COLORADO
Air Pollution Control Division
Department of Public Health & Environment

Technical Services Program

2015 Ambient Air Monitoring Network Assessment

July 1, 2015

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GLOSSARY

AADT	Annual Average Daily Traffic
APCD	Air Pollution Control Division
AQS	Air Quality System (EPA database)
AQS ID	9-digit site identification number used in the AQS database
ARS	Air Resources Specialists
BLM	Bureau of Land Management
CAA	Clean Air Act
CAMP	Continuous Air Monitoring Program
CAQCC	Air Quality Control Commission
CDOT	Colorado Department of Transportation
CDPHE	Colorado Department of Public Health and Environment
CFR	Code of Federal Regulations
CO	Carbon monoxide
CSA	Combined Statistical Area
FEM	Federal Equivalent Method
FRAPPÉ	Front Range Air Pollution and Photochemisty Éxperiment
FRM	Federal Reference Method
GIS	Geographic Information System
HEEJ	Health Equity and Environmental Justice collaborative
LUR	Land-Use Regression
MSA	Metropolitan Statistical Area
NAAQS	National Ambient Air Quality Standards
NCore	National Core multi-pollutant monitoring stations
NO	Nitric oxide
NO_2	Nitrogen dioxide
NO_x	Reactive nitrogen oxides
NO_y	Total reactive nitrogen
NOAA	National Oceanic and Atmospheric Administration
O_3	Ozone
NPS	National Park Service
$PM_{2.5}$	Particulate matter with an equivalent diameter less than or equal to 2.5 μm
PM_{10}	Particulate matter with an equivalent diameter less than or equal to 10 μm
PMSA	Principal Metropolitan Statistical Area
PWEI	Population Weighted Emissions Index
QA/QC	Quality Assurance/Quality Control
RAQC	Regional Air Quality Council
SDoH	Social Determinants of Health index
SIP	State Implementation Plan
SLAMS	State or Local Air Monitoring Stations
SO_2	Sulfur dioxide
SPM	Special Purpose Monitor
SUIT	Southern Ute Indian Tribe
TSP	Total Suspended Particulates
µg	Microgram (10^{-6} grams)
US EPA	United States Environmental Protection Agency
USFS	United States Forest Service
VOC	Volatile Organic Compound
WLC	Weighted Linear Combination

EXECUTIVE SUMMARY

On October 17, 2006, the U.S. Environmental Protection Agency (EPA) amended its ambient air monitoring regulations to include a requirement that all state and local air quality monitoring agencies prepare a technical assessment of their monitoring networks once every five years. This document describes the Colorado Department of Public Health and Environment (CDPHE) Air Pollution Control Division's (APCD) 2015 Ambient Air Monitoring Network Assessment.

Purpose of the Assessment

The mission of the APCD is to provide our customers with excellent air quality management services that contribute to the protection of public health, the protection of ecosystems, and continual improvement of air quality related aesthetic values (e.g., visibility). The technical assessment presented here will provide decision-makers with the information needed to maximize the efficiency and effectiveness of Colorado's ambient air monitoring network. The assessment also ensures that APCD and its partners have the information needed to protect human health and the environment for current and future generations in Colorado.

As of May 1, 2015, APCD operated a network of 73 air pollution monitors at 48 monitoring sites. The data obtained from these monitors serves a variety of needs. The APCD has chosen the following eleven objectives as being those that most accurately define the overall purposes of the network:

1. To determine background concentrations,
2. To establish regulatory compliance,
3. To track pollutant concentration trends,
4. To assess population exposure,
5. To evaluate emissions reductions,
6. To evaluate the accuracy of model predictions,
7. To assist with forecasting
8. To locate maximum pollutant concentrations
9. To assure proper spatial coverage of regions,
10. To assist in source apportionment, and
11. To address environmental justice concerns.

Assessment

To relate the value of its monitoring activities to its objectives and priorities, the APCD has evaluated the state network on a pollutant-by-pollutant basis to assess the relative value of each pollutant monitor and to identify areas where the inclusion of new monitoring sites would be most beneficial. This assessment was conducted in broad accordance with EPA guidance; however, the analyses and tools used here were assigned relative weights to reflect the unique objectives and priorities of the APCD within the context of the state of Colorado.

Findings

Overall, the APCD monitoring network meets all federal requirements and adequately supports APCD monitoring objectives. However, while wholesale changes are not necessary at this time, there are several specific, targeted changes that could be made to improve the overall efficiency and effectiveness of the network. The resources saved from these modifications should be reinvested to address monitoring gaps and high priority future monitoring requirements.

Recommendations

Sites recommended for closure:

1) Discontinue carbon monoxide monitoring at the Grand Junction - Pitkin site due to low concentration values and a low relative value within the network.
2) Discontinue ozone monitoring activities at the Welch site due to relatively low concentrations and high redundancy with nearby monitors.
3) Discontinue PM_{10} monitoring activities at Alamosa - Municipal, Parachute, and Mt. Crested Butte due to the low relative value of these sites.

Sites recommended for relocation:

1) Relocate the Colorado Springs Highway 24 SO_2 monitor to an area of higher maximum concentrations based on modeling studies.
2) Relocate the South Boulder Creek ozone monitor to a site nearer the city of Boulder or in the foothills immediately to the west.
3) Relocate the Aspen Park ozone monitor to a more suitable location nearby.

Recommended new sites/monitors:

1) Collocated NO_2 monitors would be useful at high concentration ozone monitoring sites in the Front Range, particularly at NREL and Fort Collins - West.
2) Consider the addition of new O_3 monitoring sites in Pueblo, in Alamosa/Trinidad, around the Continental Divide, and in northern Weld County.
3) Add a PM_{10} monitoring site in northeastern Colorado to determine the spatial extent of windblown dust events.

1 INTRODUCTION

The Air Pollution Control Division (APCD) of the Colorado Department of Public Health and Environment (CDPHE) has prepared the 2015 Ambient Air Monitoring Network Assessment as an examination and evaluation of the APCD's network of air pollution monitoring stations. The Network Assessment is an extension of the Network Plan, which is required to be submitted annually. The Network Assessment is required to be performed and submitted to the U.S. Environmental Protection Agency (EPA) every 5 years, with this second assessment due on July 1, 2015. The assessment must include specific analyses of the monitoring network, including: (1) a re-evaluation of the objectives and priorities for air monitoring, (2) an evaluation of the network's effectiveness and efficiency relative to its monitoring objectives, and (3) recommendations for network reconfigurations and improvements.

1.1 Background and Key Issues

The priorities and objectives of ambient air monitoring programs can change and evolve over time. Monitoring networks must therefore be re-evaluated and reconfigured on a periodic basis to ensure that objectives are obtained. Monitoring objectives may change for a number of different reasons, such as in response to changes in air quality. Air quality in the United States has improved dramatically since the adoption of the Clean Air Act and National Ambient Air Quality Standards (NAAQS).[1] For example, lead (Pb) concentrations in ambient air declined rapidly during the 1980s due to the phase-out of leaded gasoline (Eisenreich et al., 1986), and Pb monitoring activities were therefore deemphasized by the APCD and many other monitoring agencies. Changes in population and consumption patterns are another factor often motivating the re-evaluation of air monitoring programs. For instance, the U.S. population has become increasingly concentrated in suburban and exurban regions over the past 60 years, and rates of vehicle ownership and average distance driven have increased dramatically as the population has spread away from high-density urban centers (Kahn, 2000). This trend has resulted in the need for increased monitoring downwind of pollution sources due to enhanced production of photochemical smog in exurban and even rural environments (Sillman, 1999). Monitoring objectives may also change in response to the establishment of new air quality rules and regulations. Ambient air quality standards are periodically re-evaluated and reviewed by the EPA to ensure that they provide adequate health and environmental protection. This review process has often resulted in the establishment of new standards, including those that pertain to air toxics, fine particulate matter ($PM_{2.5}$), and regional haze. The EPA is currently considering the adoption of a lower standard for ozone, which would likely necessitate enhanced ozone monitoring in the APCD network and in many other regions nationwide. Objectives can also change due to improvements in our understanding of air quality processes or enhanced monitoring capabilities. The basic understanding of air quality issues and the capability to monitor air quality have both improved dramatically over the last five decades.

As a result of such changes, the APCD's air monitoring network may have unnecessary or redundant monitors. Alternatively, the network may be found to have inefficient network configurations for some pollutants, while other regions or pollutants may benefit from enhanced monitoring. This assessment will help the APCD to optimize its current network to help better protect today's population and environment, while maintaining the ability to understand long-term historical air quality trends.

1.2 Study Objectives

The objectives of this network assessment are three-fold: (1) to determine whether the existing network is meeting its intended monitoring objectives, (2) to evaluate the network's adequacy for characterizing

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[1] http://www.epa.gov/airtrends/

current air quality and impacts from future industrial and population growth, and (3) to identify potential areas where new monitors can be sited or existing monitors removed to support network optimization and/or to meet new monitoring goals. To meet these objectives, a suite of analyses were performed to address the following questions:

- How well does the current monitoring network support current objectives? Which objectives are being met; which objectives are not being met? Are unmet objectives appropriate concerns for APCD? If so, what monitoring is necessary to meet those unaddressed objectives? What are potential future objectives for the monitoring network?
- Are the existing sites collectively capable of characterizing all criteria pollutants? Are the existing sites capable of characterizing criteria pollutant trends (spatially and temporally)? If not, what areas lack appropriate monitoring? If needed, where should new monitors be placed? Does the existing network support future emissions assessment, reconciliation, and modeling studies? Are there parameters at existing sites that need to be added to support these objectives?
- Is the current monitoring network sufficient to adequately assess regional air quality conditions with respect to all criteria pollutants? If not, where should monitors be relocated or added to improve the overall effectiveness of the monitoring network? How can the effectiveness of the monitoring network be maximized?

1.3 Guide to this Report

Section 1 resumes with an overview of the Colorado air monitoring network, including some general background on the geography of Colorado and the current state of air quality in the region, and ends with a general description of the assessment methodologies used in this report. Section 2 consists of a quantitative site-to-site comparison of the existing monitoring sites in the APCD network. In this section, a series of assessments are used to assign a relative score to each site to determine its comparative value within the network. Each assessment is assigned a weight and each site within the APCD monitoring network is then ranked by the weighted average of the analyses. Section 3 uses a Geographic Information System (GIS) driven suitability model to locate areas where the existing monitoring network does not adequately represent potential air pollution problems, and where additional sites are potentially needed. This evaluation has been conducted using a series of data maps representing a variety of indicators related to monitoring objectives. The maps are reclassified into a congruous ranking system and organized into three areas: source-oriented, population-oriented, and spatially-oriented. Each area and indicator is then assigned a weight and the spatial average of each weighted indicator is computed. This spatial average is then used to determine the optimal locations at which new monitors should be deployed. Section 4 consists of an assessment of the APCD monitoring network in its relation to environmental justice and social equity concerns. In this section, census tract-level socio-demographic data is examined and the spatial equity of APCD's monitoring network is assessed using the proximity of populations to network monitors as a surrogate for regulatory protection. Section 5 provides recommendations based upon the evaluations described in the preceding sections. Recommendations concerning the addition of new sites or the relocation/discontinuation of existing sites reflect a variety of factors considered in the preceding evaluations, such as population density, pollution sources, monitoring history, compliance with air quality standards, and environmental justice concerns.

1.4 Overview of the Colorado Air Monitoring Network

The APCD currently operates monitors at 54 locations statewide. Ozone (O_3) and particulate matter (PM) monitors, including those for total suspended particulates (TSP), particulate matter < 10 µm in diameter

(PM_{10}), and particulate matter < 2.5 µm in diameter ($PM_{2.5}$), are the most abundant and widespread. Currently, there are PM_{10} monitors at 28 separate locations, $PM_{2.5}$ monitors at 17 locations, and O_3 monitors at 20 locations. APCD also operates 20 meteorological sites. These sites monitor wind speed, wind direction, and temperature. Three meteorological sites are also equipped to measure relative humidity.

Seven of the 28 PM_{10} monitoring sites and 13 of the 17 $PM_{2.5}$ monitoring sites are equipped with continuous “hourly” monitors. This difference reflects the age of the technology, as well as the availability and focus of EPA funding. Increasing the amount of automated versus manual filter-based monitoring will require modifications to the particulate network, as the current network utilizes primarily filter-based operated monitors.

Forty-two of the 54 current monitoring sites have been in operation for ten or more years, while 24 of these have been in operation for 20 or more years. Six monitoring sites have been in operation for more than 40 years. These sites are: Denver CAMP (50 years), Greeley - Hospital (48 years), Alamosa - Adams State College (45 years), Welby (42 years), Pagosa Springs School (40 years), and Steamboat Springs (40 years).

Three of the ozone monitoring sites that are located on the western slope and have data included in this report are operated and maintained by a third party contractor, Air Resource Specialists (ARS). These are the Rifle, Palisade and Cortez ozone monitoring sites. ARS keeps these sites in proper working order and performs regular QC checks and data retrieval, while the APCD conducts the independent auditing of the sites for Quality Assurance (QA) purposes.

1.4.1 APCD Monitoring History

The State of Colorado has been monitoring air quality statewide since the mid-1960s when high volume and tape particulate samplers, dustfall buckets, and sulfation candles were the state of the art for defining the magnitude and extent of the very visible air pollution problem (Riehl and Crow, 1962). Monitoring for gaseous pollutants (CO, SO_2, NO_2, and O_3) began in 1965 when the federal government established the Continuous Air Monitoring Program (CAMP) station in downtown Denver at the intersection of 21st Street and Broadway, which was the area that was thought at the time to represent the best probability for detecting maximum levels of most of the pollutants of concern. Instruments were primitive by comparison with those of today and were frequently out of service.

Under provisions of the original Federal Clean Air Act of 1970, the Administrator of the U.S. EPA established National Ambient Air Quality Standards (NAAQS) designed to protect the public’s health and welfare. Standards were set for TSP, CO, SO_2, NO_2, and O_3. In 1972, the first State Implementation Plan (SIP) was submitted to the EPA. It included an air quality surveillance system in accordance with EPA regulations of August 1971. That plan proposed a monitoring network of 100 monitors (particulate and gaseous) statewide. The system established as a result of that plan and subsequent modifications consisted of 106 monitors.

The 1977 Clean Air Act Amendments required States to submit revised SIPs to the EPA by January 1, 1979. The portion of the Colorado SIP pertaining to air monitoring was submitted separately on December 14, 1979, after a comprehensive review, and upon approval by the Colorado Air Quality Control Commission. The 1979 EPA requirements as set forth in 40 CFR 58.20 have resulted in considerable modification to the network. These and subsequent modifications were made to ensure consistency and compliance with Federal monitoring requirements. Station location, probe siting, sampling methodology, quality assurance and quality control practices, and data handling procedures are all maintained throughout any changes made to the network.

1.4.2 Network Modification Procedures

The APCD develops changes to its monitoring network in several ways. New monitoring locations have been added as a result of community concerns about air quality, such as the PM_{10} monitors in Cripple Creek and Hygiene established in 1998. Other monitors have been established in support of special studies, such as the O_3 monitoring sites in Aurora, Rifle, Cortez, Aspen Park, Palisade, Rist Canyon, and Lay Peak.

Changes in property ownership represent the most common factor motivating network reconfigurations. The APCD owns neither the land nor the buildings where most of the monitors are located, and it is becoming increasingly difficult to get property owner’s permission for use due to risk management issues. Other common reasons for relocating or removing monitors from the network are that either the land or building is modified in such a way that the site no longer meets current EPA siting criteria, or the area surrounding the monitor is being modified in a way that necessitates a change in the monitoring location. The most current examples of this are the removal of the Auraria meteorological monitoring station and the relocation of the NCore Denver Municipal Animal Shelter (DMAS) site. The Auraria station was removed due to the construction of a tall building in the immediate vicinity of the monitor that obstructed airflow around the monitoring site. The DMAS site was relocated due to a change in property ownership and land use. Monitors are also removed from the network after review of the data shows that pollutant levels have dropped to the point where it is no longer necessary to continue monitoring at a specific location.

Finally, all monitors are reviewed on a regular basis to determine if they are continuing to meet their monitoring objectives. If the population, land use, or vegetation around the monitor change undesirably over time, a more suitable location for the monitor is sought. An example of this is the O_3 monitor previously located at the Arvada monitoring site. It was shut down on 12/31/2011, and relocated to the Denver - CAMP location beginning 3/1/2012.

Detailed site descriptions of each monitoring location can be found in Table A.1 (Appendix A), which summarizes the locations and monitoring parameters of each site currently in operation, by county, alphabetically. The shaded lines in the table list the site AQS identification numbers, address, site start-up date, elevation, and longitude and latitude coordinates. Beneath each site description the table lists each monitoring parameter in operation at that site, the orientation and spatial scale, which national monitoring network it belongs to, the type of monitor in use, and the sampling frequency. The parameter date is the date when valid data were first collected.

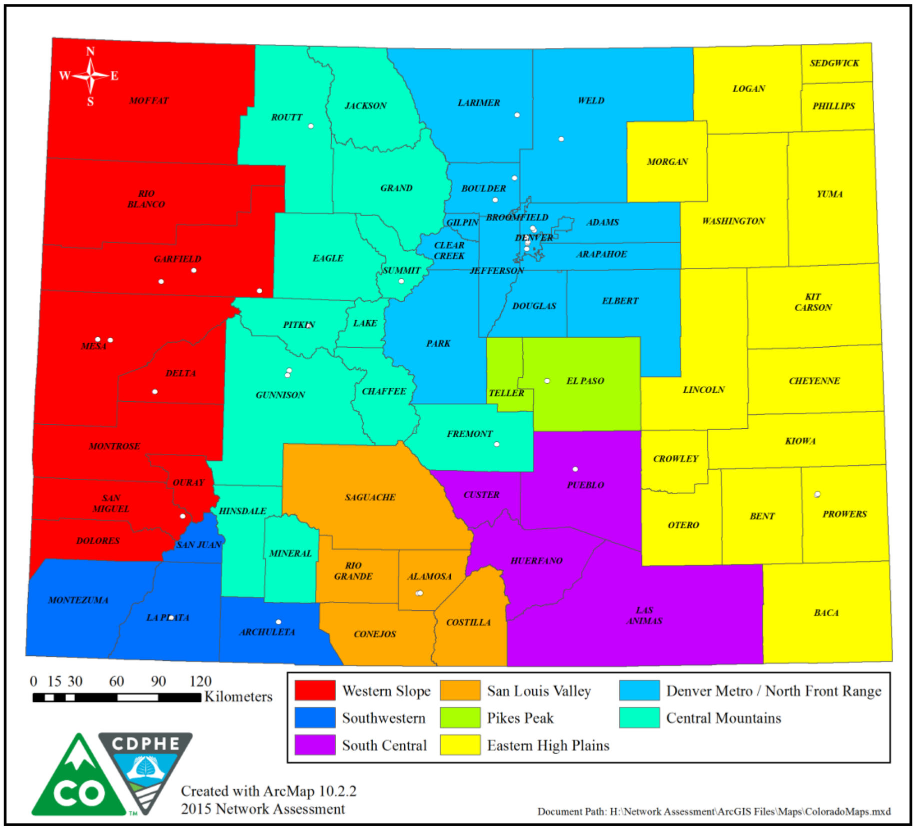
1.4.3 Description of Monitoring Regions in Colorado

The state has been divided into eight multi-county areas that are generally based on topography and have similar airshed characteristics (see Section 1.4.4). These areas are the Central Mountains, Denver Metro/North Front Range, Eastern High Plains, Pikes Peak, San Luis Valley, South Central, Southwestern, and Western Slope regions. Figure 1 shows the approximate boundaries of these regions.

1.4.3.1 Central Mountains

The Central Mountains region consists of 12 counties in the central area of the state. The Continental Divide passes through much of this region. Mountains and mountain valleys are the dominant landscape features. Leadville, Steamboat Springs, Cañon City, Salida, Buena Vista, and Aspen represent the larger communities. The population of this region is 225,907, according to the 2010 U.S. Census. Skiing, tourism, ranching, mining, and correctional facilities are the primary industries. Black Canyon of the Gunnison National Park is located in this region. All of the area complies with federal air quality standards.

The primary monitoring concern in this region is centered around particulate pollution from wood burning and road dust. Currently, there are five particulate monitoring sites operated by the APCD in the Central Mountains region. APCD does not currently operate any gaseous monitors in this region.



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2015 Network Assessment

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Figure 1. Counties and multi-county monitoring regions discussed in this report. Air quality monitoring sites measuring O_3, CO, NO_2, SO_2, PM_{10}, and $PM_{2.5}$ are symbolized with white circles.

1.4.3.2 Denver Metro/North Front Range

The Denver-Metro/North Front Range region is comprised of 13 counties. It includes the largest population area of the state, with 2.5 million people living in the ten-county Denver-Aurora-Lakewood Metropolitan Statistical Area (MSA) and another 847,000 living in the northern Front Range areas of Boulder, Larimer, and Weld counties. This area includes Rocky Mountain National Park and several other wilderness areas.

Since 2002, the region complies with all NAAQS, except for ozone. The area has been exceeding the EPA's current ozone standards since the early 2000s, and in 2007 was formally designated as a "nonattainment" area. This designation was re-affirmed in 2012 when the EPA designated the region as a "marginal" nonattainment area after a more stringent ozone standard was adopted in 2008.

In the past, the Denver-metropolitan area has violated health-based air quality standards for carbon monoxide and fine particles. In response, the Regional Air Quality Council (RAQC), the Colorado Air Quality Control Commission (CAQCC), and the APCD developed, adopted, and implemented air quality improvement plans to reduce each of these pollutants.

For the rest of the Northern Front Range, Fort Collins, Longmont, and Greeley were nonattainment areas for carbon monoxide in the 1980s and early 1990s, but have met the federal standards since 1995. Air quality improvement plans have been implemented for each of these communities.

Currently, there are 27 gaseous pollutant monitors at 16 sites and 25 particulate monitors at 15 sites in the Northern Front Range Region, not including collocated monitors. There are six CO, 14 O_3, four NO_2, one NO_y, and three SO_2 monitoring sites. There are 10 PM_{10} and 13 $PM_{2.5}$ monitoring sites. There are two air toxics monitoring sites, one located at CAMP, and one at Platteville.

1.4.3.3 Eastern High Plains

The Eastern High Plains region encompasses the counties on the plains of eastern Colorado. The area is semiarid and often windy. The area's population is approximately 137,009 according to the 2010 U.S. Census. Its major population centers have developed around farming, ranching, and trade centers such as Sterling, Fort Morgan, Limon, La Junta, and Lamar. The agricultural base includes both irrigated and dry land farming. All of the area complies with federal air quality standards.

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. Along the I-70 corridor, only the community of Limon has been monitored for particulates. Along the US-50/Arkansas River corridor, the Division has monitored for particulates in the communities of La Junta and Rocky Ford. These monitoring sites were all discontinued in the late 1970s and early 1990s after a review showed that the concentrations were well below the standard and trending downward.

For the Eastern High Plains region there is currently one PM_{10} monitoring site in Lamar and no gaseous pollutant monitoring sites in the area.

1.4.3.4 Pikes Peak

The Pikes Peak region includes El Paso and Teller counties. The area has a population of approximately 645,613 according to the 2010 U.S. Census. Eastern El Paso County is rural prairie, while the western part of the region is mountainous. The U.S. Government is the largest employer in the area, and major industries include Fort Carson and the U.S. Air Force Academy in Colorado Springs, both military installations. Aerospace and technology are also large employers in the area. All of the area is currently in compliance with federal air quality standards.

Currently, there are four gaseous pollutants monitors at three sites and one particulate monitoring site in the Pikes Peak Region. There is one CO monitor, one SO_2 monitor, and two O_3 monitors, as well as one PM_{10} and one $PM_{2.5}$ monitor in the region.

1.4.3.5 San Luis Valley

Colorado's San Luis Valley region is in the south central portion of Colorado and is comprised of a broad alpine valley situated between the Sangre de Cristo Mountains on the northeast and the San Juan

Mountains of the Continental Divide to the west. The valley is some 114 km wide and 196 km long, extending south into New Mexico. The average elevation is 2290 km. Principal towns include Alamosa, Monte Vista, and Del Norte. The population is about 45,315 according to U.S. Census Bureau estimates. Agriculture and tourism are the primary industries. The valley is semiarid and croplands of potatoes, head lettuce, and barley are typically irrigated. The valley is home to Great Sand Dunes National Park. All of the area complies with federal air quality standards.

Currently, there are no gaseous and two particulate monitoring sites in the area. The two PM_{10} monitoring sites are both located in Alamosa.

1.4.3.6 South Central

The South Central region is comprised of Pueblo, Huerfano, Las Animas, and Custer counties. Its population is approximately 185,536 according to the 2010 U.S. Census. Population centers include Pueblo, Trinidad, and Walsenburg. The region has rolling semiarid plains to the east and is mountainous to the west. All of the area complies with federal air quality standards.

In the past the APCD has conducted particulate monitoring in both Walsenburg and Trinidad, but that monitoring was discontinued in 1979 and 1985, respectively, due to low concentrations.

Currently, there are no gaseous pollutant monitoring sites and one particulate monitoring site in the South Central Region. There is one PM_{10} and one $PM_{2.5}$ monitor located in Pueblo.

1.4.3.7 Southwest

The Southwestern region includes the Four Corners area counties of Montezuma, La Plata, Archuleta, and San Juan. The population of this region is about 89,652, according to the 2010 U.S. Census. The landscape includes mountains, plateaus, high valleys, and canyons. Durango and Cortez are the largest towns, while lands of the Southern Ute and Ute Mountain Ute tribes make up large parts of this region. The region is home to Mesa Verde National Park. Tourism and agriculture are the dominant industries, although the oil and gas industry is becoming increasingly important. All of the area complies with federal air quality standards.

Currently there is one gaseous and three particulate monitoring stations in the region. There is one O_3 monitor, two PM_{10} monitors, and one $PM_{2.5}$ monitor.

1.4.3.8 Western Slope

The Western Slope region includes nine counties on the far western border of Colorado. A mix of mountains on the east, and mesas, plateaus, valleys, and canyons to the west form the landscape of this region. Grand Junction is the largest urban area, and other cities include Telluride, Montrose, Delta, Rifle, Glenwood Springs, Meeker, Rangely, and Craig. The population of this region is about 309,660, according to the 2010 U.S. Census. Primary industries include ranching, agriculture, mining, energy development, and tourism. Dinosaur and Colorado National Monuments are located in this region.

The Western Slope, along with the central mountains, are projected to be the fastest growing areas of Colorado through 2020 with greater than two percent annual population increases, according to the Colorado Department of Local Affairs. All of the area complies with federal air quality standards.

Currently, there are three gaseous pollutant monitoring sites and six particulate monitoring sites in the Western Slope region.

1.4.4 Topography and Air Quality in Colorado

The “airshed” concept has been a useful tool in air quality management. Borrowed from the field of hydrology, the concept is based upon the assumption that topography separates regions of similar air quality and similar sources of air pollution. To the extent that air quality is affected by sources within an airshed, the airshed concept provides an easy way to identify the region of greatest impact associated with a source or group of sources.

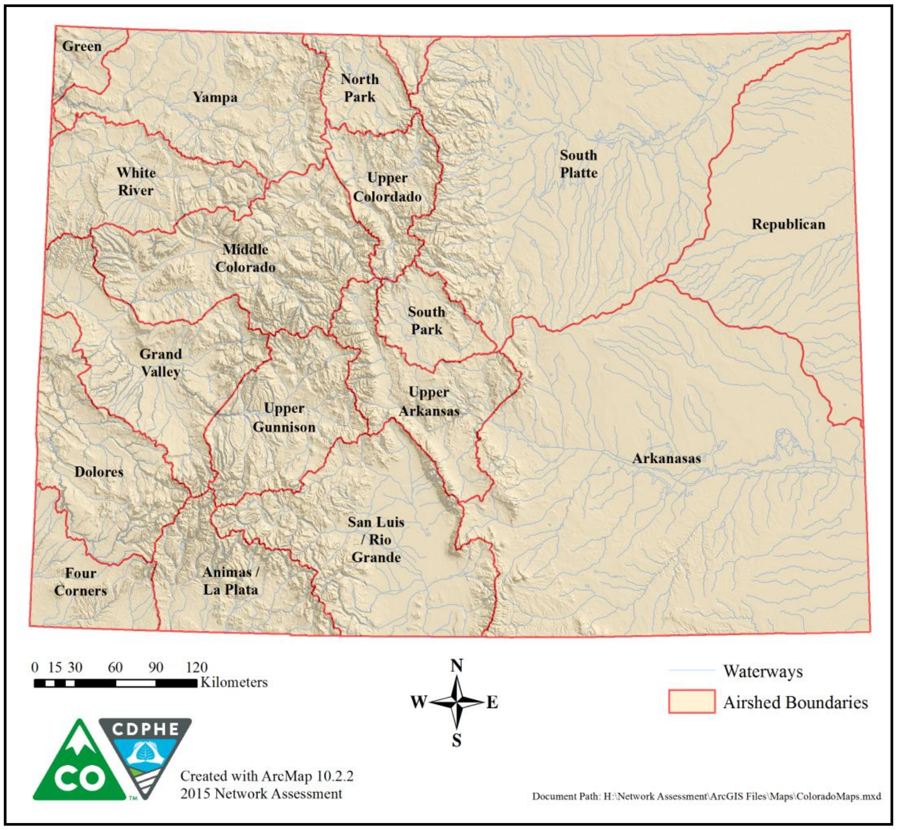

Figure 2. Shaded relief map highlighting the major airsheds of Colorado. Basin drainage patterns are symbolized with light blue lines.

The airshed concept is particularly relevant in mountainous areas and other regions of complex terrain (Greenland and Carleton, 1982). Daytime heating of elevated terrain creates localized low pressure that draws air up valleys and slopes toward ridge tops. This happens on both sides of an airshed boundary (ridge). In the absence of significant synoptic or regional-scale winds, flows diverge over ridge tops and return in an elevated “current” toward the center of the basin. This tends to isolate the daytime air in each basin. At night, radiational cooling creates slope flows that start at ridge tops (in the absence of synoptic-scale winds) and merge to form drainage flows in the valleys. These fill valleys with cooler air and form inversions that will tend to fill the entire depth of a mountain valley, regardless of the actual depth of the valley in question. Thus, to summarize, as long as larger-scale weather systems do not interfere, a mountain valley system tends to breath, with thermally-driven upslope flows during the day and down-valley slope and drainage flows at night (Doran, 1996).

The APCD has delineated the major airsheds of Colorado through a detailed examination of wind profiler data and temperature measurements across the state. The Colorado airshed scheme is based on the basin-defining topography of the state and estimated scales of basin flows and dispersion when synoptic-scale winds are minimal. This scheme is shown in Figure .

The Colorado airshed scheme will be used in this report in support of certain analytical techniques where it is necessary to account for the presence of distinct meteo-geographical boundaries within the state. These analytical techniques are described in detail in subsequent sections.

1.4.5 State-Wide Population Statistics

Colorado population data obtained from the 2010 U.S. Census is summarized in Table 1. Counties have been grouped by both MSA and state monitoring region, as defined above. A map of population density by county is presented in Figure .

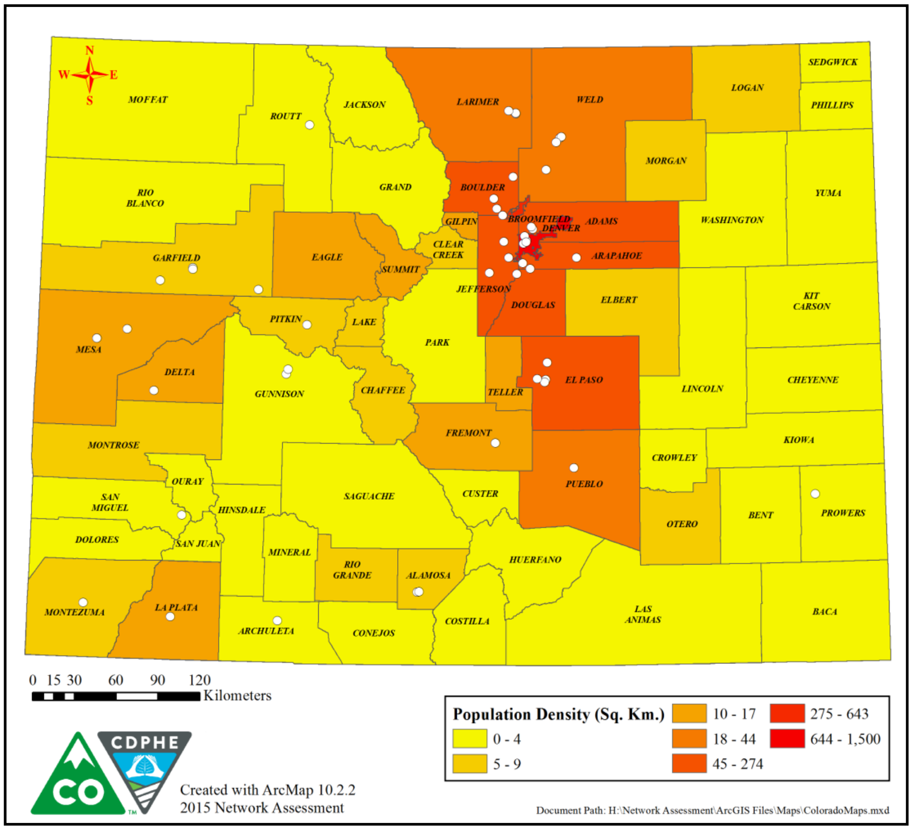

Figure 3. Population density (persons per km^2) by county. Class breaks have been determined using the Jenks optimization method. Air quality monitoring sites measuring O_3, CO, NO_2, SO_2, PM_{10}, and $PM_{2.5}$ are symbolized with white circles.

Table 1. (Cont.)[2] Population data grouped by county, monitoring region, and Metropolitan Statistical Area (MSA).

Region	MSA/County	Population (2010)	Projected Population (2020)	% Change (2010-2020)
Central Mountains		**225,907**	**288,527**	**2.8%**
	Chaffee	17,809	23,052	2.9%
	Eagle	52,197	71,076	3.6%
	Fremont	46,824	54,217	1.6%
	Grand	14,843	20,090	3.5%
	Gunnison	15,324	17,895	1.7%
	Hinsdale	843	1,027	2.2%
	Jackson	1,394	1,598	1.5%
	Lake	7,310	9,642	3.2%
	Mineral	712	870	2.2%
	Pitkin	17,148	21,929	2.8%
	Routt	23,509	28,563	2.1%
	Summit	27,994	38,568	3.8%
Denver Metro / North Front Range		**3,390,504**	**4,023,313**	**1.9%**
	BOULDER MSA (Boulder County)	***294,567***	***332,107***	***1.3%***
	DENVER-AURORA-LAKEWOOD MSA	***2,543,482***	***2,999,591***	***1.8%***
	Adams	441,603	544,258	2.3%
	Arapahoe	572,003	673,230	1.8%
	Broomfield	55,889	71,211	2.7%
	Clear Creek	9,088	10,710	1.8%
	Denver	600,158	686,613	1.4%
	Douglas	285,465	373,308	3.1%
	Elbert	23,086	38,173	6.5%
	Gilpin	5,441	6,519	2.0%
	Jefferson	534,543	571,753	0.7%
	Park	16,206	23,816	4.7%
	FORT COLLINS MSA (Larimer County)	***299,630***	***360,274***	***2.0%***
	GREELEY MSA (Weld County)	***252,825***	***331,341***	***3.1%***
Eastern High Plains		**137,009**	**151,837**	**1.1%**
	Baca	3,788	3,893	0.3%
	Bent	6,499	6,832	0.5%
	Cheyenne	1,836	2,082	1.3%
	Crowley	5,823	6,643	1.4%
	Kiowa	1,398	1,509	0.8%
	Kit Carson	8,270	8,893	0.8%
	Lincoln	5,467	6,193	1.3%

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[2] (Cont.) denotes a table that is either continued on the next page or has continued from the previous page.

Table 1. (Cont.)[2] Population data grouped by county, monitoring region, and Metropolitan Statistical Area (MSA).

Region	MSA/County	Population (2010)	Projected Population (2020)	% Change (2010-2020)
	Logan	22,709	25,734	1.3%
	Morgan	28,159	32,209	1.4%
	Otero	18,831	20,802	1.0%
	Phillips	4,442	4,670	0.5%
	Prowers	12,551	13,633	0.9%
	Sedgwick	2,379	2,689	1.3%
	Washington	4,814	5,054	0.5%
	Yuma	10,043	11,001	1.0%
Pikes Peak		**645,613**	**763,004**	**1.8%**
	COLORADO SPRINGS MSA	***645,613***	***763,004***	***1.8%***
	El Paso	622,263	734,862	1.8%
	Teller	23,350	28,142	2.1%
San Luis Valley		**45,315**	**51,972**	**1.5%**
	Alamosa	15,445	17,860	1.6%
	Conejos	8,256	9,253	1.2%
	Costilla	3,524	3,871	1.0%
	Rio Grande	11,982	13,887	1.6%
	Saguache	6,108	7,101	1.6%
South Central		**185,536**	**217,837**	**1.7%**
	Custer	4,255	5,866	3.8%
	Huerfano	6,711	7,527	1.2%
	Las Animas	15,507	19,217	2.4%
	PUEBLO MSA (Pueblo County)	***159,063***	***185,227***	***1.6%***
Southwest		**89,652**	**115,796**	**2.9%**
	Archuleta	12,084	17,127	4.2%
	La Plata	51,334	66,714	3.0%
	Montezuma	25,535	31,171	2.2%
	San Juan	699	784	1.2%
Western Slope		**309,660**	**387,704**	**2.5%**
	Delta	30,952	41,311	3.3%
	Dolores	2,064	2,436	1.8%
	Garfield	56,389	76,939	3.6%
	GRAND JUNCTION MSA (Mesa County)	***146,723***	***171,581***	***1.7%***
	Moffat	13,795	15,464	1.2%
	Montrose	41,276	54,718	3.3%
	Ouray	4,436	5,832	3.1%
	Rio Blanco	6,666	9,056	3.6%
	San Miguel	7,359	10,367	4.1%

1.5 Assessment Methodology

1.5.1 Parameters Assessed

This Network Assessment will address the criteria pollutants monitored by APCD during the period 2010-2014: carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), ozone (O_3), and two size fractions of particulate matter, PM_{10} (particles < 10 µm in diameter), and $PM_{2.5}$ (particles < 2.5 µm in diameter).

1.5.1.1 Carbon Monoxide (CO)

CO is a colorless and odorless gas formed when carbon compounds in fuel undergo incomplete combustion. The majority of CO emissions to ambient air originate from mobile sources (i.e., transportation), particularly in urban areas, where as much as 85% of all CO emissions may come from automobile exhaust. CO can cause harmful health effects by reducing oxygen delivery to the body's organs and tissues. High concentrations of CO generally occur in areas with heavy traffic congestion. In Colorado, peak CO concentrations typically occur during the colder months of the year when CO automotive emissions are highest and nighttime temperature inversions are more frequent (Reddy et al., 1995).

The EPA first set air quality standards for CO in 1971. For protection of both public health and welfare, EPA set an 8-hour primary standard at 9 parts per million (ppm) and a 1-hour primary standard at 35 ppm. In a review of the standards completed in 1985, the EPA revoked the secondary standards (for public welfare) due to a lack of evidence of adverse effects on public welfare at or near ambient concentrations. The last review of the CO NAAQS was completed in 1994 and the EPA chose not to revise the standards at that time.

The 8 CO monitors currently operated by the APCD are associated both with State Maintenance Plan requirements and CFR requirements. However, the EPA has revised the minimum requirements for CO monitoring by requiring CO monitors to be sited near roads in certain urban areas. EPA has also specified that monitors required in CBSAs of 2.5 million or more persons are to be operational by January 1, 2015, and that monitors required in CBSAs of one million or more persons are required to be operational by January 1, 2017. A monitor has been collocated with the near roadway NO_2 site (Denver I-25) to satisfy these requirements.

1.5.1.2 Nitrogen Dioxide (NO_2)

NO_2 is one of a group of highly reactive gasses known as "oxides of nitrogen," or nitrogen oxides (NO_x). Other NO_x species include nitric oxide (NO), nitrous acid (HNO_2), and nitric acid (HNO_3). The EPA’s National Ambient Air Quality Standard uses NO_2 as the indicator for the larger group of nitrogen oxides. NO_2 forms quickly from emissions from cars, trucks and buses, power plants, and off-road equipment. In addition to contributing to the formation of ground-level ozone, and fine particle pollution, NO_2 is linked with a number of adverse effects on the respiratory system (Kampa and Castanas, 2008).

The EPA first set standards for NO_2 in 1971, setting both a primary standard (to protect health) and a secondary standard (to protect the public welfare) at 0.053 parts per million (53 ppb), averaged annually. The Agency has reviewed the standards twice since that time, but chose not to revise the annual standards at the conclusion of each review. In January 2010, the EPA established an additional primary standard at 100 ppb, averaged over one hour. Together the primary standards protect public health, including the health of sensitive populations; i.e., people with asthma, children, and the elderly (Weinmayr et al., 2010).

The APCD has monitored NO_2 at eight locations in Colorado in the past. In 2015, the APCD will operate 4 NO_2 monitors. The Denver CAMP monitor exceeded the NO_2 standard in 1977, though the Welby monitor has never exceeded the standard of 53 ppb as an annual average. NO_2 concentrations have exhibited a gradual decline over the past 20 years.

The EPA has established requirements for an NO_2 monitoring network that will include monitors at locations where maximum NO_2 concentrations are expected to occur, including within 50 meters of major roadways, as well as monitors sited to measure area-wide NO_2 concentrations that occur more broadly across communities. Per these requirements, at least one monitor must be located near a major road in any urban area with a population greater than or equal to 500,000 people. A second monitor is required near another major road in areas with either: (1) population greater than or equal to 2.5 million people, or (2) one or more road segments with an annual average daily traffic (AADT) count greater than or equal to 250,000 vehicles. In addition to the near roadway monitoring, there must be one monitoring station in each CBSA with a population of 1 million or more persons to monitor a location of expected highest NO_2 concentrations representing the neighborhood or larger spatial scales. The CAMP and Welby sites satisfy this requirement.

1.5.1.3 Sulfur Dioxide (SO_2)

Sulfur dioxide (SO_2) is one of a group of highly reactive gasses known as “oxides of sulfur,” or sulfur oxides (SO_x). The largest sources of SO_2 emissions are from fossil fuel combustion at power plants (73%) and other industrial facilities (20%). Smaller sources of SO_2 emissions include industrial processes such as extracting metal from ore, and the burning of high sulfur containing fuels by locomotives, large ships, and non-road equipment. SO_2 is linked with a number of adverse effects on the respiratory system (Kampa and Castanas, 2008; Ware et al., 1986). Furthermore, SO_2 dissolves in water and is oxidized to form sulfuric acid, which is a major contributor to acid rain, as well as fine sulfate particles in the $PM_{2.5}$ fraction, which degrade visibility and represent a human health hazard.

The EPA first promulgated standards for SO_2 in 1971, setting a 24-hour primary standard at 140 ppb and an annual average standard at 30 ppb (to protect health). A 3-hour average secondary standard at 500 ppb was also adopted to protect the public welfare. In 1996, the EPA reviewed the SO_2 NAAQS and chose not to revise the standards. However, in 2010, the EPA revised the primary SO_2 NAAQS by establishing a new 1-hour standard at a level of 75 parts per billion (ppb). The two existing primary standards were revoked because they were deemed inadequate to provide additional public health protection given a 1-hour standard at 75 ppb.

The APCD has monitored SO_2 at eight locations in Colorado in the past. Currently, there are four monitoring sites in operation. No area of the country has been found to be out of compliance with the current SO_2 standards.

SO_2 monitoring requirements include the need for calculating a Population Weighted Emissions Index (PWEI). This figure is calculated for each MSA by multiplying the population of the MSA by the SO_2 emissions for that MSA and dividing by 1 million. This PWEI value is then used to determine areas in need of SO_2 monitoring. A sum of the most recent emissions data by county give a total for SO_2 emissions of 15,235 tons per year for the Denver PMSA. The calculated PWEI for this region is 37,930 million persons-tons per year. This indicates the need for one SO_2 monitor in the Denver MSA according to the EPAs monitoring rules for SO_2. The CAMP, La Casa, and Welby sites satisfy this requirement.

Using the same calculation for the Colorado Springs MSA, the calculated PWEI is 8,207 million persons-tons per year. Because of the increase in population in Colorado Springs, there is a need for one SO_2 monitor in this MSA. The Highway 24 site satisfies this requirement.

1.5.1.4 Ozone (O_3)

O_3 is an atmospheric oxidant composed of three oxygen atoms. It is not usually emitted directly into the air, but at ground-level is formed via photochemical reactions among NO_x and volatile organic compounds (VOCs) in the presence of sunlight (Monks, 2005). Emissions from industrial facilities and electric utilities, motor vehicle exhaust, gasoline vapors, and chemical solvents are some of the major sources of NO_x and VOCs. Breathing ozone can trigger a variety of health problems, particularly for children, the elderly, and people of all ages who have lung diseases such as asthma (Kampa and Castanas, 2008; Lippmann, 1989). Urban areas generally experience the highest ozone concentrations, but even rural areas may be subject to increased ozone levels because air masses can carry ozone and its precursors hundreds of kilometers away from their original source regions (Holland et al., 1999; National Research Council, 1992).

Sunlight and warm weather facilitate the ozone formation process and lead to high concentrations. Ozone is therefore considered to be primarily a summertime pollutant, with an “ozone season” being active in Colorado from March to September. However, ozone can also be a wintertime pollutant in some areas. Emerging science is indicating that snow-covered oil and gas-producing basins in the western U.S. are subject to wintertime ozone concentrations well in excess of current air quality standards. High ozone concentrations in winter are thought to occur when stable atmospheric conditions allow for a build-up of precursor chemicals, and the reflectivity of the snow cover increases the rate of UV-driven reactions during the day. Ozone and its precursors are then effectively trapped under the inversion. The Upper Green River Basin in Wyoming has been studied to model such effects (Carter and Seinfeld, 2012). Exceptionally high ozone concentrations have also been measured in the Uintah basin in Utah under such conditions (Edwards et al., 2014).

In 1971, the EPA promulgated the first NAAQS for photochemical oxidants, setting a 1-hour primary standard at 80 pbb (O_3 is one of a number of chemicals that are common atmospheric oxidants). The level of the primary standard was then revised in 1979 from 80 ppb to 120 ppb and the chemical designation of the standard was changed from “photochemical oxidants” to “ozone.” In 1993, the EPA reviewed the O_3 NAAQS and chose not to revise the standards. However, in 1997, the EPA promulgated a new level of the NAAQS for O_3 of 80 ppb as an annual fourth-highest daily maximum eight-hour concentration, averaged over three years. The O_3 NAAQS was then revised again in 2008 when the EPA set an 8-hour standard of 75 ppb. This change had a significant impact on the number of O_3 monitors in Colorado that were in violation of the standard, with the APCD now operating 4 sites out of 19 (5 sites including Highland, which is not currently in operation) that have three-year design values (2012 - 2014) in excess of the current eight-hour O_3 NAAQS standard of 75 ppb (only three of these sites have design values in excess of 80 ppb). On November 26, 2014, the EPA again proposed lowering the O_3 NAAQS standard from its current value of 75 ppb to a level between 65 ppb and 70 ppb. The EPA must finalize a new rule by November 2015 under court order.

The EPA’s monitoring requirements for O_3 include placing certain numbers of monitors in areas with high populations. For example, in Metropolitan Statistical Areas (MSAs) with a population greater than ten million people, the EPA recommends the placement of at least four monitors in areas with design value concentrations that are greater than or equal to 85% of the O_3 standard. The largest MSA in Colorado is the Denver-Aurora-Lakewood MSA. This MSA includes the counties of Adams, Arapahoe, Broomfield, Denver, Douglas, Elbert, Gilpin, Jefferson, and Park, and has a population of approximately 2.5 million. The table below lists EPAs O_3 monitoring requirements.

Table 2. EPA’s minimum ozone monitoring requirements.

MSA population	**Most recent 3-year design value concentrations ≥ 85% of any O_3 NAAQS**	**Most recent 3-year design value concentrations < 85% of any O_3 NAAQS**
> 10 million	4	2
4 - 10 million	3	1
350,000 - 4 million	2	1
50,000 - 350,000	1	0

1.5.1.5 Particulate Matter (PM)

Atmospheric particulate matter (PM) is microscopic solid or liquid mass suspended in the air. PM can be made up of a number of different components, including acidic aerosols (i.e., nitrates and sulfates), organic carbon, 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, or composition.

Particle size is the factor most directly linked to the health impacts of atmospheric PM. Particles of less than 10 micrometers (µm) in diameter (PM_{10}) are inhalable and thus pose a health threat. Particles less than 2.5 µm in diameter ($PM_{2.5}$) can penetrate deeply into the alveoli, while the smallest particles, such as those less than 0.1 µm in diameter (ultrafine particles), can penetrate all the way into the bloodstream. Exposure to such particles can affect the lungs, the heart, and the cardiovascular system (Pope III and Dockery, 2006). Particles with diameters between 2.5 µm and 10 µm ($PM_{10\text{-}2.5}$) represent less of a health concern, although they can irritate the eyes, nose, and throat, 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). Note that PM_{10} encompasses all particles smaller than 10 microns, including the $PM_{2.5}$ and ultrafine fractions.

EPA first established standards for PM in 1971. The reference method specified for determining attainment of the original standards was the high-volume sampler, which collects PM up to a nominal size of 25 to 45 µm (referred to as total suspended particulates or TSP). The primary standards, as measured by the indicator TSP, were 260 µg m^{-3} (as a 24-hour average) not to be exceeded more than once per year, and 75 µg m^{-3} (as an annual geometric mean). In October 1979, the EPA announced the first periodic review of the air quality criteria and NAAQS for PM, and significant revisions to the original standards were promulgated in 1987. In that decision, the EPA changed the indicator for particles from TSP to PM_{10}. EPA also revised the level and form of the primary standards. The EPA promulgated significant revisions to the NAAQS again in 1997. In that decision, the EPA revised the PM NAAQS in several respects. While it was determined that the PM NAAQS should continue to focus on particles less than or equal to 10 µm in diameter (i.e., PM_{10}), the EPA also decided that the fine and coarse fractions of PM_{10} should be considered separately. The Agency’s decision to modify the standards was based on evidence that serious health effects were associated with short- and long-term exposure to fine particles in areas that met the existing PM_{10} standards (Heal et al., 2012). The EPA added new standards, using $PM_{2.5}$ as the indicator for fine particles and using PM_{10} as the indicator for the $PM_{10\text{-}2.5}$ fraction. The EPA established two new $PM_{2.5}$ standards: an annual standard of 15 µg m^{-3}, based on the 3-year average of annual arithmetic mean $PM_{2.5}$ concentrations from single or multiple community-oriented monitors, and a 24-

hour standard of 65 µg m^{-3}, based on the 3-year average of the 98th percentile of 24-hour $PM_{2.5}$ concentrations at each population-oriented monitor within an area. These standards were modified again in 2006 and 2012. The current NAAQS for PM_{10} is a primary 24-hour standard of 150 µg m^{-3} not to be exceeded more than once per year on average over 3 years. There are currently three NAAQS for $PM_{2.5}$: (1) a primary annual standard of 12 µg m^{-3}, based on the 3-year average of annual arithmetic mean $PM_{2.5}$ concentrations, (2) a secondary annual standard of 15 µg m^{-3}, based on the 3-year average of annual arithmetic mean $PM_{2.5}$ concentrations, and (3) and a 24-hour standard of 35 µg m^{-3}, based on the 3-year average of the 98th percentile of 24-hour $PM_{2.5}$ concentrations.

PM_{10}

In 2015, the APCD plans to operate 36 PM_{10} monitors at 28 different locations. 27 of these sites use manual filter-based PM_{10} samplers and six are also equipped with collocated continuous (i.e., “hourly”) monitors. There are five sites with collocated filter-based samplers (CAMP, La Casa, Crested Butte, Longmont, and Grand Junction - Powell Bldg.).

$PM_{2.5}$

$PM_{2.5}$ concentration values are reported in four different groups of readings by the APCD. Data from instruments sampling according to the Federal Reference Method (FRM) are reported with the 88101 parameter code, data from continuous samplers that reasonably compare to the FRM are reported with the 88500 parameter code, data from continuous samplers that don't compare reasonably to the FRM are reported with the 88501 parameter code, and speciation data is reported with the 88502 parameter code. There are 18 FRM instruments at 15 sites. Of these 15 sites, 8 are collocated with a continuous instrument and two are collocated with an FRM; one site (Rifle) has a continuous $PM_{2.5}$ monitor but no FRM. Speciation samples are taken at three sites, which are all collocated with an FRM instrument.

1.5.2 Current State of Air Quality in Colorado

Table 3 summarizes the 2014 criteria pollutant design value data for all sites operated by the APCD. Detailed site information is provided in subsequent sections of this Introduction and in Table A-1 of Appendix A.

Currently, all State and Local Air Monitoring Station (SLAMS) and Special Purpose Monitor (SPM) sites are in attainment for CO, NO_2, SO_2, PM_{10}, and $PM_{2.5}$. There are five O_3 monitoring sites in the APCD network that have three-year average fourth-highest daily maximum eight-hour concentrations in excess of the O_3 NAAQS in 2014. These sites are all located in the Denver Metro/North Front Range region. There were 13 total exceedances of the PM_{10} standard at four different monitoring sites in 2014. Nine of these exceedances were recorded at the Lamar Municipal (08-099-0002) site. These high concentration events are due to naturally occurring episodes (i.e., regional dust storms). Data from a number of natural events that have not yet received concurrence from EPA are listed here.

Table 3. Summary of 2014 CO, NO_2, SO_2, O_3, PM_{10}, and $PM_{2.5}$ design values.

Site Name	**Pollutant**								
	CO (ppm)		**NO_2 (ppb)**		**SO_2 (ppb)**	**O_3 (ppb)**	**PM_{10} ($\mu g\ m^{-3}$)**	**$PM_{2.5}$ ($\mu g\ m^{-3}$)**	
	8-Hr	**1-Hr**	**Annual**	**1-Hr**	**1-Hr**	**4th Max 8-Hr**	**24-Hr**	**Annual**	**24-Hr**
ACC								6.5	17
Alamosa - ASC							172		
Alamosa - Mun.							201		
Alsup							117	8.7	25
Aspen							38		
Aspen Park						73			
Aurora East						71			
Boulder - Chamber							56	6.1	15
CAMP	2.2	3.1	21.6	77	30	65	98	7.7	21
Cañon City							55		
Carbondale							46		
Chatfield						81		5.8	13
Colorado College							41	6.2	13
Cortez						65		5.7	9
Crested Butte							116		
Delta - Health Dept.							108		
Denver VC							72		
Durango							38		
Ft. Collins - CSU							48	6.9	16
Ft. Collins - Mason	1.3	2.7				73			
Ft. Collins - West						78			
GJ - Pitkin	0.9	1.9							
GJ - Powell Bldg.							46	7.9	16
Greeley - Annex	1.7	2.7							
Greeley - Hospital							71	7.5	35
Highland						79[3]			
HWY 24	2.4	3.5			57				
La Casa	1.9	2.9	21.2	64	26	68	66	7.5	22
Lamar - Mun.							387		
Longmont - Mun.							58	7.3	20
Manitou Springs						69			
Mt. Crested Butte									
NREL						80			
Pagosa							55		
Palisade						66			
Parachute							39		
Platteville								7.7	32
Pueblo							174	6.3	15
Rifle - Health Dept.						63			
Rifle - Henry Bldg.							47		
Rocky Flats						82			
S. Boulder Creek						75			
Steamboat Springs							84		
Telluride							118		
USAFA						71			
Welby	1.5	3.5	18.4	61	25	73	77		
Welch						75			
Weld Co. Tower						74			

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[3] The Highland O_3 monitor did not operate during 2014 but is not permanently closed. The 2011-2013 design value is used here.

1.5.3 Technical Approach

A number of different quantitative indicators are used in this report to compare sites within the existing network and to identify areas where the inclusion of new monitoring sites would be most beneficial. The indicators were chosen to represent a number of variables relevant to air pollution: population density, traffic volume, stationary source density, modeled and measured concentrations, etc. However, each indicator is not necessarily of equal importance to the overall analysis, and the relative importance of each indicator should be expected to vary among pollutants. For example, while traffic volume and point source density (i.e., "source-oriented" indicators) may be good predictors of CO, SO_2, and NO_2 concentration, these indicators are less relevant for O_3, a secondary pollutant whose concentration is often reduced via NO_x titration in areas immediately surrounding pollution sources. To reflect this variability among the factors addressed in the assessment, APCD has determined weights of relative importance to use when combining the individual indicators for each parameter assessed.

Decisions regarding the types of indicators used and their weights of relative importance were ultimately based on the purposes, objectives, and priorities of the APCD monitoring network as decided by technical experts and program managers at the APCD. Before beginning the network assessment, the objectives of the network were reviewed and prioritized. The APCD has chosen the following eleven objectives as being those that most accurately define the overall purposes of the network:

1. To determine background concentrations,
2. To establish regulatory compliance,
3. To track pollutant concentration trends,
4. To assess population exposure,
5. To evaluate emissions reductions,
6. To evaluate the accuracy of model predictions,
7. To assist with forecasting,
8. To locate maximum pollutant concentrations,
9. To assure proper spatial coverage of regions,
10. To assist in source apportionment, and
11. To address environmental justice concerns.

Each analytical technique used in the technical assessment was selected to support a specific objective of the overall network. This technical assessment consists of two phases: site-to-site comparisons and suitability modeling. These two assessment phases are briefly described below.

1.5.3.1 Phase I: Site-to-Site Comparisons

Site-by-site comparison analyses, described in detail in Section 2, assign a ranking to individual monitors according to a specific monitoring purpose. These analyses are good for assessing which monitors might be candidates for modification or removal.

Several steps are involved in a site-by-site analysis:

1. Determine which monitoring purposes are most important,
2. Assess the history of the monitor (including original purposes),
3. Select a list of site-by-site analysis indicators based on purposes and available resources,
4. Weight indicators based on the importance of their related purpose,
5. Score monitors for each indicator,
6. Sum scores and rank monitors, and
7. Examine lowest ranking monitors for possible resource reallocation.

The low-ranking monitors should be examined carefully on a case-by-case basis. There may be regulatory or historical reasons to retain a specific monitor. Also, the site could be made potentially more useful by monitoring a different pollutant or using a different technology.

Table 4 describes the site-to-site comparison analyses used in Section 2 of the assessment.

Table 4. Site-to-site comparison analyses used in this report.

Analysis	Description	Objectives Assessed
Number of Parameters Monitored	Multiple pollution parameters monitored at a site make that site more cost-effective. This analysis is the primary indicator of economic value of a site.	Evaluate model predictions Source apportionment
Trends Impact	This analysis ranks sites by the length of their continuous monitoring records. Monitors that have longer historical records are more valuable for tracking long-term trends.	Track concentration trends Evaluate emissions trends
Measured Concentration	This analysis ranks sites by their design value. Sites measuring higher concentrations are more important from a regulatory perspective.	Locate max concentrations Establish regulatory compliance
Deviation from the NAAQS	This analysis ranks sites by the difference between their design value and the NAAQS. Sites near the NAAQS are considered more important. Sites well above or below the NAAQS do not provide as much information in terms of regulatory compliance.	Establish regulatory compliance Assist with forecasting
Monitor-to-Monitor Correlation	Measured concentrations at one monitor are compared to those measured at other monitors to determine if concentrations correlate temporally. Monitors with lower correlations have more unique value and are ranked higher.	Assure proper spatial coverage
Removal Bias	Measured values for each individual pollutant are interpolated across the entire study area. Sites are systematically removed and the interpolation is repeated. The difference between the measured concentration and the predicted concentration is the site's removal bias. The greater a site’s bias, the higher its ranking.	Assure proper spatial coverage Evaluate model predictions
Area Served	Sites are ranked based on their spatial coverage. Sites serving larger areas are ranked higher.	Assure proper spatial coverage Determine background
Population Served	Using the Area Served polygons, the number of people living within each polygon is calculated. Sites serving higher populations are ranked higher.	Assess population exposure Environmental justice
Emissions Inventory	Total annual emissions are aggregated by site using the Area Served polygons. Sites with higher emissions are ranked higher.	Evaluate emissions reductions Locate maximum concentrations
Traffic Counts	Uses current Annual Average Daily Traffic (AADT) data from both highways and major roads within the study area. Area Served polygons are used to assign a traffic volume to each monitoring site. A second indicator of road density is also calculated for each polygon, and a weighted average is created. Sites with higher traffic counts are ranked higher.	Evaluate emissions reductions Locate maximum concentrations

1.5.3.2 Phase II: Suitability Modeling

Suitability modeling, which is described in detail in Section 3, has been conducted to determine areas where the existing monitoring network does not adequately represent potential air pollution problems, and where additional sites are potentially needed. This is considered a “bottom-up” technique, as it examines directly the phenomena that are thought to cause high pollutant concentrations and/or population exposure, such as emissions (traffic and stationary) and population density. For example, emissions inventory data can be used to determine the areas of maximum expected concentrations of pollutants directly emitted (i.e., primary emissions). Emission inventory data are less useful to understand secondary pollutants formed in the atmosphere (i.e., O_3, $PM_{2.5}$). Suitability models are developed using a series of data maps representing a variety of indicators. The maps are reclassified into a congruous ranking system and organized into three purpose areas: source-oriented, population-oriented, and spatially-oriented. Each area and indicator is then assigned a weight, and the spatial average of each weighted indicator is computed. This spatial average is then used to determine the optimal locations at which new monitors should be deployed. In general, the results of these analyses indicate where monitors are best located based on specific objectives and expected pollutant behavior. However, the development of a useful suitability model relies on a thorough understanding of the phenomena that cause air quality problems, including the often complex source/sink relationships that determine pollutant concentrations in ambient air.

Table 5 describes the indicators used in the suitability model, the results of which are described in Section 3 of the assessment.

Table 5. Suitability model indicators used in this report.

	Analysis	**Description**	**Objectives Assessed**
Source - Oriented	Emissions Inventory	Uses the point-source emissions inventory data from Section 2 to identify areas of the highest point source pollution that are least represented by existing monitors.	Evaluate emissions reductions Locate maximum concentrations
	Traffic Counts	Uses traffic density and road density maps from Section 2 to identify areas of the highest traffic pollution that are least represented by existing monitors.	
Population-Oriented	Population Density	Uses population density maps from Section 2 to identify areas of high population density that are least represented by existing monitors.	Assess population exposure Environmental justice
Spatially-Oriented	Distance from an Existing Monitor	Uses the ground distance between existing monitoring sites to identify areas of the state least represented by existing monitors.	Assure proper spatial coverage Determine background
	Interpolation Map	Uses interpolation maps generated with monitoring data to identify areas of high pollutant concentration that are least represented by existing monitors.	Locate max concentrations Establish regulatory compliance Evaluate model predictions
	Modeled Concentration	Uses modeled concentration output obtained from various sources to identify areas of high pollutant concentration that are least represented by existing monitors.	

1.5.4 Data Sources

Raw air pollution data for all of the analyses were obtained from the EPA's Air Quality System (AQS) database. Data were extracted for the five-year period 2010-2014. Yearly and five-year averages were derived from the raw data. Other summary statistics were calculated as needed, such as maximum values or the fourth-highest 8-hour O_3 concentration at a particular monitoring site. For the monitor-to-monitor correlation study, concentration data was averaged over 24-hour periods for all criteria pollutants. One advantage of averaging data at a single time resolution is that this technique normalizes data that has been collected at differing intervals; e.g., PM_{10} concentrations that had been collected at 24-hour intervals vs. gaseous pollutant concentrations that are typically reported on an hourly basis.

Population data were obtained from the 2010 U.S. Census, while additional socio-demographic data were obtained from the 2007-2011 American Community Survey Estimates.

Point source emissions data was obtained from the 2014 APCD facilities inventory, which lists reported emissions for over 10,000 permitted sources within Colorado.

Road data and average annual daily traffic (AADT) counts were obtained from the Colorado Department of Transportation (CDOT). The most current available traffic count data from 2013 were used exclusively in this assessment.

1.5.5 Sites Considered in this Network Assessment

This network assessment takes into account all monitoring sites included in the AQS database and located within Colorado, including those sites operated by the U.S. Forest Service (USFS), the National Park Service (NPS), the Bureau of Land Management (BLM), the Southern Ute Indian Tribe (SUIT), the EPA, and the city of Aspen. Since most analytical assessments take into account the spatial location of existing monitoring sites, it is logical to include sites operated by other agencies, especially since data from these sites are available in the AQS database. Inclusion of these other sites also greatly increases the power of spatial interpolations, which were frequently used in this assessment. However, only APCD sites are explicitly evaluated here. Five APCD-operated sites with data available in the AQS database are not assessed in this report. These sites include two $PM_{2.5}$ monitoring stations (Boulder - CU - Athens and NJH-E) that are equipped only with continuous monitors. These sites are not included in the assessment because the hourly data obtained with these monitors is not comparable to that obtained from the filter-based FRM samplers. Furthermore, because the continuous $PM_{2.5}$ network addresses the monitoring objective of providing timely data to the public, an objective that is not addressed explicitly in the assessment, that network will not be evaluated here. Other sites not considered include the Lamar Port of Entry and DESCI sites, which do not measure any criteria pollutants, and the near-road site (I-25 Denver), which was established specifically to monitor trends in the near-road micro-environment.

Table 6 lists all of the APCD sites used in this assessment, while sites operated by other agencies are listed in Table 7. Note that the location and information about each one of these sites comes from the AQS database; site acronyms and local site names were not always listed or up-to-date in AQS. In these cases an assumed site acronym or local name was created and is consistently used throughout this assessment. These site acronyms or local names might be different from that used by the individual agency, but that is inconsequential as the site can always be referenced by the official AQS numbers listed here.

Table 6. APCD monitoring sites considered in this assessment. Detailed site descriptions can be found in Appendix A.

AQS Site Number	**Site Name**	**County**	**Parameters Monitored**					
			O_3	CO	NO_2	SO_2	PM_{10}	$PM_{2.5}$
08-001-0006	Alsup Elementary School	Adams					**X**	**X**
08-001-3001	Welby	Adams	**X**	**X**	**X**	**X**	**X**	
08-003-0001	Alamosa – Adams State College	Alamosa					**X**	
08-003-0003	Alamosa – Municipal Bldg.	Alamosa					**X**	
08-005-0002	Highland Reservoir	Arapahoe	**X**					
08-005-0005	Arapaho Community College	Arapahoe						**X**
08-005-0006	Aurora - East	Arapahoe	**X**					
08-007-0001	Pagosa Springs School	Archuleta					**X**	
08-013-0003	Longmont - Municipal Bldg.	Boulder					**X**	**X**
08-013-0011	South Boulder Creek	Boulder	**X**					
08-013-0012	Boulder Chamber of Commerce	Boulder					**X**	**X**
08-029-0004	Delta - Health Dept.	Delta					**X**	
08-031-0002	CAMP	Denver	**X**	**X**	**X**	**X**	**X**	**X**
08-031-0017	Denver Visitor Center	Denver					**X**	
08-031-0026	La Casa	Denver	**X**	**X**		**X**	**X**	**X**
08-035-0004	Chatfield State Park	Douglas	**X**					**X**
08-041-0013	U.S. Air Force Academy	El Paso	**X**					
08-041-0015	Highway 24	El Paso		**X**		**X**		
08-041-0016	Manitou Springs	El Paso	**X**					
08-041-0017	Colorado College	El Paso					**X**	**X**
08-043-0003	Cañon City	Fremont					**X**	
08-045-0005	Parachute	Garfield					**X**	
08-045-0007	Rifle – Henry Bldg.	Garfield					**X**	**X**
08-045-0012	Rifle – Health Dept.	Garfield	**X**					
08-045-0018	Rocky Mtn. School (Carbondale)	Garfield					**X**	
08-051-0004	Crested Butte	Gunnison					**X**	
08-051-0007	Mt. Crested Butte	Gunnison					**X**	
08-059-0005	Welch	Jefferson	**X**					
08-059-0006	Rocky Flats - N	Jefferson	**X**					
08-059-0011	NREL	Jefferson	**X**					
08-059-0013	Aspen Park	Jefferson	**X**					
08-067-0004	Durango – River City Hall	La Plata					**X**	
08-069-0009	Fort Collins – CSU - Edison	Larimer					**X**	**X**
08-069-0011	Fort Collins - West	Larimer	**X**					
08-069-1004	Fort Collins - Mason	Larimer	**X**	**X**				
08-077-0017	Grand Junction (GJ) – Powell Bldg	Mesa					**X**	**X**
08-077-0018	Grand Junction (GJ) - Pitkin	Mesa		**X**				
08-077-0020	Palisade - Water Treatment	Mesa	**X**					
08-083-0006	Cortez – Health Dept	Montezuma	**X**					**X**
08-097-0006	Aspen - Library	Pitkin					**X**	
08-099-0002	Lamar - Municipal Bldg.	Prowers					**X**	
08-101-0015	Pueblo – Fountain School	Pueblo					**X**	**X**
08-107-0003	Steamboat Springs	Routt					**X**	
08-113-0004	Telluride	San Miguel					**X**	
08-123-0006	Greeley - Hospital	Weld					**X**	**X**
08-123-0008	Platteville Middle School	Weld						**X**
08-123-0009	Greeley –County Tower	Weld	**X**					
08-123-0010	Greeley – West Annex	Weld		**X**				

Table 7. Parameters monitored at sites operated by other agencies in Colorado, including the U.S. Forest Service (USFS), the National Park Service (NPS), the Bureau of Land Management (BLM), the Southern Ute Indian Tribe (SUIT), the EPA, and the city of Aspen.

AQS Site Number	**Site Name**	**Operating Agency**	**Parameters Monitored**					
			O_3	CO	NO_2	SO_2	PM_{10}	$PM_{2.5}$
08-103-0005	Meeker	BLM	**X**		**X**			**X**
08-103-0006	Rangely	BLM	**X**		**X**			**X**
08-097-0007	Aspen Pumphouse	City of Aspen	**X**					
08-051-9991	Gothic	EPA	**X**					
08-069-9991	Rocky Mountain NP (CASTNET)	EPA	**X**		**X**			
08-067-1004	Shamrock	NPS	**X**		**X**			
08-069-0007	Rocky Mountain NP (NPS)	NPS	**X**					
08-077-1001	Colorado National Monument	NPS	**X**					
08-083-0101	Mesa Verde NP	NPS	**X**					
08-067-7001	Ignacio	SUIT	**X**	**X**	**X**			**X**
08-067-7003	Animas River Valley	SUIT	**X**		**X**			**X**
08-013-0007	Eldora Ski Area	USFS[4]	**X**					
08-097-0002	Ajax Mountain	NPS	**X**					
08-015-0001	Trout Creek Pass	USFS	**X**					
08-019-0004	Goliath Peak	USFS	**X**					
08-019-0005	Mount Evans	USFS	**X**					
08-045-0014	Flattops #3	USFS	**X**					
08-045-0015	Ripple Creek Pass	USFS	**X**					
08-045-0016	Sunlight Mountain	USFS	**X**					
08-045-0017	Wilson	USFS	**X**					
08-051-0008	McClure Pass	USFS	**X**					
08-077-0021	Grand Mesa	USFS	**X**					
08-077-0022	Silt-Collbran	USFS	**X**					
08-093-0001	Kenosha Pass	USFS	**X**					
08-113-0008	Norwood	USFS	**X**					
08-119-0003	Manitou Experimental Forest	USFS	**X**					
08-123-0011	Briggsdale	USFS	**X**					
08-123-0012	Pawnee Buttes	USFS	**X**					

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[4] USFS O_3 monitors are typically operated only during the March-September “ozone season.”

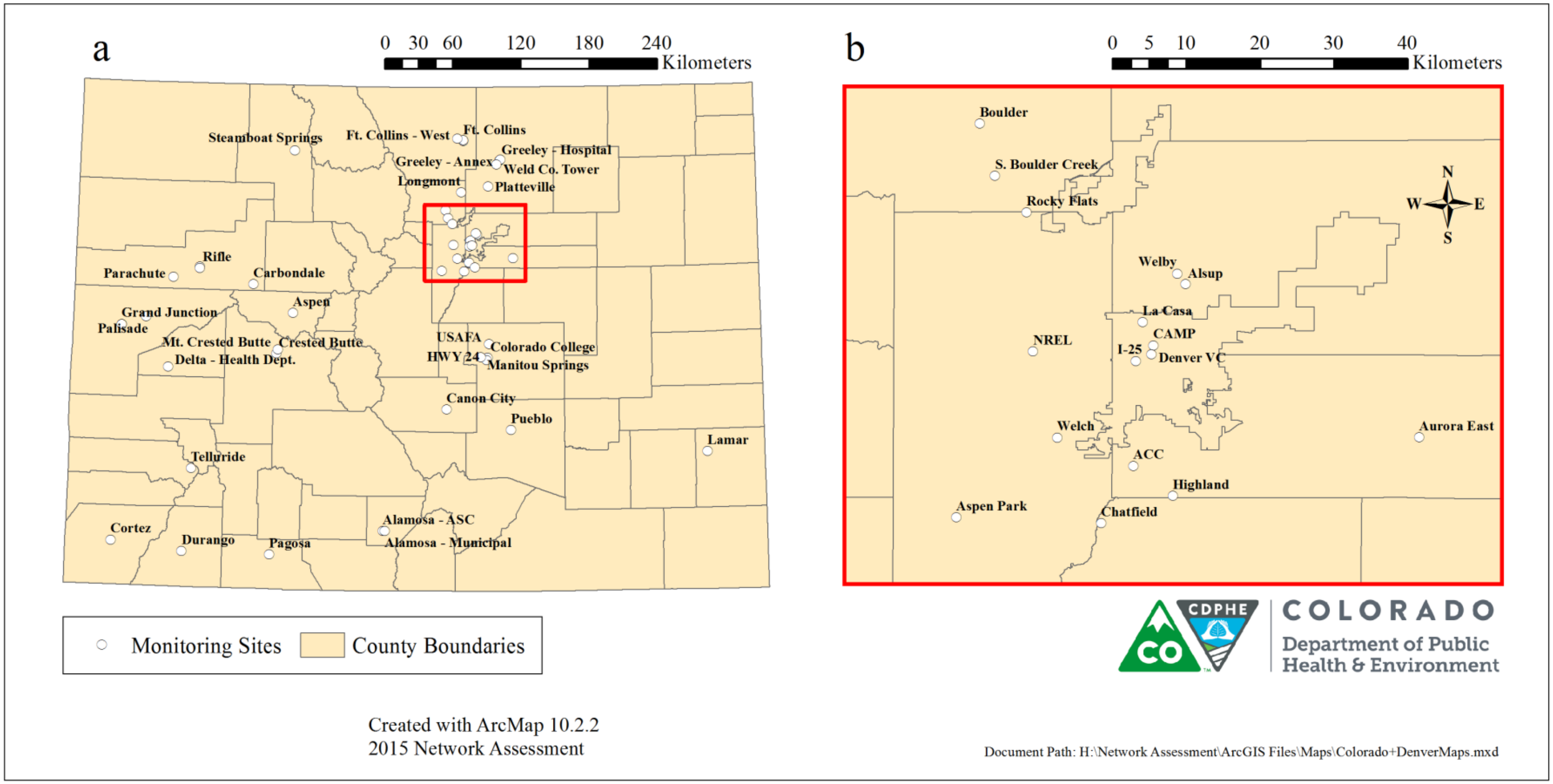


Figure 4. Map of (a) Colorado with an inset map of (b) the Denver metropolitan area showing the location of all criteria pollutant monitoring sites operated by the APCD and listed in Table 6. Note that the I-25 near-road site is shown in (b), although it is not assessed in this report on account of its unique monitoring objectives. For the purpose of improving the readability of (a), site labels for the Ft. Collins - CSU and Ft. Collins - Mason sites have been combined as “Ft. Collins,” the Rifle - Henry Bldg. and Rifle - Health Department site labels have been combined as “Rifle,” and the Grand Junction - Powell Bldg. and Grand Junction - Pitkin site labels have been combined as “Grand Junction.” Detailed site information, including AQS identification numbers, site descriptions and histories, addresses and coordinates, monitoring start dates, site elevations, site orientation/scale designations, etc., can be found in Appendix A.

2 SITE-TO-SITE COMPARISONS

In this section, the existing APCD monitoring network is assessed in a series of quantitative site-to-site comparison analyses. Each analysis assigns a ranking to individual monitors within each network based on a particular indicator (see Table 4). Each indicator is assigned a weight that reflects its overall importance relative to APCD's monitoring objectives and each monitor within each APCD monitoring network is then ranked by the weighted average of the analyses. These rankings are then used for subsequent analyses, including assessing which sites may no longer be needed and can be terminated. Indicators have been chosen to represent a number of different variables; e.g., economic cost-effectiveness, proximity to population and pollution sources, measured and modeled pollutant concentrations, etc. The objective of using many different, often competing, indicators is to provide a comprehensive evaluation technique that attempts to address all of the APCD's monitoring objectives, which are themselves often conflicting; e.g., the assessment of population exposure in areas of maximum pollutant concentrations and the determination of background concentrations are fundamentally different objectives requiring separate monitoring strategies. Weighting factors are used to emphasize indicators of particular relevance within each of the APCDs pollutant monitoring networks.

2.1 Number of Parameters Monitored

This analysis was performed by simply counting the number of parameters measured at each monitoring site. Sites having the most parameters measured were ranked highest and sites with the same number of parameters measured were ranked equally. Each monitoring instrument was counted as one parameter; i.e., collocated monitors were each counted individually.

While criteria pollutants are the primary focus of this analysis, wind speed/direction and temperature difference parameters were also considered, as these data are valuable for forecasting and modeling purposes and thus are entered into the AQS database. Note that many APCD sites also record measurements of other non-criteria pollutants and meteorological parameters such as temperature, barometric pressure, and relative humidity, which have not been considered in this analysis.

By emphasizing the intensity and complementarity of monitoring activities at a given location over the spatial distribution of all monitoring activities, this analysis addresses two of the APCD's monitoring network purposes: model evaluation and source apportionment. Furthermore, sites with collocated measurements of several pollutants are more cost-effective to maintain compared to sites measuring only one or two parameters, making this a good method for assessing a site's relative economic value. The main advantages of this method include its simplicity to perform and its applicability to all pollutant parameters. A disadvantage of the method is that it does not differentiate between different pollutant types and the relative importance of each. For example, it gives the same weight to an O_3 monitor as to a CO monitor, even though O_3 is of much more regulatory concern within the state of Colorado.

2.1.1 Results for All Parameters

Tables 8-13 list each APCD monitoring site in the CO, NO_2, SO_2, O_3, PM_{10}, and $PM_{2.5}$ ambient networks, respectively, along with the total number of parameters monitored at each site and the score associated with each site.

Table 8. All APCD CO monitoring sites ranked by total number of parameters monitored.

Site Name	AQS Number	Total Number of Parameters Monitored	Rank
La Casa	08-031-0026	8	1
CAMP	08-031-0002	7	2
Welby	08-001-3001	6	3
Ft. Collins - Mason	08-069-1004	3	4
GJ - Pitkin	08-077-0018	2	5
HWY 24	08-041-0015	2	5
Greeley - Annex	08-123-0010	1	6

Table 9. All APCD NO_2 monitoring sites ranked by total number of parameters monitored.

Site Name	AQS Number	Total Number of Parameters Monitored	Rank
La Casa	08-031-0026	8	1
CAMP	08-031-0002	7	2
Welby	08-001-3001	6	3

Table 10. All APCD SO_2 monitoring sites ranked by total number of parameters monitored.

Site Name	AQS Number	Total Number of Parameters Monitored	Rank
La Casa	08-031-0026	8	1
CAMP	08-031-0002	7	2
Welby	08-001-3001	6	3
HWY 24	08-041-0015	2	4

Table 11. All APCD O_3 monitoring sites ranked by total number of parameters monitored.

Site Name	AQS Number	Total Number of Parameters Monitored	Rank
La Casa	08-031-0026	8	1
CAMP	08-031-0002	7	2
Welby	08-001-3001	6	3
Chatfield	08-035-0004	3	4
Ft. Collins - Mason	08-069-1004	3	4
Aspen Park	08-059-0013	2	5
Aurora East	08-005-0006	2	5
Cortez	08-083-0006	2	5
Highland	08-005-0002	2	5
Palisade	08-077-0020	2	5
Rocky Flats	08-059-0006	2	5
Welch	08-059-0005	2	5
Weld Co. Tower	08-123-0009	2	5
Ft. Collins - West	08-069-0011	1	6
Manitou Springs	08-041-0016	1	6
NREL	08-059-0011	1	6
Rifle - Health Dept.	08-045-0012	1	6
S. Boulder Creek	08-013-0011	1	6
USAFA	08-041-0013	1	6

Table 12. All APCD PM_{10} monitoring sites ranked by total number of parameters monitored.

Site Name	AQS Number	Total Number of Parameters Monitored	Rank
La Casa	08-031-0026	8	1
CAMP	08-031-0002	7	2
Welby	08-001-3001	6	3
Alsup	08-001-0006	3	4
Rifle - Henry Bldg.	08-045-0007	3	4
Boulder - Chamber of Comm.	08-013-0012	2	5
Colorado College	08-041-0017	2	5
Ft. Collins - CSU	08-069-0009	2	5
GJ - Powell Bldg.	08-077-0017	2	5
Greeley - Hospital	08-123-0006	2	5
Longmont - Municipal Bldg.	08-013-0003	2	5
Parachute	08-045-0005	2	5
Pueblo	08-101-0015	2	5
Alamosa - ASC	08-003-0001	1	6
Alamosa - Municipal	08-003-0003	1	6
Aspen	08-097-0006	1	6
Cañon City	08-043-0003	1	6
Carbondale	08-045-0018	1	6
Crested Butte	08-051-0004	1	6
Delta - Health Dept.	08-029-0004	1	6
Denver VC	08-031-0017	1	6
Durango	08-067-0004	1	6
Lamar - Municipal Bldg.	08-099-0002	1	6
Mt. Crested Butte	08-051-0007	1	6
Pagosa	08-007-0001	1	6
Steamboat Springs	08-107-0008	1	6
Telluride	08-113-0004	1	6

Table 13. All APCD $PM_{2.5}$ monitoring sites ranked by total number of parameters monitored.

Site Name	AQS Number	Total Number of Parameters Monitored	Rank
La Casa	08-031-0026	8	1
CAMP	08-031-0002	7	2
Alsup	08-001-0006	3	3
Chatfield	08-035-0004	3	3
Boulder - Chamber of Comm.	08-013-0012	2	4
Colorado College	08-041-0017	2	4
Cortez	08-083-0006	2	4
Ft. Collins - CSU	08-069-0009	2	4
GJ - Powell Bldg.	08-077-0017	2	4
Greeley - Hospital	08-123-0006	2	4
Longmont - Municipal Bldg.	08-013-0003	2	4
Pueblo	08-101-0015	2	4
ACC	08-005-0005	1	5
Platteville	08-123-0008	1	5

2.2 Trends Impact

In this analysis, monitoring sites in each network were ranked based on the length of their continuous measurement record for the pollutant of interest. Sites possessing an extended historical record are valuable for tracking long-term pollutant trends, and the continuation of these long uninterrupted records is deemed desirable. Therefore, those monitors with the longest uninterrupted historical records were scored the highest, while monitors with records of equal length were scored equally.

This analysis simply considers the number of years that a monitor has been operating continuously. Note that if a monitor had alternating periods of operation, then only the most recent operating period is considered.

This analysis is valuable in that it addresses two of the APCD’s monitoring network purposes: trend tracking and emission reduction evaluation. The main advantages of this method are its simplistic analytical approach and its usefulness for identifying sites that provide a basis for assessing long-term trends. The main disadvantages of the method are: (1) the magnitude and direction of past trends are not necessarily good predictors of future trends due to potential changes in population or emissions, and (2) the length of a continuous record does not ensure that data are of good quality throughout the entire time period.

2.2.1 Results for all Parameters

Tables 14-19 list each APCD monitoring site in the CO, NO_2, SO_2, O_3, PM_{10}, and $PM_{2.5}$ ambient networks, respectively, along with the total number of years (rounded to the nearest integer) that the site has been monitoring the pollutant of interest and the score associated with each site.

Table 14. All APCD CO monitoring sites ranked by length of monitoring record.

Site Name	Length of Continuous Monitoring Record (years)	Rank
CAMP	45	1
Welby	42	2
Ft. Collins - Mason	35	3
HWY 24	17	4
Greeley - Annex	12	5
GJ - Pitkin	12	5
La Casa	3	6

Table 15. All APCD NO_2 monitoring sites ranked by length of monitoring record.

Site Name	Length of Continuous Monitoring Record (years)	Rank
CAMP	43	1
Welby	40	2
La Casa	4	3

Table 16. All APCD SO_2 monitoring sites ranked by length of monitoring record.

Site Name	Length of Continuous Monitoring Record (years)	Rank
CAMP	49	1
Welby	42	2
HWY 24	3	3
La Casa	3	3

Table 17. All APCD O_3 monitoring sites ranked by length of monitoring record.

Site Name	Length of Continuous Monitoring Record (years)	Rank
Welby	42	1
Highland	37	2
Ft. Collins - Mason	35	3
Welch	24	4
Rocky Flats	23	5
NREL	21	6
S. Boulder Creek	21	6
USAFA	19	7
Weld Co. Tower	13	8
Manitou Springs	11	9
Chatfield	10	10
Ft. Collins - West	9	11
Palisade	7	12
Cortez	7	12
Rifle - Health Dept.	7	12
Aspen Park	4	13
Aurora East	4	13
CAMP	3	14
La Casa	3	14

Table 18. All APCD PM_{10} monitoring sites ranked by length of monitoring record.

Site Name	**Length of Continuous Monitoring Record (years)**	**Rank**
Longmont - Municipal Bldg.	30	1
CAMP	29	2
Greeley - Hospital	28	3
Lamar - Municipal Bldg.	28	3
Steamboat Springs	28	3
Alamosa - ASC	26	4
Telluride	25	5
Welby	25	5
Pagosa	25	5
Denver VC	23	6
Delta - Health Dept.	22	7
Boulder - Chamber of Comm.	21	8
Crested Butte	18	9
Ft. Collins - CSU	16	10
Parachute	15	11
Alsup	15	11
Alamosa - Municipal	13	12
Aspen	13	12
Durango	13	12
Cañon City	11	13
GJ - Powell Bldg.	11	13
Rifle - Henry Bldg.	10	14
Mt. Crested Butte	10	14
Colorado College	8	15
Pueblo	4	16
Carbondale	3	17
La Casa	3	17

Table 19. All APCD $PM_{2.5}$ monitoring sites ranked by length of monitoring record.

Site Name	**Length of Continuous Monitoring Record (years)**	**Rank**
Boulder - Chamber of Comm.	16	1
CAMP	16	1
Longmont - Municipal Bldg.	16	1
Greeley - Hospital	16	1
ACC	16	1
Ft. Collins - CSU	16	1
Platteville	16	1
Alsup	15	2
GJ - Powell Bldg.	13	3
Chatfield	11	4
Colorado College	8	5
Cortez	7	6
Pueblo	4	7
La Casa	3	8

2.3 Measured Concentrations

This analysis ranks monitors by the magnitude of pollutant concentrations that they measure. The indicator is based on each monitoring site's design value, which is generally the highest concentration measured over a particular averaging interval in a given year (Table 20). Monitors with higher design values are ranked higher than those with lower design values. The assumption of this analysis is that sites measuring high concentrations are more important for determining NAAQS compliance and assessing population exposure. A drawback of this analysis is that it does not consider monitor siting issues, as a monitor located in a high concentration area may not measure maximum potential concentrations if it has not been sited optimally. Furthermore, because this analysis focuses only on those monitors measuring high concentrations, which are often urban monitors located in high-population areas, it does not take into account low-concentration monitors that are important for other reasons, such as rural monitors that measure background pollutant concentrations and assure appropriate spatial coverage.

Table 20. National Ambient Air Quality Standards (NAAQS) for the criteria pollutants assessed in this report. Primary standards provide public health protection, while secondary standards provide public welfare protection, including protection against decreased visibility and damage to animals, crops, vegetation, and buildings. Units of measure are parts per million (ppm) by volume, parts per billion (ppb) by volume, and micrograms per cubic meter ($\mu g\ m^{-3}$).

Pollutant	Primary / Secondary	Averaging Time	Level	Form
Carbon Monoxide (CO)	Primary	8-hr	9 ppm	Not to be exceeded more than once per year
		1-hr	35 ppm	
Nitrogen Dioxide (NO_2)	Primary	1-hr	100 ppb	98th percentile of 1-hour daily maximum concentrations, averaged over 3 years
	Primary and Secondary	Annual	53 ppb	Annual mean
Sulfur Dioxide (SO_2)	Primary	1-hr	75 ppb	99th percentile of 1-hour daily maximum concentrations, averaged over 3 years
	Secondary	3-hr	0.5 ppm	Not to be exceeded more than once per year
Ozone (O_3)	Primary and Secondary	8-hr	75 ppb	Annual fourth-highest daily maximum 8-hr concentration, averaged over 3 years
PM_{10}	Primary and Secondary	24-hr	150 $\mu g\ m^{-3}$	Not to be exceeded more than once per year on average over 3 years
$PM_{2.5}$	Primary	Annual	12 $\mu g\ m^{-3}$	Annual mean, averaged over 3 years
	Secondary	Annual	15 $\mu g\ m^{-3}$	Annual mean, averaged over 3 years
	Primary and Secondary	24-hr	35 $\mu g\ m^{-3}$	98th percentile, averaged over 3 years

2.3.1 Results for All Parameters

Tables 21-26 list each APCD monitoring site in the CO, NO_2, SO_2, O_3, PM_{10}, and $PM_{2.5}$ ambient networks, respectively, along with the annual design values measured during the period 2010-2014, the average design value for that period, and the score associated with each site.

Table 21. All APCD CO monitoring sites ranked by design value.

Site Name	Max 8-Hour Concentration (ppm)						Rank
	2010	2011	2012	2013	2014	Average	
CAMP	3.1	1.9	2.7	4.4	2.2	2.86	1
La Casa	-	-	-	2.6	1.9	2.25	2
HWY 24	2.3	1.7	2.0	1.8	2.4	2.04	3
Greeley - Annex	2.5	2.0	2.3	1.7	1.7	2.04	3
Welby	1.8	2.0	1.7	2.1	1.5	1.82	4
Ft. Collins - Mason	2.0	1.5	1.8	1.7	1.3	1.66	5
GJ - Pitkin	1.2	1.1	1.1	0.9	0.9	1.04	6

Table 22. All APCD NO_2 monitoring sites ranked by design value.

Site Name	3-Year Ave. 98th Percentile of 1-Hour Daily Max Concentrations (ppb)						Rank
	2010	2011	2012	2013	2014	Average	
CAMP	71	72	72	68	77	71.8	1
Welby	56	64	64	58	61	60.6	2
La Casa	-	-	-	-	57	56.9	3

Table 23. All APCD SO_2 monitoring sites ranked by design value.

Site Name	3-Year Ave. 99th Percentile of 1-Hour Daily Max Concentrations (ppb)						Rank
	2010	2011	2012	2013	2014	Average	
HWY 24	-	-	-	58	57	57.7	1
CAMP	32	34	39	38	13	31.2	2
Welby	37	30	28	30	17	28.4	3
La Casa	-	-	-	36	15	25.6	4

Table 24. All APCD O_3 monitoring sites ranked by design value.

Site Name	3-Year Ave. 4th Highest 8-hr Daily Max Concentration (ppb)						Rank
	2010	2011	2012	2013	2014	Average	
Rocky Flats	78	78	80	83	82	80.2	1
Chatfield	76	77	82	83	81	79.8	2
NREL	72	75	79	82	80	77.6	3
Ft. Collins - West	74	76	78	80	78	77.2	4
Highland	67	74	77	79	79	75.2	5
Welch	71	73	76	78	75	74.6	6
S. Boulder Creek	73	73	74	77	75	74.4	7
Weld Co. Tower	71	72	76	76	74	73.8	8
Aspen Park	70	70	74	75	73	72.4	9
Welby	70	70	71	76	73	72.0	10
Aurora East	68	71	73	74	71	71.4	11
Manitou Springs	69	70	74	74	69	71.2	12
USAFA	66	67	72	74	71	70.0	13
La Casa	-	-	-	71	68	69.5	14
Ft. Collins - Mason	65	65	69	72	73	68.8	15
Palisade	67	66	68	67	66	66.8	16
CAMP	-	-	68	67	65	66.7	17
Cortez	64	66	68	68	65	66.2	18
Rifle - Health Dept.	64	64	66	65	63	64.4	19

Table 25. All APCD PM$_{10}$ monitoring sites ranked by design value.

Site Name	Max 24-Hour Concentration ($\mu g\ m^{-3}$)						Rank
	2010	2011	2012	2013	2014	Average	
Lamar - Municipal Bldg.	95	122	242	1220	387	413	1
Alamosa - Municipal	109	635	239	246	201	286	2
Alamosa - ASC	106	440	389	237	172	269	3
Durango	139	51	80	419	38	146	4
Pagosa	117	109	147	295	55	145	5
Mt. Crested Butte	168	65	171	187	74	133	6
Crested Butte	174	74	50	140	116	111	7
Alsup	72	82	113	144	117	106	8
Steamboat Springs	99	135	124	82	84	105	9
Pueblo	59	117	62	64	174	95	10
Telluride	133	68	80	58	118	91	11
CAMP	58	109	75	90	98	86	12
Denver VC	62	123	87	73	72	83	13
Delta - Health Dept.	125	51	65	64	108	82	14
Welby	57	67	91	88	77	76	15
GJ - Powell Bldg.	155	41	77	55	46	75	16
Parachute	125	96	65	29	39	71	17
La Casa	-	-	55	81	66	67	18
Cañon City	31	71	61	109	55	65	19
Ft. Collins - CSU	56	53	72	98	48	65	19
Greeley - Hospital	44	46	102	50	71	63	20
Aspen	70	51	87	65	38	62	21
Boulder - Chamber of Comm.	50	35	72	72	56	57	22
Colorado College	41	63	64	73	41	56	23
Rifle - Henry Bldg.	59	54	50	46	47	51	24
Longmont - Municipal Bldg.	36	36	55	47	58	46	25
Carbondale	-	-	40	45	46	44	26

Table 26. All APCD PM$_{2.5}$ monitoring sites ranked by design value.

Site Name	3-Year Ave. 98th Percentile of 24-Hour Concentrations ($\mu g\ m^{-3}$)						Rank
	2010	2011	2012	2013	2014	Average	
GJ - Powell Bldg.	37	22	24	40	16	28.0	1
Greeley - Hospital	20	23	32	21	35	26.1	2
La Casa	-	-	34	22	22	25.7	3
Alsup	22	20	25	23	25	23.0	4
Longmont - Municipal Bldg.	23	19	28	23	20	22.4	5
Platteville	17	20	22	20	32	22.2	6
CAMP	19	19	19	20	21	19.7	7
Ft. Collins - CSU	22	15	26	18	16	19.3	8
ACC	15	12	28	22	17	18.9	9
Boulder - Chamber of Comm.	22	13	17	17	15	16.8	10
Chatfield	13	16	20	17	13	15.7	11
Colorado College	12	18	17	18	13	15.5	12
Pueblo	14	14	17	17	15	15.3	13
Cortez	13	15	12	12	9	12.4	14

2.4 Deviation from the NAAQS

In this analysis, sites that measure design values close to the NAAQS exceedance threshold (Table 20) are ranked higher than those sites with design values well above or below it. Sites that are closest to the threshold are considered most valuable for the purpose of determining compliance with the NAAQS, whereas sites measuring values well above or below the NAAQS do not provide as much information in this regard. The purpose of this technique is to give weight to those sites that are closest to the standard; therefore, the absolute value of the difference between the measured design value and the standard is used to score each monitor. Monitors with the smallest absolute difference will rank as most important. This analysis has a disadvantage in that monitors with design values higher than the standard (i.e., those in violation of the standard) may be considered more valuable from the standpoint of compliance and public health than those with design values lower than the standard, but with a similar absolute difference. The objectives assessed by this analysis are regulatory compliance and forecasting assistance.

Design values for APCD monitoring sites are typically well below the NAAQS for most criteria pollutants, making this indicator redundant with the Measured Concentrations indicator for those networks. For this reason, the Deviation from the NAAQS indicator was applied only to those networks having sites with design values both above and below the NAAQS, which are the pollutants of highest concern within the state of Colorado (e.g., O_3 and PM_{10}).

On November 26, 2014, EPA proposed lowering the ozone standard from its current design value of 75 ppb to a level between 65 ppb and 70 ppb. EPA must finalize a new rule by October 1, 2015 under court order. Due to the uncertainty that currently exists regarding the value of the O_3 standard in the future, in this analysis we have assumed a value of 70 ppb, which is the midpoint between the active standard and lowest value currently under consideration.

2.4.1 Results for all Parameters

Tables 27-28 list each APCD monitoring site in the O_3 and PM_{10} ambient networks, respectively, along with the annual design values measured during the period 2010-2014, the average design value for that period, the difference between the average design values and the level of the NAAQS, and the score associated with each site.

Table 27. All APCD O_3 monitoring sites ranked by deviation from a proposed O_3 NAAQS of 70 ppb.

Site Name	Design Values (ppb)								Rank
	2010	2011	2012	2013	2014	Average	NAAQS	Dev.	
USAFA	66	67	72	74	71	70.0	70	0.0	1
La Casa				71	68	69.5	70	-0.5	2
Manitou Springs	69	70	74	74	69	71.2	70	1.2	3
Ft. Collins - Mason	65	65	69	72	73	68.8	70	-1.2	3
Aurora East	68	71	73	74	71	71.4	70	1.4	4
Welby	70	70	71	76	73	72.0	70	2.0	5
Aspen Park	70	70	74	75	73	72.4	70	2.4	6
Palisade	67	66	68	67	66	66.8	70	-3.2	7
CAMP			68	67	65	66.7	70	-3.3	8
Weld Co. Tower	71	72	76	76	74	73.8	70	3.8	9
Cortez	64	66	68	68	65	66.2	70	-3.8	9
S. Boulder Creek	73	73	74	77	75	74.4	70	4.4	10
Welch	71	73	76	78	75	74.6	70	4.6	11
Highland	67	74	77	79	79	75.2	70	5.2	12
Rifle - Health Dept.	64	64	66	65	63	64.4	70	-5.6	13
Ft. Collins - West	74	76	78	80	78	77.2	70	7.2	14
NREL	72	75	79	82	80	77.6	70	7.6	15
Chatfield	76	77	82	83	81	79.8	70	9.8	16
Rocky Flats	78	78	80	83	82	80.2	70	10.2	17

Table 28. All APCD PM_{10} monitoring sites ranked by deviation from the primary PM_{10} NAAQS.

Site Name	Max 24-Hour Concentration (μg m^{-3})								Rank
	2010	2011	2012	2013	2014	Average	NAAQS	Dev.	
Durango	139	51	80	419	38	146	150	-4.5	1
Pagosa	117	109	147	295	55	145	150	-5.4	2
Mt. Crested Butte	168	65	171	187	74	133	150	-17.0	3
Crested Butte	174	74	50	140	116	111	150	-39.2	4
Alsup	72	82	113	144	117	106	150	-44.4	5
Steamboat Springs	99	135	124	82	84	105	150	-45.2	6
Pueblo	59	117	62	64	174	95	150	-54.8	7
Telluride	133	68	80	58	118	91	150	-58.6	8
CAMP	58	109	75	90	98	86	150	-64.0	9
Denver VC	62	123	87	73	72	83	150	-66.6	10
Delta - Health Dept.	125	51	65	64	108	82	150	-67.6	11
Welby	57	67	91	88	77	76	150	-74.0	12
GJ - Powell Bldg.	155	41	77	55	46	75	150	-75.2	13
Parachute	125	96	65	29	39	71	150	-79.2	14
La Casa	-	-	55	81	66	67	150	-82.7	15
Cañon City	31	71	61	109	55	65	150	-84.6	16
Ft. Collins - CSU	56	53	72	98	48	65	150	-84.6	16
Greeley - Hospital	44	46	102	50	71	63	150	-87.4	17
Aspen	70	51	87	65	38	62	150	-87.8	18
Boulder - Chamber of Comm.	50	35	72	72	56	57	150	-93.0	19
Colorado College	41	63	64	73	41	56	150	-93.6	20
Rifle - Henry Bldg.	59	54	50	46	47	51	150	-98.8	21
Longmont - Municipal Bldg.	36	36	55	47	58	46	150	-103.6	22
Carbondale	-	-	40	45	46	44	150	-106.3	23
Alamosa - ASC	106	440	389	237	172	269	150	118.8	24
Alamosa - Municipal	109	635	239	246	201	286	150	136.0	25
Lamar - Municipal Bldg.	95	122	242	1220	387	413	150	263.2	26

2.5 Monitor-to-Monitor Correlation

In this analysis, sites are ranked based on the correlation of their measured concentrations with those of the other monitors in the network. Monitors measuring concentrations that correlate well with those measured at other sites are considered redundant, and are consequently assigned a lower ranking. Monitors with concentrations that do not correlate with other monitors are considered unique, and as such have more value for spatial monitoring objectives and are therefore assigned a higher ranking. The advantages of this method are: (1) it gives a measure of the site's uniqueness and representativeness, and (2) it is useful for identifying redundant sites. The disadvantages are that it requires large amounts of data with a high data completeness rate, and that the correlations are likely pollutant specific. The objectives assessed by this analysis are model evaluation, spatial coverage, and interpolation.

To conduct this analysis, 24-hour average concentration values were compiled for each criteria parameter monitored within Colorado for the period 2010-2014. Data obtained from sites in Colorado operated by other federal, local, and tribal agencies were considered in this analysis to ensure a spatially robust sample; however, the correlations observed between these sites and those in the APCD network are not considered when ranking the APCD monitors. The concentrations measured at each monitoring site were compared to those measured at every other monitoring site in the state using a matrix format, in which each monitoring pair was subjected to linear regression from which a Pearson correlation coefficient (r^2) was generated. The maximum correlation was then recorded for each site, as well as the number of sites well-correlated with that site. It is assumed here that sites having an r^2 value of 0.6 or greater are well-correlated. Sites were ranked based on both their maximum correlation and the number of sites well-correlated with them. A distance matrix was also developed, and a correlogram plot of distance vs. correlation was created for each parameter.

2.5.1 Carbon Monoxide (CO)

Table 29. CO monitor-to-monitor correlation analysis scores.

Site Name	Max. Correlation		$r^2 \geq 0.6$		Average
	Value	Rank	No. of Sites	Rank	Rank
GJ - Pitkin	0.29	1	0	1	1.0
HWY 24	0.59	2	0	1	1.5
Greeley - Annex	0.68	3	1	2	2.5
Ft. Collins - Mason	0.68	3	1	2	2.5
CAMP	0.74	4	1	2	3.0
Welby	0.74	4	1	2	3.0
La Casa	0.74	4	2	3	3.5

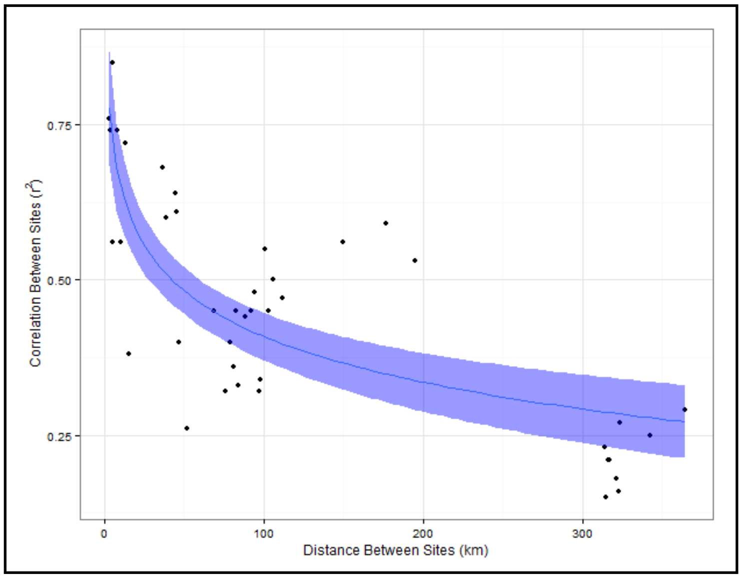


Figure 5. Correlogram for all CO monitoring sites in Colorado.

2.5.2 Nitrogen Dioxide (NO_2)

Table 30. NO_2 monitor-to-monitor correlation analysis scores.

Site Name	Max. Correlation		$r^2 \geq 0.6$		Average
	Value	**Rank**	**No. of Sites**	**Rank**	**Rank**
CAMP	0.50	1	0	1	1.0
Welby	0.50	1	0	1	1.0
La Casa	0.42	2	0	1	1.5

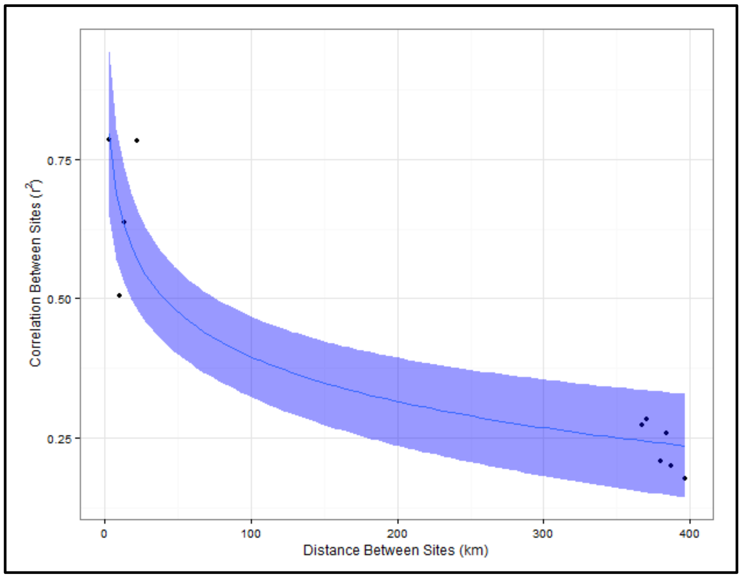


Figure 6. Correlogram for all NO_2 monitoring sites in Colorado.

2.5.3 Sulfur Dioxide (SO_2)[5]

Table 31. SO_2 monitor-to-monitor correlation analysis scores.

Site Name	Max. Correlation		$r^2 \geq 0.6$		Average
	Value	**Rank**	**No. of Sites**	**Rank**	**Rank**
HWY 24	0.02	1	0	1	1.0
Welby	0.09	2	0	1	1.5
CAMP	0.20	3	0	1	2.0
La Casa	0.20	3	0	1	2.0

---

[5] No correlogram is shown for SO_2 due to the limited number of existing monitoring sites and the low correlations observed.

2.5.4 Ozone (O_3)

Table 32. O_3 monitor-to-monitor correlation analysis scores.

Site Name	Max. Correlation		$r^2 \geq 0.6$		Average
	Value	**Rank**	**No. of Sites**	**Rank**	**Rank**
Cortez	0.71	1	2	1	1.0
USAFA	0.72	2	9	5	3.5
Palisade	0.86	7	2	1	4.0
Rifle - Health Dept.	0.86	7	4	2	4.5
Welby	0.84	6	5	3	4.5
Aspen Park	0.76	4	10	6	5.0
Manitou Springs	0.75	3	11	7	5.0
Ft. Collins - West	0.75	3	12	8	5.5
Ft. Collins - Mason	0.87	8	8	4	6.0
Aurora East	0.81	5	11	7	6.0
Weld Co. Tower	0.87	8	11	7	7.5
S. Boulder Creek	0.89	9	11	7	8.0
NREL	0.89	9	11	7	8.0
Rocky Flats	0.89	9	11	7	8.0
Highland	0.92	11	13	9	10.0
Chatfield	0.92	11	13	9	10.0
Welch	0.90	10	14	10	10.0
La Casa	0.90	10	14	10	10.0
CAMP	0.90	10	15	11	10.5

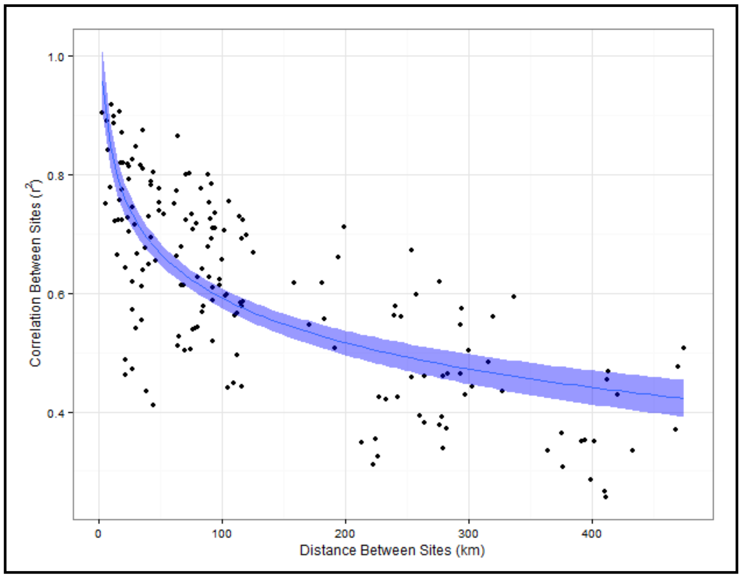


Figure 7. Correlogram for all O_3 monitoring sites in Colorado.

2.5.5 PM_{10}

Table 33. PM_{10} monitor-to-monitor correlation analysis scores.

Site Name	Max. Correlation		$r^2 \geq 0.6$		Average
	Value	Rank	No. of Sites	Rank	Rank
Lamar - Municipal Bldg.	0.22	1	0	1	1.0
Steamboat Springs	0.24	2	0	1	1.5
Carbondale	0.32	3	0	1	2.0
Ft. Collins - CSU	0.34	4	0	1	2.5
GJ - Powell Bldg.	0.42	5	0	1	3.0
Colorado College	0.42	5	0	1	3.0
Pueblo	0.47	6	0	1	3.5
Delta - Health Dept.	0.47	6	0	1	3.5
Cañon City	0.47	6	0	1	3.5
Parachute	0.62	7	1	2	4.5
Rifle - Henry Bldg.	0.62	7	1	2	4.5
Boulder - Chamber of Comm.	0.64	8	1	2	5.0
Pagosa	0.62	7	2	3	5.0
Greeley - Hospital	0.72	9	1	2	5.5
Aspen	0.75	11	1	2	6.5
Longmont - Municipal Bldg.	0.72	9	3	4	6.5
Welby	0.74	10	3	4	7.0
Alsup	0.74	10	4	5	7.5
Alamosa - ASC	0.85	14	1	2	8.0
Alamosa - Municipal	0.85	14	1	2	8.0
Denver VC	0.85	14	2	3	8.5
Crested Butte	0.78	12	4	5	8.5
CAMP	0.84	13	4	5	9.0
Mt. Crested Butte	0.90	15	3	4	9.5
La Casa	0.85	14	4	5	9.5
Durango	0.90	15	4	5	10.0
Telluride	0.90	15	4	5	10.0

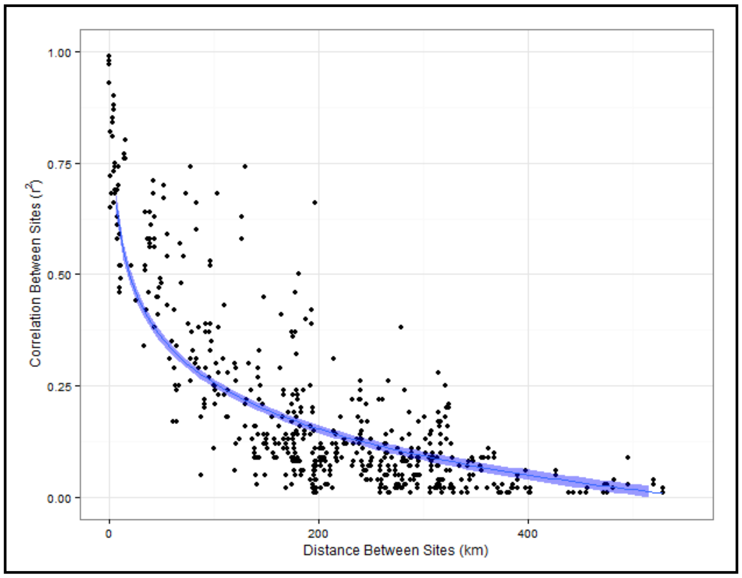


Figure 8. Correlogram for all PM_{10} monitoring sites in Colorado.

2.5.6 $PM_{2.5}$

Table 34. $PM_{2.5}$ monitor-to-monitor correlation analysis scores.

Site Name	**Max. Correlation**		**$r^2 \geq 0.6$**		**Average**
	Value	**Rank**	**No. of Sites**	**Rank**	**Rank**
GJ - Powell Bldg.	0.24	1	0	1	1.0
Cortez	0.24	1	0	1	1.0
Pueblo	0.45	2	0	1	1.5
Colorado College	0.52	3	0	1	2.0
Ft. Collins - CSU	0.58	4	0	1	2.5
Chatfield	0.76	7	1	2	4.5
Greeley - Hospital	0.74	6	2	3	4.5
Platteville	0.74	6	2	3	4.5
Longmont - Municipal Bldg.	0.73	5	4	4	4.5
CAMP	0.82	9	2	3	6.0
ACC	0.80	8	4	4	6.0
Boulder - Chamber of Comm.	0.85	11	1	2	6.5
Alsup	0.84	10	4	4	7.0
La Casa	0.85	11	4	4	7.5

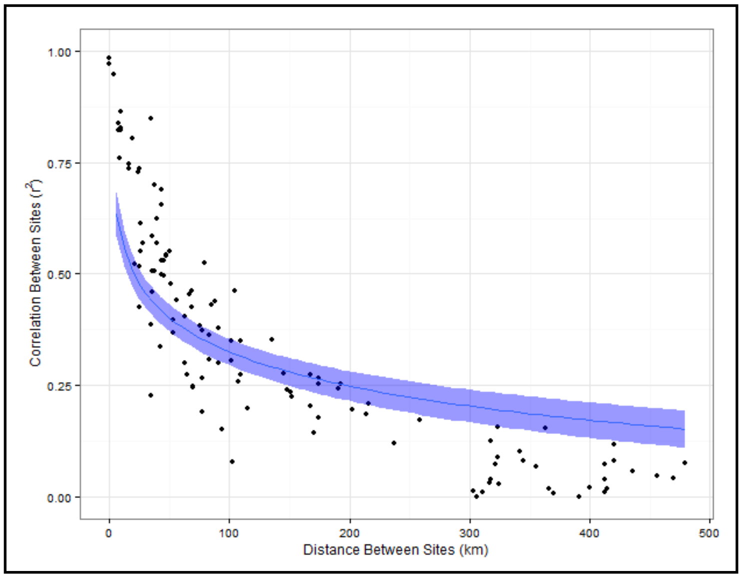


Figure 9. Correlogram for all $PM_{2.5}$ monitoring sites in Colorado.

2.6 Removal Bias

This analysis evaluates the contribution of each monitoring site to the creation of an interpolation map. The procedure is outlined schematically in Figure 10. For each pollutant parameter, an interpolation map is created which incorporates all federal, state, local, and tribal monitoring data. Each APCD monitoring site is then systematically removed from the dataset and the interpolation map is regenerated. The difference between the actual value measured at the monitoring site and the predicted value from the interpolation once the site was removed is recorded; this is the removal bias. Sites are then ranked using the absolute value of the difference, with higher values being given higher rankings.

Five-year (2010-2014) average concentration values have been used in this analysis for each pollutant parameter, thus this analysis focuses on the long-term contributions that each site makes in determining the monitored pollution surface. The removal bias technique would likely result in a different interpretation if a different temporal scale were used; however, this network assessment has other analysis techniques that focus on shorter averaging periods (e.g., Measured Concentration).

Removal bias is a useful technique for noting redundancies in the monitoring network. Sites with a high removal bias are important for creating an accurate interpolation map, thus their values add a unique perspective to the overall pollution surface. On the other hand, sites with a low removal bias difference could possibly be redundant with other sites, at least in the long-term temporal scale.

This analysis has disadvantages in that not every pollutant parameter has enough sites to create an interpolation map; in this case, NO_2 and SO_2 have not been subjected to this analysis. A limitation of the technology used in creating interpolation maps is that the map is bounded by the outer-most monitoring sites, which do not contribute fully to the creation of the map (known as the “edge effect”); it is important to keep in mind that the interpretation of the removal bias indicator may be ambiguous for those sites at the edge of the APCD monitoring region.

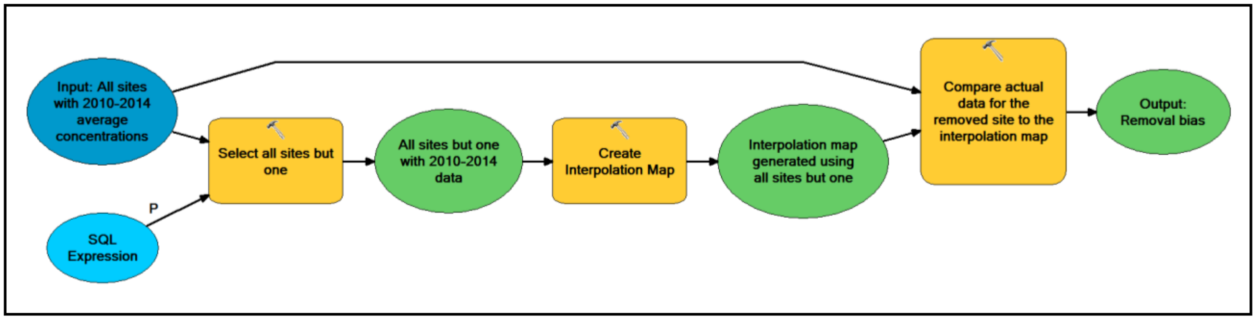


Figure 10. Schematic of the removal bias algorithm.

In the following sections, an interpolation map of the predicted pollution surface generated using all federal, state, local, and tribal monitoring data is shown for O_3, PM_{10}, and $PM_{2.5}$, which were the only pollutant networks subjected to this analysis. The accompanying tables show the results of the removal bias analysis and the associated rankings for each site. Note that there are not enough sites in the CO, NO_2, and SO_2 monitoring networks to apply this analysis.

2.6.1 Ozone (O_3)

Table 35. O_3 monitoring sites ordered and ranked by removal bias.

Site Name	Avg. Concentration (2010-2014)	Interpolated Concentration	Removal Bias	Rank
Ft. Collins - Mason	0.050	0.057	0.0073	1
Ft. Collins - West	0.058	0.051	-0.0068	2
Rifle - Health Dept.	0.050	0.056	0.0054	3
Rocky Flats	0.059	0.054	-0.0049	4
Aurora East	0.057	0.052	-0.0047	5
Chatfield	0.057	0.053	-0.0043	6
NREL	0.057	0.053	-0.0043	6
CAMP	0.046	0.050	0.0042	7
Welby	0.054	0.050	-0.0041	8
Weld Co. Tower	0.056	0.052	-0.0039	9
Highland	0.055	0.052	-0.0031	10
Cortez	0.052	0.055	0.0026	11
S. Boulder Creek	0.055	0.057	0.0015	12
Manitou Springs	0.056	0.055	-0.0009	13
Welch	0.054	0.053	-0.0008	14
La Casa	0.049	0.049	0.0006	15
Aspen Park	0.053	0.054	0.0005	16
USAFA	0.055	0.055	-0.0003	17
Palisade	0.054	0.054	-0.0001	18

Average O_3 concentrations in Colorado are highest at high elevation sites, particularly in the mountainous areas of the Central Mountains and Denver Metro/North Front Range regions, where annual average O_3 concentrations reach values as high as 60-62 ppb (Figure 11). The observation of enhanced O_3 concentrations with elevation in Colorado has been attributed to the low availability of nitric oxide (NO), which typically acts to reduce O_3 concentrations, and the increased importance of stratospheric O_3 transport at high elevation (Musselman and Korfmacher, 2014). High average concentrations are also observed in the suburban and rural regions immediately surrounding the Denver Metro area. Removal bias tends to be highest for these sites due to the steep gradient in average O_3 concentration that exists from the city center to the outlying suburban and rural regions. This gradient is a well-known feature of the spatial distribution of O_3 concentrations in and around large cities, where concentrations are depressed via NO_x titration in the urban center and reach maximum values along the suburban fringe (Sillman, 1999).

In Figure 12, measured values are plotted against modeled (i.e., interpolated) values. From inspection of this figure, it is clear that the pollution surface generated via interpolation does not provide an accurate representation of true spatial trends in O_3 concentrations in Colorado. For this reason, later sections of this report will emphasize predicted O_3 surfaces derived from dynamical atmospheric models rather than those generated from geostatistical analyses of monitoring data.

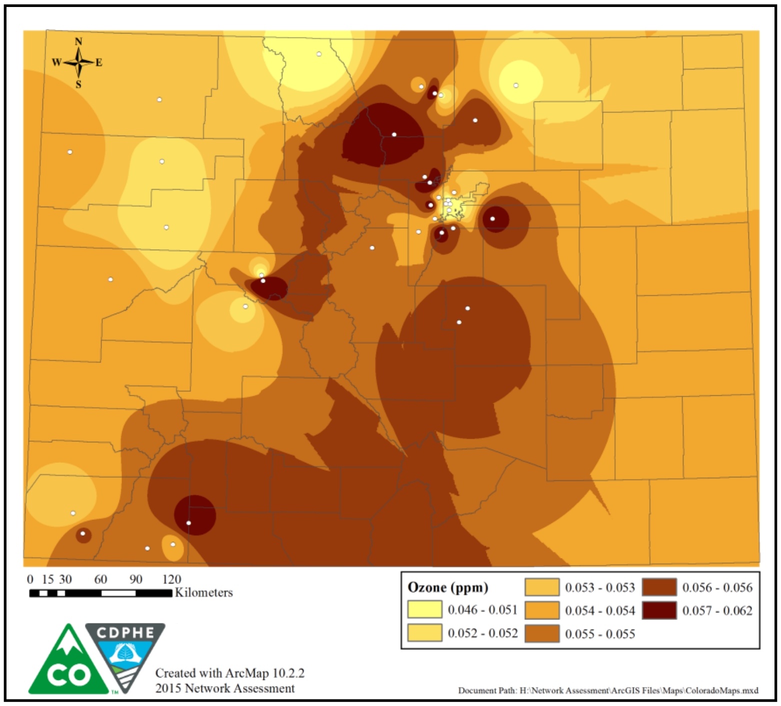


Figure 11. Interpolation map for O_3. The federal, state, local, and tribal monitors used to generate the map are symbolized by white circles.

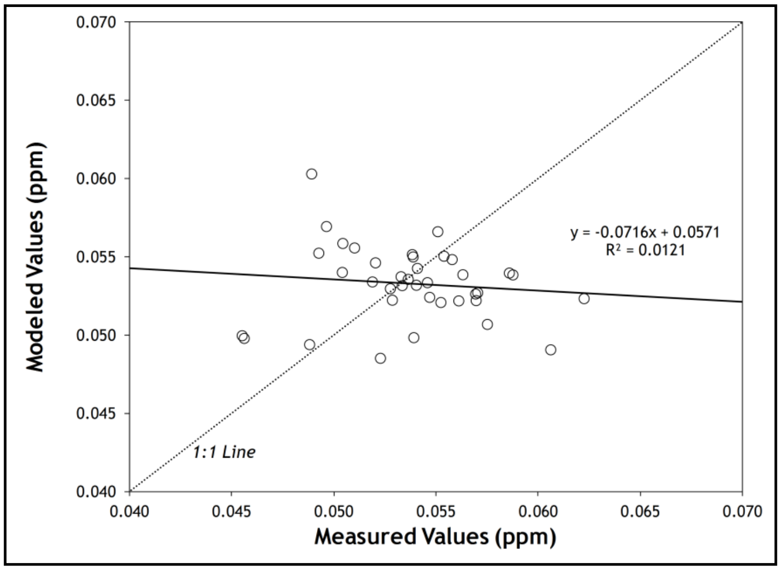


Figure 12. Removal bias for O_3 with actual concentration values plotted against modeled (i.e., interpolated) values.

2.6.2 PM_{10}

Table 36. PM_{10} monitoring sites ordered and ranked by removal bias.

Site Name	Avg. Concentration (2010-2014)	Interpolated Concentration	Removal Bias	Rank
GJ - Powell Bldg.	19.6	27.9	8.31	1
Alamosa - Municipal	31.4	24.0	-7.40	2
Alamosa - ASC	24.0	31.3	7.37	3
Carbondale	11.5	18.5	7.02	4
Crested Butte	21.8	14.8	-6.99	5
Mt. Crested Butte	14.8	21.7	6.89	6
CAMP	30.2	24.8	-5.34	7
Cañon City	18.2	22.4	4.21	8
Telluride	16.1	20.1	4.04	9
Denver VC	25.0	28.8	3.82	10
Boulder - Chamber of Comm.	20.0	23.3	3.33	11
Welby	23.6	27.0	3.33	11
Longmont - Municipal Bldg.	19.8	23.0	3.23	12
Alsup	27.2	24.0	-3.18	13
Lamar - Municipal Bldg.	24.6	27.6	3.00	14
La Casa	24.3	27.3	2.99	15
Colorado College	19.3	22.3	2.98	16
Delta - Health Dept.	22.6	20.2	-2.35	17
Steamboat Springs	20.4	18.2	-2.22	18
Rifle - Henry Bldg.	20.8	18.7	-2.10	19
Ft. Collins - CSU	20.3	22.3	1.99	20
Aspen	15.4	17.0	1.59	21
Pagosa	21.9	20.5	-1.35	22
Pueblo	20.4	21.6	1.24	23
Parachute	19.3	20.5	1.18	24
Greeley - Hospital	21.6	22.7	1.11	25
Durango	19.5	19.8	0.25	26

Average annual PM_{10} concentrations in Colorado are typically highest in the Denver Metro/North Front Range region, particularly at monitoring sites located near the city center, where emission density is typically highest (Figure 13). However, high average concentrations are also observed in the San Louis Valley and Eastern High Plains regions, where regional dust storms can lead to 24-hour average concentrations in excess of 1,000 $\mu g\ m^{-3}$ (Table 25).

Although dust storms occur infrequently, these events have a significant effect on the statistics calculated from the data (Table 37). Sites impacted by dust storms have median values that are 3-7 $\mu g\ m^{-3}$ lower than their mean values, and coefficients of variation (CV, the ratio of the standard deviation to the mean) that are greater than or equal to one. In other words, although average PM_{10} concentrations in the San Louis Valley and Eastern High Plains regions appear in Figure 13 to be the highest in the state, this is mostly a result of windblown dust events that skew the statistics. In terms of median values, the highest concentrations are observed at the CAMP, Welby, and Alsup sites, all located in central Denver. There is no apparent spatial trend in the removal bias results, although sites impacted by dust storms do tend to rank high in this analysis.

The interpolated PM_{10} pollution surface does not provide an accurate representation of true spatial trends in PM_{10} concentrations in Colorado, although the relationship observed between measured and interpolated values is somewhat stronger than that for O_3. Later sections of this report will emphasize predicted PM_{10} surfaces derived from land-use regression modeling rather than those generated from geostatistical analyses of monitoring data.

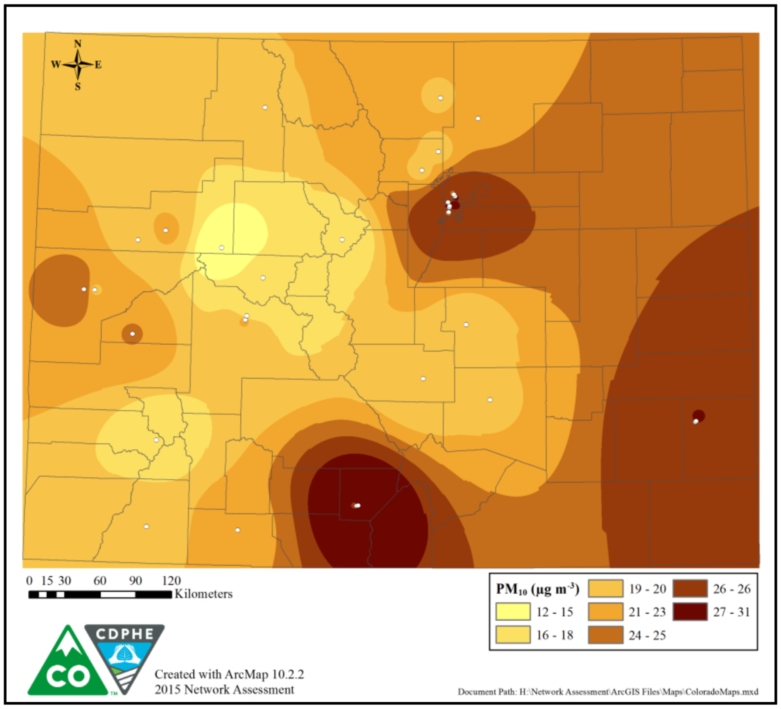


Figure 13. Interpolation map for PM_{10}. The federal, state, local, and tribal monitors used to generate the map are symbolized by white circles.

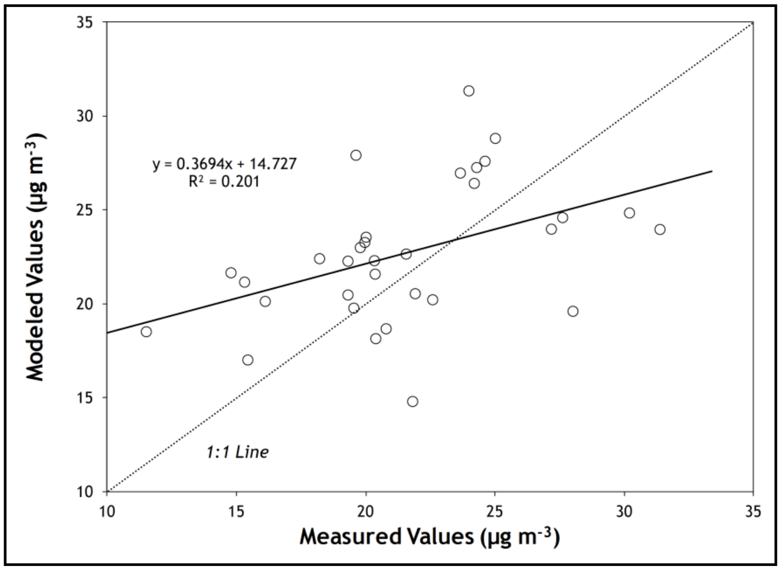


Figure 14. Removal bias for PM_{10} with actual concentration values plotted against modeled (i.e., interpolated) values.

Table 37. Statistics for 2010-2014 PM_{10} monitoring data.

Site Name	**Concentration Statistics (µg m^{-3})**			
	Mean	**Median**	**Std. Dev.**	**CV**
Alamosa - Municipal	31.4	24	31.1	**1.0**
CAMP	30.2	28	14.3	0.5
Alsup	27.2	25	14.7	0.5
Denver VC	25.0	23	11.1	0.4
Lamar - Municipal Bldg.	24.6	19	39.6	**1.6**
La Casa	24.3	21	11.6	0.5
Alamosa - ASC	24.0	19	29.4	**1.2**
Welby	23.6	26	15.4	0.7
Delta - Health Dept.	22.6	21	11.8	0.5
Pagosa	21.9	19	21.4	**1.0**
Crested Butte	21.8	19	15.3	0.7
Greeley - Hospital	21.6	20	11.7	0.5
Rifle - Henry Bldg.	20.8	19	9.7	0.5
Steamboat Springs	20.4	17	14.0	0.7
Pueblo	20.4	18	10.8	0.5
Ft. Collins - CSU	20.3	19	10.9	0.5
Boulder - Chamber of Comm.	20.0	18	10.1	0.5
Longmont - Municipal Bldg.	19.8	19	9.0	0.5
GJ - Powell Bldg.	19.6	19	12.1	0.6
Durango	19.5	16	27.5	**1.4**
Colorado College	19.3	19	11.3	0.6
Parachute	19.3	17	11.4	0.6
Cañon City	18.2	16	12.1	0.7
Telluride	16.1	13	23.4	**1.5**
Aspen	15.4	14	9.5	0.6
Mt. Crested Butte	14.8	12	12.3	0.8
Carbondale	11.5	11	7.1	0.6

2.6.3 $PM_{2.5}$

Table 38. $PM_{2.5}$ monitoring sites ordered and ranked by removal bias.

Site Name	**Max. Correlation**		**$r^2 \geq 0.6$**		**Average**
	Value	**Rank**	**Value**	**Rank**	**Rank**
GJ - Powell Bldg.	0.24	1	0	1	1.0
Cortez	0.24	1	0	1	1.0
Pueblo	0.45	2	0	1	1.5
Colorado College	0.52	3	0	1	2.0
Ft. Collins - CSU	0.58	4	0	1	2.5
Chatfield	0.76	7	1	2	4.5
Greeley - Hospital	0.74	6	2	3	4.5
Platteville	0.74	6	2	3	4.5
Longmont - Municipal Bldg.	0.73	5	4	4	4.5
CAMP	0.82	9	2	3	6.0
ACC	0.80	8	4	4	6.0
Boulder - Chamber of Comm.	0.85	11	1	2	6.5
Alsup	0.84	10	4	4	7.0
La Casa	0.85	11	4	4	7.5

Average annual $PM_{2.5}$ concentrations in Colorado are typically highest at sites located in the Denver Metro/North Front Range region (Figure 15). Due to steep gradients in $PM_{2.5}$ concentrations in and around this area, removal bias also tends to be higher for these sites. High $PM_{2.5}$ concentrations are also observed in the Western Slope monitoring region at the APCD’s Grand Junction - Powell Bldg. site.

From inspection of Figure 16, it is clear that the interpolated $PM_{2.5}$ pollution surface provides a more accurate representation of true spatial trends in concentration as compared to the O_3 and PM_{10} surfaces. Later sections of this report will incorporate both predicted $PM_{2.5}$ surfaces derived from land-use regression modeling and the interpolated surface shown in Figure 15.

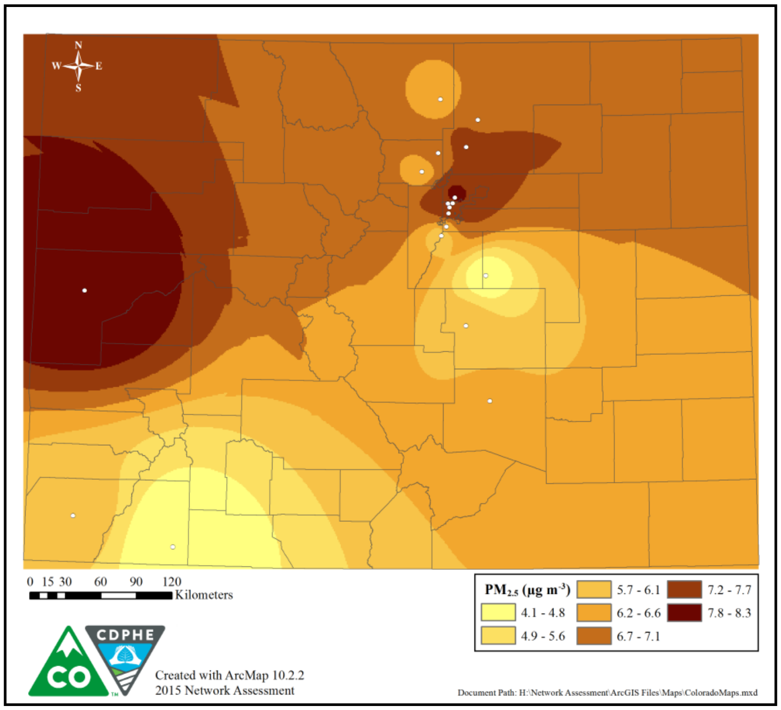


Figure 15. Interpolation map for $PM_{2.5}$. The federal, state, local, and tribal monitors used to generate the map are symbolized by white circles.

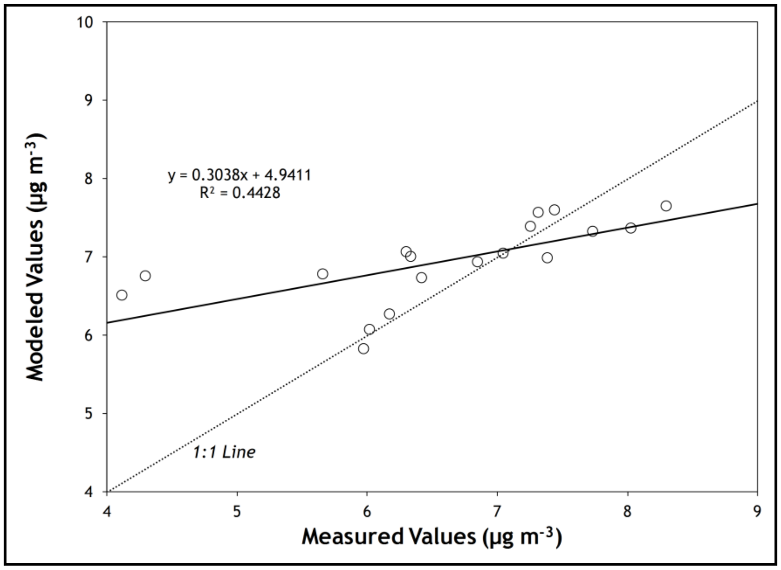


Figure 16. Removal bias results for $PM_{2.5}$.

2.7 Area Served

This analysis ranks monitoring sites in each network based on the extent of their spatial coverage; i.e., the size of their Area Served polygons. Conceptually, this zone represents the area around the monitoring site that is close enough to be represented by the concentrations measured at the monitor. The appropriate size and shape of this area is difficult to define precisely. The most common technique used to determine the spatial coverage of an air pollution monitor involves applying Thiessen polygons (also known as Voronoi diagrams) to represent each monitor's area of representation (Pope and Wu, 2014). Thiessen polygons are commonly used in geography to assign a zone of influence around a point or in place of interpolation techniques to generalize a set of sample measurements to the areas closest to them. They are created by delineating an area around a monitoring site in which each point is closer to that monitoring site than any other monitoring site. Thiessen polygons constructed for the APCD's $PM_{2.5}$ monitoring network using ArcGIS are shown in Figure 17.

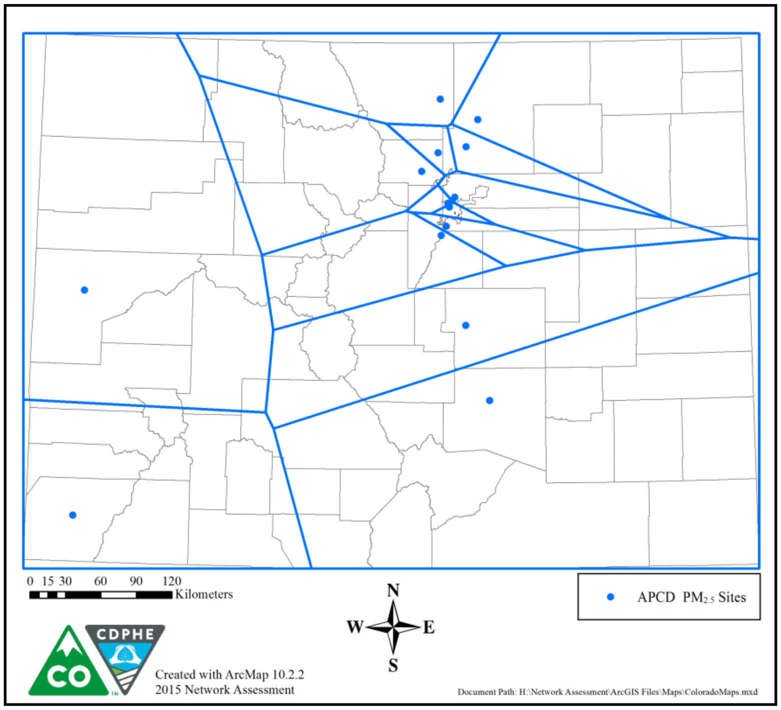


Figure 17. Thiessen polygons for APCD's $PM_{2.5}$ monitoring network.

The Thiessen polygon technique is a purely spatial construct and does not take into account meteorology, landscape topography, or other factors that may influence the extent of a monitor's spatial coverage. Therefore, while the technique may be appropriate for states with dense monitoring networks (e.g., California) or simple topography (e.g., Florida), its utility is limited in Colorado due to the sparseness of monitoring sites and the complexity of the terrain. For example, the presence of distinct meteo-geographical boundaries within Colorado (e.g., the Continental Divide, Palmer Divide, Cheyenne Ridge, etc.) limits atmospheric transport between airsheds, effectively separating regions of similar air quality and similar sources of air pollution (see Section 1.4.4). This can lead to some unreasonable results in the application of the Thiessen polygon technique, such as the five polygons in Figure 17 that intersect the Continental Divide. Therefore, the Thiessen polygon approach has been modified in the present case: for airsheds possessing only one monitor, Thiessen polygons have not be constructed; rather, the entire area of the airshed has been assigned to that monitor. For airsheds possessing multiple monitors, Thiessen polygons have been drawn to assign coverage areas to each monitor within the airshed; however, as shown in Figure 18, the polygons were clipped such that they would not intersect airshed boundaries.

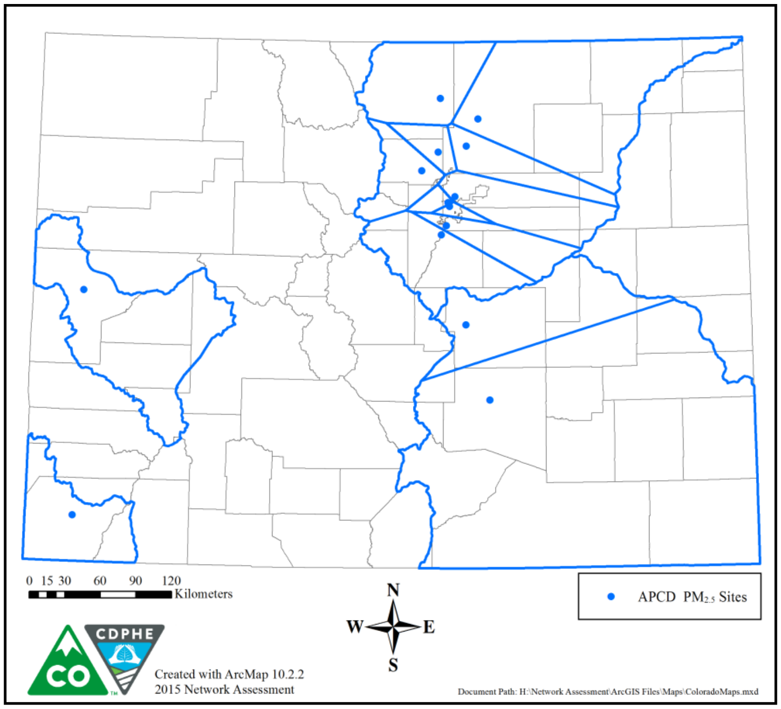


Figure 18. $PM_{2.5}$ Thiessen polygons restricted by airshed boundaries.

Restricting the Area Served polygons to airshed boundaries produces a more reasonable approximation of the extent of each monitoring site's spatial coverage; however, from inspection of Figure 18, it is clear that some polygons are so large that the monitoring point could not be said to adequately represent the entire area. For example, several of the polygons in Figure 18 have dimensions of over 100 km, while the monitor-to-monitor correlation study described in Section 2.5.6 suggests that $PM_{2.5}$ concentrations are only weakly correlated over this distance of separation (Figure 9). Therefore, we have imposed a further restriction on the ultimate size of each monitor's area of representation: for each pollutant network, we have used the parameter correlograms presented in Section 2.5 to define a maximum radius of spatial extent as the distance where the correlation coeffiecient between monitors drops below an r^2 value of 0.6 (i.e., the maximum distance at which sites are still well-correlated according to the monitor-to-monitor correlation study). This maximum radius of spatial extent was then used as an upper-limit on the size of each Area Served polygon. The maximum spatial extent values for the CO, NO_2, O_3, PM_{10}, and $PM_{2.5}$ networks are 16.5, 17.1, 91.3, 11.4, and 17.1 km, respectively. The correlogram for SO_2 was not robust enough to derive a maximum radius value due to the limited availability of data from within the state; therefore, we have assumed a value of 11.4 km for the SO_2 network (i.e., the value obtained from the CO correlogram).

In the following section, maps are presented showing the Area Served polygons derived for each APCD monitoring network. The accompanying tables show the results of the Area Served analysis and the associated rankings for each site. Note that the presence of monitoring sites operated by other agencies in Colorado has not been considered in the delineation of the Area Served polygons for the APCD sites being assessed in this report.

2.7.1 Carbon Monoxide (CO)

Table 39. All APCD CO monitoring sites ranked by area served.

Site Name	Area Served (km^2)	Rank
Ft. Collins - Mason	855	1
Greeley - Annex	855	1
GJ - Pitkin	854	2
HWY 24	829	3
Welby	536	4
CAMP	432	5
La Casa	254	6

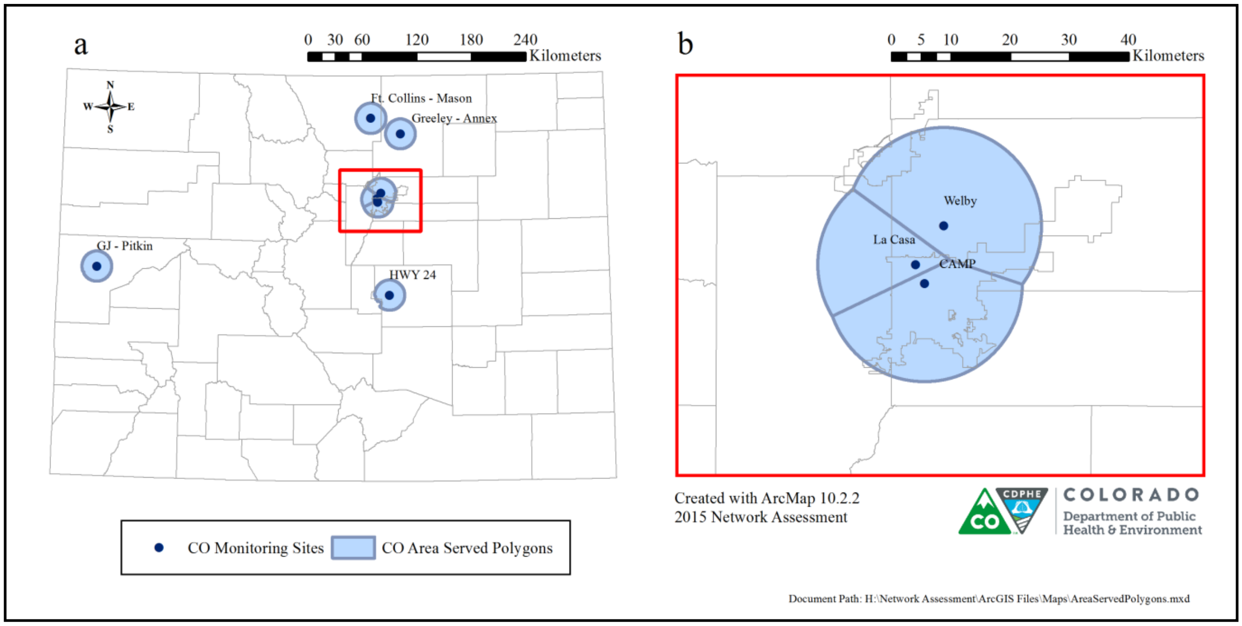


Figure 19. Map of (a) Colorado and (b) the Denver metropolitan area showing the Area served polygons derived for the CO monitoring network.

2.7.2 Nitrogen Dioxide (NO_2)

Table 40. All APCD NO_2 monitoring sites ranked by area served.

Site Name	Area Served (km^2)	Rank
Welby	570	1
CAMP	460	2
La Casa	268	3

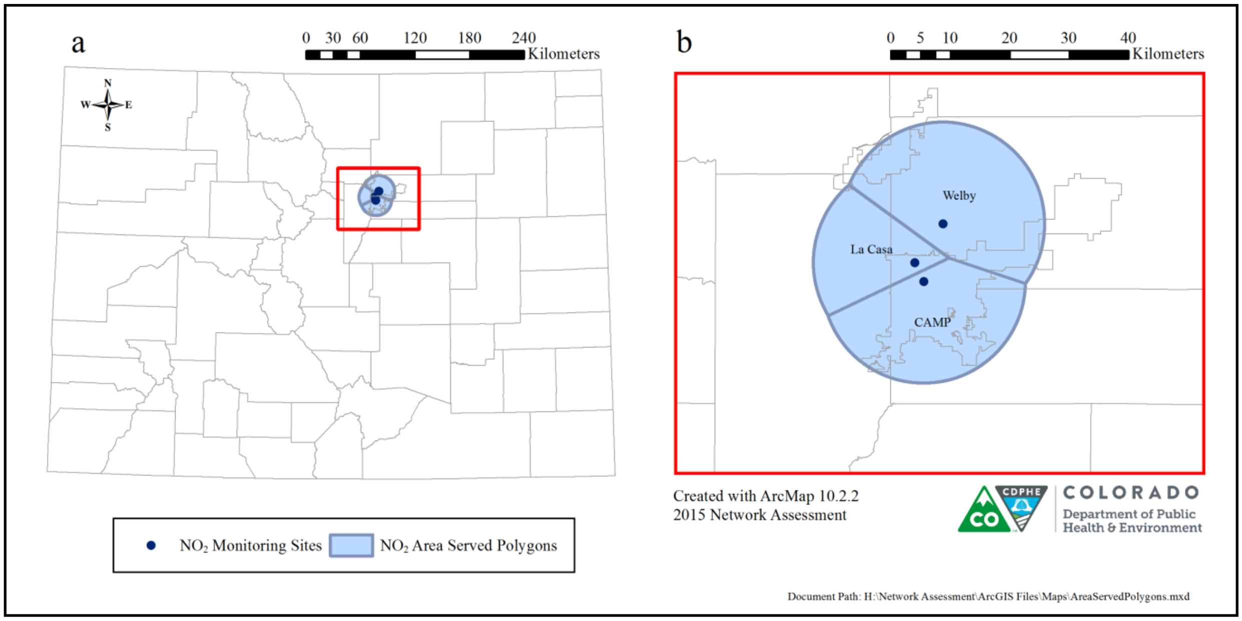


Figure 20. Map of (a) Colorado and (b) the Denver metropolitan area showing the Area served polygons derived for the NO_2 monitoring network.

2.7.3 Sulfur Dioxide (SO_2)

Table 41. All APCD SO_2 monitoring sites ranked by area served.

Site Name	Area Served (km^2)	Rank
HWY 24	408	1
Welby	287	2
CAMP	228	3
La Casa	148	4

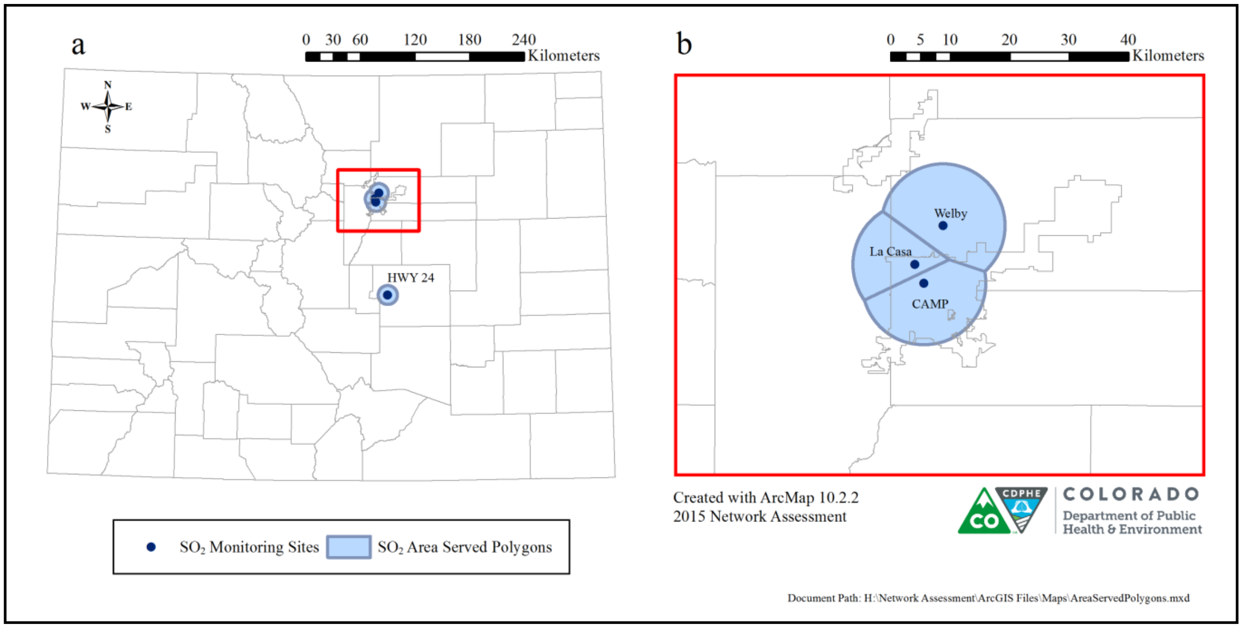
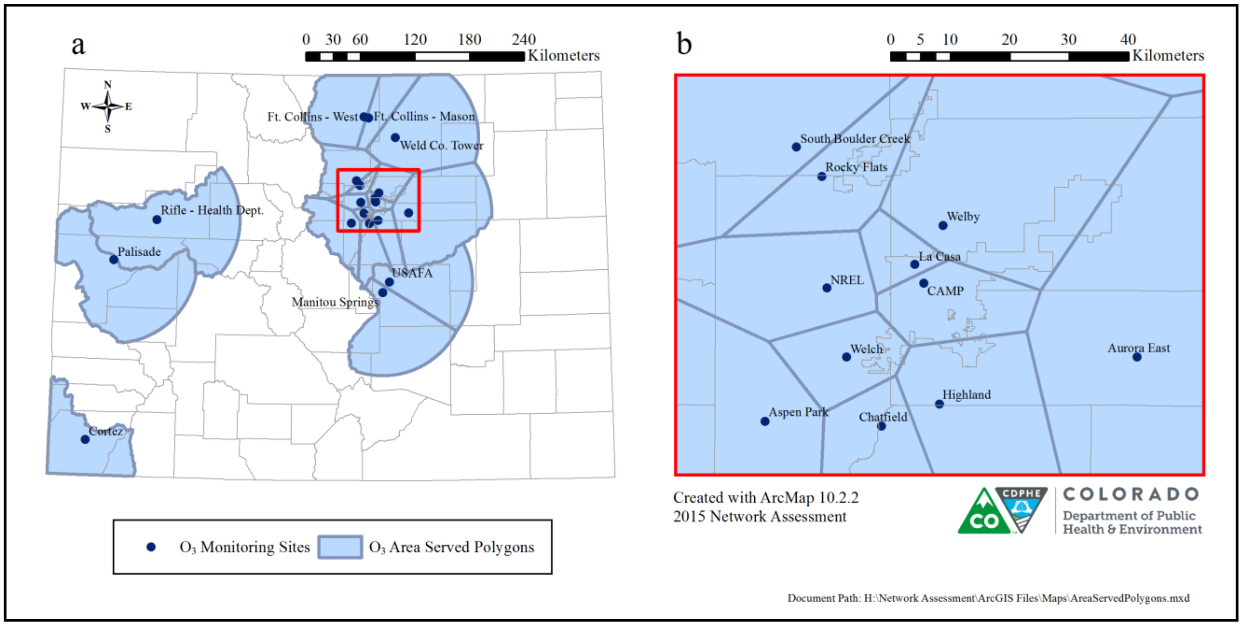


Figure 21. Map of (a) Colorado and (b) the Denver metropolitan area showing the Area served polygons derived for the SO_2 monitoring network.

2.7.4 Ozone (O_3)

Table 42. All APCD O_3 monitoring sites ranked by area served.

Site Name	Area Served (km^2)	Rank
Rifle - Health Dept.	12,092	1
Palisade	11,230	2
Weld Co. Tower	9,215	3
Aurora East	9,062	4
Manitou Springs	7,209	5
Cortez	6,089	6
USAFA	5,226	7
Ft. Collins - West	4,733	8
Aspen Park	3,032	9
S. Boulder Creek	2,597	10
Ft. Collins - Mason	2,254	11
Chatfield	1,536	12
Highland	1,348	13
Welby	1,249	14
NREL	541	15
Rocky Flats	382	16
CAMP	272	17
Welch	228	18
La Casa	111	19



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2015 Network Assessment

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Figure 22. Map of (a) Colorado and (b) the Denver metropolitan area showing the Area served polygons derived for the O_3 monitoring network.

2.7.5 PM$_{10}$

Table 43. All APCD PM$_{10}$ monitoring sites ranked by area served.

Site Name	Area Served (km^2)	Rank
Aspen	409	1
Carbondale	409	1
Colorado College	409	1
Delta - Health Dept.	409	1
Durango	409	1
Ft. Collins - CSU	409	1
GJ - Powell Bldg.	409	1
Greeley - Hospital	409	1
Lamar - Municipal Bldg.	409	1
Pagosa	409	1
Parachute	409	1
Pueblo	409	1
Rifle - Henry Bldg.	409	1
Steamboat Springs	409	1
Longmont - Municipal Bldg.	404	2
Boulder - Chamber of Comm.	404	2
Telluride	254	3
Mt. Crested Butte	248	4
Crested Butte	235	5
Alamosa - ASC	220	6
Alamosa - Municipal	220	6
Cañon City	213	7
Denver VC	202	8
Welby	176	9
Alsup	142	10
La Casa	140	11
CAMP	48	12

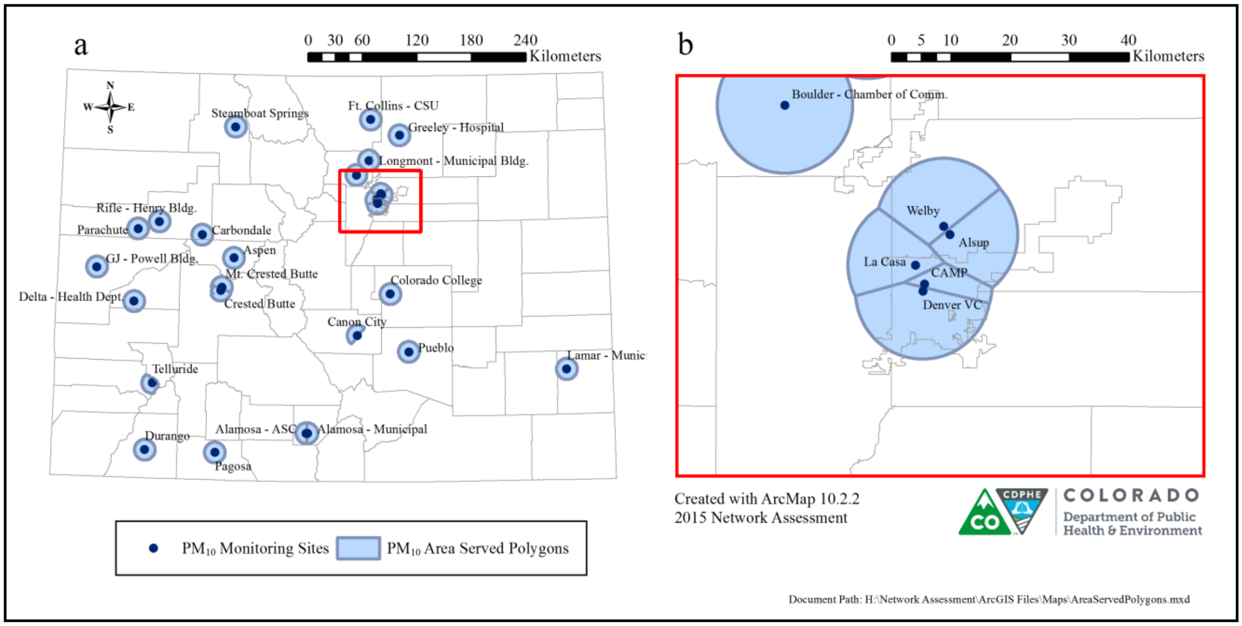

Figure 23. Map of (a) Colorado and (b) the Denver metropolitan area showing the Area served polygons derived for the PM$_{10}$ monitoring network.

2.7.6 $PM_{2.5}$

Table 44. All APCD $PM_{2.5}$ monitoring sites ranked by area served.

Site Name	Area Served (km^2)	Rank
Ft. Collins - CSU	919	1
Pueblo	919	1
GJ - Powell Bldg.	914	2
Colorado College	906	3
Cortez	881	4
Greeley - Hospital	844	5
Boulder - Chamber of Comm.	796	6
Platteville	759	7
Longmont - Municipal Bldg.	711	8
Chatfield	610	9
Alsup	553	10
ACC	422	11
La Casa	294	12
CAMP	246	13

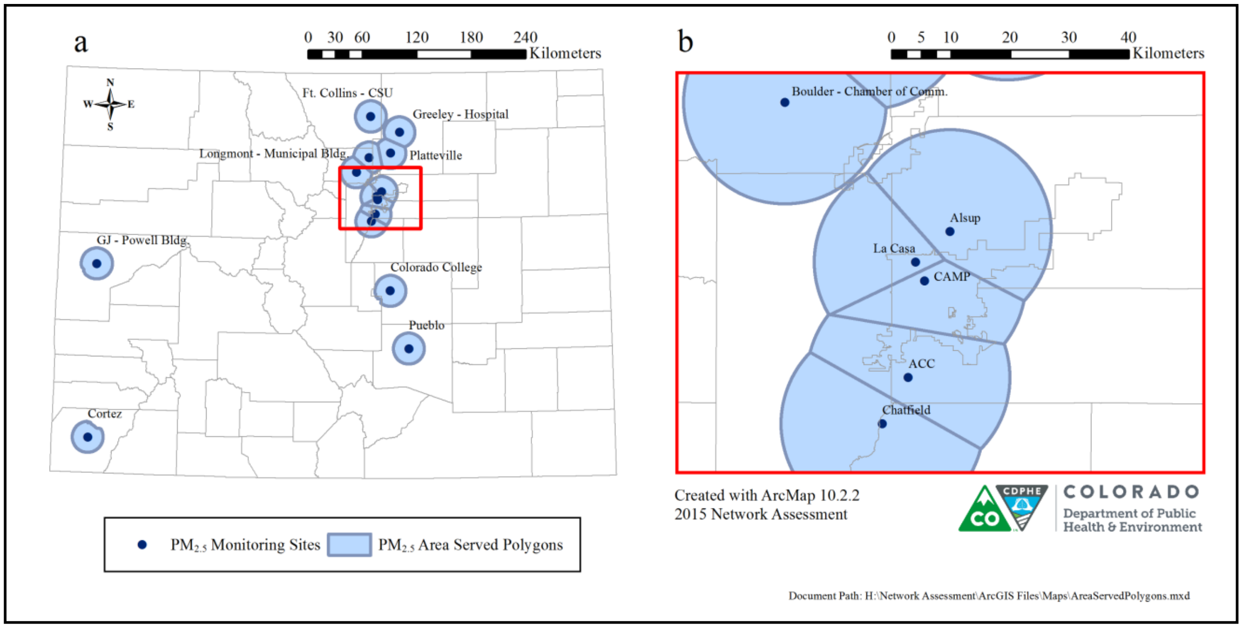

Figure 24. Map of (a) Colorado and (b) the Denver metropolitan area showing the Area served polygons derived for the $PM_{2.5}$ monitoring network.

2.8 Population Served

This analysis attempts to quantify the population represented by each monitoring site. It has been well-established that high population densities are associated with high emissions and high ambient pollutant concentrations; therefore, monitors representing more population will typically be of greater importance in determining regulatory compliance. Furthermore, the collection of data that is representative of the greatest possible number of people is an important monitoring objective; therefore, monitors with the highest population counts are given the highest rank in this analysis.

Calculating the population served by a particular monitor requires two steps: (1) a determination of the area of representation for each monitor, and (2) a determination of the population within each monitor's area of representation. Areas of representation for each monitor were determined using a modified Thiessen polygon approach as described in Section 2.7. Tract-level data from the 2010 Census was then used within ArcGIS to create a polygon coverage map of census tracts within Colorado, which is presented in Figure 25. The population within each monitor's Area Served polygon was then determined by summing the population count totals for those census tract polygons that intersect each Area Served polygon.

The advantage of this analysis is that it provides a simple technique to quantify the population represented by a particular monitor. This technique will provide more weight to sites located in areas of high population density and sites with large areas of representation.

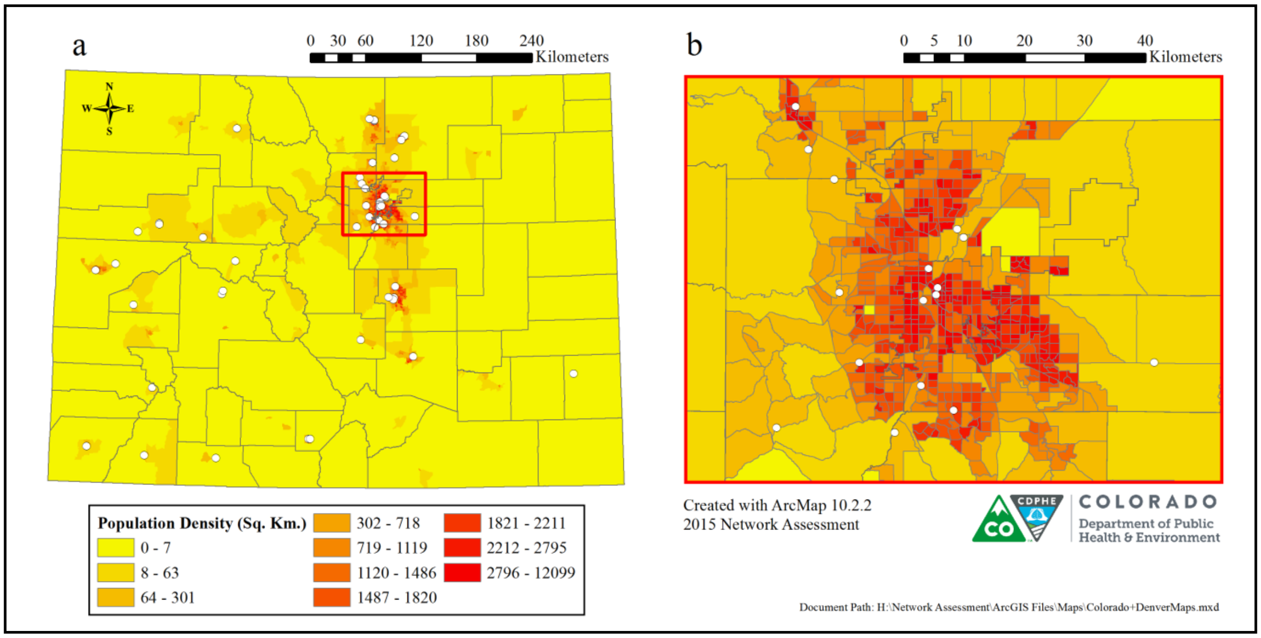

Figure 25. Population density in (a) Colorado and (b) the Denver metropolitan area at the census-tract level.

2.8.1 Results for All Parameters

Tables 45-50 list the Population Served and associated score for each APCD monitoring site in the CO, NO_2, SO_2, O_3, PM_{10}, and $PM_{2.5}$ ambient networks, respectively.

Table 45. All APCD CO monitoring sites ranked by population served.

Site Name	Population Served	Rank
CAMP	945,827	1
Welby	549,303	2
HWY 24	539,819	3
La Casa	393,331	4
Ft. Collins - Mason	256,632	5
Greeley - Annex	154,920	6
GJ - Pitkin	146,723	7

Table 46. All APCD NO_2 monitoring sites ranked by population served.

Site Name	Population Served	Rank
CAMP	986,571	1
Welby	549,303	2
La Casa	397,866	3

Table 47. All APCD SO_2 monitoring sites ranked by population served.

Site Name	Population Served	Rank
CAMP	631,272	1
Welby	396,281	2
HWY 24	382,993	3
La Casa	304,533	4

Table 48. All APCD O_3 monitoring sites ranked by population served.

Site Name	Population Served	Rank
CAMP	756,555	1
Highland	703,530	2
Welby	580,900	3
Manitou Springs	571,958	4
USAFA	396,457	5
S. Boulder Creek	346,894	6
Ft. Collins - Mason	306,740	7
Aurora East	289,164	8
Weld Co. Tower	275,851	9
La Casa	265,560	10
Welch	265,028	11
Palisade	238,014	12
Rocky Flats	228,945	13
NREL	224,116	14
Chatfield	186,378	15
Rifle - Health Dept.	144,925	16
Ft. Collins - West	108,833	17
Aspen Park	101,296	18
Cortez	39,015	19

Table 49. All APCD PM_{10} monitoring sites ranked by population served.

Site Name	Population Served	Rank
Denver VC	547,528	1
Colorado College	437,989	2
Welby	311,549	3
La Casa	290,120	4
Ft. Collins - CSU	199,741	5
CAMP	195,466	6
Boulder - Chamber of Comm.	183,968	7
Greeley - Hospital	144,565	8
Pueblo	142,043	9
Longmont - Municipal Bldg.	141,777	10
Alsup	138,105	11
GJ - Powell Bldg.	130,489	12
Durango	42,001	13
Carbondale	33,784	14
Delta - Health Dept.	24,800	15
Rifle - Henry Bldg.	24,018	16
Cañon City	23,280	17
Steamboat Springs	21,584	18
Lamar - Municipal Bldg.	17,626	19
Parachute	17,540	20
Aspen	17,148	21
Alamosa - Municipal	15,445	22
Alamosa - ASC	13,670	23
Pagosa	12,084	24
Telluride	11,000	25
Crested Butte	9,200	26
Mt. Crested Butte	7,064	27

Table 50. All APCD $PM_{2.5}$ monitoring sites ranked by population served.

Site Name	Population Served	Rank
CAMP	715,974	1
ACC	599,100	2
Alsup	556,557	3
Colorado College	553,837	4
La Casa	424,029	5
Ft. Collins - CSU	267,745	6
Boulder - Chamber of Comm.	238,978	7
Chatfield	180,579	8
Greeley - Hospital	176,532	9
Longmont - Municipal Bldg.	173,216	10
Pueblo	159,063	11
GJ - Powell Bldg.	146,723	12
Platteville	75,906	13
Cortez	25,535	14

2.9 Emissions Inventory

This analysis ranks sites based on their proximity to point sources of pollution by giving weight to each monitor according to the sum of emissions within its area of representation. Areas of representation for each monitor were determined using a modified Thiessen polygon approach as described in Section 2.7. Point source emissions data was obtained from the 2014 APCD facilities inventory, which lists reported emissions for over 10,000 permitted sources within Colorado. Emissions data for CO, NO_x, SO_2, volatile organic compounds (VOCs), PM_{10}, and $PM_{2.5}$ were spatially located within ArcGIS and then summed within each monitor's Area Served polygon. Polygons with larger total emissions were ranked higher.

2.9.1 Carbon Monoxide (CO)

CO point source emissions density is shown for illustration purposes in Figure 26. The highest emissions in the state are associated with public utilities in Colorado Springs and Pueblo. A mining operation in southeast Moffat County is also a large source of CO.

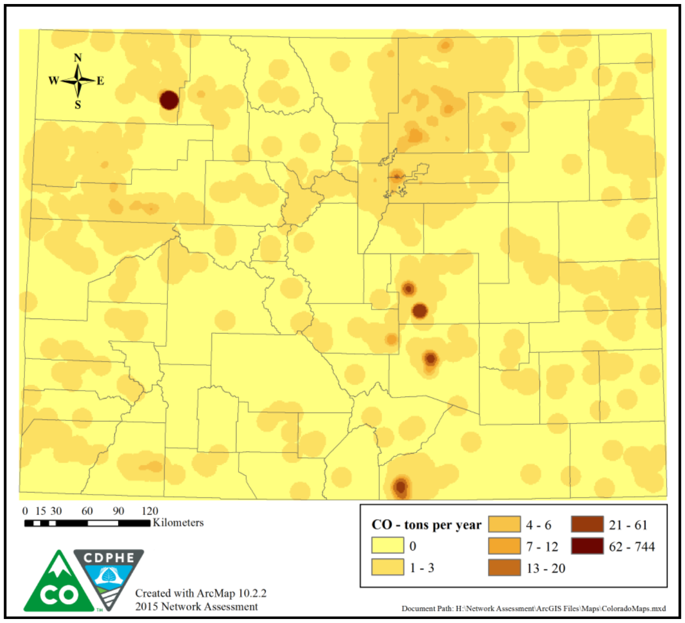

Figure 26. CO emissions density as calculated from point source data using the Kernel Density tool in ArcGIS. Class breaks have been determined using the quantile method.

Table 51. CO monitoring sites ranked by total emissions.

Site Name	Sum of CO Emissions (tons)	Max.	Rank
HWY 24	2,813	2,357	1
Greeley - Annex	2,167	274	2
Welby	1,293	386	3
CAMP	903	153	4
La Casa	467	78	5
Ft. Collins - Mason	356	94	6
GJ - Pitkin	244	68	7

2.9.2 Nitrogen Dioxide (NO_2)

NO_x point source emissions density is shown for illustration purposes in Figure 27. The highest emissions in the state are associated with public utilities in Denver, Colorado Springs, Pueblo, and rural counties of Morgan and Routt. Regions of intensive oil and gas extraction in Weld and Garfield counties are also associated with high emissions.

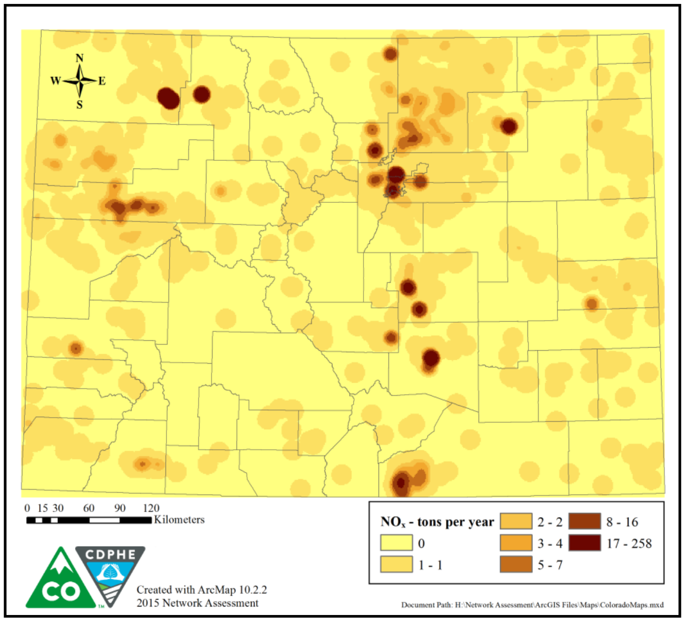

Figure 27. NO_x emissions density as calculated from point source data using the Kernel Density tool in ArcGIS. Class breaks have been determined using the quantile method.

Table 52. NO_2 monitoring sites ranked by total NO_x emissions.

Site Name	Sum of NO_x Emissions (tons)	Max.	Rank
Welby	6,273	5,172	1
CAMP	3,208	2,167	2
La Casa	749	352	3

2.9.3 Sulfur Dioxide (SO_2)

SO_2 point source emissions density is shown in Figure 28. The highest emissions in the state are associated with the same public utilities mentioned above. Emissions are particularly concentrated in the Denver Metro area.

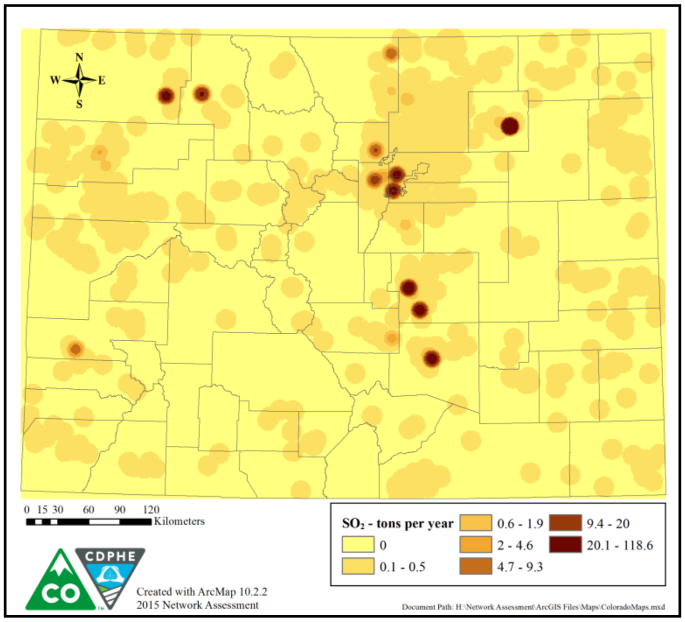

Figure 28. SO_2 emissions density as calculated from point source data using the Kernel Density tool in ArcGIS. Class breaks have been determined using the quantile method.

Table 53. SO_2 monitoring sites ranked by total emissions.

Site Name	Sum of SO_2 Emissions (tons)	Max.	Rank
HWY 24	4,906	4,792	1
CAMP	3,031	2,851	2
Welby	2,932	2,584	3
La Casa	474	328	4

2.9.4 Ozone (O_3)

Tropospheric O_3 is a secondary pollutant, meaning that it is not directly emitted, but formed *in-situ* through photochemical reactions involving VOCs and NO_x. Furthermore, although O_3 requires the presence of NO_x in its formation reaction, it is also scavenged, or destroyed, by NO_x in the atmosphere (Sillman, 1999). Because of its complex source/sink dynamics, O_3 concentrations follow much different patterns than other primary pollutants. In the short-term (i.e., several hours or less), O_3 will form near its precursor sources and increase in concentration as the plume moves downwind and has more time to react during daylight hours. At night, when photochemical cycling has ceased, O_3 concentrations within the urban area will decrease as NO_x compounds in the area scavenge them. However, outside of the urban areas, where NO_x concentrations are typically low, O_3 will persist in the environment and can last for weeks before dissipating. This causes O_3 concentrations to be much higher in the rural areas downwind of an urban area, especially when viewing concentrations averaged over long temporal periods .

Because of these dynamics, the methodology of ranking O_3 monitors in order of the total VOC and NO_x point sources is not entirely valid. It is still practical to use the method established with the other primary pollutants, as the short-term O_3 levels can still be high in the area surrounding precursor point sources. However, another method of ranking that considers O_3 averages also needs to be adopted. This will be discussed in the following section.

VOC point source emissions density is shown for illustration purposes in Figure 29, while NO_x emissions have been previously discussed and are shown in Figure 27. The highest VOC emission densities in the state occur in the Denver Metro area and in regions of intensive oil and gas extraction in Weld and Garfield counties.

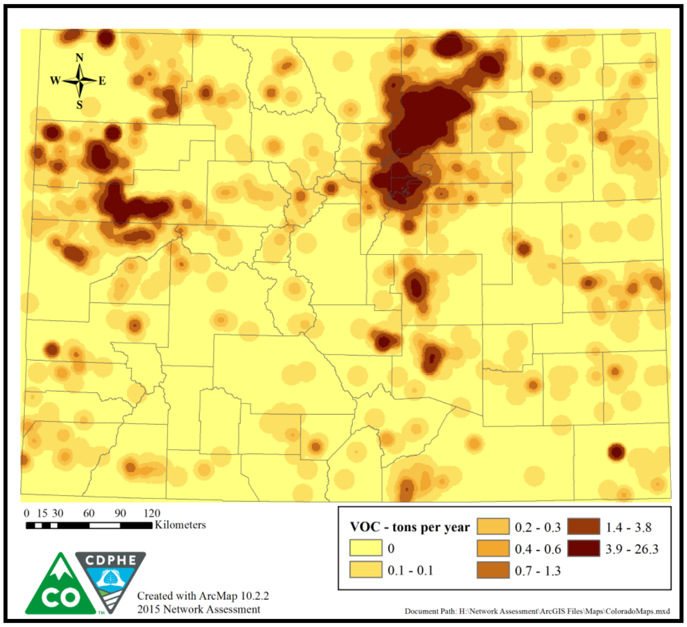

Figure 29. VOC emissions density as calculated from point source data using the Kernel Density tool in ArcGIS. Class breaks have been determined using the quantile method.

The emissions sums and maximum emission sections associated within each O_3 monitor are shown for NO_x and VOCs in Table 54 and Table 55, respectively. In Table 56, the NO_x- and VOC-based rankings have been averaged to determine an overall ranking for each site.

Table 54. O_3 monitoring sites ranked by total NO_x emissions.

Site Name	Sum of NO_x Emissions (tons)	Max.	Rank
Manitou Springs	13,286	4,807	1
Weld Co. Tower	8,615	343	2
Welby	7,456	5,172	3
Rifle - Health Dept.	7,202	326	4
South Boulder Creek	3,163	1,959	5
CAMP	3,129	2,167	6
Aurora East	1,897	768	7
Ft. Collins - West	1,413	1,361	8
NREL	1,371	752	9
Ft. Collins - Mason	915	201	10
Palisade	783	73	11
Highland	481	49	12
USAFA	434	98	13
Rocky Flats	391	118	14
Cortez	383	53	15
La Casa	286	80	16
Chatfield	87	43	17
Aspen Park	47	22	18
Welch	45	20	19

Table 55. O_3 monitoring sites ranked by total VOC emissions.

Site Name	Sum of VOC Emissions (tons)	Max.	Rank
Weld Co. Tower	31,752	962	1
Rifle - Health Dept.	11,600	699	2
Welby	5,065	416	3
Manitou Springs	3,461	237	4
Ft. Collins - Mason	2,107	275	5
CAMP	1,928	81	6
Highland	1,654	38	7
Aurora East	1,650	159	8
NREL	1,508	488	9
South Boulder Creek	1,464	58	10
Palisade	1,419	84	11
La Casa	1,137	96	12
Rocky Flats	899	75	13
USAFA	802	36	14
Aspen Park	374	179	15
Cortez	328	79	16
Welch	322	23	17
Chatfield	219	24	18
Ft. Collins - West	108	35	19

Table 56. Overall emissions inventory rankings for the O_3 monitoring network.

Site Name	Scores		Average	Rank
	VOC	NO_x		
Weld Co. Tower	1	2	1.5	1
Manitou Springs	4	1	2.5	2
Rifle - Health Dept.	2	4	3.0	3
Welby	3	3	3.0	3
CAMP	6	6	6.0	4
Aurora East	8	7	7.5	5
Ft. Collins - Mason	5	10	7.5	5
South Boulder Creek	10	5	7.5	5
NREL	9	9	9.0	6
Highland	7	12	9.5	7
Palisade	11	11	11.0	8
Ft. Collins - West	19	8	13.5	9
Rocky Flats	13	14	13.5	9
USAFA	14	13	13.5	9
La Casa	12	16	14.0	10
Cortez	16	15	15.5	11
Aspen Park	15	18	16.5	12
Chatfield	18	17	17.5	13
Welch	17	19	18.0	14

2.9.5 PM_{10}

PM_{10} point source emissions density is shown in Figure 30. The highest emissions in the state are associated with a large coal mining operation in southern Moffat County.

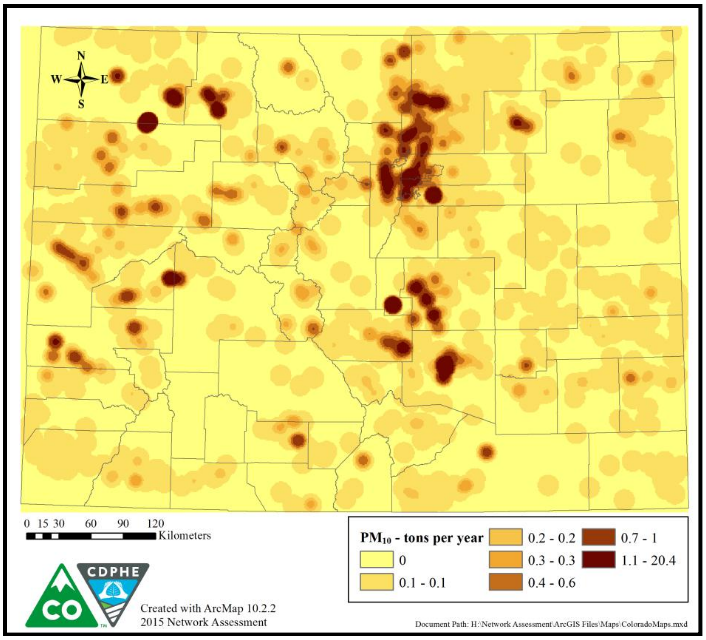

Figure 30. PM_{10} emissions density as calculated from point source data using the Kernel Density tool in ArcGIS. Class breaks have been determined using the quantile method.

Table 57. PM_{10} monitoring sites ranked by total emissions.

Site Name	Sum of PM_{10} Emissions (tons)	Max.	Rank
Pueblo	794	405	1
Alsup	624	262	2
Colorado College	464	150	3
Greeley - Hospital	423	86	4
La Casa	254	49	5
Denver VC	214	64	6
Longmont - Municipal Bldg.	194	39	7
GJ - Powell Bldg.	161	20	8
Ft. Collins - CSU	131	62	9
Delta - Health Dept.	122	59	10
Rifle - Henry Bldg.	115	31	11
Parachute	102	42	12
Carbondale	72	37	13
Lamar - Municipal Bldg.	54	24	14
Boulder - Chamber of Comm.	52	28	15
CAMP	50	21	16
Welby	49	21	17
Durango	33	17	18
Aspen	27	20	19
Cañon City	17	8	20
Pagosa	14	8	21
Steamboat Springs	13	6	22
Telluride	9	7	23
Crested Butte	5	5	24
Alamosa - Municipal	3	2	25
Alamosa - ASC	3	2	25
Mt. Crested Butte	0	0	26

2.9.6 $PM_{2.5}$

$PM_{2.5}$, like O_3, can be considered a secondary pollutant, although it can also be directly emitted to the atmosphere. Nitrate (NO_3^-) and sulfate (SO_4^{2-}) are particularly important components of secondary $PM_{2.5}$. Because these chemical species originate from the oxidation of NO_x and SO_2, respectively, NO_x and SO_2 point source emissions are also considered in the ranking of the $PM_{2.5}$ sites.

$PM_{2.5}$ point source emissions density is shown for illustration purposes in Figure 31, while NO_x and SO_2 emissions have been previously discussed and are shown in Figure 27 and Figure 28, respectively. The highest $PM_{2.5}$ emission densities in the state occur in the Denver Metro area and in Weld County. Other large point sources include a landfill in Arapahoe County, coal mining operations in southern Moffet County, a refinery locate in the Denver metro area, and a power plant in Pueblo.

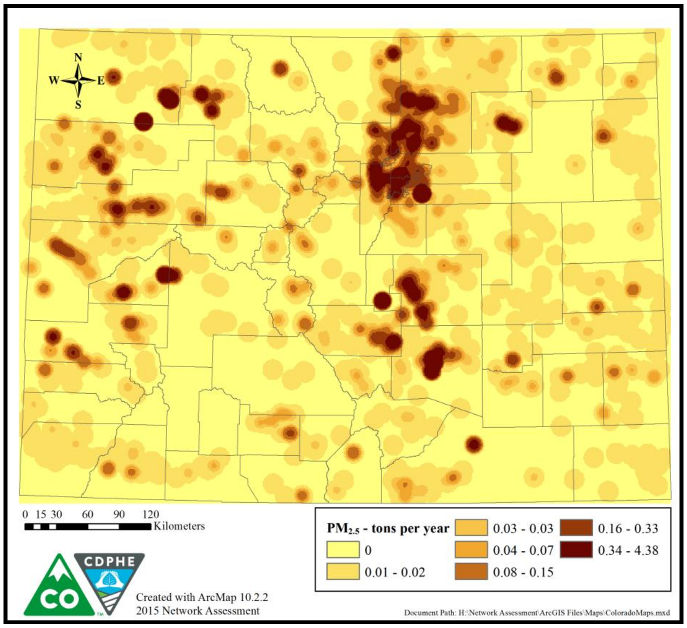

Figure 31. $PM_{2.5}$ emissions density as calculated from point source data using the Kernel Density tool in ArcGIS. Class breaks have been determined using the quantile method.

Table 58. $PM_{2.5}$ monitoring sites ranked by total $PM_{2.5}$ emissions.

Site Name	**Sum of $PM_{2.5}$ Emissions (tons)**	**Max.**	**Rank**
Pueblo	648	223	1
Alsup	491	241	2
Greeley - Hospital	331	99	3
Platteville	286	54	4
Colorado College	214	39	5
Longmont - Municipal Bldg.	180	47	6
La Casa	163	31	7
Boulder - Chamber of Comm.	90	32	8
ACC	82	24	9
CAMP	74	9	10
GJ - Powell Bldg.	74	10	10
Ft. Collins - CSU	71	19	11
Chatfield	36	17	12
Cortez	4	2	13

Table 59. $PM_{2.5}$ monitoring sites ranked by total NO_x emissions.

Site Name	Sum of NO_x Emissions (tons)	Max.	Rank
Pueblo	6,434	4,807	1
Alsup	6,413	5,172	2
Colorado College	3,400	2,793	3
Platteville	2,907	343	4
ACC	2,700	2,167	5
Boulder - Chamber of Comm.	2,544	1,959	6
Greeley - Hospital	1,708	244	7
Longmont - Municipal Bldg.	984	767	8
La Casa	757	352	9
CAMP	713	171	10
Ft. Collins - CSU	506	174	11
GJ - Powell Bldg.	156	50	12
Chatfield	94	43	13
Cortez	30	25	14

Table 60. $PM_{2.5}$ monitoring sites ranked by total SO_2 emissions.

Site Name	Sum of SO_2 Emissions (tons)	Max.	Rank
Colorado College	4,916	4,792	1
Pueblo	3,882	3,496	2
ACC	3,045	2,851	3
Alsup	2,940	2,584	4
Boulder - Chamber of Comm.	1,103	1,056	5
La Casa	492	328	6
Greeley - Hospital	155	132	7
Ft. Collins - CSU	89	55	8
Platteville	48	20	9
Longmont - Municipal Bldg.	44	15	10
CAMP	42	11	11
GJ - Powell Bldg.	24	14	12
Chatfield	7	3	13
Cortez	0	0	14

Table 61. Overall emissions inventory rankings for the $PM_{2.5}$ monitoring network.

Site Name	Scores			Average	Rank
	$PM_{2.5}$	NO_x	SO_2		
Pueblo	1	1	2	1.3	1
Alsup	2	2	4	2.7	2
Colorado College	5	3	1	3.0	3
Greeley - Hospital	3	7	7	5.7	4
Platteville	4	4	9	5.7	4
ACC	9	5	3	5.7	4
Boulder - Chamber of Comm.	8	6	5	6.3	5
La Casa	7	9	6	7.3	6
Longmont - Municipal Bldg.	6	8	10	8.0	7
Ft. Collins - CSU	11	11	8	10.0	8
CAMP	10	10	11	10.3	9
GJ - Powell Bldg.	10	12	12	11.3	10
Chatfield	12	13	13	12.7	11
Cortez	13	14	14	13.7	12

2.10 Traffic Counts

Point sources typically account for only a portion of the pollution emissions within an area. The Traffic Count analysis considers transportation and mobile source emissions. This analysis evaluates the mobile source emissions within the influence of a monitoring site; these data, along with point source data from the Emissions Inventory analysis described in Section 2.9, are used to assess the total effect of emissions within each site's area of representation (i.e., Area Served polygon).

Emissions from mobile sources can vary greatly; factors which can affect the amount of pollution released include road type (e.g., fast-moving vehicles on a freeway generally emit less pollution per unit ditsance than vehicles on arterial roads and collectors), vehicle type (e.g., diesel vs. gasoline powered vehicles), traffic congestion, age and size of vehicles, etc. Ideally, a method which attempts to account for traffic emissions would account for all of these variables in a spatially resolved model. Unfortunately, such traffic modeling is outside of the scope of this network assessment. Instead, traffic counts and road density are used in this analysis as proxies for mobile source pollution.

Annual average daily traffic (AADT) counts were obtained from the Colorado Department of Transportation for 2013, the most recent year with available data. The dataset includes counts for highways and major roads with comprehensive sample location coverage; however, it is difficult to ascertain if AADT sample locations include all arterial roads with the same density (see Figure 32) and it is likely that additional new roads were not sampled. To account for variations in sampling density in different parts of the state, the total AADT counts within each site's Area Served polygon were normalized by the average distance between sampling locations. The rankings based on normalized AADT counts were then averaged together with rankings based on road density and each site was ranked based on this overall score. To further normalize the AADT counts, this analysis also considers the road density within each site's Area Served polygon when calculating the final rankings.

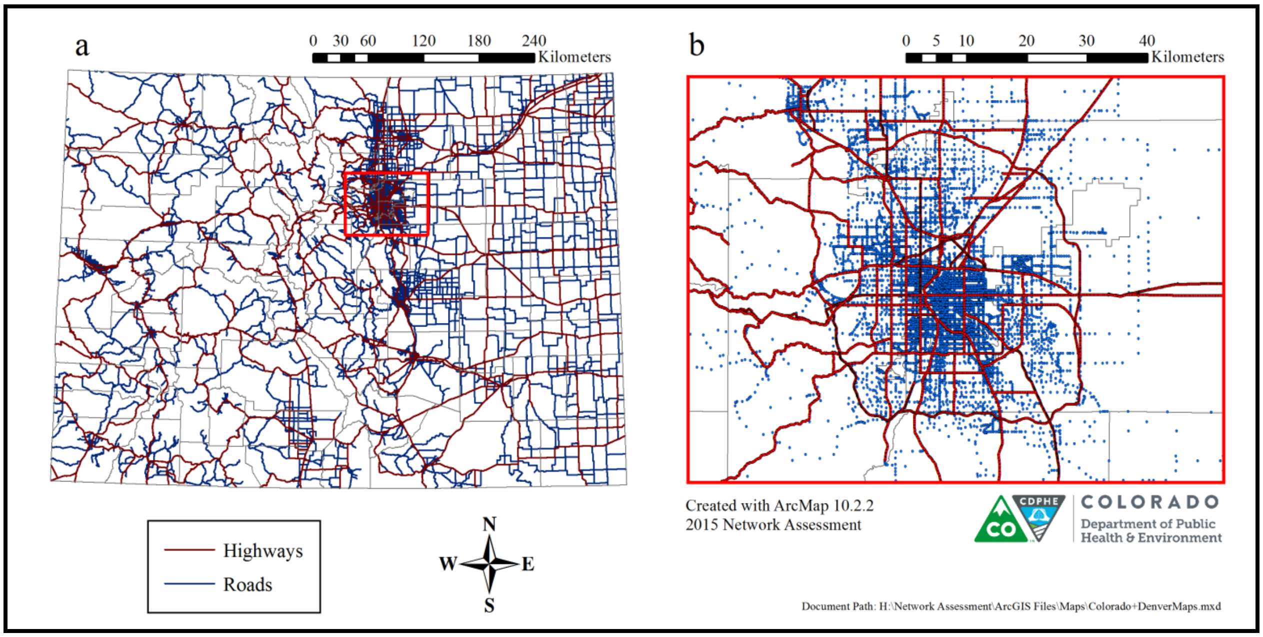

Figure 32. Highways and major roads in (a) Colorado and (b) the Denver metropolitan area. Note that the individual CDOT AADT monitors visible in (b) become increasingly dispersed on roads outside of central Denver.

2.10.1 Carbon Monoxide (CO)

Table 62. CO monitoring sites ranked by traffic counts.

Site Name	Sum of AADT Counts		Total Normalized AADT Counts	Rank
	Major Roads	Highways		
CAMP	56,963,710	252,744,500	78,374	1
La Casa	12,335,120	130,138,400	70,819	2
Welby	13,216,230	143,919,500	66,514	3
HWY 24	12,528,340	71,563,300	54,508	4
Ft. Collins - Mason	5,765,140	28,781,200	27,633	5
GJ - Pitkin	7,322,830	21,474,160	18,345	6
Greeley - Annex	2,566,740	21,302,380	16,535	7

Table 63. CO monitoring sites ranked by road density.

Site Name	Size of Area Served Polygon (km^2)	Total Road Length (km)	Road Density (m/km^2)	Rank
CAMP	432	687	1,590	1
La Casa	254	314	1,236	2
Welby	536	445	831	3
HWY 24	829	513	619	4
Ft. Collins - Mason	855	360	421	5
Greeley - Annex	855	344	402	6
GJ - Pitkin	854	274	321	7

Table 64. Overall traffic counts rankings for the CO monitoring network.

Site Name	Ranks			Rank
	Traffic Counts	Road Density	Average	
CAMP	1	1	1	1
La Casa	2	2	2	2
Welby	3	3	3	3
HWY 24	4	4	4	4
Ft. Collins - Mason	5	5	5	5
GJ - Pitkin	6	7	6.5	6
Greeley - Annex	7	6	6.5	6

2.10.2 Nitrogen Dioxide (NO_2)

Table 65. NO_2 monitoring sites ranked by traffic counts.

Site Name	Sum of AADT Counts		Total Normalized AADT Counts	Rank
	Major Roads	Highways		
CAMP	58,042,550	257,369,500	78,228	1
La Casa	12,422,670	131,741,400	70,057	2
Welby	13,602,040	148,040,500	64,265	3

Table 66. NO_2 monitoring sites ranked by road density.

Site Name	Size of Area Served Polygon (km^2)	Total Road Length (km)	Road Density (m/km^2)	Rank
CAMP	460	716	1,556	1
La Casa	268	322	1,201	2
Welby	570	469	822	3

Table 67. Overall traffic counts rankings for the NO_2 monitoring network.

Site Name	Ranks			Rank
	Traffic Counts	Road Density	Average	
CAMP	1	1	1	1
La Casa	2	2	2	2
Welby	3	3	3	3

2.10.3 Sulfur Dioxide (SO_2)

Table 68. SO_2 monitoring sites ranked by traffic counts.

Site Name	Sum of AADT Counts		Total Normalized AADT Counts	Rank
	Major Roads	Highways		
CAMP	48,313,590	156,378,000	98,475	1
La Casa	9,900,780	107,371,400	77,103	2
Welby	7,788,880	108,618,200	75,590	3
HWY 24	9,962,370	52,267,600	61,851	4

Table 69. SO_2 monitoring sites ranked by road density.

Site Name	Size of Area Served Polygon (km^2)	Total Road Length (km)	Road Density (m/km^2)	Rank
CAMP	228	438	1,923	1
La Casa	148	223	1,509	2
Welby	287	257	897	3
HWY 24	408	358	877	4

Table 70. Overall traffic counts rankings for the SO_2 monitoring network.

Site Name	Ranks			Rank
	Traffic Counts	Road Density	Average	
CAMP	1	1	1	1
La Casa	2	2	2	2
Welby	3	3	3	3
HWY 24	4	4	4	4

2.10.4 Ozone (O_3)

Table 71. O_3 monitoring sites ranked by traffic counts.

Site Name	Sum of AADT Counts		Total Normalized AADT Counts	Rank
	Major Roads	Highways		
CAMP	50,261,030	163,487,600	83,635	1
La Casa	8,601,000	93,102,400	79,695	2
Highland	14,063,420	176,189,000	65,763	3
Welby	15,299,810	159,056,700	53,713	4
Welch	3,112,210	41,224,500	43,238	5
NREL	4,028,510	84,067,780	40,106	6
Rocky Flats	3,337,920	36,032,500	35,850	7
Chatfield	904,060	35,091,700	24,941	8
Ft. Collins - Mason	7,097,530	50,235,400	24,697	9
USAFA	5,485,630	49,401,280	21,450	10
Manitou Springs	12,271,540	110,847,360	19,320	11
South Boulder Creek	5,918,580	62,482,630	18,455	12
Aspen Park	261,950	30,609,580	12,187	13
Weld Co. Tower	3,810,480	70,330,670	11,132	14
Rifle - Health Dept.	1,028,260	58,598,380	11,094	15
Palisade	9,312,240	45,111,940	8,242	16
Aurora East	2,115,240	24,378,100	7,964	17
Ft. Collins - West	759,950	11,206,760	5,466	18
Cortez	308,570	12,277,120	4,529	19

Table 72. O_3 monitoring sites ranked by road density.

Site Name	Size of Area Served Polygon (km^2)	Total Road Length (km)	Road Density (m/km^2)	Rank
CAMP	272	501	1,842	1
La Casa	111	177	1,592	2
Welch	228	157	688	3
Rocky Flats	382	213	556	4
NREL	541	272	502	5
Welby	1,249	625	500	6
Highland	1,348	540	400	7
South Boulder Creek	2,597	643	248	8
Ft. Collins - Mason	2,254	540	239	9
USAFA	5,226	964	184	10
Manitou Springs	7,209	1,273	177	11
Chatfield	1,536	226	147	12
Weld Co. Tower	9,215	1,351	147	12
Aspen Park	3,032	332	109	13
Aurora East	9,062	892	98	14
Palisade	11,230	1,038	92	15
Ft. Collins - West	4,733	423	89	16
Cortez	6,089	510	84	17
Rifle - Health Dept.	12,092	817	68	18

Table 73. Overall traffic counts rankings for the O_3 monitoring network.

Site Name	**Ranks**			**Rank**
	Traffic Counts	**Road Density**	**Average**	
CAMP	1	1	1	1
La Casa	2	2	2	2
Welch	5	3	4	3
Welby	4	6	5	4
Highland	3	7	5	4
Rocky Flats	7	4	5.5	5
NREL	6	5	5.5	5
Ft. Collins - Mason	9	9	9	6
South Boulder Creek	12	8	10	7
USAFA	10	10	10	7
Chatfield	8	12	10	7
Manitou Springs	11	11	11	8
Weld Co. Tower	14	12	13	9
Aspen Park	13	13	13	9
Aurora East	17	14	15.5	10
Palisade	16	15	15.5	10
Rifle - Health Dept.	15	18	16.5	11
Ft. Collins - West	18	16	17	12
Cortez	19	17	18	13

2.10.5 PM_{10}

Table 74. PM_{10} monitoring sites ranked by traffic counts.

Site Name	Sum of AADT Counts		Total Normalized AADT Counts	Rank
	Major Roads	Highways		
Alsup	3,811,500	45,334,500	26,227	1
Welby	5,494,580	74,426,000	25,535	2
La Casa	9,822,880	103,069,700	22,710	3
Denver VC	35,712,900	147,055,400	22,672	4
Colorado College	10,960,170	56,001,600	16,522	5
CAMP	13,118,840	20,838,000	13,898	6
Boulder - Chamber of Comm.	3,411,730	29,789,400	12,664	7
Ft. Collins - CSU	5,184,310	19,994,400	11,552	8
Longmont - Municipal Bldg.	2,229,880	25,354,600	10,028	9
GJ - Powell Bldg.	7,285,550	17,385,600	8,975	10
Pueblo	2,884,320	28,296,900	8,048	11
Greeley - Hospital	2,323,340	16,183,900	7,471	12
Durango	545,410	9,743,700	7,002	13
Parachute	-	4,405,640	6,664	14
Carbondale	132,810	6,172,200	5,995	15
Aspen	148,360	3,325,800	5,265	16
Pagosa	22,800	2,691,200	4,872	17
Rifle - Henry Bldg.	243,040	5,828,100	4,639	18
Mt. Crested Butte	18,400	-	4,600	19
Delta - Health Dept.	245,480	4,461,350	3,607	20
Steamboat Springs	276,830	3,398,800	3,545	21
Alamosa - ASC	105,140	2,910,070	3,349	22
Cañon City	347,820	1,179,500	3,172	23
Alamosa - Municipal	94,910	1,144,700	2,513	24
Crested Butte	13,000	788,000	2,460	25
Lamar - Municipal Bldg.	176,450	2,438,500	2,250	26
Telluride	9,680	940,500	1,434	27

Table 75. PM_{10} monitoring sites ranked by road density.

Site Name	Size of Area Served Polygon (km^2)	Total Road Length (km)	Road Density (m/km^2)	Rank
CAMP	48	117	2,450	1
Denver VC	202	361	1,787	2
La Casa	140	212	1,513	3
Welby	176	189	1,075	4
Colorado College	409	389	952	5
Alsup	142	98	687	6
Pueblo	409	247	604	7
Ft. Collins - CSU	409	236	576	8
Longmont - Municipal Bldg.	404	223	553	9
Greeley - Hospital	409	222	544	10
Boulder - Chamber of Comm.	404	189	468	11
GJ - Powell Bldg.	409	189	463	12
Alamosa - ASC	220	64	290	13
Durango	409	100	244	14
Delta - Health Dept.	409	90	221	15
Rifle - Henry Bldg.	409	89	218	16
Lamar - Municipal Bldg.	409	80	195	17
Steamboat Springs	409	78	190	18
Carbondale	409	68	167	19
Alamosa - Municipal	220	36	162	20
Cañon City	213	32	152	21
Telluride	254	37	146	22
Aspen	409	43	106	23
Parachute	409	41	100	24
Pagosa	409	36	89	25
Crested Butte	235	21	88	26
Mt. Crested Butte	248	3	10	27

Table 76. Overall traffic counts rankings for the PM_{10} monitoring network.

Site Name	Ranks			Rank
	Traffic Counts	Road Density	Average	
La Casa	3	3	3	1
Welby	2	4	3	1
Denver VC	4	2	3	1
Alsup	1	6	3.5	2
CAMP	6	1	3.5	2
Colorado College	5	5	5	3
Ft. Collins - CSU	8	8	8	4
Longmont - Municipal Bldg.	9	9	9	5
Boulder - Chamber of Comm.	7	11	9	5
Pueblo	11	7	9	5
GJ - Powell Bldg.	10	12	11	6
Greeley - Hospital	12	10	11	6
Durango	13	14	13.5	7
Carbondale	15	19	17	8
Rifle - Henry Bldg.	18	16	17	8
Delta - Health Dept.	20	15	17.5	9
Alamosa - ASC	22	13	17.5	9
Parachute	14	24	19	10
Aspen	16	23	19.5	11
Steamboat Springs	21	18	19.5	11
Pagosa	17	25	21	12
Lamar - Municipal Bldg.	26	17	21.5	13
Cañon City	23	21	22	14
Alamosa - Municipal	24	20	22	14
Mt. Crested Butte	19	27	23	15
Telluride	27	22	24.5	16
Crested Butte	25	26	25.5	17

2.10.6 $PM_{2.5}$

Table 77. $PM_{2.5}$ monitoring sites ranked by traffic counts.

Site Name	Sum of AADT Counts		Total Normalized AADT Counts	Rank
	Major Roads	Highways		
ACC	15,435,840	162,455,800	25,093	1
Alsup	14,570,050	138,340,600	22,331	2
La Casa	13,259,310	149,358,700	21,643	3
CAMP	47,589,400	158,572,000	21,283	4
Colorado College	12,892,170	76,944,700	15,419	5
Chatfield	887,350	25,590,300	11,813	6
Boulder - Chamber of Comm.	4,770,780	45,729,400	11,386	7
Longmont - Municipal Bldg.	2,846,710	42,077,600	10,337	8
Ft. Collins - CSU	6,187,150	30,613,700	9,614	9
Pueblo	3,100,140	32,724,600	7,273	10
GJ - Powell Bldg.	7,340,110	21,898,880	7,058	11
Greeley - Hospital	2,630,250	21,596,080	6,369	12
Platteville	666,090	13,488,100	5,073	13
Cortez	254,200	5,311,500	2,745	14

Table 78. $PM_{2.5}$ monitoring sites ranked by road density.

Site Name	**Size of Area Served Polygon (km^2)**	**Total Road Length (km)**	**Road Density (m/km^2)**	**Rank**
CAMP	246	467	1,903	1
La Casa	294	353	1,201	2
ACC	422	413	980	3
Alsup	553	451	815	4
Colorado College	906	542	598	5
Longmont - Municipal Bldg.	711	322	452	6
Ft. Collins - CSU	919	384	418	7
Greeley - Hospital	844	341	404	8
Boulder - Chamber of Comm.	796	318	399	9
Pueblo	919	331	360	10
GJ - Powell Bldg.	914	283	310	11
Platteville	759	210	276	12
Chatfield	610	152	249	13
Cortez	881	157	178	14

Table 79. Overall traffic counts rankings for the $PM_{2.5}$ monitoring network.

Site Name	**Ranks**			**Rank**
	Traffic Counts	**Road Density**	**Average**	
ACC	1	3	2	1
CAMP	4	1	2.5	2
La Casa	3	2	2.5	2
Alsup	2	4	3	3
Colorado College	5	5	5	4
Longmont - Municipal Bldg.	8	6	7	5
Boulder - Chamber of Comm.	7	9	8	6
Ft. Collins - CSU	9	7	8	6
Chatfield	6	13	9.5	7
Greeley - Hospital	12	8	10	8
Pueblo	10	10	10	8
GJ - Powell Bldg.	11	11	11	9
Platteville	13	12	12.5	10
Cortez	14	14	14	11

2.11 Results

The purpose of using many different, often competing, indicators is to provide a comprehensive evaluation technique that attempts to address all of the APCD's monitoring objectives, which are themselves often conflicting; e.g., the assessment of population exposure in areas of maximum pollutant concentrations and the determination of background concentrations are fundamentally different objectives requiring separate monitoring strategies. However, the various indicators used are not necessarily of equal importance to the overall analysis and the relative importance of each indicator should be expected to vary between pollutants. For example, the Measured Concentration indicator is widely believed to be the most relevant to the Network Assessment (Pope and Wu, 2014). However, in the case of the APCD PM_{10} network, an overreliance on the Measured Concentration indicator would result in an analysis that is highly biased toward sites that are impacted by regional dust storms. Because these are exceptional events beyond the division's control, the APCD feels that the Deviation from the NAAQS indicator is a more appropriate metric by which to assess the PM_{10} network. Furthermore, while traffic volume and point source density (i.e., "source-oriented" indicators) may be highly correlated with SO_2 and NO_2 concentrations in ambient air (Gulliver et al., 2011; Beelen et al., 2013), these sources are less relevant in determining the concentration of O_3, a secondary pollutant whose concentration is often reduced via NO_x titration in areas immediately surrounding pollution sources (Sillman, 1999). Therefore, the APCD feels that these indicators should be deemphasized in the case of O_3. Another point that must be considered is that many of the indicators used in the site-to-site comparsion analysis are spatially collocated and therefore correlated. For example, population density, traffic volume, and point source emissions all tend to be highest in areas of maximum economic activity (e.g., the central business distrcit). To simply combine these indicators without weighting factors would result in an anlaysis that is biased heavily toward urban areas. This would be particularly problematic in the case of O_3, the pollutant of most concern within Colorado, which typically reaches its highest concentrations at suburban, rural, and high elevation sites. To reflect the variability among the factors addressed in the assessment, APCD has determined weights of relative importance to use when combining the individual indicators for each parameter assessed. These weighting factors were then used to produce a weighted score from the raw rankings derived from each analysis.

The weighting factors chosen for the CO, NO_2, SO_2, O_3, PM_{10}, and $PM_{2.5}$ networks are shown in the following tables.

Table 80. Weighting factors applied to the site-to-site comparison results for each network.

Analysis	**CO Weight**	**NO_2 Weight**	**SO_2 Weight**	**O_3 Weight**	**PM_{10} Weight**	**$PM_{2.5}$ Weight**
Number of Parameters Monitored	12.6%	12.7%	7.0%	5.0%	3.8%	6.6%
Trends Impact	9.2%	8.9%	7.4%	6.7%	8.7%	8.9%
Measured Concentration	24.2%	23.3%	25.6%	21.1%	11.3%	21.8%
Deviation from the NAAQS	-	-	-	13.3%	14.2%	-
Monitor-to-Monitor Correlation	7.4%	2.0%	2.8%	8.7%	8.3%	6.3%
Removal Bias	-	-	-	12.3%	8.6%	7.4%
Area Served	4.4%	6.0%	5.7%	9.2%	11.0%	9.7%
Population Served	17.1%	16.7%	18.9%	9.5%	17.2%	15.0%
Point Source Emissions	7.4%	17.4%	28.4%	11.5%	11.7%	16.0%
Traffic Counts	17.7%	13.0%	4.2%	2.7%	5.2%	8.3%

2.11.1 Parameter Details

In this section, the raw rankings derived from each analysis are converted to scores. For each monitoring network, the number of possible points is equivalent to the number of sites in the network (e.g., for the CO network, the maximum possible score is seven). Sites ranking first in a given analysis are assigned the maximum number of points (e.g., seven for the CO network), while those ranking second are assigned the second highest score (e.g., six for the CO network), etc.

The following figures and tables show the results of the overall analysis for each pollutant network. The final rankings are based on the weighted average score, with the highest scoring monitor being given a one, the second highest scoring monitor being given a two, etc.

2.11.1.1 Carbon Monoxide (CO)

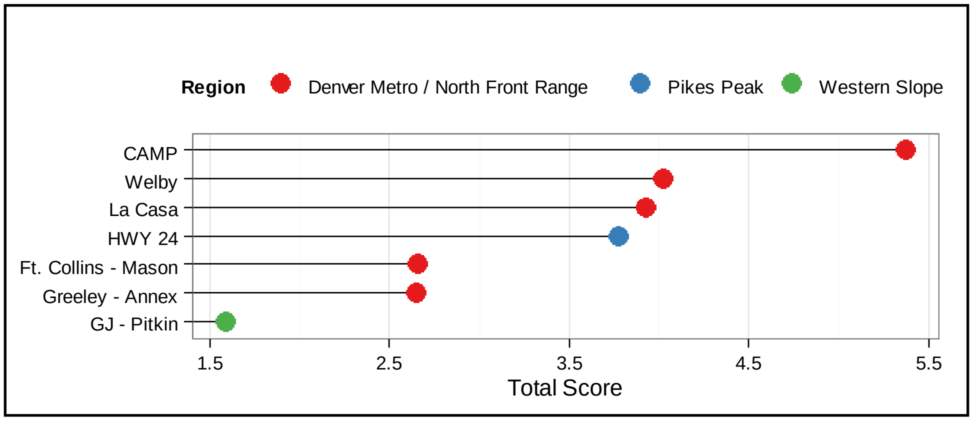

Figure 33. Cleveland dot plot showing the weighted total score for each site in the CO monitoring network.

Table 81. Raw scores and weighted averages for the CO site-to-site comparison analyses.

Site Name	Parameters Monitored	Trends Impact	Measured Concentration	Monitor-to-Monitor Correlation	Area Served	Population Served	Point Source Emissions	Traffic Counts	Weighted Total Score	Rank
CAMP	5	6	6	1.5	2	7	4	6	5.37	1
Welby	4	5	3	1.5	3	6	5	4	4.02	2
La Casa	6	1	5	1.0	1	4	3	5	3.93	3
HWY 24	2	3	4	3.0	4	5	7	3	3.77	4
Ft. Collins - Mason	3	4	2	2.0	6	3	2	2	2.66	5
Greeley - Annex	1	2	4	2.0	6	2	6	1	2.65	6
GJ - Pitkin	2	2	1	3.5	5	1	1	1	1.59	7
Weight	13%	9%	24%	7%	4%	17%	7%	18%		

2.11.1.2 Sulfur Dioxide (SO_2)

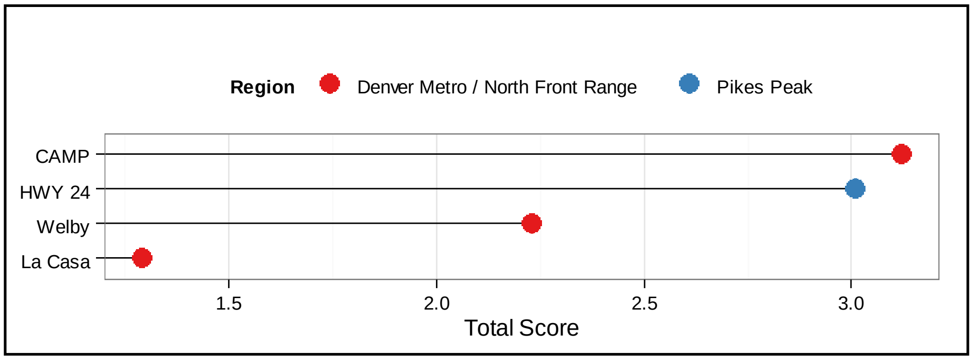

Figure 34. Cleveland dot plot showing the weighted total score for each site in the SO_2 monitoring network.

Table 82. Raw scores and weighted averages for the SO_2 site-to-site comparison analyses.

Site Name	Parameters Monitored	Trends Impact	Measured Concentration	Monitor-to-Monitor Correlation	Area Served	Population Served	Point Source Emissions	Traffic Counts	Weighted Total Score	Rank
CAMP	3	3	3	1.0	2	4	3	4	3.12	1
HWY 24	1	1	4	2.0	4	2	4	1	3.01	2
Welby	2	2	2	1.5	3	3	2	2	2.23	3
La Casa	4	1	1	1.0	1	1	1	3	1.29	4
WEIGTH	7%	7%	26%	3%	6%	19%	28%	4%		

2.11.1.3 Nitrogen Dioxide (NO_2)

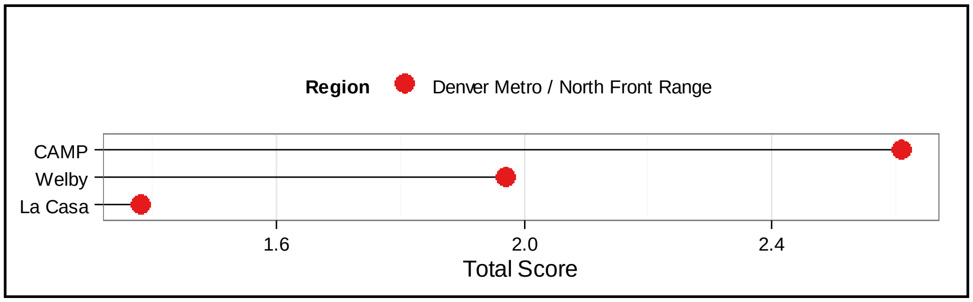

Figure 35. Cleveland dot plot showing the weighted total score for each site in the NO_2 monitoring network.

Table 83. Raw scores and weighted averages for the NO_2 site-to-site comparison analyses.

Site Name	**Parameters Monitored**	**Trends Impact**	**Measured Concentration**	**Monitor-to-Monitor Correlation**	**Area Served**	**Population Served**	**Point Source Emissions**	**Traffic Counts**	**Weighted Total Score**	**Rank**
CAMP	2	3	3	1.5	2	3	2	3	2.61	1
Welby	1	2	2	1.5	3	2	3	1	1.97	2
La Casa	3	1	1	1.0	1	1	1	2	1.38	3
Weight	13%	9%	23%	2%	6%	17%	17%	13%		

2.11.1.4 Ozone (O_3)

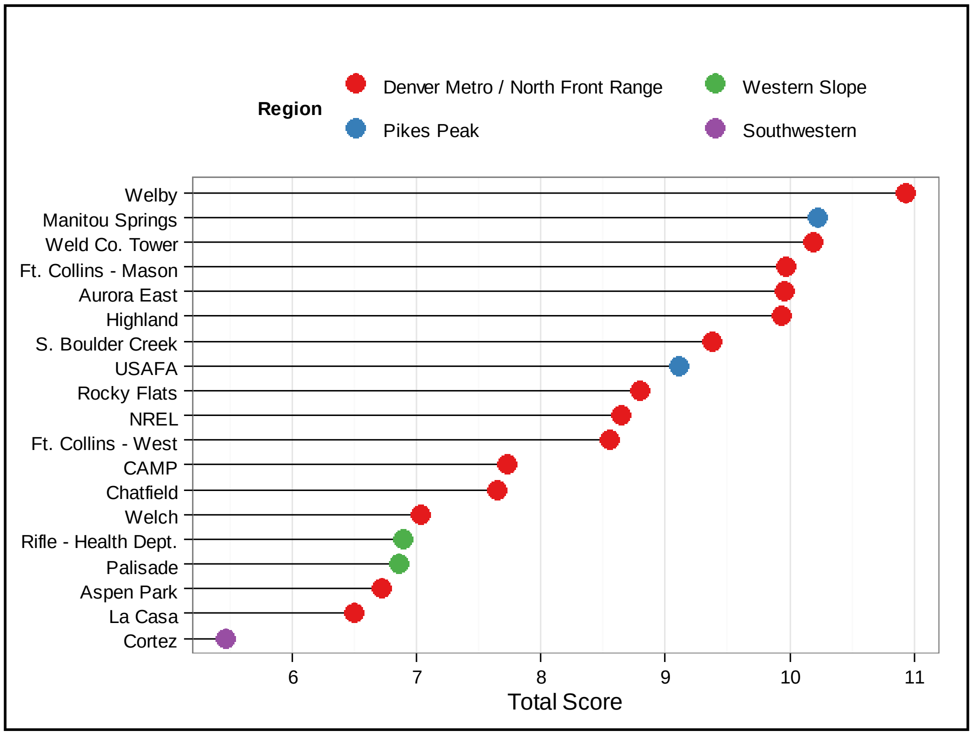

Figure 36. Cleveland dot plot showing the weighted total score for each site in the O_3 monitoring network.

Table 84. Raw scores and weighted averages for the O_3 site-to-site comparison analyses.

Site Name	**Parameters Monitored**	**Trends Impact**	**Measured Concentration**	**Deviation from the NAAQS**	**Monitor-to-Monitor Correlation**	**Removal Bias**	**Area Served**	**Population Served**	**Point Source Emissions**	**Traffic Counts**	**Weighted Total Score**	**Rank**
Welby	4	14	10	13	7.0	11	6	17	12	10	10.93	1
Manitou Springs	1	6	8	15	6.5	6	15	16	13	6	10.23	2
Weld Co. Tower	2	7	12	9	4.0	10	17	11	14	5	10.19	3
Ft. Collins - Mason	3	12	5	15	5.5	18	9	13	10	8	9.97	4
Aurora East	2	2	9	14	5.5	14	16	12	10	4	9.96	5
Highland	2	13	15	6	1.5	9	7	18	8	10	9.94	6
S. Boulder Creek	1	9	13	8	3.5	7	10	14	10	7	9.38	7
USAFA	1	8	7	17	8.0	2	13	15	6	7	9.11	8
Rocky Flats	2	10	19	1	3.5	15	4	7	6	9	8.80	9
NREL	1	9	17	3	3.5	13	5	6	9	9	8.65	10
Ft. Collins - West	1	4	16	4	6.0	17	12	3	6	2	8.55	11
CAMP	5	1	3	10	1.0	12	3	19	11	13	7.73	12
Chatfield	3	5	18	2	1.5	13	8	5	2	7	7.65	13
Welch	2	11	14	7	1.5	5	2	9	1	11	7.03	14
Rifle - Health Dept.	1	3	1	5	7.0	16	19	4	12	3	6.90	15
Palisade	2	3	4	11	7.5	1	18	8	7	4	6.86	16
Aspen Park	2	2	11	12	6.5	3	11	2	3	5	6.72	17
La Casa	6	1	6	16	1.5	4	1	10	5	12	6.50	18
Cortez	2	3	2	9	10.5	8	14	1	4	1	5.47	19
Weight	5%	7%	21%	13%	9%	12%	9%	10%	12%	3%		

2.11.1.5 PM$_{10}$

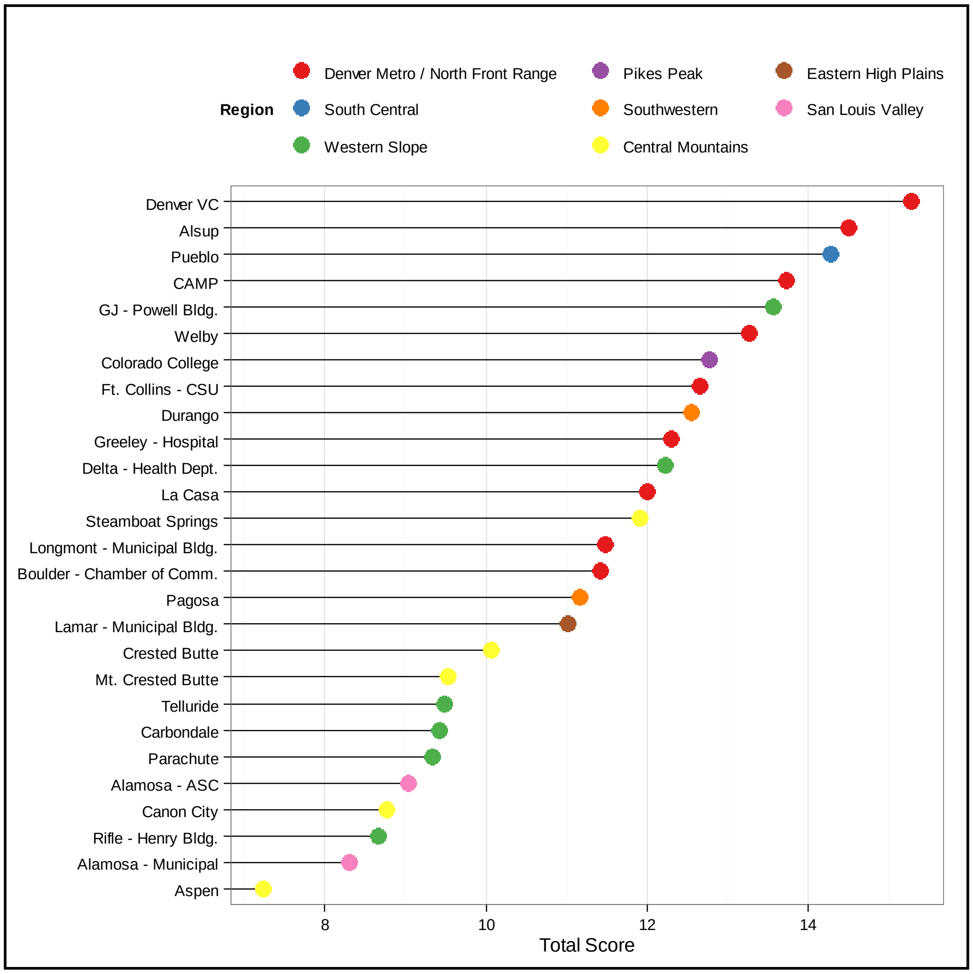

Figure 37. Cleveland dot plot showing the weighted total score for each site in the PM$_{10}$ monitoring network.

Table 85. Raw scores and weighted averages for the PM_{10} site-to-site comparison analyses.

Site Name	**Parameters Monitored**	**Trends Impact**	**Measured Concentration**	**Deviation from the NAAQS**	**Monitor-to-Monitor Correlation**	**Removal Bias**	**Area Served**	**Population Served**	**Point Source Emissions**	**Traffic Counts**	**Weighted Total Score**	**Rank**
Denver VC	1	12	14	17	2.5	17	5	27	21	17	15.28	1
Alsup	3	7	19	22	3.5	14	3	17	25	16	14.50	2
Pueblo	2	2	17	20	7.5	4	12	19	26	13	14.28	3
CAMP	5	16	15	18	2.0	20	1	22	11	16	13.73	4
GJ - Powell Bldg.	2	5	11	14	8.0	26	12	16	19	12	13.56	5
Welby	4	13	12	15	4.0	16	4	25	10	17	13.27	6
Colorado College	2	3	4	7	8.0	11	12	26	24	15	12.77	7
Ft. Collins - CSU	2	8	8	11	8.5	7	12	23	18	14	12.66	8
Durango	1	6	23	26	1.0	1	12	15	9	11	12.55	9
Greeley - Hospital	2	15	7	10	5.5	2	12	20	23	12	12.30	10
Delta - Health Dept.	1	11	13	16	7.5	10	12	13	17	9	12.23	11
La Casa	6	1	9	12	1.5	12	2	24	22	17	12.00	12
Steamboat Springs	1	15	18	21	9.5	9	12	10	5	7	11.91	13
Longmont - Municipal	2	17	2	5	4.5	15	11	18	20	13	11.48	14
Boulder - Chamber	2	10	5	8	6.0	16	11	21	12	13	11.42	15
Pagosa	1	13	22	25	6.0	5	12	4	6	6	11.16	16
Lamar - Municipal Bldg.	1	15	26	1	10.0	13	12	9	13	5	11.02	17
Crested Butte	1	9	20	23	2.5	22	8	2	3	1	10.07	18
Mt. Crested Butte	1	4	21	24	1.5	21	9	1	1	3	9.53	19
Telluride	1	13	16	19	1.0	18	10	3	4	2	9.49	20
Carbondale	1	1	1	4	9.0	23	12	14	14	10	9.42	21
Parachute	2	7	10	13	6.5	3	12	8	15	8	9.33	22
Alamosa - ASC	1	14	24	3	3.0	24	7	5	2	9	9.04	23
Cañon City	1	5	8	11	7.5	19	6	11	7	4	8.77	24
Rifle - Henry Bldg.	3	4	3	6	6.5	8	12	12	16	10	8.66	25
Alamosa - Municipal	1	6	25	2	3.0	25	7	6	2	4	8.31	26
Aspen	1	6	6	9	4.5	6	12	7	8	7	7.23	27
Weight	4%	9%	11%	14%	8%	9%	11%	17%	12%	5%		

2.11.1.6 PM$_{2.5}$

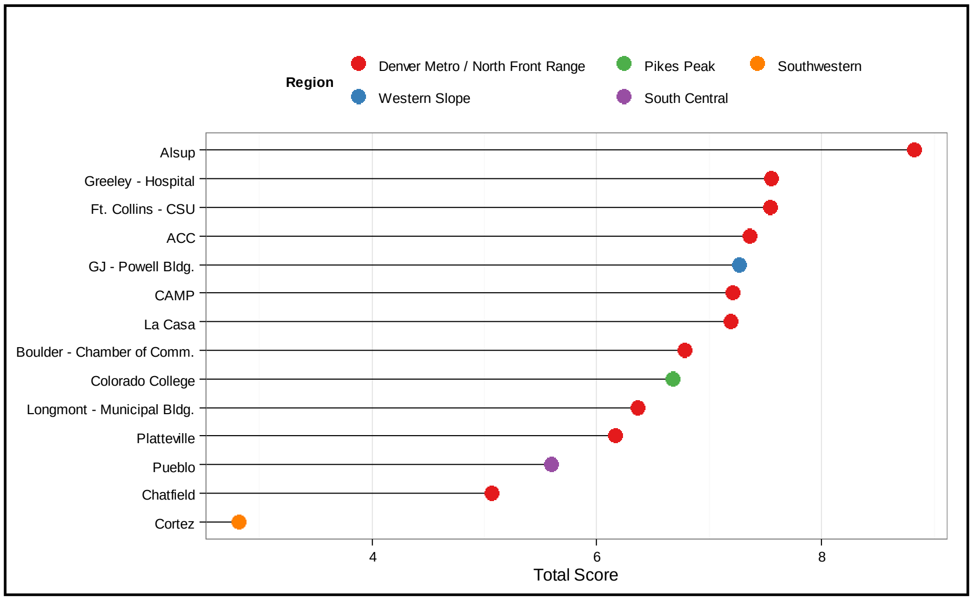

Figure 38. Cleveland dot plot showing the weighted total score for each site in the PM$_{2.5}$ monitoring network.

Table 86. Raw scores and weighted averages for the PM$_{2.5}$ site-to-site comparison analyses.

Site Name	**Parameters Monitored**	**Trends Impact**	**Measured Concentration**	**Monitor-to-Monitor Correlation**	**Removal Bias**	**Area Served**	**Population Served**	**Point Source Emissions**	**Traffic Counts**	**Weighted Total Score**	**Rank**
Alsup	3	7	11	1.5	11	4	12	11	9	8.82	1
Greeley - Hospital	2	8	13	4.0	1	9	6	9	4	7.55	2
Ft. Collins - CSU	2	8	7	6.0	12	13	9	5	6	7.54	3
ACC	1	8	6	2.5	7	3	13	9	11	7.36	4
GJ - Powell Bldg.	2	6	14	7.5	10	12	3	3	3	7.27	5
CAMP	4	8	8	2.5	9	1	14	4	10	7.21	6
La Casa	5	1	12	1.0	6	2	10	7	10	7.19	7
Boulder - Chamber	2	8	5	2.0	13	8	8	8	6	6.78	8
Colorado College	2	4	3	6.5	2	11	11	10	8	6.68	9
Longmont - Municipal	2	8	10	4.0	3	6	5	6	7	6.37	10
Platteville	1	8	9	4.0	8	7	2	9	2	6.17	11
Pueblo	2	2	2	7.0	4	13	4	12	4	5.60	12
Chatfield	3	5	4	4.0	14	5	7	2	5	5.07	13
Cortez	2	3	1	7.5	5	10	1	1	1	2.82	14
Weight	7%	9%	22%	6%	7%	10%	15%	16%	8%		

3 SUITABILITY MODELING

Suitability modeling and analysis is a common and valuable application of Geographic Information Systems (GIS) in the field of environmental planning and management. Broadly defined, suitability analysis aims to identify the most appropriate spatial pattern for a particular land use or activity according to specific requirements, preferences, or predictors. Suitability analysis is applied in a wide variety of fields including ecology, agriculture, and commerce, but its use is most widespread in environmental management and urban and regional planning (Malczewski, 2004). The most commonly used approaches are based on the concept of overlay analysis, in which multiple evaluation criteria map layers ("input maps") are combined to obtain a composite suitability map ("output map"). For example, an agricultural suitability model may combine data pertaining to elevation, slope, aspect, precipitation, and soil chemistry to identify the most appropriate areas for planting a particular crop. Suitability models in the field of air pollution monitoring typically consider data related to population exposure and the source/sink relationships determining the concentration of pollutants in ambient air (Pope and Wu, 2014).

In this section, suitability analysis is used to identify areas where the existing APCD monitoring network does not adequately represent potential air pollution problems, and where additional sites are potentially needed. This has been accomplished using a weighted linear combination (WLC) technique, which is based on the concept of a weighted average. In this approach, technical experts and program managers at the APCD directly assigned weights of relative importance to a series of attribute map layers ("indicator maps"). The maps were then reclassified into a congruous ranking system (1-10 scale) and organized into three purpose areas: source-oriented, population-oriented, and spatially-oriented. The spatially averaged suitability map was then obtained by the multiplying the importance weight assigned to each attribute by that attribute's value. This spatial average was then used to determine the optimal locations at which new monitors should be deployed. This procedure is outlined schematically for CO in Figure 39.

In general, the results of these analyses indicate where monitors are best located based on specific objectives and expected pollutant behavior. However, the development of a useful suitability model relies on a thorough understanding of the phenomena that cause reduced air quality. The various indicator maps used in this section were introduced in Section 1.5 (see Table 5) and are described below.

3.1 Description of Indicators

Indicators maps have been grouped into three categories: source-oriented, population-oriented, and spatially oriented. This categorization has been used to simplify the assignment of weights and to make the weighting process transparent. Different weighting schemes have been used in the evaluation of each network due to the unique characteristics of each pollutant. For example, emissions inventory data can be used to determine the areas of maximum expected concentrations of pollutants directly emitted (i.e., primary emissions). However, emission inventory data are less useful to understand secondary pollutants formed in the atmosphere (i.e., O_3 and $PM_{2.5}$). Therefore, the emissions inventory indicator map was assigned a lower weight in the case of secondary pollutants (see Section 3.2).

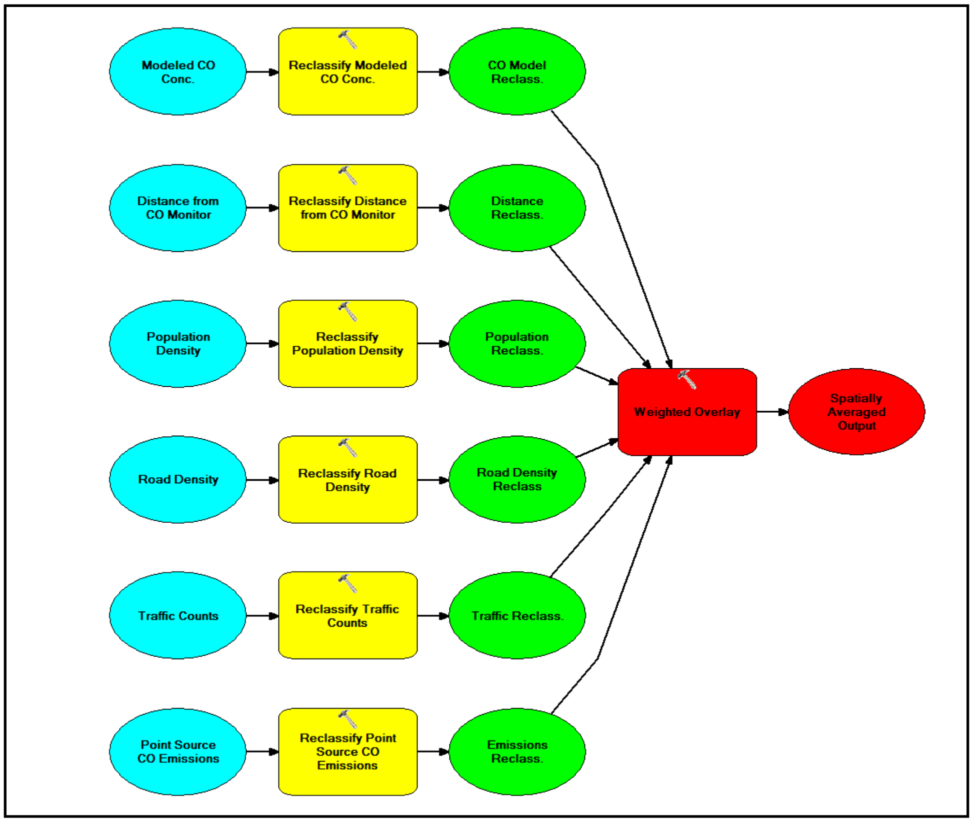

Figure 39. Schematic of the CO suitability model. Raster data is symbolized with ovals, while model processes are symbolized with rounded rectangles.

3.1.1 Source-Oriented

3.1.1.1 Emissions Inventory

In this analysis, raster maps of point emission sources were created for each pollutant network using APCD emissions inventory data (see Section 2.9). Emission sources for each pollutant were spatially aggregated in ArcGIS using a 4 km^2 fishnet grid and the sum of emissions in each sector (“emission section”) was used as the raster value in the resulting indicator map. For CO, SO_2, and PM_{10}, only primary emission sources of these species were considered. For NO_2, emissions of both NO and NO_2 (i.e., NO_x) were considered. For O_3, both NO_x and VOC emissions were considered. For $PM_{2.5}$, NO_x, SO_2, and primary $PM_{2.5}$ emissions were considered. When reclassifying the raster maps, the entire distribution of emission sections was divided into 10 classes using the Jenks classification method and assigned a score of 1-10 with 10 being the highest score. This same approach was taken in the reclassification of all the indicator maps described below.

3.1.1.2 Traffic Counts

The association of road traffic and air pollution, particularly CO and NO_2, is a well-known phenomenon (Briggs et al., 2000). In this analysis, the normalized AADT counts derived in Section 2.10 were spatially aggregated using a 4 km^2 fishnet grid and the sum of normalized AADT in each sector was then used to create a raster map. The same AADT indicator map was used in the suitability model for each pollutant network.

3.1.1.3 Road Density

Similar to the approach discussed in Section 2.10, this analysis uses CDOT spatial data for highways and major roads within Colorado to create a raster map of road density using a 4 km^2 fishnet grid. The same road density indicator map was used in the suitability model for each pollutant network.

3.1.2 Population-Oriented

3.1.2.1 Population Density

In this analysis, a population density map was created using 2010 U.S. Census data (see Section 1.4.5). The population density of each census tract was calculated as the total population divided by the area of the census tract and this value was used in the resulting raster map. The same population density indicator map was then used in the suitability model for each pollutant network.

3.1.3 Spatially-Oriented

3.1.3.1 Distance from an Existing Monitor

This indicator calculates and spatially assigns scores based on the ground distance between existing monitoring sites. The assumption underlying this analysis is that it is more desirable to have a new monitoring site located farther away from an existing site. The score increases the farther away in space that the location is from existing monitoring sites.

3.1.3.2 Interpolation Map

This analysis uses pollutant interpolation maps generated with monitoring data to account for actual (i.e., measured) pollutant concentration surfaces. As previously discussed, not every pollutant parameter has enough sites to create an interpolation map, and those parameters (i.e., CO, NO_2, and SO_2) have not been subjected to this analysis. Furthermore, the accuracy of the interpolation maps, which was explored previously in the Removal Bias analysis (see Section 2.6), can be expected to vary between pollutant parameters. For example, the interpolated $PM_{2.5}$ pollution surface shown in Figure 15 provides a more accurate representation of true spatial trends in concentration as compared to the O_3 and PM_{10} surfaces generated via interpolation. The variable accuracy of these maps has been accounted for using weighting factors (i.e., the $PM_{2.5}$ interpolation map has been assigned a higher weight of relative importance within the $PM_{2.5}$ suitability model on account of its greater accuracy).

For the $PM_{2.5}$ suitability models, we have used the interpolation map shown in Figure 15. However, for the O_3 suitability model, we have used a concentration indicator map that was generated through an interpolation of measured O_3 values obtained during a three-week period in the summer of 2014 (19 June - 9 August). The CDPHE O_3 monitoring network was supplemented during this time by short-term measurement campaigns in the Denver Metro/North Front Range monitoring region associated with the FRAPPÉ (Front Range Air Pollution and Photochemisty Éxperiment) study.[6] By incorporating the data obtained by various research groups during FRAPPÉ, along with routine data obtained by other agencies operating in Colorado during this time (USFS, NPS, BLM, SUIT, NOAA), an interpolation map was created using data from a total of 46 monitoring stations throughout the state, 28 of these sites being located in the Denver Metro/North Front Range monitoring region. A map based on an interpolation of

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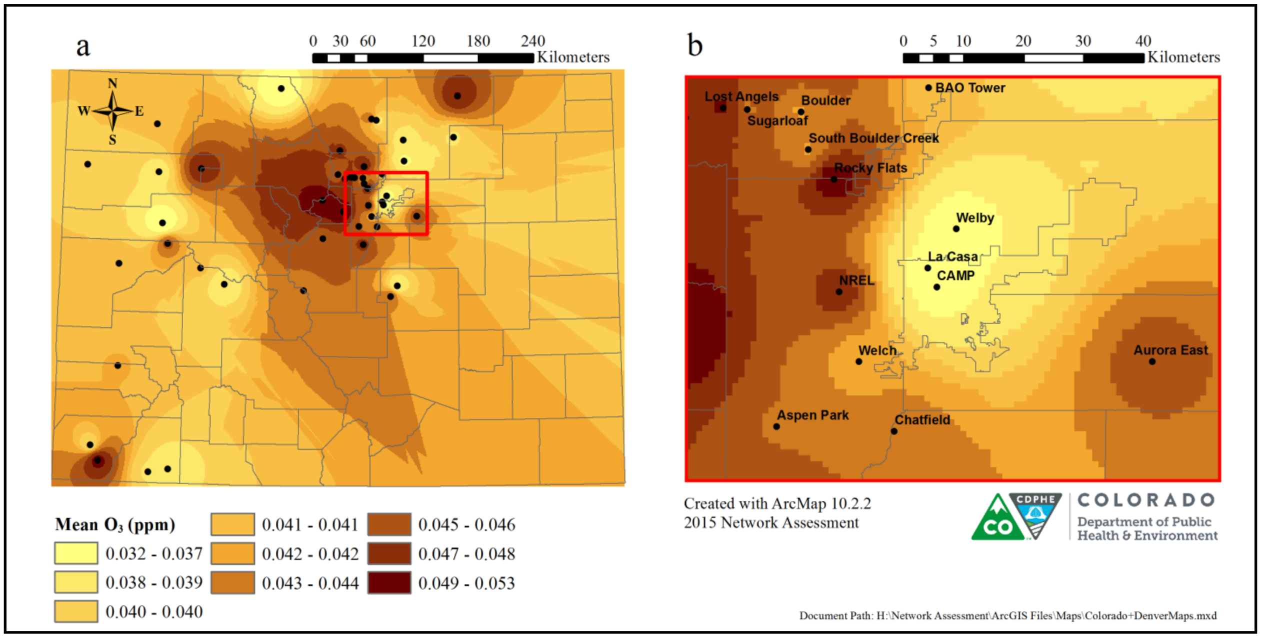
[6] https://www2.acd.ucar.edu/frappe

the average value measured at each site during this period (Figure 40) is much more detailed and spatially resolved than one based on CDPHE site data alone (Figure 11).



Created with ArcMap 10.2.2
2015 Network Assessment

Document Path: H:\Network Assessment\ArcGIS Files\Maps\Colorado+DenverMaps.mxd

Figure 40. Interpolation map of average O_3 values during the period 19 June - 9 August 2014 showing (a) Colorado and (b) the Denver metropolitan area. The monitoring sites measuring O_3 during this period are indicated with black circles. Note that some of these sites (e.g., Boulder, BAO Tower, etc.) are short-term stations that only collected data during the FRAPPÉ field campaign.

As previously discussed, average O_3 concentrations in Colorado are typically highest at high elevation sites, particularly in the mountainous areas of the Central Mountains and Denver Metro/North Front Range monitoring regions, where average O_3 concentrations reached values as high as 50-53 ppb during the FRAPPÉ campaign. The CDPHE monitoring sites with the lowest and highest average O_3 values during this period were the Welby and Rocky Flats sites, respectively, with average values of 34 ppb at Welby and 53 ppb at Rocky Flats. These sites are both located within the Denver metropolitan region and separated by a distance of only 22 kilometers (Figure 40b). A closer inspection of the diurnal variability in the data obtained at these two sites (Figure 41) reveals an interesting trend: a lower average O_3 value is calculated for Welby primarily because of the extremely low values observed during the late night and early morning hours at that site, while mid-day maximum O_3 concentrations are comparable at the two sites (median ≅ 60 ppb). The low values measured in the early morning at Welby are likely due to this site's proximity to NO_x emission sources within Denver; conversely, Rocky Flats is located outside of the city and is removed from emission sources and thus less impacted by NO_x titration (Godowitch et al., 2008). This observation suggests that, while average concentrations are approximately 19 ppb lower within central Denver compared to outlying regions, maximum values and exceedance probability are likely quite similar for these two areas. For this reason, we have decided to use an interpolation map based on maximum 8-hour average O_3 values for the O_3 suitability model. This map is presented in Figure 42.

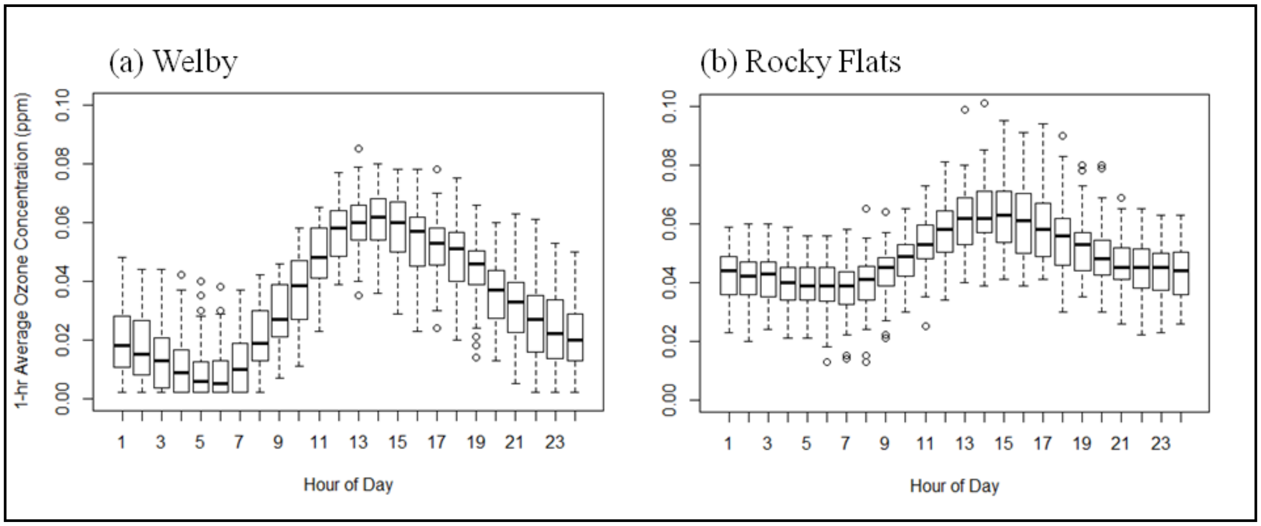
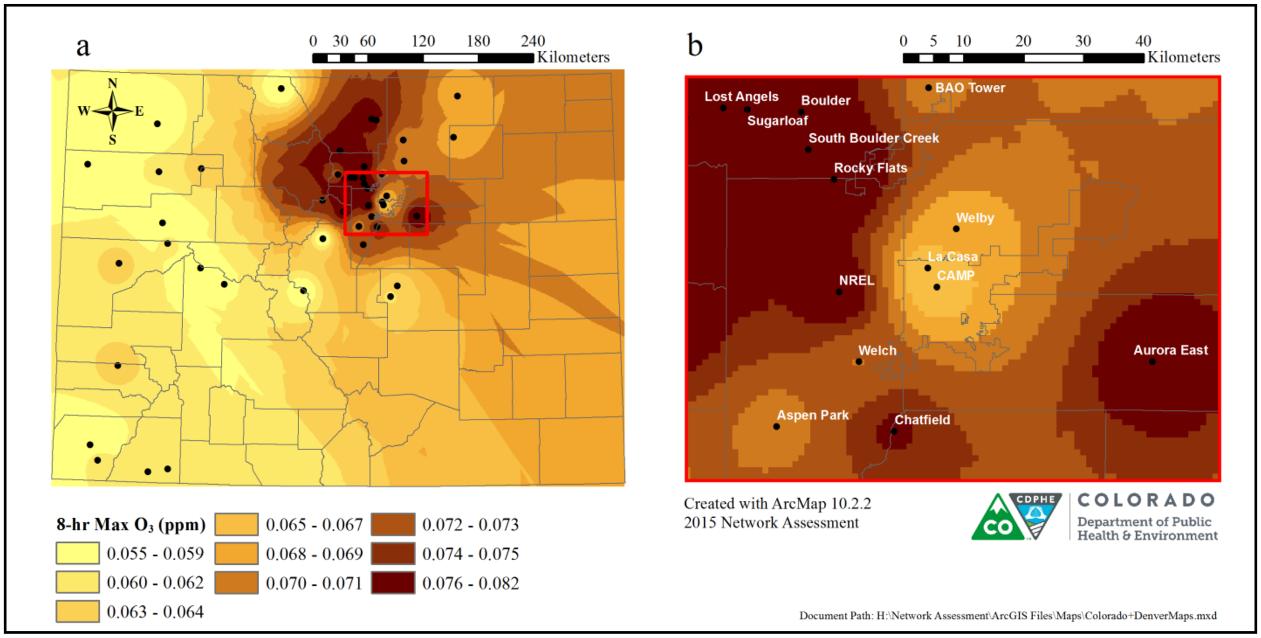


Figure 41. Diurnally averaged box plots of O_3 measurements obtained at the (a) Welby and (b) Rocky Flats sites during the period 19 June - 9 August 2014. The box plot indicates the interquartile range (box) and the median (line), maximum, and minimum 1-hr average values. Outlier values are denoted with circles.



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2015 Network Assessment

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Figure 42. Interpolation map of maximum 8-hr O_3 values during the period 19 June - 9 August 2014 showing (a) Colorado and (b) the Denver metropolitan area. The monitoring sites measuring O_3 during this period are indicated with black circles. Note that some of these sites (e.g., Boulder, BAO Tower, etc.) are short-term stations that only collected data during the FRAPPÉ field campaign.

3.1.3.3 Modeled Concentration

This analysis uses indicator maps of average pollutant concentration generated via air quality modeling to account for pollutant concentration surfaces. For CO, SO_2, and O_3, output generated via photochemical dispersion modeling for the calendar year 2008 was used for the modeled concentration indicator maps, which are shown in the following figures.

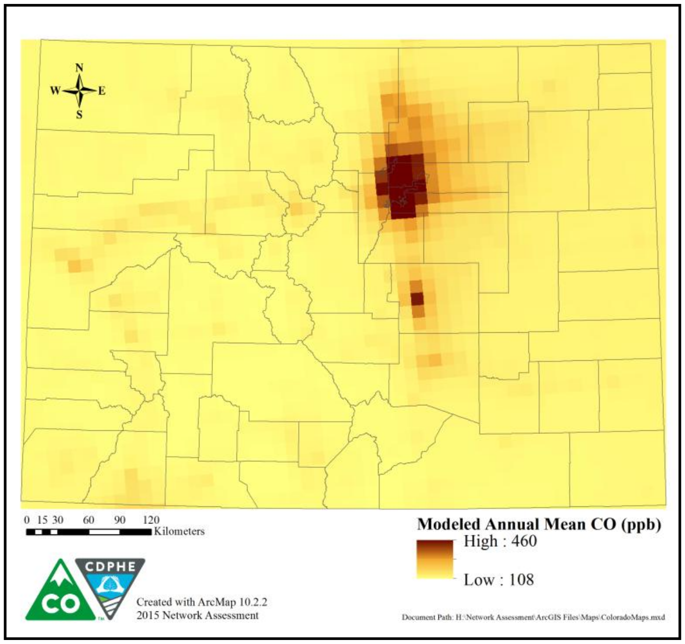

Figure 43. Modeled annual average CO concentration derived from WestJumpAQMS.

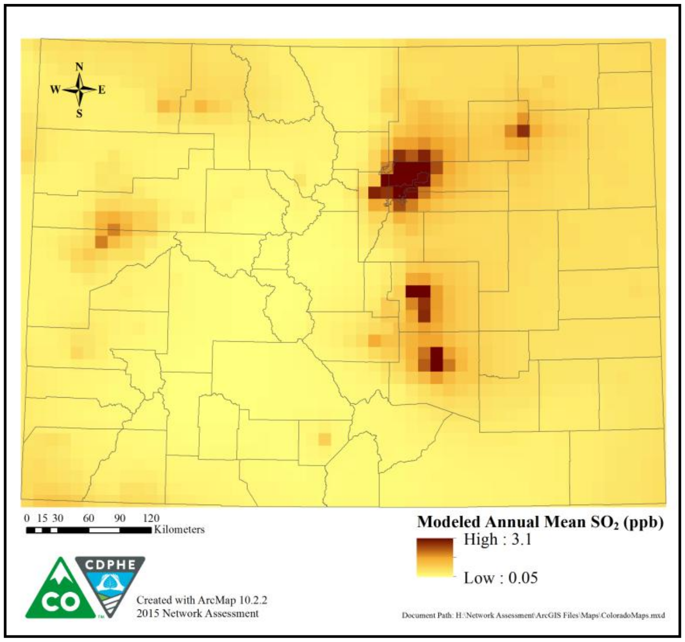

Figure 44. Modeled annual average SO_2 concentration derived from WestJumpAQMS.

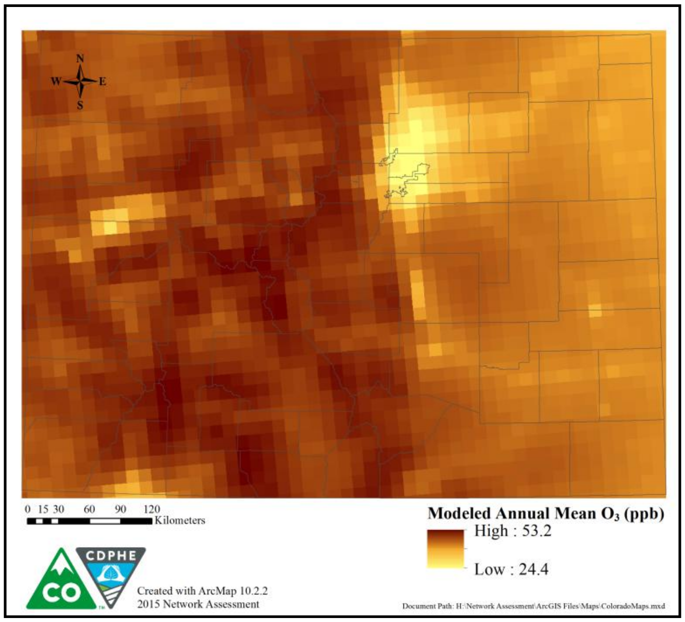

Figure 45. Modeled annual average O_3 concentration derived from WestJumpAQMS.

The CO, SO_2, and O_3 modeling effort was conducted within the framework of the WestJump Air Quality Modeling Study (WestJumpAQMS), a comprehensive analysis that used a suite of models, including a photochemical model, to generate meteorological and emissions inputs and simulate air quality, visibility, and deposition across the western United States.[7] Photochemical air quality models have become widely recognized and routinely utilized tools for regulatory analysis and attainment demonstrations by assessing the effectiveness of control strategies. For example, the EPA has recently proposed an option that would allow state and local air monitoring agencies to use air quality modeling to determine whether areas across the United States meet the 2010 air quality standards for SO_2. The WestJumpAQMS study used the Comprehensive Air quality Model with extensions (CAMx), a large-scale Eulerian grid model that simulates spatial and temporal variations in pollutant concentrations using a set of mathematical equations characterizing the chemical and physical processes in the atmosphere (Tesche et al., 2006). The CAMx model simulates air quality over many geographic scales and treats a wide variety of inert and chemically active pollutants, including CO, O_3, SO_2, and other toxics. The indicator maps derived from the WestJumpAQMS study represent annual average concentration values with a spatial resolution of 12 km. WestJumpAQMS output was also available for NO_2, PM_{10}, and $PM_{2.5}$; however, much more accurate and spatially resolved models were available for input into the suitability models for these pollutants.

For the NO_2 suitability model, output generated via land-use regression (LUR) modeling for the calendar year 2006 was used as the modeled concentration indicator map (Figure 46).

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[7] http://www.wrapair2.org/WestJumpAQMS.aspx

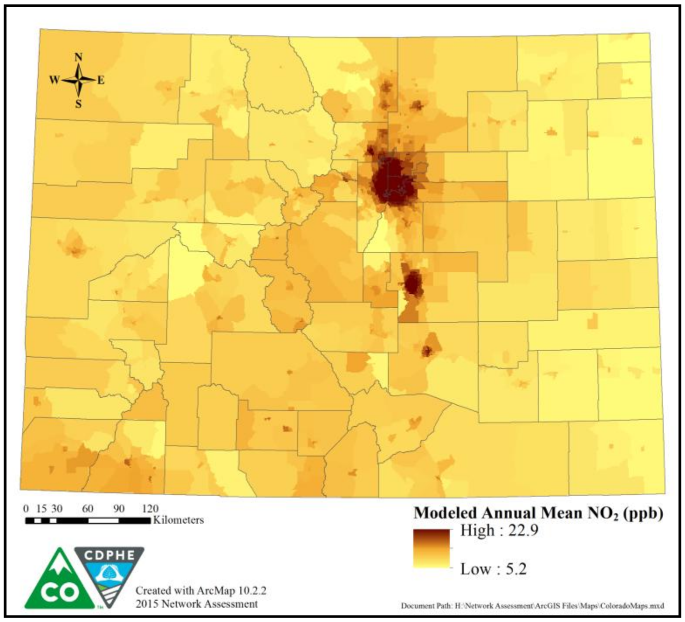

Figure 46. Modeled annual average NO_2 concentration derived from LUR modeling (Novotny et al., 2011).

LUR is based on the principle that pollutant concentrations at any location depend on the environmental characteristics of the surrounding area, particularly those characteristics that influence or reflect emission intensity and dispersion efficiency. LUR modeling is done by constructing multiple regression equations describing the relationship between measured concentrations at a sample of monitoring locations, and relevant environmental variables computed, using GIS, for zones of influence around each site. The resulting equation is then used to predict concentrations at unmeasured locations on the basis of these predictor variables (Hoek et al., 2008).

The NO_2 LUR output shown in Figure 46 is based on ground- and satellite-based NO_2 measurements, as well as geographic characteristics such as population density, land-use (based on satellite data), and distance to major roads and highways (Novotny et al., 2011). The indicator map derived from this land-use regression model represent annual average NO_2 concentration values with a spatial resolution at the census tract level.

LUR modeling output was also used for the modeled concentration indicator maps in the PM_{10} and $PM_{2.5}$ suitability models. Like the NO_2 indicator map, the PM_{10} and $PM_{2.5}$ maps are based on geographic data, such as emissions, elevation, traffic density, and land-use, as well as routine PM monitoring data collected by federal and state agencies. However, the PM LUR models also consider meteorological data associated with regional dust storms and low-level inversions, events that often result in high PM concentrations, particularly in Colorado and other western states (Yanosky et al., 2014). These models provide a highly accurate representation of average PM_{10} and $PM_{2.5}$ concentrations at a spatial resolution of 6 km. The LUR maps used in the PM_{10} and $PM_{2.5}$ suitability models are shown in Figure 47 and Figure 48, respectively.

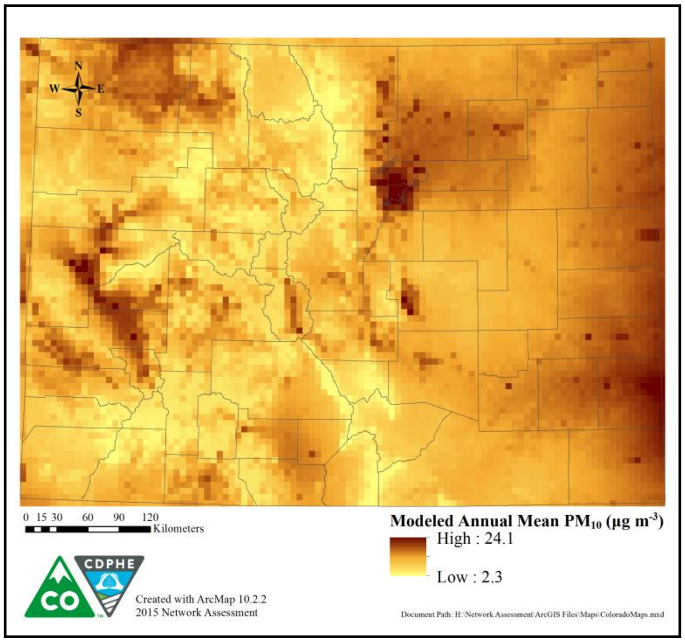

Figure 47. Modeled annual average PM_{10} concentration derived from LUR modeling (Yanosky et al., 2014).

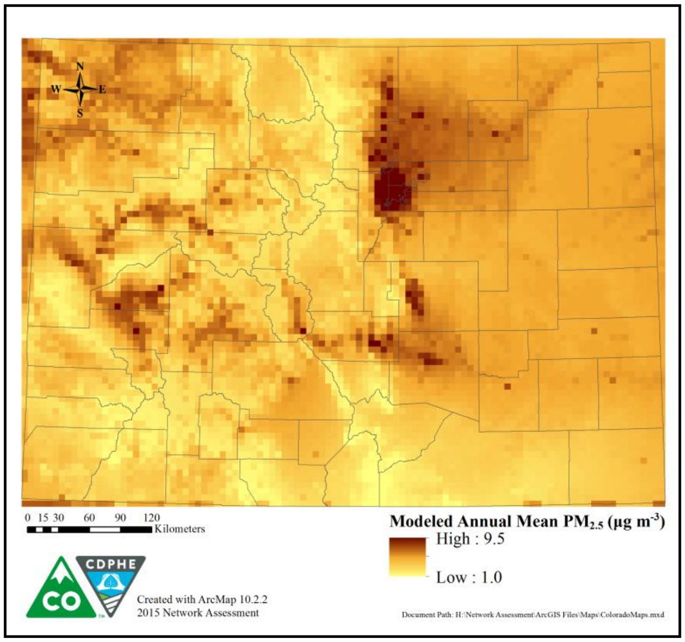

Figure 48. Modeled annual average $PM_{2.5}$ concentration derived from LUR modeling (Yanosky et al., 2014).

3.1.3.4 Elevation

As discussed in Section 2.6.1, O_3 in Colorado exhibits a strong positive correlation with elevation. The observation of enhanced O_3 concentrations with elevation in Colorado has been attributed to the low availability of nitric oxide (NO), which reacts with O_3, and the increased importance of stratospheric O_3 transport at high elevation (Jaffe, 2010; Musselman and Korfmacher, 2014). Because of this relationship, we have used a digital elevation model (DEM) as a weighted indicator map in the O_3 suitability model (Figure 49).

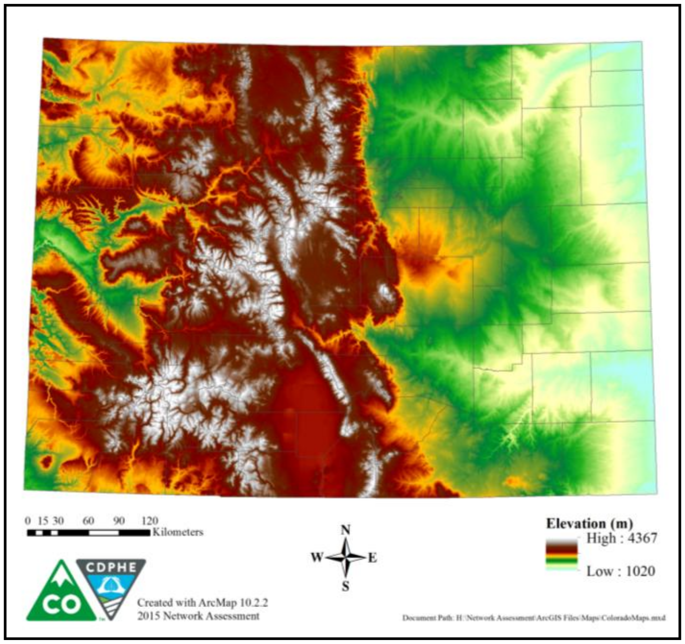

Figure 49. Digital elevation model of Colorado.

3.2 Results for All Parameters

In the following sections, the weights of relative importance assigned to the indicator maps in each pollutant suitability model are presented and a brief justification of the chosen weighting scheme is provided. The final weighted suitability model for each network is then presented in the form of a raster map with a spatial resolution of 1 km. Values of the raster maps are suitability scores, which represent the suitability of the location for the addition of a new monitoring site. Possible suitability scores are 1-10; however, because these scores represent an average of all the input variables, the results never go over 8 in this analysis.

3.2.1 Carbon Monoxide (CO)

Table 87. Weights applied in the CO suitability model.

Analysis	Weight Percentage
Source-Oriented	***42.5%***
Point Source Emissions	11.7%
Traffic Counts	18.3%
Road Density	12.5%
Population-Oriented	***28.2%***
Population Density	28.2%
Spatially-Oriented	***29.3%***
Distance from an Existing Monitor	11.8%
Modeled Concentration	17.5%

CO is generally non-reactive, thus concentrations are directly correlated to emission sources. The source-oriented indicators have therefore been given a large relative weighting in the CO suitability model. The majority of CO emissions to ambient air originate from mobile sources (i.e., transportation), particularly in urban areas, where as much as 85% of all CO emissions may come from automobile exhaust. Therefore, the mobile source indicators (i.e., Traffic Counts and Road Density) have been assigned almost three times the total weight given to the point source indicator.

CO pollution is a public health concern and is highly associated with traffic congestion and urbanized environments (e.g., street canyons). Representing the largest possible number of citizens impacted by traffic-generated CO is a key objective of the APCD CO monitoring network, and the Population Density indicator was therefore assigned the largest relative weight.

Correlations between CO monitoring sites decrease rapidly with distance between sites (Figure 5). This suggests that CO sites can be located relatively close together without producing redundant data. Therefore, the Distance from an Existing Monitor indicator was given a relatively low weight. The Modeled Concentration indicator was given a relatively large weight, as this represents the best available estimate of the spatial variability in CO at unmonitored locations.

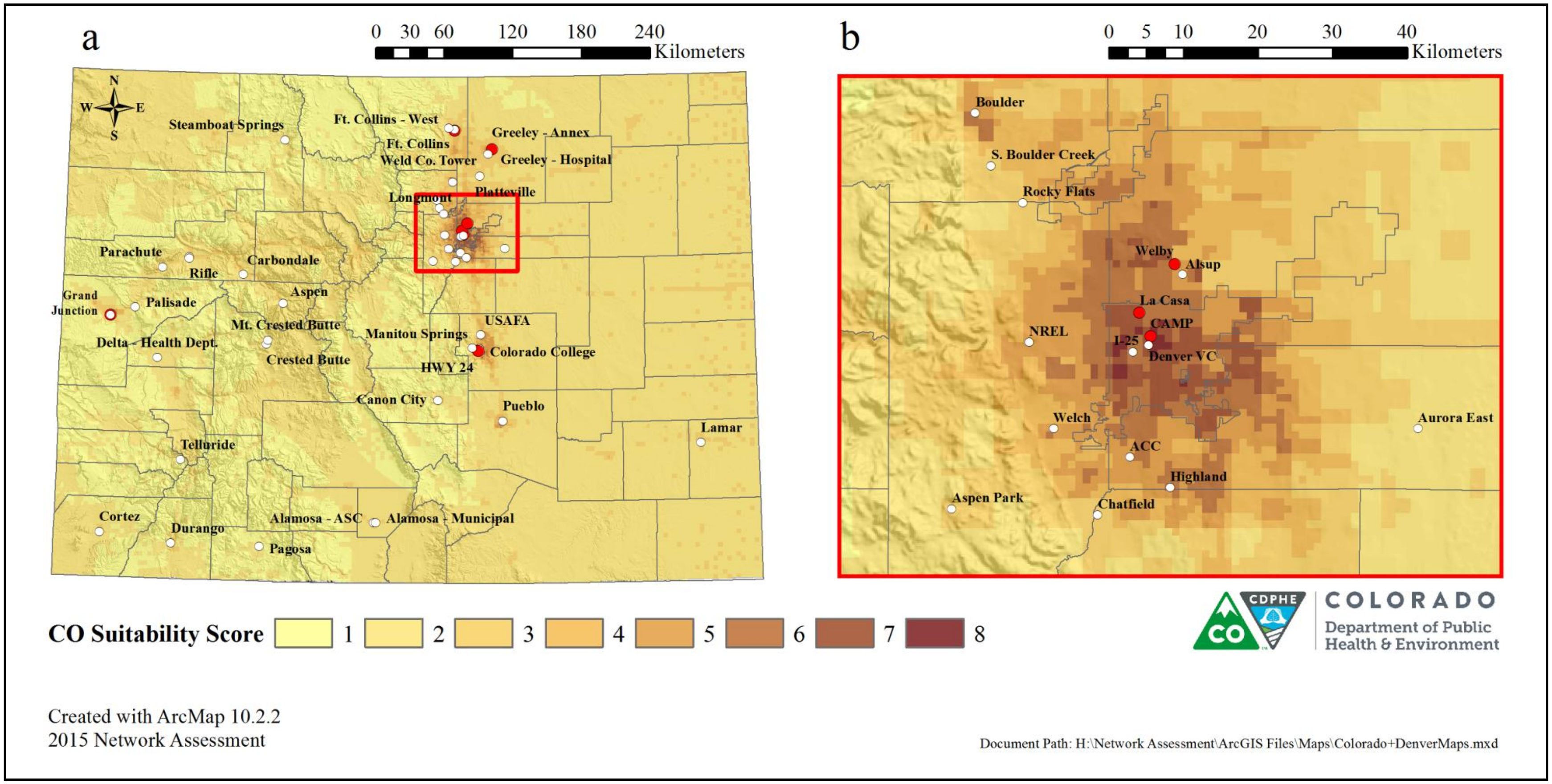

Figure 50. Results of the CO suitability model showing (a) Colorado and (b) the Denver metropolitan area. Criteria pollutant monitoring sites operated by the APCD and listed in Table 6 are symbolized with white circles. APCD CO sites are symbolized with red circles. Note that the I-25 near-road site is shown in (b), although it is not assessed in this report on account of its unique monitoring objectives. For the purpose of improving the readability of (a), site labels for the Ft. Collins - CSU and Ft. Collins - Mason sites have been combined as “Ft. Collins,” the Rifle - Henry Bldg. and Rifle - Health Department site labels have been combined as “Rifle,” and the Grand Junction - Powell Bldg. and Grand Junction - Pitkin site labels have been combined as “Grand Junction.” Detailed site information, including AQS identification numbers, site descriptions and histories, addresses and coordinates, monitoring start dates, site elevations, site orientation/scale designations, etc., can be found in Appendix A.

3.2.2 Nitrogen Dioxide (NO_2)

Table 88. Weights applied in the NO_2 suitability model.

Analysis	Weight Percentage
Source-Oriented	***48.3%***
Point Source Emissions	20.8%
Traffic Counts	16.7%
Road Density	10.8%
Population-Oriented	***19.7%***
Population Density	19.7%
Spatially-Oriented	***32.0%***
Distance from an Existing Monitor	14.5%
Modeled Concentration	17.5%

NO_2 emissions are associated with both point sources (mostly fuel combustion) and mobile sources (i.e., transportation), and NO_2 concentrations in ambient air are directly correlated with emission sources (Briggs et al., 2000). For this reason, the source-oriented indicators were given almost half of the total weight in the NO_2 suitability model, with the mobile source indicators being given a higher total weight (27.5%) than the point source indicator (20.8%).

NO_2 is a public health concern and it is an objective of the APCD to maximize the number of citizens represented by each NO_2 monitor. However, NO_2 is also an important precursor to O_3, which tends to have a greater impact on regions of lower population density (see Section 3.1.3.2). The collocation of NO_2 and O_3 monitors at high O_3 sites could provide useful information regarding the balance between ozone production and destruction, which can be used to assess and validate model predictions and further optimize the network's configuration. Therefore, the Population Density indicator was assigned a lower weight in the NO_2 suitability model (19.7%) as compared to the CO suitability model (28.2%).

As with CO, the monitor-to-monitor correlation study described in Section 2.5 suggests that NO_2 sites can be located relatively close together without producing redundant data. Therefore, the Distance from an Existing Monitor indicator was given a relatively low weight. The Modeled Concentration indicator was given a relatively large weight, as this represents a robust best estimate of the spatial variability in NO_2 at unmonitored locations (Novotny et al., 2011).

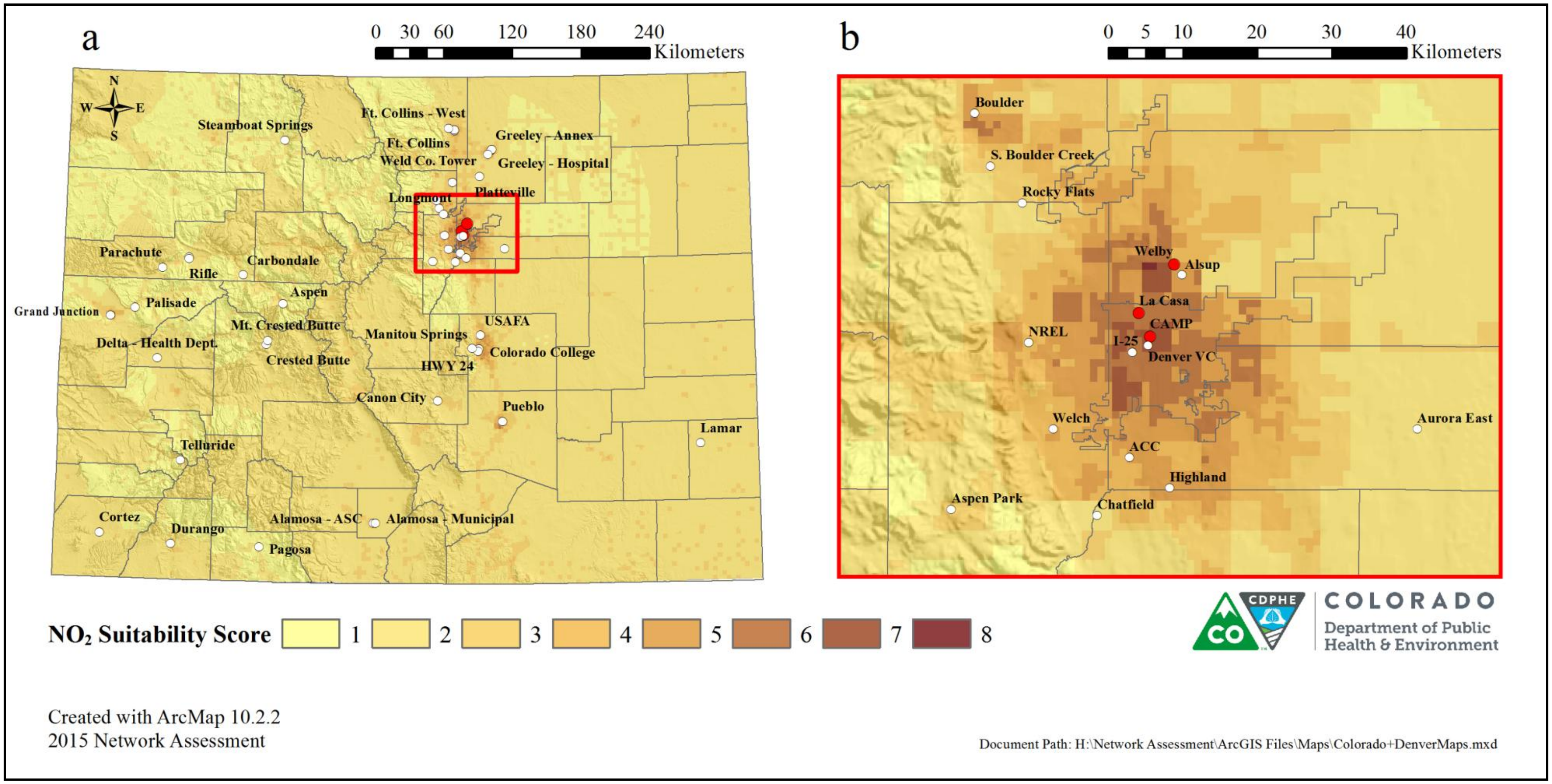

Figure 51. Results of the NO_2 suitability model showing (a) Colorado and (b) the Denver metropolitan area. Criteria pollutant monitoring sites operated by the APCD and listed in Table 6 are symbolized with white circles. APCD NO_2 sites are symbolized with red circles. Note that the I-25 near-road site is shown in (b), although it is not assessed in this report on account of its unique monitoring objectives. For the purpose of improving the readability of (a), site labels for the Ft. Collins - CSU and Ft. Collins - Mason sites have been combined as “Ft. Collins,” the Rifle - Henry Bldg. and Rifle - Health Department site labels have been combined as “Rifle,” and the Grand Junction - Powell Bldg. and Grand Junction - Pitkin site labels have been combined as “Grand Junction.” Detailed site information, including AQS identification numbers, site descriptions and histories, addresses and coordinates, monitoring start dates, site elevations, site orientation/scale designations, etc., can be found in Appendix A.

3.2.3 Sulfur Dioxide (SO_2)

Table 89. Weights applied in the SO_2 suitability model.

Analysis	Weight Percentage
Source-Oriented	***45.8%***
Point Source Emissions	30.8%
Traffic Counts	8.3%
Road Density	6.7%
Population-Oriented	***20.8%***
Population Density	20.8%
Spatially-Oriented	***33.3%***
Distance from an Existing Monitor	10.8%
Modeled Concentration	22.5%

The largest sources of SO_2 emissions in Colorado are from fossil fuel combustion at power plants, while mobile sources contribute less than 1 percent.[8] For this reason, the point source indicator was assigned a relatively high weight in the SO_2 suitability model (30.8%), while the mobile source indicators were assigned a relatively low total weight (15.0%).

The monitor-to-monitor correlation study described in Section 2.5 showed very low correlations among the three SO_2 sites located in central Denver ($r^2 = 0.09$-0.20), suggesting that SO_2 sites can be located relatively close together without producing redundant data. Therefore, the Distance from an Existing Monitor indicator was given a relatively low weight in the SO_2 suitability model. The Modeled Concentration indicator was given a relatively large weight, as this represents the best available estimate of the spatial variability in SO_2 at unmonitored locations.

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[8] http://www.epa.gov/air/emissions/

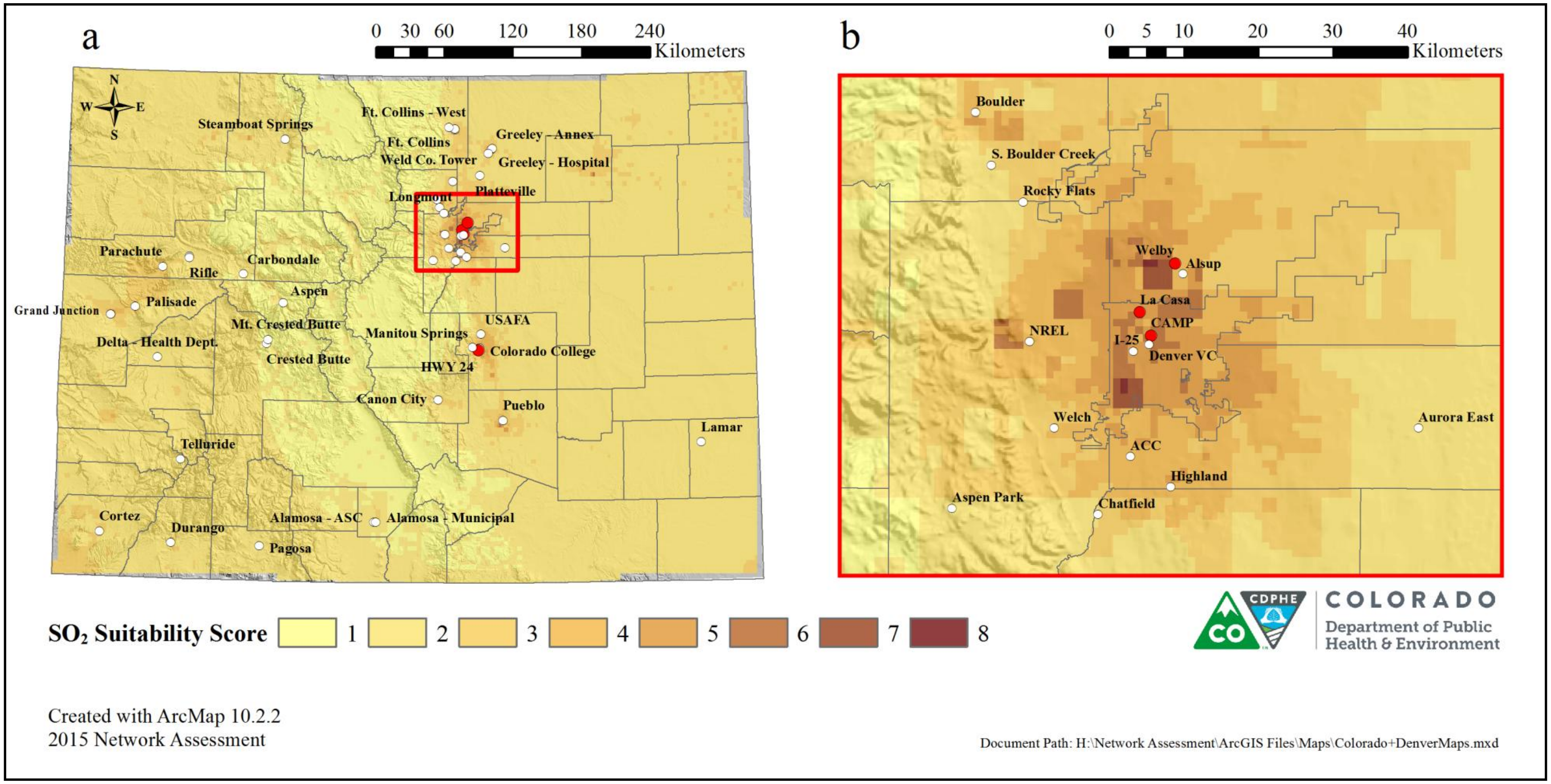


Figure 52. Results of the SO_2 suitability model showing (a) Colorado and (b) the Denver metropolitan area. Criteria pollutant monitoring sites operated by the APCD and listed in Table 6 are symbolized with white circles. APCD SO_2 sites are symbolized with red circles. Note that the I-25 near-road site is shown in (b), although it is not assessed in this report on account of its unique monitoring objectives. For the purpose of improving the readability of (a), site labels for the Ft. Collins - CSU and Ft. Collins - Mason sites have been combined as "Ft. Collins," the Rifle - Henry Bldg. and Rifle - Health Department site labels have been combined as "Rifle," and the Grand Junction - Powell Bldg. and Grand Junction - Pitkin site labels have been combined as "Grand Junction." Detailed site information, including AQS identification numbers, site descriptions and histories, addresses and coordinates, monitoring start dates, site elevations, site orientation/scale designations, etc., can be found in Appendix A.

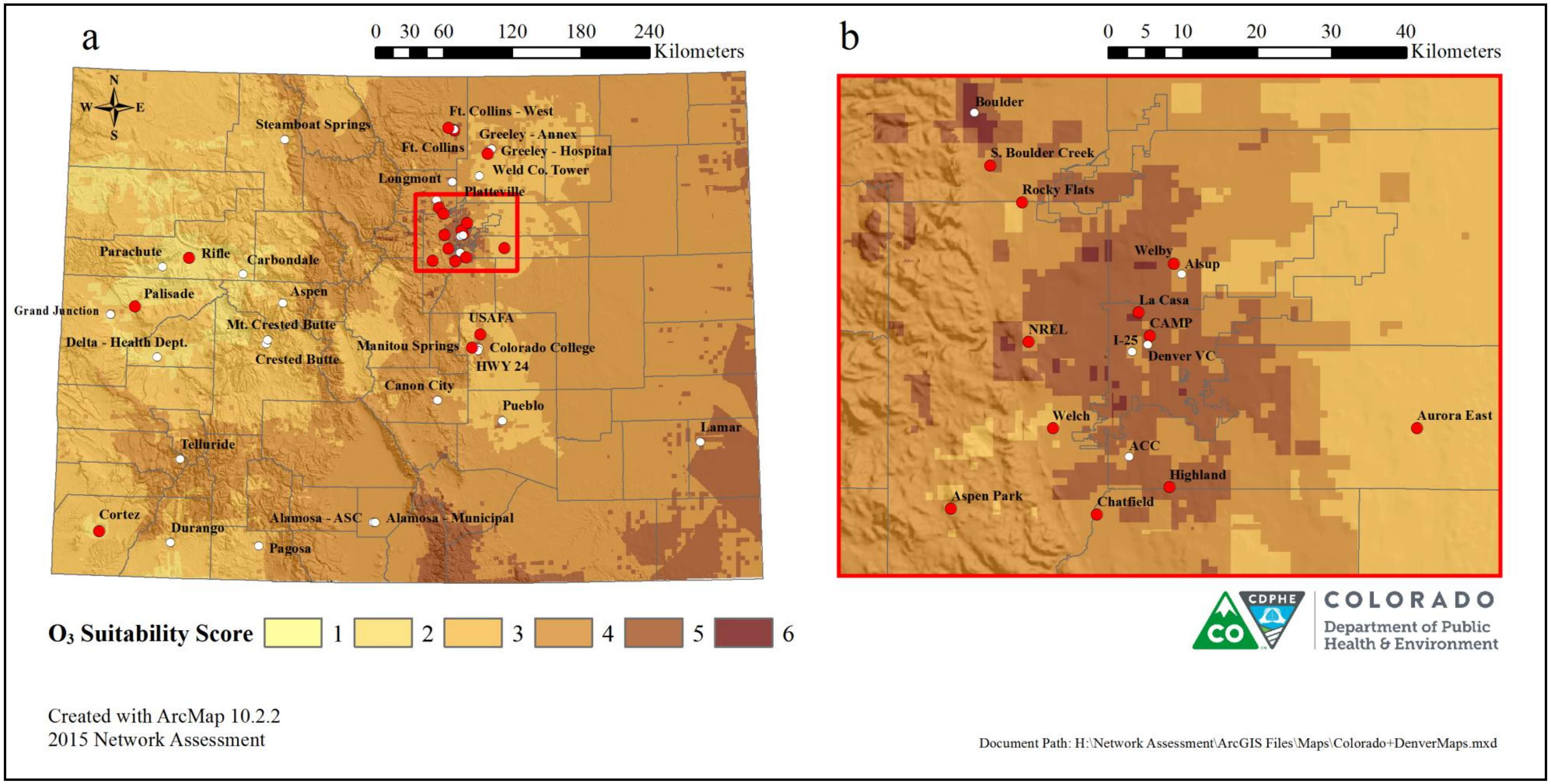
3.2.4 Ozone (O_3)

Table 90. Weights applied in the O_3 suitability model.

Analysis	Weight Percentage
Source-Oriented	***22.6%***
Point Source Emissions	10.8%
Traffic Counts	6.5%
Road Density	5.3%
Population-Oriented	***15.7%***
Population Density	15.7%
Spatially-Oriented	***61.7%***
Distance from an Existing Monitor	18.4%
Measured Concentration	24.2%
Modeled Concentration	13.8%
Elevation	5.3%

As discussed in Section 2.9.4, O_3 is a secondary pollutant and its spatial variability is only indirectly related to precursor emissions sources. Therefore, the source-oriented indicators were assigned a relatively small weight in the O_3 suitability model. Similarly, because O_3 concentrations tend to be reduced via NO_x titration in heavily populated areas, the population indicator was also assigned a lower weight compared to the other pollutant models.

O_3 monitoring sites tend to be well correlated over distances of approximately 90 km (see Section 2.5.4, Figure 7). This suggests that a dense network of O_3 monitoring sites is an inefficient use of resources as it will produce redundant data. Therefore, the Distance from an Existing Monitor indicator was given a relatively high weight in the O_3 suitability model. Because the measured concentration indicator in this case is based on maximum 8-hr values (see Section 3.1.3.2), which are more relevant from a regulatory perspective, this input was assigned a higher weight compared to the modeled concentration indicator.



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2015 Network Assessment

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Figure 53. Results of the O_3 suitability model showing (a) Colorado and (b) the Denver metropolitan area. Criteria pollutant monitoring sites operated by the APCD and listed in Table 6 are symbolized with white circles. APCD O_3 sites are symbolized with red circles. Note that the I-25 near-road site is shown in (b), although it is not assessed in this report on account of its unique monitoring objectives. For the purpose of improving the readability of (a), site labels for the Ft. Collins - CSU and Ft. Collins - Mason sites have been combined as “Ft. Collins,” the Rifle - Henry Bldg. and Rifle - Health Department site labels have been combined as “Rifle,” and the Grand Junction - Powell Bldg. and Grand Junction - Pitkin site labels have been combined as “Grand Junction.” Detailed site information, including AQS identification numbers, site descriptions and histories, addresses and coordinates, monitoring start dates, site elevations, site orientation/scale designations, etc., can be found in Appendix A.

3.2.5 PM_{10}

Table 91. Weights applied in the PM_{10} suitability model.

Analysis	Weight Percentage
Source-Oriented	***36.2%***
Point Source Emissions	20.0%
Traffic Counts	8.8%
Road Density	7.4%
Population-Oriented	***22.8%***
Population Density	22.8%
Spatially-Oriented	***41.0%***
Distance from an Existing Monitor	14.0%
Modeled Concentration	27.0%

PM_{10} concentrations typically have a strong relationship with point sources. Furthermore, dust from paved and unpaved roads is a particular problem in Colorado and the western U.S. in general. For this reason, the point and mobile source indicators were assigned relatively high weights, with the point source indicator being given a slightly larger weight than the mobile source indicators.

As with CO and NO_2, the monitor-to-monitor correlation study described in Section 2.5 suggests that PM_{10} sites can be located relatively close together without producing redundant data. Therefore, the Distance from an Existing Monitor indicator was given a relatively low weight. The modeled concentration indicator was given a relatively large weight, as this represents a robust best estimate of the spatial variability in PM_{10} at unmonitored locations (Yanosky et al., 2014).

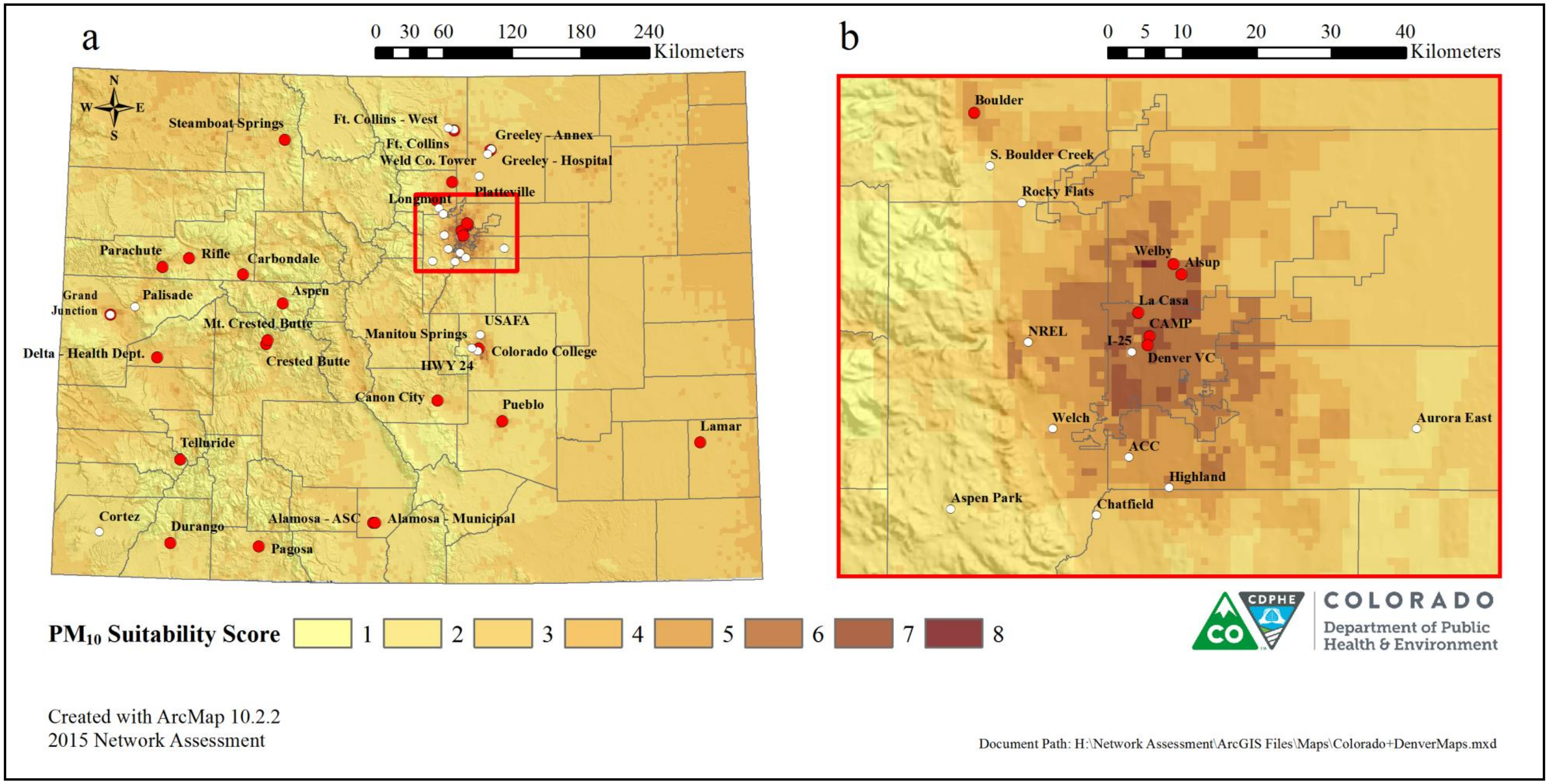

Figure 54. Results of the PM$_{10}$ suitability model showing (a) Colorado and (b) the Denver metropolitan area. Criteria pollutant monitoring sites operated by the APCD and listed in Table 6 are symbolized with white circles. APCD PM$_{10}$ sites are symbolized with red circles. Note that the I-25 near-road site is shown in (b), although it is not assessed in this report on account of its unique monitoring objectives. For the purpose of improving the readability of (a), site labels for the Ft. Collins - CSU and Ft. Collins - Mason sites have been combined as “Ft. Collins,” the Rifle - Henry Bldg. and Rifle - Health Department site labels have been combined as “Rifle,” and the Grand Junction - Powell Bldg. and Grand Junction - Pitkin site labels have been combined as “Grand Junction.” Detailed site information, including AQS identification numbers, site descriptions and histories, addresses and coordinates, monitoring start dates, site elevations, site orientation/scale designations, etc., can be found in Appendix A.

3.2.6 $PM_{2.5}$

Table 92. Weights applied in the $PM_{2.5}$ suitability model.

Analysis	Weight Percentage
Source-Oriented	***25.0%***
Point Source Emissions	10.0%
Traffic Counts	9.0%
Road Density	6.0%
Population-Oriented	***21.2%***
Population Density	21.2%
Spatially-Oriented	***53.8%***
Distance from an Existing Monitor	12.0%
Measured Concentration	13.0%
Modeled Concentration	28.8%

Like O_3, $PM_{2.5}$ is a secondary pollutant and its spatial variability is only indirectly related to precursor emissions sources. Therefore, the source-oriented indicators were assigned a relatively small weight in the $PM_{2.5}$ suitability model, with the mobile source indicators being given a slightly larger weight than the point source indicators.

As with PM_{10}, the monitor-to-monitor correlation study described in Section 2.5 suggests that $PM_{2.5}$ sites can be located relatively close together without producing redundant data. Therefore, the Distance from an Existing Monitor indicator was given a relatively low weight in the $PM_{2.5}$ suitability model. The modeled concentration indicator was given a relatively large weight, as this represents a robust best estimate of the spatial variability in $PM_{2.5}$ at unmonitored locations (Yanosky et al., 2014).

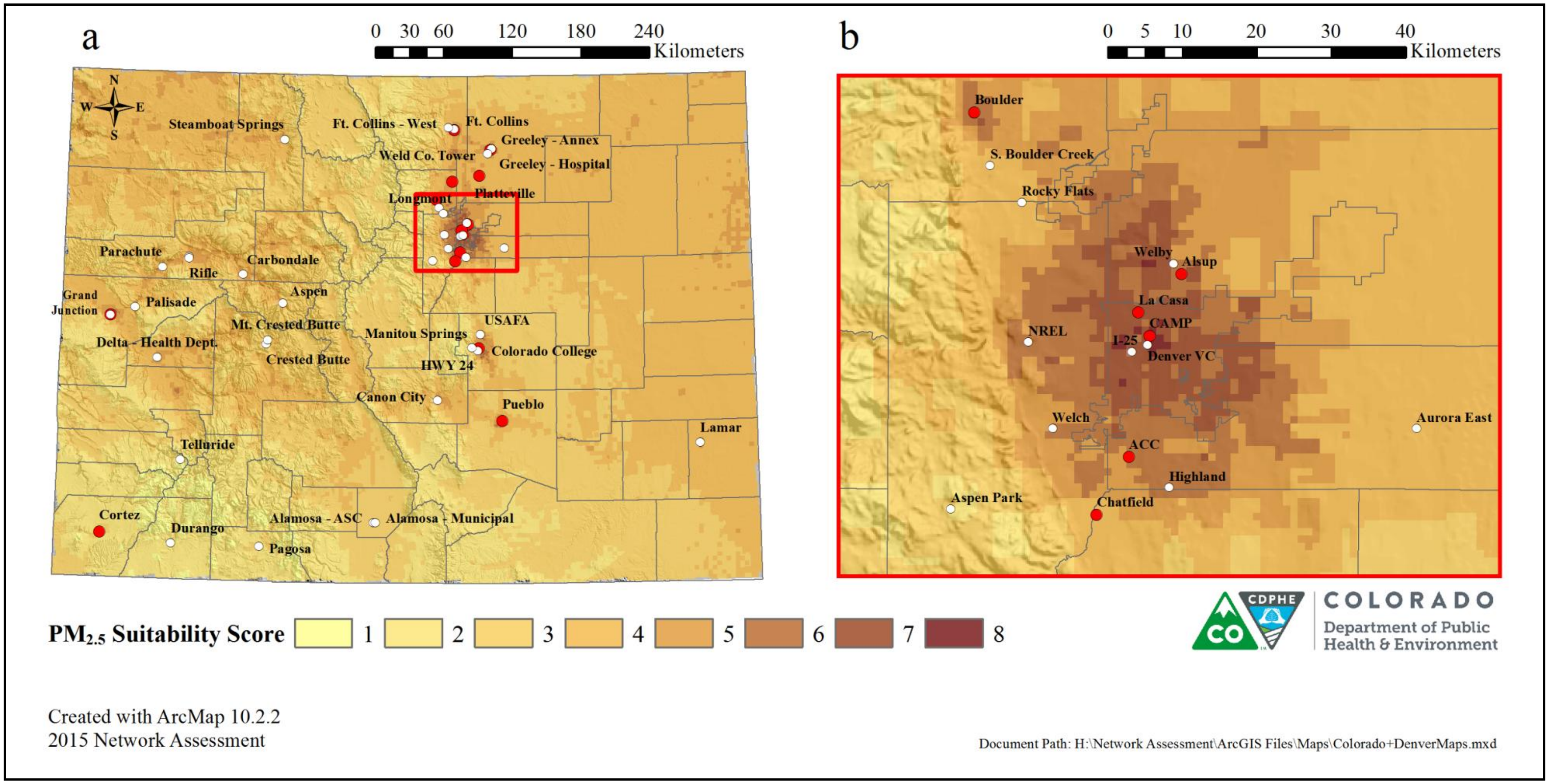

Figure 55. Results of the $PM_{2.5}$ suitability model showing (a) Colorado and (b) the Denver metropolitan area. Criteria pollutant monitoring sites operated by the APCD and listed in Table 6 are symbolized with white circles. APCD PM_{10} sites are symbolized with red circles. Note that the I-25 near-road site is shown in (b), although it is not assessed in this report on account of its unique monitoring objectives. For the purpose of improving the readability of (a), site labels for the Ft. Collins - CSU and Ft. Collins - Mason sites have been combined as “Ft. Collins,” the Rifle - Henry Bldg. and Rifle - Health Department site labels have been combined as “Rifle,” and the Grand Junction - Powell Bldg. and Grand Junction - Pitkin site labels have been combined as “Grand Junction.” Detailed site information, including AQS identification numbers, site descriptions and histories, addresses and coordinates, monitoring start dates, site elevations, site orientation/scale designations, etc., can be found in Appendix A.

4. ENVIRONMENTAL JUSTICE ANALYSIS

Environmental justice is defined by the EPA as "…the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies." The EPA has the stated goal of providing an environment where everyone enjoys the same degree of protection from environmental and health hazards and equal access to the decision-making process to have a healthy environment in which to live, learn, and work.[9] Several recent studies have demonstrated that economically disadvantaged and minority communities are disproportionately exposed to ambient air pollution and other environmental hazards (Jerrett et al., 2001; Morello-Frosch et al., 2002; Maantay, 2007). These observations raise important questions regarding social equity in regulatory, planning, and other environmental protection and economic decisions, as they suggest that poor and racial minority communities bear a disproportionate burden of the costs associated with economic activity, while also being less likely to share in the benefits.

4.1 Proximity Analysis

In this section, we examine the social distributional impacts of the APCD's air quality monitoring network in an effort to assess the network in its relation to environmental justice and social equity concerns. Specifically, we are interested in how the spatial design of the network may affect protection of populations from exposure to harmful levels of air pollution. To address this question, we have employed proximity analysis to study the comparative location of all air quality monitoring network sites with respect to residential population demographics. Here, we use proximity to air quality network sites as a surrogate for how representative regulatory monitoring data are of the exposures of a given population subgroup. In other words, the closer a population subgroup resides to monitoring sites, the more we expect that their exposures are relatively well represented and regulated by the existing air quality management system.

In performing this analysis, we have leveraged a GIS-based study conducted by the CDPHE Health Equity and Environmental Justice (HEEJ) collaborative. This study involved the development of a geodatabase to allow data users at the CDPHE to visualize and identify the geographic relationships among data representing select environmental facility locations, aggregated health outcomes, and socio-demographic characteristics at the census-tract level. For the purpose of quantifying the socio-demographic status of each census tract in Colorado, the HEEJ collaborative developed a combined score referred to as the Social Determinants of Health (SDoH) index. This index is a cumulative score based on seven socio-demographic indicators:

1. Proportion of the population that is non-white (2010 U.S. Census)
2. Proportion of unemployed adults (2007-2011 American Community Survey Estimates)
3. Median household income (2007-2011 American Community Survey Estimates)
4. Proportion of individuals with annual income below the federal poverty level (2007-2011 American Community Survey Estimates)
5. Proportion of households in linguistic isolation (2007-2011 American Community Survey Estimates)
6. Proportion of population (age ≥ 25) without a high school diploma (2007-2011 American Community Survey Estimates)
7. Proportion of units that are owner-occupied (2010 U.S. Census)

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[9] http://www.epa.gov/environmentaljustice/

Each census tract was assigned a value of 1-5 (quantile ranking) for each of the 7 indicators and these values were then summed and assigned to each census tract as a cumulative score ranging from 7-35. Finally the SDoH index score (1-5) was determined based on the quantile interval of the cumulative score. Census-tract SDoH scores are displayed in Figure 56 along with all APCD criteria pollutant monitoring sites.

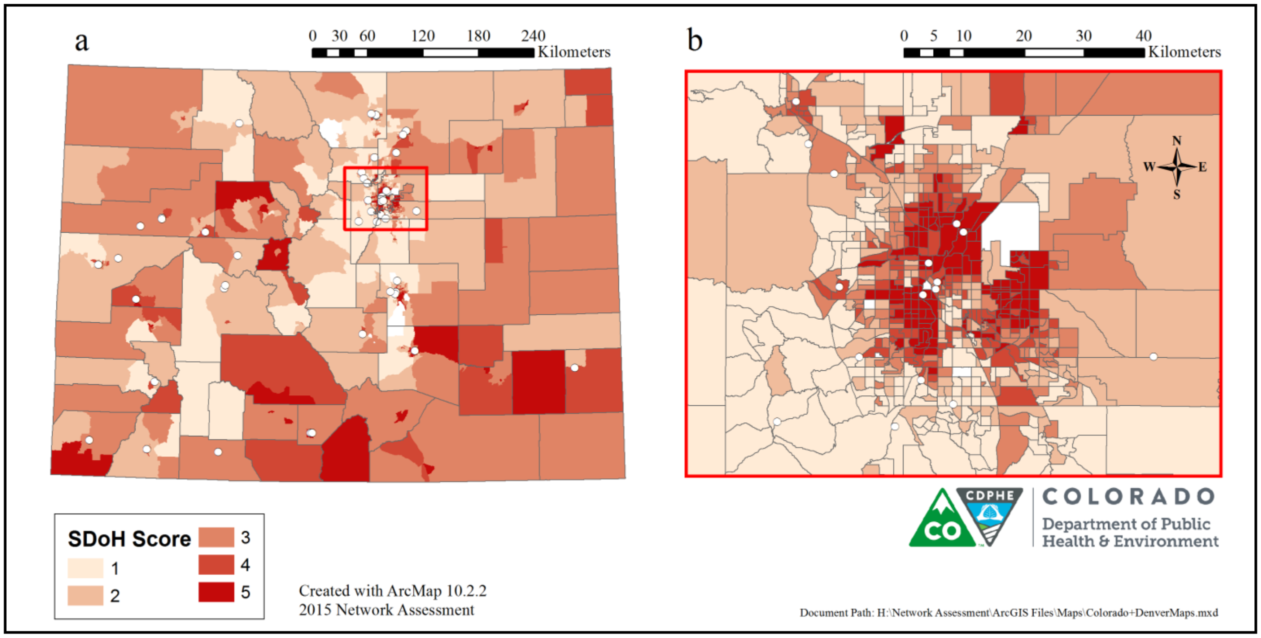

Figure 56. Census-tracts in (a) Colorado and (b) the Denver metropolitan region with associated SDoH scores. CO, NO_2, SO_2, O_3, PM_{10}, and $PM_{2.5}$ monitoring sites operated by the APCD are symbolized with white circles.

In conducting proximity analysis on this dataset, we wish to address the following question: do census tracts with high SDoH scores (i.e., environmental justice communities) tend to be located farther away from air quality monitoring sites than those with low SDoH scores? In other words, is there a systematic social bias in the configuration of the APCD's monitoring network? There are several factors that could lead to such a result. For example, in order to represent exposures for the largest possible proportion of the population using the fewest possible number of monitors, air monitoring agencies have tended to focus on sites that are distant from local emission sources and therefore representative of large spatial areas. Suburban neighborhoods are typically characterized by homogeneous land-use and lower emission densities compared to urban areas, and this may lead to a site selection preference for suburban neighborhoods, which tend to be disproportionately white and middle class. Therefore, the objective of reducing cost by minimizing the number of monitoring sites may contribute to a systematic underrepresentation of minorities and the poor by the air quality monitoring network.

To address this question, the census tract polygons shown in Figure 56 were converted to centroid points in ArcGIS and the ground distance between each census tract centroid and its nearest monitoring site was computed. Census tracts were then grouped by SDoH score and the mean distances to the nearest monitoring site were compared by grouping, as shown in Figure 57. After log transformation of the data to account for its highly skewed distribution, these groupings were analyzed for statistically significant differences using analysis of variance (ANOVA), a statistical test used to compare means across many groups. The ANOVA test was significant ($p < 0.001$, 99.9% confidence level), indicating larger differences among the SDoH group means than would be expected from chance alone. In order to identify where these differences lie, Tukey's honest significant difference (HSD) test was used for post-hoc pairwise comparisons. The results of these tests, shown in Table 105, suggest that differences between SDoH groups are not significant at the 95% confidence level, except in the case of SDoH group 2, which exhibits a significantly larger mean distance to the nearest monitoring site compared to SDoH groups 4 and 5 (Figure 57). Therefore, this analysis suggests that there is no systematic social bias in the configuration of the APCD monitoring network.

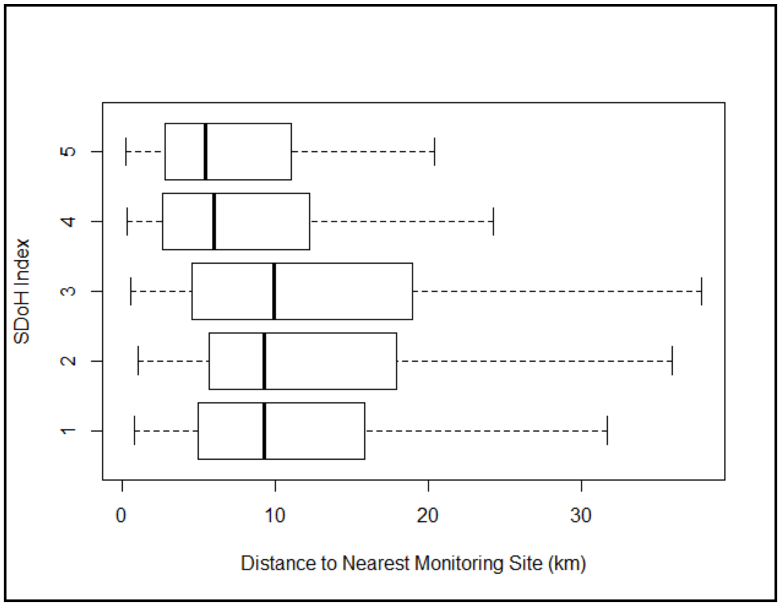

Figure 57. Box plot of proximity to air quality monitoring sites for all census tracts in Colorado as a function of SDoH score. Outliers have been removed from the plot.

Table 93. P-values derived from pairwise Tukey's honest significant difference (HSD) tests between SDoH groups. Significant differences are indicated by $p < 0.05$ (95% confidence level).

SDoH Score	1	2	3	4	5
1	-	-	-	-	-
2	> 0.05	-	-	-	-
3	> 0.05	> 0.05	-	-	-
4	> 0.05	< 0.05	> 0.05	-	-
5	> 0.05	< 0.05	> 0.05	> 0.05	-

4.2 Minority Population Served

Environmental justice research is typically focused on racial and ethnic minorities and their proximity to pollution sources or regulatory monitors. The population of Colorado is 70.0% non-Hispanic white, 20.7% Hispanic, and 5.0% black (30.0% total minority). The geographic distribution of minority population in Colorado is shown in Figure 58. In an effort to examine the racial composition of the population represented by each APCD monitoring network, we have grouped the individuals associated with each site's Population Served metric (see Section 2.8) by race and compared the expected racial composition (i.e., the Colorado average) with the racial composition observed in each site's Area Served polygon (see Section 2.7). Results of this analysis are presented for each APCD monitoring network in Tables 106-111. It can be seen from these tables that the observed minority population represented by APCD monitoring networks is consistently higher in proportion than what would be expected based on the Colorado average. The only exceptions are for the secondary pollutant networks (i.e., O_3 and $PM_{2.5}$), where minority population served is almost exactly equal to that expected based on the statewide average. It can be concluded from this analysis that minorities in Colorado are well-represented by air pollution monitors.

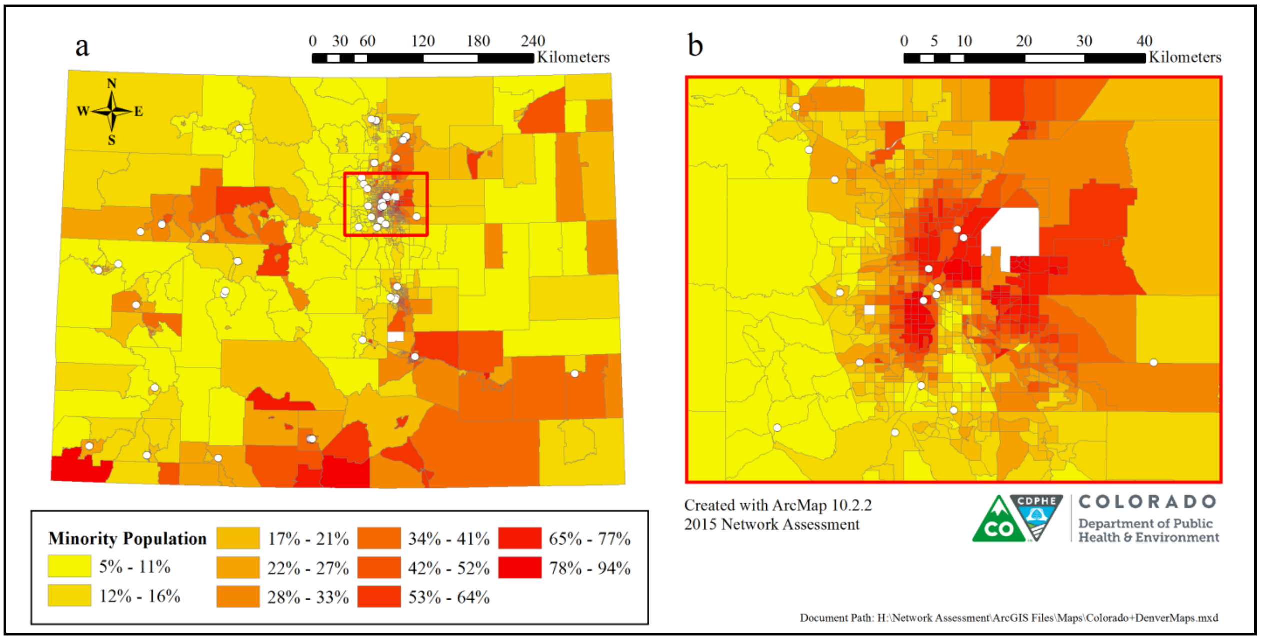

Figure 58. Census-tracts in (a) Colorado and (b) the Denver metropolitan region showing the geographic distribution of minority population. Monitoring sites operated by the APCD and listed in Table 6 are symbolized with white circles.

Table 94. Observed and expected racial composition of the population served by the APCD CO monitoring network.

	Non-Hispanic White	Black	Hispanic	Minority
Observed	1,918,362	201,787	734,127	1,068,193
Expected	2,090,800	148,349	616,817	895,755
Proportion Observed	0.64	0.07	0.25	0.36
Proportion Expected	0.70	0.05	0.21	0.30

Table 95. Observed and expected racial composition of the population served by the APCD NO_2 monitoring network.

	Non-Hispanic White	Black	Hispanic	Minority
Observed	1,140,643	149,575	558,349	799,028
Expected	1,357,907	96,348	400,603	581,764
Proportion Observed	0.59	0.08	0.29	0.41
Proportion Expected	0.70	0.05	0.21	0.30

Table 96. Observed and expected racial composition of the population served by the APCD SO_2 monitoring network.

	Non-Hispanic White	Black	Hispanic	Minority
Observed	895,790	110,663	460,616	637,399
Expected	1,073,341	76,157	316,652	459,848
Proportion Observed	0.58	0.07	0.30	0.42
Proportion Expected	0.70	0.05	0.21	0.30

Table 97. Observed and expected racial composition of the population served by the APCD O_3 monitoring network.

	Non-Hispanic White	Black	Hispanic	Minority
Observed	4,270,995	305,016	1,186,915	1,759,164
Expected	4,221,538	299,532	1,245,417	1,808,621
Proportion Observed	0.71	0.05	0.20	0.29
Proportion Expected	0.70	0.05	0.21	0.30

Table 98. Observed and expected racial composition of the population served by the APCD PM_{10} monitoring network.

	Non-Hispanic White	Black	Hispanic	Minority
Observed	2,057,244	166,919	800,695	1,096,340
Expected	2,207,732	156,646	651,314	945,852
Proportion Observed	0.65	0.05	0.25	0.35
Proportion Expected	0.70	0.05	0.21	0.30

Table 99. Observed and expected racial composition of the population served by the APCD $PM_{2.5}$ monitoring network.

	Non-Hispanic White	Black	Hispanic	Minority
Observed	2,902,802	235,817	955,999	1,390,972
Expected	3,005,946	213,282	886,799	1,287,828
Proportion Observed	0.68	0.05	0.22	0.32
Proportion Expected	0.70	0.05	0.21	0.30

5. CONCLUSIONS AND RECOMMENDATIONS

Colorado's ambient air monitoring network has been and will continue to be in a constant state of flux. Change within the network is most notably driven by changes to the NAAQS, changes in population demographics, and changes in land use. For example, in the late 1990s, APCD's air monitoring network expanded significantly to include monitoring of fine particulate matter ($PM_{2.5}$) following a revision to the NAAQS in 1997. Concurrent with this expansion was a contraction of Colorado's TSP lead monitoring network, and to a lesser extent, the PM_{10} monitoring network.

In 2008, the EPA promulgated a more stringent ozone standard of 75 ppb, forcing Colorado's Front Range solidly into non-attainment. Between 2008 and 2011, the State expanded its ozone network in the Front Range and on the Western Slope in response to the revised NAAQS. Expansion in the Front Range included two sites in the western foothills, the Rist Canyon site (AQS # 080690012), which is now closed, and the Aspen Park site, as well one site on the eastern edge of the Denver-metro area (Aurora East). These sites were established to better define the spatial extent of the Front Range's ozone problem and to validate model projections which had suggested that high concentrations may occur in these areas. Expansion on the Western Slope included the installation of three sites located near areas of proposed or active oil and gas development: Palisade, Rifle - Health Department, and Lay Peak (AQS # 080810002). These sites were added to further Colorado's understanding of ozone development in areas of significant precursor production. These recent trends play a significant role in the understanding of how Colorado's air monitoring network will evolve in the future. In 2015, the APCD will establish two additional sites on the Western Slope. The Elk Springs site (AQS #080810003) in Moffat county will replace the Lay Peak site, and a new site will be installed near Paradox in Montrose county.

There are several emerging factors that will drive Colorado's air monitoring network in the future. Most notably, the EPA has recently proposed lowering the ozone standard even further (65 to 70 ppb) to become more in line with recommendations proposed by the Clean Air Scientific Advisory Committee (CASAC)[10]. This standard will be promulgated in November 2015. The lowering of the ozone standard will require the APCD to enhance its ozone monitoring, identify potential precursor sources, and to refine its scientific understanding of Colorado's ozone problems. The new ozone rule will likely require monitoring in at least one of Colorado's smaller metropolitan areas. To further understand regional background ozone concentrations, additional ozone monitoring in Pueblo is being considered, and the APCD is currently conducting a special study to determine the spatial distribution of ozone concentrations in this area.

The following section contains suggestions for modifications to the APCD monitoring network to be considered over the next five years. Results of the analyses presented in previous sections are used to suggest the addition, removal, or relocation of individual monitors or monitoring sites. These suggestions are ultimately based upon the EPA requirements for monitoring sites (e.g., site objective and number of required sites) and the objectives and priorities of the APCD as stated in Section 1.5.3. In addition to the analysis presented in this report, the APCD has also developed an interactive web-based Network Assessment that will be available in the coming years to aid in decision making and network planning. This tool is available at http://www.colorado.gov/airquality/na_maps.aspx.

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[10] http://www.epa.gov/airquality/ozonepollution/actions.html#current

5.1 Parameter-Specific Recommendations

5.1.1 Carbon Monoxide (CO)

The current CO monitoring network configuration adequately supports APCD monitoring objectives and meets all federal requirements. CO concentrations are typically well below the NAAQS and no state-operated monitor has recorded a violation of the 8-hour standard since 1996. For this reason, it is the opinion of APCD program managers and technical experts that CO monitoring should be deemphasized and funds shifted to monitoring objectives of higher priority (e.g., increased O_3 precursor monitoring). However, most Colorado CO monitoring sites are in place in support of state maintenance plans, which necessitates that monitoring activities continue until these plans expire. The only site eligible for discontinuation is the Grand Junction - Pitkin site, which happens to be the lowest ranked monitor in the CO network site-to-site comparison analysis (see Section 2.11.1.1). It is recommended that this site be discontinued.

5.1.2 Nitrogen Dioxide (NO_2)

The current NO_2 monitoring network meets all federal requirements and adequately supports most APCD monitoring objectives. NO_2 concentrations are typically well below the NAAQS and no state-operated monitor has recorded a violation of the annual standard since 1977. However, despite the decreased relevance of NO_2 as an ambient air pollutant, the APCD feels that the monitoring network should be expanded due to the importance of NO_2 as an O_3 precursor. Furthermore, the collocation of O_3 and NO_2 monitors can be very helpful in understanding ozone dynamics at a particular site. Total oxidant, or “odd oxygen,” estimates can be derived by simply adding NO_2 and O_3 concentrations. These estimates provide an important indicator of the O_3 production potential at a location, and help to differentiate low O_3 production potential from NO_x scavenging. As such, they can shed light on the meaning of day-of-week differences in O_3 concentrations which can be an important step in understanding what areas may be NO_x or VOC limited. Therefore, we recommend adding supplemental NO_2 monitoring at high-concentration ozone monitoring sites in the Front Range, possibly including Rocky Flats, Chatfield, NREL, and Fort Collins - West. These additions would provide concurrent ozone and NO_2 data needed to test and validate model predictions. The NO_2 suitability model (see Figure 51) suggests that NREL and Fort Collins - West are likely the best candidates for the addition of an NO_2 monitor.

The only currently planned change is the addition of a second near-roadway site in the Denver area.

5.1.3 Sulfur Dioxide (SO_2)

The current SO_2 monitoring network meets all federal requirements and adequately supports APCD monitoring objectives. All sites have 2014 design values less than half of the NAAQS, except for the Colorado Springs Highway 24 site, which had a design value of 57 ppb. There is some concern this area of Colorado Springs may exceed the SO_2 NAAQS due to its proximity to the Martin Drake Power Plant. This site may be relocated in the near future site to an area of higher maximum concentrations based on modeling studies.

5.1.4 Ozone (O_3)

The current O_3 monitoring network supports the APCD’s monitoring objectives reasonably well. Areas of high concentrations, as well as background concentration areas are being monitored all along the Front Range and in several areas on the Western Slope. Most sites are in place in support of state maintenance plans. With the impending new lower NAAQS for ozone, the network will need to be expanded to monitor more areas of Colorado in the future.

The monitor-to-monitor correlation study presented in Section 2.5.4 suggests that O_3 monitors sited less than approximately 90 km apart are likely to produce redundant data. This is a concern in the Denver Metro / North Front Range region, where O_3 monitors are highly concentrated and several are separated by distances of less than 10 km. This is a likely to be an efficient use of resources that could be employed elsewhere; therefore, we recommend that some urban sites be considered for closure or relocation. The Welch site is likely to be the best candidate for closure. This site shows a high level of redundancy with other sites in the Denver Metro region (see Table 32) and was ranked 14th out of the 19 existing O_3 sites in the site-to-site comparison analysis.

The Aspen Park and South Boulder Creek sites are good candidates for relocation. The Aspen Park monitor does not show a high level of redundancy with other monitors, but it has never exceeded the NAAQS, even though modeling studies have suggested that this is an O_3 hot spot. It is the opinion of technical experts at the APCD that this site is likely impacted by NO_x titration due to its siting near a major road and gas station. The O_3 suitability model suggests that there are several nearby areas in the foothills that may be better suited for O_3 monitoring and we recommend that these areas be investigated. We further recommend that the South Boulder Creek site be relocated to provide more spacing from the Rocky Flats monitor, thus reducing the redundancy in the data collected at these two sites. The O_3 suitability model suggests that a site closer to the city of Boulder (or in the foothills to the west) would be more suitable for O_3 monitoring.

The O_3 suitability model suggests that there are several areas around the state that are candidates for the addition of a new O_3 monitor (see Figure 53). These areas include: 1) Pueblo, which is already being studied, 2) the southern Colorado border area in the vicinity of Alamosa and Trinidad, 3) several areas around the foothills and Continental Divide to the west of the Denver Metro Area, and 4) northern Weld County. We recommend that these areas be considered for O_3 monitoring.

5.1.5 PM_{10}

The current PM_{10} monitoring network meets all federal requirements and adequately supports APCD monitoring objectives. The APCD has decreased the size of its PM_{10} monitoring network over the past 10-15 years and removed the monitors deemed to be of lowest value. This was done to make funding available for other monitoring networks of higher priority within the state of Colorado (e.g., O_3 and $PM_{2.5}$). We recommend that some of the lowest ranked sites in the site-to-site comparison analysis presented here (see Table 85) should be considered for closure. These sites include Alamosa - Municipal, Parachute, and Mt. Crested Butte, which ranked 26th, 22nd, and 19th, respectively, out of the 27 sites in the PM_{10} network. Other low value sites are associated with SIPs or federal regulations and cannot be removed or relocated. We further recommend the addition of a PM_{10} monitor in northeastern Colorado based on the results of the PM_{10} suitability model.

5.1.6 $PM_{2.5}$

The current $PM_{2.5}$ monitoring network meets all federal requirements and adequately supports APCD monitoring objectives. There are no suggested changes for this network.

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APPENDIX A: MONITORING SITE DESCRIPTIONS

This appendix provides detailed information for all monitoring sites considered in this Network Assessment. Table A-1 summarizes the locations and monitoring parameters of each site currently in operation, by county, alphabetically. The shaded lines in the table list the site AQS identification numbers, address, site start-up date, elevation, and longitude and latitude coordinates. Beneath each site description the table lists each monitoring parameter in operation at that site, the orientation and spatial scale, which national monitoring network it belongs to, the type of monitor in use, and the sampling frequency. The parameter date is the date when valid data were first collected.

Table A-1. (Cont.) Monitoring locations and parameters monitored.

AQS #	*Site Name*	*Address*		*Started*	*Elevation (m)*	*Latitude*	*Longitude*
	Parameter	**POC**	**Started**	**Orient/Scale**	**Monitor**	**Type**	**Sample**
Adams							
08 001 0006	*Alsup Elementary School*	*7101 Birch St.*		*Jan-01*	*1,565*	*39.826007*	*-104.937438*
	PM$_{10}$	1	Jan-01	P.O. Neigh	Partisol 2025	SLAMS	1 in 1
	PM$_{2.5}$	1	Jan-01	P.O. Neigh	Partisol 2025	SLAMS	1 in 3
	PM$_{2.5}$ Collocated	2	Jan-01	P.O. Neigh	Partisol 2025	SLAMS	1 in 6
	PM$_{2.5}$	3	Jun-03	P.O. Neigh	TEOM-1400ab	SPM	Continuous
	PM$_{2.5}$ Speciation	5	Feb-01	P.O. Neigh	SASS	Trends Spec	1 in 6
	PM$_{2.5}$ Carbon	5	Feb-07	P.O. Neigh	URG 3000N	Trends Spec	1 in 6
	WS/WD/Temp	1	Jun-03	Other	Met - One	Other	Continuous
08 001 3001	*Welby*	*3174 E. 78th Ave.*		*Jul-73*	*1,554*	*39.838119*	*-104.949840*
	CO	1	Jul-73	P.O. Neigh	Thermo 48C	SLAMS	Continuous
	SO$_2$	2	Jul-73	P.O. Neigh	TAPI 100E	SLAMS	Continuous
	NO	2	Jan-76	P.O. Urban	TAPI 200E	Other	Continuous
	NO$_2$	1	Jan-76	P.O. Urban	TAPI 200E	SLAMS	Continuous
	O$_3$	2	Jul-73	P.O. Neigh	TAPI 400E	SLAMS	Continuous
	WS/WD/Temp	1	Jan-75	Other	Met - One	Other	Continuous
	PM$_{10}$	1	Feb-92	P.O. Neigh	SA/GMW-1200	SLAMS	1 in 6
	PM$_{10}$	3	Jun-90	P.O. Neigh	TEOM-1400ab	SLAMS	Continuous
Alamosa							
08 003 0001	*Alamosa - ASC*	*208 Edgemont Blvd*		*Jan-70*	*2,302*	*37.469391*	*-105.878691*
	PM$_{10}$	1	Jul-89	P.O. Neigh	SA/GMW-1200	SLAMS	1 in 1
08 003 0003	*Alamosa - Municipal*	*425 4th St.*		*Apr-02*	*2,301*	*37.469584*	*-105.863175*
	PM$_{10}$	1	May-02	P.O. Neigh	SA/GMW-1200	SLAMS	1 in 1
Arapahoe							
08 005 0002	*Highland Reservoir*	*8100 S. University Blvd.*		*Jun-78*	*1,747*	*39.567887*	*-104.957193*
	O$_3$	1	Jun-78	P.O. Neigh	TAPI 400E	SLAMS	Continuous
	WS/WD/Temp	1	Jul-78	Other	Met - One	Other	Continuous

Table A-1. (Cont.) Monitoring locations and parameters monitored.

AQS #	*Site Name*	*Address*		*Started*	*Elevation (m)*	*Latitude*	*Longitude*
	Parameter	**POC**	**Started**	**Orient/Scale**	**Monitor**	**Type**	**Sample**
08 005 0005	*Arapahoe Comm. Coll.*	*6190 S. Santa Fe Dr.*		*Dec-98*	*1,636*	*39.604399*	*-105.019526*
	PM$_{2.5}$	1	Mar-99	P.O. Neigh	Partisol 2025	SLAMS	1 in 3
08 005 0006	*Aurora - East*	*36001 E. Quincy Ave.*		*Apr-11*	*1,552*	*39.638540*	*-104.569130*
	O$_3$	1	Apr-11	P.O. Region	TAPI 400E	SLAMS	Continuous
	WS/WD/Temp	1	Jun-11	Other	Met - One	Other	Continuous
Archuleta							
08 007 0001	*Pagosa Springs School*	*309 Lewis St.*		*Aug-75*	*2,165*	*37.26842*	*-107.009659*
	PM$_{10}$	3	Sep-90	P.O. Neigh	SA/GMW-1200	SLAMS	1 in 1
Boulder							
08 013 0003	*Longmont - Municipal*	*350 Kimbark St.*		*Jun-85*	*1,520*	*40.164576*	*-105.100856*
	PM$_{10}$	2	Sep-85	P.O. Neigh	SA/GMW-1200	SLAMS	1 in 6
	PM$_{2.5}$	1	Jan-99	P.O. Neigh	Partisol 2025	SLAMS	1 in 3
	PM$_{2.5}$	3	Nov-05	P.O. Neigh	TEOM 1400ab	SPM	Continuous
08 013 0011	*South Boulder Creek*	*1405 S. Foothills Pkwy.*		*Jun-94*	*1,669*	*39.957212*	*-105.238458*
	O$_3$	1	Jun-94	H.C. Urban	TAPI 400E	SLAMS	Continuous
08 013 0012	*Boulder - Chamber*	*2440 Pearl St.*		*Dec-94*	*1,619*	*40.021097*	*-105.263382*
	PM$_{10}$	1	Oct-94	P.O. Neigh	SA/GMW-1200	SLAMS	1 in 6
	PM$_{2.5}$	1	Jan-99	P.O. Middle[2]	Partisol 2025	SLAMS	1 in 3
Delta							
08 029 0004	*Delta Health Dept*	*560 Dodge St.*		*Aug-93*	*1,511*	*38.739213*	*-108.073118*
	PM$_{10}$	1	May-93	P.O. Neigh	SA/GMW-1200	SLAMS	1 in 3
Denver							
08 031 0002	*CAMP*	*2105 Broadway St.*		*Jan-65*	*1,593*	*39.751184*	*-104.987625*
	CO	2	Jan-71	P.O. Micro	Thermo 48C	SLAMS	Continuous
	SO$_2$	1	Jan-67	P.O. Neigh	TAPI 100E	SLAMS	Continuous
	O$_3$	6	Mar-12	P.O. Neigh	TAPI 400E	SLAMS	Continuous
	NO	1	Jan-73	Other	TAPI 200E	Other	Continuous
	NO$_2$	1	Jan-73	P.O. Neigh	TAPI 200E	SLAMS	Continuous
	WS/WD/Temp	1	Jan-65	Other	Met - One	Other	Continuous
	PM$_{10}$	1	Aug-86	P.O. Micro[1]	SA/GMW-1200	SLAMS	1 in 6
	PM$_{10}$ Collocated	2	Dec-87	P.O. Micro[2]	SA/GMW-1200	SLAMS	1 in 6
	PM$_{10}$	3	Jan-88	P.O. Micro[2]	TEOM-1400ab	SLAMS	Continuous
	PM$_{2.5}$	1	Jan-99	P.O. Micro[2]	Partisol 2025	SLAMS	1 in 1
	PM$_{2.5}$ Collocated	2	Sep-01	P.O. Micro[2]	Partisol 2025	SLAMS	1 in 6
	PM$_{2.5}$	3	Oct-01	P.O. Micro[2]	TEOM FDMS	SPM	Continuous

Table A-1. (Cont.) Monitoring locations and parameters monitored.

AQS #	*Site Name*	*Address*		*Started*	*Elevation (m)*	*Latitude*	*Longitude*
	Parameter	**POC**	**Started**	**Orient/Scale**	**Monitor**	**Type**	**Sample**
08 031 0013	*NJH-E*	*14th Ave. & Albion St.*		*Jan-83*	*1,620*	*39.738578*	*-104.939925*
	PM$_{2.5}$	3	Oct-03	P.O. Neigh	TEOM FDMS	SPM	Continuous
08 031 0017	*Denver Visitor Center*	*225 W. Colfax Ave.*		*Dec-92*	*1,597*	*39.740342*	*-104.991037*
	PM$_{10}$	1	Dec-92	P.O. Middle	SA/GMW-1200	SLAMS	1 in 1
08 031 0026	*La Casa*	*4587 Navajo St.*		*Jan-13*	*1,594*	*39.779429*	*-105.005174*
	CO (Trace)	1	Jan-12	P.O. Neigh	Thermo 48i-TLE	NCore	Continuous
	SO$_2$ (Trace)	1	Jan-12	P.O. Neigh	TAPI 100EU	NCore	Continuous
	NO$_Y$	1	Jan-12	P.O. Neigh	TAPI 200EU	NCore	Continuous
	O$_3$	1	Jan-12	Neigh/Urban	TAPI 400E	NCore	Continuous
	WS/WD/Temp	1	Jan-12	P.O. Neigh	Met - One	NCore	Continuous
	Relative Humidity	1	Jan-12	P.O. Neigh	Met - One	NCore	Continuous
	Temp (Lower)	2	Jan-12	P.O. Neigh	Met - One	NCore	Continuous
	PM$_{10}$	1	Jan-12	P.O. Neigh	Partisol 2025	SLAMS	1 in 3
	PM$_{10}$ Collocated/Pb	2	Jan-12	P.O. Neigh	Partisol 2025	SLAMS	1 in 6
	PM$_{10}$	3	Jan-12	P.O. Neigh	TEOM-1400ab	SLAMS	Continuous
	PM$_{2.5}$	1	Jan-12	P.O. Neigh	Partisol 2025	NCore	1 in 3
	PM$_{2.5}$	3	Jan-12	P.O. Neigh	TEOM FDMS	SPM	Continuous
	PM$_{2.5}$ Speciation	5	Jan-12	P.O. Neigh	SASS	Supplem. Spec.	1 in 3
	PM$_{2.5}$ Carbon	5	Jan-12	P.O. Neigh	URG 3000N	Supplem. Spec.	1 in 3
Douglas							
08 035 0004	*Chatfield State Park*	*11500 N. Roxborough Pk Rd*		*Apr-04*	*1,676*	*39.534488*	*-105.070358*
	O$_3$	1	May-05	H.C. Urban	TAPI 400E	SLAMS	Continuous
	WS/WD/Temp	1	Apr-04	Other	Met - One	Other	Continuous
	PM$_{2.5}$	1	Jul-05	P.O. Neigh	Partisol 2025	SPM	1 in 3
	PM$_{2.5}$	3	May-04	P.O. Neigh	TEOM FDMS	SPM	Continuous
El Paso							
08 041 0013	*U. S. Air Force Academy*	*USAFA Rd. 640*		*May-96*	*1,971*	*39.958341*	*-104.817215*
	O$_3$	1	Jun-96	P.O. Urban	TAPI 400E	SLAMS	Continuous
08 041 0015	*Highway 24*	*690 W. Hwy. 24*		*Nov-98*	*1,824*	*39.830895*	*-104.839243*
	CO	1	Nov-98	P.O. Micro	Thermo 48i-TLE	SLAMS	Continuous
	SO$_2$	1	Jan-13	P.O. Micro	TAPI 100T	SLAMS	Continuous
08 041 0016	*Manitou Springs*	*101 Banks Pl.*		*Apr-04*	*1,955*	*38.853097*	*-104.901289*
	O$_3$	1	Apr-04	P.O. Neigh	TAPI 400E	SLAMS	Continuous

Table A-1. (Cont.) Monitoring locations and parameters monitored.

AQS #	*Site Name*	*Address*		*Started*	*Elevation (m)*	*Latitude*	*Longitude*
	Parameter	**POC**	**Started**	**Orient/Scale**	**Monitor**	**Type**	**Sample**
08 041 0017	*Colorado College*	*130 W. Cache La Poudre*		*Dec-07*	*1,832*	*38.848014*	*-104.828564*
	PM$_{10}$	1	Dec-07	P.O. Neigh	Partisol 2000	SLAMS	1 in 6
	PM$_{2.5}$	1	Dec-07	P.O. Neigh	Partisol 2025	SLAMS	1 in 3
	PM$_{2.5}$	3	Jan-08	P.O. Neigh	TEOM FDMS	SLAMS	Continuous
Fremont							
08 043 0003	*Cañon City - City Hall*	*128 Main St.*		*Oct-04*	*1,626*	*38.438290*	*-105.245040*
	PM$_{10}$	1	Oct-04	P.O. Neigh	SA/GMW-1200	SLAMS	1 in 6
Garfield							
08 045 0005	*Parachute*	*100 E. 2nd St.*		*Jan-82*	*1,557*	*38.453654*	*-108.053269*
	PM$_{10}$	1	May-00	P.O. Neigh	SA/GMW-1200	SLAMS	1 in 3
	WS/WD/Temp	1	Mar-11	Other	RM Young /Vaisala	Other	Continuous
08 045 0007	*Rifle - Henry Bldg*	*144 3rd St.*		*May-05*	*1,627*	*39.531813*	*-107.782298*
	PM$_{10}$	1	May-05	P.O. Neigh	SA/GMW-1200	SPM	1 in 3
	PM$_{2.5}$	3	Sep-08	P.O. Neigh	Thermo 1405 DF	SPM	Continuous
	PM$_{10}$	3	Sep-08	P.O. Neigh	Thermo 1405 DF	SPM	Continuous
	PM$_{10-2.5}$	3	Sep-08	P.O. Neigh	Thermo 1405 DF	SPM	Continuous
	WS/WD/Temp	1	Sep-08	Other	RM Young /Vaisala	Other	Continuous
08 045 0012	*Rifle - Health Dept*	*195 W. 14th Ave.*		*Jun-08*	*1,629*	*39.541820*	*-107.784125*
	O$_3$	1	Jun-08	P.O. Neigh	TAPI 400E	SLAMS	Continuous
08 045 0018	*Carbondale*	*1493 County Road 106*		*May-12*	*1868*	*39.412240*	*-107.230413*
	PM$_{10}$	1	Aug-12	P.O. Neigh	SA/GMW-1200	SLAMS	1 in 3
Gunnison							
08 051 0004	*Crested Butte*	*603 6th St.*		*Sep-82*	*2,714*	*38.867595*	*-106.981436*
	PM$_{10}$	2	Mar-97	P.O. Neigh	SA/GMW-1200	SLAMS	1 in 3
	PM$_{10}$ Collocated	3	Oct-08	P.O. Neigh	SA/GMW-1200	SLAMS	1 in 6
08 051 0007	*Mt. Crested Butte*	*19 Emmons Rd.*		*Jul-05*	*2,866*	*38.900392*	*-106.966104*
	PM$_{10}$	1	Jul-05	P.O. Neigh	SA/GMW-1200	SLAMS	1 in 1
Jefferson							
08 059 0005	*Welch*	*12400 W. Hwy. 285*		*Aug-91*	*1,742*	*39.638781*	*-105.139480*
	O$_3$	1	Aug-91	P.O. Urban	TAPI 400E	SLAMS	Continuous
	WS/WD/Temp	1	Nov-91	Other	Met - One	Other	Continuous
08 059 0006	*Rocky Flats - N*	*16600 W. Hwy. 128*		*Jun-92*	*1,802*	*39.912799*	*-105.188587*
	O$_3$	1	Sep-92	H.C. Urban	TAPI 400E	SLAMS	Continuous
	WS/WD/Temp	1	Sep-92	Other	Met - One	Other	Continuous

Table A-1. (Cont.) Monitoring locations and parameters monitored.

AQS #	***Site Name***	***Address***		***Started***	***Elevation (m)***	***Latitude***	***Longitude***
	Parameter	**POC**	**Started**	**Orient/Scale**	**Monitor**	**Type**	**Sample**
08 059 0011	*NREL*	*2054 Quaker St.*		*Jun-94*	*1,832*	*39.743724*	*-105.177989*
	O_3	1	Jun-94	H.C. Urban	TAPI 400E	SLAMS	Continuous
08 059 0013	*Aspen Park*	*26137 Conifer Rd.*		*Apr-11*	*2,467*	*39.540321*	*-105.296512*
	O_3	1	Apr-11	P.O. Neigh	TAPI 400E	SLAMS	Continuous
	WS/WD/Temp	1	Jun-11	Other	Met - One	Other	Continuous
La Plata							
08 067 0004	*Durango*	*1235 Camino del Rio*		*Sep-85*	*1,988*	*37.277798*	*-107.880928*
	PM_{10}	1	Dec-02	P.O. Neigh	SA/GMW-1200	SLAMS	1 in 3
Larimer							
08 069 0009	*Fort Collins - CSU*	*251 Edison Dr.*		*Dec-98*	*1,524*	*40.571288*	*-105.079693*
	PM_{10}	1	Jul-99	P.O. Neigh	SA/GMW-1200	SLAMS	1 in 3
	PM_{10}	3	Jun-11	P.O. Neigh	Thermo 1405 DF	SPM	Continuous
	$PM_{2.5}$	1	Jul-99	P.O. Neigh	Partisol 2025	SLAMS	1 in 3
	$PM_{2.5}$	3	Jun-11	P.O. Neigh	Thermo 1405 DF	SPM	Continuous
	$PM_{10-2.5}$	3	Jun-11	P.O. Neigh	Thermo 1405 DF	SPM	Continuous
08 069 0011	*Fort Collins - West*	*3416 La Porte Ave.*		*May-06*	*1,571*	*40.592543*	*-105.141122*
	O_3	1	May-06	H.C. Urban	TAPI 400E	SLAMS	Continuous
08 069 1004	*Fort Collins - Mason*	*708 S. Mason St.*		*Dec-80*	*1,524*	*40.577470*	*-105.078920*
	CO	1	Dec-80	P.O. Neigh	Thermo 48C	SLAMS	Continuous
	O_3	1	Dec-80	P.O. Neigh	TAPI 400E	SLAMS	Continuous
	WS/WD/Temp	1	Jan-81	Other	Met - One	Other	Continuous
Mesa							
08 077 0017	*Grand Junction - Powell*	*650 South Ave.*		*Feb-02*	*1,398*	*39.063798*	*-108.561173*
	PM_{10} & NATTS Toxics	3	Jan-05	P.O. Neigh	Partisol 2025	SLAMS	1 in 3
	PM_{10} Collocated & NATTS	4	Mar-05	P.O. Neigh	Partisol 2000	SLAMS	1 in 6
	$PM_{2.5}$	1	Nov-02	P.O. Neigh	Partisol 2025	SLAMS	1 in 3
	PM_{10}	3	Jul-11	P.O. Neigh	Thermo 1405 DF	SPM	Continuous
	$PM_{2.5}$	3	Jan-05	P.O. Neigh	Thermo 1405 DF	SPM	Continuous
	$PM_{10-2.5}$	3	Jul-11	P.O. Neigh	Thermo 1405 DF	SPM	Continuous
08 077 0018	*Grand Junction - Pitkin*	*645 Pitkin Ave.*		*Jan-04*	*1,398*	*39.064289*	*-108.56155*
	CO	1	Jan-04	P.O. Micro	Thermo 48C	SLAMS	Continuous
	WS/WD/Temp	1	Jan-04	Other	Met - One	Other	Continuous
	Relative Humidity	1	Jan-04	Other	Rotronic	Other	Continuous
08 077 0020	*Palisade Water Treatment*	*Rapid Creek Rd.*		*May-08*	*1,512*	*39.130575*	*-108.313853*
	O_3	1	Apr-08	P.O. Urban	TAPI 400E	SLAMS	Continuous
	WS/WD/Temp	1	Apr-08	Other	RM Young	Other	Continuous

Table A-1. (Cont.) Monitoring locations and parameters monitored.

AQS #	*Site Name*	*Address*		*Started*	*Elevation (m)*	*Latitude*	*Longitude*
	Parameter	**POC**	**Started**	**Orient/Scale**	**Monitor**	**Type**	**Sample**
			Montezuma				
08 083 0006	*Cortez - Health Dept.*	*106 W. North St.*		*Jun-06*	*1,890*	*37.350054*	*-108.592337*
	O$_3$	1	Jun-08	P.O. Urban	TAPI 400E	SLAMS	Continuous
	PM$_{2.5}$	1	Jun-08	P.O Region	Partisol 2000	SPM	1 in 6
			Pitkin				
08 097 0006	*Aspen - Library*	*120 Mill St.*		*May-02*	*2,408*	*39.191040*	*-106.818864*
	PM$_{10}$	1	May-02	P.O. Neigh	SA/GWM 1200	SLAMS	1 in 3
			Prowers				
08 099 0002	*Lamar Municipal*	*104 E. Parmenter St.*		*Dec-76*	*1,107*	*38.084688*	*-102.618641*
	PM$_{10}$	2	Mar-87	P.O. Neigh	SA/GMW-1200	SLAMS	1 in 1
			Pueblo				
08 101 0015	*Pueblo - Fountain School*	*925 N. Glendale Ave.*		*Jun-11*	*1,433*	*38.276099*	*-104.597613*
	PM$_{10}$	1	Apr-11	P.O. Neigh	SA/GMW-1200	SLAMS	1 in 3
	PM$_{2.5}$	1	Apr-11	P.O. Neigh	Partisol 2025	SLAMS	1 in 3
			Routt				
08 107 0003	*Steamboat Springs*	*136 6th St.*		*Sep-75*	*2,054*	*40.485201*	*-106.831625*
	PM$_{10}$	2	Mar-87	P.O. Neigh	SA/GMW-1200	SLAMS	1 in 1
			San Miguel				
08 113 0004	*Telluride*	*333 W. Colorado Ave.*		*Mar-90*	*2,684*	*37.937872*	*-107.813061*
	PM$_{10}$	1	Mar-90	P.O. Neigh	SA/GMW-1200	SLAMS	1 in 3
			Weld				
08 123 0006	*Greeley-Hospital*	*1516 Hospital Rd.*		*Apr-67*	*1,441*	*40.414877*	*-104.706930*
	PM$_{10}$	2	Mar-87	P.O. Neigh	SA/GMW-1200	SLAMS	1 in 3
	PM$_{2.5}$	1	Feb-99	P.O. Neigh	Partisol 2025	SLAMS	1 in 3
	PM$_{2.5}$	3	Feb-99	P.O. Neigh	TEOM – 1400ab	SPM	Continuous
08 123 0008	*Platteville Middle School*	*1004 Main St.*		*Dec-98*	*1,469*	*40.209387*	*-104.824050*
	PM$_{2.5}$	1	Aug-99	P.O. Region	Partisol 2025	SLAMS	1 in 3
	PM$_{2.5}$ Speciation	5	Aug-99	P.O. Region	SASS	Spec Trends	1 in 6
	PM$_{2.5}$ Carbon	5	Apr-11	P.O. Neigh	URG 3000N	Spec Trends	1 in 6
08 123 0009	*Greeley - County Tower*	*3101 35th Ave.*		*Jun-02*	*1,484*	*40.386368*	*-104.737440*
	O$_3$	1	Jun-02	P.O. Neigh	TAPI 400E	SLAMS	Continuous
	WS/WD/Temp	1	Feb-12	Other	Met - One	Other	Continuous
08 123 0010	*Greeley - West Annex*	*905 10th Ave.*		*Dec-03*	*1,421*	*40.423432*	*-104.694790*
	CO	1	Dec-03	P.O. Neigh	Thermo 48C	SLAMS	Continuous

Alsup Elementary School (Commerce City), 7101 Birch Street (08 001 0006):

The Alsup Elementary School site is located in a predominantly residential area with a large commercial and industrial district. It is located north of the Denver Central Business District (CBD) near the Platte River Valley, downstream from the Denver urban air mass. There are two schools in addition to the Alsup Elementary School in the immediate vicinity, a middle school to the north, and a high school to the southeast. There is a large industrial area to the south and east and gravel pits about a kilometer to the west and northwest.

PM_{10} and $PM_{2.5}$ monitoring began in January 2001 and continues to this day. There are a collocated set of monitors, along with a continuous monitor, a trends speciation monitor, and a $PM_{2.5}$ carbon monitor all in operation.

Meteorological monitoring began in June of 2003.

Welby, 3174 E. 78th Avenue (08 001 3001):

Located 13 km north-northeast of the Denver Central Business District (CBD) on the bank of the South Platte River, this site is ideally located to measure nighttime drainage of the air mass from the Denver metropolitan area and the thermally driven, daytime upriver flows. Monitoring data suggests that elevated CO concentrations are associated with winds from the south-southwest. While this is the direction of five of the six major sources in the area, it is also the direction of the primary drainage winds along the South Platte River. This monitor is a population-oriented, neighborhood scale SLAMS monitor.

CO monitoring began in 1973 and continued through the spring of 1980. Monitoring was stopped from the spring of 1980 until October 1986 when it began again as a special study. Welby has not recorded an exceedance of either the one-hour or eight-hour CO standard since January 1988. In the last few years, its primary value has been as an indicator of changes in the air quality index (AQI).

O_3 monitoring began at Welby in July of 1973. The Welby monitor has not recorded an exceedance of the old one-hour O_3 standard since 1998. However, the trend in the 3-year average of the 4th maximum eight-hour average has been increasing since 2002.

The Welby NO_2 monitor began operation in July 1976. The site's location provides an indication of possible exceedance events before they impact the Denver metro area. The site serves as a good drainage location, but it may be a target for deletion or relocation farther down the South Platte River Valley from Denver.

The Welby SO_2 monitor began operation in July of 1973.

PM_{10} monitoring began at Welby in June and July of 1990. The continuous monitor began operation in June, while the high volume monitor began operation in July.

Meteorological monitoring began in January of 1975.

Alamosa – Adams State College, 208 Edgemont Boulevard (08 003 0001):

The Alamosa – Adams State College site is located on the science building of Adams State College in a principally residential area. The only significant traffic is along US 160 through the center of town. The site is adjacent to this highway but far enough away to limit direct impacts on PM_{10} levels.

Meteorological data are not available from the area. The city has a population of 8,780 (2010 Census data). This is an increase of 10.3% from the 2000 census. The major particulate source is wind-blown dust. This site began operation in 1973 as a TSP monitor and was changed to a PM_{10} monitor in June 1990. This is a population-oriented, neighborhood scale SLAMS monitor on a daily sampling schedule.

Alamosa - Municipal, 425 4th Street (08 003 0003):

The Alamosa 425 4th St. site was started in May 2002. The site was established closer to the center of the city to be more representative of the population exposure in the area. This is a population-oriented, neighborhood scale SLAMS monitor on a daily sampling schedule.

Highland Reservoir, 8100 S. University Boulevard (08 005 0002):

The Highlands site began operation in June of 1978. It was intended to be a background location. However, with urban growth and the construction of C-470, it has become a long-term trend site that monitors changes in the air quality of the area. It is currently believed to be near the southern edge of the high urban O_3 concentration zone although it may not be in the area of maximum concentrations. This is a population-oriented, neighborhood scale SLAMS monitor.

Meteorological monitoring began in July of 1978.

In September of 2010 the site and meteorological tower were relocated to the east by approximately 30 meters to allow for the construction of an emergency generator system. This emergency generator system is located approximately 20 meters northwest of the new site location.

Arapahoe Community College (ACC), 6190 S. Santa Fe Drive (08 005 0005):

The ACC site is located in south suburban metropolitan Denver. It is located on the south side of the Arapahoe Community College campus in a distant parking lot. The site is near the bottom of the Platte River Valley along Santa Fe Drive (Hwy. 85) in the city of Littleton. It is also near the city of Englewood. There is a large residential area located to the east across the railroad and Light Rail tracks. The $PM_{2.5}$ monitor is located on a mobile shelter in the rarely used South parking lot. Located at 6190 S. Santa Fe Drive, this small trailer is close to the Platte River and the monitor has excellent 360° exposure. Based on the topography and meteorology of the area, ACC is in an area where $PM_{2.5}$ emissions may accumulate. This location may capture high concentrations during periods of upslope flow and temperature inversion in the valley. However, since it is further south in a more sparsely populated area, the concentrations are usually not as high as other Denver locations.

Winds are predominately out of the south-southwest and south, with secondary winds out of the north and north-northeast (upslope). Observed distances and traffic estimates easily fall into the neighborhood scale in accordance with federal guidelines found in the 40 CFR, Part 58, Appendix D. The site meets all other neighborhood scale criteria, making the monitor a population oriented neighborhood scale SLAMS monitor on a 1 in 3 day sampling schedule.

Aurora – East, 36001 Quincy Ave (08 005 0006):

The Aurora - East site began operation in June 2009. It is intended to act as a regional site and an aid in the determination of the easternmost extent of the high urban O_3 concentration zone. It is located along the eastern edge of the former Lowry bombing range, on a flat, grassy plains area. This site is currently outside of the rapid urban growth area taking place around Aurora Reservoir. This was a special projects monitor (SPM) for a regional scale and became a SLAMS monitor in 2013.

Pagosa Springs School, 309 Lewis Street (08 007 0001):

The Pagosa Springs School site was located on the roof of the Town Hall from April 24, 2000 through May 2001. When the Town Hall building was planned to be demolished, the PM_{10} monitor was relocated to the Pagosa Springs Middle School and the first sample was collected on June 7, 2001.

The Pagosa Springs School site is located next to Highway 160 near the center of town. Pagosa Springs is a small town spread over a large area. The San Juan River runs through the south side of town. The town sits in a small bowl like setting with hills all around. A small commercial strip area along Highway 160 and single-family homes surrounds this location. It is representative of residential neighborhood exposure. Pagosa Springs was a PM_{10} nonattainment area and a SIP was implemented for this area. PM_{10} concentrations were exceeded a few times in the late 1990s.

Winds in this area are predominantly northerly, with secondary winds from the north-northwest and the south. The predominant wind directions closely follow the valley topography in this rugged terrain. McCabe Creek, which is very near the meteorological station that was on the Town Hall building, runs north-south through this area. However, the highest wind gusts come from the west and southwest during regional dust storms. This is a population-oriented, neighborhood scale SLAMS monitor on a daily sampling schedule.

Longmont – Municipal Bldg., 350 Kimbark Street (08 013 0003):

The town of Longmont is a growing, medium sized Front Range community. Longmont is located between the Denver/Boulder metro area and Fort Collins. Longmont is both suburban and rural in nature. The town of Longmont is located approximately 50 km north of Denver along the St. Vrain Creek and is about 10 km east of the foothills. Longmont is partly a bedroom community for the Denver-Boulder area. The elevation is 517 meters. The Front Range peaks rise to an elevation of 4300 meters just to the west of Longmont. In general, the area experiences low relative humidity, light precipitation and abundant sunshine.

The station began operation in 1985 with the installation of a PM_{10} monitor and $PM_{2.5}$ monitors were added in 1999.

Longmont's predominant wind direction is from the north through the west due to winds draining from the St. Vrain Creek Canyon. The PM_{10} site is near the center of the city near both commercial and residential areas. This location provides the best available monitoring for population exposure to particulate matter. The distance and traffic estimate for the controlling street easily falls into the neighborhood scale in accordance with federal guidelines found in 40 CFR, Part 58, and Appendix D. This is a population oriented neighborhood scale SLAMS monitor on a 1 in 6 day sampling schedule.

South Boulder Creek, 1405½ S. Foothills Parkway (08 013 0011):

The city of Boulder is located about 50 km to the northwest of Denver. The Boulder Foothills, South Boulder Creek site was established as a special-purpose O_3 monitor within the framework of the "summer 1993 Denver O_3 Study." In 1994, the monitor was converted from an SPM to a seasonal SLAMS monitor. In 1995 it was converted to a year-round O_3 monitoring site when the instruments were moved into a new shelter.

This is a highest concentration-oriented urban scale SLAMS monitor.

Boulder Chamber of Commerce, 2440 Pearl Street (08 013 0012):

The city of Boulder is located on the eastern edge of the Rocky Mountain foothills. Most of the city sits on rolling plains. The Boulder $PM_{2.5}$ site is approximately 2,134 meters east of the base of the Front Range foothills and about 15 meters south of a small branch of Boulder Creek, the major creek that runs through Boulder.

PM_{10} monitoring began at this site in December of 1994 and $PM_{2.5}$ monitoring began in January of 1999.

The predominant wind direction at the Division's closest meteorological site (Rocky Flats – North) is from the west with secondary maximum frequencies from the west-northwest and west-southwest. The distance and traffic estimate for Pearl Street and Folsom Street falls into the middle scale, but the site has been justified to represent a neighborhood scale site in accordance with federal guidelines found in 40 CFR, Part 58 and Appendix D. This is a population-oriented, neighborhood scale SLAMS monitoring site on a 1 in 6 day sampling schedule.

Delta - Health Department, 560 Dodge Street (08 029 0004):

Delta is a small agricultural community midway between Grand Junction and Montrose. The topography in and around Delta is relatively flat as it sits in the broad Uncompaghre River Valley surrounded by high mesas and mountains. Delta sits in a large bowl-shaped basin that can effectively trap air pollution, especially during persistent temperature inversions.

The Delta County Health Department site was chosen because it is a one story building near the downtown area. The site began operation in August 1993, and is representative of the large basin with the potential for high PM_{10} due to agricultural burning, automobile traffic, and the former Louisiana Pacific wafer board plant. This is a population-oriented, neighborhood scale SLAMS monitor on a 1 in 3 day sampling schedule.

CAMP, 2105 Broadway (08 031 0002):

The City and County of Denver is located approximately 50 km east of the foothills of the Rocky Mountains. Denver sits in a basin, and the terrain of the city is characterized by gently rolling hills, with the Platte River running from southwest to northeast just west of the downtown area. The CAMP site is located in downtown Denver.

CO monitoring began in February 1965 as a part of the Federal Continuous Air Monitoring Program. It was established as a maximum concentration (micro-scale), population-oriented monitor. The CAMP site measures the exposure of the people who work or reside in the central business district (CBD). Its location in a high traffic street canyon causes this site to record most of the high pollution episodes in the metro area. The street canyon effect at CAMP results in variable wind directions for high CO levels and as a result wind direction is less relevant to high concentrations than wind speed. Wind speeds less than 1 mph, especially up-valley, combined with temperature inversions trap the pollution in the area. Sampling for all parameters at the site was discontinued from June of 1999 to July of 2000 for the construction of a new building.

The NO_2 monitor began operation in January 1973 at this location.

The SO_2 monitor began operation in January 1967.

O_3 monitoring began originally in 1972 and has been intermittently conducted to this day.

The O_3 monitor began operation in February 2012.

The PM_{10} monitoring began in 1986 with the installation of collocated monitors, and was furthered by the addition of a continuous monitor in 1988.

The $PM_{2.5}$ monitoring began in 1999 with a continuous and an FEM monitor, and was furthered by the addition of a collocated FEM monitor in 2001.

Meteorological monitoring began at this site in January of 1965.

NJH-E, 14th Avenue & Albion Street (08 031 0013):

This site is located 5 km east of the Denver CBD, close to a very busy intersection (Colorado Boulevard and Colfax Avenue). The current site began operations in 1982. Two previous sites were located just west of the current location. The first operated for only a few months before it was moved to a new site in the corner of the laboratory building at the corner of Colorado Boulevard and Colfax Avenue. Data from this continuous TEOM monitor is not compared with the NAAQS. It is used for short term forecasting and public notifications. The monitor here is a population-oriented middle scale special project monitor.

Denver Visitor Center, 225 W. Colfax Avenue (08 031 0017):

The Denver Visitor Center site is located near the corner of Colfax Avenue and Tremont Street. It began operation on December 28, 1992. In 1993, this site, along with the Denver CAMP and Gates monitors, recorded the first exceedances of the 24-hour PM_{10} standard in the Denver metropolitan area since 1987. Since then, high values have been observed, but have been below the NAAQS of 150 $\mu g\ m^{-3}$. In the past ten years, the 24-hour maximum levels have trended downward. This is a population-oriented middle scale SLAMS monitor operating on a daily sampling schedule.

La Casa, 4587 Navajo Street (08 031 0026):

The La Casa site was established in January of 2013 as a replacement for the Denver Municipal Animal Shelter (DMAS) site when a land use change forced the relocation of the site. The La Casa location has been established as the NCore site for the Denver Metropolitan area. In late 2012, the DMAS site was decommissioned and moved to La Casa in northwest Denver and includes a trace gas/precursor-level CO analyzer and a NO_y analyzer, in addition to the trace level SO_2, O_3, meteorology, and particulate monitors. La Casa was certified in 2013 as an NCore compliant site by the EPA. The site represents a population-oriented neighborhood scale monitoring area.

The trace level SO_2, CO, and NO_y analyzers began operation in January 2013.

The meteorological monitoring began at La Casa in January 2013.

PM_{10} monitoring began at La Casa in January 2013. Currently, there is a pair of collocated high volume samplers, and a Lo-Vol PM_{10} on the shelter roof. These concurrent PM_{10} measurements will be compared prior to removing the Hi-Vol PM_{10} monitors. The Lo-Vol PM_{10} concentrations are more useful as they can be used with the $PM_{2.5}$ measurements to calculate $PM_{10-2.5}$ or coarse PM.

$PM_{2.5}$ monitoring began at La Casa in January 2013 with an FRM monitor, a continuous TEOM/FDMS FEM instrument, a supplemental $PM_{2.5}$ speciation monitor, and a carbon speciation monitor. PM_{10}/lead (Pb-TSP) monitoring began in January 2013.

Chatfield State Park, 11500 N. Roxborough Park Road (08 035 0004):

The Chatfield State Park location was established as the result of the 1993 Summer O_3 Study. The original permanent site was located at the campground office. This site was later relocated on the south side of Chatfield State Park at the park offices. This location was selected over the Corps of Engineers Visitor Center across the reservoir because it was more removed from the influence of traffic along C-470. Located in the South Platte River drainage, this location is well suited for monitoring southwesterly O_3 formation in the Denver metro area.

$PM_{2.5}$ monitoring began at this site in 2004 with the installation of a continuous monitor, and was furthered by the addition of an FEM monitor in 2005.

Meteorological monitoring began in April of 2004.

United States Air Force Academy, USAFA Road 640 (08 041 0013):

The United States Air Force Academy site was installed as a replacement maximum concentration O_3 monitor for the Chestnut Street (08 041 0012) site. Modeling in the Colorado Springs area indicates that high O_3 concentrations should generally be found along either the Monument Creek drainage to the north of the Colorado Springs central business district (CBD), or to a lesser extent along the Fountain Creek drainage to the west of the CBD. The decision was made to locate this site near the Monument Creek drainage, approximately 15 km north of the CBD. This location is near the south entrance of the Academy but away from any roads. This is a population-oriented urban scale SLAMS monitor.

Colorado Springs Hwy-24, 690 W. Highway 24 (08 041 0015):

The Highway 24 site is located just to the west of I-25 and just to the east of the intersection of U.S. Highway 24 and 8th Street, approximately 1 km to the west of the Colorado Springs CBD. Commencing operation in November 1998, this site is a replacement for the Tejon Street (08 041 0004) CO monitor. The site is located in the Fountain Creek drainage and is in one of the busiest traffic areas of Colorado Springs. Additionally, traffic is prone to back-up along Highway 24 due to a traffic light at 8th Street. Thus, this site is well suited for the SLAMS network to monitor maximum concentrations of CO in the area both from automotive sources and also from nearby industry, which includes a power plant. It also provides a micro-scale setting for the Colorado Springs area, which has not been possible in the past. In January of 2013, an SO_2 monitor was added to the Highway 24 site to meet monitoring criteria for an increased population found during the 2010 census.

Manitou Springs, 101 Banks Place (08 041 0016):

Manitou Springs is a located 6 km west of Colorado Springs. It was established because of concern that the high concentration urban O_3 area was traveling farther up the Fountain Creek drainage and the current monitoring network was not adequate. The Manitou Springs monitor began operations in April 2004. It is located in the foothills above Colorado Springs in the back of the city maintenance facility. It has not recorded any levels greater than the current standard. This is a population-oriented neighborhood scale SLAMS monitor.

Colorado College, 130 W. Cache la Poudre Street (08 041 0017):

The Colorado College monitoring site was established in January 2007 after the revised particulate regulations required that Colorado Springs needed a continuous $PM_{2.5}$ monitor. The Division elected to collocate the new $PM_{2.5}$ monitor with the corresponding filter based monitors from the RBD site at the Colorado College location, which included a FRM $PM_{2.5}$ monitor and added a low volume FEM PM_{10} monitor in November 2007. The continuous monitor began operation in April of 2008.

The nearest representative meteorological site is located at the Colorado Springs Airport. Wind flows at the Colorado College site are affected by its proximity to Fountain Creek, so light drainage winds will follow the creek in a north/south direction. The three monitoring sites here are population-oriented neighborhood scale monitors, two on the SLAMS network (PM_{10} and $PM_{2.5}$) and one that is a special projects monitor ($PM_{2.5}$ continuous).

Cañon City - City Hall, 128 Main Street (08 043 0003):

Cañon City is located 63 km west of Pueblo. Particulate monitoring began on January 2, 1969 with the operation of a TSP monitor located on the roof of the courthouse building at 7th Avenue and Macon Street. The Macon Street site was relocated to the City Hall in October of 2004.

The Cañon City PM_{10} site began operation in December 1987. On May 6, 1988, the Macon Street monitor recorded a PM_{10} concentration of 172 $\mu g/m^3$. This is the only exceedance of either the 24-hour or annual NAAQS since PM_{10} monitoring was established at Cañon City. This is a population-oriented neighborhood scale SLAMS monitor on a 1 in 6 day sampling schedule.

Parachute – Elementary School, 100 E. 2nd Street (08 045 0005):

The Parachute site began operation in May 2000 with the installation of a PM_{10} monitor at the high school. This is a population-oriented neighborhood scale SLAMS monitor on a 1 in 3 day sampling schedule.

Rifle - Henry Building, 144 3rd Street (08 045 0007):

The first Rifle site began monitoring for particulates in June 1985 and ended operation in May 1986. The next site began operation in December 1987 and continued until 2001. The levels at that site, with the exception of the March 31, 1999 high wind event, were always less than one half of both the annual and the 24-hour standards. The current location at the Henry Building began operation in May of 2005 with the installation of a PM_{10} monitor as a part of the Garfield County study. There are now two population-oriented neighborhood scale special project PM_{10} monitoring sites: one on a 1 in 3 day sampling schedule, and one that is continuous. There is also a continuous monitor measuring $PM_{2.5}$ and PM_{10}, as well as meteorological monitors.

Rifle - Health Dept., 195 14th Ave (08 045 0012):

The Rifle Health Department site is located at the Garfield County Health Department building. The site is 1 km to the north of the downtown area and next to the Garfield County fairgrounds. The site is uphill from the downtown area. A small residential area is to the north and a commercial area to the east. This site was established to measure O_3 in Rifle, which is the largest population center in the oil and gas impacted area of the Grand Valley. Monitoring commenced in June 2008. This is a SLAMS monitor with a neighborhood scale.

Rocky Mountain School (Carbondale), 1493 County Road 106 (08 045 0018):

Carbondale is in the fairly narrow Roaring Fork valley between Aspen and Glenwood Springs. The Carbondale site is located just south of the confluence of the Crystal and Roaring Fork rivers and was established to monitor PM_{10} in January of 2013. This is a population-oriented neighborhood scale special project monitoring site.

Crested Butte, 603 6th Street (08 051 0004):

The Crested Butte PM_{10} site began operation in June 1985. Crested Butte is a high mountain ski town. The monitor is at the east end of town near the highway and in the central business district. Any wood burning from the residential area to the west directly affects this location. The physical setting of the town, near the end of a steep mountain valley, makes wood burning, street sanding, and wintertime inversions a major concern. The town is attempting to regulate the number of wood burning appliances, since this is a major source of wintertime PM_{10}.

There are two population oriented neighborhood scale monitors here, one in the SLAMS network (1 in 3 day sampling schedule) and one that is a continuous monitor.

Mt. Crested Butte, 19 Emmons Road (08 051 0007):

Mount Crested Butte is located at an elevation of 2,725 m at the base of the Crested Butte Mountain Resort ski area. Mount Crested Butte is a unique location for high particulate matter concentrations because it is located on the side of a mountain (Crested Butte, 3,707 m), not in a bowl, valley, or other topographic feature that would normally trap air pollutants. There is not a representative meteorological station in or near Mt. Crested Butte.

The location for the Mt. Crested Butte site was selected because it had an existing PM_{10} site that had several high PM_{10} concentrations including five exceedances of the 24-hour standard in 1997 and one in 1998. Mt. Crested Butte also exceeded the PM_{10} annual average standard in 2011. A CMB source apportionment from 10 PM_{10} filters identified crustal material as the mostly likely source (91%) of PM_{10}. Carbon, which is most likely from residential wood smoke, made up 8% of the statistically composite sample and secondary species made up the remaining one percent. The Mt. Crested Butte site was also selected because it is an area representative of the residential impact of PM_{10}. This is a population-oriented neighborhood scale SLAMS monitor on a daily sampling schedule.

Welch, 12400 W. Highway 285 (08 059 0005):

The Division conducted a short-term O_3 study on the grounds of Chatfield High School from June 14, 1989 until September 28, 1989. The Chatfield High School location was chosen because it sits on a ridge southwest of the Denver CBD. Wind pattern studies showed a potential for elevated O_3 levels in the area on mid to late afternoon summer days. There were no exceedances of the NAAQS recorded at the Chatfield High School site, but the levels were frequently higher than those recorded at the other monitoring sites south of the metro area.

One finding of the study was the need for a new, permanent site further north of the Chatfield High School location. As with most Denver locations, the predominant wind pattern is north/south. The southern flow occurs during the upslope, daytime warming period. The northern flow occurs during late afternoon and nighttime when drainage is caused by cooling and settling. The major drainages of Bear Creek and Turkey Creek were selected as target downwind transport corridors. These are the first major topographical features north of the Chatfield High School site. A point midway between the valley floor (Englewood site) and the foothill's hogback ridge was modeled to be the best estimate of the maximum downwind daytime transport area. These criteria were used to evaluate available locations. The Welch site best met these conditions. This site is located off State Highway 285 between Kipling Street and C-470. This is a population-oriented urban scale SLAMS monitor.

Rocky Flats - N, 16600 W. Highway 128 (08 059 0006):

The Rocky Flats - North site is located north-northeast of the plant on the south side of Colorado Highway 128, approximately 2 km to the west of Indiana Street. The site began operation in June 1992 with the installation of an O_3 monitor and meteorological monitors as a part of the first phase of the APCD's monitoring effort around the Rocky Flats Environmental Technology Site.

O_3 monitoring began as a part of the Summer 1993 Ozone Study. The monitor recorded some of the highest O_3 levels of any of the sites during that study. Therefore, it was included as a regular part of the APCD O_3 monitoring network. The Rocky Flats - North monitor frequently exceeds the current standard. This is a highest concentration oriented urban scale SLAMS monitor.

NREL Solar Radiation Research Laboratory, 2054 Quaker Street (08 059 0011):

The National Renewable Energy Laboratory (NREL) site is located on the south rim of South Table Mountain, near Golden, and was part of the Summer 1993 Ozone Study. Based on the elevated concentrations found at this location, it was made a permanent monitoring site in 1994. This site typically records some of the higher eight-hour O_3 concentrations in the Denver area, frequently exceeding the current standard. This is a highest concentration oriented urban scale SLAMS monitor.

Aspen Park, 26137 Conifer Road (08 059 0013):

The Aspen Park site began operation in May 2009. It is intended to verify/refute model predictions of above normal O_3 levels. In addition, passive O_3 monitors used in the area in a 2007 study indicated the possibility of higher O_3 levels. The monitor is located in an urban setting at a Park and Ride facility off of Highway 285, at an elevation of just over 2,500 meters. Because the site is nearly 1,000 meters higher than the average metro area elevation, it should see O_3 levels that are larger than those seen in the metro area, as O_3 concentrations increase with increasing elevation. Whether or not the increased concentrations will be a health concern will be determined with the data gathered from this monitor. This is a SLAMS neighborhood scale monitor.

Durango - River City Hall, 1235 Camino del Rio (08 067 0004):

Durango is the second largest city on the western slope. The town is situated in the Animas River Valley in southwestern Colorado. Its elevation is approximately 1,981 meters above mean sea level. The Animas valley through Durango is steep and narrow. Even though little meteorological information is available for the area, the microclimate of Colorado mountain communities is typically characterized by cold air subsidence, or drainage flows during the evening and early morning hours and up valley flows during afternoon and early evening hours when solar heating is highest. Temperature inversions that trap air pollutants near the surface are common during night and early morning hours. This is a population-oriented neighborhood scale SLAMS monitor that samples continuously.

Fort Collins – CSU – Edison, 251 Edison Street (08 069 0009):

Fort Collins does not have the population to require a particulate monitor under Federal regulations. However, it is one of the largest cities along the Front Range. There are two population oriented neighborhood scale SLAMS monitors, a PM_{10} and a $PM_{2.5}$, that sample on a 1 in 3 day sampling schedule. There is also continuous monitor measuring PM_{10} and $PM_{2.5}$.

Fort Collins - West, 3416 W. La Porte Avenue (08 069 0011):

The Fort Collins - West monitor began operation in May of 2006. The location was established based on modeling and to satisfy permit conditions for a major source in the Fort Collins area. The levels recorded for the first season of operation showed consistently higher concentrations than the 708 S. Mason Street monitor. This is a highest concentration oriented urban scale SLAMS monitor.

Fort Collins- Mason, 708 S. Mason Street (08 069 1004):

The 708 S. Mason Street site began operation in December 1980 and is located one block west of College Avenue in the Central Business District. The one-hour CO standard of 35 ppm as a one-hour average has only been exceeded on December 1, 1983, at 4:00 P.M. and again at 5:00 P.M. The values reported were 43.9 ppm and 43.2 ppm respectively. The eight-hour standard of 9 ppm was exceeded one or more times a year from 1980 through 1989. The last exceedances were in 1991 on January 31 and December 6 when values of 9.8 ppm and 10.0 ppm, respectively, were recorded.

Fort Collins does not have the population to require a CO monitor under Federal regulation. However, it is one of the largest cities along the Front Range and was declared in nonattainment for CO in the mid-1970s after exceeding the eight-hour standard in both 1974 and 1975. The current level of monitoring is in part a function of the resulting CO State Maintenance Plan (SMP) for the area. This is a population-oriented neighborhood scale SLAMS monitor.

O_3 monitoring began in 1980 and continues today.

In March 2012, the meteorological tower was relocated from a freestanding tower on the west side of the shelter to a shelter mounted tower on the south side of the shelter due to the Mason Street Redevelopment Project.

Grand Junction - Powell, 650 South Avenue (08 077 0017):

Grand Junction is the largest city on the western slope in the broad valley of the Colorado River. The monitors are on county owned buildings in the south side of the city. The site is on the southern end of the central business district and close to the industrial area along the train tracks. It is about a 1 km north of the river and about 0.5 km east of the railroad yard. This site monitors for 24-hour and hourly PM_{10} as well as for 24-hour and hourly $PM_{2.5}$.

Grand Junction - Pitkin, 645¼ Pitkin Avenue (08 077 0018):

The Grand Junction-Pitkin CO monitor began operation in January 2004. This monitor replaced the site at the Stocker Stadium. The Stocker Stadium location had become less than ideal with the growth of the trees surrounding the park and the Division felt that a location nearer to the CBD would provide a better representation of CO concentration values for the city. The CO concentrations at the Stocker Stadium site had been declining from an eight-hour maximum in 1991 of 7.8 ppm to 3.3 ppm in 2003. This is a population-oriented, micro-scale SLAMS monitor.

Meteorological monitors were installed in 2004, and include wind speed, wind direction, temperature and relative humidity sensors.

Palisade Water Treatment, Rapid Creek Rd (08 077 0020):

The Palisade site is located at the Palisade Water Treatment Plant. The site is 4 km to the east-northeast of downtown Palisade, just into the De Beque Canyon area. The site is remote from any significant population and was established to measure maximum concentrations of O_3 that may result from summertime up-flow conditions into a topographical trap. Monitoring commenced in May 2008. This is an urban scale special purpose monitor.

Cortez, 106 W. North St (08 083 0006):

The Cortez site is located in downtown Cortez at the Montezuma County Health Department building. Cortez is the largest population center in Montezuma County in the southwest corner of Colorado. Currently, there are O_3 and $PM_{2.5}$ monitors in operation at this site.

The O_3 site was established to address community concerns of possible high O_3 from oil and gas and power plant emissions in the area. Many of these sources are in New Mexico. Monitoring commenced in May 2008. This is an urban scale SLAMS monitor.

Aspen - Library, 120 Mill Street (08 097 0006):

Aspen is at the upper end of a steep mountain valley. Aspen does not have an interstate running through it. Aspen was classified as nonattainment for PM_{10}, but it is now under an attainment/maintenance plan. The valley is more restricted at the lower end, and thus forms a tighter trap for pollutants. The transient population due to winter skiing and summer mountain activities greatly increases the population and traffic during these seasons. There is also a large down valley population that commutes to work each day from as far away as the Glenwood Springs area, which is 66 km to the northeast.

The population-oriented neighborhood scale SLAMS monitor is operating on a 1 in 3 sampling schedule.

Lamar - Municipal Building, 104 Parmenter Street (08 099 0002):

The Lamar Municipal site was established in January of 1996 as a more population-oriented location than the Power Plant. The Power Plant site was located on the northern edge of town (until it was decommissioned in 2012), while the Municipal site is near the center of the town. Both sites have recorded exceedances of the 24-hour PM_{10} standard of 150 µg m^{-3}, and both sites regularly record values above 100 µg m^{-3} as a 24-hour average. This is a population-oriented neighborhood scale SLAMS monitor on a daily sampling schedule.

Pueblo – Fountain School, 925 N. Glendale Ave (08 101 0015):

Pueblo is the third largest city in the state, not counting communities that are part of Metropolitan Denver. Pueblo is principally characterized by rolling plains and moderate slopes with elevations ranging from

1,364 to 1,467 meters. The Rocky Mountain Front Range is about 40 km west and Pikes Peak is easily visible on a clear day.

Meteorologically, Pueblo can be described as having mild weather with an average of about 300 days of sunshine per year. Generally, wind blows up valley from the southeast during the day and down valley from the west at night. Pueblo's average wind speed ranges from 11 km per hour in the fall and early winter to 18 km per hour in the spring.

This site was formerly located on the roof of the Public Works Building at 211 E. D St., in a relatively flat area two blocks northeast of the Arkansas River. At the end of June in 2011 the Public Works site was shut down and moved to the Magnet School site as the construction of a new multi-story building caused a major change in the flow dynamics of the site. The new site began operations in 2011. The distance and traffic estimate for the surrounding streets falls into the middle scale in accordance with federal guidelines found in 40 CFR, Part 58, and Appendix D.

Steamboat Springs, 136 6th Street (08 107 0003):

Like other ski towns, Steamboat Springs has problems with wintertime inversions, high traffic density, wood smoke, and street sand. These problems are exacerbated by temperature inversions that trap the pollution in the valleys.

The first site began operation in Steamboat Springs in June 1985 at 929 Lincoln Avenue. It was moved to the current location in October 1986. The 136 6th Street location not only provides a good indication of population exposure, since it is more centrally located, but it has better accessibility than the previous location. This is a population-oriented neighborhood scale SLAMS monitor on a daily sampling schedule.

Telluride, 333 W. Colorado Avenue (08 117 0002):

Telluride is a high mountain ski town in a narrow box end valley. The San Miguel River runs through the south end of town and the town is only about 1 km wide from north to south. The topography of this mountain valley regime creates temperature inversions that can last for several days during the winter. Temperature inversions can trap air pollution close to the ground. Telluride sits in a valley that trends mainly east to west, which can trap air pollutants more effectively since the prevailing winds at this latitude are the westerly and the San Miguel River Valley is closed off on the east end. This is a population-oriented neighborhood scale SLAMS monitor on a 1 in 3 day sampling schedule.

Greeley - Hospital, 1516 Hospital Road (08 123 0006):

The Greeley PM_{10} monitor is on the roof of a hospital office building at 1516 Hospital Road. Greeley Central High School is located immediately to the east of the monitoring site. Overall, this is in an area of mixed residential and commercial development that makes it a good population exposure, neighborhood scale monitor. The distance and traffic estimates for the most controlling street easily falls into the neighborhood scale in accordance with federal guidelines found in 40 CFR, Part 58. This is a population-oriented neighborhood scale SLAMS monitor on a 1 in 3 day sampling schedule.

Winds in this area are primarily out of the northwest, with dominant wind speeds less than 5 mph. Secondary winds are from the north, north-northwest and east-southeast, with the most frequent wind speeds also being less than 5 mph. The most recent available wind data for this station is for the period December 1986 to November 1987. Predominant residential growth patterns are to the west and north with large industrial growth expected to the west. There are two feedlots located about 18 km east of the town. There was a closer feedlot on the east edge of town, but it was shut down in early 1999, after the town of Greeley purchased the land in 1997.

Platteville, 1004 Main Street (08 123 0008):

Platteville is located immediately west of Highway 85 along the Platte River valley bottom approximately 8 km east of I -25, at an elevation of 1,470 meters. The area is characterized by relatively flat terrain and is located about 2 km east of the South Platte. The National Oceanic and Atmospheric Administration (NOAA) operated the Prototype Regional Observational Forecasting System Mesonet network of meteorological monitors from the early 1990s through the mid 1990s in the northern Colorado Front Range area. Based on this data, the area around Platteville is one of the last places in the wintertime that the cold pool of air that is formed by temperature inversions will burn off. This is due to solar heating. The upslope/down slope Platte River Valley drainage and wind flows between Denver and Greeley make Platteville a good place to monitor $PM_{2.5}$. These characteristics also make it an ideal location for chemical speciation sampling, which began at the end of 2001.

The Platteville site is located at 1004 Main Street at the South Valley Middle School, located on the south side of town on Main Street. The school is a one-story building and it has a roof hatch from a locked interior room providing easy access to its large flat roof. There is a 2-story gym attached to the building approximately 28 meters to the Northwest of the monitor. The location of the Platteville monitor falls into the regional transport scale in accordance with federal guidelines found in 40 CFR, Part 58, and Appendix D. There are three monitors here. Two are population oriented regional scale monitors, one of which is on the SLAMS network and the other is for supplemental speciation. The SLAMS monitor is operating on a 1 in 3 day sampling schedule, while the speciation monitor is operating on a 1 in 6 day schedule. The remaining monitor is a population oriented neighborhood scale supplemental speciation monitor on a 1 in 6 day sampling schedule.

Greeley - Weld County Tower, 3101 35th Avenue (08 123 0009):

The Weld County Tower O_3 monitor began operation in June 2002. The site was established after the 811 15th Street building was sold and was scheduled for conversion to other uses. The Weld County Tower site has generally recorded levels greater than the old site. This is a population-oriented neighborhood scale SLAMS monitor.

Meteorological monitoring began in February of 2012.

Greeley West Annex Bldg, 905 10th Avenue (08 123 0010):

Greeley does not have the population to require a CO monitor under Federal regulations. However, it is one of the larger cities along the Front Range and was declared in nonattainment for CO in the late-1970s after exceeding the eight-hour standard in 1976 and 1977. The first Greeley monitor operated from December 1976 to December 1980. It was located at 15th Street and 16th Avenue and exceeded the eight-hour standard numerous times from 1976 through 1980. The monitor is a population-oriented neighborhood scale SLAMS monitor.

The 811 15th Street location began operation in November 1981 and was discontinued in 2002. The current monitor is located in the Weld County West Annex building, and began operations in December 2003. This location is in the Greeley CBD. The levels recorded at this site are comparable but slightly lower than those at the former 811 15th Street site, about a quarter of the eight-hour standard.