APPENDIX: San Joaquin Valley 12 µg/m^3 Annual $PM_{2.5}$ (2016)

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ACRONYMS

ACHEX - Aerosol Characterization Experiment

ARCTAS - Arctic Research of the Composition of the Troposphere from Aircraft and Satellites

BEARPEX - Biosphere Effects on Aerosols and Photochemistry Experiment

CABERNET - California Airborne BVOC Emission Research in Natural Ecosystem Transects

CalNex - Research at the Nexus of Air Quality and Climate Change

CARB – California Air Resources Board

CARES - Carbonaceous Aerosols and Radiative Effects Study

CCOS - Central California Ozone Study

CIRPAS - Center for Interdisciplinary Remotely-Piloted Aircraft Studies

CRPAQS - California Regional $PM_{10}/PM_{2.5}$ Air Quality Study

CSN – Chemical Speciation Network

DISCOVER-AQ - Deriving Information on Surface Conditions from Column and Vertically Resolved Observations Relevant to Air Quality

FEM – Federal Equivalent Method

FRM – Federal Reference Method

IMPROVE - Interagency Monitoring of Protected Visual Environments

IMS - Integrated Monitoring Study

NASA – National Aeronautics and Space Administration

NOAA – National Oceanic and Atmospheric Administration

OC – Organic Carbon

OM – Organic Matter

PAMS - Photochemical Assessment Monitoring Stations

$PM_{2.5}$ – Particulate matter with aerodynamic diameter less than 2.5 μm

SJV - San Joaquin Valley

SJVAB - San Joaquin Valley Air Basin

SJVAPCD - San Joaquin Valley Air Pollution Control District

SJVAQS/AUSPEX - San Joaquin Valley Air Quality Study/Atmospheric Utilities Signatures Predictions and Experiments

SLAMS - State and Local Air Monitoring Stations

SOA – Secondary Organic Aerosol

SoCAB - Southern California Air Basin

U.S. EPA – United States Environmental Protection Agency

VOC – Volatile Organic Compounds

1. TIMELINE OF THE PLAN

Table 1-1. Timeline for Completion of the Plan

Timeline	Action
Late 2015/Early 2016	Emission Inventory Completed
Spring/Summer 2016	Modeling Completed
September 15, 2016	San Joaquin Valley Governing Board Hearing to consider the Draft Plan
October 20, 2016	ARB Board Hearing to consider the SJV Adopted Plan
October 15, 2016	Plan is due to U.S. EPA

2. DESCRIPTION OF THE CONCEPTUAL MODEL FOR THE NONATTAINMENT AREA

2.1 History of Field Studies in the Region

The San Joaquin Valley (SJV) air basin is perhaps the second most studied air basin in the world, in terms of the number of publications in peer-reviewed international scientific/technical journals and other major reports, with the Los Angeles air basin being the first. Major Field studies that have taken place in the SJV and surrounding areas are listed in Table 2-1.

The first major air quality study in the SJV, dubbed Project Lo-Jet, took place in 1970 and resulted in the identification of the Fresno Eddy (Lin and Jao, 1995 and references therein). The first Valley-wide study that formed the foundation for a SIP was the San Joaquin Valley Air Quality Study/Atmospheric Utilities Signatures Predictions and Experiments (SJVAQS/AUSPEX) study, also known as SARMAP (SJVAQS/AUSPEX Regional Modeling Adaptation Project). A 1-hour Extreme Ozone Attainment Demonstration Plan based on the SARMAP Study was submitted to the U.S. EPA in 2004 and was approved in 2010 (74 FR 33933; 75 FR 10420). The next major study was the Integrated Monitoring Study in 1995 (IMS-95), which was the pilot study for the subsequent California Regional $PM_{10}/PM_{2.5}$ Air Quality Study (CRPAQS) in 2000 (Solomon and Magliano, 1998). IMS-95 formed the technical basis for the 2003 PM10 SIP which was approved by the U.S. EPA in 2006 (71 FR 63642). The area was re-designated as attainment in 2008 (73 FR 66759). The first annual field campaign in the SJV was CRPAQS, and embedded in it was the Central California Ozone Study (CCOS) that took place during the summer of 2000 (Fujita et al., 2001). CRPAQS was a component of the technical foundation for the 2008 annual $PM_{2.5}$ SIP which was approved by the U.S. EPA in 2011 (76 FR 41338; 76 FR 69896), and CCOS was part of the technical basis for the 2007 8-hour O_3 SIP (76 FR 57846). While CRPAQS is still highly relevant to the current annual 24-hour $PM_{2.5}$ SIP, there are additional, more recent studies with relevance to $PM_{2.5}$ formation in the Valley and surrounding regions: 1) ARCTAS-CARB 2008, 2) CalNex 2010, 3) CARES 2010, 4) BEARPEX 2007 & 2009, 5) CABERNET 2011, and 6) DISCOVER-AQ 2013. Each of these studies has contributed significantly to our understanding of various atmospheric processes in the Valley.

The ARCTAS-CARB aircraft field campaign was a joint research effort by NASA and CARB and took place from June 18 to 24, 2008. During the study, DC-8 aircraft performed two flights over southern California on June 18 and 24 with a focus on the Southern California Air Basin (SoCAB), one flight over northern California with a focus

on the San Joaquin Valley Air Basin (SJVAB) on June 20, and one flight off shore on June 22 to quantify the pollutant levels in air masses entering California from the Pacific Ocean. During the campaign, large wildfires occurred in California, particularly in the north. The DC-8 aircraft encountered many of the fire plumes, which allowed for the study of fire emissions and their chemical composition, as well as evaluation of the simulated fire impacts. The ARCTAS-CARB campaign provided a unique dataset for evaluating the impacts of wildfires on ozone levels through photochemical modeling studies and for evaluating the distribution of reactive nitrogen species in California (Huang et al., 2011; Cai et al., 2016).

The CalNex May-July 2010 field campaign was organized by NOAA (NOAA, 2014) and CARB. The focus of this field study included airborne measurements using the NOAA WP-3D aircraft and the Twin Otter Remote Sensing aircraft, and surface measurements using the R/V *Atlantis* mobile platform as well as two stationary ground supersites, one of which was located in Bakersfield. Analysis of the data collected during CalNex has shown that photochemical ozone production in the southern and central portions of the Valley is transitioning to a NO_x-limited chemistry regime, where further NO_x reductions are expected to lead to a more rapid reduction in ozone than what was observed over the past decade or more (Pusede and Cohen, 2012). Studies have also shown that there is evidence for an unidentified temperature-dependent VOC emissions source on the hottest days (Pusede and Cohen, 2012; Pusede et al., 2014) and large sources of hydrocarbon compounds from petroleum extraction/processing, dairy (and other cattle) operations, and agricultural crops in SJV (Gentner et al., 2014a,b). In addition, findings also suggest that NO_x emissions control nighttime secondary organic aerosol formation in Bakersfield, thus reductions in NOx emissions should reduce organic aerosol concentrations in Bakersfield and the surrounding region (Rollins et al., 2012).

The CARES field campaign took place in the central California region, to the northeast of Sacramento in June 2010. Comprehensive data sets of trace gases and aerosols were taken from the daily evolving Sacramento urban plume under relatively well-defined and regular meteorological conditions using multiple suites of ground-based and airborne instruments onboard the Gulfstream (G-1) research aircraft. The ground-based measurements were conducted at two sites: one within the Sacramento urban source area and the other in a downwind area about 70 km to the northeast in Cool, CA. A combination of measurement and model data during CARES (Fast et al., 2012) shows that emissions from the San Francisco Bay area transported by intrusions of marine air contributed a large fraction of the carbon monoxide in the vicinity of Sacramento. The study also showed that mountain venting processes contributed to aged pollutants aloft in the valley atmosphere which are then entrained into the growing boundary layer the following day. Although the CARES study did not take place within the SJV itself, it

remains relevant to the SJV for two reasons: 1) CARES took place within the delta region north of the SJV, which can influence air quality in the northern SJV (see Section 2.4), and 2) the improved scientific understanding of the interaction between urban emissions and downwind biogenic emissions gained during CARES is applicable to the SJV, which experiences a similar confluence of anthropogenic and biogenic emissions.

BEARPEX was conducted at the University of California's Blodgett Forest Research Station during June-July 2007 and September-October 2009. Blodgett Forest is located 65 miles northeast of Sacramento. The project was designed to study chemistry downwind of urban areas where there is high VOC reactivity (due to biogenic emissions sources) and low NO_x, to understand the full oxidation sequence and subsequent fate of biogenic VOC and the processes leading to formation and removal of biogenic secondary organic aerosol (SOA) and the associated chemical and optical properties of SOA. A study by Bouvier-Brown et al., (2009) suggests that reactive and semi-volatile compounds, especially sesquiterpenes, significantly impact the gas- and particle-phase chemistry of the atmosphere at Blodgett Forest. An analysis of absolute PANs mixing ratios by Lafranchi et al. (2009) reveals a missing PANs sink that can be resolved by increasing the peroxy acetyl radicals + RO2 rate constant by a factor of three. At the BEARPEX field site, the sum of the individual biogenically derived nitrates account for two-thirds of the organic nitrate, confirming the importance of biogenic nitrates to the NO_y budget (Beaver et al., 2012).

The CABERNET field campaign was conducted in June 2011 in California. The objectives were to develop and evaluate new approaches for regional scale measurements of biogenic VOC emissions, quantify the response of biogenic VOC emissions to land cover change, investigate the vertical transport of isoprene and oxidation products, and evaluate biogenic emission models. Isoprene fluxes were measured on board the Center for Interdisciplinary Remotely-Piloted Aircraft Studies (CIRPAS) Twin Otter (http://www.cirpas.org/twinOtter.html) using the virtual disjunct eddy covariance method (Karl et al. 2013). Isoprene flux measurements from CABERNET have formed the basis for evaluating the biogenic emissions inventory used in California's SIP modeling (Misztal et al., 2016).

The DISCOVER-AQ (Deriving Information on Surface Conditions from Column and Vertically Resolved Observations Relevant to Air Quality) field campaign took place in the SJV from January 16th through mid-February 2013. The campaign was organized by NASA, with the primary goal of relating column observations (e.g., from satellites) to surface measurements of $PM_{2.5}$ and key trace gases such as O_3, NO_2, and formaldehyde. The campaign captured two elevated $PM_{2.5}$ episodes in the SJV when 24-hour $PM_{2.5}$ concentrations in Bakersfield exceeded 60 $\mu g/m^3$. During the campaign,

sampling by two aircrafts focused on agricultural and vehicle traffic emission sources from Bakersfield to Fresno. In addition to the aircraft measurements there were also intensive ground-based data collection in Fresno and Porterville. The field campaign provided unprecedented observations of $PM_{2.5}$ and its precursors with broad horizontal spatial coverage, at the surface as well as aloft, and also at a finer temporal resolution (i.e., minutes compared to daily or multiple hours in the past) than was previously available. The combination of highly resolved spatial and temporal measurements presented a unique opportunity to update the conceptual model for wintertime $PM_{2.5}$ formation in the SJV that was initially developed from CRPAQS field study. Pusede et al. (2016) analyzed the DISCOVER-AQ dataset and historical ammonium nitrate records in the SJV and concluded that NO_x emissions control in the valley in the past decade has substantially decreased nighttime ammonium nitrate formation in the nocturnal residual layer and continued reduction in NO_x emissions in the SJV will lead to fewer wintertime exceedances of the 24-hour $PM_{2.5}$ standard. This study lends support to the emissions control policies in the SJV that have historically focused on NO_x emissions.

Table 2-1. Major Field Studies in Central California and surrounding areas.

Year	Study	Significance
1970	Project Lo-Jet	Identified summertime low-level jet and Fresno eddy
1972	Aerosol Characterization Experiment (ACHEX)	First TSP chemical composition and size distributions
1979-1980	Inhalable Particulate Network	First long-term $PM_{2.5}$ and PM_{10} mass and elemental measurements in Bay Area, Five Points
1978	Central California Aerosol and Meteorological Study	Seasonal TSP elemental composition, seasonal transport patterns
1979-1982	Westside Operators	First TSP sulfate and nitrate compositions in western Kern County
1984	Southern SJV Ozone Study	First major characterization of O_3 and meteorology in Kern County
1986-1988	California Source Characterization Study	Quantified chemical composition of source emissions

1988-1989	Valley Air Quality Study	First spatially diverse, chemical characterized, annual and 24-hour $PM_{2.5}$ and PM_{10}
Summer 1990	San Joaquin Valley Air Quality Study/Atmospheric Utilities Signatures Predictions and Experiments (SJVAQS/AUSPEX) – Also known as SARMAP (SJVAQS/AUSPEX Regional Modeling Adaptation Project)	First central California regional study of O_3 and $PM_{2.5}$
July and August 1991	California Ozone Deposition Experiment	Measurements of dry deposition velocities of O_3 using the eddy correlation technique made over a cotton field and senescent grass near Fresno
Winter 1995	Integrated Monitoring Study (IMS-95, the CRPAQS Pilot Study)	First sub-regional winter study
December 1999 – February 2001	California Regional $PM_{10}/PM_{2.5}$ Air Quality Study (CRPAQS) and Central California Ozone Study (CCOS)	First year-long, regional-scale effort to measure both O_3 and $PM_{2.5}$
December 1999 to present	Fresno Supersite	First multi-year experiment with advanced monitoring technology
July 2003	NASA high-resolution lidar flights	First high-resolution airborne lidar application in SJV in the summer
February 2007	U.S. EPA Advanced Monitoring Initiative	First high-resolution airborne lidar application in SJV in the winter
August-October 2007; June-July 2009	BEARPEX (Biosphere Effects on Aerosols and Photochemistry Experiment)	Research-grade measurements to study the interaction of the Sacramento urban plume with downwind biogenic emissions
June 2008	ARCTAS - CARB	First measurement of high-time resolution (1-10s) measurements of organics

		and free radicals in SJV
May-July 2010	CalNex 2010 (Research at the Nexus of Air Quality and Climate Change)	Expansion of ARCTAS-CARB type research-grade measurements to multi-platform and expanded geographical area including the ocean.
June 2010	CARES (Carbonaceous Aerosols and Radiative Effects Study)	Research-grade measurements of trace gases and aerosols within the Sacramento urban plume to investigate SOA formation
June 2011	CABERNET (California Airborne BVOC Emission Research in Natural Ecosystem Transects)	Provided the first ever airborne flux measurements of isoprene in California
January- February 2013	DISCOVER-AQ (Deriving Information of Surface Conditions from Column and Vertically Resolved Observations Relevant to Air Quality)	Research-grade measurements of trace gases and aerosols during two $PM_{2.5}$ pollution episodes in the SJV

2.2 Description of the Ambient Monitoring Network

The San Joaquin Valley covers an area of 23,490 square miles and is home to approximately 4 million residents. The Valley is bordered on the west by the coastal mountain ranges and on the east by the Sierra Nevada range. These ranges converge at the southern end of the basin at the Tehachapi Mountains. The majority of the population is centered in the large urban areas of Bakersfield, Fresno, Modesto, and Stockton. The nonattainment area includes seven full counties (San Joaquin, Stanislaus, Merced, Madera, Fresno, Kings, and Tulare) and one partial county Kern (only the western portion of Kern County, which lies in the jurisdiction of the SJVAPCD, is included).

The Valley can be divided into three regions that are characterized by distinct geography, meteorology, and air quality: 1) northern SJV (San Joaquin, Stanislaus, and Merced counties), 2) central SJV (Madera, Fresno, and King counties), and 3) southern SJV (Tulare and Western Kern counties). A third of the Valley population lives in the

northern SJV. This lowland area is bordered by the Sacramento Valley and Delta lowland to the north, the central portion of the SJV to the south, and mountain ranges to the east and west. Because of the marine influence, which extends into this area through gaps in the coastal mountains to the west, the northern SJV experiences a more temperate climate than the rest of the Basin. These more moderate temperatures (cooler in the summer and warmer in the winter) and the predominant air flow patterns generally favor better air quality. Similar to the northern SJV, the central and southern SJV are also low lying areas, flanked by mountains on their west and east sides. The worst air quality within the Valley occurs in these two regions, where the population is primarily clustered around the Fresno and Bakersfield urban areas. In these regions the interaction between geography, climate, and a mix of natural (biogenic) and anthropogenic emissions pose significant challenges to air quality progress. The southern SJV represents the terminus of the Valley and is flanked by mountains on the south, as well. The surrounding mountains in both areas act as barriers to air flow, and combined with recirculation patterns and stable air to trap emissions and pollutants near the valley floor. The more extreme temperatures and stagnant conditions in these two regions lead to a build-up of $PM_{2.5}$ and ozone, and overall poorer air quality. In addition to the urban air quality problems, emissions and pollutants from these areas are transported downwind, resulting in poor air quality in downwind areas.

As discussed above, the Valley's diverse area includes several major metropolitan areas, vast expanses of agricultural land, industrial sources, and highways, all of which pose many issues to air quality. The San Joaquin Valley Air Pollution Control District (SJVAPCD or District), the California Air Resources Board (CARB), and the National Park Service work together and operate an extensive network of air quality monitors throughout the Valley to help improve and protect public health. The data collected from the Valley air monitoring network is used to generate daily air quality forecasts, issue health advisories as needed, support compliance with various ambient air quality standards and serves as the basis for developing long-term attainment strategies and tracking progress towards health-based air quality standards.

Figure 2-1 shows the spatial distribution of the $PM_{2.5}$, ozone, NO_x, and PAMS (Photochemical Assessment Monitoring Stations) monitors in the Valley (see Table 2-2 for longitude/latitude information for each monitor). The monitors are located throughout the Valley floor, at higher elevation locations, and within higher population density urban areas, and have been shown to sufficiently capture the highest ozone mixing ratios and the corresponding precursors under various weather conditions and in all major population centers. A detailed discussion about the monitoring network and its adequacy can be found in the Valley's 2015 Air Monitoring Network Plan (http://www.valleyair.org/aqinfo/Docs/2015-Air-Monitoring-Network-Plan.pdf) and 2014 California Infrastructure SIP (http://www.arb.ca.gov/planning/sip/infrasip/docs/i-sip.pdf).

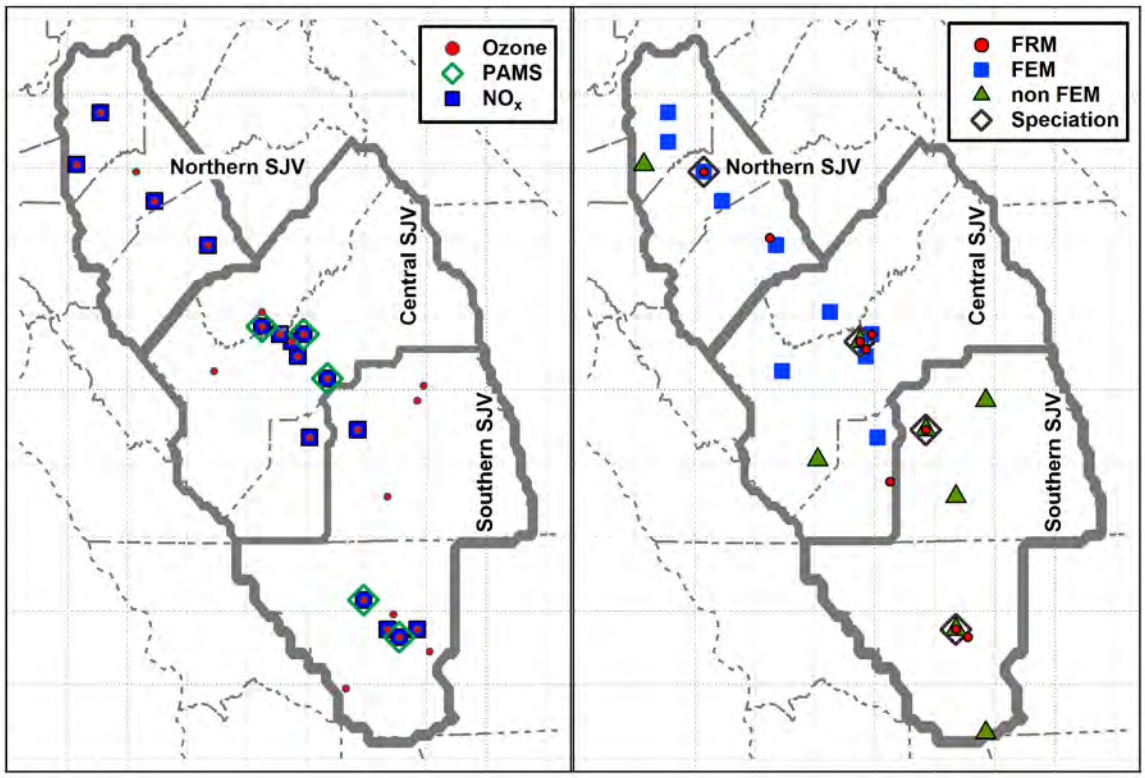

Figure 2-1. Map of the ambient monitoring network in the San Joaquin Valley.

Table 2-2. 2012-2015 San Joaquin Valley $PM_{2.5}$, ozone, NO_x, and PAMS Sites

Site ID (AQS/ARB)	Sub Region	Site	Particulate Matter				Gaseous			Location	
			FRM	FEM	non-FEM	Speciation	NO_x	Ozone	PAMS	Latitude	Longitude
Fresno County											
060195001 3026	Central SJV	Clovis-N Villa Avenue	X	X			X	X	X	36.8194	-119.7164
060190008 3009	Central SJV	Fresno-1st Street					X	X		36.7819	-119.7731
060190007 2013	Central SJV	Fresno-Drummond Street		X			X	X		36.7053	-119.7413
060190011 3781	Central SJV	Fresno-Garland	X		X	X	X	X		36.7853	-119.7742
060195025 3485	Central SJV	Fresno – Hamilton and Winery	X							36.7436	-119.7486
060190242 2844	Central SJV	Fresno-Sierra Skypark #2					X	X		36.8417	-119.8828
060192008 3768	Central SJV	Huron-16875 4th Street			X					36.1986	-120.1010
060194001 2114	Central SJV	Parlier					X	X	X	36.5974	-119.5039
060192009 3759	Central SJV	Tranquility-32650 West Adams Avenue		X				X		36.6342	-120.3823

Kern County											
060295002 3758	Southern SJV	Arvin-Di Giorgio					X			35.2367	-118.7894
060290016 3496	Southern SJV	Bakersfield-410 E Planz Road	X							35.3246	-118.9976
060290014 3146	Southern SJV	Bakersfield-5558 California Avenue	X	X	X	X	X			35.3567	-119.0628
060292012 3787	Southern SJV	Bakersfield-Municipal Airport				X	X	X		35.3313	-119.001
060290007 2312	Southern SJV	Edison				X	X			35.3458	-118.8506
060292009 3769	Southern SJV	Lebec-Beartrap Road		X						34.8415	-118.8605
060290008 2919	Southern SJV	Maricopa-Stanislaus Street					X			35.0514	-119.4028
060290232 2772	Southern SJV	Oildale-3311 Manor Street					X			35.4381	-119.0167
060296001 2981	Southern SJV	Shafter-Walker Street				X	X	X		35.5033	-119.2728
Kings County											
060310004 3194	Central SJV	Corcoran-Patterson Avenue	X							36.1022	-119.5658

060311004 3129	Central SJV	Hanford-S Irwin Street		X			X	X		36.3147	-119.6436
Madera County											
060392010 3771	Central SJV	Madera-28261 Avenue 14		X				X		36.9533	-120.0342
060390004 3211	Central SJV	Madera-Pump Yard					X	X	X	36.8672	-120.01
Merced County											
060470003 3022	Northern SJV	Merced-S Coffee Avenue		X			X	X		37.2817	-120.4336
060472510 3253	Northern SJV	Merced-2334 M Street	X							37.3092	-120.4806
San Joaquin County											
060772010 3772	Northern SJV	Manteca-530 Fishback Rd		X						37.7934	-121.2478
060771002 2094	Northern SJV	Stockton-Hazelton Street		X			X	X		37.9517	-121.2689
060773005 3696	Northern SJV	Tracy-Airport			X		X	X		37.6825	-121.4406
Stanislaus County											
060990005 2833	Northern SJV	Modesto-14th Street	X	X		X		X		37.6419	-120.9942
060990006 2996	Northern SJV	Turlock-S Minaret Street		X			X	X		37.4882	-120.8359

Tulare County

061072010 3763	Southern SJV	Porterville -1839 Newcomb Street			X			X	36.0318	-119.055
061070009 3484	Southern SJV	Sequoia and Kings Canyon Natl Park			X			X	36.4911	-118.8342
061070002 3036	Southern SJV	Sequoia Natl Park-Lower Kaweah						X	36.564	-118.773
061072002 2032	Southern SJV	Visalia-N Church Street	X		X	X	X	X	36.3325	-119.2908

2.3 $PM_{2.5}$ Air Quality Trends

Tables 2-3 and 2-4 show the annual average $PM_{2.5}$ concentration and the annual $PM_{2.5}$ design values (i.e., 3-year average), from 1999 to 2013, for FRM and FEM sites in the SJV, respectively. Based on the 2013 design value, 13 out of the 16 FRM/FEM sites exceeded the annual $PM_{2.5}$ standard of 12 μg/m^3, with the Madera-city site having the highest design value at 18.1 μg/m^3. Figure 2-2 shows the trend in peak valley-wide annual average $PM_{2.5}$ concentration and 98th percentile of the 24-hour $PM_{2.5}$ concentration, as well as the approximate number of days above the 24-hour standard in the valley from 1999 to 2015. The extreme drought conditions experienced by much of California since 2012 coupled with persistent and strong high pressure systems over the SJV in recent winters, has led to elevated levels of $PM_{2.5}$ in the SJV that have not been seen in over a decade. This is clearly illustrated by the "U" shaped curve of the 98th percentile 24-hour $PM_{2.5}$ shown in Figure 2-2. Despite the recent increase in peak 24-hour $PM_{2.5}$ levels, the SJV has seen significant improvement in $PM_{2.5}$ concentrations over the last 15 years, with steady decreases in both annual average $PM_{2.5}$ and in the number of days above the 24-hour standard, which coincide with the large emission reductions experienced in the valley (Figure 2-3).

Table 2-3: Annual Average $PM_{2.5}$ ($\mu g/m^3$)

SJV Monitoring Site	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Stockton	19.7	15.5	13.9	16.7	13.6	13.2	12.5	13.1	12.9	14.4	11.3	10.6	11.3	12.4	17.7
Manteca													10.7	8.1	11.6
Modesto	24.9	18.7	15.6	18.7	14.5	13.6	13.9	14.8	15.0	16.0	13.0	12.1	14.7	11.9	14.3
Turlock											16.1	12.5	17.1	14.8	15.0
Merced-Coffee												16.3	15.6	11.0	13.3
Merced-M	22.6	16.7	14.5	18.7	15.7	15.2	14.1	14.8	15.2	14.9	13.6	11.2	10.4	9.5	13.5
Madera-City												21.1	20.4	16.0	17.8
Fresno-First	27.6	24.5	19.8	21.5	17.8	16.3	16.7	16.8	18.8	17.4	15.1	13.0	15.5		
Fresno-Garland														14.1	16.8
Fresno-Winery		18.4	18.6	21.3	17.8	17.0	16.9	17.6	16.8	16.5	14.6	13.4	15.4	12.7	15.9
Clovis	19.8	16.3	18.0	16.2	18.5	16.4	16.3	16.4	16.4	16.2	18.3	14.7	17.9	15.4	15.9
Tranquility												7.0	8.2	7.0	8.3
Corcoran	14.3	16.4	19.2	21.5	16.2	17.4	17.5	16.9	18.4	15.8	17.7	17.9	12.8	16.5	15.6
Hanford													18.0	14.8	18.2
Visalia	27.6	23.9	22.5	23.2	18.2	17.0	18.8	18.8	20.4	19.8	16.0	13.6	16.1	14.8	18.9
Bakersfield-Golden	26.2	22.6	21.8	24.1	19.6	18.2	19.1	18.6	19.9	17.9	20.0				
Bakersfield-California	23.8	22.5	21.2	22.7	17.1	18.9	18.0	18.7	22.0	21.9	19.0	14.2	16.2	13.0	20.0
Bakersfield-Planz		20.3	20.8	23.5	17.8	17.4	19.8	19.3	21.8	23.5	22.5	17.6	14.5	14.7	22.8

Table 2-4: Annual $PM_{2.5}$ Design Value (three year average, $\mu g/m^3$)

SJV Monitoring site	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Stockton	16.4	15.3	14.7	14.5	13.1	12.9	12.8	13.5	12.9.	12.1	11.1	11.4	13.8
Manteca												12.1	10.2
Modesto	19.7	17.7	16.2	15.6	14.0	14.1	14.6	15.3	14.7	13.7	13.3	12.9	13.6
Turlock											15.3	14.9	15.7
Merced-Coffee											18.2	14.3	13.3
Merced-M	17.9	16.6	16.3	16.5	15.0	14.7	14.7	15.0	14.6	13.2	11.7	10.4	11.1
Madera-City												18.2	18.1
Fresno-First	24.0	21.9	19.7	18.6	16.9	16.6	17.4	17.7	17.1	15.2	14.5		
Fresno-Garland													15.5
Fresno-Winery	18.5	19.4	19.2	18.7	17.2	17.2	17.1	17.0	16.0	14.9	14.5	13.8	14.7
Clovis	18.0	16.8	17.6	17.0	17.1	16.4	16.4	16.3	17.0	16.4	16.8	16.0	16.4
Tranquility											7.6	7.4	7.8
Corcoran		19.0	19.0	18.4	17.0	17.2	17.6	17.0	17.3	17.1	16.2	15.8	15.0
Hanford												15.8	17.0
Visalia	24.7	23.2	21.3	19.5	18.0	18.2	19.3	19.7	18.8	16.5	15.2	14.8	16.6
Bakersfield-Golden	23.6	22.8	21.8	20.6	19.0	18.6	19.2	18.8	19.3				
Bakersfield-California	22.5	22.1	20.3	19.6	18.0	18.5	19.6	20.9	21.0	18.4	16.5	14.5	16.4
Bakersfield-Planz		21.5	20.7	19.6	18.4	18.9	20.3	21.5	22.6	21.2	18.2	15.6	17.3

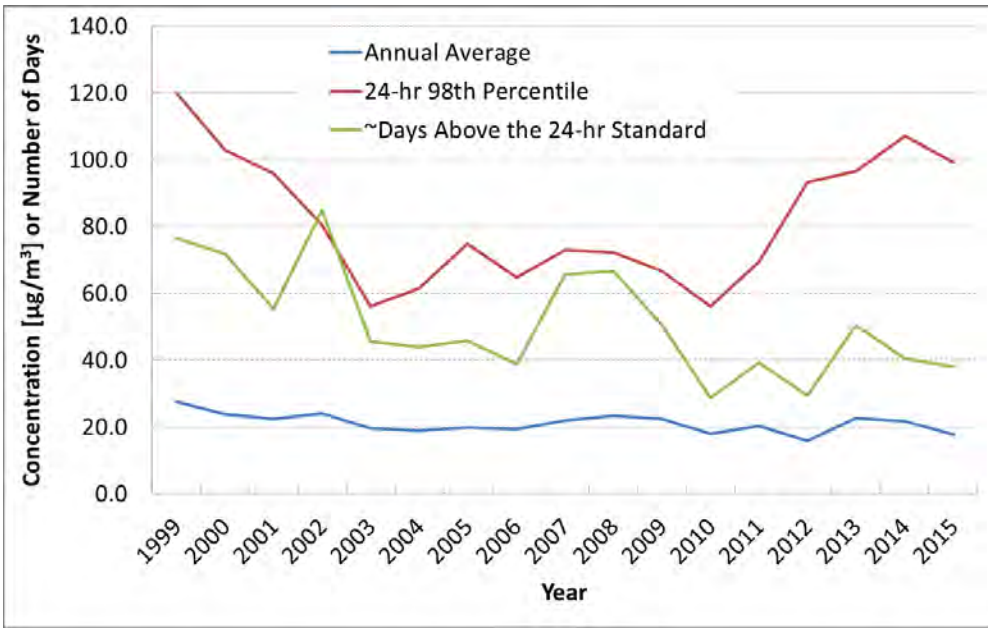

Figure 2-2. Trends in valley-wide annual average, 24-hour 98th percentile $PM_{2.5}$, and approximate number of days above the 24-hour standard (http://www.arb.ca.gov/adam/index.html).

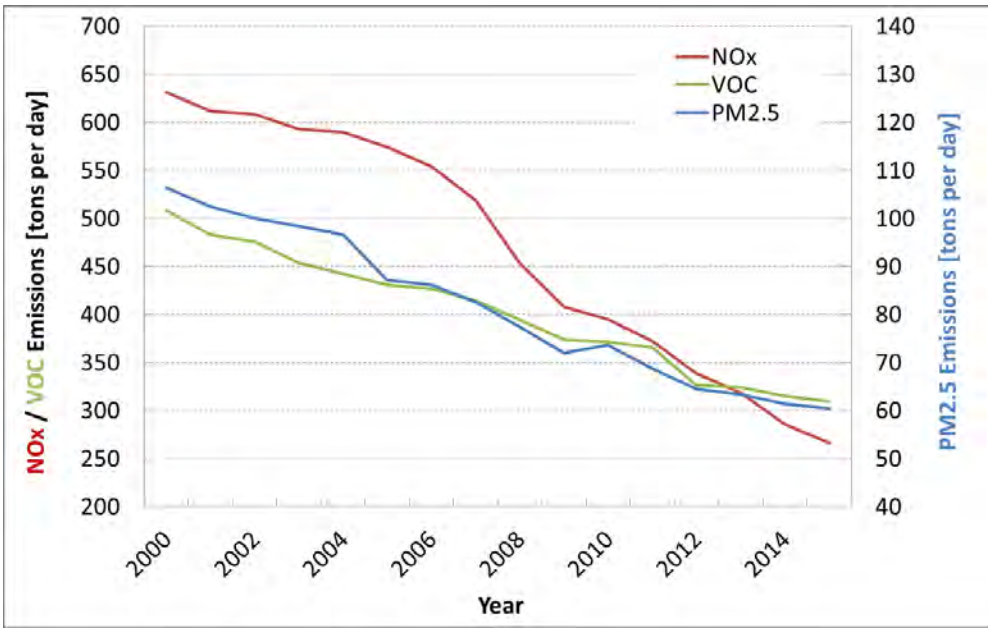

Figure 2-3. San Joaquin Valley trends in $PM_{2.5}$, NO_x, and VOC emissions.

2.4 Major $PM_{2.5}$ Components

Four monitoring sites collect $PM_{2.5}$ chemical composition data in the San Joaquin Valley: Bakersfield-California, Fresno-Garland, Modesto, and Visalia. The Bakersfield and Fresno speciation monitors are part of the national Chemical Speciation Network (CSN) while Modesto and Visalia are part of the State and Local Air Monitoring Stations (SLAMS) network. All four sites use SASS samplers (Spiral Aerosol Speciation Sampler, Met One, Grants Pass, OR.) for data collection. The CSN data are analyzed by the Research Triangle Institute and the SLAMS data are analyzed by ARB. In recent years, changes were made to the carbon sampling and analysis method. The collection method changed from the MetOne SASS to the URG3000N sampler, which is very similar to the IMPROVE module C sampler. The analytical method was changed from the NIOSH-like thermal optical transmittance method to IMPROVE_A thermal optical reflectance. At Bakersfield, Modesto, and Visalia these changes were implemented in May of 2007, and the Fresno site switched to the new carbon system in April of 2009.

Figure 2-4 illustrates the average of the 2011-2013 annual average $PM_{2.5}$ composition, as well as average of the top 10 percent of days at Bakersfield, Fresno, and Modesto over the same time period. Organic matter (OM) was calculated by multiplying measured OC by 1.5 according to the OM/OC ratio measured at Fresno (Ge et al., 2012). Ammonium nitrate is the largest contributor to $PM_{2.5}$ on annual basis, accounting for approximately 40% of the $PM_{2.5}$ mass. Its contribution is even higher on peak $PM_{2.5}$ days, accounting for 55-60% of $PM_{2.5}$ mass. Formation mechanisms for ammonium nitrate are discussed in Section 2.5. OM is the second most abundant component, constituting approximately 30% of the $PM_{2.5}$ mass on an annual basis. Activities such as residential wood combustion, cooking, biomass burning, and mobile sources contribute to OM levels in the atmosphere. In addition, OM can also be formed in the atmosphere from oxidation of VOCs. Ammonium sulfate contributes approximately 10% of the $PM_{2.5}$ on an annual basis. Its contribution is half that on peak days, at approximately 5%. Elemental carbon and crustal materials typically contribute less than 10% to $PM_{2.5}$ levels in these cities, except at Bakersfield, where crustal materials contributed more than 10% on an annual basis.

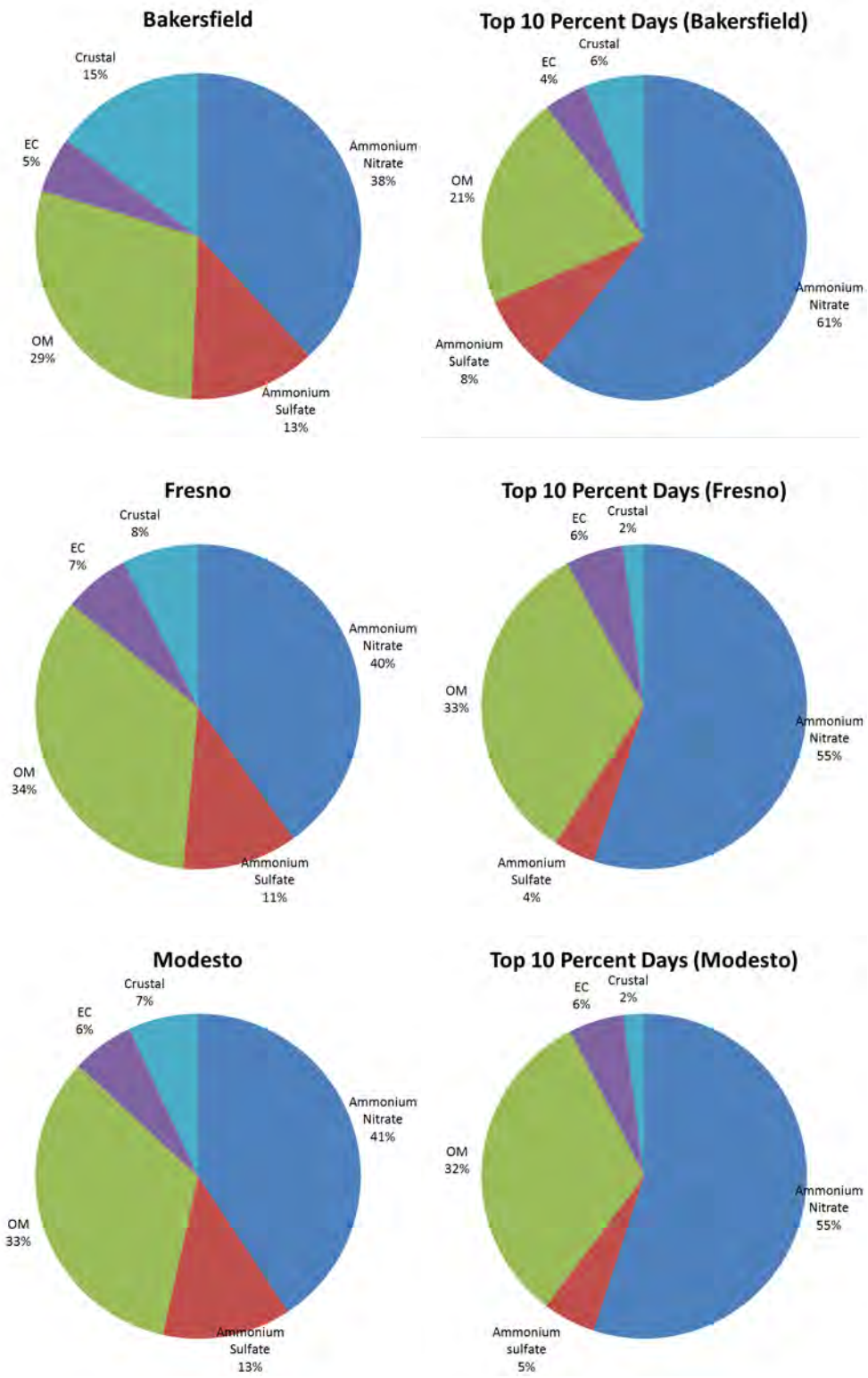

Figure 2-4. Three-year average (2011-2013) and average peak day (top 10 percent over the same three years) $PM_{2.5}$ composition at Bakersfield, Fresno, and Modesto.

2.5 Seasonality of $PM_{2.5}$ and Meteorological Conditions Leading to Elevated $PM_{2.5}$

$PM_{2.5}$ concentrations in the San Joaquin Valley exhibit a strong seasonal variability, with the highest concentrations occurring during the months of November through February. For example, Figure 2-5 represents the time series of 24-hour $PM_{2.5}$ concentrations at Bakersfield - California Avenue in 2013, which shows a vast majority of the elevated $PM_{2.5}$ episodes occurred in the first two and last two months of the year. The predominance of elevated $PM_{2.5}$ episodes during winter months results from a confluence of meteorological conditions conducive to the formation and buildup of $PM_{2.5}$, as well as wintertime sources of directly emitted $PM_{2.5}$.

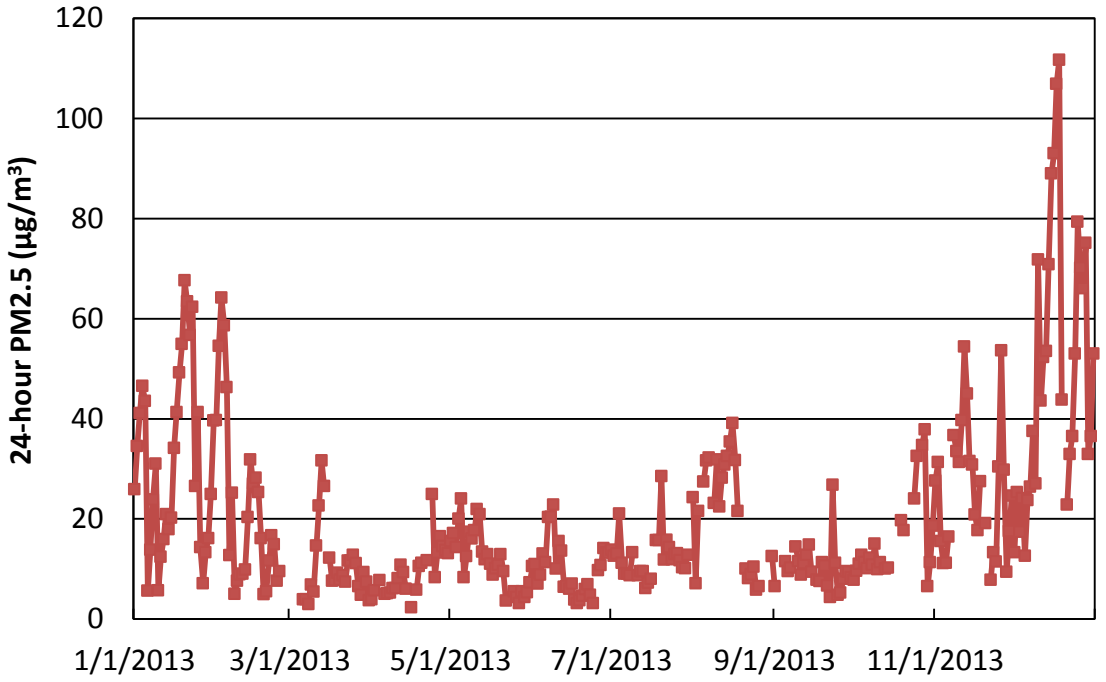

Figure 2-5. 24-hour $PM_{2.5}$ concentrations at Bakersfield- California Avenue in 2013.

High $PM_{2.5}$ concentrations typically build up during multiday episodes under stagnant winter weather when a high pressure system (the Great Basin High) reduces the ventilation in the Valley (Ferreria et al., 2005). These stagnation events, sandwiched between two weather systems, are characterized by low wind speeds, moderate temperatures, vertical atmospheric stability, and high relative humidity. This stable atmosphere prevents precursor gases and primary (or directly emitted) $PM_{2.5}$ released at the surface in the Valley from rapidly dispersing. The moderate temperatures and

high relative humidity also enhance the formation of secondary particulate matter, especially ammonium nitrate and sulfate. In contrast, hotter and drier weather conditions in summer favor the evaporation of semi-volatile species from particles. Greater mixing height in summer can also help the ventilation of air pollutants. As a result, summertime $PM_{2.5}$ concentrations in the SJV are typically much lower compared to wintertime.

Wintertime $PM_{2.5}$ episodes can last for many days. At the beginning of an episode, concentrations are low but increase daily because of both the accumulation of primary pollutants and formation of secondary pollutants (Watson et al, 2002). Concentrations continue to build until there is a change in the weather significant enough to wash out particles through rainfall or increased ventilation of the Valley. For example, the two main episodes captured during the CRPAQS field study (starting in late 1999) had up to 18 days with $PM_{2.5}$ concentrations exceeding 65 $\mu g/m^3$ (Turkiewicz et al., 2006). At the end of 2013 and the beginning of 2014, Bakersfield experienced 18 days with $PM_{2.5}$ concentrations greater than 35 $\mu g/m^3$. During such episodes, urban sites typically record elevated concentrations earlier than rural sites, and as a consequence, have a greater number of days with high concentrations. However, due to the buildup of $PM_{2.5}$ concentrations, rural sites can achieve concentrations with similar magnitude as urban sites by the end of an episode.

The elevated wintertime $PM_{2.5}$ concentrations observed during pollution episodes are the result of both directly emitted particulates (known as primary particulate matter) and particulate matter formed via chemical and physical processes in the atmosphere (known as secondary particulate matter). Ammonium nitrate, the dominant $PM_{2.5}$ component throughout the Valley, is formed in the atmosphere as a result of chemical reactions between precursor pollutants such as NO_x, VOC, and ammonia. Carbonaceous aerosol, the second most abundant component, is mostly directly emitted, and is the result of contributions from wood combustion (e.g., wood burning for heating), mobile sources, and cooking.

As shown in Figure 2-4, carbonaceous aerosols and ammonium nitrate together comprise approximately 80 percent of the $PM_{2.5}$ mass. In winter, most of the carbonaceous aerosol is emitted into the atmosphere as directly emitted particles, and its transport is much more limited compared to gaseous precursors of ammonium nitrate. Ammonium nitrate can be formed both at the surface and aloft and can be fairly uniform across urban and rural sites. The spatial homogeneity of ammonium nitrate is influenced by higher wind speeds aloft (which allow more efficient transport), and the diurnal variation in mixing heights (which allow entrainment of ammonium nitrate down to the surface).

Ammonium nitrate is also formed via both daytime and nighttime chemistry. The amount of ammonium nitrate produced will be limited by the relative abundance of its precursors in the atmosphere. In the San Joaquin Valley, the nighttime formation is considered to be the most important pathway (Lurmann et al., 2006). The nighttime pathway involves oxidation of NO_2, followed by reaction with ammonia to form ammonium nitrate. Since ammonia is abundant in the Valley in the winter, NO_x is considered to be the limiting precursor. In contrast, the daytime pathway also involves VOCs. Modeling studies that investigated winter episodes in the Valley estimated that reductions in VOC emissions have a small impact on nitrate concentrations only at very high $PM_{2.5}$ concentrations (Pun, et al., 2009). However, at current $PM_{2.5}$ levels the impact was very limited, and in some cases VOC reductions lead to an increase in $PM_{2.5}$ concentrations (Chen et al., 2014; Kleeman, et al., 2005).

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