GARFIELD COUNTY
2011 AIR QUALITY MONITORING SUMMARY

Prepared for:

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LIST OF ACRONYMNS AND ABBREVIATIONS

ARS	Air Resource Specialists, Inc.
ATSDR	Agency for Toxic Substances and Disease Registry
BMCO	Battlement Mesa, Colorado Air Quality Monitoring Site
BRCO	Bell-Melton, Colorado Air Quality Monitoring Site
BTEX	Benzene, toluene, ethylbenzene, and xylenes
CARB	California Air Resources Board
CDPHE	Colorado Department of Public Health and Environment
EPA	U.S. Environmental Protection Agency
ERG	Eastern Research Group, Inc.
FRM	Federal Reference Method
GCPHD	Garfield County Public Health Department
HAPs	Hazardous Air Pollutants
NAAQS	National Ambient Air Quality Standards
NATTS	National Air Toxics Trends Stations
NIOSH	National Institute for Occupational Safety and Health
NO_X	Oxides of nitrogen
O_3	Ozone
PACO	Parachute Creek, Colorado Air Quality Monitoring Site
$PM_{2.5}$	Particulate matter ≤ 2.5 microns in diameter
PM_{10}	Particulate matter ≤ 10 microns in diameter
RICO	Rifle, Colorado Air Quality Monitoring Site
SNMOC	Speciated non-methane organic compounds
TEI	Thermo Environmental Instruments
TEOM	Tapered Element Oscillating Microbalance
TNMOC	Total non-methane organic compounds
UATMP	Urban Air Toxics Monitoring Program
VOC	Volatile organic compounds

EXECUTIVE SUMMARY

This report summarizes air quality monitoring data collected during 2011 in Garfield County, Colorado. The air quality monitoring stations summarized here are the Parachute, Rifle, Bell-Melton, and Battlement Mesa sites, which are all in close proximity to oil and gas development in the county. Volatile organic compounds (VOCs) and meteorology are monitored at all sites; VOCs monitored include speciated non-methane hydrocarbons (SNMOC) and carbonyl compounds. Additionally, particulate matter ≤ 10 micrometers in diameter (PM_{10}) was monitored at the Parachute and Rifle sites, and particulate matter ≤ 2.5 micrometers in diameter ($PM_{2.5}$) and ozone (O_3) are also monitored at the Rifle site.

Criteria pollutants monitored in 2011 included PM_{10} at the Parachute and Rifle sites, and $PM_{2.5}$ and O_3 at the Rifle site. Criteria pollutants are pollutants subject to the National Ambient Air Quality Standards (NAAQS). In 2011, air quality measurements in Garfield County did not violate air quality standards for O_3, PM_{10}, or $PM_{2.5}$.

Highest concentrations of $PM_{2.5}$ and SNMOCs were observed during the colder winter months, and highest PM_{10} concentrations were observed during both the winter and spring. SNMOC seasonal pattern can be influenced by the seasonal variations in temperature, as VOCs deplete faster during the summer due to higher reactivity at higher temperatures. Also, some emissions, including cold-start engine emissions and residential wood burning, are higher in the winter. High PM and SNMOC measurements in the winter are affected by temperature inversions in the Colorado River Basin. During an inversion, air pollutants can build up due to stagnant conditions and limited atmospheric mixing. Springtime concentrations of higher PM_{10} coincided with high wind events, which can entrain large dust particles in the air.

Light alkanes, which are some of the simplest and lightest SNMOC compounds, made up between 85 and 91% of the total SNMOC compounds measured. Natural gas production activities are likely the largest contributing source of light alkanes (e.g., ethane, propane, iso/n-butane, and iso/n-pentane) in the area. These compounds are not considered hazardous air pollutants (HAPs), so they are of lesser concern with respect to health effects, but can contribute to O_3 formation and odor issues. Measurements since 2008 show decreasing concentrations of these parameters at all sites.

Hazardous air pollutants (HAPs) are a subset of VOCs which are considered harmful to human health. HAP concentrations in Garfield County were compared to concentrations measured by the Environmental Protection Agency (EPA) for sites in the national Urban Air Toxics Monitoring Program (UATMP) and National Air Toxics Trends Stations (NATTS) network. Compared to the range of urban averages across the US as reported by the EPA, carbonyl compounds including formaldehyde and acetone measured in Garfield County were well below average. The benzene, toluene, ethylbenzene, and xylenes (BTEX) parameters were higher in Garfield County than averages measured by EPA's urban network.

The health effects of HAPs measured in Garfield County were reported for data collected in 2008 in the *Garfield County Air Toxics Inhalation Screening Level Human Risk Assessment* (CDPHE 2010). Findings of this report indicated that, individually, the HAP components were below risk assessment criteria, but cumulative effects approached chronic (70 year exposure

period) non-hazard levels. The largest contributors to the cumulative levels were benzene and formaldehyde. Measurements since 2008 indicate that annual averages of many HAPs have consistently decreased each year since 2008, and no HAPs have seen consistent increases in concentrations between 2008 and 2011. A risk assessment based on 2009-2011 HAPs levels will be prepared in a separate annual risk assessment report prepared separately by the Colorado Department of Public Health and Environment (CDPHE) Disease Control and Environmental Epidemiology Division.

1.0 INTRODUCTION

The Garfield County Public Health Department (GCPHD) air quality monitoring network has seen large expansions in recent years. In 2005, in response to citizen concerns, the GCPHD enhanced air quality monitoring efforts to evaluate levels of particulate matter ≤ 10 micrometers in diameter (PM_{10}) and volatile organic compounds (VOCs) in the area. In 2008, the monitoring network was modified to encompass speciated non-methane hydrocarbons (SNMOC) and carbonyl compounds. Also, the regulatory monitoring network was expanded to include particulate matter ≤ 2.5 micrometers in diameter ($PM_{2.5}$) and ozone (O_3). These changes were designed to serve a wide range of purposes, including monitoring of criteria pollutant levels, ozone formation potential, toxics assessments, and source attribution.

The 2011 monitoring network in Garfield County consisted of four (4) monitoring locations. Characteristics of the monitoring locations are described below.

- Parachute (PACO): Parachute is a small urban center of approximately 1,300 people within very close proximity to oil and development and production activities. The town is located along Interstate 70 and is the transportation hub for heavily traveled roads which service the surrounding canyons.
- Rifle (RICO): Rifle is a rapidly growing urban center on the Interstate 70 corridor with estimated population of about 9,200 people. Rifle is in close proximity to oil and gas development activities, and is also central to industrial support for the oil and gas industry.
- Bell-Melton (BRCO): The Bell-Melton site is a rural homestead approximately four miles south of the town of Silt, in close proximity to moderate oil and gas development and heavy natural gas production.
- Battlement Mesa (BMCO): Battlement Mesa is a rural community located about 1.5 miles southeast of Parachute. This site began operation in September 2010 in response to a proposed large natural gas development within to community, and to begin developing baseline data in advance of the project.

Figure 1-1 is a map of the monitoring sites and Table 1-1 lists the parameters monitored. The GCPHD monitors pollutants and meteorology at these stations with technical support from several agencies (noted in Table 1-1). The GCPHD also operates a digital Web camera at the Rifle site. Camera images are collected every 15 minutes and displayed on the Garfield County Air Quality Monitoring Web site (http://www.garfieldcountyaq.net), along with associated data.

Figure 1-1. Map of Garfield County Monitoring Sites.

Table 1-1

Garfield County
Parameters Monitored by Site

Component	Method	Sampling Frequency	Supporting Agency
Rifle, Colorado			
SNMOC	TO-12	24-hour (1/6 day)	ERG
Carbonyls	TO-11A	24-hour (1/12 day)	ERG
PM_{10}	FRM	24-hour (1/3 day)	CDPHE
PM_{10}	TEOM	Hourly	ARS
$PM_{2.5}$	TEOM	Hourly	ARS
Ozone	42C	Hourly	ARS
Meteorology	Various	Hourly	ARS
Visibility Web Camera	Digital	15-min	ARS
Parachute, Colorado			
SNMOC	TO-12	24-hour (1/6 day)	ERG
Carbonyls	TO-11A	24-hour (1/12 day)	ERG
PM_{10}	FRM	24-hour (1/3 day)	CDPHE
Meteorology	Various	Hourly	ARS
Bell-Melton, Colorado			
SNMOC	TO-12	24-hour (1/6 day)	ERG
Carbonyls	TO-11A	24-hour (1/12 day)	ERG
Meteorology	Various	Hourly	GCPHD
Battlement Mesa, Colorado			
SNMOC	TO-12	24-hour (1/6 day)	ERG
Carbonyls	TO-11A	24-hour (1/12 day)	ERG
Meteorology	Various	Hourly	GCPHD

2.0 DATA COLLECTION STATISTICS

Tables 2-1 through 2-4 list the data collection statistics by site and parameter for 2011. Quarterly time series plots for all parameters collected during 2011 are presented in Appendix A. Data collection statistics exceeded 80% for most parameters at most sites. Exceptions included carbonyl samplers, where several of the scheduled 1/12 day samples were not collected. Also, the continuous PM analyzer at the Rifle site experienced numerous instrument malfunctions, and power issues at the Bell-Melton site affected meteorological and carbonyl data collection.

Table 2-1

Data Collection Statistics for Parachute Site
1/1/2011 – 12/31/2011

Parameter	Interval	Data Recovery			Valid Data		Comments
		No. Possible	No. Collected	% Collected	No. Valid	% Valid	
Relative Humidity	hourly	8760	8635	98.6%	8635	98.6%	
Precipitation	hourly	8760	8628	98.5%	8628	98.5%	
Scalar Wind Direction	hourly	8760	8500	97.0%	8500	97.0%	
Scalar Wind Speed	hourly	8760	8624	98.4%	8624	98.4%	
Ambient Temperature	hourly	8760	8635	98.6%	8635	98.6%	
PM_{10}	1/3 day	110	110	100%	110	100%	
SNMOCs	1/6 day	60	50	82.0%	50	82.0%	
Carbonyls	1/12 day	30	21	70.0%	21	70.0%	

Table 2-2

Data Collection Statistics for Rifle Site
1/1/2011 – 12/31/2011

Parameter	Interval	Data Recovery			Valid Data		Comments
		No. Possible	No. Collected	% Collected	No. Valid	% Valid	
Ozone	hourly	8760	8710	99.4%	8634	98.6%	
Continuous $PM_{2.5}$	hourly	8760	6761	77.2%	5821	66.4%	TEOM mass flow controller failures (6/20-7/18, 8/29-9/1 and 9/17-11/17)
Continuous PM_{10}	hourly	8760	6761	77.2%	5821	66.4%	
Relative Humidity	hourly	8760	8604	98.2%	8604	98.2%	
Precipitation	hourly	8760	8598	98.2%	8598	98.2%	
Vector Wind Direction	Hourly	8760	8594	98.1%	8594	98.1%	
Vector Wind Speed	Hourly	8760	8594	98.1%	8594	98.1%	
Ambient Temperature	hourly	8760	8604	98.2%	8604	98.2%	
Filter Based PM_{10}	1/3 day	110	110	100%	110	100%	
SNMOCs	1/6 day	60	51	83.6%	51	83.6%	
Carbonyls	1/12 day	30	17	56.7%	17	56.7%	

Table 2-3

Data Collection Statistics for Bell-Melton Site
1/1/2011 – 12/31/2011

Parameter	Interval	Data Recovery			Valid Data		Comments
		No. Possible	No. Collected	% Collected	No. Valid	% Valid	
Relative Humidity	hourly	8760	6644	75.8%	3128	35.7%	Power supply issues at site
Scalar Wind Direction	hourly	8760	6644	75.8%	3188	36.4%	
Scalar Wind Speed	hourly	8760	6644	75.8%	3188	36.4%	
Ambient Temperature	hourly	8760	6644	75.8%	3188	36.4%	
SNMOCs	1/6 day	60	54	88.5%	54	88.5%	
Carbonyls	1/12 day	30	6	20.0%	6	20.0%	Power supply issues at site

Table 2-4

Data Collection Statistics for Battlement Mesa Site
1/1/2011 – 12/31/2011

Parameter	Interval	Data Recovery			Valid Data		Comments
		No. Possible	No. Collected	% Collected	No. Valid	% Valid	
Barometric Pressure	hourly	8760	8758	100%	7843	89.5%	
Relative Humidity	hourly	8760	8758	100%	8705	99.4%	
Scalar Wind Direction	hourly	8760	8758	100%	8740	99.8%	
Scalar Wind Speed	hourly	8760	8758	100%	8718	99.5%	
Ambient Temperature	hourly	8760	8758	100%	8739	99.8%	
SNMOCs	1/6 day	60	49	80.3%	49	80.3%	
Carbonyls	1/12 day	30	20	66.7%	20	66.7%	

3.0 METEOROLOGICAL SUMMARIES

Meteorological data are collected along with air quality parameters to better understand the local conditions and transport of air pollutants. Meteorological data collected at all sites includes wind speed, wind direction, temperature, relative humidity, and precipitation.

Figure 3-1 presents a map overlaid with wind roses from each of the Garfield County monitoring sites depicting wind direction and wind speed measured in 2011. The direction of the bar signifies the direction the wind is coming from, the length of the bars indicate the cumulative frequency for each direction, and the colors indicate wind speed. Note that, due to power supply issues, winds at the Bell-Melton site were only collected during the latter part of the year (September – December).

The map shows that winds at the Garfield County sites are influenced by flow along the Colorado River Basin, where Interstate 70 crosses through the county. Also, airflow is influenced by various drainage flows through valleys along various Colorado River tributaries.

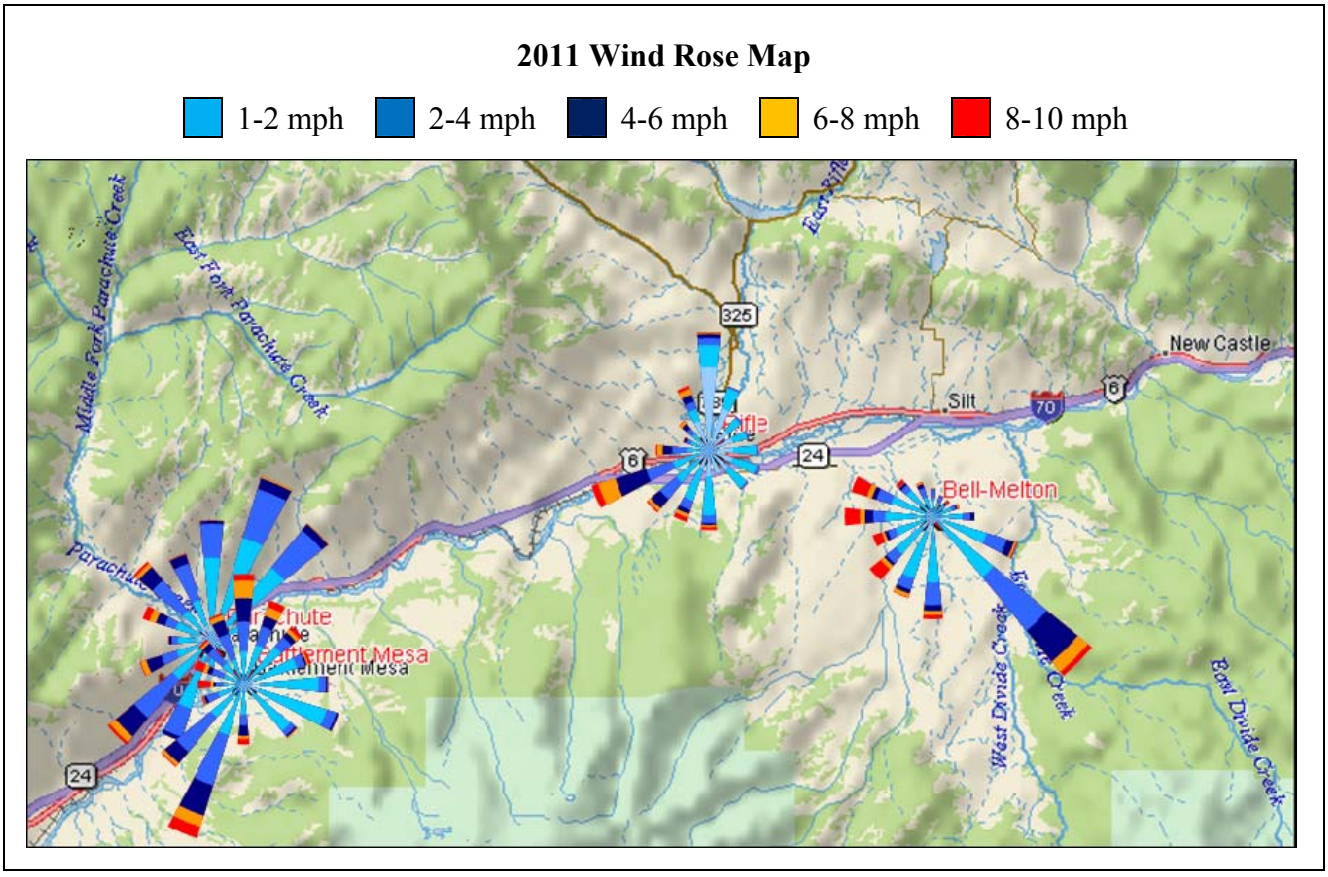

Figure 3-1. Map with Wind Roses Depicting 2011 Wind Speed and Direction Measured at the Garfield County Monitoring Sites.

4.0 CRITERIA POLLUTANT SUMMARIES

The Clean Air Act requires the Environmental Protection Agency (EPA) to set two types of National Ambient Air Quality Standards (NAAQS) for ground-level ozone (O_3), particle pollution ($PM_{2.5}$ and PM_{10}), lead, nitrogen dioxide (NO_2), carbon monoxide (CO), and sulfur dioxide (SO_2). The types of standards are as follows:

- Primary Standards: These standards are designed to protect public health with an adequate margin of safety, including the health of sensitive populations such as asthmatics, children, and the elderly.

- Secondary Standards: These standards are designed to protect public welfare from adverse effects, including visibility impairment and effects on the environment (e.g., vegetation, soils, water, and wildlife).

Filter-based PM_{10} measurements have been made every third day at the Parachute and Rifle sites for several years. Garfield County began monitoring continuous $PM_{2.5}$ and PM_{10} at the Rifle site in September 2008. The level of the national primary and secondary NAAQS for PM_{10} is a 24-hour average concentration of 150 micrograms per cubic meter ($\mu g/m^3$). A violation of the standard would occur if the number of days with a 24-hour average concentration above 150 $\mu g/m^3$ over a 3-year period is equal to or greater than one. The standards for $PM_{2.5}$ are an annual arithmetic mean of 15 $\mu g/m^3$ and a 24-hour average of 35 $\mu g/m^3$. A violation of the $PM_{2.5}$ standard occurs when the 3-year average of the weighted annual mean exceeds that annual standard, or the 3-year average of the 98th percentile 24-hour average value exceeds the 24-hour standard.

O_3 monitoring began at the Rifle site in June 2008. The current NAAQS for O_3 is 0.075 ppm (75 ppb) over an 8-hour period. An exceedance of the standard occurs when an 8-hour average O_3 concentration is greater than 75 ppb. A violation of the standard occurs when the 3-year average of the fourth highest daily maximum 8-hour average ozone concentration exceeds 75 ppb.

Values measured for O_3, $PM_{2.5}$, and PM_{10} in 2011 at the Rifle site are presented with corresponding NAAQS in Table 4-1, and PM_{10} measured at the Parachute site is presented in Table 4-2. At present, air quality measurements in Garfield County do not violate air quality standards for these criteria pollutants.

Table 4-1

2011 Standards Summary for the Rifle Site

Parameter	NAAQS		Measured	
	Averaging Time	Standard	Measured Value	Date(s)
Ozone (O_3)	Rolling 8-hour	0.075 ppm/ 75 ppb*	Highest Daily Max.: 68 ppb	6/10, 6/19
			4th Highest Daily Max.: 66 ppb	5/30, 6/14
Particulate Matter ≤2.5µm ($PM_{2.5}$)	Annual	15 µg/m^3	Arithmetic Mean: 8.2 µg/m^3	1/1-12/31
	24-hour	35 µg/m^3	Highest Max 24-hr: 31.8 µg/m^3	1/11
			2nd Highest Daily Max.: 17.5 µg/m^3	1/14
Particulate Matter ≤10µm (PM_{10})	24-hour	150 µg/m^3**	Highest Daily Max 24-hr: 54 µg/m^3	3/19
			2nd Highest Daily Max. 24-hr: 53 µg/m^3	4/9

*To attain the O_3 standard, the 3-year average of the fourth-highest daily maximum 8-hour average O_3 concentrations must not exceed the standard.

**To attain the PM_{10} standard, the average cannot exceed the standard more than once per year on average over 3 years.

Table 4-2

2011 Standards Summary for the Parachute Site

Parameter	NAAQS		Measured	
	Averaging Time	Standard	Measured Value	Date(s)
Particulate Matter ≤10µm (PM_{10})	24-hour	150 µg/m^3*	Highest Daily Max. 24-hr: 96 µg/m^3	3/22
			2nd Highest Daily Max. 24-hr: 73 µg/m^3	4/9

*To attain the PM_{10} standard, the average cannot exceed the standard more than once per year on average over 3 years.

4.1 OZONE

Ozone is a secondary pollutant, meaning it is not emitted directly from sources, but is formed from photochemical interactions of volatile organic compounds (VOCs) and oxides of nitrogen (NO_X) in the presence of sunlight. The basic formation and depletion equations for O_3 are presented below:

$NO_2 + \text{sunlight} \rightarrow NO + O$

$O + O_2 + M \rightarrow O_3 + M$ (where M is a non-reactive molecule required for this process)

$NO + O_3 \rightarrow NO_2 + O_2$

Without the presence of VOCs, the diurnal cycle is a balanced reaction, with equal production and depletion of O_3. When VOCs are present, they can react with nitric oxide (NO) to produce NO_2, as follows:

$NO + RO \rightarrow NO_2 + RO_2$ (where R represents a reactive VOC)

This effectively creates competition for NO, allowing O_3 to build up instead of being depleted by NO. Also, when NO reacts with hydrocarbons, additional NO_2 is produced without consuming O_3. The produced NO_2 can further react to produce more O_3.

Ozone measurements began in June 2008 at the Rifle site. Figure 4-1 presents the diurnal cycle of measured hourly O_3 at the Rifle station. The cycle shows lowest concentrations in the early morning hours and maximum concentrations in the late afternoon. This pattern results from daytime photochemical production from NO_X ($NO + NO_2$) and VOC precursors, and ozone loss by dry deposition and reaction with NO at night.

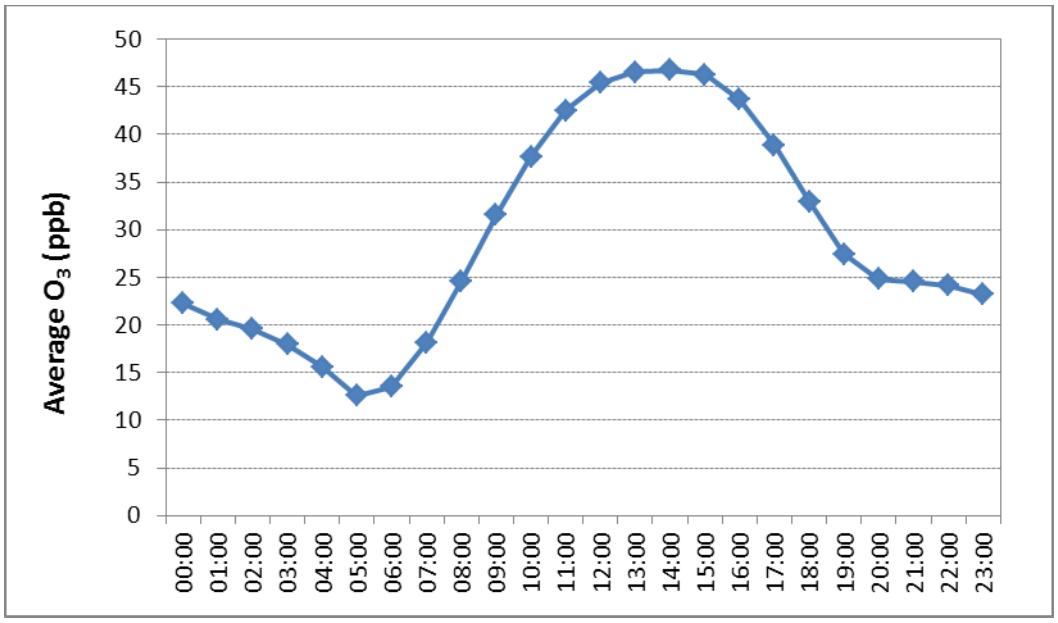

Figure 4-1. 2011 Diurnal Average Concentrations of Ozone Measured at the Rifle Site.

Figures 4-2 through 4-5 present daily maximum 8-hour averages of O_3 monitored at the site in 2008, 2009, 2010, and 2011 respectively, along with the NAAQS. It was previously thought that, due to the nature of ozone formation, elevated levels of ozone were only possible during hot summer months. Recently, high O_3 readings have been recorded during the wintertime in the Green River Basin in Wyoming, and the Uintah Basin in Utah. Wintertime O_3 formation requires, along with VOC and NO_2 emissions, distinct meteorological conditions. The meteorological conditions associated with wintertime O_3 include strong temperature inversions, low winds, snow cover, and bright sunlight. Ozone measurements at the Rifle site are highest in the summer, and Rifle has not seen the wintertime O_3 highs that have been observed in Wyoming and Utah.

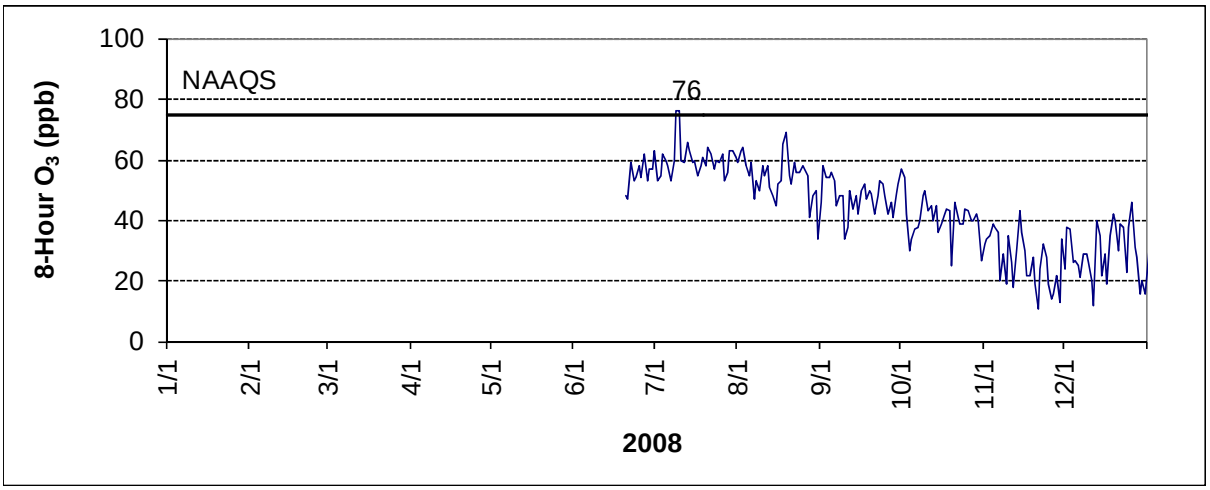

Figure 4-2. Daily Maximum 8-Hour Averages of Ozone Monitored at the Rifle Site in 2008.

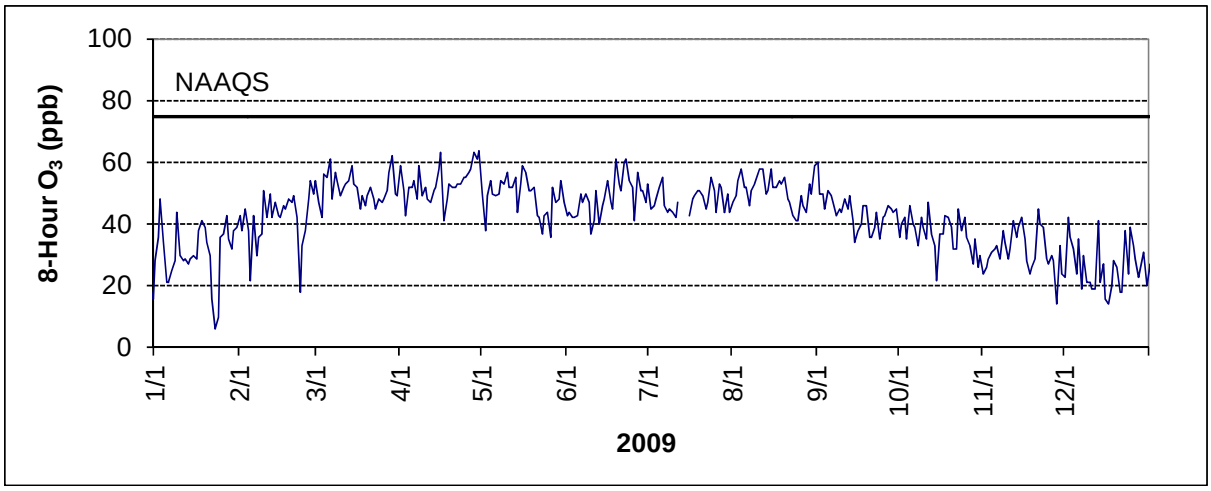

Figure 4-3. Daily Maximum 8-Hour Averages of Ozone Monitored at the Rifle Site in 2009.

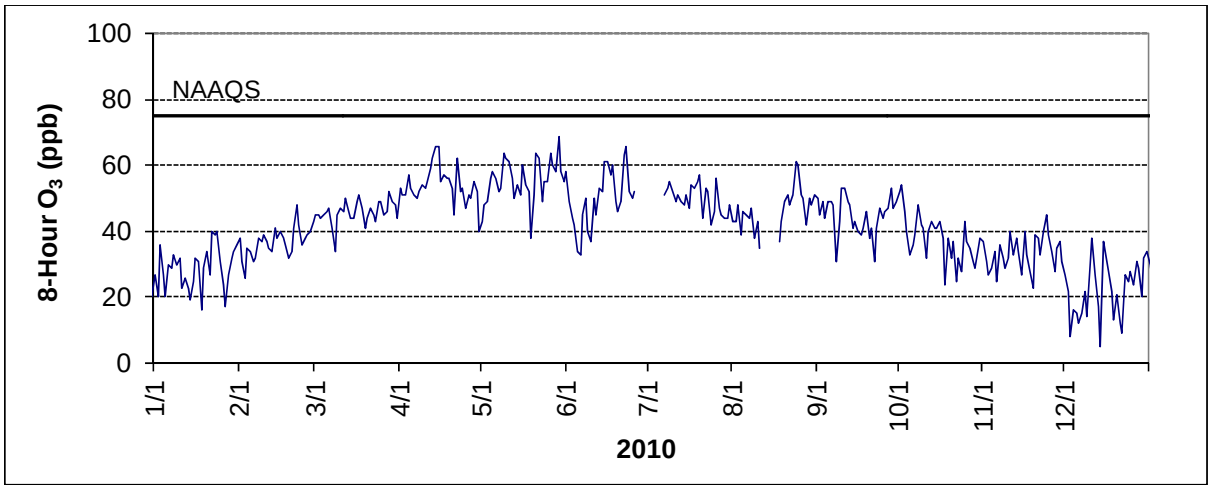

Figure 4-4. Daily Maximum 8-Hour Averages of Ozone Monitored at the Rifle Site in 2010.

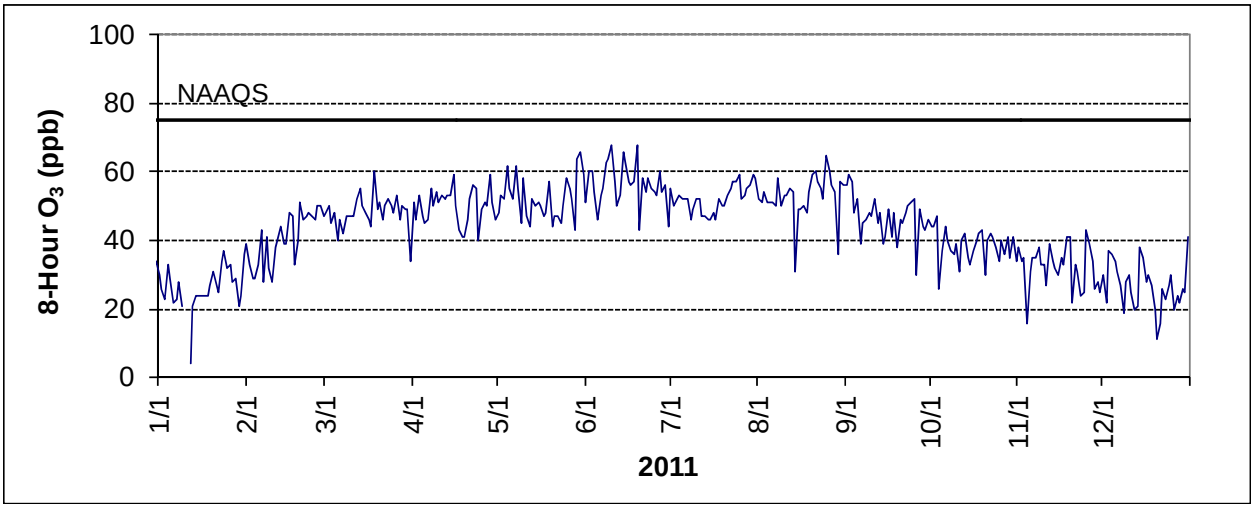

Figure 4-5. Daily Maximum 8-Hour Averages of Ozone Monitored at the Rifle Site in 2011.

4.2 PARTICULATE MATTER

Particulate matter (PM) consists of solid particles and liquid droplets that are small enough to be inhaled. The size of particles is directly linked to their potential for causing health problems. Particulate matter with diameter larger than 2.5 microns ($PM_{2.5}$) and smaller than 10 microns (PM_{10}) pose the greatest concern, because they can get deep into the lungs and cause serious health problems. Particulate matter can be emitted directly into the air or can be formed in the atmosphere through complex chemical reactions from emissions of sulfur dioxides, nitrogen oxides, and other compounds. Coarse particulate matter can come from sources like road dust, construction, and wood-burning. Particulate emissions associated with natural gas development may include grading and leveling of well pads, construction of facilities, construction of access roads to well pads, and subsequent vehicle traffic. Natural emissions like forest fires also contribute to levels of particulate matter.

Filter based PM_{10} is measured every third day at the Parachute and Rifle site. Continuous PM_{10} and $PM_{2.5}$ monitoring began at the Rifle site in September 2008. Hourly and 24-hour average values for these sites are presented in time series plots along with other parameters in Appendix A.

4.2.1 Filter Based PM_{10} Measurements

Figure 4-6 presents the annual average PM_{10} measured at the Parachute site since 2000, and Figure 4-7 presents annual average PM_{10} measured at the Rifle site since 2005. At both the Rifle and Parachute sites, the highest average recorded PM_{10} was recorded in 2008, but measurements at this site have dropped since 2009.

Figures 4-8 and 4-9 present the highest and second highest 24-hour average values measured at the Parachute and Rifle sites, respectively. The NAAQS for PM_{10} is a 24-hour average of 150 ppb, which was exceeded at the Parachute site in 2008. No exceedances have been recorded at the Rifle site. An exceedance of the standard is not a violation unless the average number of annual exceedances over a 3-year period is greater than or equal to 1.

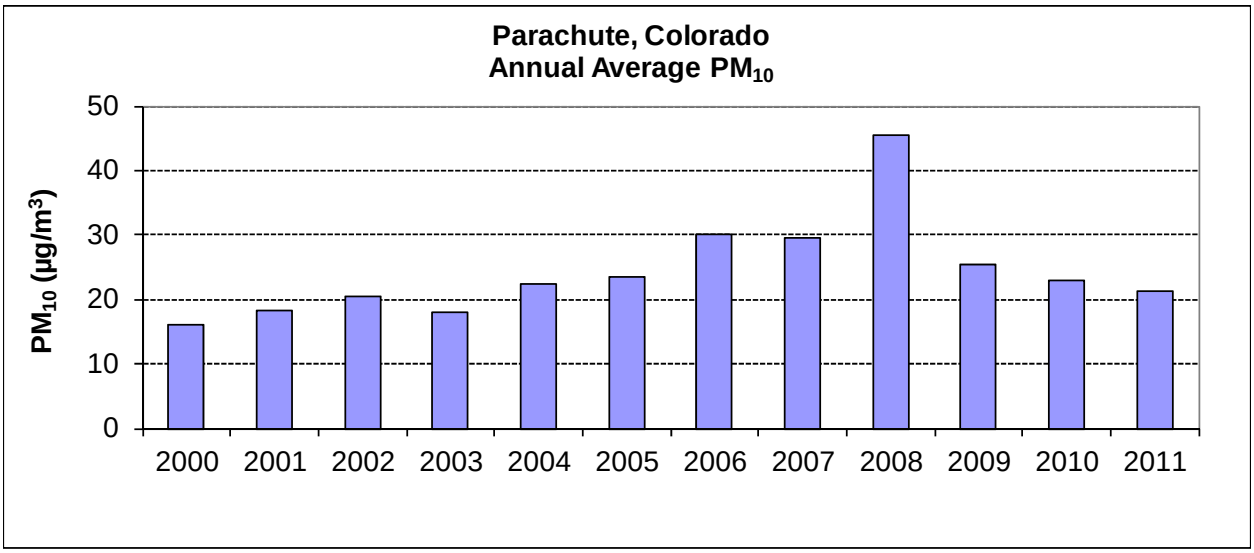

Figure 4-6. Annual Average PM_{10} Measured at the Parachute Site.

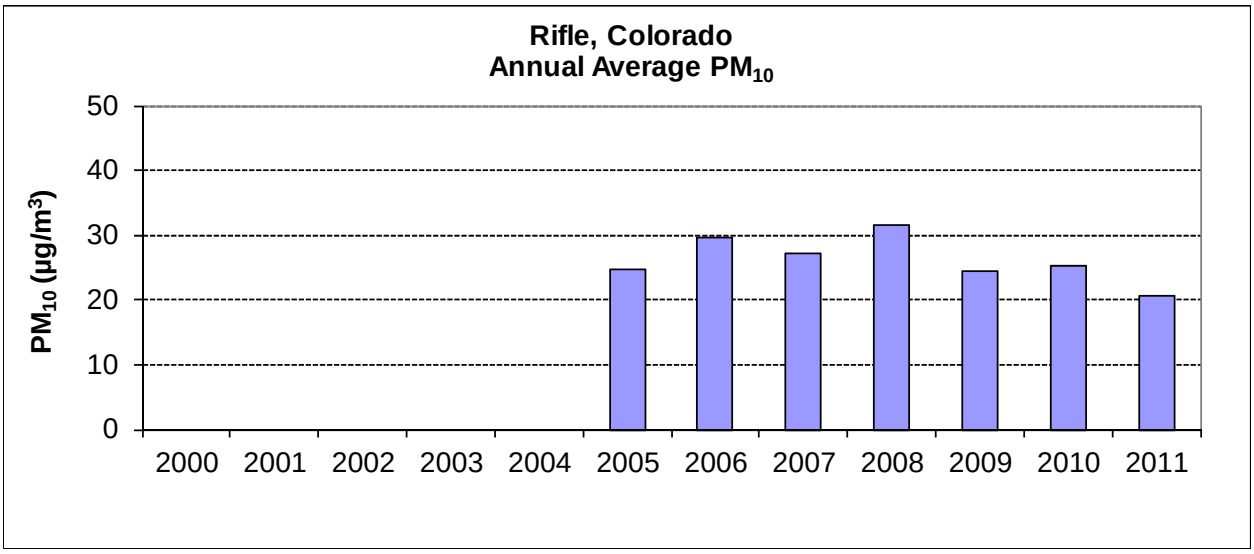

Figure 4-7. Annual Average PM_{10} Measured at the Rifle Site.

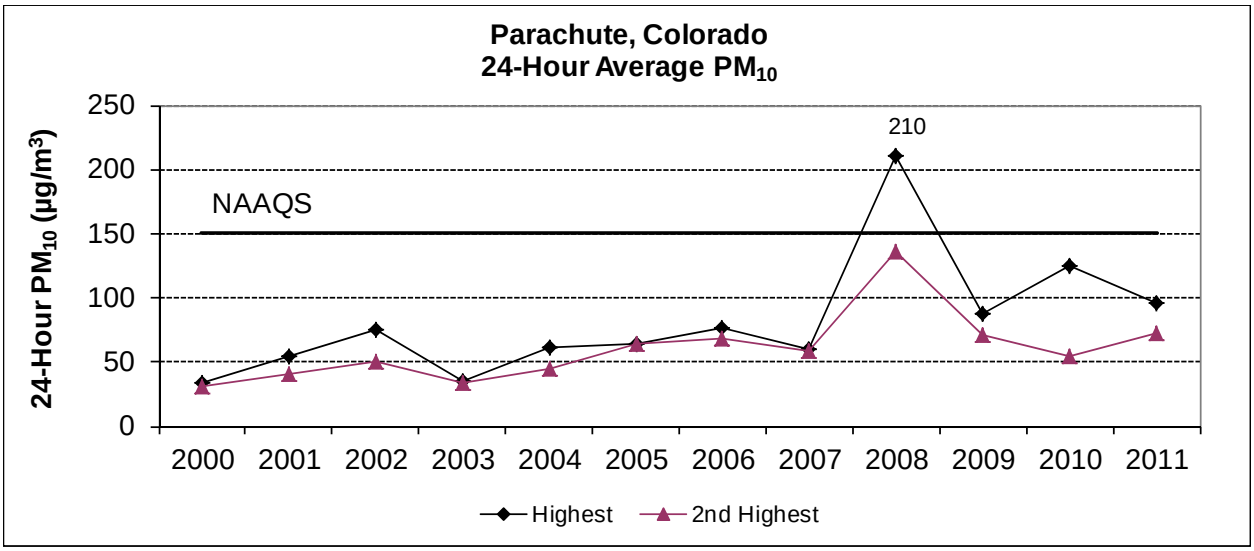

Figure 4-8. Highest and Second Highest 24-Hour Average PM_{10} Measured at the Parachute Site.

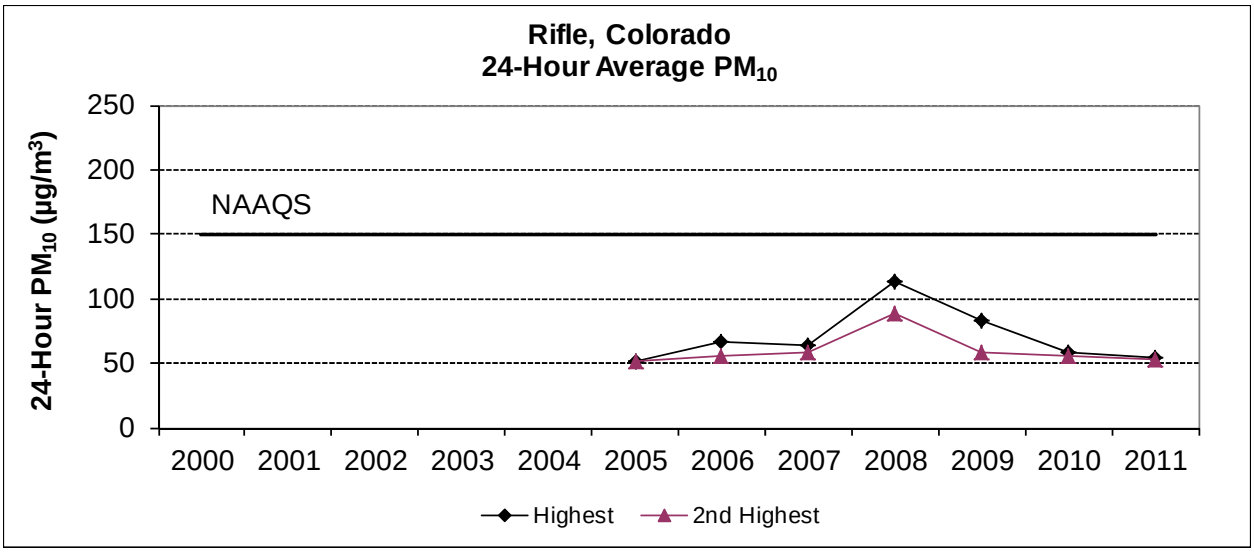

Figure 4-9. Highest and Second Highest 24-Hour Average PM_{10} Measured at the Rifle Site.

4.2.2 Collocated PM_{10} Measurements

Continuous PM_{10} is collocated with the filter based PM_{10} measurements at the Rifle site. The filter based reference method data are useful for comparison to NAAQS, but are only available every third day in 24-hour averages. Continuous data are useful to assess particulate pollution because they are available on an hourly basis, and are available in real-time. Figure 4-10 presents a correlation plot comparing 24-hour averages from both methods showing correlation between the collocated methods, which is good (R^2=0.66), but lower than previous years because of the effect of a few outliers.

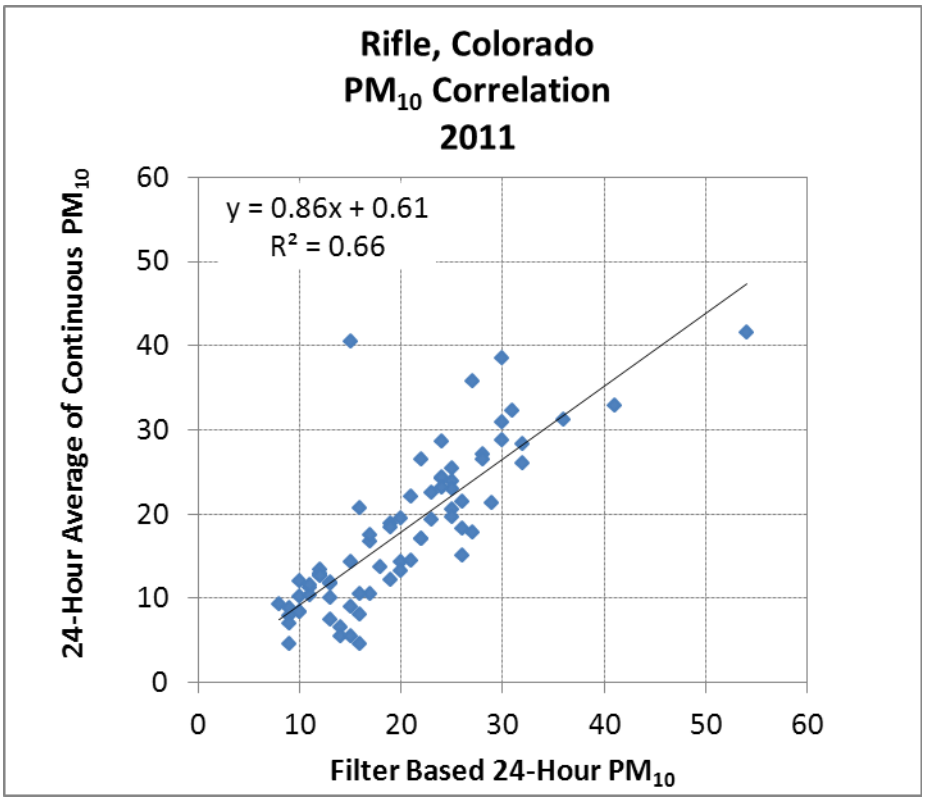

Figure 4-10. Correlation between Continuous and Filter Based Measurements at the Rifle Monitoring Site in 2011.

4.2.3 Continuous PM Measurements

Continuous PM_{10} and $PM_{2.5}$ are have been monitored at the Rifle site since mid-2008. Figure 4-11 presents the annual average of continuous $PM_{2.5}$ measured at the Rifle site since 2009, and Figures 4-12 presents the highest and 98th percentile 24-hour average values measured at the Rifle site. The NAAQS for $PM_{2.5}$ is an arithmetic mean of 15 µg/m^3 and a 24-hour average of 35 µg/m^3. A violation of the $PM_{2.5}$ standard occurs when the 3-year average of the weighted annual mean exceeds that annual standard, or the 3-year average of the 98th percentile 24-hour average value exceeds the 24-hour standard. The highest 24-hour $PM_{2.5}$ value in 2009 measured above the standard, but this is not considered an exceedance because the 98th percentile value was below the standard.

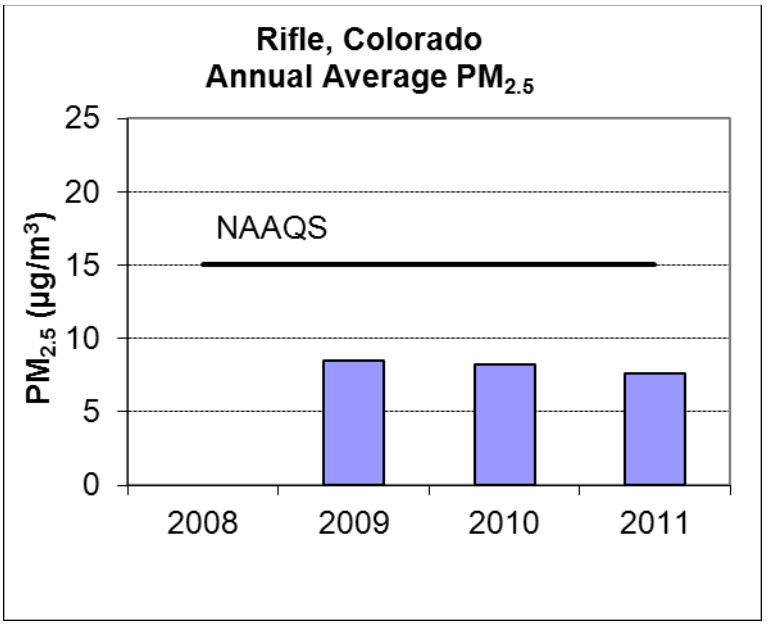

Figure 4-11. Annual Average $PM_{2.5}$ Measured at the Rifle Site.

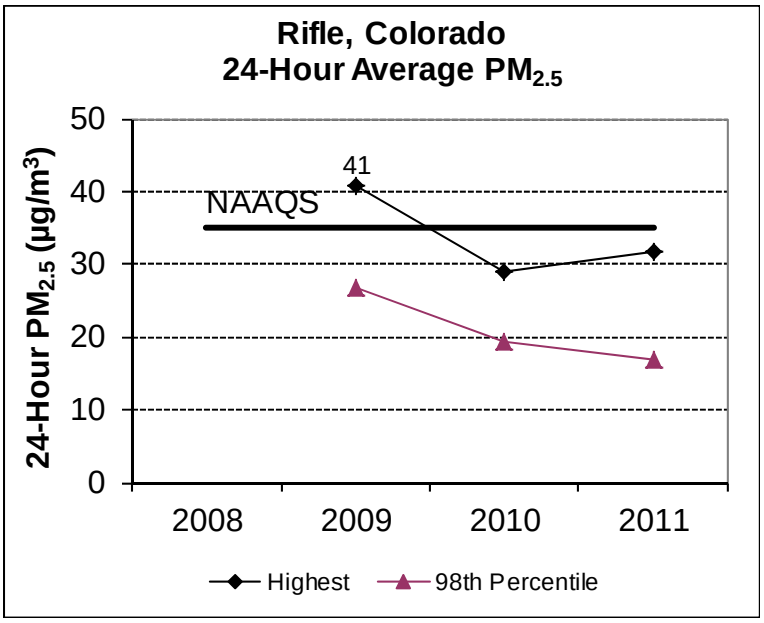

Figure 4-12. Highest and 98th Percentile 24-Hour Average $PM_{2.5}$ Measured at the Rifle Site.

5.0 VOLATILE ORGANIC COMPOUNDS

In 2011, speciated non-methane hydrocarbons (SNMOCs) and carbonyl compounds were monitored at all of the Garfield County stations. SNMOCs and carbonyl compounds are subsets of volatile organic compounds (VOCs), which are carbon- and hydrogen-based chemicals that exist in the gas phase or can evaporate from liquids. VOCs can react in the atmosphere to form ozone (O_3) and particulate matter with diameter larger than 2.5 microns ($PM_{2.5}$). Hazardous air pollutants (HAPs) are a subset of VOC compounds, and include compounds that are known or believed to cause human health effects. Summaries of SNMOCs, carbonyls, and HAP levels measured in 2011 are presented in this section. Plots of the sum of all SNMOCs measured, or total non-methane organic carbon (TNMOC) are presented along with other particulate, gaseous and meteorological measurements at each site in Appendix A.

5.1 SPECIATED NON-METHANE HYDROCARBONS

SNMOC compounds were collected and analyzed according to EPA Compendium Method TO-12, with 24-hour samples collected at all sites on a 1-in-6 day schedule. This method includes analyses for 78 different compounds. Appendix B lists minimum, maximum, and average concentrations of all detected SNMOC compounds by site.

SNMOC compounds can be grouped into classifications with similar characteristics. For these summaries, measured SNMOC compounds were grouped into the following categories:

- Light Alkanes: Alkanes are the simplest hydrocarbons, consisting of only carbon and hydrogen with single bonds. Light alkanes, which include alkanes with up to five carbon atoms (ethane, propane, iso/n-butane and iso/n-pentane), along with methane, are primary components of natural gas and gasoline vapors.

- Heavy Alkanes: The hydrocarbons in crude oil are mostly heavy alkanes, which here include alkanes with more than five carbon atoms (C5). Crude oil products include gasoline, a refined mix of predominantly C6 to C10 hydrocarbons, and diesel, which is a refined mix ranging from approximately C10 to C15.

- Alkenes: Alkenes are more complex than alkanes, with at least one carbon to carbon double bond. These compounds are not generally found in crude oil. Alkenes are much more reactive than alkanes, and will deplete quickly in the atmosphere. Alkenes are produced in refineries when larger alkane molecules are dissociated (or cracked) into smaller compounds. Some alkene compounds, including terpenes such as isoprene and a- and b-pinene, are naturally emitted from vegetation.

- Aromatics: Aromatic compounds are the most abundant compounds emitted from gas-fired engines. These compounds include the BTEX parameters (benzene, toluene, ethylbenzene, and m/p-xylenes), which are commonly associated with motor vehicles, but can also have sources associated with oil and gas production.

Figure 5-1 presents categories of measured SNMOCs in units of ppbV (parts per billion by volume) measured in 2011 at each site. In general, measured compounds consisted mostly of

light alkanes, which represented between 85 and 91% of total SNMOCs measured. Seasonal variation showed higher concentrations in winter and lower concentrations in summer. These trends can be influenced by the variations in temperature, as VOCs deplete faster during the summer due to higher reactivity at higher temperatures. Also, some emissions, including cold-start engine emissions and residential wood burning, are higher in the winter.

Figure 5-2 presents measurements by category in units of ppbC, where ppbC represents the number of carbon molecules measured (ppbV multiplied by the number of carbons in each compound). Heavier alkanes and aromatics are more significant sources of carbon than the lighter alkanes. The unknown category indicates the part of the total carbon measurements where individual species were not identified.

Carbon content in a molecule is related to the compound reactivity, which contributes to ozone formation potential. Ozone is formed from photochemical interactions of VOCs and NO_X in the presence of sunlight, as described in Section 4.1. The light alkanes that dominate measurements by volume are the least reactive compounds but could theoretically contribute significantly to O_3 formation potential. Highly reactive compounds including aromatics such as toluene and m/p-xylenes, which are less abundant, but have greater potential to contribute to the O_3 formation due to their higher reactivity. Currently, Garfield County does not violate O_3 standards, but if O_3 levels become more of a concern in Garfield County, it would be useful to monitor NO_2, and to target further controls for emissions for VOCs that have the greatest potential to contribute to O_3 formation.

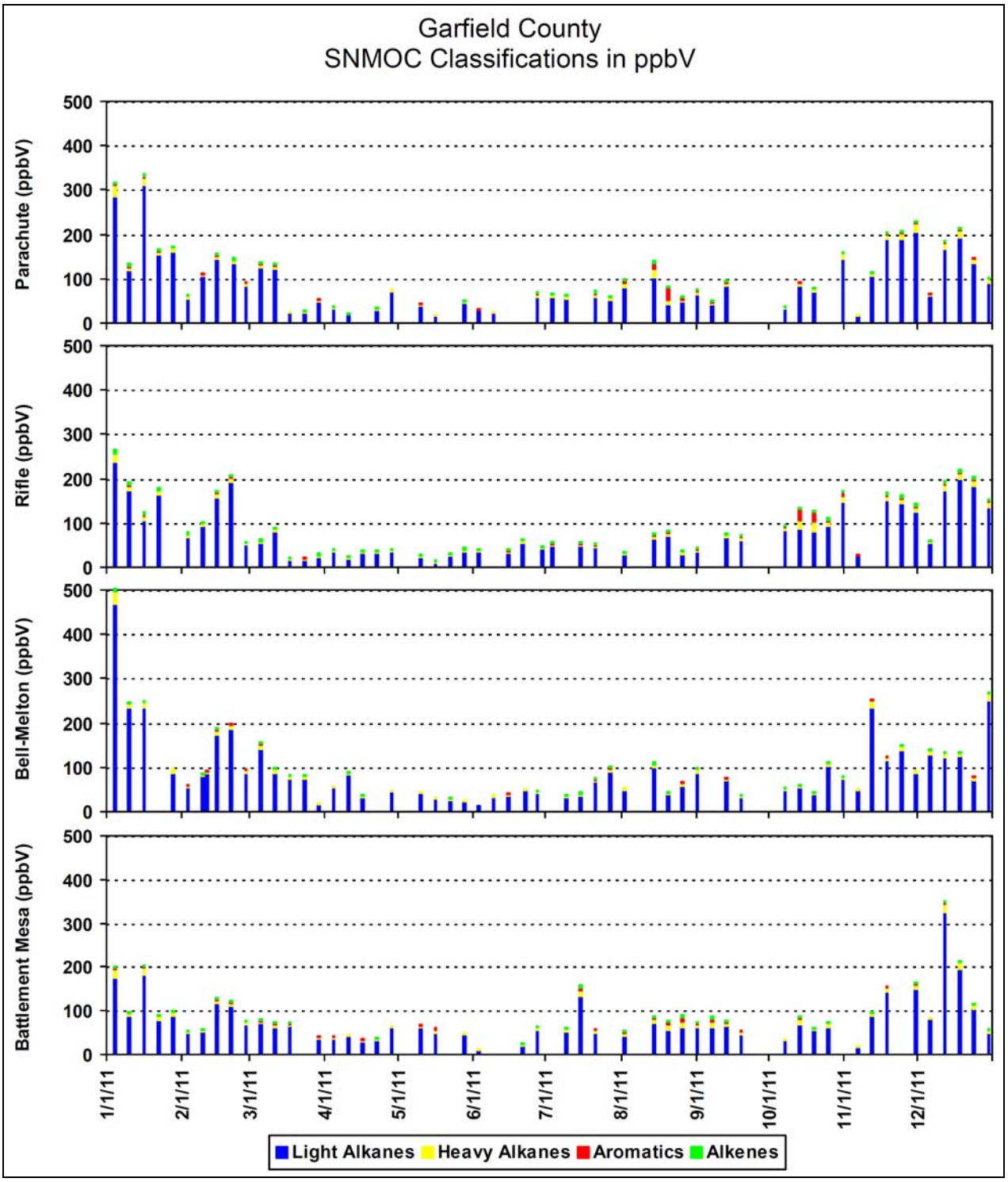

Figure 5-1. 2011 24-Hour SNMOC Measurements by Category in Units of ppbV.

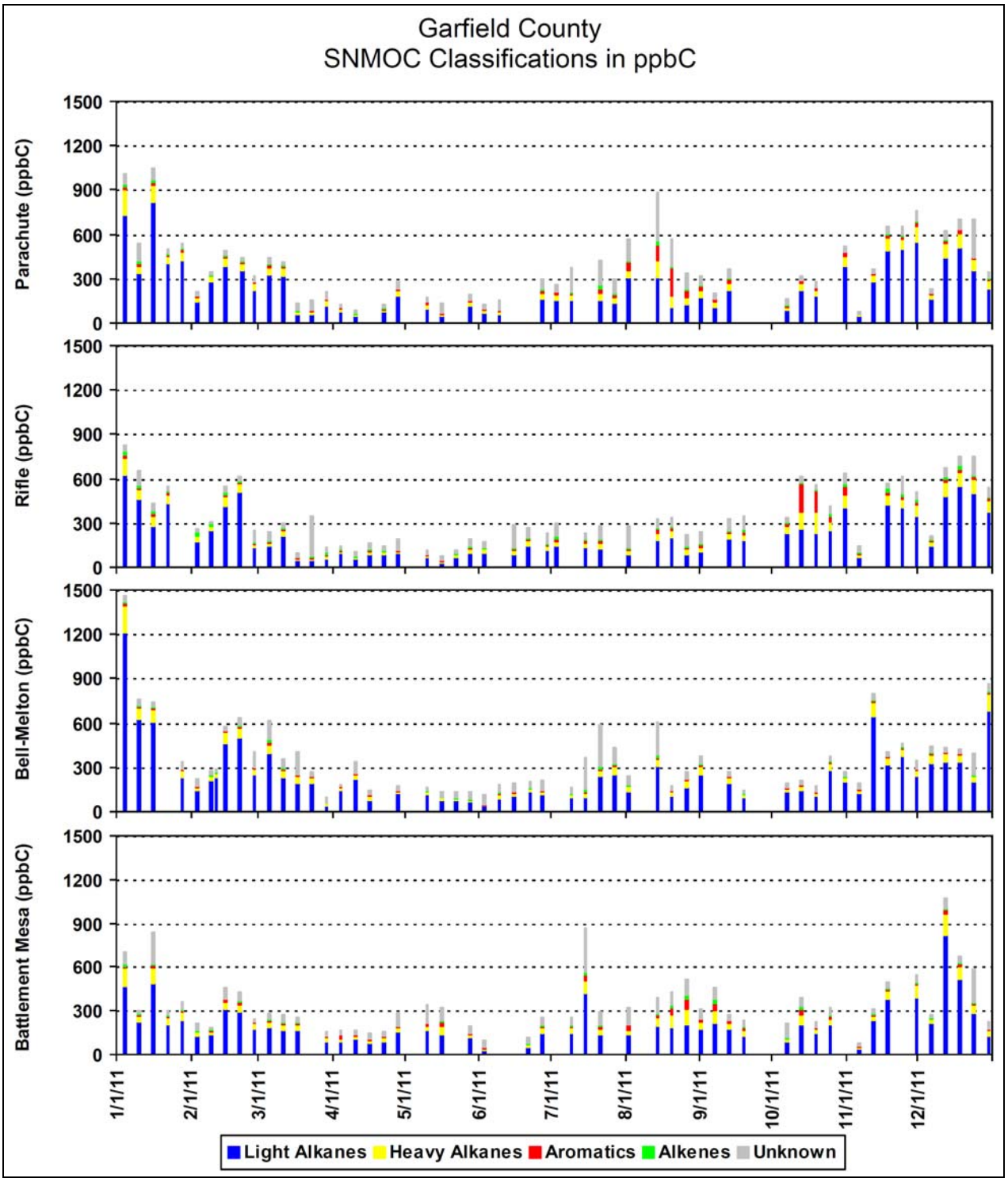

Figure 5-2. 2011 24-Hour SNMOC Measurements by Category in Units of ppbC.

5.1.1 Weighted Wind Roses

Weighted wind roses were constructed for 2011 to examine potential regional influences to SNMOC compounds measured at the site. A wind rose shows the frequency of wind direction and uses different shading to represent wind speeds, while a weighted wind roses show wind direction and wind speed only for select conditions.

Some pollutants affecting air quality are emitted locally, while others may be transported from other regions. Wind directions and speeds measured during the highest pollutant measurements are most instructive for pollutants that may be transported from other regions. Transport distance can depend on atmospheric lifetimes which, for VOC compounds, are highly variable depending on the reactivity of the compound and other removal pathways. Benzene, for example, can have a lifetime of up to 84 hours in the atmosphere before oxidizing; formaldehyde for up to 26 hours; and 1,3-butadiene for about 2.8 hours (http://www.scorecard/chemical-profiles/).

Figures 5-3 and 5-4 present maps overlaid with weighted wind roses, where only wind speed and direction measured during hours when TNMOC, or the sum of all SNMOC hydrocarbons measured, was among the highest 20% and lowest 20%, respectively, of values measured at each site. SNMOCs were sampled every 6 days, so the 20% best and worst sampled days represent about 10 days in a year. Note that TNMOC measurements are 24-hour measurements, and all winds as measured on a 1-hour basis during the 24-hour period with highest and lowest TNMOC are plotted on the maps.

Variations from normal wind patterns, which were summarized for 2011 in Section 3.0, are considered here to indicate whether conditions that favor higher or lower pollutant measurements are different from normal wind patterns at a site. The weighted wind rose maps indicate that highest TNMOC measurements were generally similar in shape to the wind roses for all days, with flow influenced by the Colorado River Basin and the various valleys along various Colorado River tributaries. The Rifle site showed the most variation from normal wind patterns, with calmer winds more frequently out of the south on the higher TNMOC days.

For the lowest days, a higher percentage of winds, as compared to the annual average winds, were measured along the Colorado River Basin at the Parachute and Rifle sites. The Bell-Melton site had higher occurrences of winds from the north-northeast and south-southwest, as compared to the normal wind patterns, but it should be noted that meteorological data at the Bell-Melton site were only available during the latter half of the year (September through December). The Battlement Mesa site did not have any notable variations from normal wind patterns on the lowest (and highest) measured TNMOC days, indicating that wind patterns do not significantly influence the TNMOC at the site.

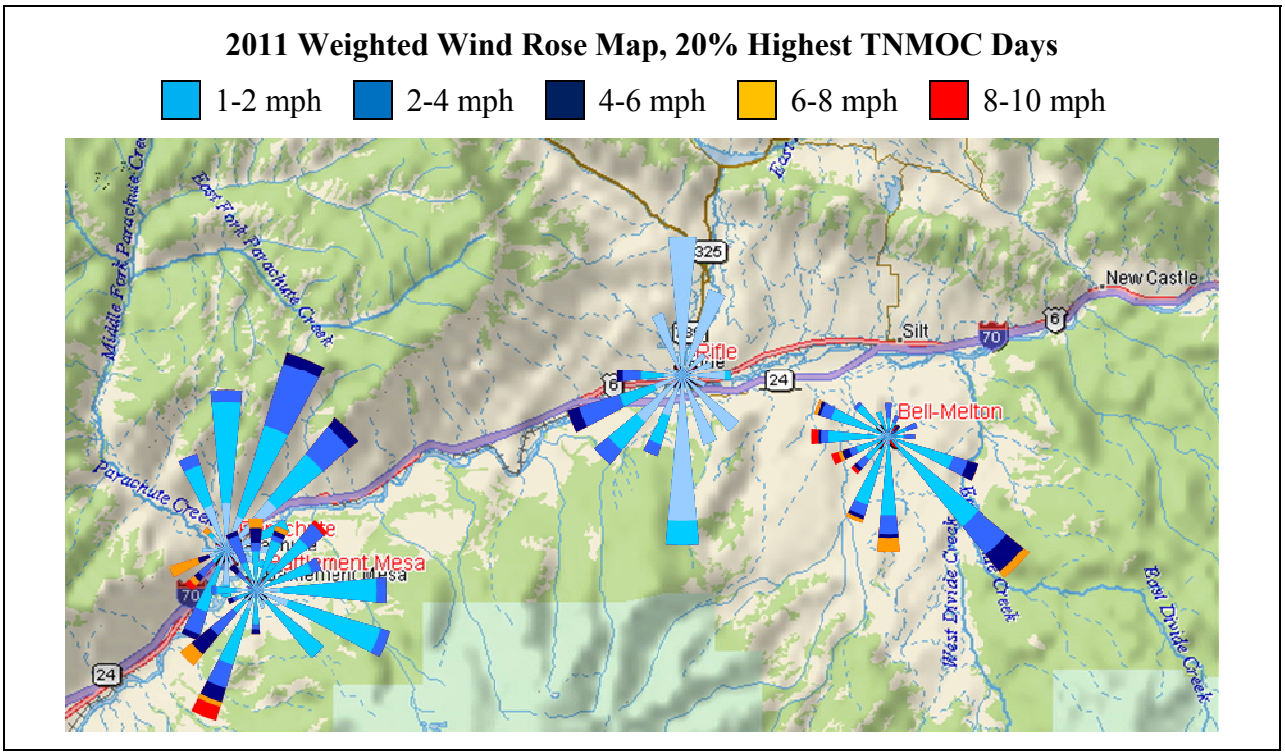

Figure 5-3. Wind Rose Map Representing Wind Direction and Wind Speed Measured on Highest 20% TNMOC days.

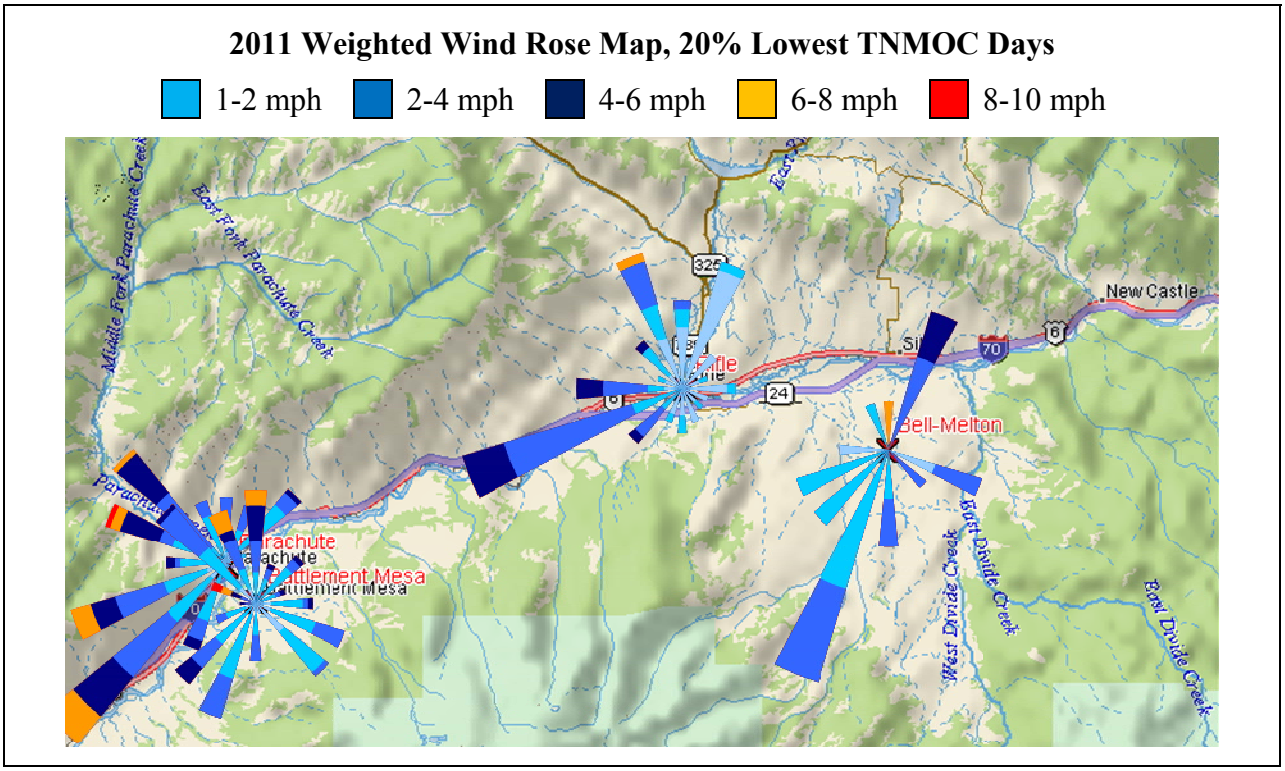

Figure 5-4. Wind Rose Map Representing Wind Direction and Wind Speed Measured on Lowest 20% TNMOC days.

5.1.2 Annual Average SNMOCs

Garfield County began collecting SNMOC data at the Parachute, Rifle and Bell-Melton sites in 2008, and at the Battlement Mesa (BMCO) in September 2010. Figure 5-5 presents comparisons of annual average SNMOC data collected between 2008 and 2011. For sites that monitored all three years (PACO, RICO and BRCO), SNMOC concentrations have been decreasing since 2008. This is due mostly to decreased light alkane concentrations, which are the primary components of natural gas.

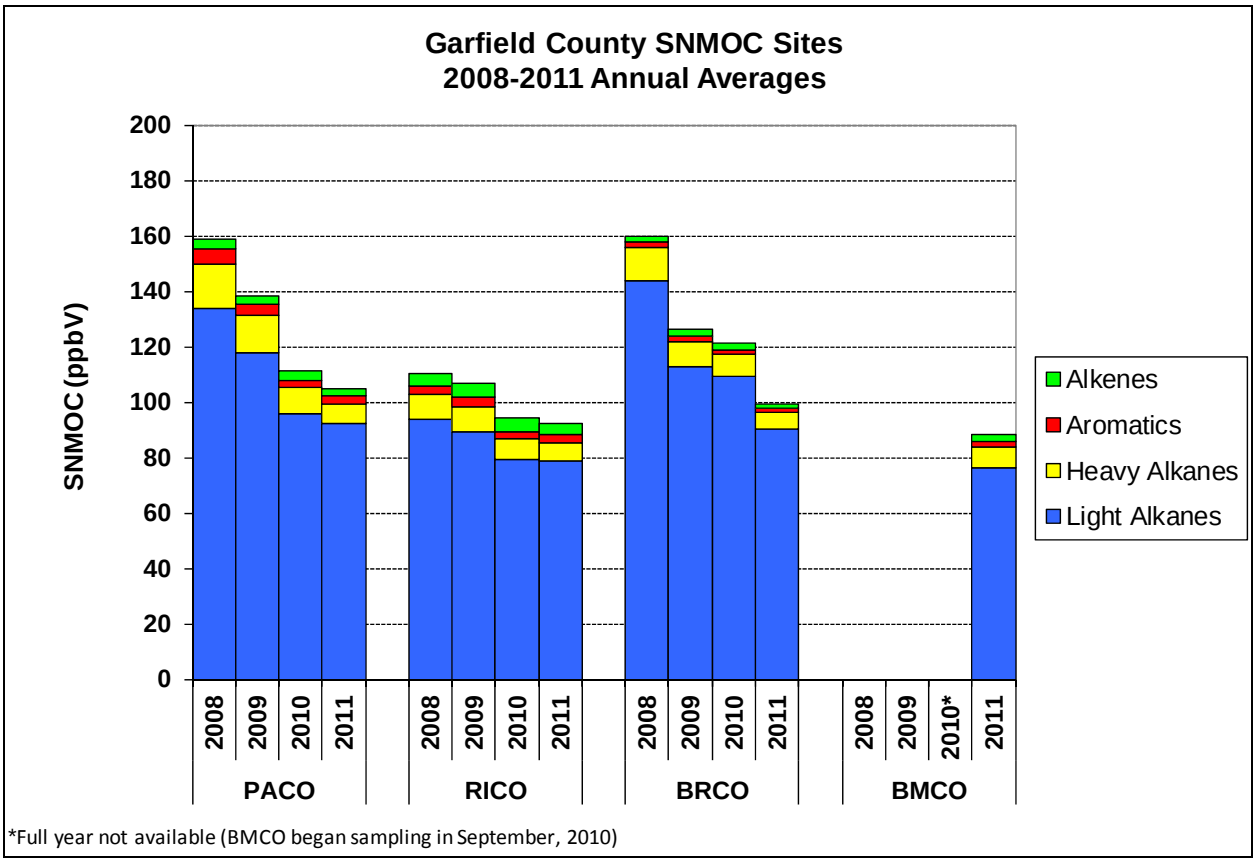

Figure 5-5 Average SNMOC Concentrations Measured by the Garfield County Air Monitoring Program between 2008 and 2011.

5.2 CARBONYLS

Carbonyl compounds were collected and analyzed according to EPA Compendium Method TO-11A, with 24-hour samples collected at all four sites on a 1-in-12 day schedule. This method includes analysis for 12 different carbonyl compounds.

Carbonyls are highly reactive and play a critical role in the formation of O_3. Some carbonyls, including formaldehyde and acetaldehyde, also have adverse chronic and acute health

effects. The major sources of directly emitted carbonyls are fuel combustion, mobile sources, and process emissions from oil refineries (CARB 2009).

Appendix C lists minimum, maximum, and average concentrations of all detected carbonyl compounds. Figure 5-6 presents a time series of the major compounds, Major compounds included formaldehyde, acetaldehyde, and acetone, measured in 2011. Carbonyl sampling at the Bell-Melton site was temporarily interrupted due to power failures in early 2011, with sampling resuming in September 2011. In general, carbonyl compounds were highest during the summertime. The formation of these compounds during warm months is influenced by photochemical production.

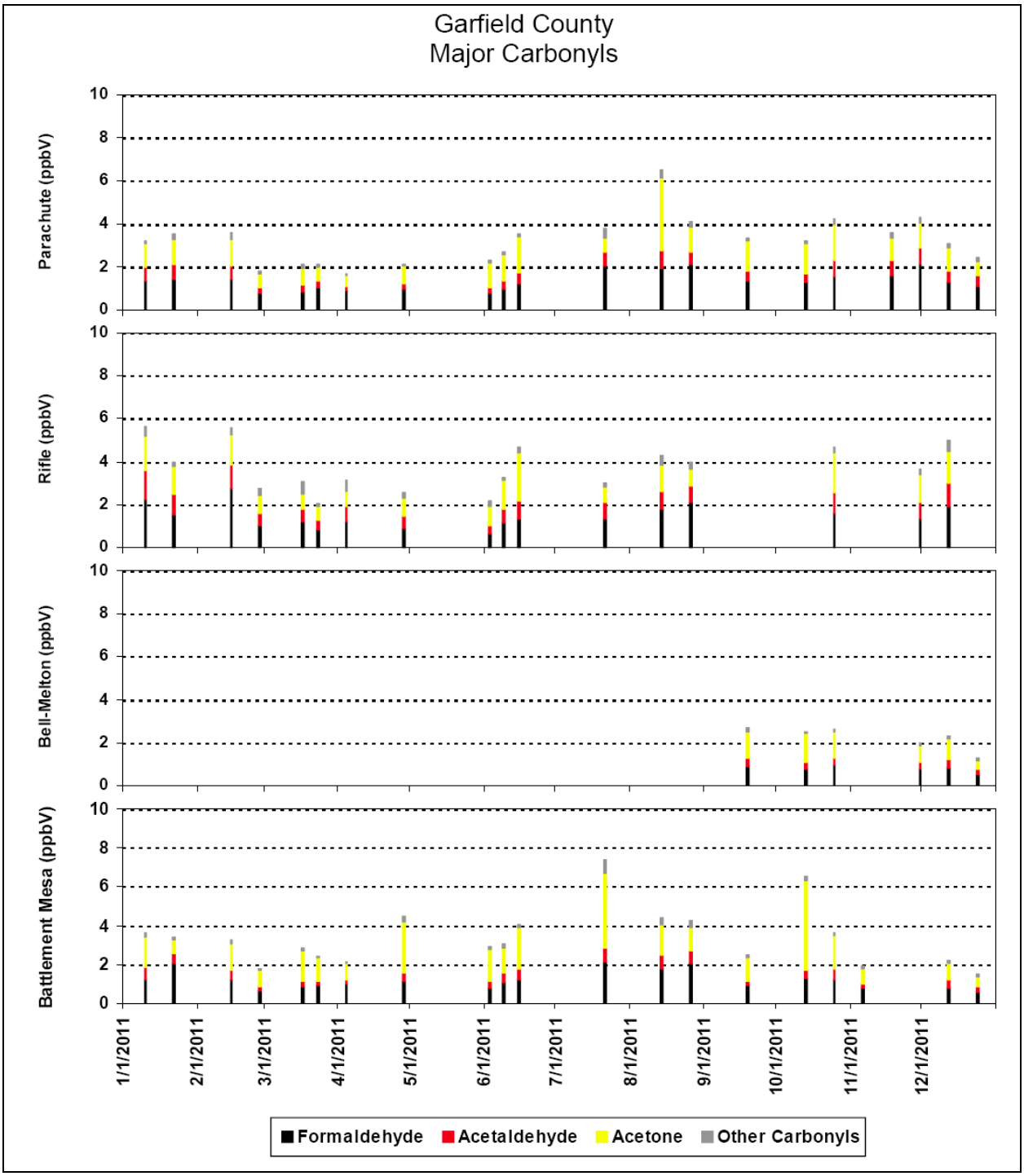

Figure 5-6. 2011 24-Hour Major Carbonyl Compound Concentrations in Units of ppbV.

5.2.1 Annual Average Carbonyl Concentrations

Garfield County began collecting SNMOC data at the Parachute, Rifle, and Bell-Melton sites in 2008, and at the Battlement Mesa (BMCO) in September 2010. Figure 5-7 presents comparisons of annual average carbonyl data collected between 2008 and 2011. In 2011 total measured carbonyl levels were slightly lower than 2010 at the Rifle and Bell-Melton sites, but slightly higher than 2011 higher at the Parachute site, although not as high as 2008 and 2009.

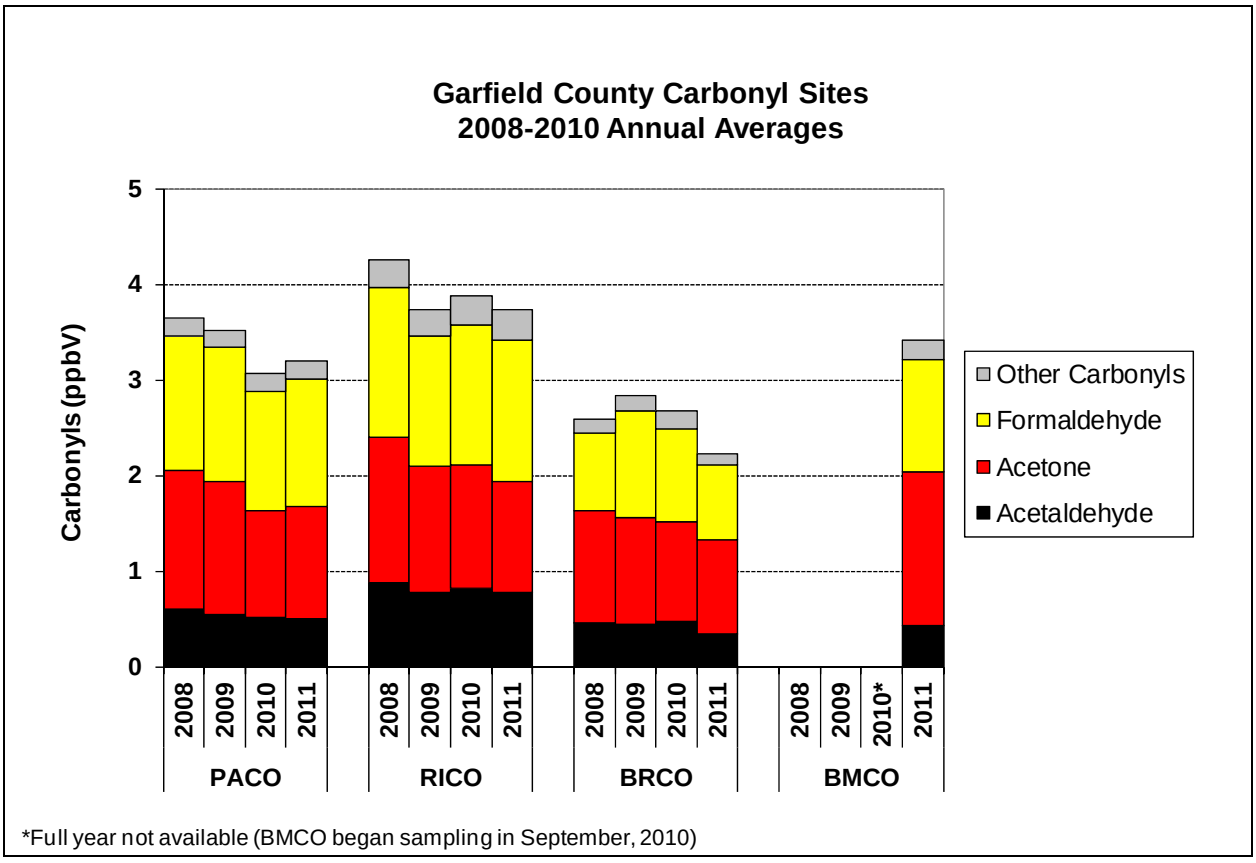

Figure 5-7. Average Carbonyl Concentrations Measured by the Garfield County Air Monitoring Program between 2008 and 2011.

5.3 HAZARDOUS AIR POLLUTANTS SUMMARIES

VOCs include a class of compounds called hazardous air pollutants (HAPs). The EPA has designated approximately 190 VOC compounds as HAPs, including benzene, toluene, ethyl-benzene and xylenes (also known as the BTEX compounds). No NAAQS or any other ambient air standards exist for VOCs. Instead, emissions limits on industrial sources have been set, and the EPA has developed a set of risk factors for both acute and chronic exposures for HAPs. In addition, risk factors from the Agency for Toxic Substances and Disease Registry (ATSDR), the California Air Resources Board (CARB), the National Institute for Occupational Safety and Health (NIOSH), and others can be used to determine potential risks from exposure to VOCs.

Of the 78 SNMOC and 12 carbonyl compounds measured in Garfield County, 21 compounds have been identified as HAPs. *The Garfield County Air Toxics Inhalation Screening Level Human Risk Assessment* (CDPHE 2010) assessed data collected in 2008, and risk assessments based on 2009 through 2011 HAP levels will be prepared in separate risk assessment report prepared by the CDPHE Disease Control and Environmental Epidemiology Division. Findings of the 2008 report indicated that, individually, the HAP components were below risk assessment criteria, but cumulative effects approached chronic (70 year exposure period) non-hazard levels. The largest contributors to the cumulative levels were benzene and formaldehyde. Summaries below look at annual averages of HAPs measured in Garfield County and regionally, but do not address health effects of these compounds.

5.3.1 Annual Average HAP Concentrations

Figures 5-8 through 5-11 present annual averages of HAP concentrations measured between 2008 and 2011. The EPA publishes an annual report encompassing data collected from sites across the country as part of the Urban Air Toxics Monitoring Program (UATMP) and National Air Toxics Trends Stations (NATTS). The most recent EPA report includes summaries of 2009 data (EPA, 2011). For perspective on concentrations measured in Garfield County, the average, maximum and minimum of annual average data reported for 45 urban sites across the US in 2009, excluding the Garfield County sites, is also presented in Figures 5-8 through 5-11. Specific observations are listed below:

- Compounds that have been consistently decreasing between 2008 at 2011 include cyclohexane, the xylenes, n-hexane and n-nonane at the BRCO and PACO sites, acetone at the BRCO and RICO sites, 1,3,5-trimethylbenzene, n-propylbenzene and acectaldehyde at the PACO site, and methylcyclohexane and toluene at the BRCO site. Several compounds have been variable year to year, but no compounds at any of the Garfield County sites have shown consistent increases since monitoring began in 2008.

- Compounds that averaged lower than the 2009 US average at Garfield County sites included styrene, acetaldehyde, crotonaldehdye, formaldehyde, and propioaldehyde. Concentration of these compounds at the Garfield County sites are among the lowest regional measurements, indicating that these values might be more representative of background concentrations with limited local sources.

- Compounds that measured higher than the regional averages and had 2008-2011 maximum annual averages higher than the 2009 regional maximum included cyclohexane, methylhexane, n-hexane, and n-nonane at all sites, and 1,3,5 trimethylbenzene, ethylbenzene, m/p-xylenes, n-propylbenzene, and toluene at the Parachute and Rifle sites. Most of the US sites in the EPA averages were more urban in nature, with fewer oil and gas sources, indicating that these compounds are likely related to the oil and gas sources in Garfield County.

- For the BTEX parameters, benzene, toluene, and the m/p-xylenes measured in Garfield County averaged higher than the urban US average for all sites, and ethylbenzene and the o-xylenes averages higher at all but the BRCO site.

It is important to note that annual average values summarized here do not necessarily indicate a health risk. Actual magnitudes of these HAP compounds related to possible health risk will be evaluated in CDPHE's risk assessment reports.

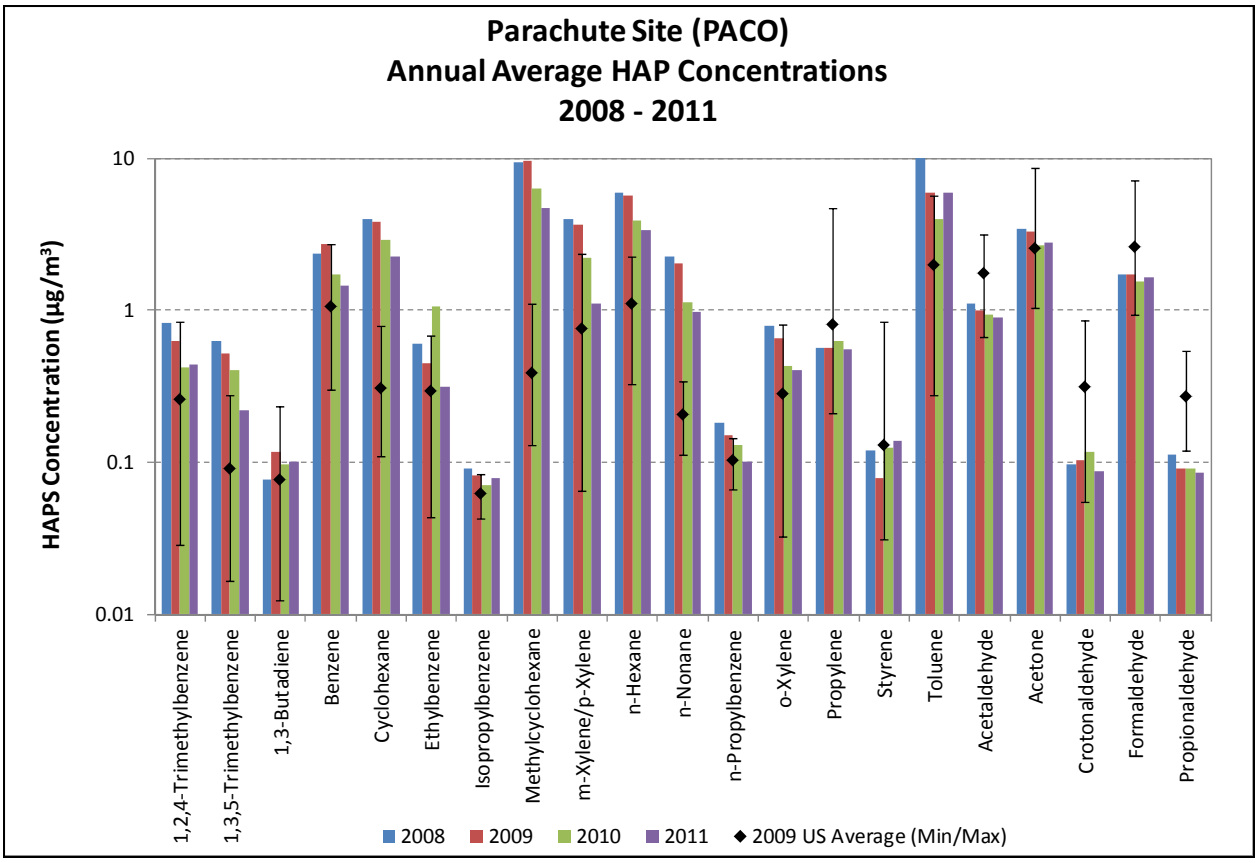

Figure 5-8. Annual Average HAP Concentrations Measured at the Parachute Site between 2008 and 2011, along with 2009 US Average, Minimum, and Maximum Annual Average Values as Reported by the EPA.

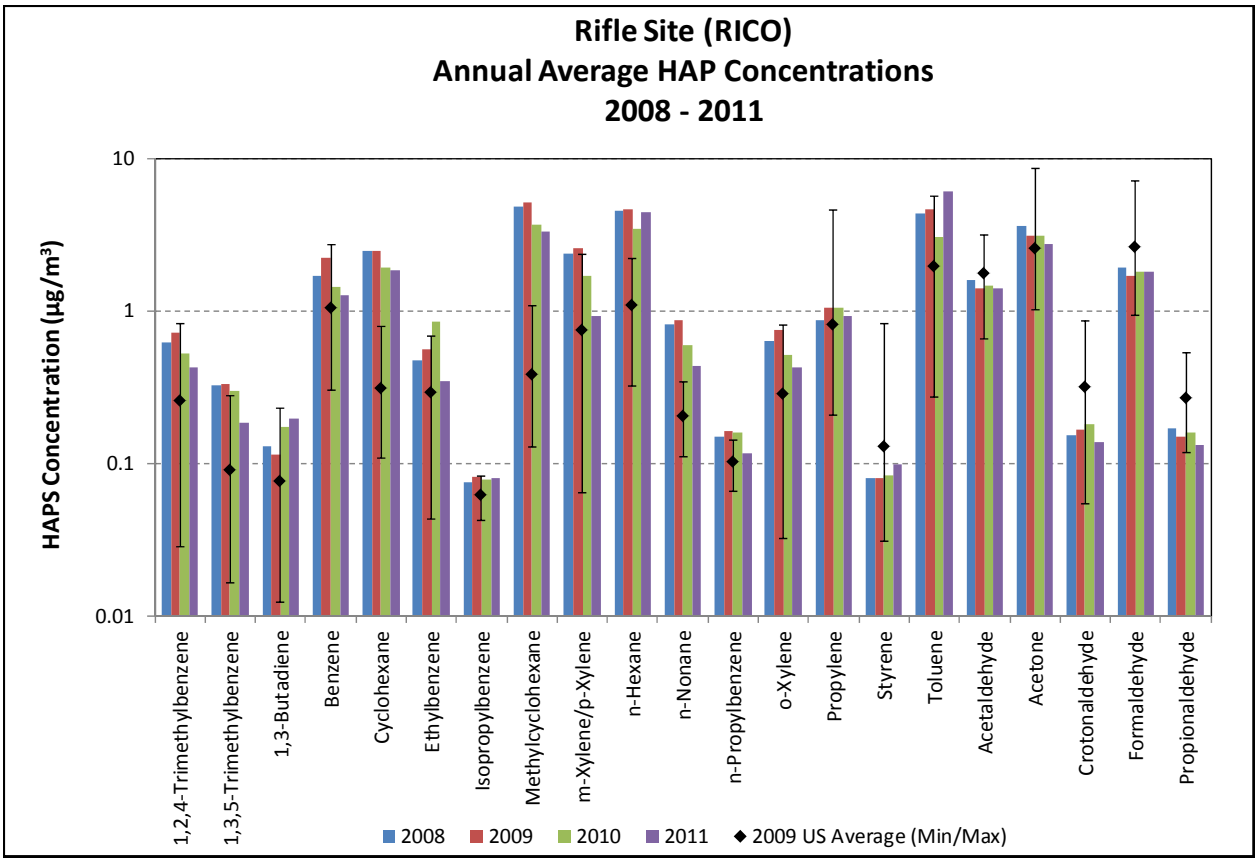

Figure 5-9. Annual Average HAP Concentrations Measured at the Rifle Site between 2008 and 2011, along with 2009 US Average, Minimum, and Maximum Annual Average Values as Reported by the EPA.

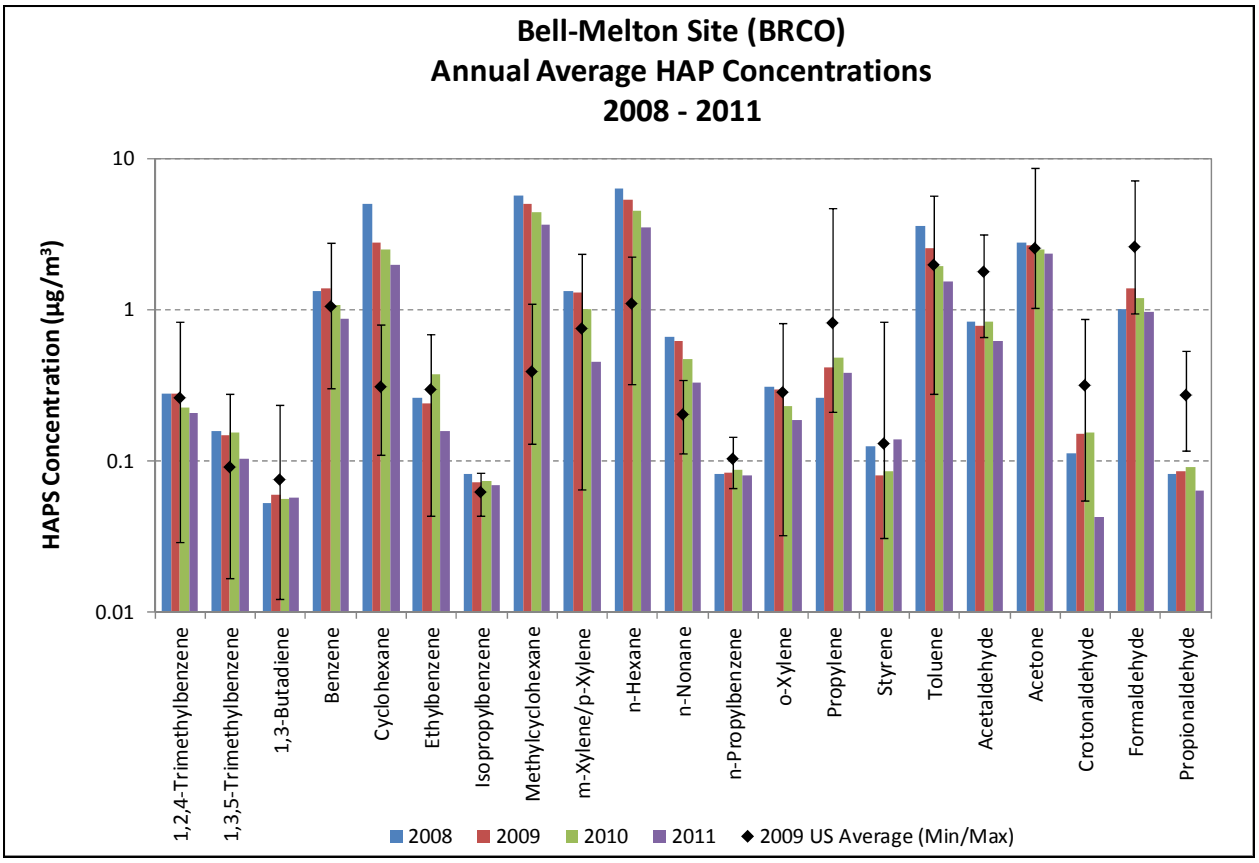

Figure 5-10. Annual Average HAP Concentrations Measured at the Bell-Melton Site between 2008 and 2011, along with 2009 US Average, Minimum, and Maximum Annual Average Values as Reported by the EPA.

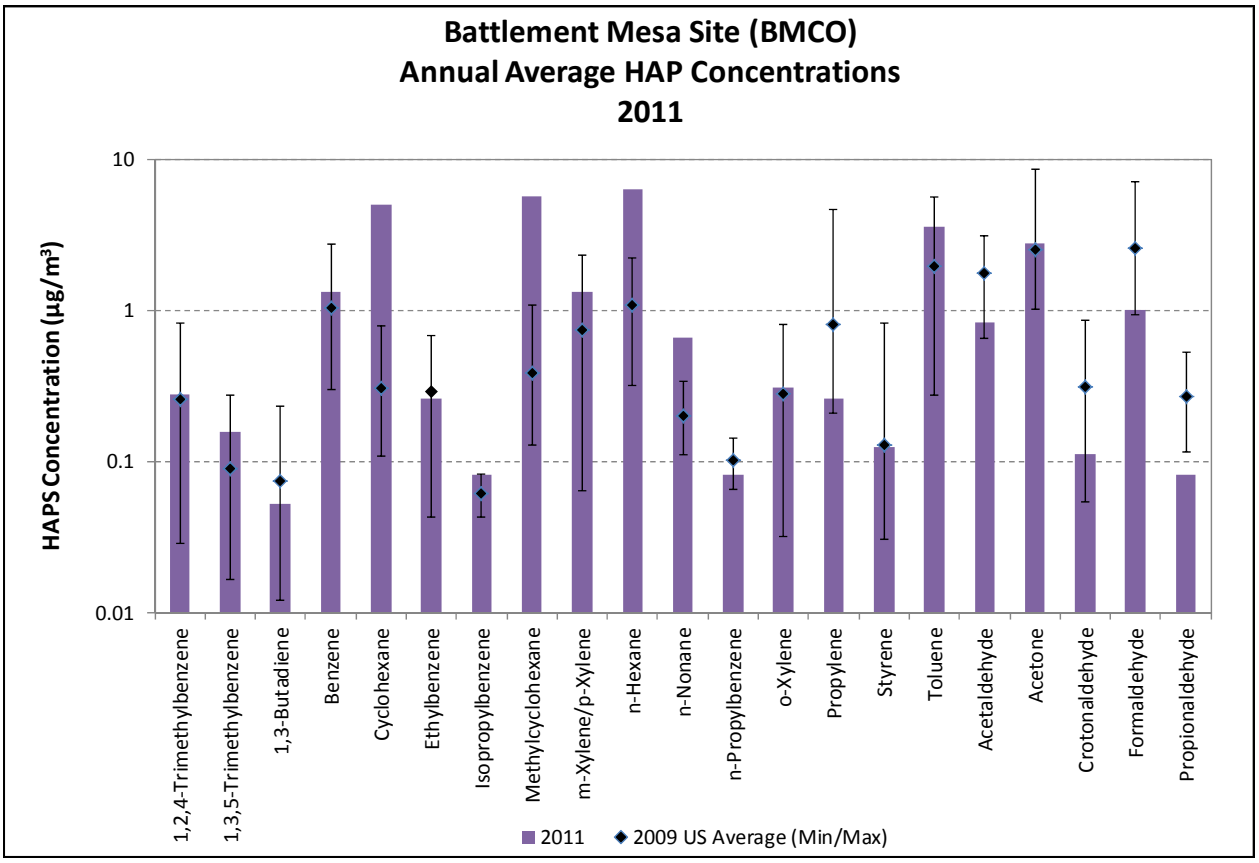

Figure 5-11. Annual Average HAP Concentrations Measured at the Battlement Mesa Site in 2011, along with 2009 US Average, Minimum and Maximum Annual Average Values as Reported by the EPA.

6.0 REFERENCES

CDPHE, 2010, Garfield County Air Toxics Inhalation: Screening Level Human Health Risk Assessment (June 2010).

The Environmental Protection Agency (EPA), 2011, 2008-2009 National Monitoring Programs (UATMP, NATTS, and CSATAM) http://www.epa.gov/ttnamti1/uatm.html (December 2011)

APPENDIX A

Garfield County

2011 Quarterly Time Series Plots

Acronyms Used on Plots:

TNMOC = Total Non-Methane Organic Carbon
PM_{10} = Particulate Matter ≤ 10 μm
$PM_{2.5}$ = Particulate Matter ≤ 2.5 μm
O_3 = Ozone
RH = Relative Humidity
AT = Atmospheric Temperature
VWD = Vector Wind Direction
SWS = Scalar Wind Speed

Figure A-1

Garfield County, CO

Parachute Site

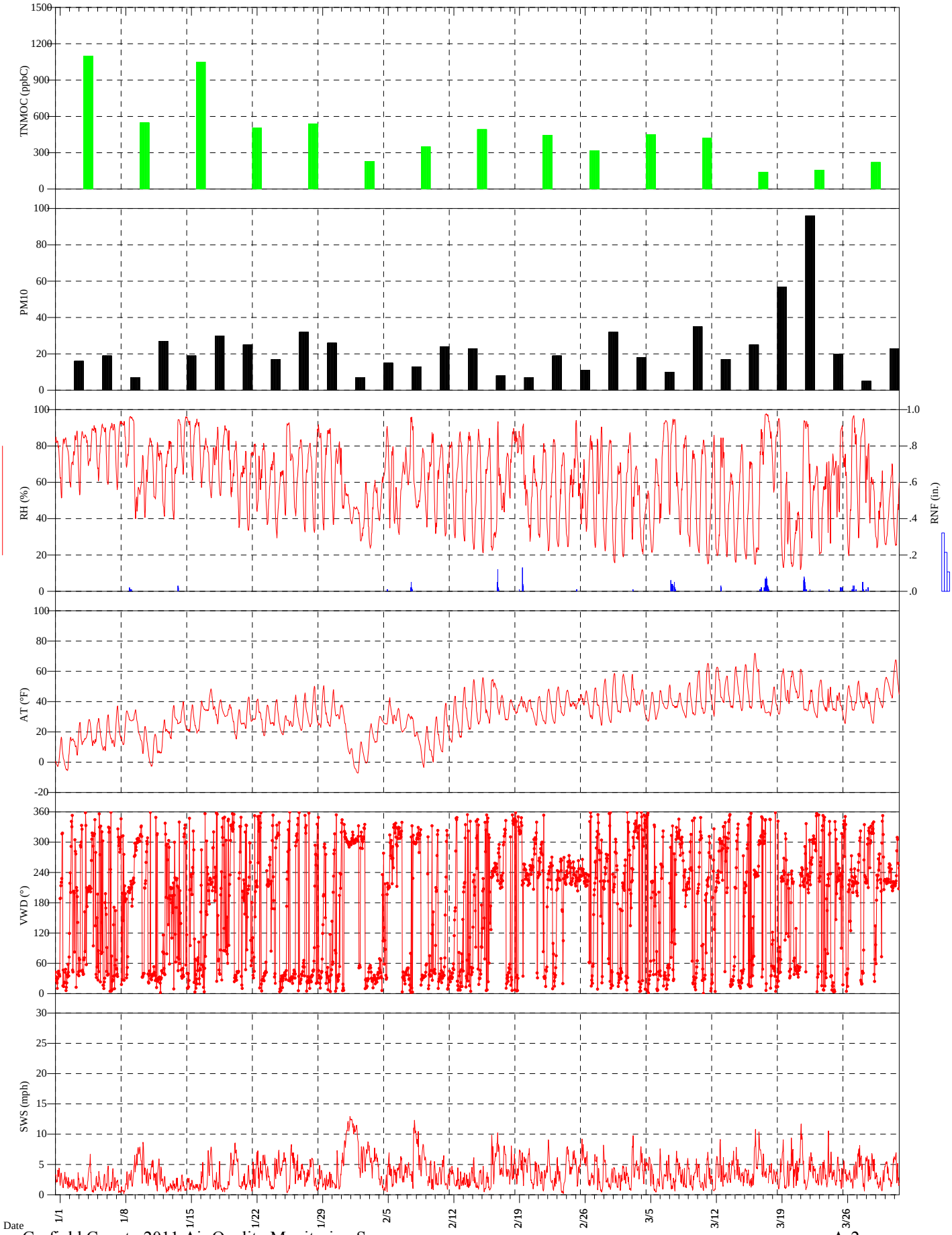

Figure A-2

Garfield County, CO

Parachute Site

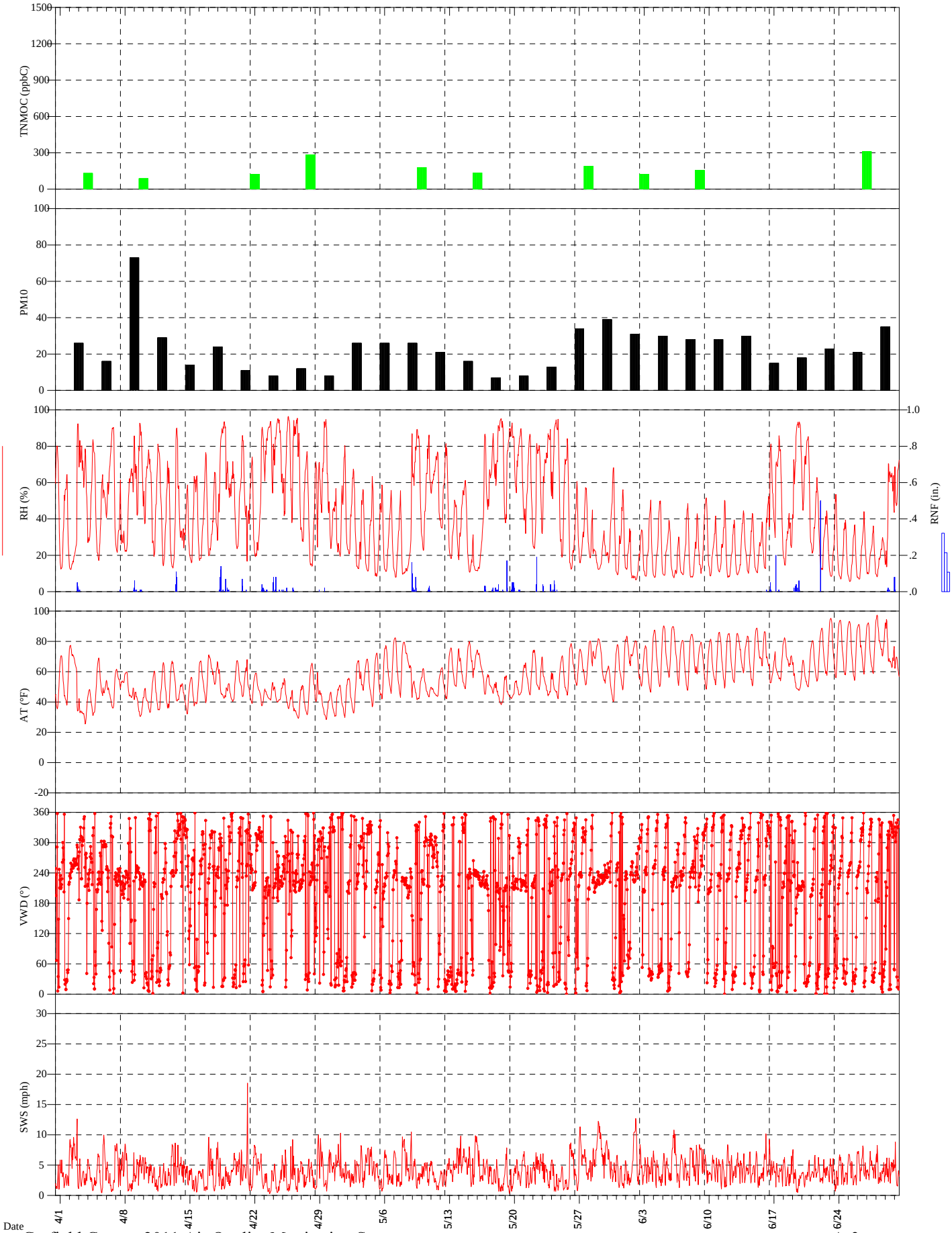

Figure A-3

Garfield County, CO

Parachute Site

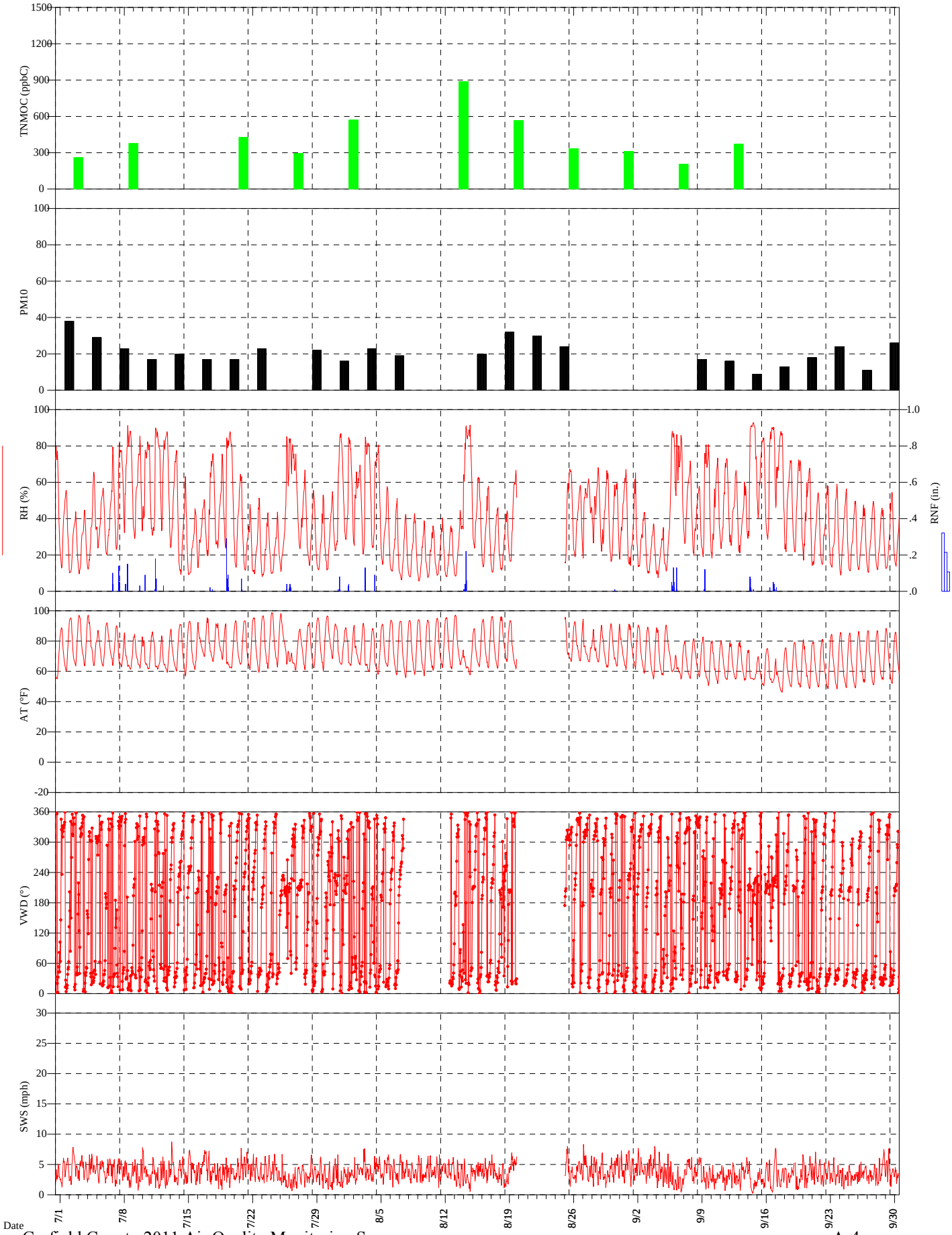

Figure A-4

Garfield County, CO

Parachute Site

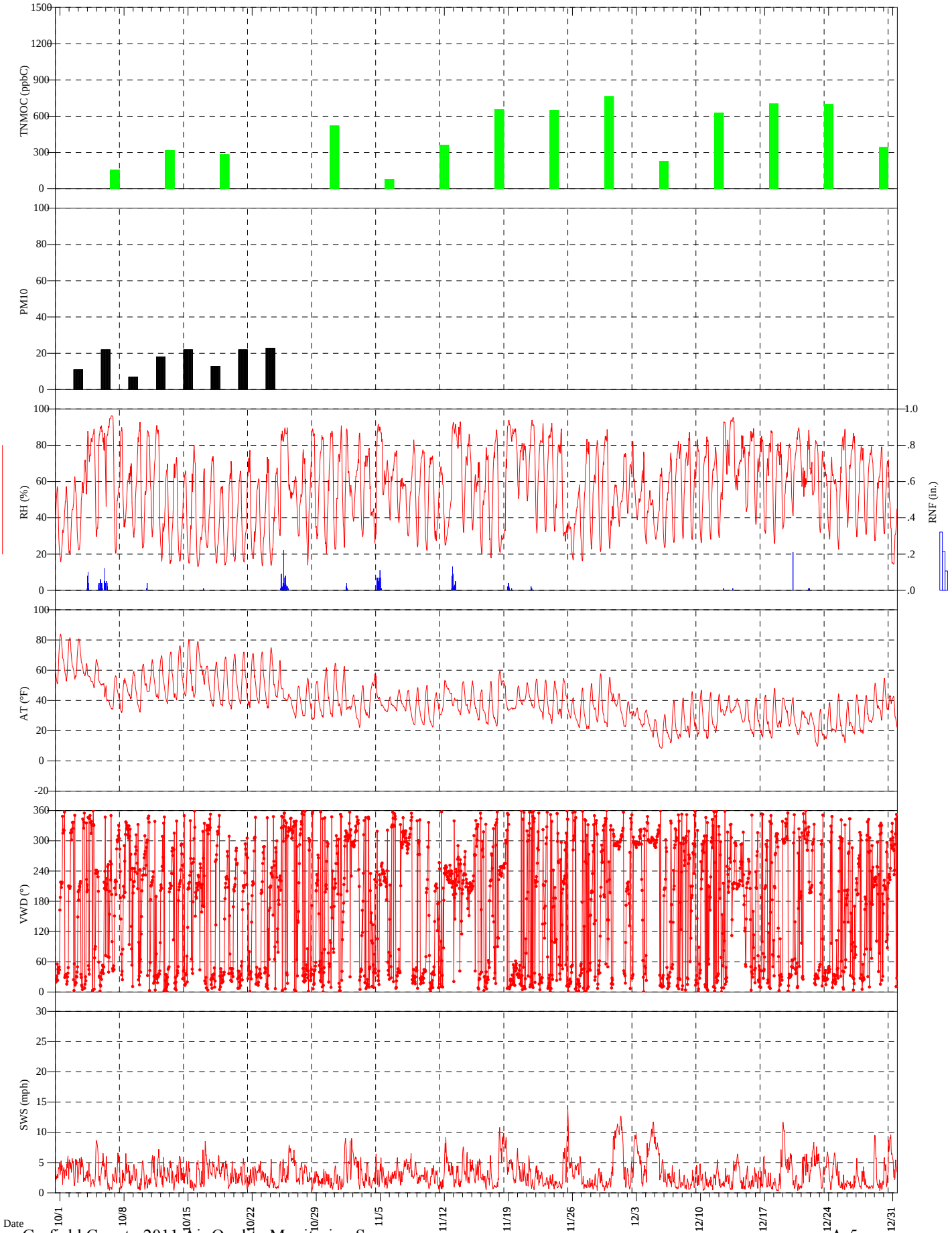

Figure A-5

Garfield County, CO

Rifle Site

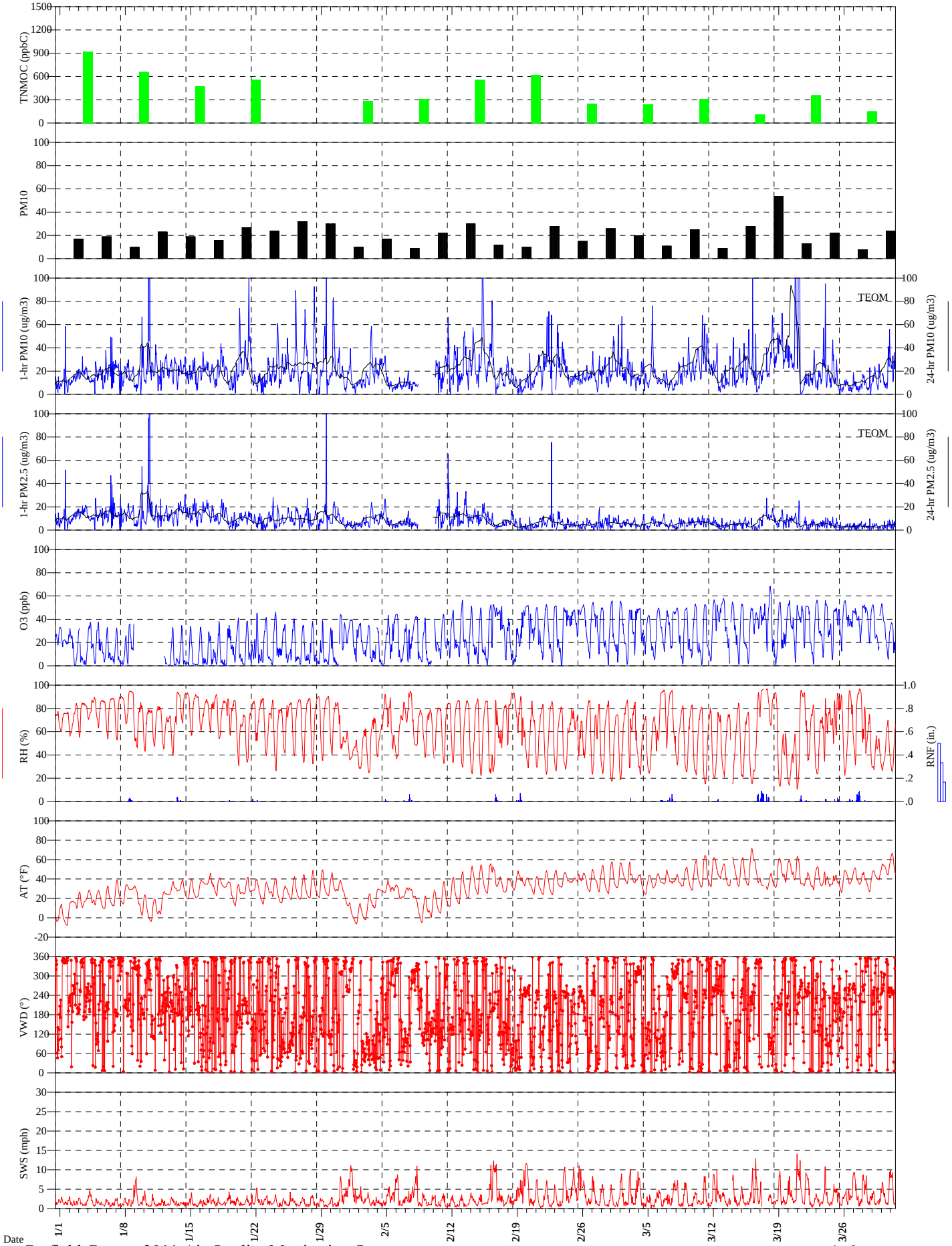

Figure A-6

Garfield County, CO

Rifle Site

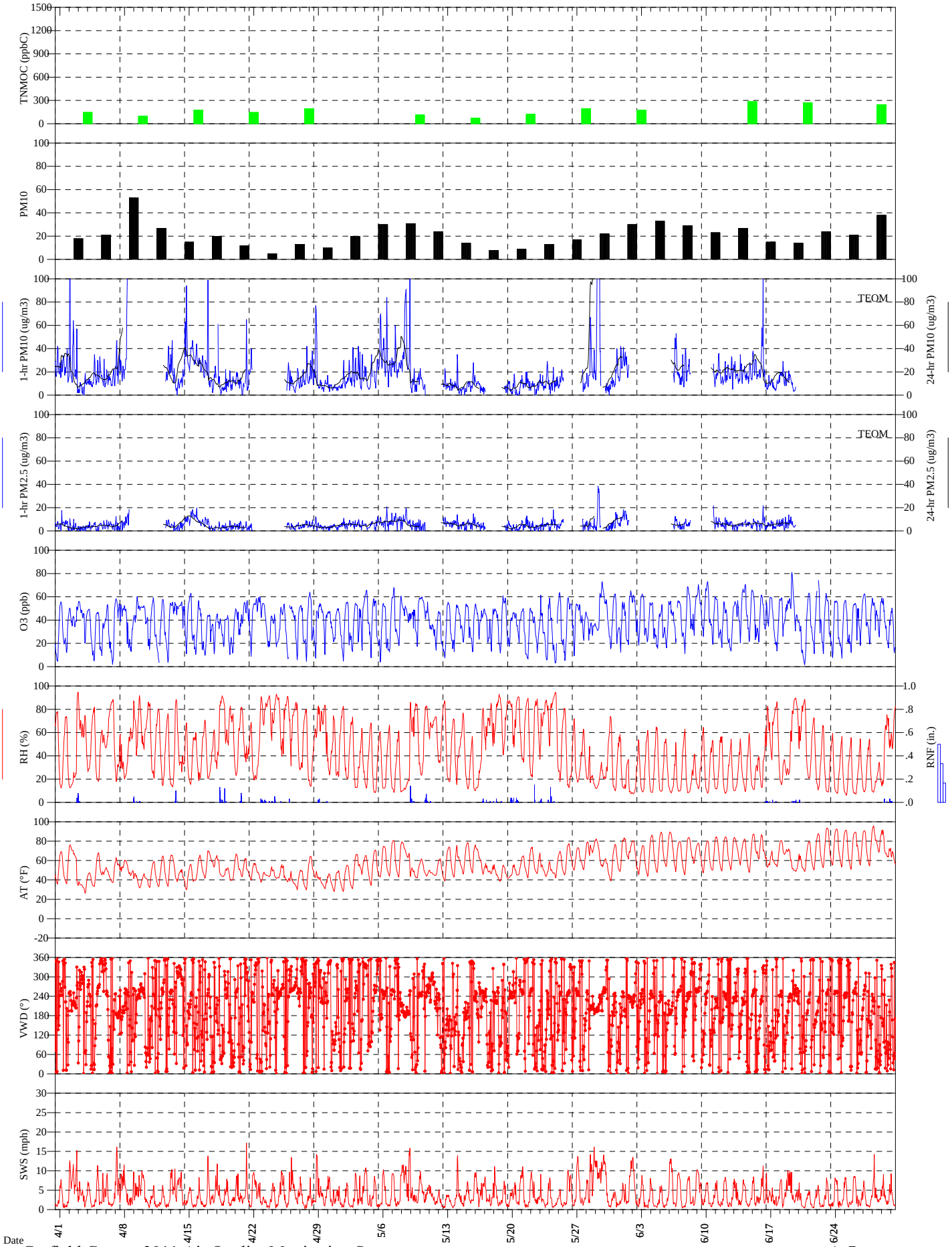

Figure A-7

Garfield County, CO

Rifle Site

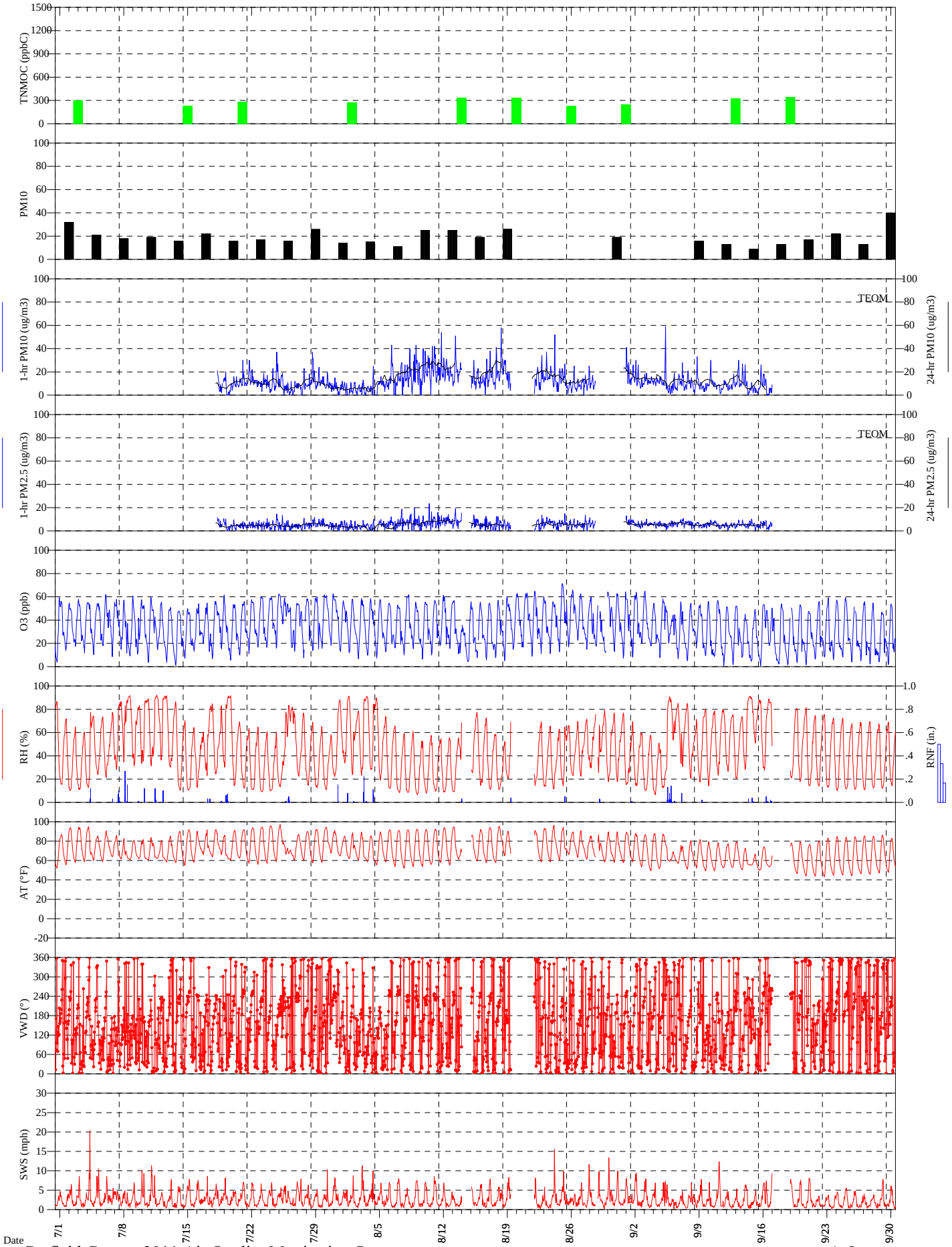

Figure A-8

Garfield County, CO

Rifle Site

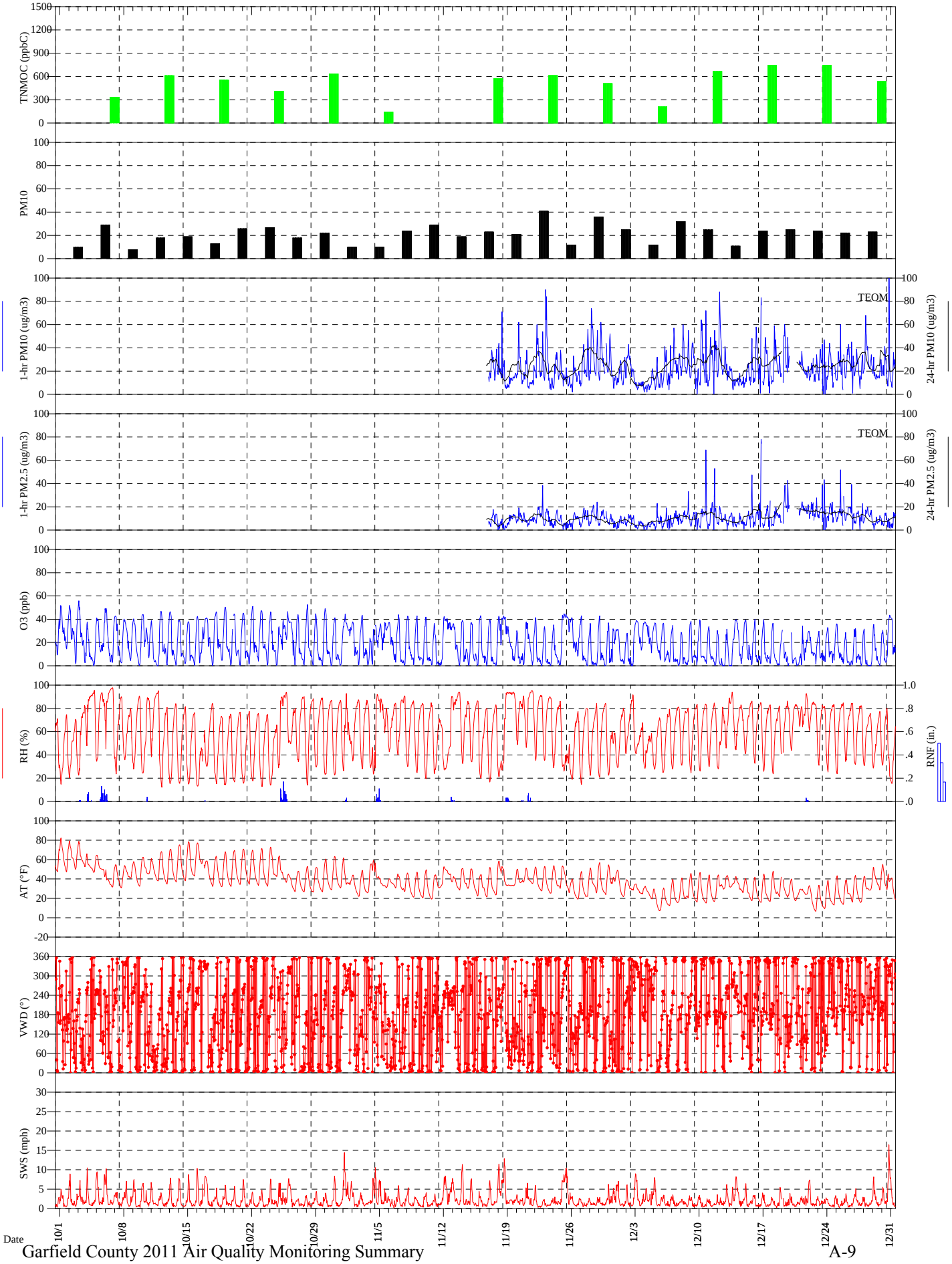

Figure A-9

Garfield County, CO
Battlement Mesa Site

Figure A-10

Garfield County, CO
Battlement Mesa Site

Figure A-11

Garfield County, CO
Battlement Mesa Site

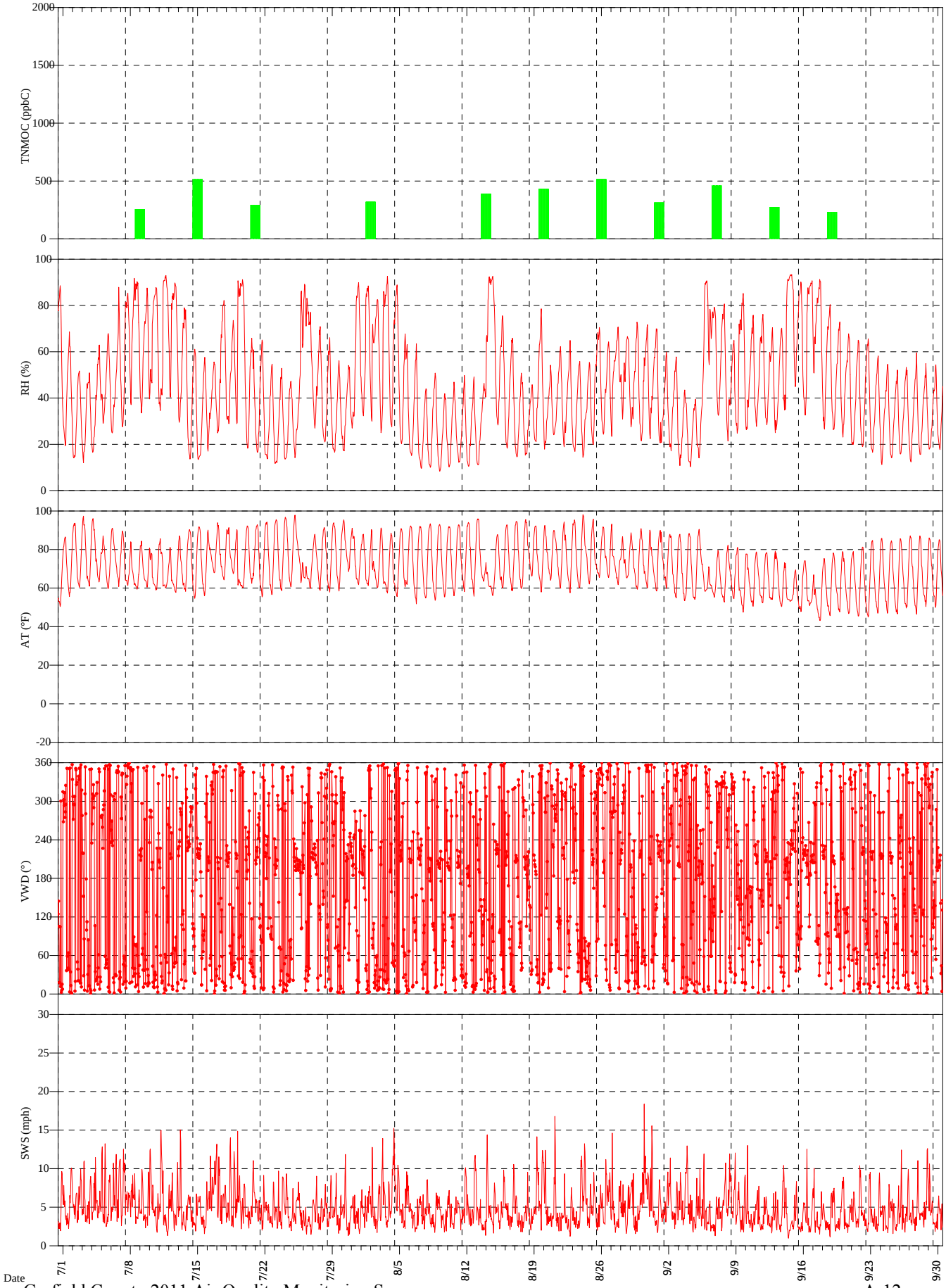

Figure A-12

Garfield County, CO
Battlement Mesa Site

Figure A-13

Garfield County, CO
Bell Melton Site

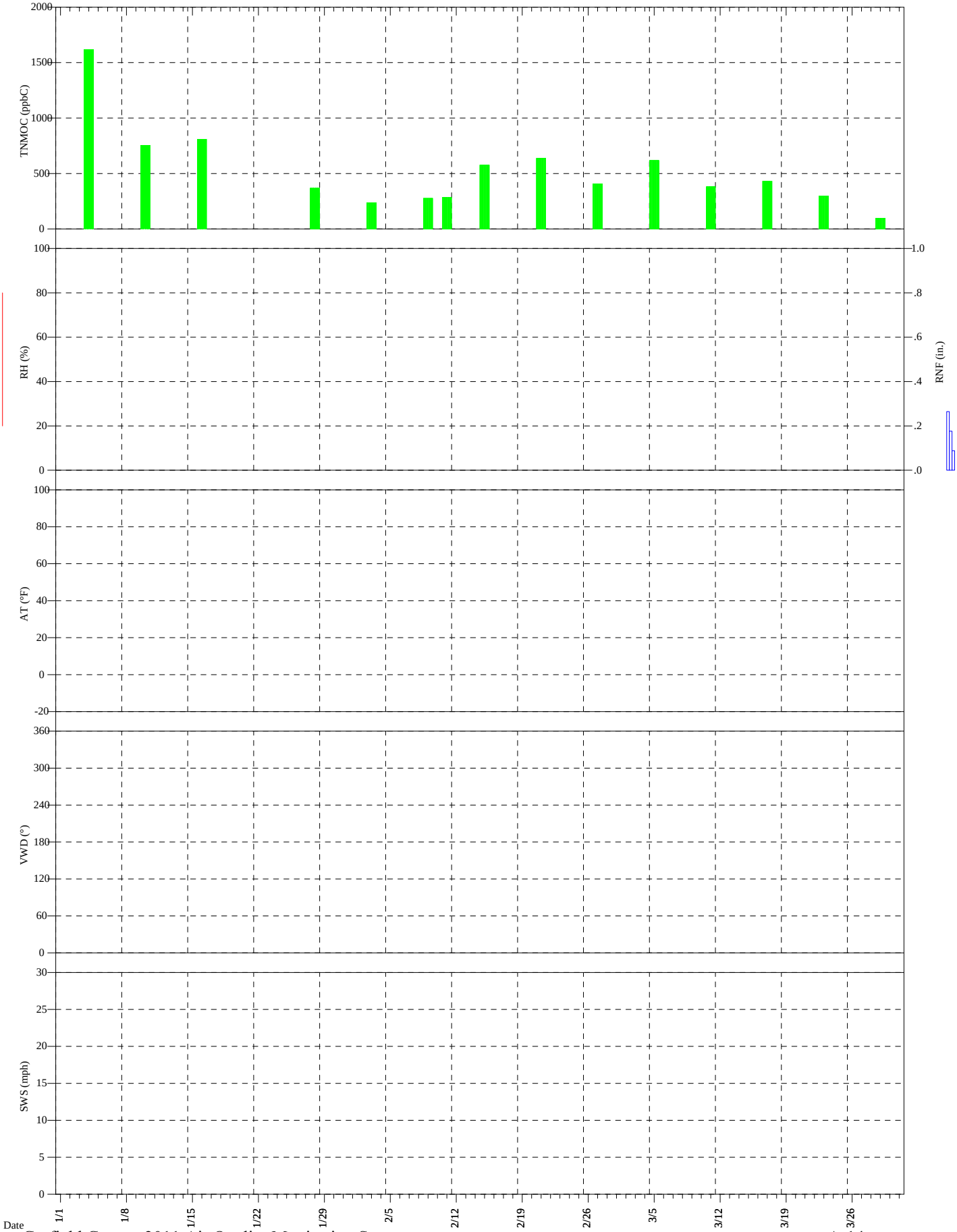

Figure A-14

Garfield County, CO
Bell Melton Site

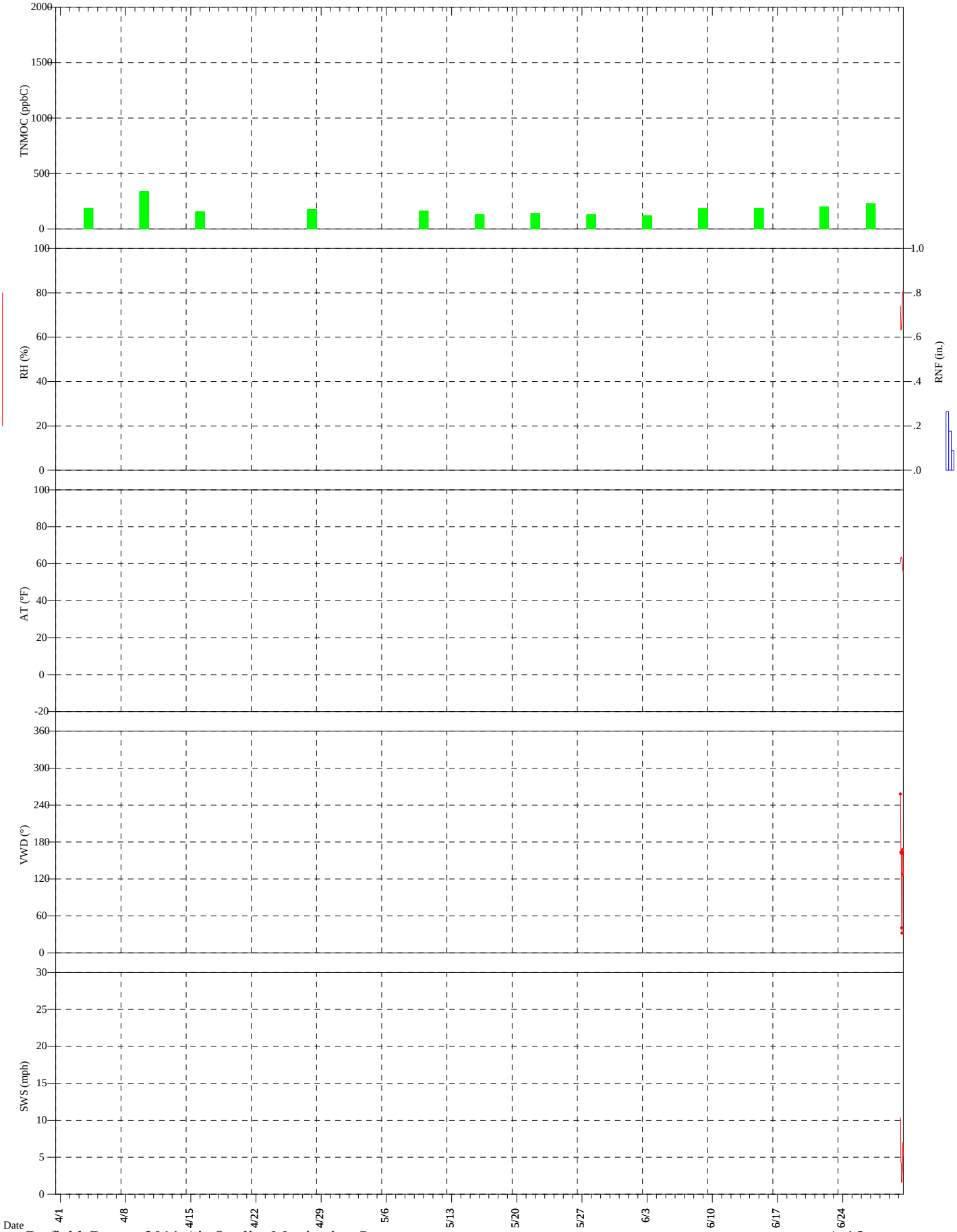

Figure A-15

Garfield County, CO
Bell Melton Site

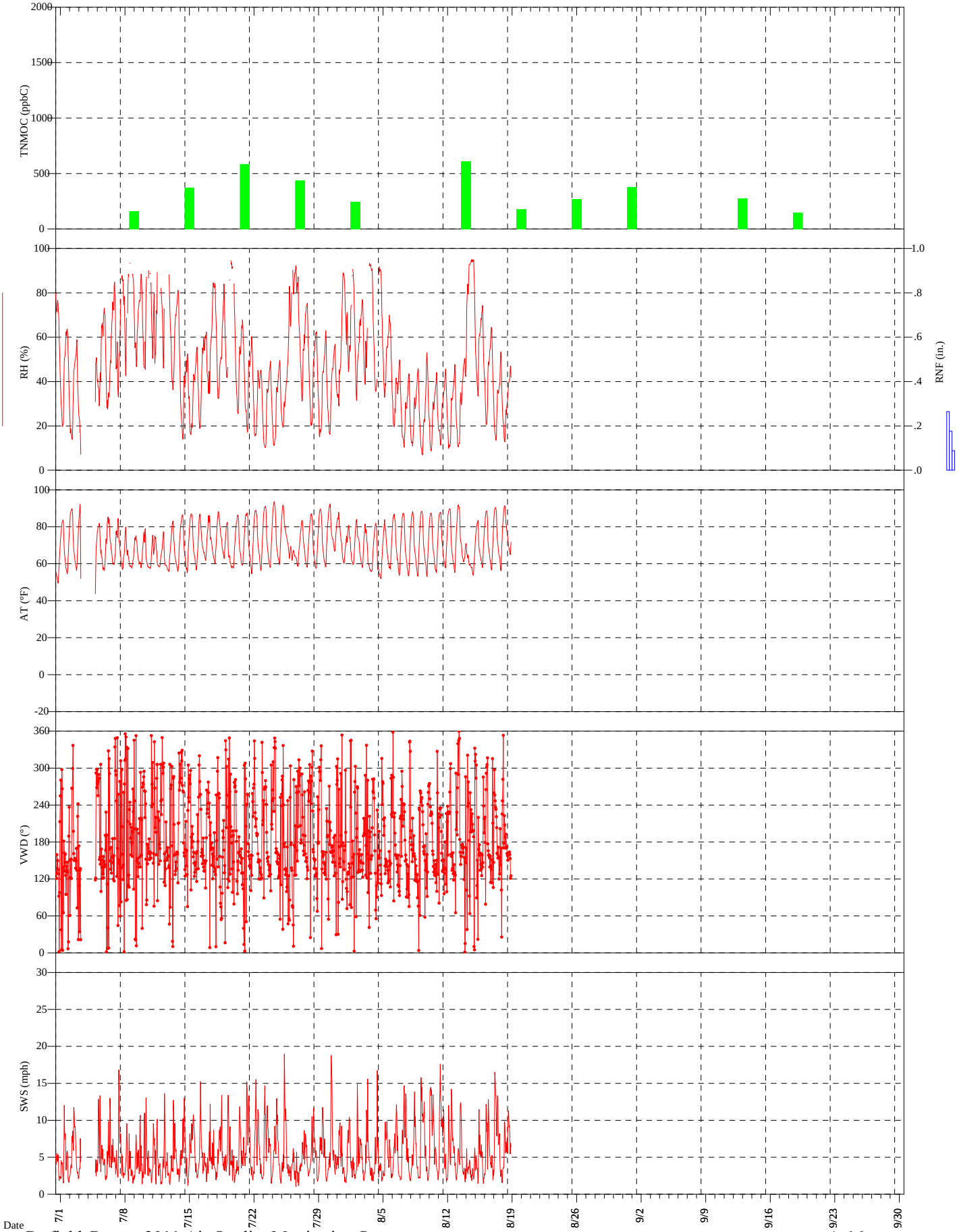

Figure A-16

Garfield County, CO
Bell Melton Site

APPENDIX B

Garfield County

2011 SNMOC Concentrations

Table B-1
Garfield County SNMOC Monitoring
Parachute (PACO)
1/4/2011-12/30/2011 (every sixth day)

	Sample Count		Concentration (ppbV)		
Detected Compound (CAS Number)	**# Samples**	**# Detects**	**Minimum**	**Maximum**	**Average***
1,2,3-Trimethylbenzene (526-73-8)	50	44	0.01	0.09	0.02
1,2,4-Trimethylbenzene (95-63-6)	50	50	0.03	1.13	0.09
1,3,5-Trimethylbenzene (108-67-8)	50	32	0.03	0.10	0.04
1,3-Butadiene (106-99-0)	50	20	0.01	0.15	0.05
1-Dodecene (112-41-4)	50	39	0.01	0.71	0.04
1-Heptene (592-76-7)	50	46	0.04	0.55	0.13
1-Hexene (592-41-6)	50	42	0.01	0.09	0.04
1-Nonene (124-11-8)	50	21	0.01	0.40	0.04
1-Octene (111-66-0)	50	24	0.02	0.09	0.03
1-Pentene (109-67-1)	50	48	0.02	0.16	0.04
1-Tridecene (2437-56-1)	50	2	0.01	0.01	0.02
1-Undecene (821-95-4)	50	6	0.01	0.10	0.01
2,2,3-Trimethylpentane (564-02-3)	50	18	0.02	0.07	0.02
2,2,4-Trimethylpentane (540-84-1)	50	20	0.02	0.31	0.03
2,2-Dimethylbutane (75-83-2)	50	50	0.02	0.45	0.15
2,3,4-Trimethylpentane (565-75-3)	50	39	0.01	0.14	0.02
2,3-Dimethylbutane (79-29-8)	50	44	0.03	0.64	0.21
2,3-Dimethylpentane (565-59-3)	50	50	0.02	0.32	0.11
2,4-Dimethylpentane (108-08-7)	50	50	0.01	0.25	0.08
2-Methyl-1-butene (563-46-2)	50	25	0.02	0.23	0.04
2-Methyl-1-pentene (763-29-1)	50	1	0.02	0.02	0.03
2-Methyl-2-butene (513-35-9)	50	39	0.02	0.30	0.05
2-Methylheptane (592-27-8)	50	50	0.02	0.39	0.13
2-Methylhexane (591-76-4)	50	50	0.08	0.97	0.31
2-Methylpentane (107-83-5)	50	50	0.16	3.47	0.89
3-Methylheptane (589-81-1)	50	50	0.02	0.28	0.11
3-Methylhexane (589-34-4)	50	49	0.06	0.95	0.29
3-Methylpentane (96-14-0)	50	50	0.09	1.98	0.53
4-Methyl-1-pentene (691-37-2)	50	1	0.03	0.03	0.03
Acetylene (74-86-2)	50	50	0.20	1.76	0.69
a-Pinene (80-56-8)	50	11	0.01	0.17	0.02
Benzene (71-43-2)	50	49	0.12	1.16	0.45
b-Pinene (127-91-3)	50	7	0.01	0.09	0.02
cis-2-Butene (590-18-1)	50	44	0.01	0.26	0.05
cis-2-Hexene (7688-21-3)	50	4	0.02	0.03	0.03
cis-2-Pentene (627-20-3)	50	31	0.01	0.12	0.03
Cyclohexane (110-82-7)	50	50	0.11	2.68	0.65
Cyclopentane (287-92-3)	50	49	0.04	1.47	0.19
Cyclopentene (142-29-0)	50	12	0.02	0.29	0.04
Ethane (74-84-0)	50	50	8.85	185.00	53.59
Ethylbenzene (100-41-4)	50	50	0.02	0.36	0.07
Ethylene (74-85-1)	50	50	0.57	3.22	1.39

*Samples reported as non-detects (ND) were included in averages as 1/2 minimum detection limits.

Table B-1 (continued)
Garfield County SNMOC Monitoring
Parachute (PACO)
1/4/2011-12/30/2011 (every sixth day)

	Sample Count		Concentration (ppbV)		
Detected Compound (CAS Number)	**# Samples**	**# Detects**	**Minimum**	**Maximum**	**Average***
Isobutane (75-28-5)	50	50	0.68	18.60	5.43
Isobutene/1-Butene (115-11-7 / 106-98-9)	50	13	0.26	0.82	0.13
Isopentane (78-78-4)	50	48	0.50	22.00	4.10
Isoprene (78-79-5)	50	41	0.02	0.54	0.08
Isopropylbenzene (98-82-8)	50	37	0.01	0.03	0.02
m-Diethylbenzene (141-93-5)	50	44	0.01	0.16	0.04
Methylcyclohexane (108-87-2)	50	50	0.20	4.73	1.17
Methylcyclopentane (96-37-7)	50	50	0.09	2.22	0.55
m-Ethyltoluene (620-14-4)	50	50	0.01	0.10	0.05
m-Xylene/p-Xylene (108-38-3 / 106-42-3)	50	28	0.08	1.08	0.25
n-Butane (106-97-8)	50	44	0.75	18.68	5.10
n-Decane (124-18-5)	50	50	0.02	0.21	0.09
n-Dodecane (112-40-3)	50	50	0.01	0.20	0.05
n-Heptane (142-82-5)	50	50	0.09	1.66	0.46
n-Hexane (110-54-3)	50	50	0.15	4.10	0.96
n-Nonane (111-84-2)	50	50	0.03	1.22	0.19
n-Octane (111-65-9)	50	50	0.06	1.12	0.34
n-Pentane (109-66-0)	50	50	0.29	14.36	2.55
n-Propylbenzene (103-65-1)	50	43	0.01	0.05	0.02
n-Tridecane (629-50-5)	50	7	0.01	0.01	0.02
n-Undecane (1120-21-4)	50	49	0.01	0.16	0.05
o-Ethyltoluene (611-14-3)	50	46	0.01	0.07	0.03
o-Xylene (95-47-6)	50	50	0.02	0.44	0.09
p-Diethylbenzene (105-05-5)	50	40	0.01	0.06	0.02
p-Ethyltoluene (622-96-8)	50	49	0.01	0.06	0.03
Propane (74-98-6)	50	50	2.88	68.67	20.47
Propylene (115-07-1)	50	49	0.14	0.71	0.32
Propyne (74-99-7)	50	1	0.04	0.04	0.02
Styrene (100-42-5)	50	8	0.01	0.41	0.03
Toluene (108-88-3)	50	50	0.12	24.71	1.58
trans-2-Butene (624-64-6)	50	47	0.02	0.36	0.07
trans-2-Hexene (4050-45-7)	50	2	0.03	0.04	0.03
trans-2-Pentene (646-04-8)	50	42	0.02	0.25	0.04

*Samples reported as non-detects (ND) were included in averages as 1/2 minimum detection limits.

Table B-2
Garfield County SNMOC Monitoring
Rifle (RICO)
1/4/2011-12/30/2011 (every sixth day)

	Sample Count		Concentration (ppbV)		
Detected Compound (CAS Number)	**# Samples**	**# Detects**	**Minimum**	**Maximum**	**Average***
1,2,3-Trimethylbenzene (526-73-8)	51	51	0.01	0.05	0.03
1,2,4-Trimethylbenzene (95-63-6)	51	51	0.03	0.18	0.09
1,3,5-Trimethylbenzene (108-67-8)	51	35	0.02	0.10	0.04
1,3-Butadiene (106-99-0)	51	40	0.03	0.24	0.09
1-Decene (872-05-9)	51	1	0.06	0.06	0.01
1-Dodecene (112-41-4)	51	41	0.01	0.13	0.03
1-Heptene (592-76-7)	51	49	0.02	0.34	0.11
1-Hexene (592-41-6)	51	46	0.02	0.09	0.04
1-Nonene (124-11-8)	51	22	0.01	0.06	0.02
1-Octene (111-66-0)	51	23	0.02	0.07	0.02
1-Pentene (109-67-1)	51	51	0.03	0.14	0.07
1-Tridecene (2437-56-1)	51	1	0.01	0.01	0.02
1-Undecene (821-95-4)	51	11	0.01	0.07	0.01
2,2,3-Trimethylpentane (564-02-3)	51	19	0.02	0.09	0.02
2,2,4-Trimethylpentane (540-84-1)	51	41	0.01	0.28	0.04
2,2-Dimethylbutane (75-83-2)	51	51	0.03	0.35	0.13
2,3,4-Trimethylpentane (565-75-3)	51	50	0.01	0.07	0.03
2,3-Dimethylbutane (79-29-8)	51	41	0.04	0.55	0.19
2,3-Dimethylpentane (565-59-3)	51	51	0.04	0.25	0.11
2,4-Dimethylpentane (108-08-7)	51	51	0.02	0.19	0.07
2-Methyl-1-butene (563-46-2)	51	45	0.02	0.20	0.07
2-Methyl-1-pentene (763-29-1)	51	1	0.01	0.01	0.03
2-Methyl-2-butene (513-35-9)	51	47	0.02	0.66	0.09
2-Methylheptane (592-27-8)	51	51	0.02	0.35	0.10
2-Methylhexane (591-76-4)	51	51	0.10	0.67	0.27
2-Methylpentane (107-83-5)	51	51	0.13	3.00	0.96
3-Methyl-1-butene (563-45-1)	51	1	0.03	0.03	0.02
3-Methylheptane (589-81-1)	51	51	0.02	0.30	0.08
3-Methylhexane (589-34-4)	51	50	0.05	0.66	0.25
3-Methylpentane (96-14-0)	51	51	0.09	3.68	0.61
4-Methyl-1-pentene (691-37-2)	51	2	0.02	0.02	0.03
Acetylene (74-86-2)	51	51	0.35	3.02	1.26
a-Pinene (80-56-8)	51	14	0.02	0.07	0.02
Benzene (71-43-2)	51	49	0.16	0.87	0.39
b-Pinene (127-91-3)	51	5	0.02	0.11	0.01
cis-2-Butene (590-18-1)	51	47	0.04	0.30	0.10
cis-2-Hexene (7688-21-3)	51	8	0.01	0.07	0.03
cis-2-Pentene (627-20-3)	51	48	0.01	0.07	0.04
Cyclohexane (110-82-7)	51	51	0.07	1.78	0.54
Cyclopentane (287-92-3)	51	51	0.04	0.45	0.17
Cyclopentene (142-29-0)	51	17	0.03	0.28	0.04
Ethane (74-84-0)	51	51	5.50	137.50	42.17

*Samples reported as non-detects (ND) were included in averages as 1/2 minimum detection limits.

Table B-2 (continued)
Garfield County SNMOC Monitoring
Rifle (RICO)
1/4/2011-12/30/2011 (every sixth day)

	Sample Count		Concentration (ppbV)		
Detected Compound (CAS Number)	**# Samples**	**# Detects**	**Minimum**	**Maximum**	**Average***
Ethylbenzene (100-41-4)	51	51	0.04	0.20	0.08
Ethylene (74-85-1)	51	51	0.94	4.44	2.09
Isobutane (75-28-5)	51	51	0.52	18.35	5.40
Isobutene/1-Butene (115-11-7 / 106-98-9)	51	23	0.25	3.20	0.34
Isopentane (78-78-4)	51	49	0.68	13.16	4.18
Isoprene (78-79-5)	51	50	0.03	0.62	0.09
Isopropylbenzene (98-82-8)	51	40	0.01	0.03	0.02
m-Diethylbenzene (141-93-5)	51	47	0.01	0.18	0.04
Methylcyclohexane (108-87-2)	51	51	0.10	2.66	0.83
Methylcyclopentane (96-37-7)	51	51	0.07	3.58	0.59
m-Ethyltoluene (620-14-4)	51	51	0.02	0.11	0.06
m-Xylene/p-Xylene (108-38-3 / 106-42-3)	51	28	0.15	0.80	0.21
n-Butane (106-97-8)	51	42	0.71	17.00	5.15
n-Decane (124-18-5)	51	51	0.02	0.12	0.06
n-Dodecane (112-40-3)	51	51	0.01	0.29	0.05
n-Heptane (142-82-5)	51	51	0.08	1.11	0.38
n-Hexane (110-54-3)	51	51	0.11	11.32	1.25
n-Nonane (111-84-2)	51	51	0.02	0.32	0.08
n-Octane (111-65-9)	51	51	0.06	0.81	0.22
n-Pentane (109-66-0)	51	51	0.26	7.54	2.26
n-Propylbenzene (103-65-1)	51	49	0.01	0.06	0.02
n-Tridecane (629-50-5)	51	4	0.00	0.02	0.02
n-Undecane (1120-21-4)	51	51	0.01	0.40	0.04
o-Ethyltoluene (611-14-3)	51	50	0.01	0.07	0.04
o-Xylene (95-47-6)	51	51	0.04	0.27	0.10
p-Diethylbenzene (105-05-5)	51	45	0.01	0.06	0.02
p-Ethyltoluene (622-96-8)	51	51	0.02	0.09	0.04
Propane (74-98-6)	51	51	2.09	60.00	17.97
Propylene (115-07-1)	51	51	0.25	1.06	0.54
Propyne (74-99-7)	51	3	0.04	0.07	0.02
Styrene (100-42-5)	51	15	0.01	0.13	0.02
Toluene (108-88-3)	51	51	0.18	24.86	1.60
trans-2-Butene (624-64-6)	51	48	0.03	0.36	0.12
trans-2-Hexene (4050-45-7)	51	6	0.01	0.02	0.03
trans-2-Pentene (646-04-8)	51	51	0.03	0.20	0.07

*Samples reported as non-detects (ND) were included in averages as 1/2 minimum detection limits.

Table B-3
Garfield County SNMOC Monitoring
Bell-Melton (BRCO)
1/4/2011-12/30/2011 (every sixth day)

	Sample Count		Concentration (ppbV)		
Detected Compound (CAS Number)	**# Samples**	**# Detects**	**Minimum**	**Maximum**	**Average***
1,2,3-Trimethylbenzene (526-73-8)	54	42	0.01	0.06	0.02
1,2,4-Trimethylbenzene (95-63-6)	54	54	0.01	0.25	0.04
1,3,5-Trimethylbenzene (108-67-8)	54	34	0.01	0.09	0.02
1,3-Butadiene (106-99-0)	54	7	0.01	0.07	0.03
1-Dodecene (112-41-4)	54	39	0.01	0.19	0.03
1-Heptene (592-76-7)	54	51	0.03	0.51	0.11
1-Hexene (592-41-6)	54	44	0.02	0.07	0.03
1-Nonene (124-11-8)	54	17	0.01	0.04	0.02
1-Octene (111-66-0)	54	24	0.01	0.05	0.02
1-Pentene (109-67-1)	54	48	0.02	0.10	0.04
1-Tridecene (2437-56-1)	54	4	0.01	0.01	0.02
1-Undecene (821-95-4)	54	5	0.01	0.16	0.01
2,2,3-Trimethylpentane (564-02-3)	54	13	0.01	0.04	0.02
2,2,4-Trimethylpentane (540-84-1)	54	20	0.01	0.13	0.02
2,2-Dimethylbutane (75-83-2)	54	54	0.02	0.49	0.12
2,3,4-Trimethylpentane (565-75-3)	54	38	0.01	0.03	0.02
2,3-Dimethylbutane (79-29-8)	54	43	0.03	0.59	0.17
2,3-Dimethylpentane (565-59-3)	54	53	0.03	0.34	0.09
2,4-Dimethylpentane (108-08-7)	54	54	0.02	0.27	0.07
2-Methyl-1-butene (563-46-2)	54	16	0.03	0.12	0.03
2-Methyl-2-butene (513-35-9)	54	22	0.02	0.12	0.03
2-Methylheptane (592-27-8)	54	53	0.02	0.29	0.09
2-Methylhexane (591-76-4)	54	53	0.07	0.92	0.24
2-Methylpentane (107-83-5)	54	54	0.26	4.72	0.90
3-Methylheptane (589-81-1)	54	53	0.02	0.17	0.06
3-Methylhexane (589-34-4)	54	52	0.06	0.85	0.22
3-Methylpentane (96-14-0)	54	54	0.09	2.50	0.48
4-Methyl-1-pentene (691-37-2)	54	1	0.02	0.02	0.03
Acetylene (74-86-2)	54	54	0.18	1.42	0.60
a-Pinene (80-56-8)	54	13	0.01	0.08	0.02
Benzene (71-43-2)	54	53	0.10	0.82	0.27
b-Pinene (127-91-3)	54	3	0.02	0.11	0.01
cis-2-Butene (590-18-1)	54	31	0.02	0.06	0.03
cis-2-Hexene (7688-21-3)	54	1	0.02	0.02	0.03
cis-2-Pentene (627-20-3)	54	27	0.02	0.04	0.02
Cyclohexane (110-82-7)	54	54	0.08	2.82	0.58
Cyclopentane (287-92-3)	54	54	0.04	0.71	0.17
Cyclopentene (142-29-0)	54	13	0.03	0.45	0.05
Ethane (74-84-0)	54	54	4.97	279.00	48.64
Ethylbenzene (100-41-4)	54	53	0.01	0.08	0.04
Ethylene (74-85-1)	54	54	0.52	1.98	1.02
Isobutane (75-28-5)	54	54	1.04	32.25	6.00

*Samples reported as non-detects (ND) were included in averages as 1/2 minimum detection limits.

Table B-3 (continued)
Garfield County SNMOC Monitoring
Bell-Melton (BRCO)
1/4/2011-12/30/2011 (every sixth day)

	Sample Count		Concentration (ppbV)		
Detected Compound (CAS Number)	**# Samples**	**# Detects**	**Minimum**	**Maximum**	**Average***
Isobutene/1-Butene (115-11-7 / 106-98-9)	54	12	0.03	1.97	0.14
Isopentane (78-78-4)	54	53	0.62	16.32	3.93
Isoprene (78-79-5)	54	43	0.02	0.59	0.07
Isopropylbenzene (98-82-8)	54	31	0.01	0.02	0.01
m-Diethylbenzene (141-93-5)	54	47	0.01	0.14	0.04
Methylcyclohexane (108-87-2)	54	54	0.11	4.14	0.90
Methylcyclopentane (96-37-7)	54	54	0.06	2.38	0.47
m-Ethyltoluene (620-14-4)	54	52	0.01	0.12	0.03
m-Xylene/p-Xylene (108-38-3 / 106-42-3)	54	30	0.07	0.36	0.10
n-Butane (106-97-8)	54	43	0.74	20.48	5.39
n-Decane (124-18-5)	54	54	0.01	0.11	0.04
n-Dodecane (112-40-3)	54	52	0.01	0.10	0.04
n-Heptane (142-82-5)	54	54	0.05	1.70	0.39
n-Hexane (110-54-3)	54	54	0.12	5.75	0.98
n-Nonane (111-84-2)	54	54	0.01	0.20	0.06
n-Octane (111-65-9)	54	54	0.04	0.62	0.19
n-Pentane (109-66-0)	54	54	0.31	12.92	2.62
n-Propylbenzene (103-65-1)	54	39	0.01	0.04	0.02
n-Tridecane (629-50-5)	54	3	0.02	0.19	0.02
n-Undecane (1120-21-4)	54	49	0.01	0.07	0.03
o-Ethyltoluene (611-14-3)	54	44	0.01	0.06	0.02
o-Xylene (95-47-6)	54	54	0.02	0.13	0.04
p-Diethylbenzene (105-05-5)	54	40	0.01	0.06	0.02
p-Ethyltoluene (622-96-8)	54	50	0.01	0.06	0.02
Propane (74-98-6)	54	54	2.42	125.33	22.98
Propylene (115-07-1)	54	53	0.11	0.45	0.22
Styrene (100-42-5)	54	8	0.01	0.63	0.03
Toluene (108-88-3)	54	54	0.10	2.13	0.41
trans-2-Butene (624-64-6)	54	37	0.02	1.38	0.08
trans-2-Pentene (646-04-8)	54	37	0.02	0.07	0.03

*Samples reported as non-detects (ND) were included in averages as 1/2 minimum detection limits.

Table B-4
Garfield County SNMOC Monitoring
Battlement Mesa (BMCO)
1/4/2011-12/30/2011 (every sixth day)

	Sample Count		Concentration (ppbV)		
Detected Compound (CAS Number)	**# Samples**	**# Detects**	**Minimum**	**Maximum**	**Average***
1,2,3-Trimethylbenzene (526-73-8)	50	45	0.01	0.15	0.03
1,2,4-Trimethylbenzene (95-63-6)	50	50	0.02	0.48	0.09
1,3,5-Trimethylbenzene (108-67-8)	50	35	0.01	0.22	0.05
1,3-Butadiene (106-99-0)	50	8	0.03	0.07	0.03
1-Decene (872-05-9)	50	1	0.43	0.43	0.02
1-Dodecene (112-41-4)	50	38	0.01	0.14	0.03
1-Heptene (592-76-7)	50	50	0.03	0.42	0.14
1-Hexene (592-41-6)	50	39	0.02	0.09	0.04
1-Nonene (124-11-8)	50	20	0.01	0.12	0.02
1-Octene (111-66-0)	50	22	0.01	0.05	0.02
1-Pentene (109-67-1)	50	48	0.02	0.29	0.06
1-Tridecene (2437-56-1)	50	2	0.01	0.02	0.02
1-Undecene (821-95-4)	50	10	0.01	0.10	0.01
2,2,3-Trimethylpentane (564-02-3)	50	15	0.02	0.08	0.02
2,2,4-Trimethylpentane (540-84-1)	50	25	0.01	0.18	0.03
2,2-Dimethylbutane (75-83-2)	50	50	0.03	0.35	0.14
2,3,4-Trimethylpentane (565-75-3)	50	44	0.01	0.10	0.03
2,3-Dimethylbutane (79-29-8)	50	40	0.05	0.61	0.19
2,3-Dimethylpentane (565-59-3)	50	50	0.03	0.33	0.12
2,4-Dimethylpentane (108-08-7)	50	50	0.01	0.22	0.08
2-Methyl-1-butene (563-46-2)	50	25	0.03	0.42	0.07
2-Methyl-1-pentene (763-29-1)	50	4	0.03	0.06	0.03
2-Methyl-2-butene (513-35-9)	50	38	0.03	0.57	0.09
2-Methylheptane (592-27-8)	50	50	0.02	0.39	0.12
2-Methylhexane (591-76-4)	50	50	0.05	0.84	0.32
2-Methylpentane (107-83-5)	50	50	0.18	2.53	0.93
3-Methyl-1-butene (563-45-1)	50	3	0.10	0.16	0.03
3-Methylheptane (589-81-1)	50	50	0.02	0.30	0.09
3-Methylhexane (589-34-4)	50	49	0.05	0.86	0.30
3-Methylpentane (96-14-0)	50	50	0.10	1.48	0.54
4-Methyl-1-pentene (691-37-2)	50	2	0.02	0.03	0.03
Acetylene (74-86-2)	50	50	0.17	1.38	0.54
a-Pinene (80-56-8)	50	13	0.01	0.08	0.02
Benzene (71-43-2)	50	50	0.11	2.15	0.49
b-Pinene (127-91-3)	50	3	0.03	0.12	0.01
cis-2-Butene (590-18-1)	50	46	0.02	0.59	0.09
cis-2-Hexene (7688-21-3)	50	10	0.01	0.06	0.03
cis-2-Pentene (627-20-3)	50	38	0.01	0.29	0.05
Cyclohexane (110-82-7)	50	50	0.10	2.07	0.61
Cyclopentane (287-92-3)	50	50	0.05	0.49	0.18
Cyclopentene (142-29-0)	50	18	0.02	0.32	0.05
Ethane (74-84-0)	50	50	5.10	209.00	43.11

*Samples reported as non-detects (ND) were included in averages as 1/2 minimum detection limits.

Table B-4 (continued)
Garfield County SNMOC Monitoring
Battlement Mesa (BMCO)
1/4/2011-12/30/2011 (every sixth day)

	Sample Count		Concentration (ppbV)		
Detected Compound (CAS Number)	**# Samples**	**# Detects**	**Minimum**	**Maximum**	**Average***
Ethylbenzene (100-41-4)	50	50	0.02	0.43	0.08
Ethylene (74-85-1)	50	50	0.57	2.04	1.04
Isobutane (75-28-5)	50	50	0.50	15.95	4.46
Isobutene/1-Butene (115-11-7 / 106-98-9)	50	16	0.04	1.66	0.20
Isopentane (78-78-4)	50	49	0.64	13.32	4.24
Isoprene (78-79-5)	50	41	0.02	0.31	0.07
Isopropylbenzene (98-82-8)	50	37	0.01	0.04	0.02
m-Diethylbenzene (141-93-5)	50	44	0.01	0.24	0.05
Methylcyclohexane (108-87-2)	50	50	0.14	3.91	1.07
Methylcyclopentane (96-37-7)	50	50	0.09	1.67	0.56
m-Ethyltoluene (620-14-4)	50	50	0.01	0.30	0.06
m-Xylene/p-Xylene (108-38-3 / 106-42-3)	50	28	0.06	1.71	0.26
n-Butane (106-97-8)	50	40	0.70	16.10	3.99
n-Decane (124-18-5)	50	50	0.01	0.91	0.10
n-Dodecane (112-40-3)	50	50	0.01	0.13	0.05
n-Heptane (142-82-5)	50	50	0.07	1.50	0.45
n-Hexane (110-54-3)	50	50	0.13	3.08	0.96
n-Nonane (111-84-2)	50	50	0.02	0.62	0.13
n-Octane (111-65-9)	50	50	0.06	1.11	0.27
n-Pentane (109-66-0)	50	50	0.38	7.50	2.43
n-Propylbenzene (103-65-1)	50	42	0.01	0.14	0.03
n-Tridecane (629-50-5)	50	7	0.00	0.03	0.02
n-Undecane (1120-21-4)	50	50	0.01	0.34	0.06
o-Ethyltoluene (611-14-3)	50	47	0.01	0.23	0.04
o-Xylene (95-47-6)	50	50	0.01	0.56	0.11
p-Diethylbenzene (105-05-5)	50	41	0.01	0.10	0.02
p-Ethyltoluene (622-96-8)	50	49	0.01	0.22	0.04
Propane (74-98-6)	50	50	1.91	67.33	15.99
Propylene (115-07-1)	50	49	0.10	0.41	0.25
Styrene (100-42-5)	50	6	0.02	0.09	0.02
Toluene (108-88-3)	50	50	0.15	3.27	0.80
trans-2-Butene (624-64-6)	50	48	0.02	0.67	0.11
trans-2-Hexene (4050-45-7)	50	6	0.02	0.09	0.03
trans-2-Pentene (646-04-8)	50	44	0.02	0.53	0.08

*Samples reported as non-detects (ND) were included in averages as 1/2 minimum detection limits.

APPENDIX C

Garfield County

2011 Carbonyl Concentrations

Table C-1
Garfield County Carbonyl Monitoring
Parachute (PACO)
1/10/2011-12/24/2011 (every twelfth day)

	Sample Count		Concentration (ppbV)		
Compound (CAS Number)	**# Samples**	**# Detects**	**Minimum**	**Maximum**	**Average***
2,5-Dimethylbenzaldehyde (5779-94-2)	21	0	ND	ND	0.00
Acetaldehyde (75-07-0)	21	21	0.20	0.84	0.50
Acetone (67-64-1)	21	21	0.54	3.38	1.17
Benzaldehyde (100-52-7)	21	21	0.01	0.05	0.02
Butyraldehyde (123-72-8)	21	21	0.01	0.07	0.04
Crotonaldehyde (123-73-9)	21	20	0.01	0.12	0.03
Formaldehyde (50-00-0)	21	21	0.75	2.13	1.33
Hexaldehyde (66-25-1)	21	21	0.00	0.09	0.02
Isovaleraldehyde (590-86-3)	21	0	ND	ND	0.00
Propionaldehyde (123-38-6)	21	19	0.01	0.09	0.04
Tolualdehydes (NA)	21	20	0.01	0.11	0.03
Valeraldehyde (110-62-3)	21	21	0.00	0.04	0.01

*Samples reported as non-detects (ND) are included in averages as 1/2 minimum detection limits.

Table C-2
Garfield County Carbonyl Monitoring
Rifle (RICO)
1/10/2011-12/12/2011 (every twelfth day)

	Sample Count		Concentration (ppbV)		
Compound (CAS Number)	**# Samples**	**# Detects**	**Minimum**	**Maximum**	**Average***
2,5-Dimethylbenzaldehyde (5779-94-2)	17	0	ND	ND	0.00
Acetaldehyde (75-07-0)	17	17	0.39	1.30	0.78
Acetone (67-64-1)	17	17	0.65	2.23	1.15
Benzaldehyde (100-52-7)	17	17	0.01	0.07	0.03
Butyraldehyde (123-72-8)	17	17	0.01	0.18	0.05
Crotonaldehyde (123-73-9)	17	17	0.01	0.14	0.05
Formaldehyde (50-00-0)	17	17	0.67	2.76	1.48
Hexaldehyde (66-25-1)	17	17	0.01	0.24	0.06
Isovaleraldehyde (590-86-3)	17	0	ND	ND	0.00
Propionaldehyde (123-38-6)	17	17	0.02	0.12	0.06
Tolualdehydes (NA)	17	15	0.02	0.14	0.04
Valeraldehyde (110-62-3)	17	17	0.00	0.09	0.02

*Samples reported as non-detects (ND) are included in averages as 1/2 minimum detection limits.

Table C-3
Garfield County Carbonyl Monitoring
Bell-Melton (BRCO)
9/19/2011-12/24/2011 (every twelfth day)

	Sample Count		Concentration (ppbV)		
Compound (CAS Number)	**# Samples**	**# Detects**	**Minimum**	**Maximum**	**Average***
2,5-Dimethylbenzaldehyde (5779-94-2)	6	0	ND	ND	0.00
Acetaldehyde (75-07-0)	6	6	0.21	0.41	0.34
Acetone (67-64-1)	6	6	0.43	1.33	0.99
Benzaldehyde (100-52-7)	6	6	0.01	0.03	0.02
Butyraldehyde (123-72-8)	6	6	0.01	0.06	0.02
Crotonaldehyde (123-73-9)	6	5	0.01	0.03	0.02
Formaldehyde (50-00-0)	6	6	0.53	0.94	0.78
Hexaldehyde (66-25-1)	6	6	0.01	0.01	0.01
Isovaleraldehyde (590-86-3)	6	0	ND	ND	0.00
Propionaldehyde (123-38-6)	6	5	0.02	0.06	0.03
Tolualdehydes (NA)	6	6	0.01	0.02	0.02
Valeraldehyde (110-62-3)	6	6	0.00	0.02	0.01

*Samples reported as non-detects (ND) are included in averages as 1/2 minimum detection limits.

Table C-4
Garfield County Carbonyl Monitoring
Battlement Mesa (BMCO)
1/10/2011-12/24/2011 (every twelfth day)

	Sample Count		Concentration (ppbV)		
Compound (CAS Number)	**# Samples**	**# Detects**	**Minimum**	**Maximum**	**Average***
2,5-Dimethylbenzaldehyde (5779-94-2)	20	0	ND	ND	0.00
Acetaldehyde (75-07-0)	20	20	0.21	0.73	0.42
Acetone (67-64-1)	20	20	0.53	4.60	1.61
Benzaldehyde (100-52-7)	20	20	0.01	0.36	0.05
Butyraldehyde (123-72-8)	20	20	0.02	0.06	0.03
Crotonaldehyde (123-73-9)	20	19	0.00	0.11	0.03
Formaldehyde (50-00-0)	20	20	0.58	2.13	1.18
Hexaldehyde (66-25-1)	20	20	0.01	0.03	0.02
Isovaleraldehyde (590-86-3)	20	0	ND	ND	0.00
Propionaldehyde (123-38-6)	20	19	0.02	0.08	0.03
Tolualdehydes (NA)	20	16	0.01	0.11	0.02
Valeraldehyde (110-62-3)	20	19	0.00	0.03	0.01

*Samples reported as non-detects (ND) are included in averages as 1/2 minimum detection limits.