78		99
CDPHE	O_3	1	104			1.8	1.8	+	-1.89	4.38		
CDPHE	O_3	2	115			2.2	1.9	+	-2.91	5.05		
CDPHE	O_3	3	127			2.0	1.7	+	-2.6	4.48		
CDPHE	O_3	4	123			2.7	2.2		-4.61	5.05		
CDPHE	O_3	2011	449	99	99	2.1	1.7	+	-3.05	4.78	99	97

6.4. Particulate Criteria Pollutants

6.4.1 Quality Objectives for Measurement Data

The Quality Objectives for the APCD ambient air monitoring of particulate criteria pollutants are shown in Table 45, below.

Table 45. Data Quality Objectives for Particulate Pollutants

Data Quality Indicator	APCD Goal	EPA Requirement
Precision High-Vol Filters	10%	10%
Precision Low-Vol Filters	10%	10%
Precision PM_{10} Continuous	10%	10%
Precision $PM_{2.5}$ Continuous	4%	4%
Precision Completeness	90%	75%
Bias Low-Vol / PEP	10%	10%
Accuracy High-Vol	10%	10%
Accuracy Low-Vol	4%	4%
Accuracy PM_{10} Continuous	10%	10%
Accuracy $PM_{2.5}$ Continuous	4%	4%
Accuracy Audits (Performance Evaluations) Completeness	1 audit per analyzer per quarter	25% of analyzers quarterly
Overall Data Completeness	90%	75%
90% Probability Intervals	Meet EPA requirement	95% of audit values

6.4.2 Particulate Data Quality Assessment

6.4.2.1 Summary

Assessment of the data quality for APCD particulate criteria pollutants showed that all samplers met minimum EPA criteria and most monitoring sites met APCD goals for accuracy, precision, completeness, and bias. There were some notable problems in the particulate network during 2011, which included the following:

1) The $PM_{2.5}$ background site, Elbert County stopped operating 4/22/2011 due to a change in property ownership. A new $PM_{2.5}$ background site has been located and will be installed sometime during 2012.

2) The DMAS building was prescribed for demolition in Aug. of 2011. A Low Volume manual PM_{10} sampler was added to the Denver Municipal Animal Shelter (DMAS) site trailer to aid in meeting NCORE criteria in Dec. 2010 and to replace the DMAS site building High Volume sampler removal. Scaffolding was set up next to the DMAS NCORE site trailer for the TSP samplers that were removed from the DMAS shelter building due to demolition.

3) The site operator for the Alamosa Municipal site was unavailable for much of 2011, which affected data quality and data completeness.

4) The $PM_{2.5}$ TEOM in Grand Junction at the Powell Building was removed in June of 2011. A new Thermo 1405 $PM_{2.5}$, PM_{coarse} and PM_{10} automated instrument was installed in December 2010. The new Thermo instrument malfunctioned for most of 2011. Various parts were replaced throughout the year on the instrument. The APCD invalidated two months of data from the new 1405 instrument in AQS (Nov. and Dec. 2011). There was so little data produced by this instrument that no statistical analyses were performed.

5) The PM_{10} BAM sampler from Grand Junction was taken out of service in April of 2011.

6.4.2.2 Precision

The CV for filter-based particulate monitoring is determined from the collocated precision data collected (i.e., two identical samplers operated in the identical manner). Due to the anticipated poor precision for very low levels of pollutants, only collocated measurements at or above a minimum level (greater than or equal 15 μg/m^3 for PM$_{10,}$ 20 ug/m^3 for Total Suspended Particulate or TSP, and 3 μg/m^3 for PM$_{2.5}$) would be called "Valid Pairs" and are used to evaluate precision. The Coefficient of Variation was calculated with 52 Valid Pairs for DMAS TSP and DMAS TSP collocated, which was 10.6% just outside the limit. The other particulate parameters fell within the DQO limits. The calculations for the statistical presentations in Table 5 and figure 3 can be found in 40CFR58 Appendix A parts 4.2.

The CV for continuous based particulate monitoring is determined by the monthly flow verification (precision checks) performed on the continuous particulate monitors. The calculations for the statistical presentations in Table 6 are the same calculations that were performed on the gaseous analyzers precision data.

Figure 52 shows the Coefficient of Variation for the manual Particulate network. The CV was calculated using collocated vs. the primary manual particulate sampler "Valid Pair" filter concentrations per 40CFR58 Appendix A parts 4.2.

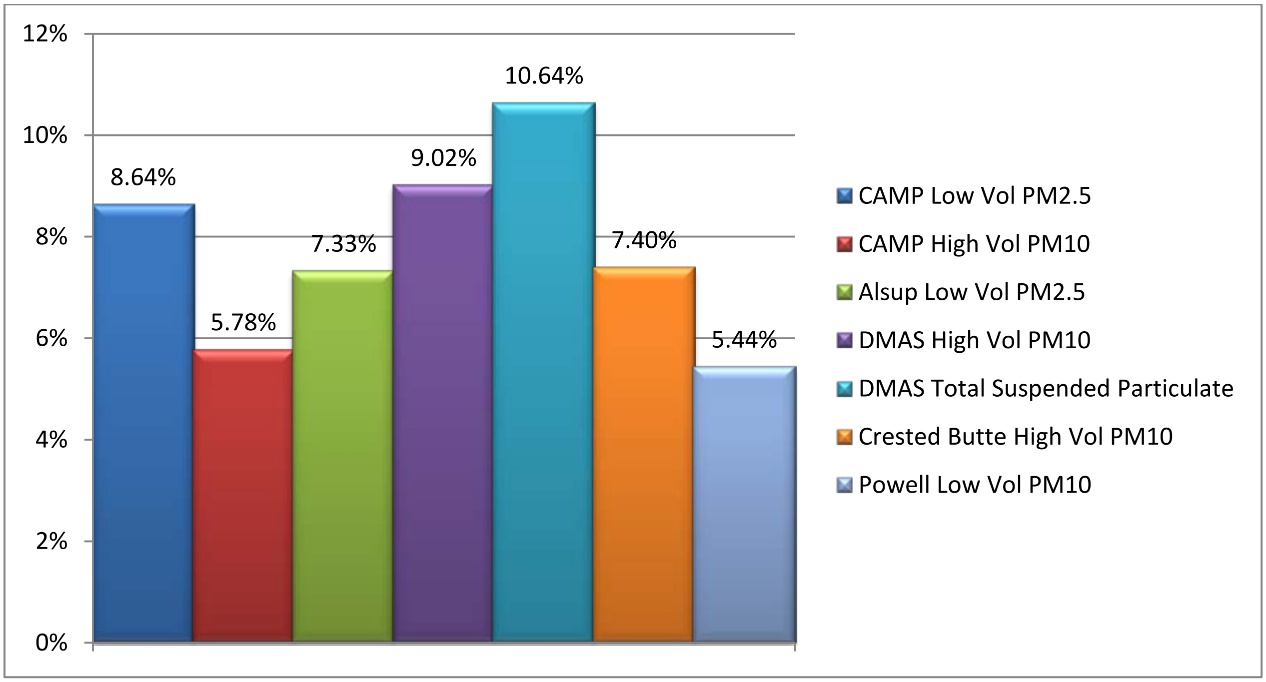

Figure 52. Percent Coefficient of Variation for Collocated Manual Particulate Samplers

6.4.2.3 Bias

Results of the annual flow rate audits conducted by APCD personnel are shown in Table 46 below. There is no requirement for bias on the High-Vol filter-based particulate monitoring, since the precision is based on collocated sampling. For the filter-based particulate monitoring, Table 46 summarizes bias based on the audits that were performed during the year, since APCD performs particulate audits four times more frequently than the EPA requires. These additional audits are conducted to compensate for the lack of a flow verification precision check program in place for the High-Vol samplers. The bias calculations were also conducted using the Low-Vol audit results since the flow verifications performed on the Low-Vol samplers are not reported to the EPA AQS database, and because the PEP results for 2011 have not been made available to CDPHE by the EPA. The bias for the continuous particulate monitoring was calculated on the monthly flow verification precision checks with the same calculations that were used to determine the gaseous bias, and can be found in Table 47.

6.4.2.4 Performance Evaluations (Accuracy Audits)

Audits were performed at least quarterly on every particulate sampler within the APCD network during the 2011 calendar year, with the exception of Cortez (only one audit). The primary goal of these audits is to evaluate the analyzer performance and calibration. Other factors are also noted during these audits such as operator performance, station operational criteria, record keeping, site upkeep issues, and general safety problems.

All Performance Evaluations (accuracy audits) performed for all particulate analyzers during 2011 passed the APCD objectives with the following exceptions:

1) One of the 266 High-Vol PM_{10} audits performed, failed the portion of the audit that evaluates the calibration of the sampler (Pagosa Springs School, Sampler 2 on12/15/2011) and five of these audits fell into the warning range. Of the 266 High-Vol audits performed, 12 failed for the portion of the audit designed to catch design flow (operational flow) problems, and 27 of these audits fell into the warning range for design flow criteria. For these audits a warning means greater than +/- 7% and failed means greater than +/-10%. The design flow changes daily due to changing weather conditions, and are evaluated in the particulate database before being loaded to AQS. Any sample deemed to have a failing design flow is flagged in the database, and the appropriate null code is loaded to AQS.

2) The main flow rate from one Boulder Continuous Particulate audit failed to meet the +/-4% criteria in the first quarter of 2011. The main flow rate from one Colorado College Continuous Particulate audit failed to meet the +/-4% criteria in the fourth quarter of 2011.

6.4.2.5 Completeness

Data Completeness for the year is shown by site in the 5th to last column in Table 5 and in the last column of Table 6. Precision Completeness is shown in the column to the right of “Precision Count” in table 6 and is based on the number of monthly flow verifications that were performed. Precision Completeness is shown to the right of “# valid pairs” in Table 5, and is based on the number of pairs collected. Precision completeness is evaluated against the number of checks that should have been performed at each site during the year. Completeness for accuracy audits met or exceeded all APCD DQO goals for every particulate analyzer, with a minimum of two audits performed on every analyzer.

6.4.2.6 PEP / NPAP Particulate Audits

High Vol NPAP audits were not performed by EPA in 2011. NPAP audits for the High-Vol particulate networks are required every three years, and the APCD performed these analyses, which were then evaluated by Region 8 EPA, in 2009. The 2009 results for High-Vol PM_{10} and TSP NPAP audits are available upon request.

At the time this document was created the $PM_{2.5}$ PEP audits were not in AQS due to an action item started by EPA. There was a problem associating the audit results with the site id and it is currently being investigated. Those results should be in AQS relatively soon and would be available upon request from APCD at that time.

6.4.2.7 Lead

Lead analysis was performed by the CDPHE Laboratory Services Division on filters from TSP samples at Centennial Airport and Denver Municipal Animal Shelter (DMAS). All lead concentrations were lower than .02 *u*g/m^3 required for collocated precision calculations prescribed by 40CFR Appendix A parts 4.2. Due to the low concentration shown by the lead samples available for analysis no official statistics were performed for this Data Quality Assessment.

Blind EPA RTI test strips were sent to APCD’s contract lead analysis lab in 2011 to test the performance of the lab. Inductively Coupled Plasma - Mass Spectrometry (ICPMS) was used for the analysis. The lab analyzed a total of 24 blind EPA lead test strips in 2011. The results were statistically analyzed per instruction in 40CFR58 Appendix A part 4, equation 24 for this assessment. The assessment is a % Bias based on an analysis of the quarterly flow audits and the blind test strip results and can be found at the bottom of table 5 for each lead site.

Figure 53 below shows the individual percent difference between the blind lead strip “True Value” and the APCD Laboratory Services Division result. This is for all 24 blind lead strips analyzed in 2011.

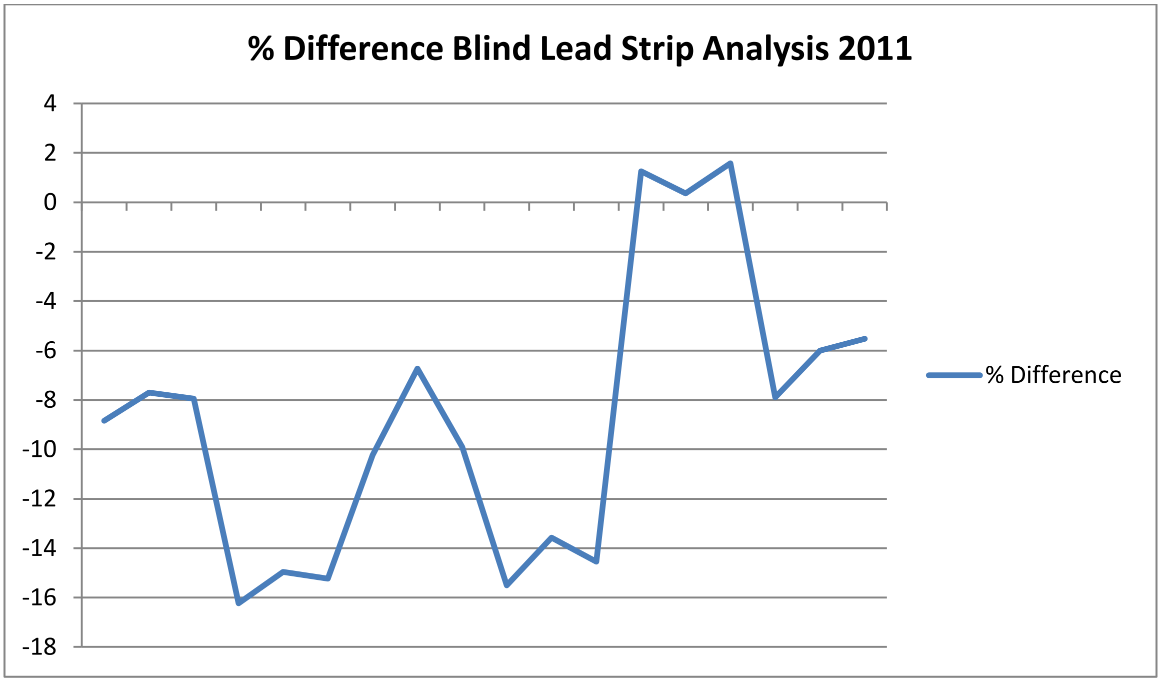

Figure 53. Percent Difference Blind Lead Strip Analysis

Table 46 summarizes statistical evaluations for all filter-based particulate precision, accuracy, bias, and completeness data. The values were calculated as described in 40CFR58 Appendix A part 4.2.

Table 46. Summary of Precision, Accuracy, Bias, and Completeness Data for Filter Based Particulate Monitoring

Site or Organization	Parameter	Notes	Performance Evaluations (Accuracy)				Data Completeness	Collocated Precision Statistics			
			# of audits	Bias (%)	LPL (%)	UPL (%)		Total # Pairs	Valid # Pairs	Completeness	CV
Alamosa Muni	High-Vol PM_{10}		16	3.0	-6.5	3.0	83				
Alamosa ASC	High-Vol PM_{10}		16	-3.2	-6.4	2.4	90				
Aspen	High-Vol PM_{10}		8	3.6	-6.6	5.31	98				
Boulder	High-Vol PM_{10}		4	-3.2	-4.0	-0.12	98				
Breckenridge	High-Vol PM_{10}		16	-3.3	-6.7	2.5	87				
CAMP	High-Vol PM_{10}		4	-4.6	-8.1	2.8	97				
CAMP	High-Vol PM_{10}	collocated	4				92	54	48	94	5.8
Canon City	High-Vol PM_{10}		4	-3.0	-3.7	-0.09	92				

Site or Organization	Parameter	Notes	Performance Evaluations (Accuracy)				Data Complet	Collocated Precision Statistics			
Clifton	High-Vol PM_{10}		8	-4.1	-7.8	5.0	99				
Crested Butte	High-Vol PM_{10}		8	-4.1	-8.1	3.0	95				
Crested Butte	High-Vol PM_{10}	collocated	4				97	58	39	97	7.4
Delta	High-Vol PM_{10}		8	-3.9	-6.9	2.5	100				
DMAS	High-Vol PM_{10}		6	-3.5	-6.6	3.4	100				
DMAS	High-Vol PM_{10}	collocated	6				100	36	28	95	9.0
Durango	High-Vol PM_{10}		8	-5.0	-9.0	3.2	98				
DVC	High-Vol PM_{10}		16	-3.0	-6.7	4.0	99				
Ft. Collins CSU	High-Vol PM_{10}		8	-1.8	-2.9	0.46	97				
Greeley	High-Vol PM_{10}		8	-2.6	-4.9	2.5	98				
Lamar Municipal	High-Vol PM_{10}		16	-2.5	-4.7	1.1	96				
Lamar Power Plant	High-Vol PM_{10}		16	-2.6	-4.5	0.37	100				
Longmont	High-Vol PM_{10}		4	-3.2	-5.6	2.8	95				
Mt. Crested Butte	High-Vol PM_{10}		16	-2.3	-4.7	2.0	96				
Pagosa School	High-Vol PM_{10}		16	-5.3	-10.7	3.2	93				
Parachute	High-Vol PM_{10}		8	-3.6	-6.6	2.5	93				
Pueblo	High-Vol PM_{10}		8	3.1	-5.8	3.5	83				
Rifle	High-Vol PM_{10}		8	-2.4	-3.9	0.58	96				
Steamboat	High-Vol PM_{10}		16	-3.5	-7.2	2.8	94				
Telluride	High-Vol PM_{10}		8	-2.6	-4.4	1.0	95				
Welby	High-Vol PM_{10}		4	-2.0	-2.8	0.1	97				
CDPHE	High-Vol PM_{10}	organization	266	-2.5	-6.5	2.6	95	204	115	95	2.5
Colorado College	Low-Vol PM_{10}		4	-1.3	-2.1	0.72	97				
Commerce City	Low-Vol PM_{10}		4	-1.3	-1.8	0.1	96				
DMAS	Low-Vol		5	-1.9	-2.3	-0.63	99				

Site or Organization	Parameter	Notes	Performance Evaluations (Accuracy)				Data Complet	Collocated Precision Statistics			
	PM_{10}										
Grand Junction	Low-Vol PM_{10}		4	2.2	-3.9	3.3	94				
Grand Junction	Low-Vol PM_{10}	collocated	4				100	52	30	85	5.4
CDPHE	Low-Vol PM_{10}	organization	21	-1.3	-2.7	1.0	95	52	30	85	5.4
A.C.C.	Low-Vol $PM_{2.5}$		4	2.0	-3.3	2.8	93				
Boulder	Low-Vol $PM_{2.5}$		4	4.5	-5.9	6.8	83				
CAMP	Low-Vol $PM_{2.5}$		4	0.9	-1.3	1.0	97				
CAMP	Low-Vol $PM_{2.5}$	collocated	4				100	64	60	100	8.6
Chatfield	Low-Vol $PM_{2.5}$		4	-1.6	-2.3	1.0	98				
Colorado College	Low-Vol $PM_{2.5}$		4	3.1	-2.5	4.5	94				
Commerce City	Low-Vol $PM_{2.5}$		4	-0.9	-1.3	0.4	100				
Commerce City	Low-Vol $PM_{2.5}$	collocated	4				93	61	55	92	7.3
Cortez	Low-Vol $PM_{2.5}$		1	0.7	0.7	0.7	97				
DMAS	Low-Vol $PM_{2.5}$		4	-2.2	-3.3	1.0	99				
Elbert	Low-Vol $PM_{2.5}$		1	-2.7	-2.7	-2.7	75				
Ft. Collins CSU	Low-Vol $PM_{2.5}$		4	2.2	-3.5	1.9	92				
Grand Junction	Low-Vol $PM_{2.5}$		4	2.2	-3.9	3.3	99				
Greeley	Low-Vol $PM_{2.5}$		4	1.5	-2.2	2.1	98				
Longmont	Low-Vol $PM_{2.5}$		4	-2.3	-3.0	0.4	98				
Platteville	Low-Vol $PM_{2.5}$		4	1.6	-2.4	1.9	84				
Pueblo	Low-Vol $PM_{2.5}$		4	-2.4	-3.6	0.1	90				
Swansea	Low-Vol $PM_{2.5}$		4	4.3	-6.5	3.6	94				
CDPHE	Low-Vol $PM_{2.5}$	organization	67	1.3	-3.3	2.3	93	125	115	96	7.7
CDPHE	All Low-Vol Particulate	organization	88	1.3	-3.2	2.0	93				
Centennial	TSP		4	7.6	-12.0	10.1	97				

Site or Organization	Parameter	Notes	Performance Evaluations (Accuracy)				Data Complet	Collocated Precision Statistics			
Airport											
DMAS	TSP		5	3.6	-6.6	4.6	92				
DMAS	TSP	collocated	5				93	56	52	100	10.6
CDPHE	TSP	organization	14	3.8	-7.7	5.3	90	56	52	100	10.6
Centennial Air.	Pb		4	21.1	*NA*	*NA*	97				
DMAS	Pb		5	16.5	*NA*	*NA*	90				

Figure 54 below shows the upper and lower probability limits for 2011 for the TSP, High-Vol PM_{10} and Low-Vol combined (both PM_{10} and $PM_{2.5}$) networks. Since collocated data is used to evaluate precision, and APCD performs audits quarterly, these statistics were calculated from the accuracy audit results.

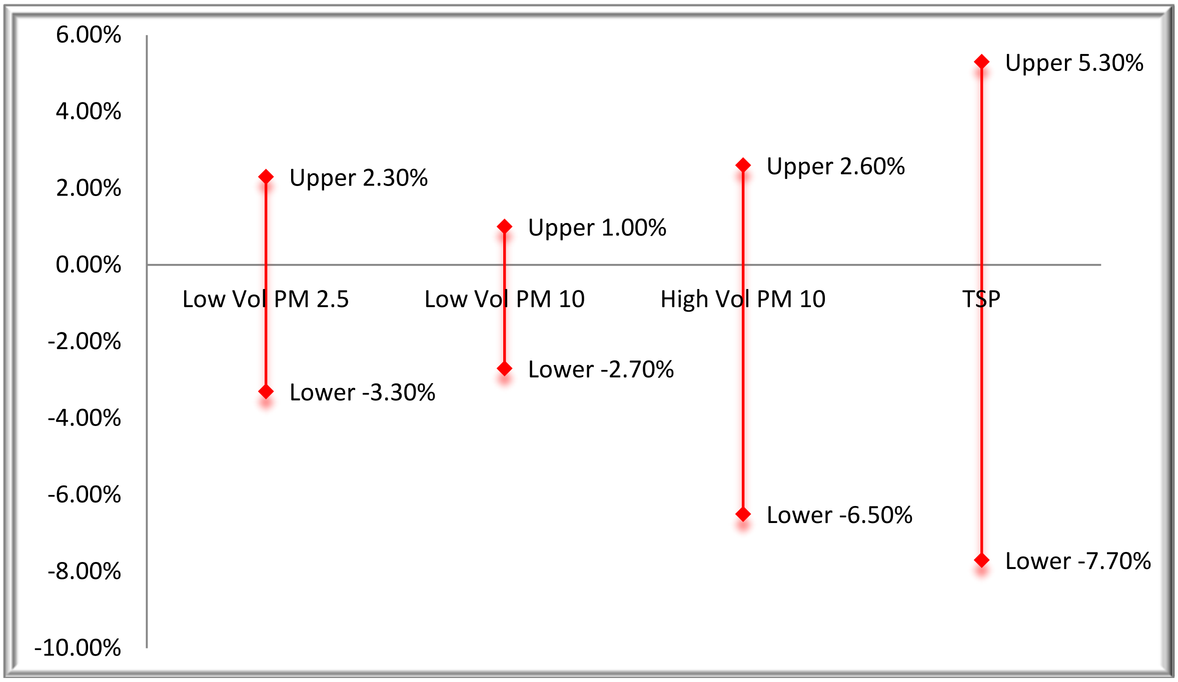

Figure 54. Filter Based Particulate Probability Limits

Table 47 below summarizes statistical evaluations for all continuous particulate precision, accuracy, bias, and completeness data. The values were calculated in the same manner as the gaseous statistics using the monthly flow rate verification precision checks.

Table 47. Summary of Precision, Accuracy, Bias, and Completeness Data for Continuous Particulate Monitoring

Site or Organization	Particulate Parameter	Quarter or Year	Precision Count	Precision Completeness (%)	Prec. Within DQO Limit	CV (%)	Bias (%)	+/- on bias	90% Probability Interval Probability Limits		% of Audit Points within Probability Limits	Data Completeness (%)
									Lower	Upper		
Welby	PM_{10} TEOM	2011	21	100		1.2	0.9		-1.8	1.8		93
CAMP	PM_{10} TEOM	2011	20	100		1.0	0.9		-1.8	1.3		91

Site or Organization	Particulate Parameter	Quarter or Year	Precision Coun	Precision Completeness (%)	Prec. Within DQO	CV (%)	Bias (%)	+/- on bias	90% Probability Interval Probability Limits		% of Audit Points within	Data Completeness
DMAS	PM$_{10}$ TEOM	2011	11	75		2.2	2.0	+	-2.1	3.9		88
CDPHE	PM$_{10}$ TEOM	1	12			1.4	1.0		-2.1	1.7		
CDPHE	PM$_{10}$ TEOM	2	14			1.6	1.3		-2.0	2.6		
CDPHE	PM$_{10}$ TEOM	3	14			1.2	1.0		-1.4	2.0		
CDPHE	PM$_{10}$ TEOM	4	12			1.9	1.5		-2.7	2.6		
CDPHE	PM$_{10}$ TEOM	2011	52	92	100	1.8	1.8		-4.0	3.8	100	93
Ft. Collins 1405	FDMS PM$_{2.5}$	2011	9	75		3.0	2.5	-	-4.7	3.0		86
Ft. Collins 1405	PM Coarse	2011	8	67		6.1	4.6		-6.8	8.5		93
Boulder - Marine St.	FDMS PM$_{2.5}$	2011	7	42		1.4	1.0		-1.5	1.8		77
CAMP	FDMS PM$_{2.5}$	2011	21	100		0.8	2.4	-	-3.5	-0.9		95
NJH	FDMS PM$_{2.5}$	2011	24	100		0.9	1.8	-	-2.9	-0.1		96
DMAS	FDMS PM$_{2.5}$	2011	12	92		2.0	1.7		-2.3	3.4		85
Colorado College	FDMS PM$_{2.5}$	2011	6	50		2.5	1.9		-2.0	3.6		89
Commerce City	PM$_{2.5}$ TEOM	2011	22	100		1.2	1.3	-	-2.7	1.1		99
Longmont	PM$_{2.5}$ TEOM	2011	8	67		1.6	1.2		-2.0	1.9		83
Chatfield	PM$_{2.5}$ TEOM	2011	12	92		0.9	0.8		-1.6	1.0		84
Greeley	PM$_{2.5}$ TEOM	2011	11	92		3.1	2.4		-4.7	3.7		95
CDPHE	PM$_{2.5}$ TEOM	1	26			2.0	1.7		-3.7	2.7		
CDPHE	PM$_{2.5}$ TEOM	2	31			1.7	1.9	-	-4.0	1.7		
CDPHE	PM$_{2.5}$ TEOM	3	33			1.5	1.5	-	-3.3	1.7		
CDPHE	PM$_{2.5}$ TEOM	4	32			1.5	1.5	-	-3.2	1.8		
CDPHE	PM$_{2.5}$ TEOM	2011	122	82	100	1.5	1.5		-3.5	2.0	100	89

Figure 55 below shows the 2011 upper and lower probability limits for the CDPHE's continuous particulate network. These intervals were established from the monthly flow rate verification/precision checks performed at each site.

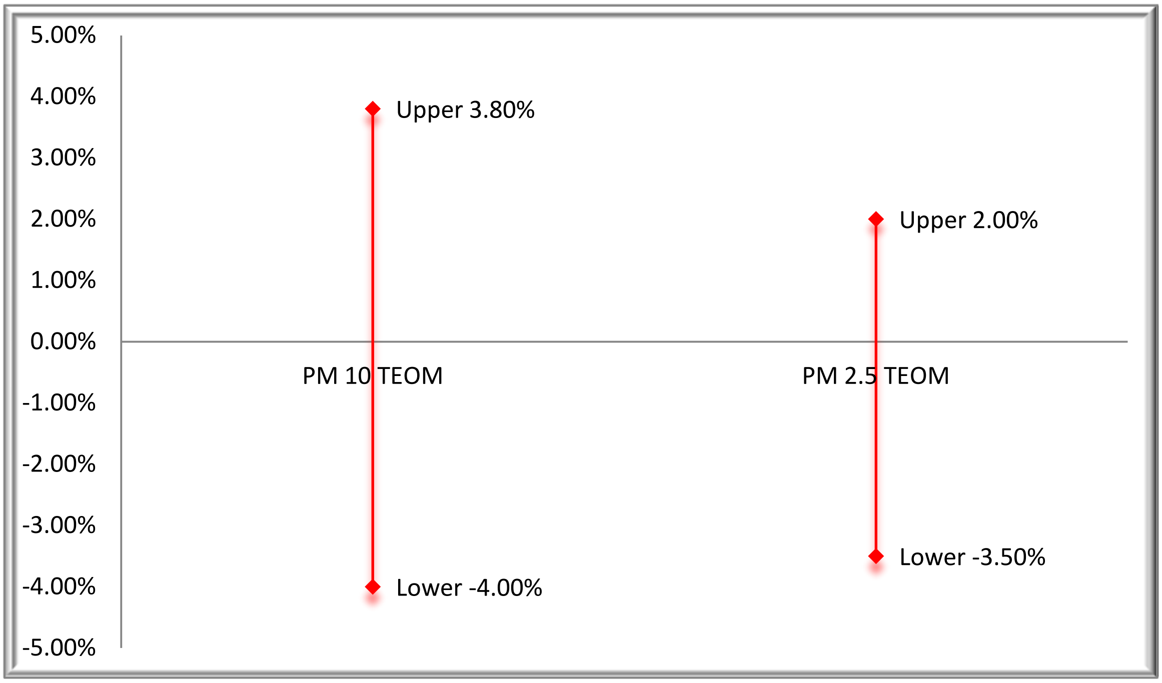

Figure 55. Continuous Based Particulate Probability Intervals

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