Appendix A: Weight of Evidence

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Introduction

The U.S. Environmental Protection Agency (U.S. EPA) recommends that states supplement required air quality modeling with additional analyses to enhance the assessment of whether emissions reductions outlined in the State Implementation Plan (SIP) will result in attainment of the relevant National Ambient Air Quality Standard (NAAQS or standard).[1] Employing multiple analytical methods in a Weight of Evidence (WOE) approach yields a better understanding of the overall air quality problem and the level and mix of emissions controls needed for attainment. It also provides a more broadly informed basis for the attainment strategy.

Following U.S. EPA guidance on how to deal with the uncertainty inherent in predicting absolute fine particulate matter (PM2.5) concentrations in the future, an attainment demonstration that shows modeled design values falling either just above or just below the standard in the attainment year should be accompanied by a WOE demonstration to support the attainment demonstration. U.S. EPA recognizes the importance of a comprehensive assessment of air quality data and modeling and encourages this type of broad assessment for all attainment demonstrations. Further, U.S. EPA notes that the results of supplementary analyses may be included in a WOE determination to show that attainment is likely despite modeled results which may be inconclusive.

U.S. EPA recommends the WOE supplement the air quality modeling by including analyses of trends in ambient air quality and emissions, observational models and diagnostic analyses, and additional modeling evaluations. The scope of the WOE analysis is different for each nonattainment area, depending on the complexity of the air quality problem, how far into the future the attainment deadline is, and the amount of data and modeling available. For example, less analysis is needed for an area that is projecting attainment near-term and by a wide margin, and for which recent air quality trends have demonstrated significant progress, than for areas like the San Joaquin Valley (Valley) with more severe air quality challenges.

The following sections present the WOE assessment that supports the attainment demonstration for the *2024 Plan for the 2012 Annual PM2.5 Standard* (2024 PM2.5 Plan) for the Valley.

PM2.5 Standards and Health Effects

Fine particulate matter up to 2.5 micrometers in diameter—PM2.5—is made up of many constituent particles and liquid droplets that vary in size and chemical composition. PM2.5 contains a diverse set of substances including elements such as carbon and metals;

1 U.S. EPA, 2018, Modeling Guidance for Demonstrating Attainment of Air Quality Goals for Ozone, PM2.5 and Regional Haze, available at *https://www.epa.gov/sites/default/files/2020-10/documents/o3-pm-rh-modeling_guidance-2018.pdf*

compounds such as nitrates, sulfates, and organic materials; and complex mixtures such as diesel exhaust and soil or dust. Some of the particles (primary PM2.5) are directly emitted into the atmosphere while others (secondary PM2.5) result when gases are transformed into particles through physical and chemical processes in the atmosphere.

Numerous health effects studies have linked exposure to PM2.5 to increased severity of asthma attacks, development of chronic bronchitis, decreased lung function in children, increased respiratory and cardiovascular hospitalizations, and even premature death in people with existing cardiac or respiratory disease. In addition, California has identified particulate exhaust from diesel engines as a toxic air contaminant suspected to cause cancer, other serious illnesses, and premature death. Those most sensitive to PM2.5 pollution include people with existing respiratory and cardiac problems, children, and older adults.

NAAQS establish the levels above which PM2.5 may cause adverse health effects. In 1997, U.S. EPA adopted the first set of PM2.5 air quality standards, a 24-hour standard of 65 micrograms per cubic meter ($\mu g/m^3$) and an annual standard of 15 $\mu g/m^3$. In 2006, the 24-hour standard was tightened to 35 $\mu g/m^3$, and in 2012, the annual standard was lowered to 12.0 $\mu g/m^3$. In February 2024, U.S. EPA further strengthened the annual PM2.5 standard to a level of 9.0 $\mu g/m^3$.

Nature and Extent of the PM2.5 Problem

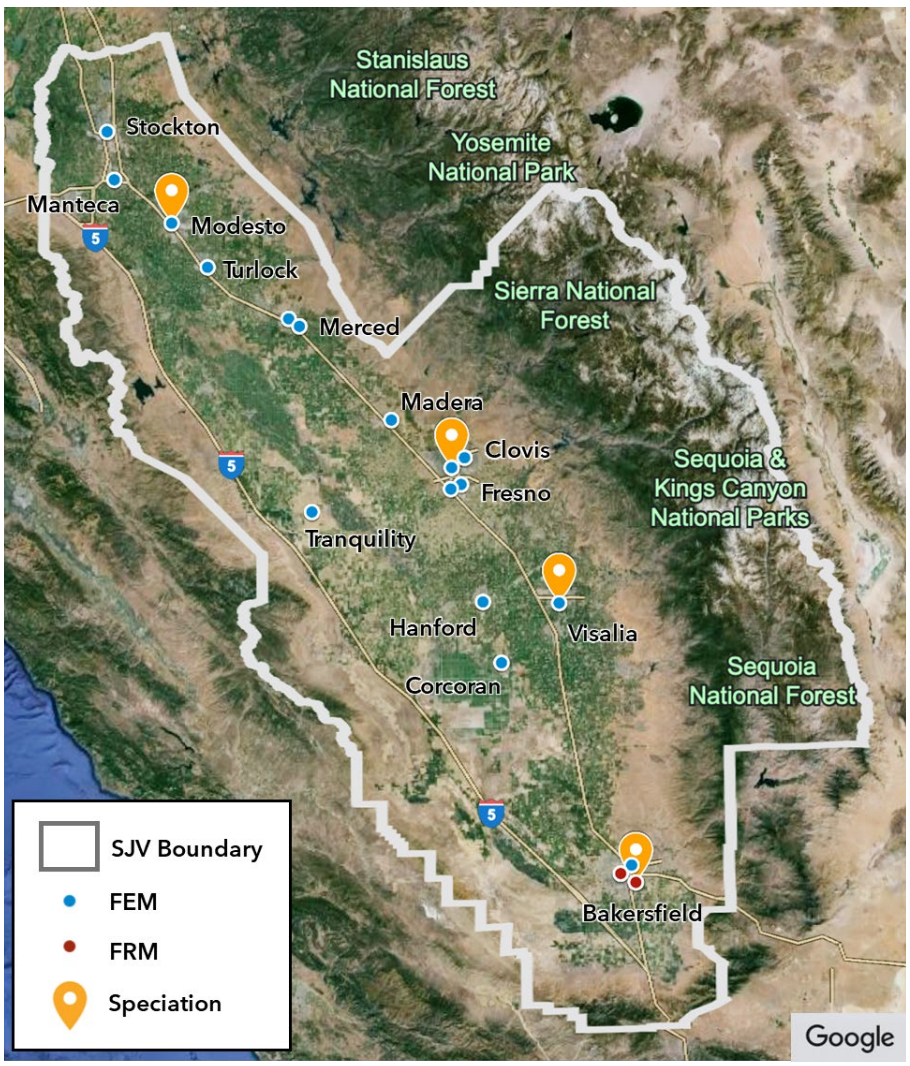
The San Joaquin Valley is a large geographic area covering nearly 25,000 square miles with a string of major cities and a population of roughly four million. The Valley is a lowland area bordered by the Sierra Nevada Mountains to the east, the Pacific Coast Range to the west, and the Tehachapi Mountains to the south. The surrounding mountains and meteorology create ideal conditions for air pollution formation and retention in the Valley. Geography and large-scale regional and local weather patterns influence the accumulation, formation, and dispersion of air pollutants in the Valley. The mountains act as air flow barriers, with the resulting stagnant conditions favoring the accumulation of pollutants. To the north, the Valley borders the Sacramento Valley and Delta lowland, which allows for some level of pollutant dispersion. Because of geography and meteorology, PM2.5 concentrations are generally higher in the southern and central portions of the Valley. Both the emission levels and the meteorology conditions make it exceedingly difficult for the Valley to meet the NAAQS for both PM2.5 and ozone.

This section will (1) introduce the existing air quality monitoring network in the Valley, (2) discuss field studies conducted in the Valley that have contributed to CARB’s understanding of air quality science in the Valley, (3) describe the current PM2.5 air quality conditions in the Valley, (4) describe the chemical composition of PM2.5 in the Valley, and (5) discuss the important emission sources in the Valley.

I. Established Monitoring Network

An extensive network of PM2.5 monitors throughout the San Joaquin Valley, shown in Figure 1, provides data to understand the extent of the PM2.5 problem. The locations of monitoring sites are selected to capture population exposure. Currently, eighteen sites operate either Federal Reference Method (FRM) monitors or Federal Equivalent Method (FEM) monitors, or a combination of the two monitors running parallel to each other. Many sites operate multiple monitoring instruments running in parallel. Additionally, four sites have speciation monitors which collect information on the chemical compositions of PM2.5. Data collected at these monitors, as well as other non-regulatory monitors, serve to report air quality conditions to the public and support forecasting for the District's Smoke Management System and residential wood burning curtailment programs. More detailed information about the monitoring sites can be found in Appendix 1 of this WOE.

Figure 1: San Joaquin Valley PM2.5 monitoring network (FRM, FEM and Chemical Speciation monitors).



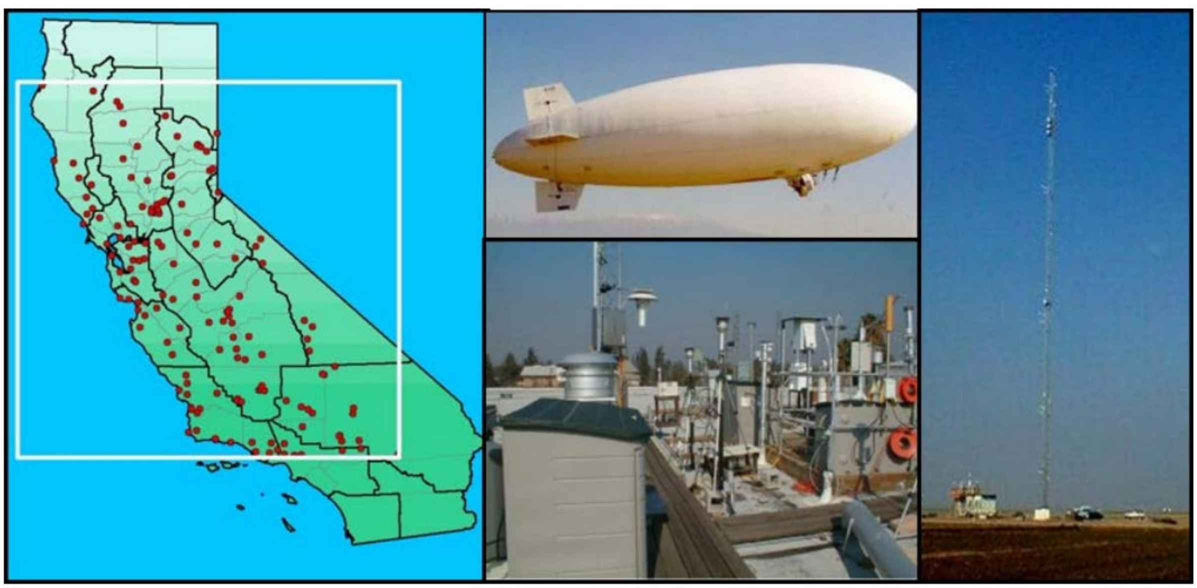
II. Field Studies

The San Joaquin Valley is one of the most studied air basins in the world. Dozens of major reports and publications have appeared in peer-reviewed international scientific and technical journals. Since 1970, close to 20 major field studies have been conducted in the Valley and surrounding areas that have shed light on various aspects of the nature and causes of ozone and particulate matter pollution.

The first major study specifically focused on particulate matter was the Integrated Monitoring Study in 1995 (IMS-95). IMS-95 formed the technical basis for the San Joaquin Valley 2003 PM10 Plan (approved by U.S. EPA in 2004),[2] and acted as the pilot study for the subsequent California Regional Particulate Air Quality Study (CRPAQS), conducted between December 1999 and February 2001.

CRPAQS was a public/private partnership study designed to advance the understanding of the nature of PM2.5 in the Valley and guide development of effective control strategies. The study included monitoring at over 100 sites (Figure 2).

Figure 2. CRPAQS monitoring locations and equipment for ground-based and upper air data collection.



Other relevant field studies include the California portion of the 2008 Arctic Research of the Composition of the Troposphere from Aircraft and Satellites (ARCTAS-CARB) (Jacob et al., 2010) and the California Research at the Nexus of Air Quality and Climate Change (CalNex2010)[3] study conducted in 2010. The monitoring operations for both studies occurred from early to mid-summer and extended over Southern California and the Central

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[2] 69 Fed. Reg. 30,006

[3] National Oceanic and Atmospheric Administration (NOAA), *www.esrl.noaa.gov/csd/calnex/*

Valley. The final CalNex2010 report to CARB was a synthesis of policy relevant findings designed to help formulate scientifically sound policies (NOAA, 2016).

An additional field study, Deriving Information on Surface Conditions from Column and Vertically Resolved Observations Relevant to Air Quality (DISCOVER-AQ),[4] gathered air quality data in the Valley with the objective to provide an integrated dataset of airborne and surface observations relevant to the diagnosis of surface air quality conditions from space. DISCOVER-AQ was conducted from mid-January through mid-February 2013; data results and implications for the San Joaquin Valley are still being evaluated.

Findings from CRPAQS, CalNex2010, DISCOVER-AQ, and other studies have been integrated into the conceptual model of PM2.5 in the San Joaquin Valley. This conceptual model provides the scientific foundation for the WOE analysis supporting the attainment demonstration. Specific findings are integrated into the various WOE analysis sections of this document.

III. Current Air Quality

To determine attainment for the annual PM2.5 standard, the corresponding design value at each monitoring site must be calculated following protocol in 40 Code of Federal Regulations (CFR) Appendix N to Part 50. A design value is a statistic that describes the air quality status of a given location relative to the level of the NAAQS. The annual design value represents a three-year average of the annual average PM2.5 concentrations measured at a certain site. If the annual design value is equal to or below the 12.0 µg/m^3 standard, the site meets the standard. All sites in the nonattainment area must meet the standard for the Valley to attain the standard. Since 2023 PM2.5 data were recently certified but the chemical speciation data are still unavailable, 2022 PM2.5 air quality data are used for the majority of the analysis. A short summary of 2023 PM2.5 air quality data is included below.

Where noted, the design values presented in this analysis excluded a list of days impacted by exceptional events such as wildfires. The list of the removed wildfire days and the criteria of screening the wildfire days are detailed in Appendix 2 of this WOE.

A. 2020-2022 PM2.5 Levels

Figure 3 illustrates the 2022 levels of PM2.5 annual design values at all regulatory monitoring sites in the Valley, ordered north to south.[5] Eight out of eighteen monitoring

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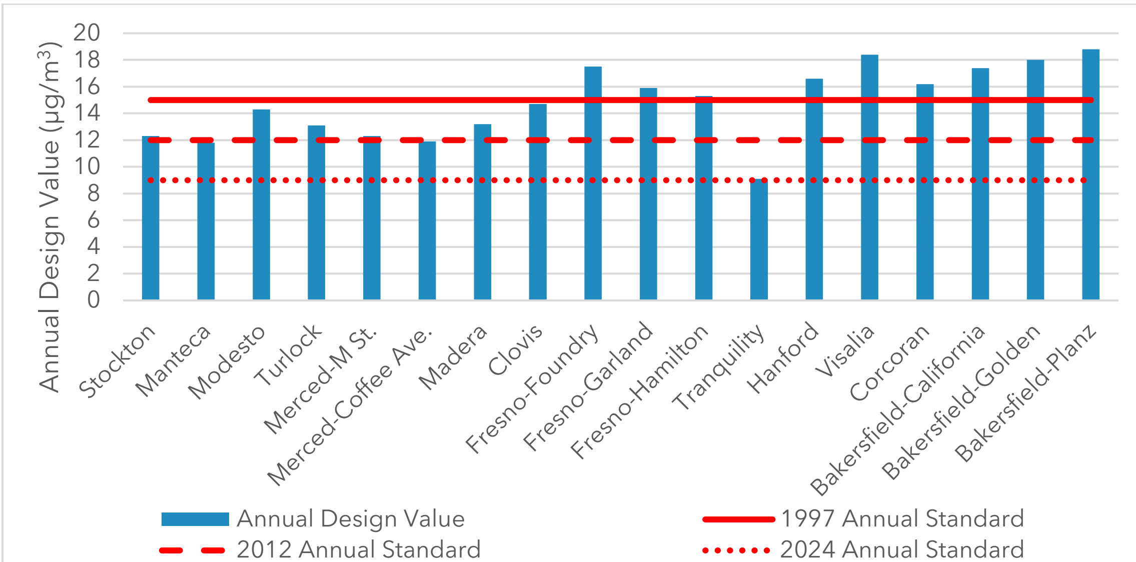
[4] National Aeronautics and Space Administration (NASA), *https://www-air.larc.nasa.gov/missions/discover-aq/discover-aq.html*

[5] PM2.5 exhibits a geographic pattern, with concentrations increasing in magnitude from north to south. Figure 3 through Figure 8 all illustrate this geographic pattern, as the northern sites tend to have lower design values and lower PM2.5 levels through the season compared to the central and southern sites. Tranquility, which is at the central west of the Valley, tends to be the site with the lowest concentration level due to its distance from the populated areas along the CA-99 highway and its location in the upwind direction.

sites currently meet the 1997 15.0 µg/m^3 PM2.5 annual standard (Figure 3). The Bakersfield-Planz monitoring site had the highest annual PM2.5 design value of 18.8 µg/m^3 in the Valley, followed closely by Visalia-Ashland/Church (AQS ID 061072003/061072002)[6] with a design value of 18.4 µg/m^3.

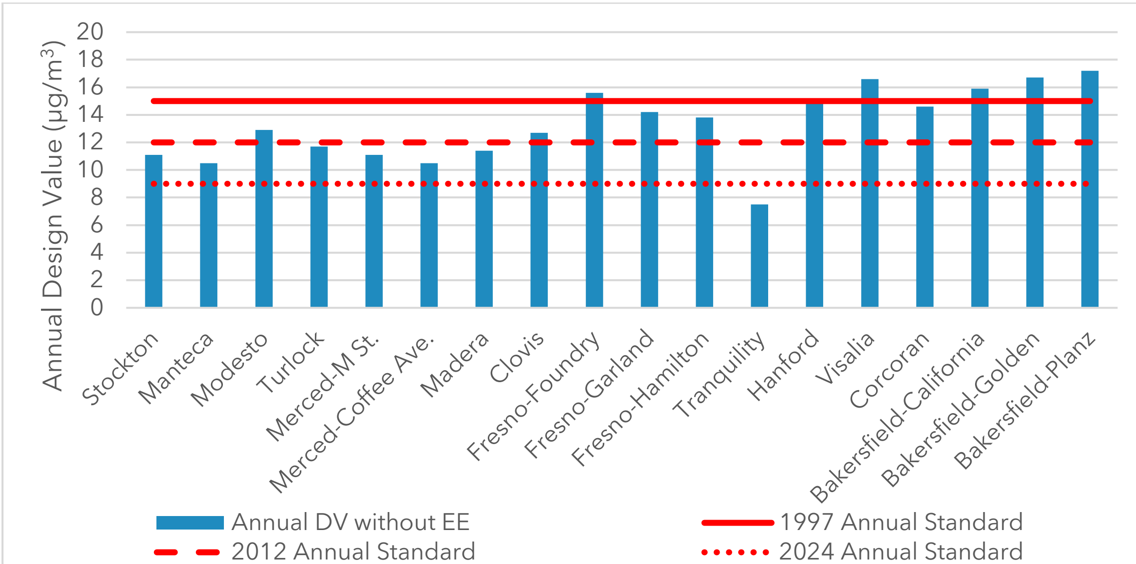
Figure 3: 2022 PM2.5 annual design values from all regulatory monitoring sites in the San Joaquin Valley nonattainment area. The sites are sorted geographically from north to south.



California was hit by historic wildfire during the span of 2020-2022 and the design values were severely impacted. Removing the wildfire days from the 2020-2022 design value calculation, as shown in Figure 4, thirteen of the eighteen sites sit below the 1997 15.0 µg/m^3 standard. Seven sites would attain the 2012 12.0 µg/m^3 standard, while two other sites (Clovis and Modesto) are very close to attainment. These lower design value sites are mostly located in the northern part of the Valley, while the highest sites (Bakersfield and Visalia) are in the southern part of the Valley.

[6] Visalia-N. Church St. (AQS ID 061072002) was relocated to Visalia-W. Ashland Ave. (AQS ID 061072003) at the beginning of 2022. The Visalia site data in this WOE combine data from both sites.

Figure 4: 2022 PM2.5 annual design values from all regulatory monitoring sites in the San Joaquin Valley nonattainment area without wildfire days. The sites are sorted geographically from north to south.



PM2.5 exhibits a distinctive seasonal pattern throughout the Valley. Figure 5 summarizes the seasonal pattern of PM2.5 levels at four sites in the Valley. These four sites were selected for this analysis to represent areas in the northern (Modesto), central (Fresno-Garland), and southern (Bakersfield-Planz and Visalia) geographic regions of the Valley. Each of these four sites follows a similar seasonal pattern, with lower levels in spring and summer, and higher levels in fall and winter. However, due to the historic wildfire impacts to California in 2020-2022, the summer (July to September) PM2.5 levels appear to be abnormally higher than typical levels. This deviation is observed among all the four sites in Figure 5.

Figure 5: Monthly average PM2.5 levels at four sites in the Valley (2020-2022).

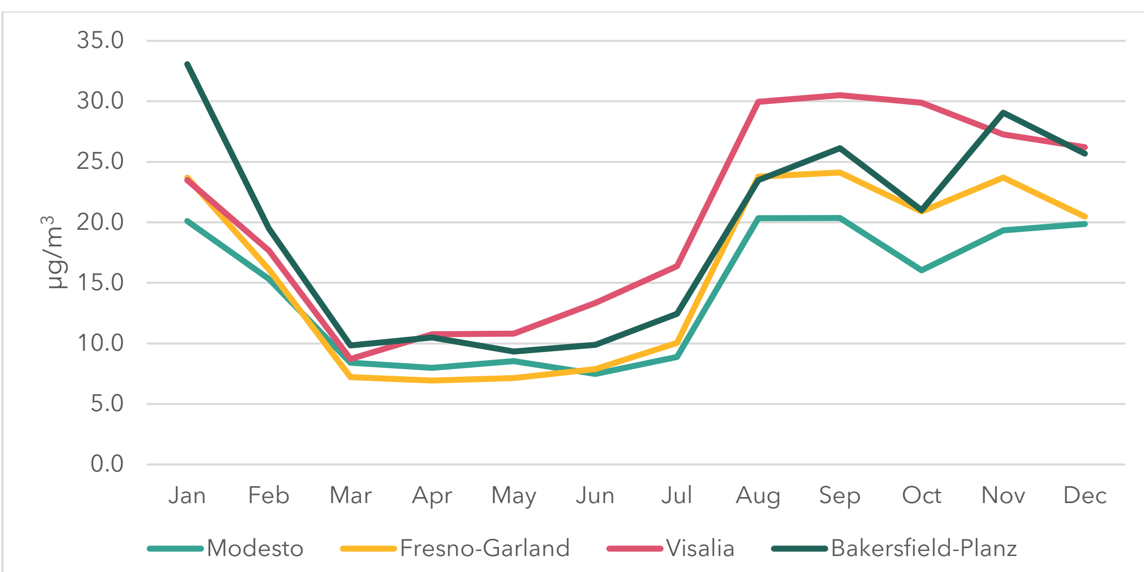
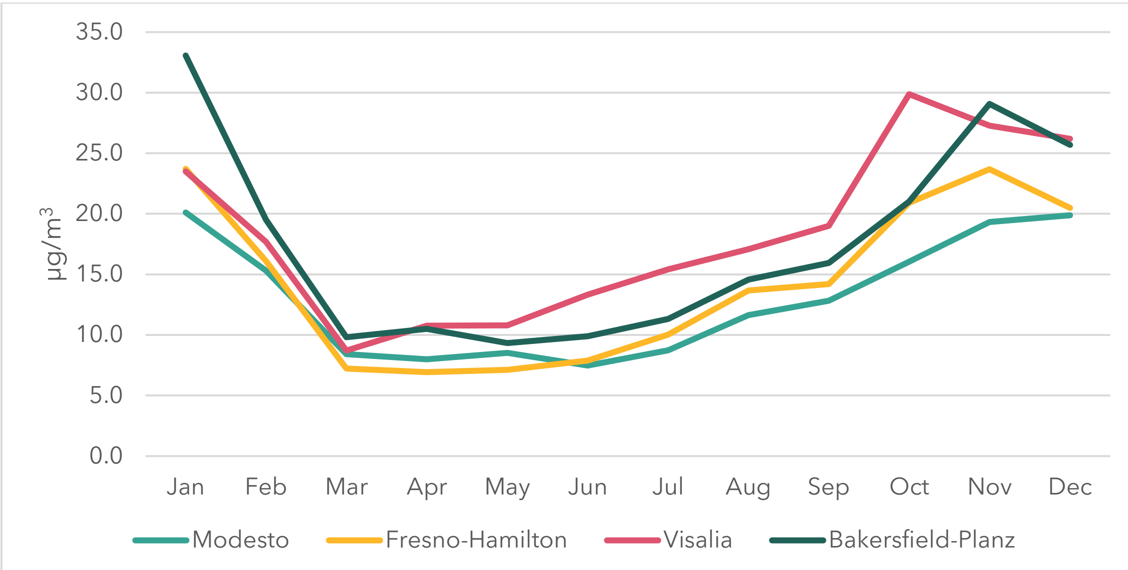


Figure 6 presents the seasonal pattern after removing wildfire days from the calculation. The elevated PM2.5 levels in July to September drop to a more representative level, and the months between November to February are clearly the highest throughout the year.

Figure 6: Monthly PM2.5 average levels at four sites in the Valley with wildfire days removed (2020-2022).



B. 2023 PM2.5 Levels

Air quality data for 2023 were recently certified and indicate air quality improvement. In 2023, California was mostly free of wildfire impact and had abundant rainfall. The PM2.5 levels observed in 2023 were thus more representative of the typical scenario for California and were more useful in examining the air quality progress.

Figure 7 presents the preliminary 2023 annual design values for all monitoring locations in the Valley, ordered north to south. The 2023 design values are overall 2-3 μg/m3 less than that of 2022. Only three sites remain nonattainment for the 15 μg/m3 standard based on 2023 design values. The highest site is still Bakersfield-Planz, but the design value drops to 16.2 μg/m3 compared to 18.4 μg/m3 in 2022.

Figure 7: 2023 PM2.5 annual design values from all regulatory monitoring sites in the San Joaquin Valley nonattainment area. The sites are sorted geographically from north to south.

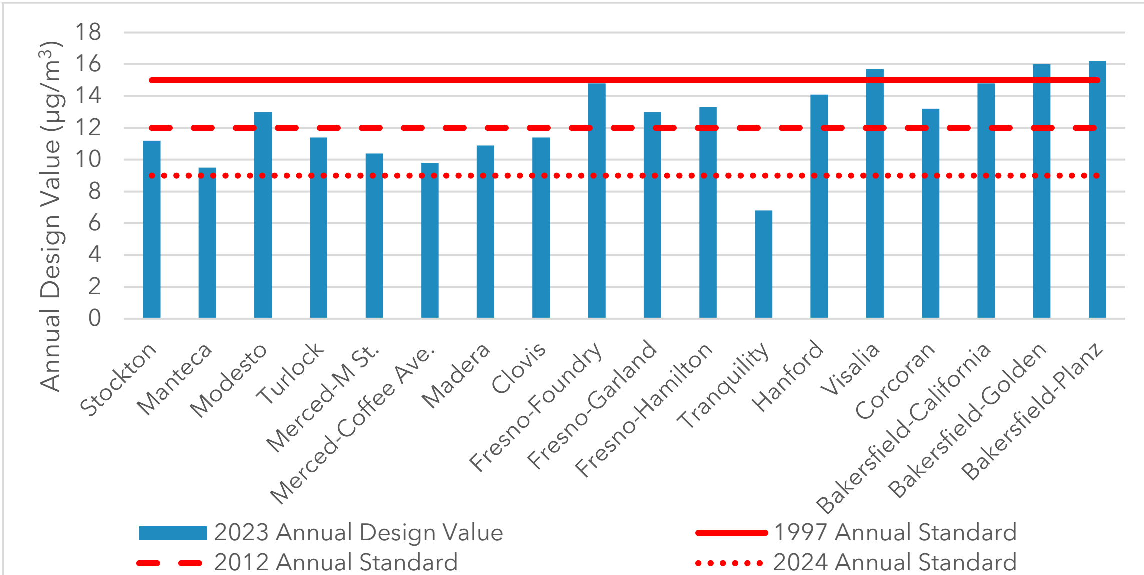
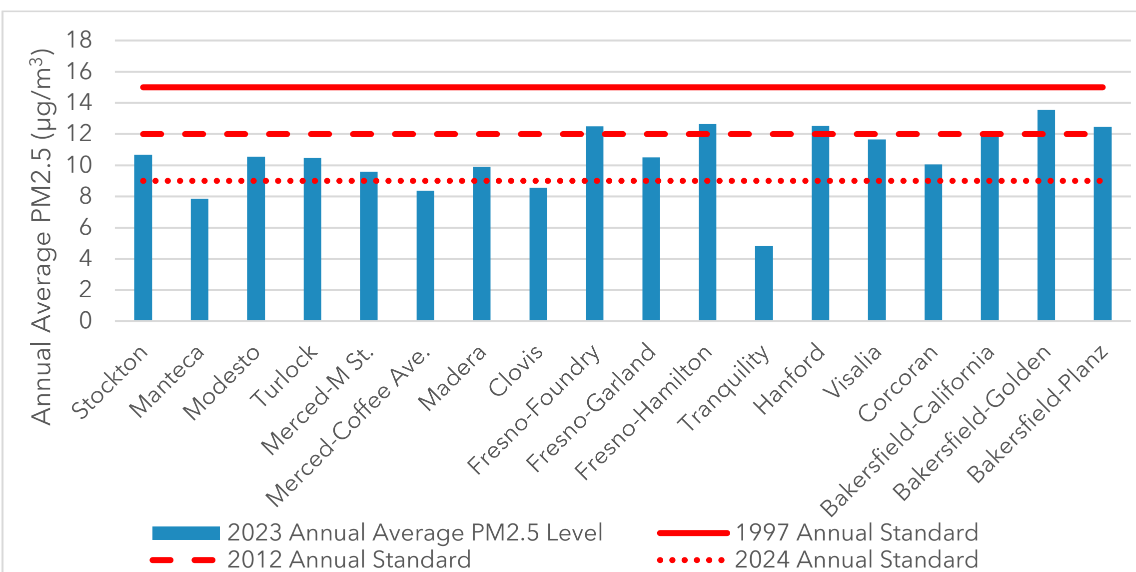


Figure 8 presents the annual average PM2.5 levels for all the sites in the San Joaquin Valley in 2023. 2023 would be a clean year for the 1997 annual standard because all sites had annual average PM2.5 levels below 15.0 µg/m3. In fact, only five sites had an annual average level above 12.0 µg/m3 in 2023.

Figure 8: 2023 PM2.5 annual average levels from all regulatory monitoring sites in the San Joaquin Valley nonattainment area.

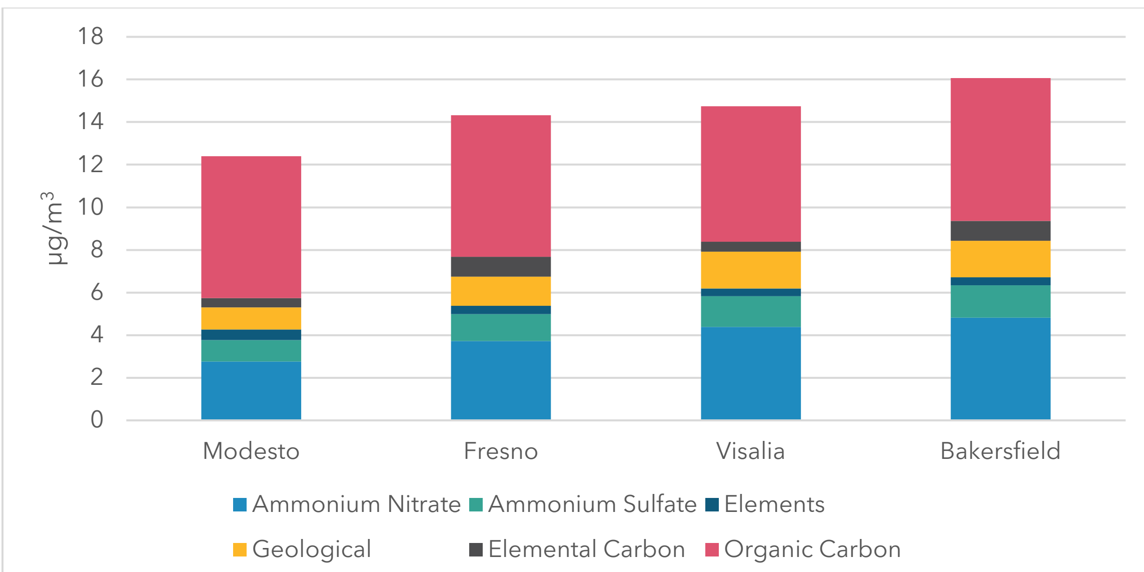


IV. Chemical Composition and Secondary Aerosol Formation

Examination of the chemical composition of PM2.5 with speciated monitoring data provides another important element in understanding the nature of PM2.5 in the Valley and identifying contributing sources. The charts in Figure 9 show the chemical components that contribute to PM2.5 levels on an annual average basis at urban sites in Modesto, Fresno-Garland, Visalia, and Bakersfield in the northern, central, and southern regions of the Valley. It is clear from the charts that the biggest share of PM2.5 is comprised of ammonium nitrate and carbonaceous aerosols (elemental and organic carbon) in the Valley, followed by ammonium sulfate and geological PM2.5.

Ammonium nitrate is about one third of annual average PM2.5 levels in the Valley (Figure 9). The difference in PM2.5 levels across the four sites is due in large part to ammonium nitrate. Ammonium nitrate is formed in the atmosphere through two distinct pathways (daytime and nighttime) that convert nitrogen dioxide (NO2) to nitric acid (HNO3), which then reacts with ammonia (NH3) to form ammonium nitrate. The daytime pathway is initiated by the hydroxyl radical (OH), which is formed through complex photochemistry of VOCs and other trace gases in the atmosphere, while the nighttime pathway is initiated by ozone. Sources emitting nitrogen oxides (NOx) include motor vehicles and stationary combustion sources, while the largest sources of ammonia are livestock operations and fertilizer application. The stagnant, cold, and damp conditions that occur during the winter promote the formation and accumulation of ammonium nitrate.

Figure 9: PM2.5 chemical component levels at four sites in San Joaquin Valley during 2020-2022.



Carbonaceous aerosol is another large contributor to PM2.5 levels in the Valley, consisting about half of the annual average PM2.5 levels (Figure 9). Carbonaceous aerosols include both organic carbon matter, comprised of primary organic aerosols (POAs) and secondary organic aerosols (SOAs), and elemental carbon (EC). POAs are directly emitted into the atmosphere from activities such as residential wood combustion, cooking, biomass burning, wildfire, and direct tailpipe emissions from mobile sources. SOAs are formed in the atmosphere through the oxidation of POAs and reactive organic gases (ROGs) from numerous anthropogenic and biogenic emissions sources. EC is directly emitted PM2.5 and comes from mobile and stationary combustion sources, with significant contributions from diesel sources.

Ammonium sulfate, geological materials and elements make up for the rest of the total PM2.5, which are roughly twenty percent to one third on average. Ammonium sulfate forms in the atmosphere when oxides of sulfur (SOx) emitted from combustion sources react with ammonia. Geological material or dust is directly emitted PM2.5 and comes from dust suspended into the air in from traffic activities on roads or off roads, and soil from agricultural activities, etc. Elements are trace amounts of metal and ions found in the air, which include iron, silicon, aluminum, and chlorine, etc.

Since ammonium nitrate and carbonaceous aerosol are the two largest components of the PM2.5 in the Valley, their monthly pattern (Figure 10) largely follows that of the overall PM2.5 (Figure 7). Based on Figure 10, between 2020-2022, both ammonium nitrate and carbonaceous aerosol (specifically, organic carbon) peak at winter months. The peak of ammonium nitrate is the result of the cold, damp weather condition during the winter that favors the formation of ammonium nitrate in the Valley. The residential wood burning during the winter season contributes to the high levels of carbonaceous matters. Figure 11 illustrates the percentage contribution from each component to the total PM2.5 level in each month over 2020-2022. The combined contribution from ammonium nitrate and carbonaceous PM2.5 accounts for almost 90% of the total PM2.5 during winter. However, the ammonium nitrate levels during spring and summer are very low, and only accounts for 10% of the total PM2.5.

Figure 10: Seasonal trend of PM2.5 chemical components for 2020-2022 across the four sites in San Joaquin Valley.

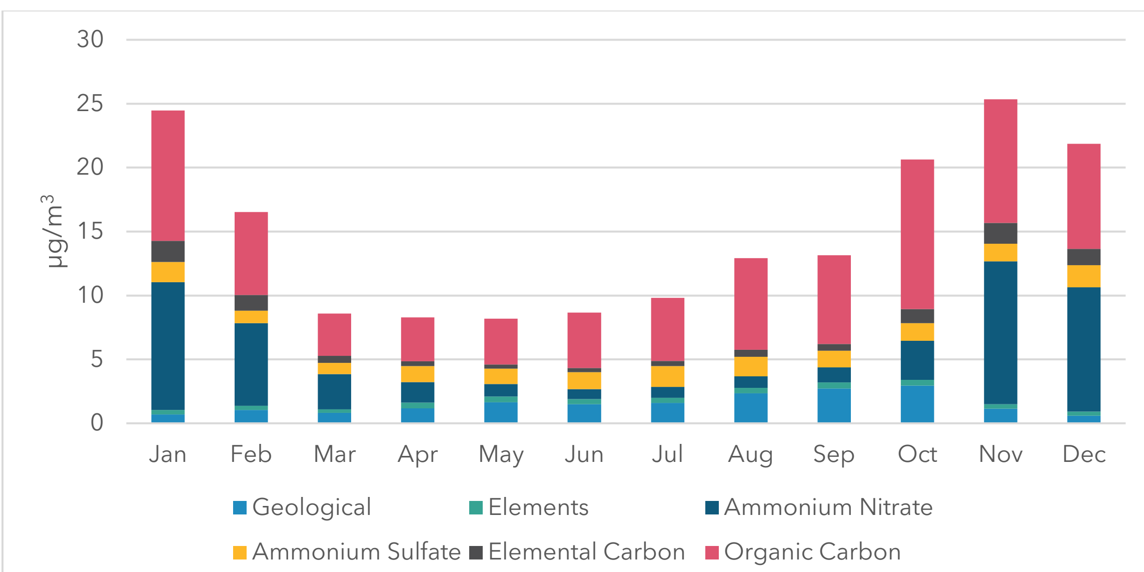
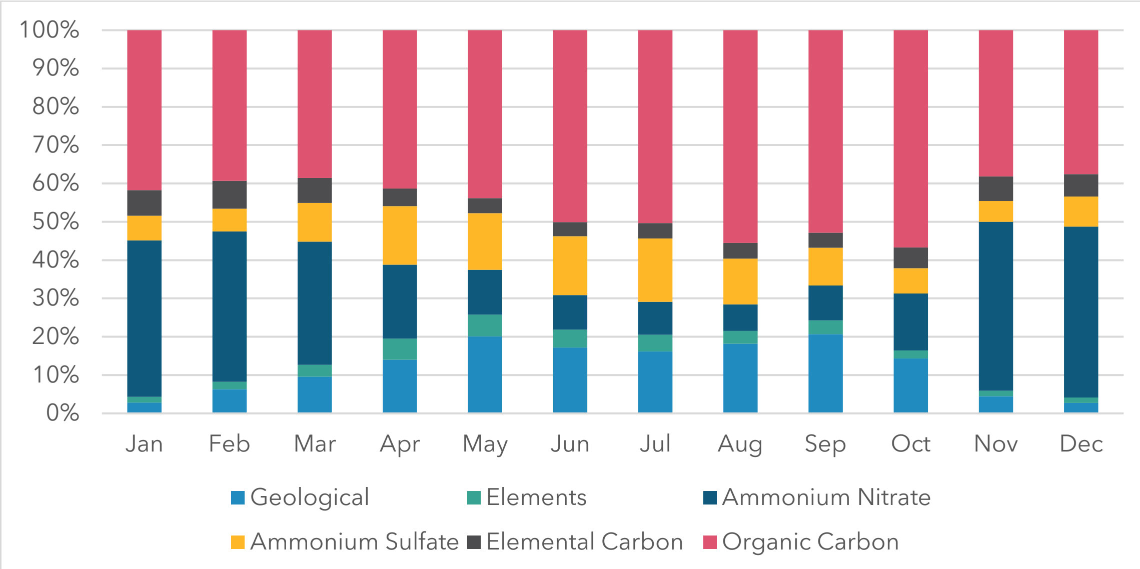
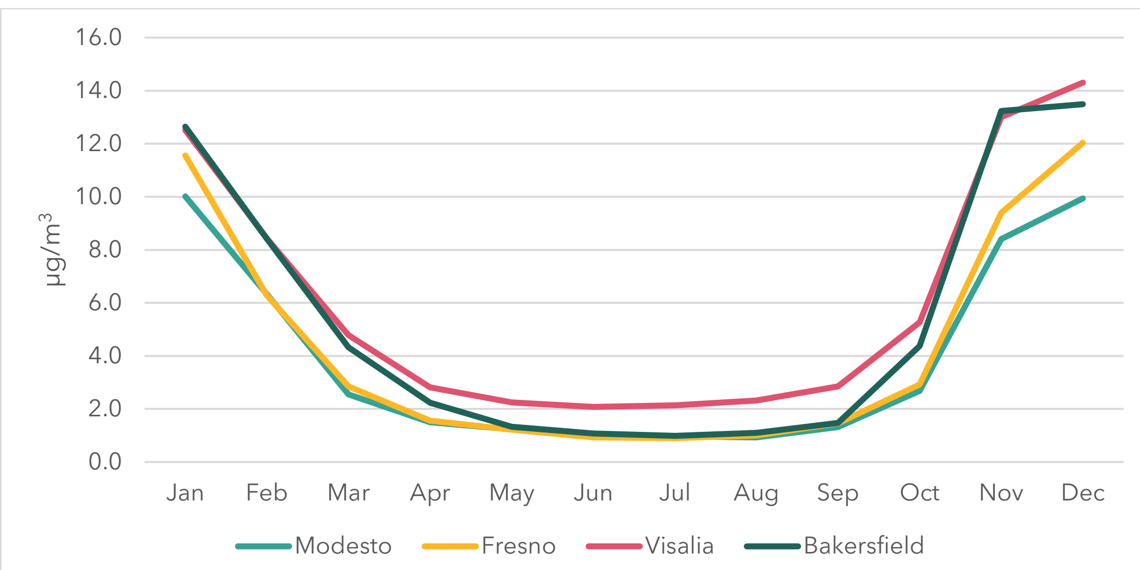


Figure 2: Seasonal trend of PM2.5 chemical components percentage contributions for 2020-2022 across the four sites in San Joaquin Valley.



The ammonium nitrate levels appear to be higher in the southern part of the Valley (Visalia and Bakersfield) than the northern and central Valley (Modesto and Fresno) and this is especially evident in the winter months, as is shown in Figure 12. This is likely a result of the northeast prevailing wind direction in the winter season.

Figure 32: Seasonal trend of ammonium nitrate levels at the four sites in San Joaquin Valley in 2020-2022.



V. Emission Sources in the Valley

To understand the emission sources in the Valley, it is important to establish the emission inventories that provide emission estimates for sources of primary PM2.5 and NOx.

It has been well established that the Valley is in a NOx-limited regime for ammonium nitrate formation. In this regime, the reduction in ammonia emissions has very limited effect in the reduction of ammonium nitrate formation. This is a result of the sharp decrease in NOx emissions in the Valley for the past two decades.[7] For this reason, the WOE analysis will focus on NOx emissions rather than ammonia emissions. The SOAs generated from the primary ROGs emission can potentially be a major contributor to organic carbon matter PM2.5 levels in the summer when values are low. However, it has been shown that anthropogenic ROG emissions contribute to a very small portion of the total PM2.5 level on an annual basis.[8,9] Primary PM2.5 emissions dominate the total organic carbon matter in the Valley. For these reasons, the WOE will focus on the emission sources and their reduction progress of primary NOx and primary PM2.5. The planning emission inventory is based on CARB's California Emissions Projection Analysis Model (CEPAM) for 2022 PM2.5 Plans (Version 1.00) for San Joaquin Valley with a baseline year of 2017.

Table 1 lists the 2022 anthropogenic emissions of NOx and primary PM2.5 in the three types and major categories in San Joquin Valley. Figure 13 illustrates the percentage breakdown of source types. NOx is dominated by mobile source emissions from both on-road and off-road vehicles. Primary PM2.5 emissions are dominated by areawide sources, notably from residential wood burning and farming operations.

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[7] More discussion on the historical trend of NOx in the latter sections.

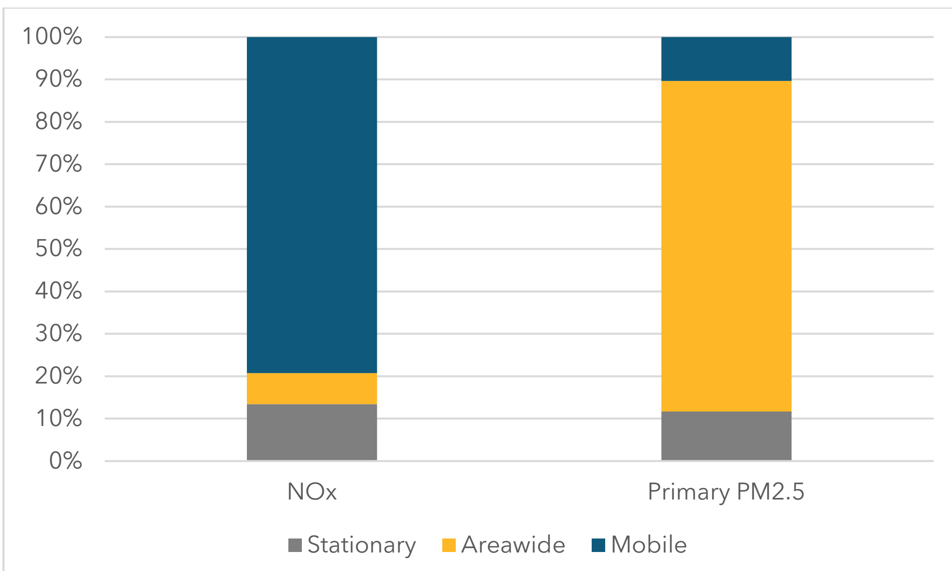
[8] Chen, J., Ying, Q., and Kleeman, M.J., 2010, Source apportionment of wintertime secondary organic aerosol during the California regional PM10/PM2.5 air quality study, Atmospheric Environment, 44(10), 1331-1340.

[9] Chen, J., Lu, J., Avise, J.C., DaMassa, J.A., Kleeman, M.J., and Kaduwela, A.P., 2014, Seasonal Modeling of PM2.5 in California's San Joaquin Valley, Atmospheric Environment, 92, 182-190.

Table 1: Anthropogenic emission inventory for NOx and PM2.5 in San Joaquin Valley in 2022 (tons per day).

Source Types and Categories	NOx	PM2.5
Areawide	11.7	49.4
Miscellaneous Processes	11.7	49.4
Mobile	126.1	6.6
On-Road Motor Vehicles	54.4	1.6
Other Mobile Sources	71.7	5.0
Stationary	21.3	7.4
Cleaning And Surface Coatings	0.0	0.4
Fuel Combustion	16.8	4.2
Industrial Processes	3.9	2.5
Petroleum Production and Marketing	0.3	0.1
Waste Disposal	0.3	0.2
Grand Total	159.1	63.3

Figure 4: Percentage contribution from anthropogenic stationary, areawide and mobile source types to the total NOx and primary PM2.5 emissions in San Joaquin Valley in 2022.



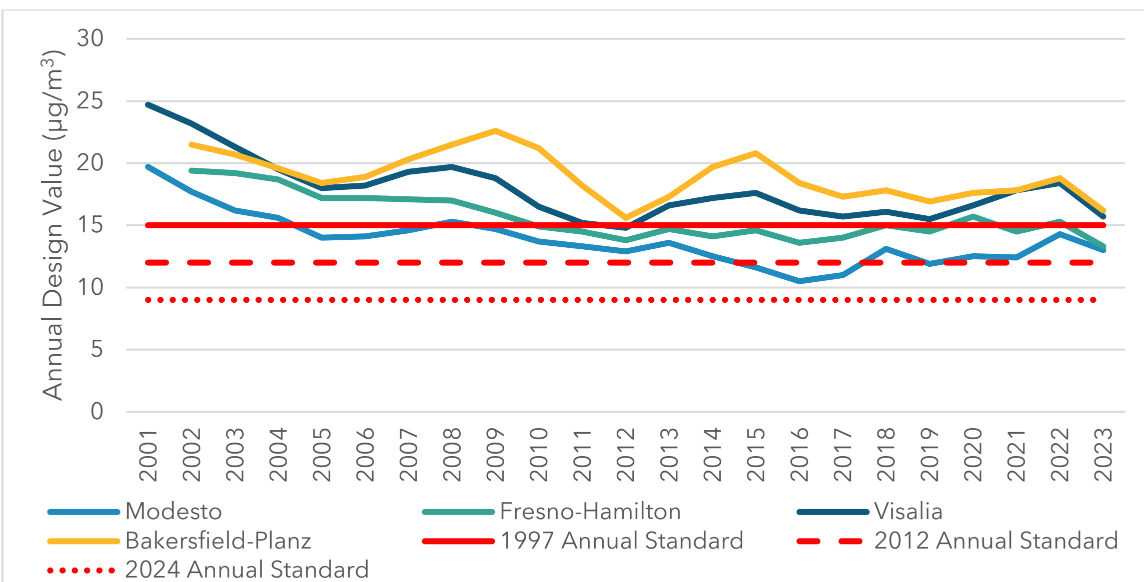
PM2.5 Air Quality and Emission Progress

I. PM2.5 Concentration Trends

A. Design Value Trends

The annual design value of PM2.5 reflects the three-year average condition of PM2.5 levels in the Valley. On an annual basis, PM2.5 air quality has improved over the last two decades. It is worth mentioning that the design values do not completely match those used in the modeling demonstration that incorporated design values of three years and data from five years. Figure 14 presents the trend of the annual design values in the four sites (Modesto, Fresno-Hamilton[10], Visalia and Bakersfield-Planz) that represent the northern, central, and southern regions of the Valley. The northern and central parts of the Valley are attaining the 1997 15.0 µg/m³ annual PM2.5 standard. The southern part of the Valley remains challenged for the 2020-2022 period, given that the 2020-2021 period had some of the worst wildfire seasons in the history of California plus a severe drought. But 2023 annual PM2.5 design values dropped significantly for the four sites and were in line with levels before the wildfire-impacted 2020-2022 period. Even with the impact from the wildfire and drought in recent years, the annual PM2.5 design values from the four sites remains lower than typical values before 2010.

Figure 5: PM2.5 annual design value trend in San Joaquin Valley (preliminary data for 2023)

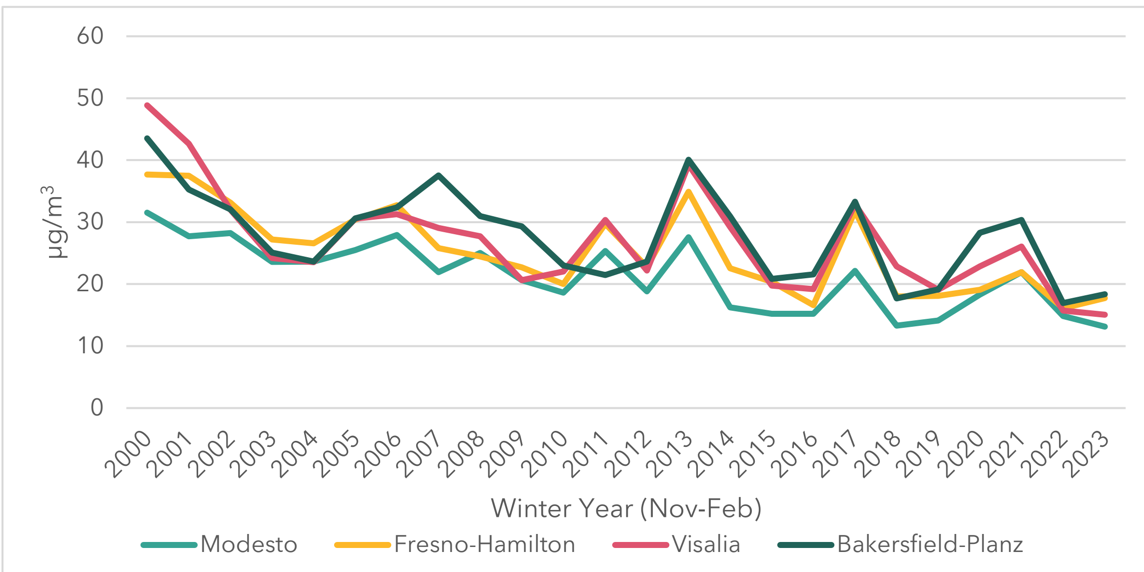


[10] Fresno-Hamilton (AQS ID 060195025) has the longest PM2.5 monitoring history among the sites in Fresno.

B. Winter PM2.5 Level Trends

The highest PM2.5 levels in the Valley typically occur during the winter months (November through February) due to the meteorological conditions that favor the production of ammonium nitrate and primary PM2.5 emissions from wood burning activities. Figure 15 shows the annual winter average PM2.5 levels for the past decades for the four sites.[11] The winter average values in this figure are not averaged over three years, so the fluctuation would appear more drastic than those observed in the figures of design values. It is obvious that the winter PM2.5 levels go through a cycle of high and low every few years. The winter PM2.5 levels of 2020 and 2021 were roughly 20-40% higher than that of 2019, 2022, and 2023,[12] depending on the specific sites. However, the overall trend for both the high and low winter years is going downwards, which is a good indication of the reduction of primary PM2.5 and PM precursor (NOx) during the winter season.

Figure 6: Winter average PM2.5 concentrations at four sites in San Joaquin Valley. (2022-2023 winter contains 2023-2024 preliminary data)



C. Summer PM2.5 Level Trends

PM2.5 levels in summer months (July to September) are lower than annual averages levels but are more sensitive to impacts from wildfires. Figure 16 shows the summer average PM2.5 levels from the four sites. The historic wildfire seasons in 2020 and 2021 created a sharp increase in the trend of summer PM2.5 levels at all the four sites. This is a clear indication of the severity and the size of the wildfire impact to the air quality of the Valley. After removing the wildfire days from the calculation for all years, which is shown in

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[11] A winter year is defined as the November and December of a certain year and the January and February of the following year.

[12] 2022 and 2023 winter PM2.5 data are partly from preliminary data sources. All 2023 PM2.5 data are from EPA AQS (acquired on 4/30/2024), while 2024 PM2.5 data are from CARB's AQMIS (acquired on 4/30/2024).

Figure 17, the summer PM2.5 levels in 2020-2021 align well with the rest of the years. Unlike the annual PM2.5 design values or the winter PM2.5 levels, there is no obvious downward trend in PM2.5 summer levels. This suggests that the reductions in winter emissions are the main driving factor of the reduction of the annual design values.

Figure 7: Summer average PM2.5 concentrations at four sites in San Joaquin Valley. (Preliminary data for 2023)

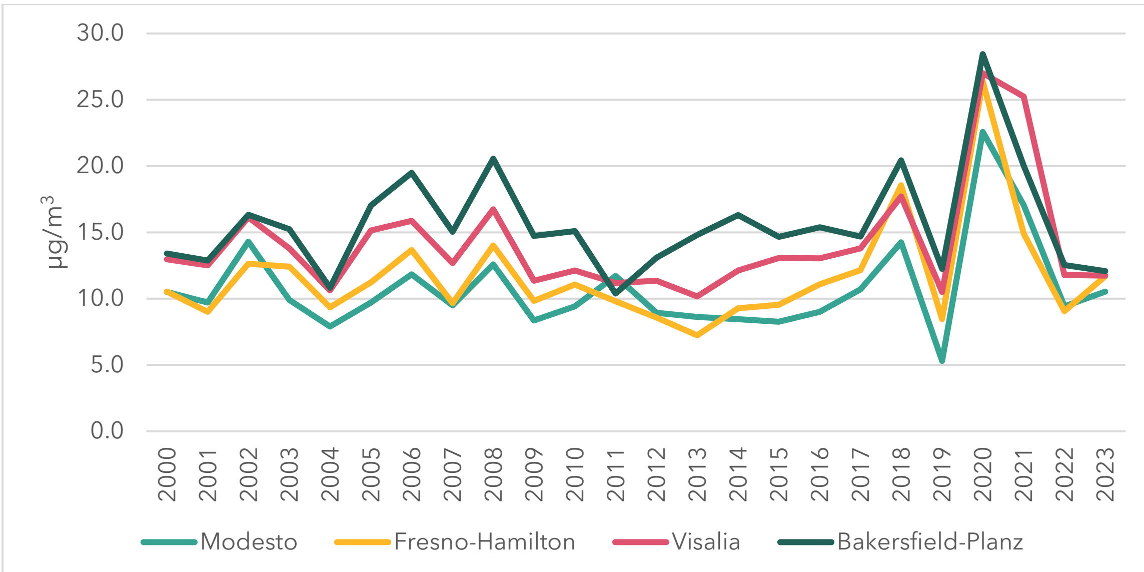
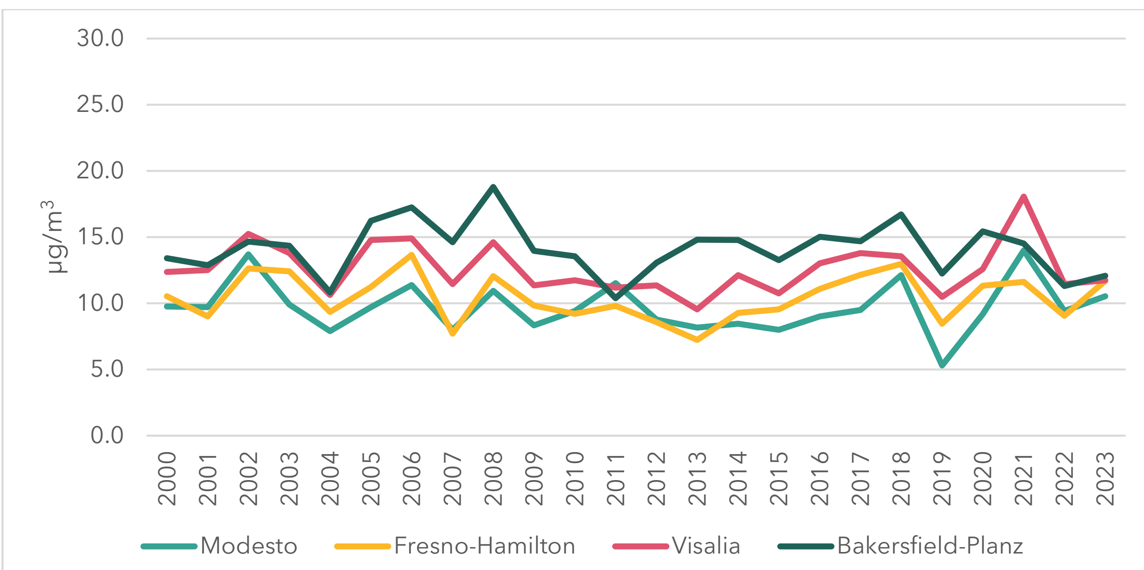


Figure 8: Summer average PM2.5 concentrations at four sites in San Joaquin Valley with wildfire days removed from calculation. (Preliminary data for 2023)



II. Chemical Composition Trends

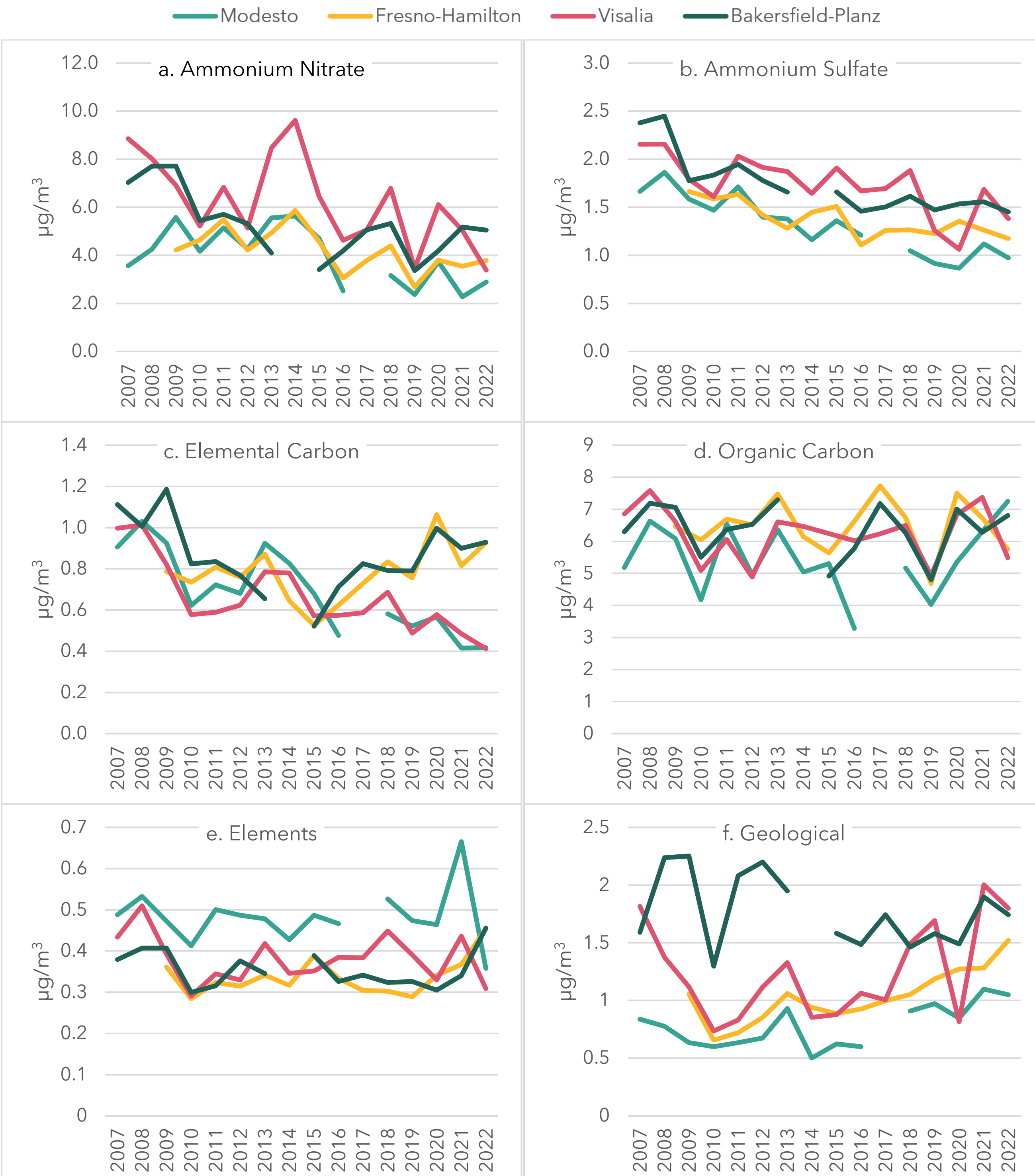
Figure 18 lists the trends of each PM2.5 chemical component for the four sites that featured speciated PM2.5 monitoring (Modesto, Fresno-Garland, Visalia, and Bakersfield-California). Ammonium nitrate (Figure 18a) and ammonium sulfate (Figure 18b) show the most obvious downward trend over the last two decades among the four monitoring locations. Comparing the three-year average level between 2010-2012 and 2020-2022, there were reductions in ammonium nitrate of around 12-22% for Fresno, Visalia, and Bakersfield and 35% for Modesto. The trend is similar for ammonium sulfate, which had around 18-25% reductions in Fresno, Visalia, and Bakersfield, and 35% in Modesto. The reductions in these two PM2.5 components are likely the main reasons for the overall downward trend of PM2.5 levels in the Valley.

The trends of elemental carbon levels show a divergence after 2016 (Figure 18c). Before 2016, the elemental carbon levels at the four locations all dropped around 30% for the previous ten years. The elemental carbon levels continued to drop in Modesto and Visalia, and the 2020-2022 level was, respectively, 31% and 17% lower than those in 2010-2012. However, the elemental carbon levels in Fresno and Bakersfield started to increase after 2016 and the 2020-2022 level was around 20% higher than those in 2010-2012. The increase in EC may be associated with a sampling method change along with wildfires.

Organic carbon (Figure 18d) is currently the biggest component of PM2.5 levels in the Valley since the ammonium nitrate level has been declining continuously while the organic carbon level has remained steady over the past two decades. Comparing the three-year average levels of 2010-2012 and 2020-2022, the organic carbon levels in Fresno and Bakersfield were similar, while the levels in Modesto and Visalia were 20% higher in 2020-2022. Unlike elemental carbon, there were no clear divergence in the trend among the sites after 2016. The historic wildfires in 2020-2021 had contributed to the high levels of organic carbon and may have masked the progress made in the reduction of primary PM2.5 emissions.

Elements (Figure 18e) and geological (Figure 18f) are relatively small components of PM2.5 in the Valley. The levels of both these components do not present a clear trend in the past two decades. The contribution of element PM2.5 is steady throughout the four sites. Modesto, which is typically the site with the lowest PM2.5 levels among the four sites, features the highest element PM2.5 among them. For geological PM2.5, some significant upward trend can be found in Modesto, Fresno, and Visalia, while the level in Bakersfield, though highest among all, is trending downward. The temporal and geographical trend for geological PM2.5 is the least revealing among all the PM2.5 components' trends.

Figure 9: PM2.5 chemical composition trends at four speciation sites in San Joaquin Valley.



Levoglucosan is a chemical tracker of wood burning emissions, and levoglucosan level monitoring was conducted at Modesto and Visalia sites until 2020. Figure 19 illustrates the trend in levoglucosan concentrations during wintertime (November to February), and there was a slight downward trend at both sites during the span of 2017-2020. No levoglucosan data were available for 2021 and 2022. Winter organic carbon levels and levoglucosan levels are positively correlated on an annual basis at both Visalia and Modesto (Figure 20), indicating that wood burning is an important contributor to winter PM2.5 levels.

Figure 1910: Wintertime (November to February) levoglucosan level trend for Modesto and Visalia.

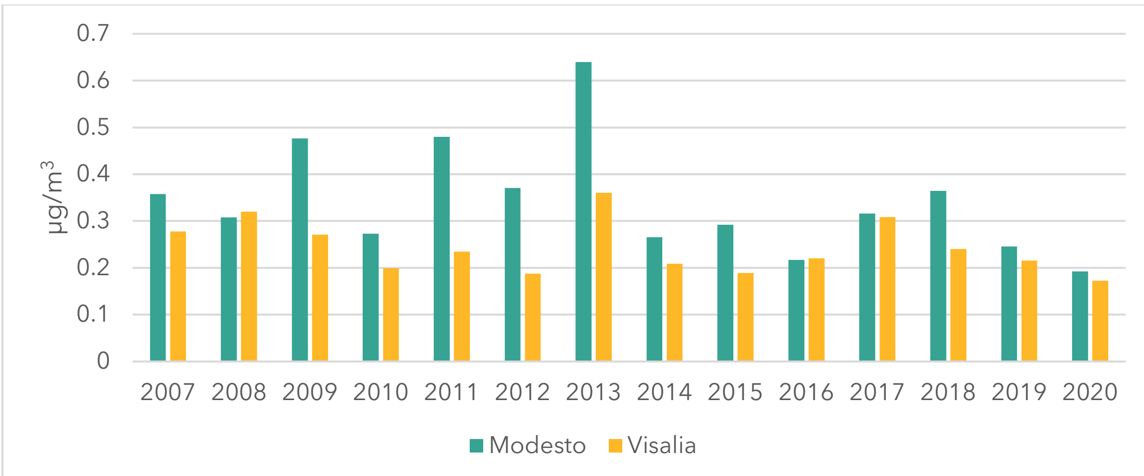
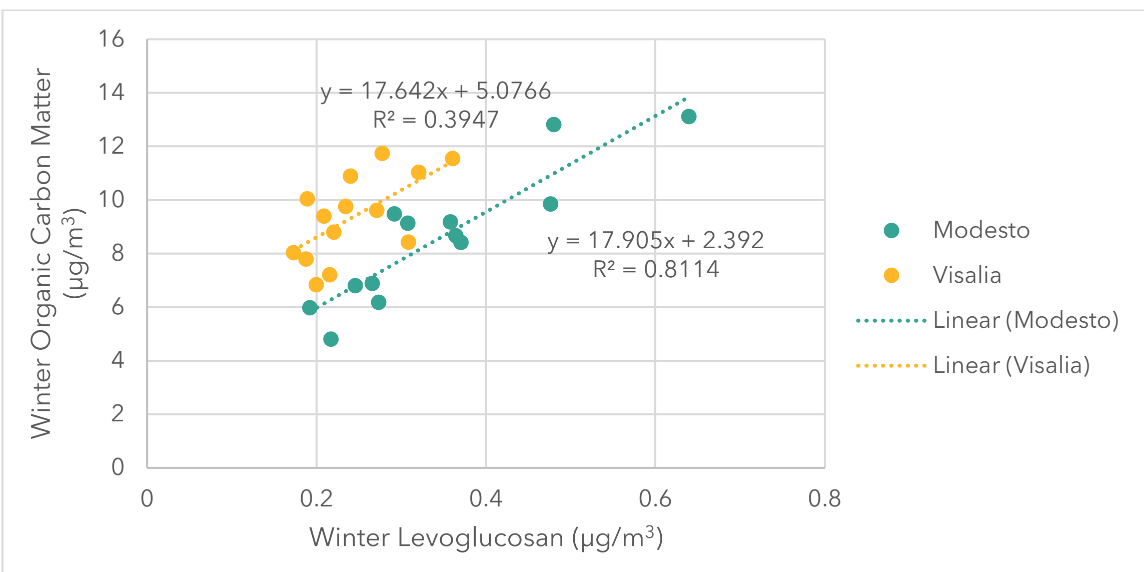


Figure 11: Wintertime levoglucosan and organic carbon correlations at Modesto and Visalia.

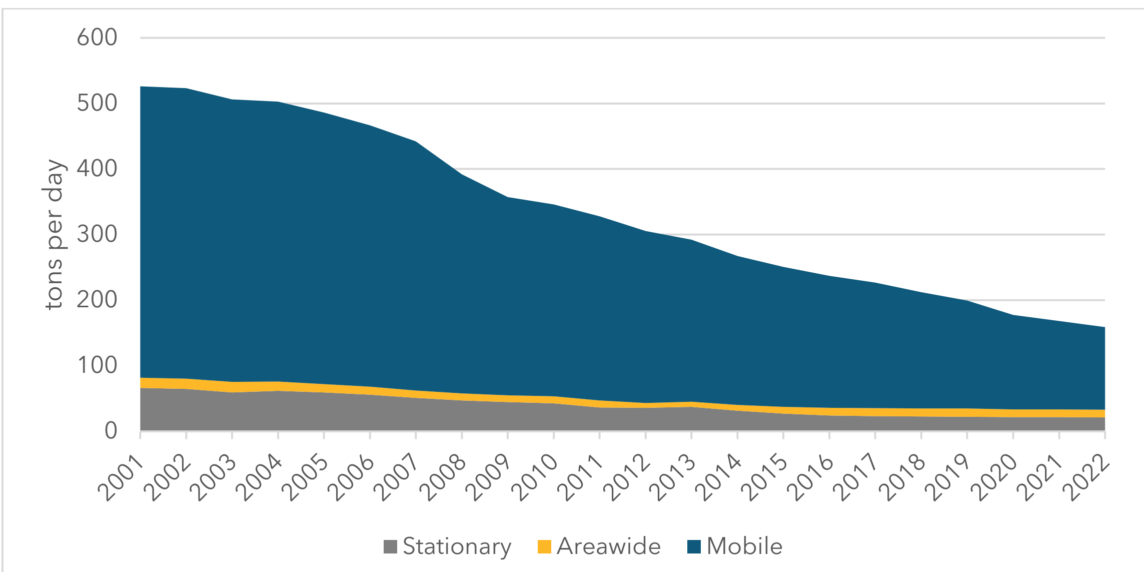


III. Emission Trends and Effectiveness of Emission Controls

Reductions in anthropogenic emissions of primary PM2.5 and the precursor NOx are key to reducing PM2.5 levels in the Valley. Model sensitivity simulations were performed for the 2024 PM2.5 Plan, following U.S. EPA guidance, to evaluate the impact of reducing emissions of different PM2.5 precursors on PM2.5 levels in the Valley. This modeling shows that NOx and directly emitted PM2.5 are significant precursors to PM2.5 in the Valley, while ROG, SOx, and ammonia are not considered significant. Thus, this section focuses on NOx and PM2.5 emissions, presenting the emission reduction progress made in the past two decades in the Valley. The planning emission inventory is based on CARB's California Emissions Projection Analysis Model (CEPAM) for 2022 PM2.5 Plans (Version 1.00) for San Joaquin Valley with a baseline year of 2017.

Figure 21 illustrates the reductions in NOx emissions in the past two decades. NOx emissions have decreased by 360 tpd or 70% from 2001 to 2022. Most of the reductions were from mobile sources, notably, from heavy-duty trucks, off-road farm equipment, and light-duty passenger vehicles. The reduction in both heavy-heavy-duty trucks and light-duty passenger vehicles were close to 90% of the 2001 level. These are direct results from the aggressive emission control programs by CARB. Stationary and areawide sources had a combined reduction of 60% from 2001 to 2022, due to regulations from the District.

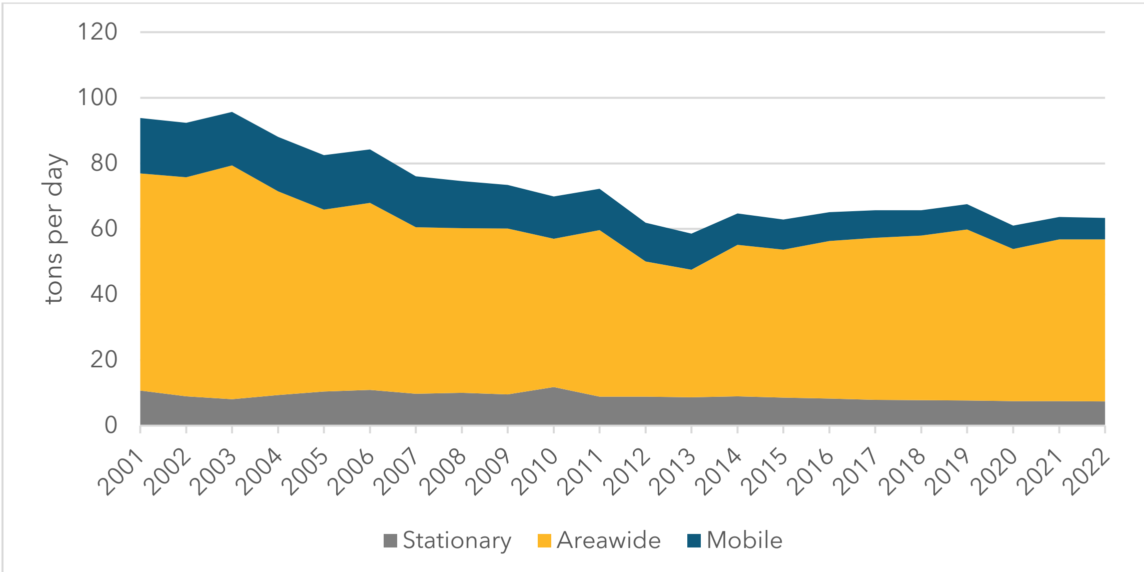
Figure 12: NOx emission trends in San Joaquin Valley.



Primary PM2.5 emissions decreased by 30 tpd or 31% in total from 2001 to 2022 (Figure 22). Most of the reduction occurred in areawide sources, notably, from residential fuel combustion, farming operations, agricultural burning, and fugitive windblown dust.

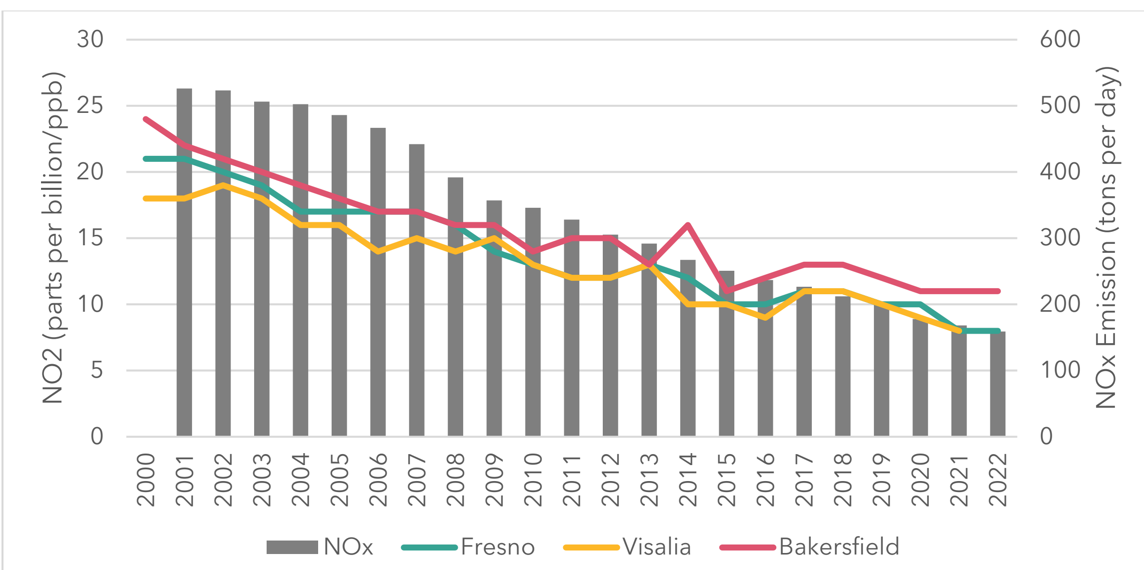
Heavy-heavy-duty vehicles also had a nearly 90% reduction in primary PM2.5 emission within the same period.

Figure 13: Primary PM2.5 emission trends in San Joaquin Valley.



The emissions reduction progress for the past two decades largely matched with the observed decreases in the ambient levels of ammonium nitrate and carbonaceous PM2.5 levels described in the Chemical Composition Trend section. Ambient monitoring of NO2 concentrations in the Valley also corroborates the NOx emissions reduction progress in the Valley (Figure 23).

Figure 23: Trends of Annual Average Ambient NO2 Concentrations and San Joaquin Valley Anthropogenic NOx Emissions.



This evidence strongly supports the conclusion that the lowered levels of PM2.5 in the Valley are direct results of the aggressive control measures and regulations effort in California. Ongoing implementation of CARB and District control programs has had substantial benefits improving air quality in the Valley and further emission reductions in the future are expected to provide continuing progress towards attaining the 12 μg/m3 PM2.5 standard.

Future Attainment Demonstration

I. Modeled Emission Inventories Projection

CARB's CEPAM estimates the projected emissions inventory for primary PM2.5 and NOx in the Valley for future years and attainment based on adopted and expected regulations on sources. These projected emission reductions are the keys of the continued improvement on ambient PM2.5 levels and the eventual attainment of the annual PM2.5 standard. Figure 24 illustrates the projected emissions inventories for NOx and primary PM2.5, while Table 2 provides the detailed emissions numbers for each source types and categories for selected years. The year of 2017 is the base year of the 2022 CEPAM that was constructed for this planning purpose, and the year 2030 is the attainment year for this round of SIP planning for San Joaquin Valley. The Clean Air Act requires a reasonable further progress year (2025) and the post-attainment reasonable further progress year (2031) for this section to demonstrate the emission reduction progress.

The expected reductions in mobile source emissions of NOx continue to be the main driving force of the emission reductions and the decreased level of ambient PM2.5 in San Joaquin Valley. Compared to 2017 levels, about 57% total reduction in NOx emissions are expected in the attainment year of 2030. For on-road vehicles, the reduction in NOx is roughly 86 tpd and for other mobile sources the reduction is roughly 40 tpd. Substantial NOx reductions are also expected in stationary sources and areawide sources.

A reduction of 15% in primary PM2.5 emissions in the Valley can be expected through 2030 compared to 2017, with most reductions in areawide sources.

Table 2a: NOx emission inventory projections and reductions from 2017 levels in San Joaquin Valley.

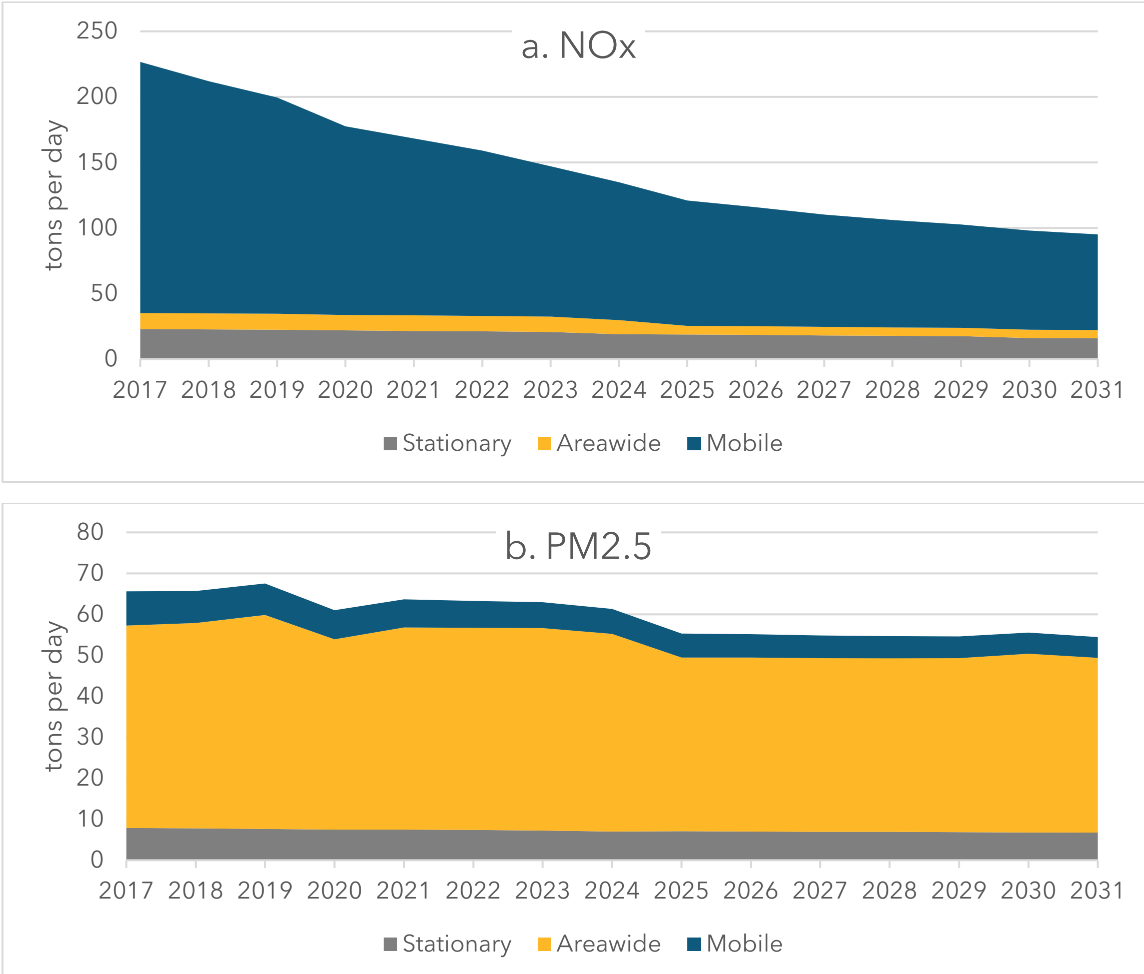
Source Type and Category	**2017**	**2025**	**2030**	**2031**
Stationary	23.0	18.8	16.2	16.0
Fuel Combustion	18.7	15.1	13.5	13.3
Waste Disposal	0.3	0.2	0.2	0.2
Cleaning and Surface Coatings	0.0	0.0	0.0	0.0
Petro. Production and Marketing	0.3	0.2	0.2	0.1
Industrial Processes	3.6	3.3	2.3	2.3
Areawide	12.3	6.5	6.3	6.2

Source Type and Category	2017	2025	2030	2031
Solvent Evaporation	0.0	0.0	0.0	0.0
Miscellaneous Processes	12.3	6.5	6.3	6.2
Mobile	191.4	95.7	75.7	73.0
On-Road Motor Vehicles	104.3	32.4	22.0	20.8
Other Mobile Sources	87.1	63.3	53.7	52.2
Total	226.7	121.1	98.2	95.2
Total Reduction from 2017		47%	57%	58%

Table 3b: PM2.5 emission inventory projections and reductions from 2017 levels in San Joaquin Valley.

Source Type and Category	2017	2025	2030	2031
Stationary	7.9	7.1	6.8	6.8
Fuel Combustion	4.7	4.0	3.6	3.6
Waste Disposal	0.2	0.2	0.2	0.2
Cleaning and Surface Coatings	0.3	0.4	0.4	0.4
Petro. Production and Marketing	0.1	0.1	0.1	0.1
Industrial Processes	2.6	2.5	2.5	2.6
Areawide	49.4	42.4	43.6	42.6
Solvent Evaporation	0.0	0.0	0.0	0.0
Miscellaneous Processes	49.4	42.4	43.6	42.6
Mobile	8.4	5.9	5.2	5.1
On-Road Motor Vehicles	2.7	1.4	1.3	1.3
Other Mobile Sources	5.7	4.5	3.9	3.8
Total	65.7	55.3	55.6	54.4
Total Reduction from 2017		16%	15%	17%

Figure 14: Emissions inventory projection for future years and attainment years.



II. Modeled PM2.5 Levels Projection

Photochemical modeling plays a crucial role in demonstrating attainment of the NAAQS based on projected future year emissions. The current modeling approach draws on the products of large-scale scientific studies as well as past PM2.5 SIPs in the region, collaboration among technical staff at state and local regulatory agencies, and from participation in technical and policy groups in the region. In this work, the Weather Research and Forecasting (WRF) model version 3.6 was utilized to generate the annual meteorological fields. The Community Multiscale Air Quality (CMAQ) Model version 5.3.3 with state-of-the science aerosol treatment was used for modeling annual PM2.5 in the Valley. Other model inputs and configuration, including the modeling domain definition, chemical mechanism, initial and boundary conditions, and emission processing can be found in Appendices in the 2024 PM2.5 Plan.

The U.S. EPA modeling guidance[13] outlines the approach for using models to predict future year annual PM2.5 DVs. The guidance recommends using model predictions in a "relative" rather than "absolute" sense. In this relative approach, the fractional change (or ratio) in PM2.5 concentration between the model future year and model baseline year are calculated for all valid monitors. These ratios are called relative response factors (RRFs). Since PM2.5 is comprised of different chemical species, which respond differently to changes in emissions of various pollutants, separate RRFs are calculated for the individual PM2.5 species. Baseline DVs are then projected to the future on a species-by-species basis, where the DV is separated into individual PM2.5 species and each species is multiplied by its corresponding RRF. The individual species are then summed to obtain the future year PM2.5 DV.

Based on analysis of recent years' ambient PM2.5 levels and meteorological conditions leading to elevated PM2.5 concentrations, the year 2017 was selected for baseline modeling calculations. In order to minimize the influence of year-to-year variability in demonstrating attainment, the U.S. EPA optionally allows the averaging of three design values, where one of the years is the baseline emissions inventory and modeling year. For the 2017 baseline design values in this demonstration, the annual design values of 2017, 2018, and 2019 are averaged and the years 2015-2019 are all incorporated with different weighting. The modeling demonstration projects the annual PM2.5 design value for both the base year of 2017 and the attainment year of 2030. Table 3 lists the result of the model for all sites in the Valley. All sites can attain the 12 $\mu g/m^3$, and Bakersfield-Planz remains the site with the highest design value (11.98 $\mu g/m^3$).

[13] U.S. EPA, 2018, Modeling Guidance for Demonstrating Attainment of Air Quality Goals for Ozone, PM2.5 and Regional Haze, available at *https://www.epa.gov/sites/default/files/2020-10/documents/o3-pm-rh-modeling_guidance-2018.pdf*

Table 4: Base (2017) and future year (2030) annual PM2.5 design values for San Joaquin Valley monitoring sites.

Site AQS ID	Name	2017 Base DV (µg/m³)	2030 Annual DV (µg/m³)
060290010	Bakersfield-Planz	16.97	11.98
060311004	Hanford	15.73	11.04
060290014	Bakersfield-Golden	15.52	10.82
061072003	Visalia	15.43	10.5
060290016	Bakersfield-California	15.12	10.52
060310004	Corcoran	14.95	10.9
060195025	Fresno-Hamilton	13.99	9.81
060190011	Fresno-Garland	13.69	9.49
060990006	Turlock	12.7	9.69
060195001	Clovis	12.69	8.99
060472510	Merced-Coffee Ave.	12.28	9.31
060771003	Stockton	12.21	10.16
060392010	Madera	12.11	8.75
060470003	Merced-M St.	11.73	8.73
060990005	Modesto	11.16	8.54
060772010	Manteca	10.37	8.38
060192009	Tranquility	8.19	6.37

Note that an eighteenth monitoring site, Fresno-Foundry, was sited after the base year and therefore was not be included in the modeled attainment demonstration. Since the monitor is sited near a roadway, it typically records PM2.5 values higher than the other monitors in Fresno (see Figures 3, 4, 7, and 8). However, this monitor is projected to attain the standard in 2030. PM2.5 levels at Fresno-Foundry correlate strongly with those at Fresno-Hamilton, so it is possible to approximate a 2030 design value for Fresno-Foundry by scaling the sites' design values for 2022 (with exceptional event data removed) to the 2030 attainment year. A 13.8 µg/m3 2022 design value at Fresno-Hamilton dropping to 9.81 µg/m3 in 2030 is a decrease of 28.9%. A 28.9% decrease in Fresno-Foundry's 15.6 µg/m3 2022 design value gives an estimated 2030 design value of 11.09 µg/m3, attaining the standard.

To evaluate the impact of reducing emissions of different PM2.5 precursors to PM2.5 DVs, a series of model sensitivity simulations were performed, for which anthropogenic emissions within the San Joaquin Valley were reduced by a certain percentage from the baseline emissions. Following U.S. EPA precursor demonstration guidance[14] as well as considering the Valley's control strategies, sensitivity runs involving 30% emission reductions were performed for NOx and direct PM2.5. For other precursors (i.e., ammonia, ROGs, and SOx),

[14] U.S. EPA. PM2.5 Precursor Demonstration Guidance. 30 May 2019. *https://www.epa.gov/sites/default/files/2019-05/documents/transmittal_memo_and_pm25_precursor_demo_guidance_5_30_19.pdf*

both 30% and 70% emission reductions were performed. In addition, sensitivity simulations were performed for base year 2017 and future year 2030. The key conclusion from the sensitivity runs is that in 2030, reductions of direct PM2.5 and NOx emissions will continue to have a significant impact on annual PM2.5 DVs, while reductions of ammonia, ROG, and SOx have a much smaller impact compared to that of direct PM2.5 and NOx.

Summary

Following U.S. EPA guidance, CARB staff employed multiple analytical methods in a WOE approach to support the modeled attainment demonstration for the 2024 PM2.5 Plan that predicts attainment of the PM2.5 annual standard in San Joaquin Valley. This WOE contains data-driven trends in air quality, chemical compositions of PM2.5, and emissions of direct PM2.5 and precursors and a summary of the modeled attainment demonstration. Together, these analyses show that the control strategy is effective and focused on the appropriate emissions sources to achieve PM2.5 emissions reductions. In addition, the WOE analyses show that the modeled attainment demonstration is reasonable in concluding the San Joaquin Valley will attain the 2012 federal annual PM2.5 standard by the attainment deadline of 2030.

Appendix 1: Monitoring sites information in San Joaquin Valley for 2020-2022 period.

Table A1: Monitoring sites name and AQS ID in San Joaquin Valley.

#	Name	Short Name	AQS ID
1	Bakersfield-410 E Planz Road	Bakersfield-Planz	060290016
2	Bakersfield-5558 California Avenue	Bakersfield-California	060290014
3	Bakersfield-Golden State Highway	Bakersfield-Golden	060290010
4	Clovis-N Villa Avenue	Clovis	060195001
5	Corcoran-Patterson Avenue	Corcoran	060310004
6	Fresno-2482 Foundry Park Avenue	Fresno-Foundry	060192016
7	Fresno-Garland	Fresno-Garland	060190011
8	Fresno-Hamilton and Winery	Fresno-Hamilton	060195025
9	Hanford-S Irwin Street	Hanford	060311004
10	Madera-28261 Avenue 14	Madera	060392010
11	Manteca-530 Fishback Rd	Manteca	060772010
12	Merced-2334 M Street	Merced-M St.	060472510
13	Merced-S Coffee Avenue	Merced-Coffee Ave.	060470003
14	Modesto-14th Street	Modesto	060990005
15	Stockton-Hazelton/University Park	Stockton	060771002, 060771003
16	Tranquility-32650 West Adams Avenue	Tranquility	060192009
17	Turlock-S Minaret Street	Turlock	060990006
18	Visalia - N. Church St./W. Ashland Avenue	Visalia	061072002, 061072003

Appendix 2: Data screen method for identifying wildfire days for exclusion.

1. Calculate monthly basin-wide average for July through September using data collected during 2016, 2017 and 2019. These three years are representative of California year of typical wildfire levels.

Basin	Month	Avg PM2.5 ($\mu g/m^3$)
SJV	8	11.6
SJV	7	9.0
SJV	9	11.0

2. PM2.5 data collected between July and September, which is greater than 2.5 times monthly average gets flagged as "Exceptional".
3. Using this screening method, 227 days were flagged with "EE" flag, which implies data impacted by wildfire.
4. In addition to data screened by comparison to the monthly average, PM2.5 concentrations over the 24-hr NAAQS collected during the Camp Fire, from November 11 to 20, 2018, were also flagged as "Exceptional".

Table A2: Number of days of wildfire days screened in San Joaquin Valley.

Row Labels	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Bakersfield-410 E Planz Road				3	2		3	4	1	4	2	2				3	2	1		5		11	7	1
Bakersfield-5558 California Avenue	1	1	1	6	1	1	1	2	4	10		1			9	1	3	2	3	19	1	28	9	2
Bakersfield-Golden State Highway	1			1					1		4						1			6		9	13	2
Clovis-N Villa Avenue									1	1		3	1	1	3	1	3	1	2	20		32	13	
Corcoran-Patterson Avenue									1	1	2	15							2	22		33	12	1
Fresno-1st Street	4		1	5		1	1		4	7		1												
Fresno-2482 Foundry Park Avenue																						35	13	
Fresno-Garland															2		1		2	22	1	29	13	
Fresno-Hamilton and Winery									1	1		1								7		11	10	
Hanford-S Irwin Street												4	2		3		1		2	19		33	12	
Madera-28261 Avenue 14												3	4	4	4				3	18		31	10	
Manteca-530 Fishback Rd															5		3		4	16		24	8	
Merced-2334 M Street				1					1										1	8		8	8	
Merced-S Coffee Avenue												1			2		1		4	23		26	9	
Modesto-14th Street	3	1		1				1	2	2			1	1	2		1		4	19		23	9	
Stockton-Hazelton Street	1			1						1		1			2		3		1	24		21	7	
Stockton-University Park																								
Tranquility-32650 West Adams Avenue																		1	3	18		24	9	
Turlock-S Minaret Street											1	2	1	1	2		4		4	28		24	8	
Visalia-N Church Street	1	1		1			1	2	2	3		1			1		2			5		12	23	
Visalia-W. Ashland Avenue																								2