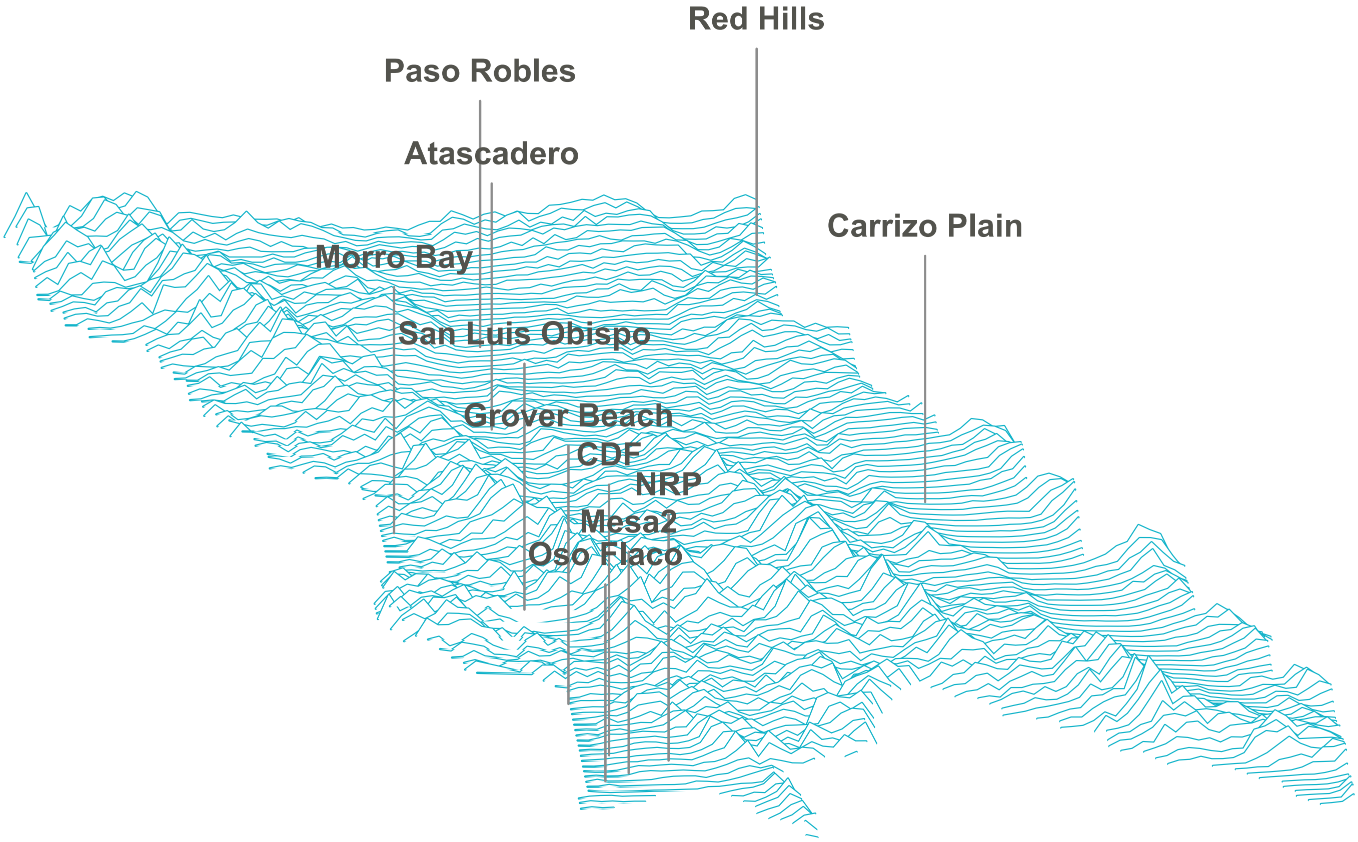
ANNUAL AIR QUALITY REPORT 2017



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Executive Summary

Ozone levels in the western portion of San Luis Obispo County remained low in 2017, though the Atascadero, Paso Robles, and Nipomo Regional Park sites each exceeded the federal standard once this year. The rural eastern portion of the county, which has been designated as a nonattainment zone for the federal standard since 2012 (see Figure 1), continued to experience occasional exceedances of the standard, with one day exceeding the standard at Carrizo Plain and six days at Red Hills. Nonetheless, a clear downward trend in ozone levels is apparent for Red Hills, which is the site most impacted by ozone pollution (Figures 7 and 8).

Smoke from wildfires had major impacts on ozone levels this year. Two large wildfires burning near California–Oregon border contributed to many of the year's highest ozone concentrations (Table 3), including the standard exceedances at Paso Robles, Atascadero, Red Hills, and Nipomo Regional Park on September 1st and/or 2nd. These were the Salmon August Complex Fire, which burned 65,000 acres Siskiyou County, and the Chetco Bar Fire, which burned nearly 200,000 acres within the Rogue River–Siskiyou National Forest in Oregon. Similarly, the July 9th exceedances at Carrizo Plain are likely related to the Alamo Fire, which began on July 6th and burned more than 28,000 acres near Twitchell Reservoir, and/or the Whittier Fire, which began July 8th and burned over 18,000 acres in Santa Barbara County.

South County air quality continues to be impacted by dust blown from the Oceano Dunes State Vehicular Recreation Area (ODSVRA) along the coast. While the federal PM_{10} standard was not exceeded at any site in 2017, the more stringent state standard was exceeded on more than a quarter of days on the Nipomo Mesa, which is an increase from the previous year. In addition, the Rule 1001 performance standard was violated 66 times. With regard to $PM_{2.5}$, neither 24-hour nor the annual average standards were exceeded anywhere in the county this year.

While windblown dust was the predominant source of high particulate matter levels in the South County, smoke from wildfires also contributed to high particulate events throughout the county. All of the year's highest PM_{10} and $PM_{2.5}$ values at Atascadero, Paso Robles, and San Luis Obispo (Table 4) were due to either the Thomas Fire, which burned 280,000 acres in Ventura and Santa Barbara Counties in December, or the October Northern California wildfires, which collectively burned nearly 250,000 acres. These fires also caused some of year's peak values at Nipomo Regional Park, Oso Flaco, and Mesa2. Construction-related dust caused at least one exceedance of the state PM_{10} standard this year, specifically on December 4th at Mesa2, which was the highest recorded value for that site in 2017.

There were no exceedances of the standards for nitrogen dioxide or sulfur dioxide at any stations this year.

This report contains two appendices. Appendix A presents a new approach for evaluating the effects of ODSVRA dust control projects on downwind PM_{10}. Appendix B reports the results of respirable crystalline silica sampling conducted in 2017 and 2018 at CDF. None of the 9 samples exceeded the OSHA workplace silica standard; however, we cannot conclude that there is no risk since our results may underestimate actual silica levels. See the appendix for details.

Finally, there were some network outages in 2017 that affect the data in this report:

- The Oso Flaco site was temporarily shut down from December 15, 2016, through March 25, 2017.
- The PM_{10} monitor at the Paso Robles site (which is managed by the Air Resources Board) experienced 3 separate outages lasting one to four weeks each. As a result, the monitor fails annual data completeness requirements.

The air quality database for San Luis Obispo County is a public record and is available from the District office in various forms, including comprehensive records of all hourly or other sample values acquired anywhere in the county. Data summaries are published in Annual Air Quality Reports, like this one. Summary data appear weekly in the Saturday edition of The Tribune, a local newspaper. Ambient monitoring data is added to separate archives maintained by EPA and ARB. Summary data from San Luis Obispo County can be found in EPA and ARB publications and on the world wide web at the following websites:

www.slocleanair.org
APCD website
www.arb.ca.gov
ARB website
www.epa.gov
US EPA website
www.airnow.gov
Air Quality Index site

Air Quality Monitoring and Data

Air quality in San Luis Obispo County was measured by a network of 11 permanent ambient air monitoring stations in 2017; their locations are depicted in Figure 1. The San Luis Obispo County Air Pollution Control District (District) owns and operates seven permanent stations: Nipomo Regional Park (NRP), Grover Beach, Morro Bay, Atascadero, Red Hills, Carrizo Plain, and the CDF fire station on the Nipomo Mesa. The California Air Resources Board (ARB) operates stations in San Luis Obispo and Paso Robles. Two stations are owned by third parties but operated by the District: Mesa2, located on the Nipomo Mesa and owned by the Phillips 66 refinery, and Oso Flaco, located within the ODSVRA and owned by the California Department of Parks and Recreation. See Table 2 for a summary of the pollutants monitored at each station.

Air quality monitoring is subject to rigorous federal and state quality assurance and quality control requirements, and equipment and data are audited periodically to ensure data validity. Gaseous pollutant levels are measured every few seconds and averaged to yield hourly values. Particulate matter ($PM_{2.5}$ and PM_{10}) is sampled hourly using Beta Attenuation Monitors (BAMs). All monitoring instruments are Environmental Protection Agency (EPA)-approved Federal Equivalent Methods (FEMs) or Federal Reference Methods (FRMs).

The 2017 data reviewed in this report was extracted from the EPA's Air Quality System (AQS) database. Prior to being uploaded to AQS, all data were thoroughly reviewed and validated by the collecting agency (i.e., ARB for data from Paso Robles and San Luis Obispo and the District for all other sites). The raw data and the R-code used to compile the statistics and generate the graphs in this report are available online at https://github.com/sloapcdkt/2017aqrptR.

Figure 1: Map of Monitoring Stations in San Luis Obispo County

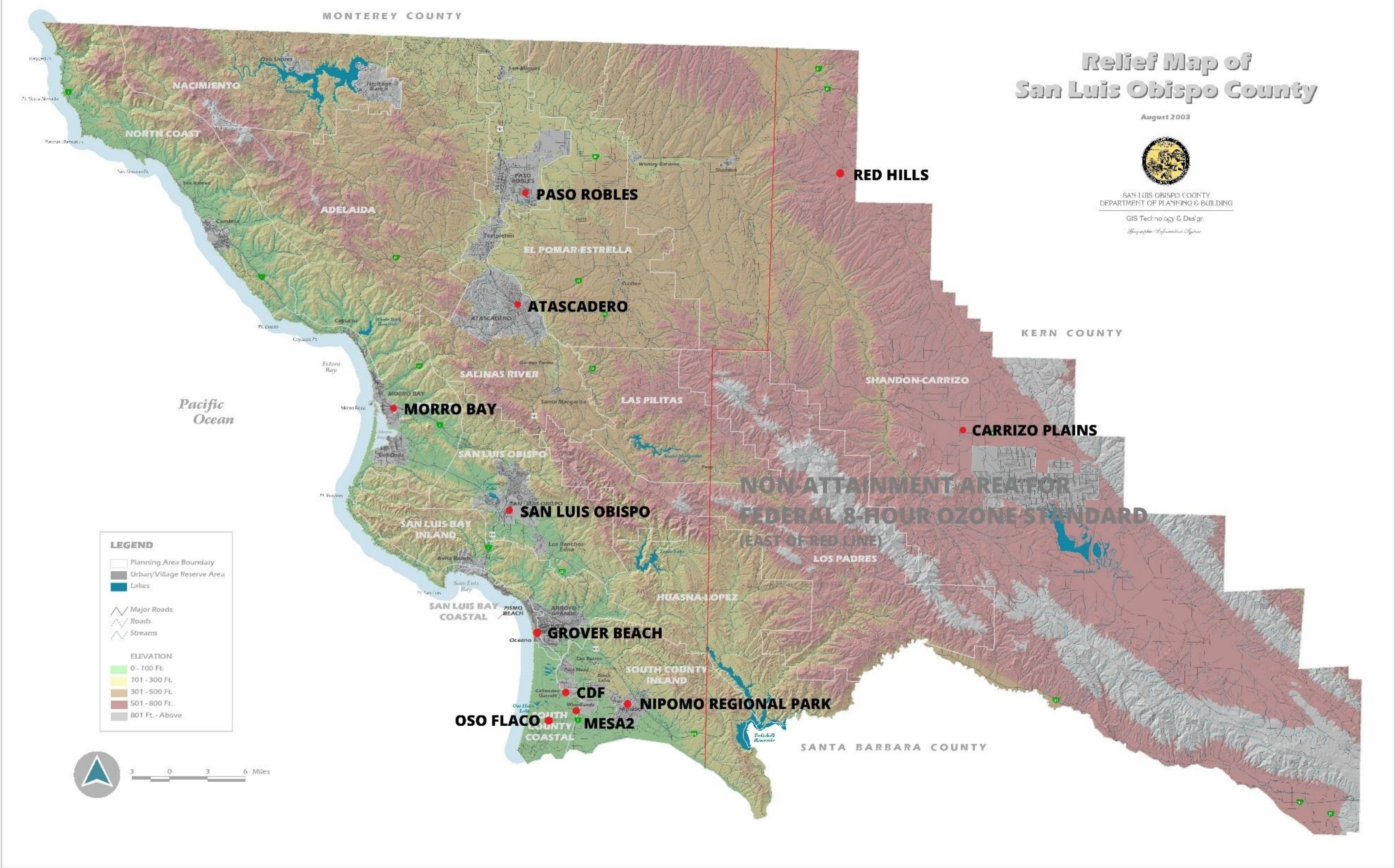

Table 1: Ambient Air Quality Parameters Monitored in San Luis Obispo County in 2017

	O_3	NO	NO_2	NO_x	SO_2	PM_{10}	$PM_{2.5}$	WS	WD	ATM
APCD Permanent Stations										
Atascadero	X	X	X	X		X	X	X	X	X
Morro Bay	X							X	X	
Nipomo Regional Park	X	X	X	X		X		X	X	X
Red Hills	X							X	X	X
Carrizo Plain	X							X	X	X
CDF						X	X	X	X	
Grover Beach								X	X	
ARB Stations										
San Luis Obispo	X					X	X	X	X	X
Paso Robles	X					X		X	X	X
Operated by APCD										
Mesa2					X	X	X	X	X	X
Oso Flaco						X		X	X	X

Abbreviations and Chemical Formulas:

O_3	Ozone
NO	Nitric Oxide
NO_2	Nitrogen Dioxide
NO_x	Oxides of Nitrogen
SO_2	Sulfur Dioxide
CO	Carbon Monoxide
PM_{10}	Particulates < 10 microns
$PM_{2.5}$	Particulates < 2.5 microns
WS	Wind Speed
WD	Wind Direction
ATM	Ambient Temp

Ambient Air Pollutants Of Local Concern

Ozone

Ozone (O_3) is a gas that is naturally found near the earth's surface at low concentrations, typically 10 to 40 parts per billion (ppb). It is also a principle component of photochemical smog, produced when precursor pollutants such as volatile organic compounds and nitrogen oxides react under the influence of sunlight. Ozone precursors are emitted by many human activities, but industrial processes and motor vehicles are primary sources. The chemistry of atmospheric ozone is complex, and in the absence of sunlight, ozone is destroyed by reaction with the same precursor molecules that fuel its formation during the day. As a result, ozone concentrations typically increase as sunlight intensity increases, peaking midday or in the afternoon and gradually declining from there, typically reaching their lowest levels in the early morning hours and just before sunrise, as shown in Figure 2, below.

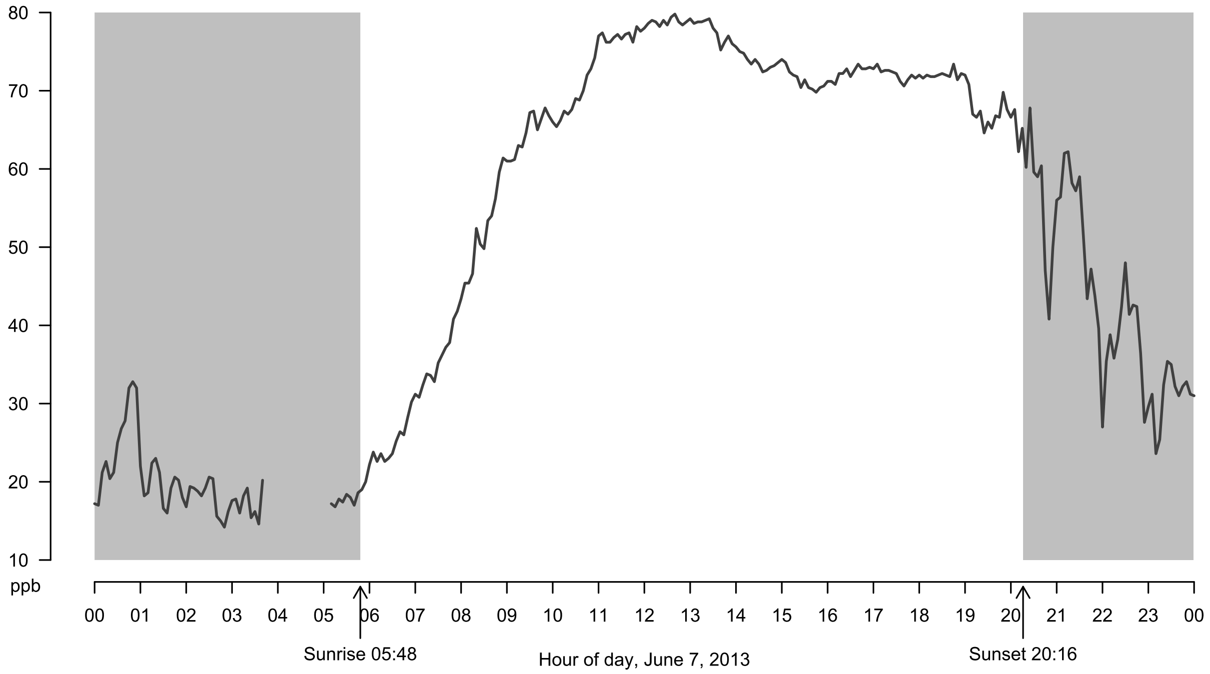

Figure 2: Example of Diurnal Ozone Pattern from Carrizo Plain

As a pollutant, ozone is a strong oxidant gas that attacks plant and animal tissues. It can cause impaired breathing and reduced lung capacity, especially among children, athletes and persons with compromised respiratory systems; it can also cause significant crop and forest damage. Ozone is a pollutant of particular concern in California where geography, climate, and emissions from industrial and commercial sources and millions of vehicles contribute to frequent violations of health-based air quality standards.

While ground level ozone is harmful to plants and animals and is considered a pollutant, upper level (stratospheric) ozone occurs naturally and protects the earth from harmful ultra-violet energy from the sun.

Particulate Matter

Ambient air quality standards have been established for two classes of particulate matter: PM_{10} (respirable particulate matter less than 10 microns in aerodynamic diameter), and $PM_{2.5}$ (fine particulate matter 2.5 microns or less in aerodynamic diameter). Both consist of many different types of particles that vary in their composition and toxicity. $PM_{2.5}$ tends to be a greater health risk since these particles can get lodged deep in the lungs or enter the blood stream, causing both short and long-term damage. Sources of particulate pollution include diesel exhaust; mineral extraction and production; combustion products from industry and motor vehicles; smoke from open burning; paved and unpaved roads; condensation of gaseous pollutants into liquid or solid particles; and windblown dust from soils disturbed by demolition and construction, agricultural operations, off-road vehicle recreation, and other activities.

In addition to its harmful health effects, particulate matter can also greatly reduce visibility.

Nitrogen Dioxide, Sulfur Dioxide, and Carbon Monoxide

Nitrogen dioxide (NO_2) is the brownish-colored component of smog. NO_2 irritates the eyes, nose and throat and can damage lung tissue. Sulfur dioxide (SO_2) is a colorless gas with health effects similar to NO_2. Both pollutants are generated by fossil fuel combustion from mobile sources such as vehicles, ships, and aircraft and at stationary sources such as industry facilities, homes, and businesses. SO_2 is also emitted by petroleum production and refining operations. These pollutants can create aerosols, which may fall as acid rain causing damage to crops, forests, and lakes. They can also exacerbate asthma and harm the human respiratory system.

Carbon monoxide (CO) is a colorless and odorless gas that can interfere with the ability of red blood cells to transport oxygen. Exposure to CO can cause headaches, fatigue, and even death. CO results from fuel combustion of all types, but motor vehicles are by far the chief contributor of CO in outdoor air.

State and National Ambient Air Quality Standards

California ARB and the U.S. EPA have adopted ambient air quality standards for six common air pollutants of primary public health concern: ozone, particulate matter (PM_{10} and $PM_{2.5}$), nitrogen dioxide, sulfur dioxide, carbon monoxide, and lead.[1] These are called "criteria pollutants" because the standards establish permissible airborne pollutant levels based on criteria developed after careful review of all medical and scientific studies of the effects of each pollutant on public health and welfare.

The National Ambient Air Quality Standards (NAAQS; see Table 2) are used by EPA to designate a region as either "attainment" or "nonattainment" for each criteria pollutant. A nonattainment designation can trigger additional regulations aimed at reducing pollution levels and bringing the region into attainment. For most pollutants, the NAAQS allow a standard to be exceeded a certain number of times each calendar year without resulting in a nonattainment designation. Additionally, exceedances caused by exceptional events (see below) may be excluded from attainment/nonattainment determinations at the discretion of the EPA.

In May 2012, the EPA designated the eastern portion of San Luis Obispo County as marginally nonattainment for the 8-hour ozone standard. This was based on data from enhanced monitoring over the previous decade that revealed previously unrecognized high ozone levels in that region; the western portion of the county retained its attainment status. (See Figure 1 for the boundary between the attainment and nonattainment areas.) In October 2015, the standard was lowered from 75 to 70 ppb, and in April 2018, the EPA designated the eastern portion of the county as a marginal non-attainment zone for the new standard. The county is currently designated as attaining all other NAAQS.

The California Ambient Air Quality Standards are generally more restrictive (i.e. lower) than the NAAQS, and typically are specified as not to be exceeded. Thus, a single exceedance is a violation of the applicable standard and triggers a nonattainment designation. As a result, San Luis Obispo County is designated as a nonattainment area for the state one-hour and 8-hour ozone standards, as well as the state 24-hour and annual PM_{10} standards. The county is designated as attaining the state annual $PM_{2.5}$ standard.

State and federal standards for NO_2 have never been exceeded here. The state standard for SO_2 was exceeded periodically on the Nipomo Mesa until 1993. Equipment and processes at the facilities responsible for the emissions were upgraded as a result, and the state SO_2 standard has not been exceeded since that time. Exceedances of the federal SO_2 standard had never been recorded here until 2014, when maintenance activities at these facilities resulted in emissions exceeding the 1-hour standard of 75 ppb. (This standard was established in 2011.) State CO standards have not been exceeded in the county since 1975. The county has never been required to conduct lead monitoring.

Exceptional Events

Exceptional events are unusual or naturally occurring events that can affect air quality but are not reasonably controllable or preventable and are unlikely to reoccur at a particular location. Examples include wildfires and tornadoes. Air quality monitoring data influenced by exceptional events can sometimes be excluded from regulatory determinations related to violations of the NAAQS, if recommended by the APCD and ARB and approved by the EPA. The APCD has not submitted any exceptional event documentation for 2017 and does not expect any data compiled in this report to be excluded from future attainment determinations.

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[1] In addition to these six pollutants, California also has standards for hydrogen sulfide, sulfate, vinyl chloride, and visibility reducing particles.

Table 2: Ambient Air Quality Standards for 2017 and Attainment Status[*]

***A standard exceedance** occurs when a measured pollutant concentration exceeds (or in some cases, equals) the applicable standard prescribed by state or federal agencies. It does not necessarily constitute a violation.*

***A standard violation** may occur following a single or cumulative series of standard exceedances. Criteria constituting a violation are unique for each pollutant.*

***A nonattainment designation** occurs when a state or federal agency formally declares an area in violation of a standard. Typically, ARB performs designations annually. Several years often pass between EPA designations.*

	Averaging Time	California Standard[†]	National Standard[†]
Ozone (O_3)	8 Hours	**70 ppb**	**70 ppb** [§]
	1 Hour	**90 ppb**	
Respirable Particulate Matter (PM_{10})	24 Hours	**50 $\mu g/m^3$**	150 $\mu g/m^3$
	1 Year[‡]	**20 $\mu g/m^3$**	
Fine Particulate Matter ($PM_{2.5}$)	24 Hours		35 $\mu g/m^3$
	1 Year[‡]	12 $\mu g/m^3$	12 $\mu g/m^3$
Carbon Monoxide (CO)	8 Hours	9.0 ppm	9 ppm
	1 Hours	20 ppm	35 ppm
Nitrogen Dioxide (NO_2)	1 Year[‡]	30 ppb	53 ppb
	1 Hour	180 ppb	100 ppb
Sulfur Dioxide (SO_2)	3 Hours		500 ppb (secondary)
	1 Hour	250 ppb	75 ppb (primary)
Lead (Pb)	3 Month		0.15 $\mu g/m^3$
	30 Day	1.5 $\mu g/m^3$	

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[*] San Luis Obispo County (in whole or in part) is designated as nonattainment for the standards in **boldface print** as of November 2018.

[†] For clarity, the ozone, SO_2, and NO_2 standards are expressed in parts per billion (ppb), however most of these standards were promulgated in parts per million (ppm). When comparing to the national PM_{10} standard, federal regulations state that measurements shall be rounded to the nearest 10 $\mu g/m^3$. Thus 24-hour averages between 150 and 154 $\mu g/m^3$ are not considered exceedances of the standard, even though they are greater (or equal to) 150 $\mu g/m^3$.

[‡] This standard is calculated as a weighted annual arithmetic mean.

Ozone and Gaseous Pollutant Summary

In 2015, the federal 8-hour ozone standard was lowered from 75 to 70 parts ppb, which is the same level as the state 8-hour standard. The old 75 ppb standard was exceeded only once in 2017: July 9th at Carrizo Plain. Exceedances of the current federal standard occurred on 7 days countywide, with 6 days at Red Hills[2] and 1 day each at Carrizo Plain, Atascadero, Paso Robles, and Nipomo Regional Park. The state 1-hour standard for ozone (90 ppb) was exceeded only once this year: July 9th at Carrizo Plain.

Standards for nitrogen dioxide and sulfur dioxide were not exceeded in 2017. In fact, there were only two hours in the entire year when sulfur dioxide levels exceeded 0 ppb.

Maximum Values

Table 3 lists the highest hourly (and for ozone, 8-hour) values recorded in 2017 for ozone, sulfur dioxide, and nitrogen dioxide at the stations where they are monitored. Concentrations are in parts per billion (ppb). The sample date appears under each pollutant value in the format "month/day." Values that exceed federal standards are shown in **bold**,[2] and those exceeding state standards are underlined.

Many of the highest 1-hour and 8-hour ozone concentrations (including standard exceedances at Paso Robles, Atascadero, Red Hills, and Nipomo Regional Park) occurred on September 1st or 2nd. These are likely related large wildfires that were burning near California–Oregon border, specifically the Salmon August Complex Fire in Siskiyou County and the Chetco Bar Fire within the Rogue River–Siskiyou National Forest in Oregon. Similarly, the July 9th 1-hour and 8-hour exceedances at Carrizo Plain are likely related to the Alamo Fire, which began on July 6th and burned more than 28,000 acres near Twitchell Reservoir, and/or the Whittier Fire in Santa Barbara County, which began July 8th burned over 18,000 acres.

Table 3: Highest Measurements for Gaseous Pollutants in 2017

Station	O_3 1-hour			O_3 8-hour				SO_2 1-hour			NO_2 1-hour		
	1st	2nd	3rd	1st	2nd	3rd	4th	1st	2nd	3rd	1st	2nd	3rd
Paso Robles	83 09/01	82 03/14	78 09/02	**74** 09/01	70 09/02	66 05/21	65 10/16						
Atascadero	77 09/01	77 09/02	75 03/14	**72** 09/01	66 09/02	62 09/28	62 10/18				39 12/14	38 12/07	38 12/13
Morro Bay	71 09/02	67 10/16	66 09/03	62 09/02	60 09/03	57 10/16	52 09/26:						
San Luis Obispo	74 09/02	72 09/01	67 04/05	66 09/01	66 09/02	61 10/16	59 09/26						
Red Hills	79 09/02	76 09/01	76 10/17	73 [2] 10/17	**72** 09/02	**72** 10/16	**71** 09/01						
Carrizo Plain	91 07/09	76 06/23	76 07/15	**80** 07/09	70 06/06	70 06/23	69 05/23						
Nipomo Regional Park	76 09/02	70 10/06	69 09/01	**71** 09/02	65 09/01	62 10/06	61 10/14				32 12/29	30 12/28	26 12/10
Mesa2, Nipomo								2 03/29	1 10/26	0 See text			

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[2] The 8-hour average for Red Hills from October 17th exceeds 70 ppb, but it is not an exceedance of the federal standard under 40 CFR 50 Appendix U because it occurred in the early morning. It is still considered an exceedance of the state standard.

Visual Ozone Summary

Figures 3 and 4 depict the ozone values from each station where it was monitored in 2017. The maximum 8-hour average for each day is shown for each site; exceedances of the 70-ppb standard are shown in red with the day of month printed beside them. The heavy “stair step” line marks the monthly median. The vertical axis extends to the annual maximum; units are ppb.

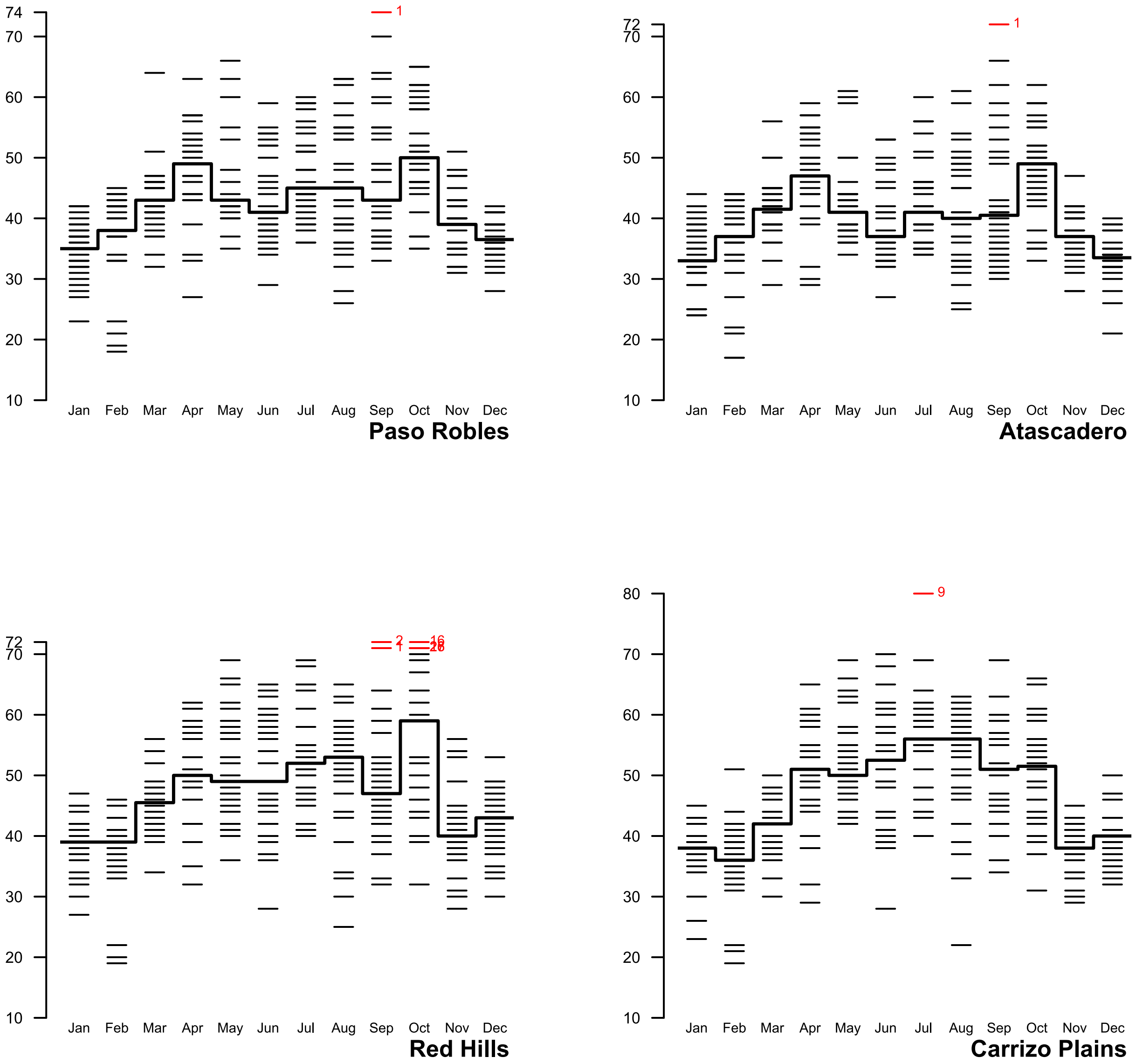

Figure 3: Daily Maximum 8-Hour Average for 2017

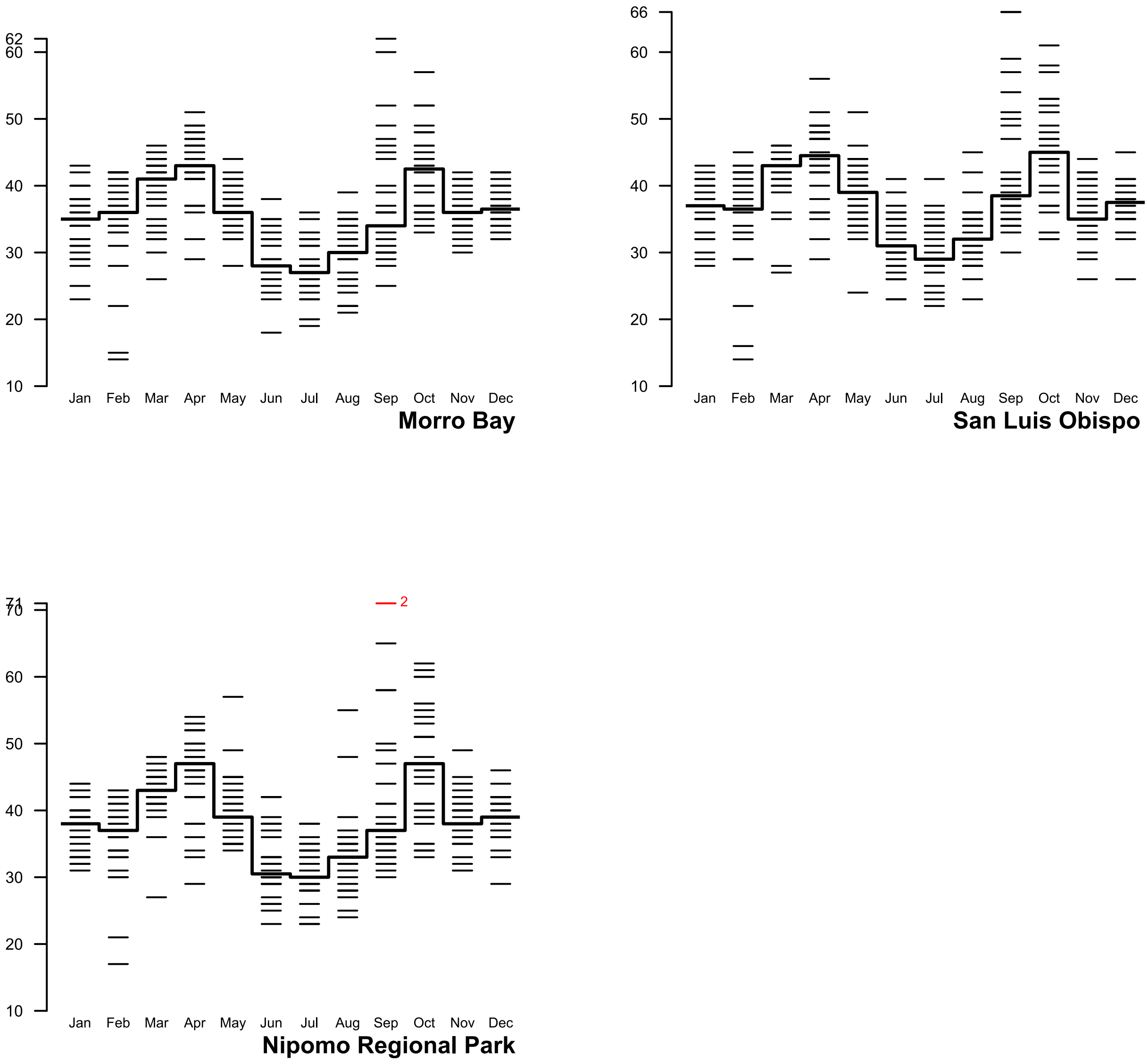

Figure 4: Daily Maximum 8-Hour Average for 2017

Particulate Matter Summary

In 2017, there were no exceedances of the federal 24-hour PM_{10} standard (150 $\mu g/m^3$) anywhere in the county. Exceedances of the state 24-hour PM_{10} standard (50 $\mu g/m^3$) were observed on 103 different days: 97 at CDF, 52 at Mesa2, 18 at NRP, 12 at Oso Flaco, 4 each at Paso Robles and San Luis Obispo, and 2 at Atascadero.[3] This year, CDF, Mesa2, NRP, and Oso Flaco exceeded the state annual average PM_{10} standard of 20 $\mu g/m^3$. For $PM_{2.5}$, the federal 24-hour standard (35 $\mu g/m^3$) and the federal and state annual average standards (both 12 $\mu g/m^3$) were not exceeded anywhere in the county this year.

Local Rule 1001, which is intended to address windblown dust emissions and downwind air quality impacts from the Oceano Dunes State Vehicular Recreation Area (ODSVRA), states that the park operator "shall ensure that if the 24-hour average PM_{10} concentration at the [riding area] Monitor is more than 20% above the 24-hour average PM_{10} concentration at the Control Site Monitor, the 24-hour average PM_{10} concentration at the [riding area] Monitor shall not exceed 55 $\mu g/m^3$."[4] For determining compliance with this standard, the CDF and Oso Flaco monitors have been designated as the riding area and control site monitors, respectively. This year there were 66 days that violated the Rule 1001 standard, as well as 10 possible violation days when the CDF 24-hour average exceeded 55 $\mu g/m^3$ but Oso Flaco was offline. (Oso Flaco was not operated from December 15, 2016, to March 26, 2017.)

Note that the PM_{10} monitors at Paso Robles and Oso Flaco operated for only part of the year and do not meet state and federal completeness requirements for computing annual averages.

Highest 24-hr Concentrations and Annual Averages

Table 4 lists the highest 24-hour concentrations recorded in 2017 and the dates on which they occurred, as well as the annual means for PM_{10} and $PM_{2.5}$ for all stations where these pollutants were monitored. Concentrations are in $\mu g/m^3$. Values exceeding federal standards are shown in **bold**; those exceeding state standards are underlined.

In general, standard exceedances at CDF, Mesa2, Nipomo Regional Park, and Oso Flaco are associated with windblown dust events. This includes this year's the top 3 PM_{10} and $PM_{2.5}$ 24-hour averages for CDF noted in Table 4.

In addition to dust, wildfires and construction caused elevated PM_{10} and $PM_{2.5}$ this year. The highest 24-hour PM_{10} value for Mesa, recorded on December 4th, is due to construction activities in the area. The Thomas Fire, which burned 280,000 acres in Ventura and Santa Barbara Counties in December, caused many of the peak 24-hour PM_{10} values noted in Table 4: December 16th at Paso Robles, Oso Flaco, Mesa2, and Nipomo Regional Park and December 17th at San Luis Obispo and Nipomo Regional Park. The first and second highest $PM_{2.5}$ values at Atascadero (December 12th and 28th) are also likely due to the Thomas Fire. The October Northern California wildfires, which collectively burned nearly 250,000 acres, contributed to the peak PM_{10} and $PM_{2.5}$ 24-hours values noted in the table for Paso Robles, Atascadero, and San Luis Obispo. Finally, the Pier Fire, previously mentioned in the ozone discussion, contributed to elevated

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[3] ARB and EPA apply different conventions to the handling of significant digits. The ARB website (http://www.arb.ca.gov/adam/topfour/topfour1.php) thus counts 82 exceedances of the state PM_{10} standard at CDF, 61 at Mesa2, 18 and Nipomo Regional Park, 13 at Oso Flaco, 6 at Paso Robles and 5 at San Luis Obispo. The database used by the ARB website may also contain erroneous values.

[4] San Luis Obispo County Air Pollution Control District, "RULE 1001 Coastal Dunes Dust Control Requirements," Adopted November 16, 2011, Revised by Court Order CV12-0013, March 7, 2016. Available online at https://www.arb.ca.gov/drdb/slo/cur.htm.

particulate levels in South County on September 2nd, including the second highest 24-hour PM$_{10}$ value for Oso Flaco and the second highest 24-hour PM$_{2.5}$ value for Mesa2.

Table 4: PM$_{10}$ and PM$_{2.5}$ Summary for 2017

Station	Highest 24-hour PM$_{10}$			Annual	Highest 24-hour PM$_{2.5}$			Annual
	1st	2nd	3rd	Average PM$_{10}$ ‡	1st	2nd	3rd	Average PM$_{2.5}$ ‡
Paso Robles *	55 12/16	55 10/17	53 10/18	17.7 *				
Atascadero	67 10/09	54 10/12	49 10/11	15.4	26.7 12/12	25.2 12/28	24.2 10/12	5.7
San Luis Obispo	67 12/17	63 10/09	57 10/13	16.7	25.6 10/12	23.1 10/13	21.6 10/11	6.8
CDF, Arroyo Grande	145 04/23	138 06/10	130 03/30	38.8	32.1 06/10	30.1 05/31	29.3 03/30	9.6
Nipomo Regional Park	101 12/16	72 06/15	68 12/17	24.9				
Oso Flaco *	97 12/16	80 09/02	63 03/30	29.0 *				
Mesa2, Nipomo	109 12/04	98 12/16	95 04/23	29.4	26.3 06/13	25.0 09/02	24.4 10/13	9.1

* Incomplete year, see text for details.

‡ Weighted arithmetic mean as calculated by an AMP450 AQS report.

Visual $PM_{2.5}$ and PM_{10} Summaries

Figures 5 and 6, below, show the 24-hour $PM_{2.5}$ and PM_{10} values from the stations where these pollutants were measured in 2017. As with the ozone plots in the previous section, these show daily concentrations by month for each site; exceedances of state and federal standards are shown in red with the day of month printed beside them. The heavy “stair step” line marks the monthly median. The vertical axis extends the annual maximum; units are $\mu g/m^3$.

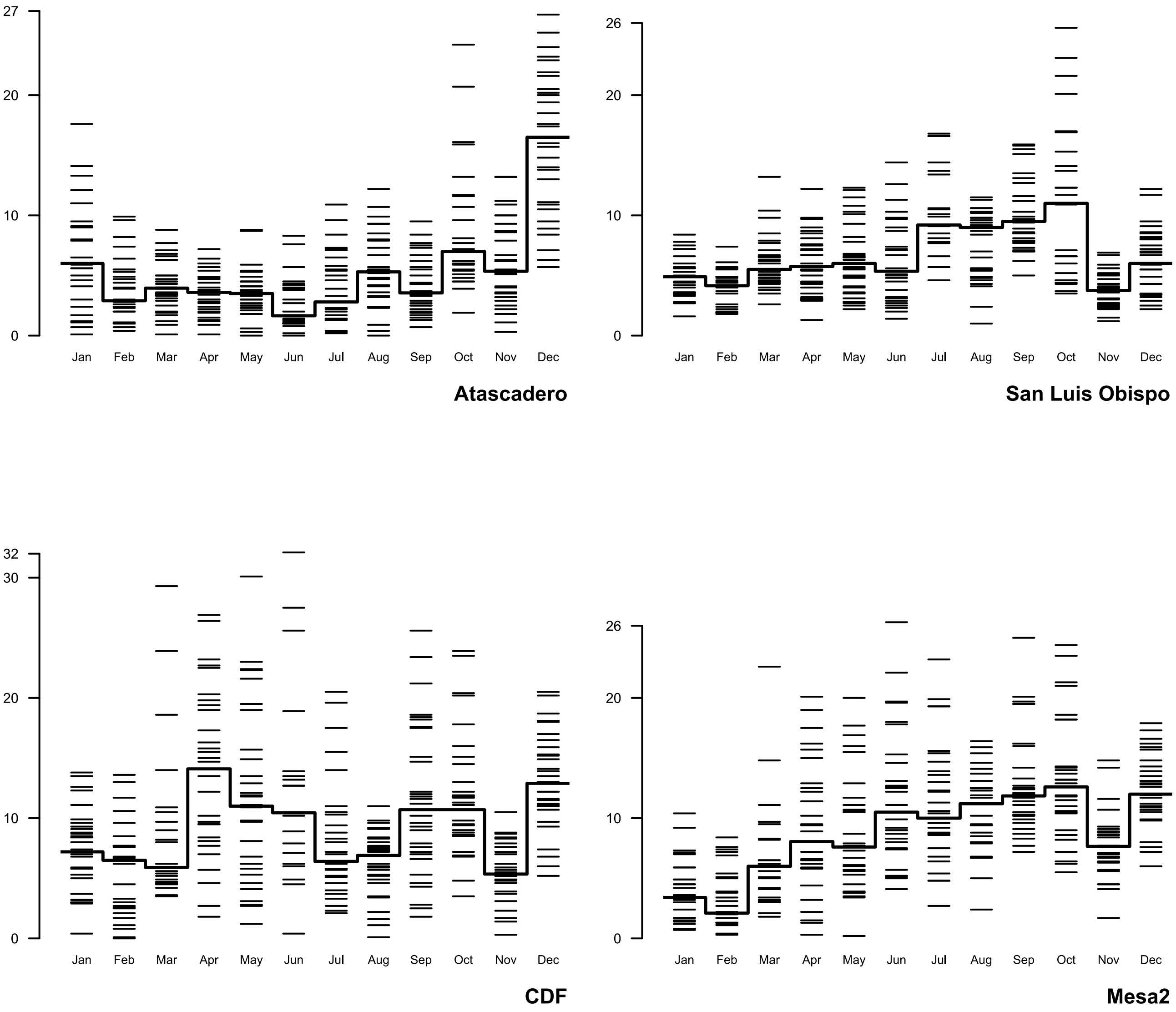

Figure 5: Daily $PM_{2.5}$ Values for 2017

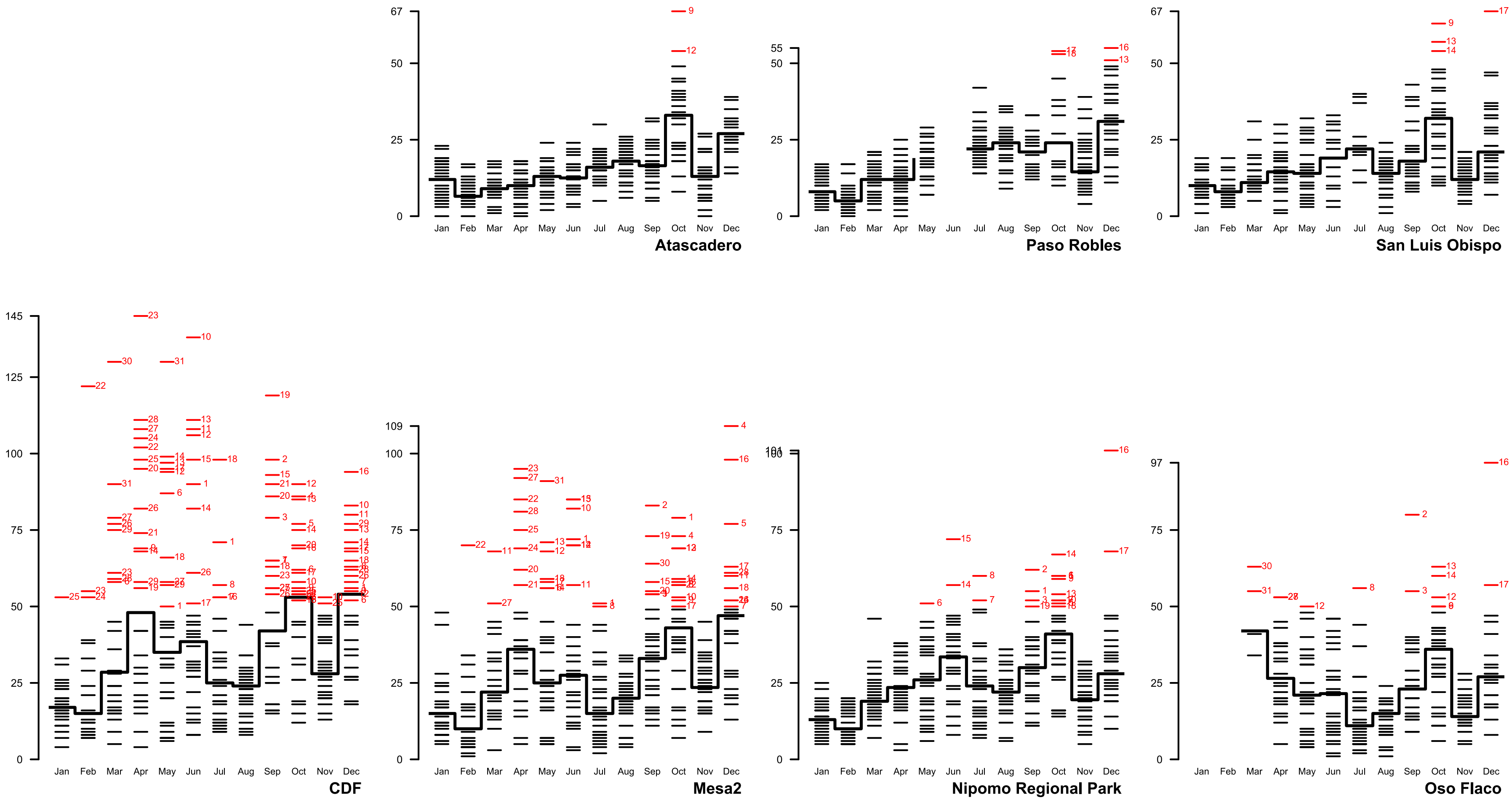

Figure 6: Daily PM_{10} Values for 2017

10-Year Trends

Ozone

Figure 7, below, depicts the total number of hours each year at each site during which the ozone concentration was at or above 65 ppb. This is a useful indicator for trends, even though there are no health standards for single-hour exposure to this level of ozone. Figure 8 shows ozone design values over the same period. Design values are used by EPA to determine whether an area attains a federal standard. For ozone, the design value is calculated by averaging the 4th highest annual 8-hour average over three consecutive years. For example, a 2016 design value is the average of the 4th highest 8-hour averages from 2014, 2015, and 2016. Only design values meeting data completeness requirements are included; the dashed red line indicates the federal 8-hour standard which changed from 75 to 70 ppb in 2015.

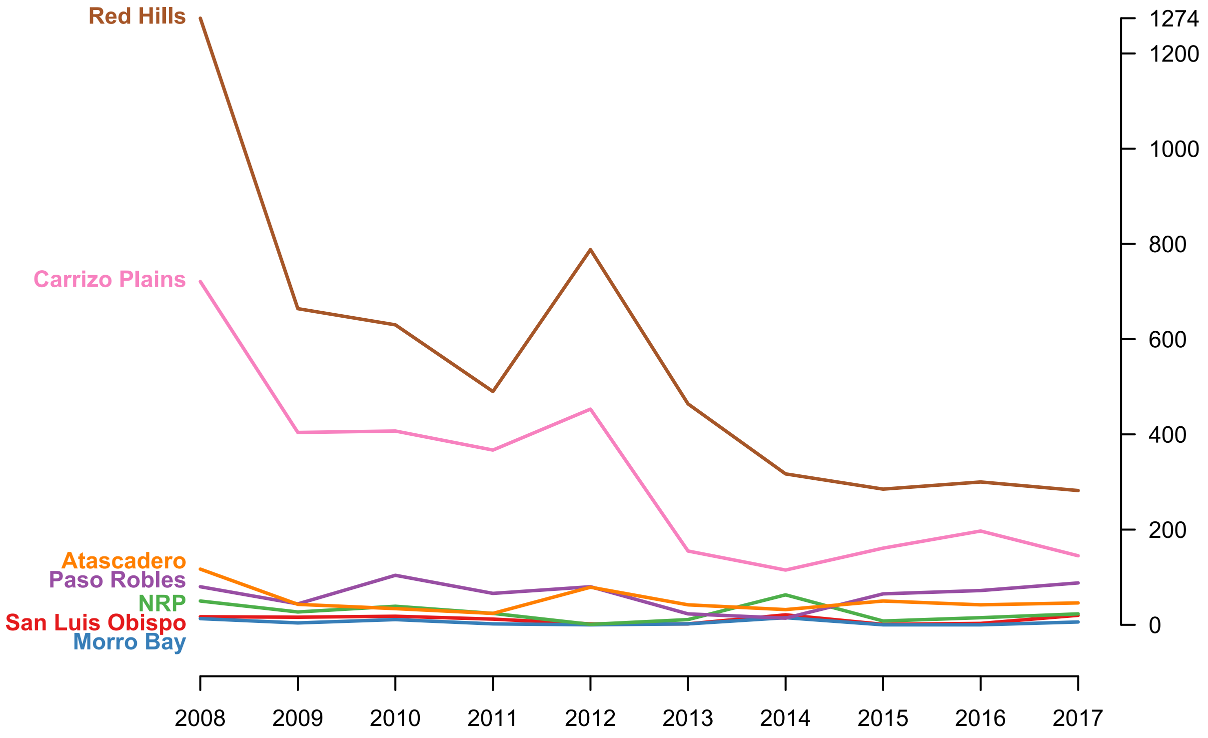

Figure 7: Hours At or Above 65 ppb Ozone, 2008-2017

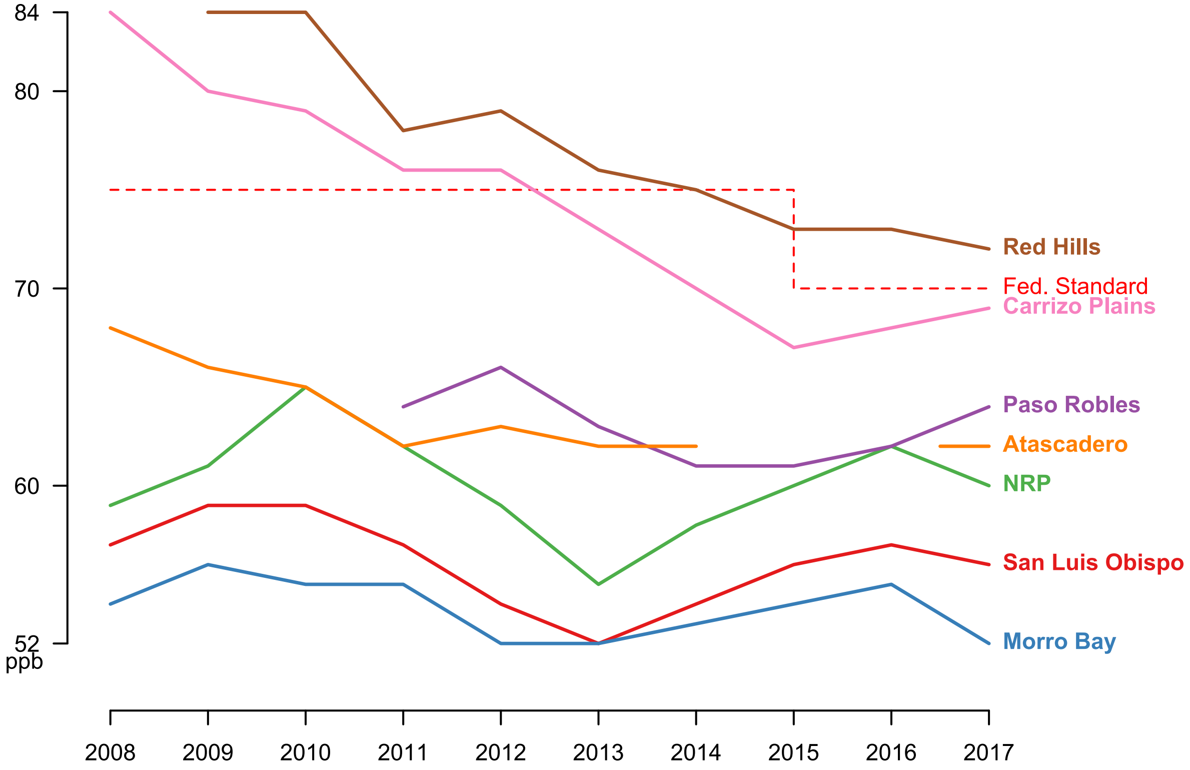

Figure 8: Ozone Design Value Trends, 2008-2017

Particulate Matter

Figure 9 (next page) shows the number of exceedances of the state PM_{10} standard at each site for each year. Collection of daily data began in mid–2009 for some sites and later for others, and years with less than 90% valid daily data are omitted, including all years for Oso Flaco.

Figure 10 plots the total number of hours each year when PM_{10} was at or above 50 $\mu g/m^3$ during the hours when people are most likely to be active (10 am to 4 pm). This metric is intended to illustrate trends in population exposure, even though there are no health standards for single-hour exposure to this level of PM_{10}. Only years with at least 90% valid hourly data are included. Oso Flaco is not included since in 2016 and 2017 its annual data capture was only 88% and 72%, respectively; however, the annual number of active hours at this site which were at or above 50 $\mu g/m^3$ were 151 and 171, respectively.

Figure 11 depicts annual average PM_{10} concentrations over the past 10 years;[5] years with partial data are omitted. The red dashed line marks the state standard for the annual mean (20 $\mu g/m^3$). While occasional exceedances of the standard occur at most sites, the monitors on the Nipomo Mesa at Nipomo Regional Park, Mesa2, and CDF are consistently higher than elsewhere in the county.

Trends in $PM_{2.5}$ annual average are depicted in Figure 12 for the four sites where it is measured. Data for the past 10 years are shown, and years with partial data are omitted. The red dashed line marks the 12 $\mu g/m^3$ state and federal $PM_{2.5}$ standard for the annual mean. As with PM_{10}, the stations on the Nipomo Mesa tend to record higher levels than those elsewhere in the county.

Ambient Air Monitoring Network Plans

The District prepares an Ambient Air Monitoring Network Plan every year. This document is an annual examination and evaluation of the network of air pollution monitoring stations in the county. The annual review is required by 40 CFR 58.10 and helps ensure continued consistency with the monitoring objectives defined in federal regulations.

Each report is a directory of existing and proposed monitors in the county network and serves as a progress report on the recommendations and issues raised in earlier network reviews. Reports also address ongoing network design issues. They are available online at http://www.slocleanair.org/airquality/monitoringstations.php.

As highlighted in the 2017 and 2018 reports, the Oso Flaco site was temporarily shut down by the California Department of Parks and Recreation on December 15, 2016. The site was reopened in March 2017.

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[5] In general, these are seasonally weighted averages as calculated by AQS. For years when sampling methodology changed or a site was moved, the average depicted is the time-weighted average of the methodologies or locations.

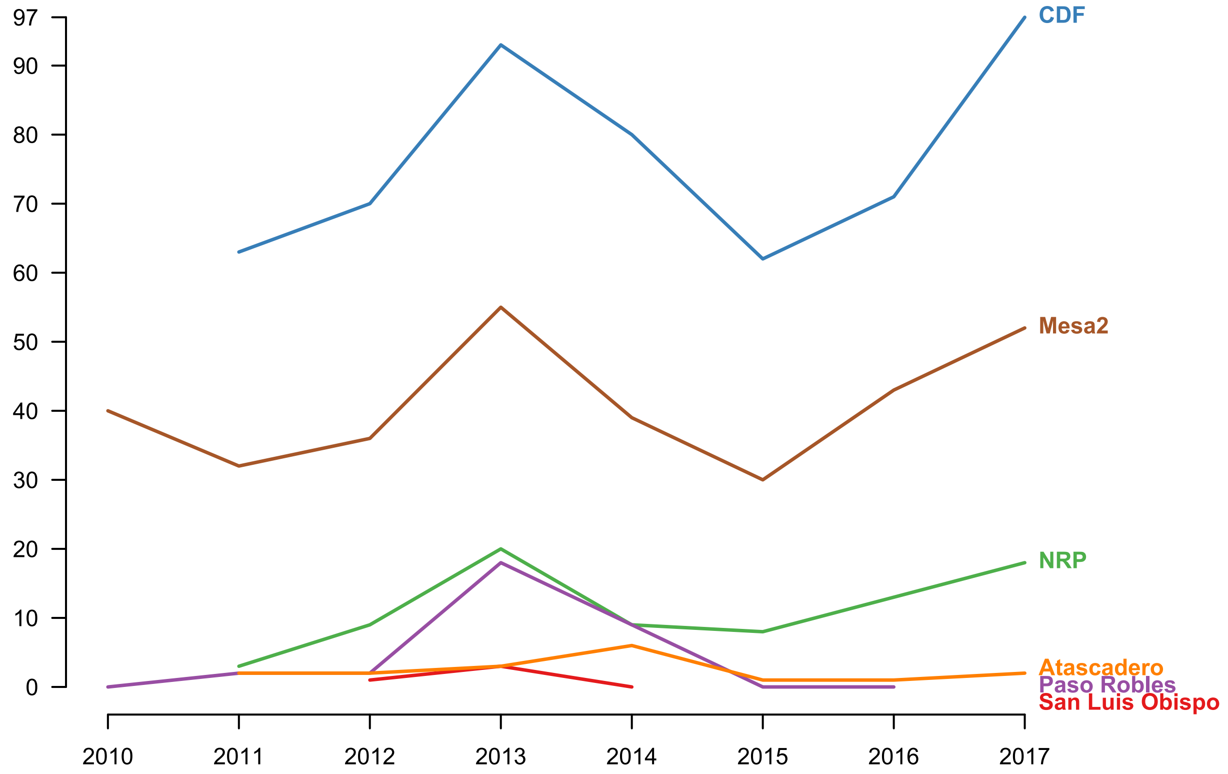

Figure 9: Exceedances of the California 24-hour PM_{10} Standard, 2010–2017

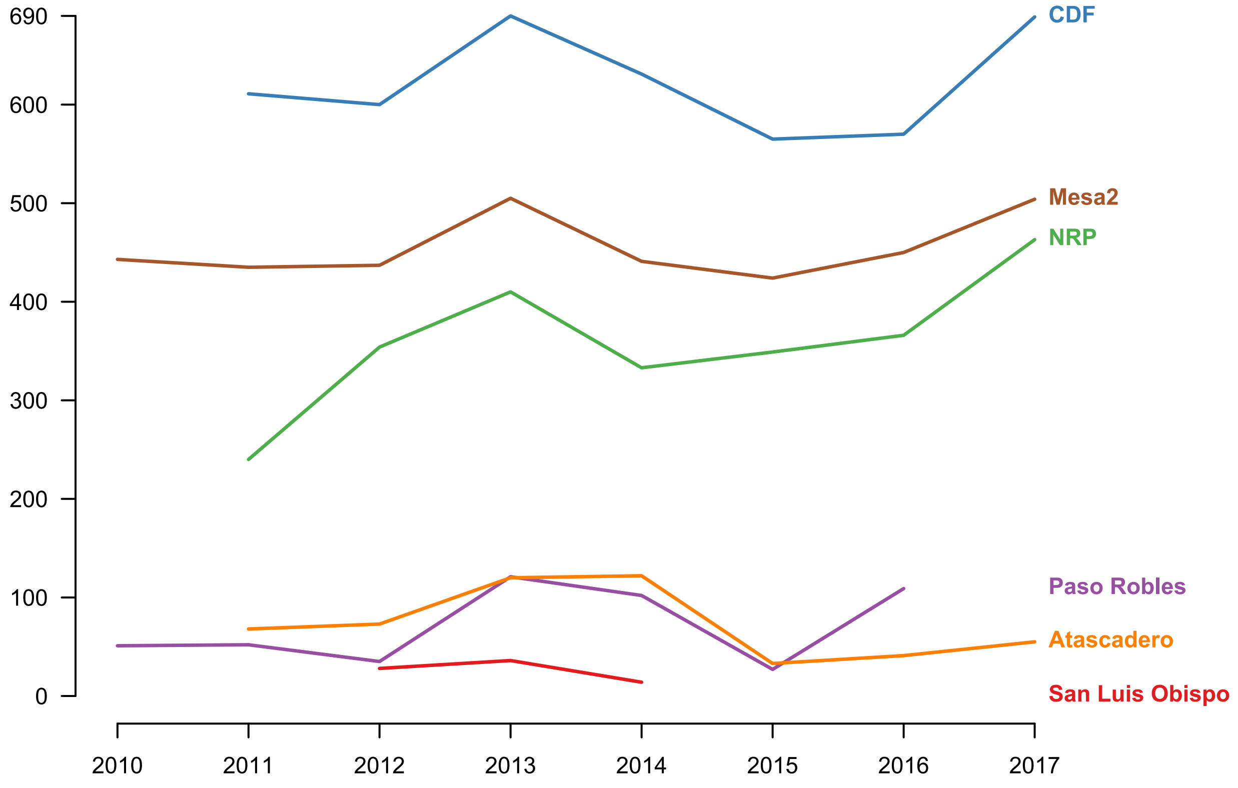

Figure 10: Hours At or Above 50 g/m^3 PM$_{10}$, 2010–2017

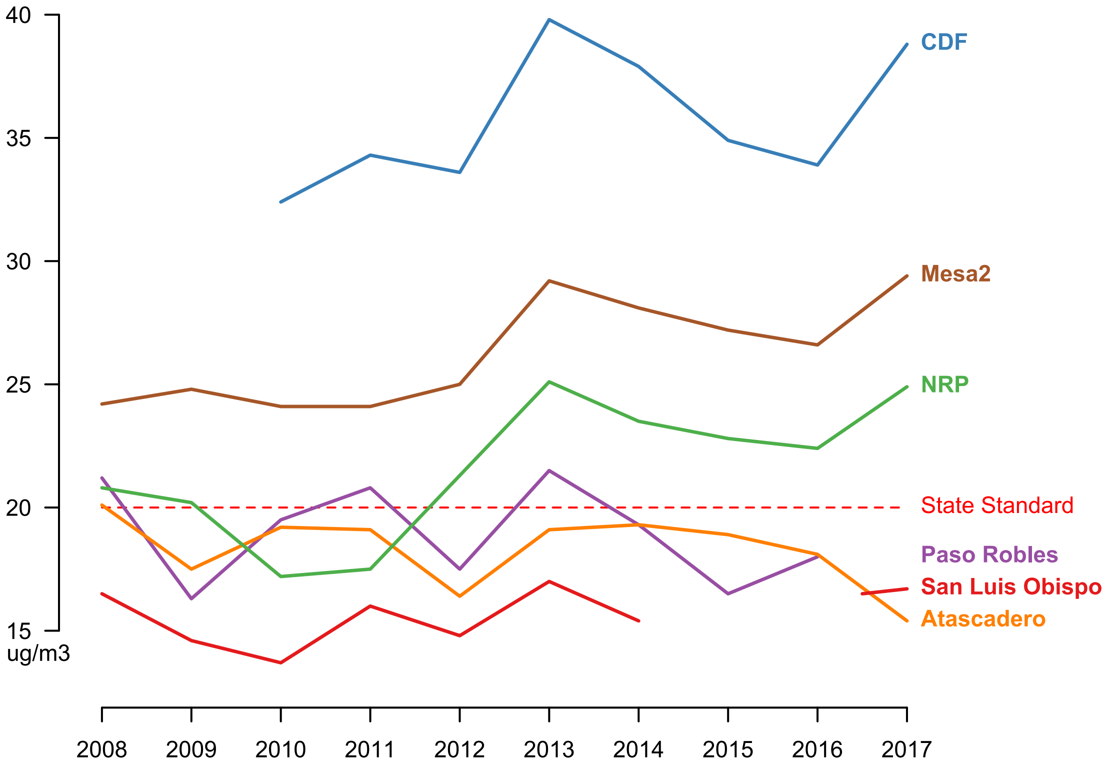

Figure 11: PM$_{10}$ Annual Averages, 2008–2017

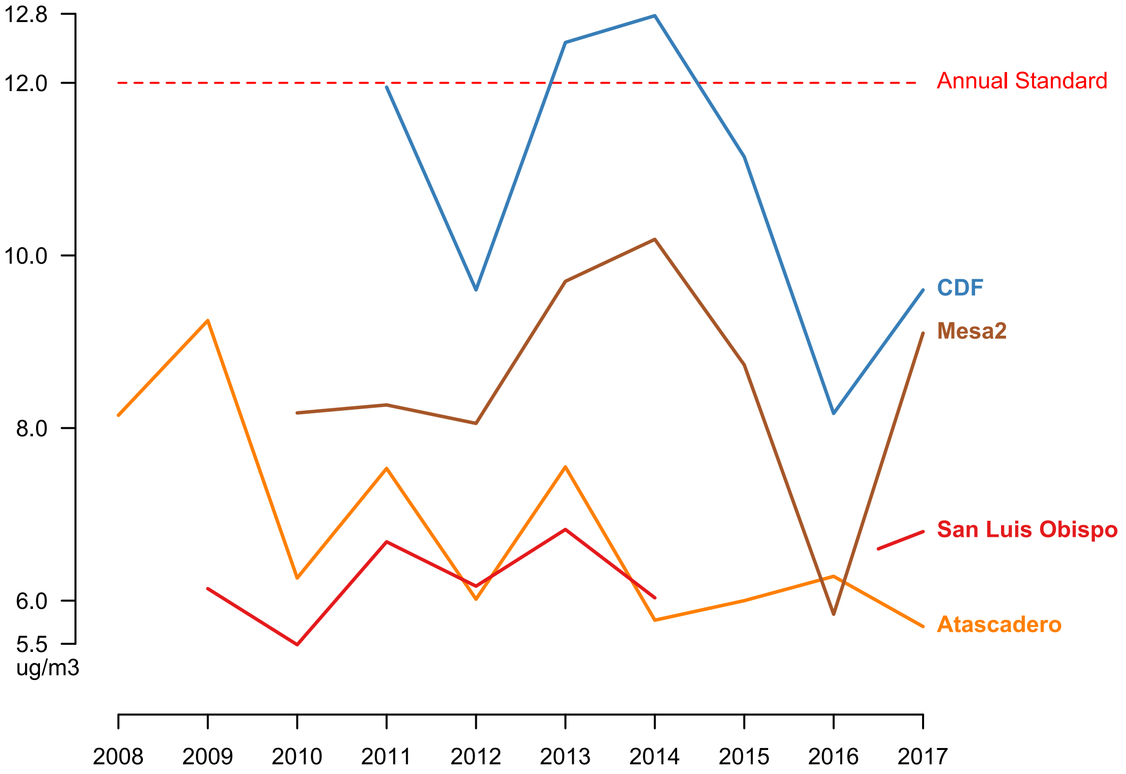

Figure 12: PM$_{2.5}$ Annual Averages, 2008-2017

Appendix A: Assessing the Effectiveness of ODSVRA Mitigations

Introduction

Previous year's Annual Air Quality Reports[6] contained appendices which analyzed recent trends in particulate matter at CDF and Mesa2. They concluded that the mitigation measures deployed by the ODSVRA operator (California Department of Parks and Recreation) in 2015 and 2016 did not detectibly reduce PM_{10} levels at CDF.

This section presents new methodology for assessing mitigation effectiveness, comparing 2016 and 2017. Since there was a relatively small change in mitigations over this period, a large change in downwind PM_{10} is not expected. Our real interest is in comparing 2018 and beyond to previous years, since the scale of mitigations dramatically increased from 2017 to 2018 and is likely to continue to rise. The comparison of 2016 and 2017, presented here, is intended to "set the stage" for next year's analysis of the ramped-up mitigation measures deployed in 2018.

Background

Enacted by the District Board in 2011, Local Rule 1001[4] requires the operator of the ODSVRA to implement dust mitigation measures with the goal of reducing PM_{10} emissions from the riding area of the park to the level of emissions from non-riding areas. Prior to 2018, these efforts included temporary fencing arrays and engineered roughness elements installed in the riding area during the windy season (April through July), straw bale arrays in non-riding areas, and permanent revegetation in non-riding areas. All project elements have been located upwind of the CDF monitoring station. Table A1, below, summarizes the mitigation efforts through 2017.[7]

In 2018, the District and State Parks entered in a stipulated order of abatement which envisions much more extensive mitigations than in previous years, with over 100 acres of fencing, straw bales, and revegetation in 2018 and likely more in subsequent years.[8] Rather than being focused upwind of CDF, these mitigations are to spread throughout the ODSVRA, and thus will likely affect PM_{10} levels at Mesa2 as well as at CDF.

Determining the effect of mitigation measures on downwind PM_{10} concentrations is difficult because while OHV activities increase the emissivity of the Dunes, it is wind that drives the actual dust emissions. Thus, all else being equal, windier years are expected to be dustier than less windy years. This effect can be seen in Figures 9, 10, and 11, above. There were no mitigations projects from 2010 to 2013, yet the exceedance count at CDF ranged from 65 to 93, likely reflecting year-to-year variation in meteorology. Similarly, the mitigation projects for 2015 and 2016 were essentially the same, yet the exceedance counts increased at both sites. In 2017, the size of the mitigation was cut in half, and PM_{10} levels increased; however, given the previously noted inter-annual variability, it is hard to attribute this change in exceedances to the change in mitigations.

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[6] San Luis Obispo County Air Pollution Control District, "2015 Annual Air Quality Report" and "2016 Annual Air Quality Report" at https://www.slocleanair.org/library/air-quality-reports.php.

[7] See District webpage, "Oceano Dunes Efforts," at https://www.slocleanair.org/air-quality/oceano-dunes-efforts.php for summaries of mitigation measure enacted thus far and related documents.

[8] San Luis Obispo County Air Pollution Control District, "Materials Related to Petition 17-01, April 30, 2018," at https://www.slocleanair.org/who/board/hearing-board/actions.php.

Table A1: Dust Mitigations on the ODSVRA

Year	Mitigation Measures		
	Fencing Array	Straw Bale Array	Other
2014	15 acres	30 acres	
2015	40 acres	"refresh" 2014's array	Revegetation: 6 acres
2016	40 acres		Engineered roughness element array: < 1 acre
2017	20 acres		

Wind speed and direction trends for this period can be summarized using wind roses, as shown in Figures A1–A3, which show time series of wind roses for CDF. Wind roses for April, May, and June are shown, since these are the months when most windblown dust events occur. These events occur exclusively when winds are out of the WNW, so it is most informative to focus on this petal of the wind roses. It is apparent that:

- There is significant inter-annual variability. For example, Figure A2 shows that for April, the frequency of WNW winds ranges from 20% in 2015 to 30% in 2011, and the frequency of strong WNW winds (those with speeds greater than 12 mph) varies from about 4% in 2015 to 10% in 2011.
- In general, April and June of 2014 and 2015 were less windy than previous and subsequent years. This trend parallels the trends in PM_{10} levels seen in Figures 9–11.
- May and June of 2017 saw more frequent and stronger winds from the WNW than 2016, a trend which also parallels PM_{10} levels.

Thus, it appears that meteorological variability alone could explain the observed trends in PM_{10} levels on the Nipomo Mesa, at least qualitatively. It is worth noting, however, that the extent of mitigations deployed on the ODSVRA also decreased from 2016 from 2017, while at the same time PM_{10} levels increased. This suggests the possibility that the effects of meteorology and mitigation on PM_{10} could be confounded.

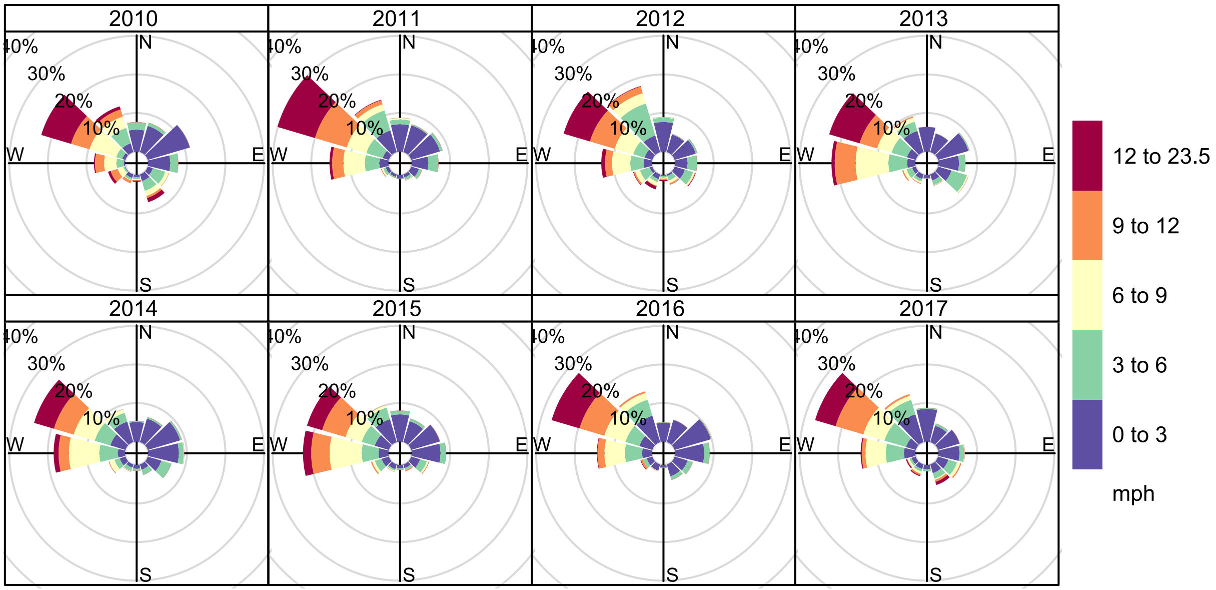

Figure A1: Wind Roses for CDF in April 2010 to 2017

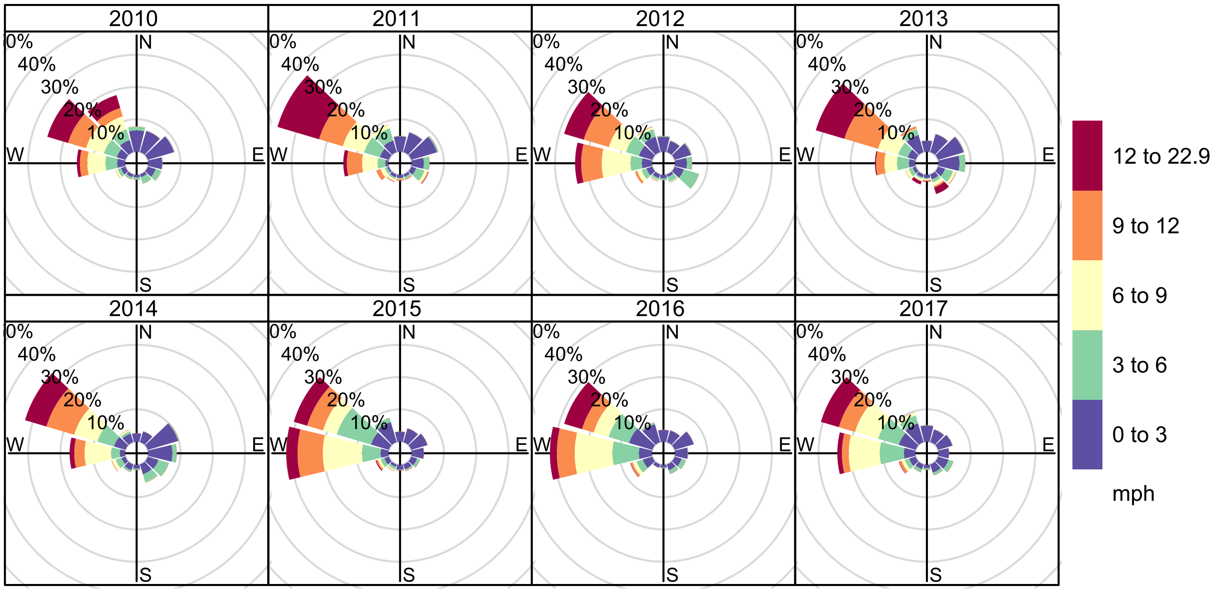

Figure A2: Wind Roses for CDF in May 2010 to 2017

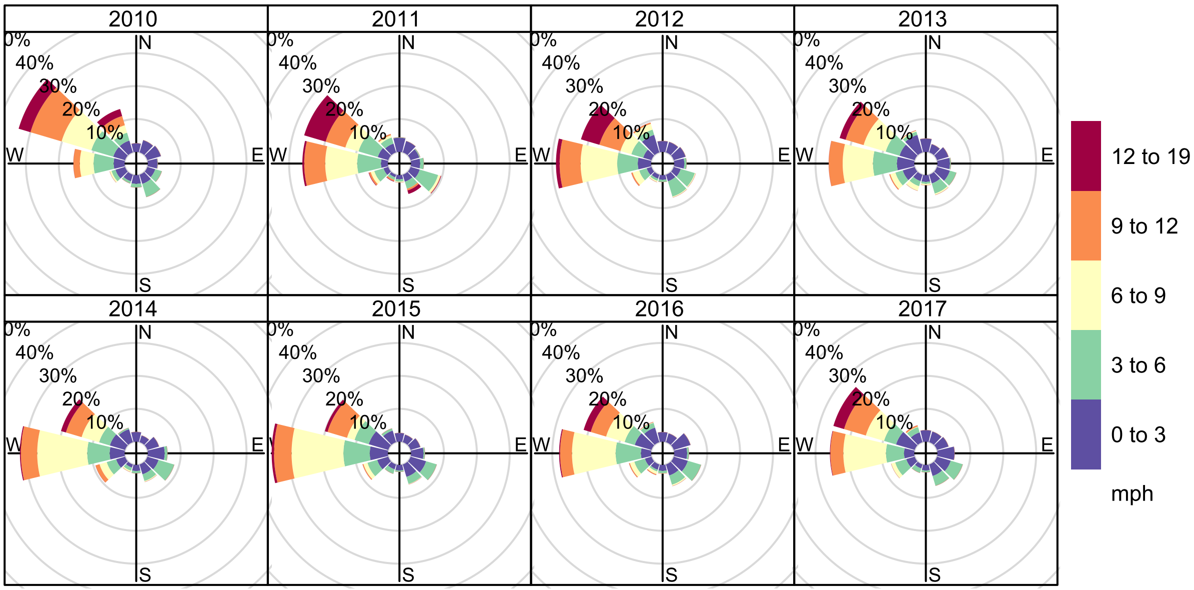

Figure A3: Wind Roses for CDF in June 2010 to 2017

Analysis

The dust control projects from 2014 to 2017 were located upwind of CDF and appear to have been designed specifically to reduce the PM_{10} levels at that monitor. These mitigation projects would not be expected to have much impact, if any, on PM_{10} levels at Mesa2. Yet, as shown in Figures 9–11, the trends in the annual average and in exceedances at CDF and Mesa2 track each other. This suggests that the dust control projects did not affect downwind PM_{10} levels. It also suggests the use of a Difference-in-Differences (DiD) approach for quantitatively assessing the effectiveness of the mitigation measures.[9]

Difference-in-Differences Approach

DiD is commonly used in econometrics and social sciences to assess the effects of policy changes and interventions. In its simplest form, it compares two groups over two time periods. The first period is the baseline, i.e. before the intervention has occurred. The second period is the post-intervention period, but critically, the intervention affects only one group—the unaffected group comprises a natural control group. The change in the intervention group across the periods is then compared to the change in the control control—this is the "difference-in-differences" estimator. The statistical significance of the DiD estimator can be determined via regression. A crucial assumption of this approach is that the intervention and control groups are sufficiently similar and that potential unobserved confounders affect the groups equally.

Here, we use DiD to assess the effects of mitigation on PM_{10} levels at CDF, using the levels at Oso Flaco as a control. The change in mitigation from 2016 to 2017 was small—about 40 acres in 2016 to 20 acres in 2017—and its effect on PM_{10} is not expected to be large or statistically significant. As noted in the introduction, the real interest is in comparing 2018 and beyond to 2016 and 2017, since the scale of mitigations dramatically increased from 2017 to 2018. Note that Mesa2 is not a suitable control site because it is also likely to be affected by the larger scale projects of 2018 and subsequent years. Oso Flaco, on the other hand, should remain unaffected by the mitigation projects.

Statistical Methods[10]

Rather than including all 24-hour PM_{10} averages from 2016 and 2017, only data from wind event days were included. This is because there are potentially several sources influencing PM_{10} values at these sites, including wildfire smoke, general background PM_{10}, aerosols transported from far away, sea spray, etc., but the only source that is likely to be affected by the mitigation projects is windblown dust from the ODSVRA. On wind event days, by far the biggest contributor to PM_{10} levels at these sites is wind-generated dust from the ODSVRA, and on these days high levels of PM_{10} are measured at both sites (with CDF typically higher than Oso Flaco). In contrast, on non-wind event days, the other sources predominate, and PM_{10} concentrations are lower and generally similar between the sites. Including data from all days dilutes any effect of the mitigations, making it harder to detect.

For this analysis, days were considered to be wind event days if they met the criteria defined in the 2015 Annual Air Quality Report.[6] In that report, a simple decision tree was developed for predicting whether an exceedance of the state PM_{10} standard was expected based on meteorology. Specifically, the decision tree used wind speed and direction data from CDF and from the S1 tower on the ODSVRA to predict PM_{10} exceedances. The tree was developed using data from 2011 through 2014, and it can be summarized as follows:

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[9] Wikipedia, "Difference in differences," at https://en.wikipedia.org/wiki/Difference_in_differences, accessed October 16, 2018.

[10] The full details of this analysis, including a working script, are available in the GitHub repository for this report at https://github.com/sloapcdkt/2017aqrptR.

24-hr average PM10 is expected to exceed 50 ug/m^3 whenever:

- Wind speed at 15:00 at S1 exceeds 9.445 m/s, and
- Wind direction at 13:00 at CDF is greater than 289.5 degrees.

These rules were applied to the 2016 and 2017 dataset to generate a subset of predicted wind event days, which was then subjected to the DiD analysis described below.

The traditional DiD analysis compares a control group to an intervention group across two time periods, one before and the other after the intervention. In this case the observations at the sites are paired—PM_{10} levels at CDF and Oso Flaco are observed at the same time, and it is the difference between them on a per-event basis that is of interest. This suggests working with the differences (or ratios) of PM_{10} levels between the sites, in a manner analogous to a paired T-test. (As is well known, when observations are paired, a paired T-test is much more powerful than an unpaired T-test.)

Since DiD analysis is a linear regression, all assumptions that usually apply to linear regression must be met if valid inferences are to be drawn. These include the assumptions of normally distributed errors and non-serially correlated errors. To satisfy these assumptions it was necessary to log transform the data and to explicitly model the serial correlation as continuous first-order autoregressive process. The DiD model that was fit was:

$$y_i = \beta_0 + \beta_1 * year_i + \varepsilon_i$$

where

$$y_i = \log(CDF\ PM10_i) - \log(Oso\ Flaco\ PM10_i)$$
$$year_i = 1\ if\ observation\ i\ is\ from\ 2017, 0\ otherwise$$
$$\beta_0 = intercept\ ;\ \beta_1 = slope$$
$$\varepsilon_i = AR(1)\ normally\ distributed\ error$$

In this model, the DiD estimator is β_1, the coefficient of the year indicator.

When run on wind event days from 2016 and 2017, the analysis yielded a β_1 value of + 0.136 with a non-significant p-value of 0.363. Diagnostic plots do not reveal any issues with the model assumptions. Thus, this analysis does not find evidence of a significant change between 2016 and 2017.

Sensitivity Analysis

That the analysis finds no difference between 2016 and 2017 is unsurprising: the mitigation projects in 2016 and 2017 were small in magnitude and didn't differ much in absolute terms: a 40 acre project in 2016 and 20 acres in 2017. Our real interest is addressing subsequent years, since in 2018 over 100 acres of mitigation were deployed, and this number will likely increase in 2019. Thus an important question is, "How big of a change in PM10 is needed for this type of analysis to yield a statistically significant result?"

This can be addressed through simulation. Future data were simulated by taking 2017 data and leaving the Oso Flaco concentrations as-is, while reducing the CDF levels by 25%. The simulated data were then compared to the actual data from 2017 using the DiD approach described above. The value for β_1 value was -0.288 as expected,[11] and the associated p-value, 0.028, was statistically significant. This indicates that

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[11] This is the expected value for the coefficient since $e^{-0.288} = 0.75$.

that this methodology ought to be able identify change of at least 25% in CDF PM_{10} levels on event days, after (implicitly) controlling for meteorological variability.

Conclusions

The 2017 dust control project did not appear to a have significant impact on PM_{10} levels downwind of the ODSVRA. This is a qualitative conclusion, based on Figures 9–11and A1–A3. Trends in PM_{10} levels approximately track in meteorology, and levels at CDF and Mesa2 continue to track each other, despite the mitigations being upwind of CDF only.

Comparing the 2016 and 2017 dust control projects, new methodology finds no difference in their effects on PM_{10} levels CDF. This is a quantitative conclusion. The projects in 2017 and earlier years were small and temporary; the project for 2018 was much larger and permanent. We intend to use this new methodology to compare 2018 and beyond to 2017 and see if the projects are having their intended effect of reducing downwind PM_{10}.

Appendix B: Ambient Respirable Crystalline Silica Monitoring

Executive Summary & Background

Inhaling very small particles of crystalline silica is known to cause lung cancer, silicosis, chronic obstructive pulmonary disease (COPD), and kidney disease, and may also be associated with autoimmune disorders and other adverse health effects. To protect workers from these effects, the Occupational Safety and Health Administration (OSHA) has set a workplace standard for respirable crystalline silica of 50 $\mu g/m^3$ averaged over 8-hours.[12,13]

In many areas, crystalline silica (in the form of quartz) is the predominant constituent of beach sand. Respirable crystalline silica particles are at least 100 times smaller than ordinary beach sand or sand used on playgrounds. Since the particulate matter measured downwind of the ODSVRA is derived from beach sand, there is concern that during wind events ambient air may have high levels of respirable crystalline silica. To address these concerns, the APCD collected 4 samples for silica analysis in 2017 and 4 more in 2018. For the sake of completeness and transparency, the results of all 8 samples will be reported here, even though this Annual Air Quality Report is specifically for the 2017 calendar year.

None of the 8 samples collected by the APCD, or the additional sample collected by State Parks, exceeded the OSHA standard. Furthermore, a statistical analysis of these samples suggests that the probability of a future exceedance is negligible. While these findings are reassuring, we cannot conclude that there is no risk. As described in further detail in the Discussion section, current silica sampling methods are not designed for outdoor ambient sampling, and the method used in our study is known to have a downward bias when ambient winds are high. Thus, our results may underestimate actual respirable crystalline silica levels and the associated exposure risk.

General Considerations

- **Regulatory Framework**. The OSHA standard applies only to workplaces—it is not an ambient air quality standard. Furthermore, it is enforced by OSHA; the APCD has no authority to act on exceedances of this standard.
- **Appropriateness of the OSHA Standard**. The OSHA standard was developed for the workplace, and thus incorporates assumptions that may not be adequate to protect the health of the general population.

  The California Office of Environmental Health Hazard Assessment (OEHHA) has derived a chronic reference exposure level (REL) for respirable crystalline silica of 3 $\mu g/m^3$.[14] A REL is a non-enforceable health benchmark: Exposure to levels less than a REL is believed to be safe. Note that this REL is for *chronic* exposure, i.e. it assumes breathing this level of respirable crystalline silica for 24 hours each day over an entire lifetime. A single 8- or 24-hour air sample exceeding this level is not necessarily an indication of a health risk; on the other hand, an annual average concentration exceeding the REL may indicate a health risk.

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[12] Centers for Disease Control and Prevention, National Institute for Occupational Health and Safety, "CDC – Silica, General Publications – NIOSH Workplace Safety & Health Topics." https://www.cdc.gov/niosh/topics/silica/default.html

[13] U.S. Department of Labor, Occupational Safety and Health Administration, "Safety and Health Topics / Silica, Crystalline." https://www.osha.gov/dsg/topics/silicacrystalline/.

[14] Office of Environmental Health Hazard Assessment (2000), "Determination of Noncancer Chronic Reference Exposure Levels. Appendix D3." https://oehha.ca.gov/media/downloads/crnr/appendixd3final.pdf.

- **Particle Size Fraction.** Both the OSHA standard and the OEHHA REL are based on *respirable* crystalline silica, which has a specific definition: roughly, the subset of crystalline silica particles less than 4 microns in aerodynamic diameter, i.e. PM_4. It is not appropriate to compare the crystalline silica content of PM_{10} sample to the OSHA standard because such a sample would not be a "respirable" sample.[15] *For the sake of brevity, the remainder of this appendix will use the term "silica" to mean "respirable crystalline silica" as defined by OSHA.*

Methodology

The District contracted with Forensic Analytical Services (Hayward, CA) for analysis of the silica samples. We collected the samples on pre-weighed filter cartridges provided by the lab using their recommended sampler, specifically the GS-3 cyclone (SKC Inc., Eighty Four, PA) operated at 2.75 L/min with a Gilian BDX II pump (Sensidyne LP, St. Petersburg, FL). This method meets the OSHA silica rule requirements for compliance sampling, but it may not be appropriate for sampling in high wind conditions as discussed later.

All samples were collected at the CDF site. The sampler was attached to the roof safety railing about 3 meters off the ground and within 2 meters of the $PM_{2.5}$ sampler. At the recommendation of the lab, the target sample time was 6 hours. Samples were collected only on days when windblown dust was forecasted to occur. In general, samples were collected from 10 am to 4 pm Pacific Standard Time, since this is when PM_{10} levels tend to peak.

The analytical laboratory used NIOSH Method 7603 (Fourier Transform Infrared Spectroscopy) for quantification of quartz, cristobalite, and tridymite, with total silica reported as the sum of these three species. In addition, total dust mass was quantified by gravimetry. The reporting limit for total silica varied from 8 to 10 $\mu g/m^3$ and for total dust from 28 to 200 $\mu g/m^3$.

Results

Table B1, below, presents the results of the 8 samples collected by the APCD as well as another collected by State Parks at CDF on March 8, 2018.[16] Note that State Parks' sample used somewhat different methodology, and in contrast to the APCD samples it was not collected during a windblown dust event. The table provides total silica and total dust results along with their corresponding reporting limits. The results for 3 of the 9 silica analyses were below the reporting limit; these are reported as "< X", where X is the reporting limit for the sample. For the total dust analyses, results for all samples except one were below the reporting limit. The table also provides the PM_{10} and $PM_{2.5}$ averages from CDF for the approximately 6-hour time periods corresponding to the silica samples. Finally, the 24-hour PM_{10} averages from CDF are also included.

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[15] International Organization for Standardization (1995), "ISO 7708:1995. Air quality — Particle size fraction definitions for health-related sampling." https://www.iso.org/obp/ui/#iso:std:iso:7708:ed-1:v1:en. The ISO/ACGIH/CEN convention definition of "respirable" is actually an equation for a sigmoid shaped curved of fraction sampled versus particle size. Particles of exactly 4 microns are sampled at 50%, with larger fractions of smaller particles sampled, and smaller fractions of large particles sampled. Particles greater than 10 microns are essentially not sampled at all. Also see page 521of reference 14 for further discussion.

[16] John W. Kelse, March 16, 2018, "DETERMINATION OF AIRBORNE CRYSTALLINE SILICA (QUARTZ) EXPOSURE AT Oceano Dunes State Vehicular Recreation Area and CDF Air Monitoring Site, 2391 Willow Road, Arroyo Grande, California San Luis Obispo County, California." http://ohv.parks.ca.gov/pages/25010/files/ODSVRA%20and%20CDF%20Airborne%20Crystalline%20Silica%20Exposure%20Determination%20-%20March%202018.pdf

Table B1: Respirable Crystalline Silica Results

Date Time	Total Silica Concentration (Reporting Limit)	Total Dust Concentration (Reporting Limit)	PM_{10} Concentration	$PM_{2.5}$ Concentration	24-hr PM_{10} Concentration
	All concentrations in $\mu g/m^3$				
4/25/17 10:00 – 16:00	20 (10)	< 200 (200)	300	57	98
4/27/17 10:00 – 16:00	10 (10)	< 200 (200)	286	59	108
5/12/17 9:05 – 16:30	< 8 (8)	< 50 (50)	212	40	94
6/12/17 10:00 – 16:05	10 (10)	< 50 (50)	275	70	106
3/8/18 * 9:15 – 18:12	< 12 (12)	< 28 (28)	35	5	28
4/11/18 10:11 – 16:11	10 (10)	< 60 (60)	155	31	54
4/12/18 10:10 – 16:33	< 10 (10)	70 (50)	209	42	77
5/17/18 10:00 – 16:10	17 (10)	< 50 (50)	273	NA	93
5/31/18 10:00 – 16:00	10 (10)	< 60 (60)	143	34	69

* Sample collected by State Parks (see text).

Discussion

None of the nine samples exceeded the OSHA standard of 50 $\mu g/m^3$; however, it is possible that exceedances occurred on days when no samples were taken. In fact, on the day that the maximum silica concentration was observed (April 25, 2017), the 24-hour PM_{10} average was only 98 $\mu g/m^3$. PM_{10} levels up to 50% higher were observed that year (Table 4), so it seems reasonable that silica levels higher than 20 $\mu g/m^3$ could also have occurred. Two approaches to assessing the likelihood of exceeding the OSHA standard are described below: a univariate approach based solely on the observed silica concentrations and correlation approach which also considers the corresponding PM_{10} levels.[10]

Univariate Approach to Assessing the Likelihood of OSHA Exceedances

A simple approach to assessing the likelihood exceeding the OSHA standard is to construct a 95% or 99% prediction interval around the sample mean and then see if the upper bound exceeds the standard. If it does, then this would mean there is non-trivial chance of exceeding the standard. This approach assumes that the 8 APCD sample represent a random sample from days when windblown dust events were forecasted.[17] It is complicated by the fact that the data are certainly not normal, since the concentrations cannot be negative, and by the fact that some observations are “censored,” meaning that they were reported as simply "less than detection limit."

The silica concentrations were assumed to follow a lognormal distribution, which is a common assumption for environmental data, and a censored lognormal distribution was fit to the data using “EnvStats” package[18] in R software environment.[19] This yielded a geometric mean and standard deviation of 10.7 and 1.4 μg/m^3, respectively, and 95% and 99% prediction interval upper bounds of 26.6 and 41.1 μg/m^3, respectively.

Neither the 95% or 99% upper bound exceeds the OSHA standard. This implies that the likelihood of exceeding the standard on a windblown dust event data on a future forecasted event day is very low, i.e. less than 0.5%.

Bivariate Approach to Assessing the Likelihood of OSHA Exceedances

It seems reasonable to assume that the silica and PM$_{10}$ concentrations are positively correlated, i.e. that higher silica concentrations are associated with higher PM$_{10}$ concentrations. The bivariate approach takes advantage of this and uses the PM$_{10}$ data to predict silica values. In this approach, the silica concentrations are regressed against the corresponding PM$_{10}$ concentrations, and a prediction interval is constructed around the regression line. If the upper bound of the prediction interval reaches the OSHA silica standard at a reasonable PM$_{10}$ level, this would imply that there is non-trivial chance of exceeding the standard. As with the univariate approach, this approach is complicated by the censoring of observations and other issues.[20]

Figure B1, below, is a scatter plot of the silica concentrations versus the corresponding PM$_{10}$ concentrations; the 3 censored silica values—i.e. those reported as “less than reporting limit”—are shown in red, while the others are in blue. The silica values for the censored results are not known, but they must be between zero and their reporting limits, so for plotting purposes, a value of half the reporting limit was used. It is not obvious from this figure whether the silica and PM10 concentrations are correlated as expected, but this can be formally tested using non-parametric, rank-based measures of association such as the Kendall (τ) or Spearman (ρ) rank correlation coefficients. These tests yield positive correlation coefficients ($\tau = 0.36$, $\rho = 0.52$) but non-significant p-values (0.19 and 0.15, respectively). Thus, neither test finds evidence for a statistically significant correlation.

The lack of evidence of a correlation between silica and PM$_{10}$ implies that the univariate approach is sufficient. The bivariate approach was explored nonetheless, as it may be useful in the future if additional silica samples are collected. The “crch” package[21] in R was used to fit a censored linear regression model

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[17] State Parks’ sample from March 8, 2018, does not meet this assumption since it was not collected on a forecasted event day. It was therefore excluded from these calculations.

[18] Millard SP (2013). “EnvStats: An R Package for Environmental Statistics.” Springer, New York. ISBN 978-1-4614-8455-4.

[19] R version 3.4.4 (2018-03-15), "Someone to Lean On". Copyright © 2018. The R Foundation for Statistical Computing. https://www.r-project.org.

[20] In contrast to the univariate approach, this approach does not rely on the assumption that the silica samples are randomly drawn from the population of forecasted event days; therefore, State Parks’ sample from March 8, 2018, is included in this analysis.

[21] Jakob W. Messner, Georg J. Mayr, Achim Zeileis (2016). “Heteroscedastic Censored and Truncated Regression with crch.” The R-Journal, 8(1), 173-181. https://journal.R-project.org/archive/2016-1/messner-mayr-zeileis.pdf

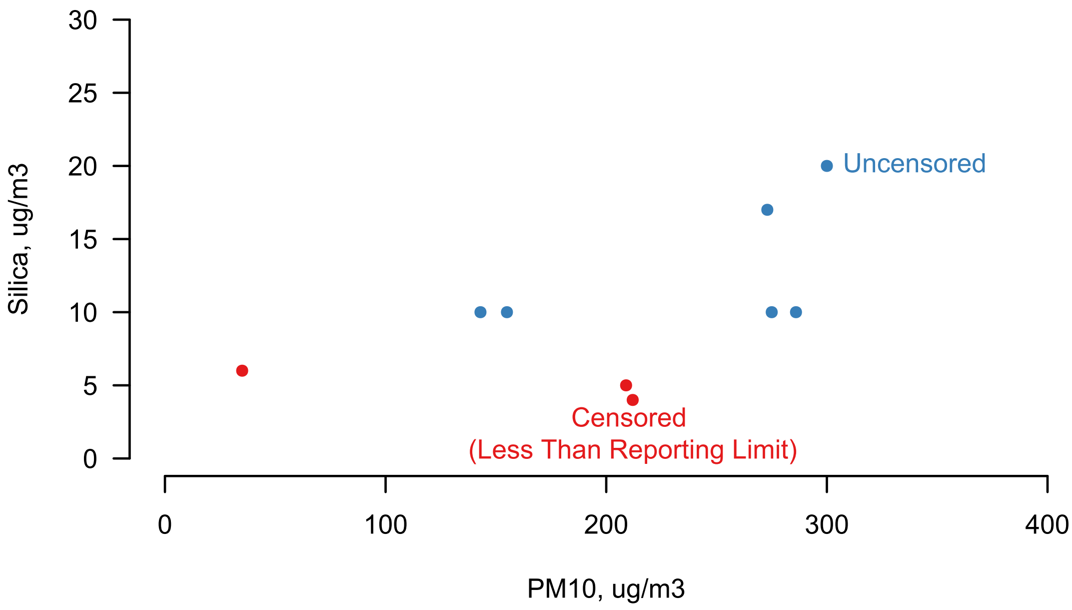

Figure B1: Silica versus PM_{10} at CDF

and generate approximate 95% prediction intervals around the fit. The slope of the regression is positive (0.44) but non-significant (p-value: 0.07), which is consistent with the results of the Kendall and Spearman rank correlation tests mentioned previously. Figure B2, below, depicts the linear fit, the 95% prediction intervals, and the OSHA standard, along with the 9 data points (using the same color scheme as in Figure B1.) For plotting purposes, the reporting limit for the silica analysis was assumed to be 10 $\mu g/m^3$, i.e. for any silica concentration predicted to be between 0 and 10 $\mu g/m^3$ the value reported be would be “less than 10 $\mu g/m^3$.” Thus, the prediction intervals and linear fit are depicted as “bottoming out” at 10 $\mu g/m^3$. (Note that for the 3 censored observations, a value of half the reporting limit was still used for their silica values.)

The main feature of Figure B2 is that the 95% prediction interval does not include the level of the OSHA standard until PM_{10} levels are over 930 $\mu g/m^3$. In other words, the model predicts that PM_{10} levels would need to be greater than 930 $\mu g/m^3$ before there is even a small chance (2.5%) of exceeding the OSHA silica standard. The district has never observed hourly PM_{10} levels this high at CDF, so it is extremely unlikely that there have been unobserved exceedances of the OSHA silica standard at this site.

Given the degree of extrapolation in Figure B2, the exact location of the intersection of the OSHA standard and the prediction interval should be taken with a grain of salt. A small change in the estimated slope or residual standard error could shift the location substantially. Furthermore, this approach assumes a linear relationship between PM_{10} and silica (and with only 9 data points, it would be hard to justify exploring more complicated models), but the true relationship may be non-linear. Finally, we have pooled our samples with State Parks’, despite differences in methods. This is another potential source of error. (Omitting State Parks’ sample from the analysis yields a lower value (785 $\mu g/m^3$) for the intersection of the prediction interval and the OSHA standard, but the overall conclusion remains the same.)

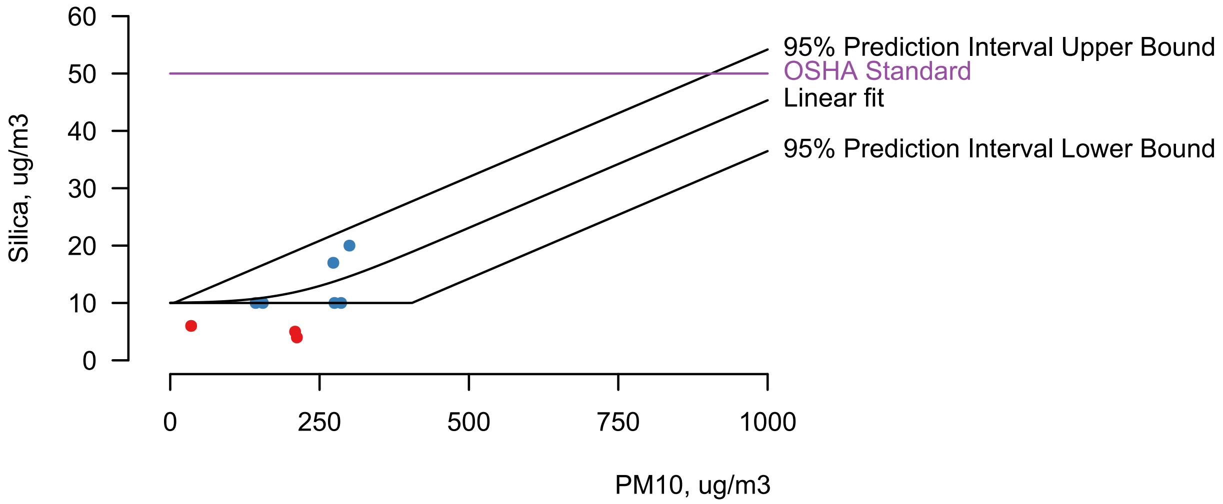

Figure B2: Calculation of Probability of OSHA Exceedance

Sampling Considerations

The OSHA silica rule applies to occupational settings which tend to be indoors or underground and where wind speeds are low; thus, samplers meant to comply with the rule are usually only tested under no- or low-wind conditions (up to 1 m/s). We used the GS-3 cyclone for this study, which is one of the few samplers whose performance has been characterized under higher wind speed. Its efficiency was found to decrease as winds increased; at 9.1 mph, which was the maximum wind speed tested, the mean bias was -9.55% (range: -3 to -20%).[22] To the best of our knowledge, this is the highest wind speed any silica sampler has been tested at.

When our silica samples were collected, wind speeds were much higher, with hourly values typically ranging from 10 to 15 mph and with gusts even higher. For this reason, it is likely that our silica samples under estimate the actual levels. (In contrast, the EPA-approved samplers used by the District for PM_{10} and $PM_{2.5}$ have been extensively tested under high ambient wind speeds, and there are no concerns about bias with these methods.)

There is some empirical evidence for under-sampling in our silica dataset. The total dust result for the June 12, 2017, sample was less than the reporting limit of 50 $\mu g/m^3$, yet the $PM_{2.5}$ concentration for the same 6-hour period was 70 $\mu g/m^3$. The "respirable" size fraction is PM_4, so by definition the total dust concentration should be larger than the corresponding $PM_{2.5}$ concentration (and smaller than the PM_{10} concentration), but in this sample it is significantly less than the $PM_{2.5}$ concentration.

Conclusion

There were no exceedances of the OSHA silica standard among the 9 samples collected at CDF by the APCD and State Parks. Furthermore, statistical analysis of these samples suggests that the probability of an exceedance on a non-sampled day is negligible. While these findings are reassuring, we cannot

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[22] Mridul Gautum and Avula Sreenath (1997). "Performance of a respirable multi-inlet cyclone sampler." J. Aerosol. Sci., 28(7), 1265-1281.

conclude that a risk does not exist since these samples may underestimate actual respirable crystalline silica levels. Furthermore, it may not be appropriate to compare ambient silica concentrations to the OSHA standard since it was not intended to apply to ambient concentrations.

The District and State Parks are considering collecting additional silica samples in 2019 using different methodology. Ideally, we would use a "respirable" size fraction sampler that has been shown to perform well in high ambient winds; however, no such samplers are commercially available to our knowledge. Instead, pending the availability of equipment, we hope to use sequential FRM samplers to collect PM_{10} and $PM_{2.5}$ samples on Teflon filters. A subset of these will be quantified for crystalline silica. Such samples will not be directly comparable to the OSHA standard, but they should be unbiased since the sequential FRM sampler has been designed and proven to perform well even under high ambient winds.