Streamlining Air Quality Dispersion Modeling to Support Quantitative Particulate Matter Hot-Spot Analysis

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15. Abstract

This report is a compilation of work products developed for Caltrans under Task Order 12 to assist Caltrans District staff in conducting or overseeing conformity-related PM hot-spot assessments. The report includes descriptions of tools that simplify key aspects of the PM hot-spot analysis, case study analyses that inform analysts about modeling best practices and emerging issues, and practical information to help facilitate Caltrans project analysts in working with interagency consultation. Key components of this report include assessments of brake wear, tire wear, and road dust calculations in PM emissions modeling; descriptions of the EM4AQ tool and the ArcGIS Web Based Map; a case study on preparing meteorological data for PM hot-spot analyses; and AERMOD scenario analyses to better understand options for modeling depressed and elevated roadways. The report also contains information about using chemical transport modeling data to estimate future-year background PM concentrations, and a brief introduction to project-level PM mitigation concepts.

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Final Report

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Cover graphic illustrates the kind of vehicles and traffic that contribute to particulate matter (PM) hot spots, as well as forms of transportation that can help mitigate PM concentrations.

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Abstract

Background: Since December 2012, the U.S. Environmental Protection Agency (EPA) has required that certain transportation projects perform a quantitative particulate matter (PM) hot-spot assessment to inform transportation conformity determinations. The PM hot-spot assessment requires several complex work steps that include travel activity data processing, emissions modeling, dispersion modeling, and ambient PM data processing. Projects that fail the conformity test may require mitigation measures and additional analysis work. This report was developed to provide technical support for Caltrans District staff who conduct or oversee conformity-related PM hot-spot assessments, and provide tools and information to help streamline the process of completing PM hot-spot assessments.

Methods: Sonoma Technology, Inc., worked closely with Caltrans headquarters as a team to identify resources, develop tools, and address practical issues in conducting PM hot-spot assessments. To help streamline the process of conducting PM hot-spot analyses, the team reviewed updated EPA guidance documents, solicited and evaluated feedback from Caltrans staff, and evaluated Interagency Consultation comments for selected hot-spot analysis projects. The team also developed a new tool (EM4AQ) to prepare AERMOD-ready emissions inputs, updated the ArcGIS Web Map to support selecting representative PM background concentrations, and developed case studies and conducted analyses to highlight current and emerging issues in emissions and dispersion modeling in the PM hot-spot context. Additional resources developed include a case study illustrating how to prepare meteorological data for use in PM hot-spot analyses, a spreadsheet with examples for using CTM-based future-year background PM concentrations, and an overview of project-level PM mitigation concepts that may help reduce PM impacts in challenging project situations.

Results: This report is a compilation of work products developed for Caltrans under Task Order 12 to assist Caltrans District staff in conducting or overseeing conformity-related PM hot-spot assessments. The report includes descriptions of tools that simplify key aspects of the PM hot-spot analysis, case study analyses that inform analysts about modeling best practices and emerging issues, and practical information to help facilitate Caltrans project analysts in working with interagency consultation. Key components of this report include assessments of brake wear, tire wear, and road dust calculations in PM emissions modeling; descriptions of the EM4AQ tool and the ArcGIS Web Map; a case study on preparing meteorological data for PM hot-spot analyses; and AERMOD scenario analyses to better understand options for modeling depressed and elevated roadways. The report also contains information about using chemical transport modeling data to estimate future-year background PM concentrations, and a brief introduction to project-level PM mitigation concepts.

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1. Introduction

The U.S. Environmental Protection Agency (EPA) has required that quantitative particulate matter (PM) hot-spot analyses be conducted to assess near-road air quality impacts from certain transportation projects. This requirement became effective December 2012 and applies in areas designated by the EPA as being PM nonattainment and maintenance areas under the U.S. Clean Air Act. PM hot-spot analysis is a complex procedure that involves detailed emissions and dispersion modeling, substantial data processing, and extensive interagency consultation.

1.1 Purpose of This Report

This report was developed to support Caltrans District staff in conducting or overseeing conformity-related PM hot-spot assessments, and provide tools and information to help streamline the process of completing a PM hot-spot analysis. The report includes descriptions of tools that simplify complex aspects of the PM hot-spot analysis, case studies that inform analysts about modeling best practices and emerging issues, and practical information that support Caltrans project analysts in the interagency consultation process. Use of this document, in conjunction with other Caltrans technical documents such as the *Quantitative Particulate Matter Hot-Spot Analysis Best Practices Guidebook* (Bai et al., 2017) and the *Quantitative Particulate Matter Hot-Spot Analysis Guidance* (Bai et al., 2014), will help Caltrans project analysts save time and effort needed to plan and execute PM hot-spot analyses.

1.2 Report Organization

The overall procedure for conducting a PM hot-spot analysis consists of eight major work steps, plus interagency consultation and documentation that are required for all work steps. **Figure 1-1** provides a precedence diagram of the analysis work steps, along with relevant sections of this report for each work step. Figure 1-1 is intended as a roadmap to show how the report contents fit into the overall PM hot-spot analysis procedure. Some work steps in the flowchart also list relevant chapters from the *Best Practices Guidebook* (Bai et al., 2017).

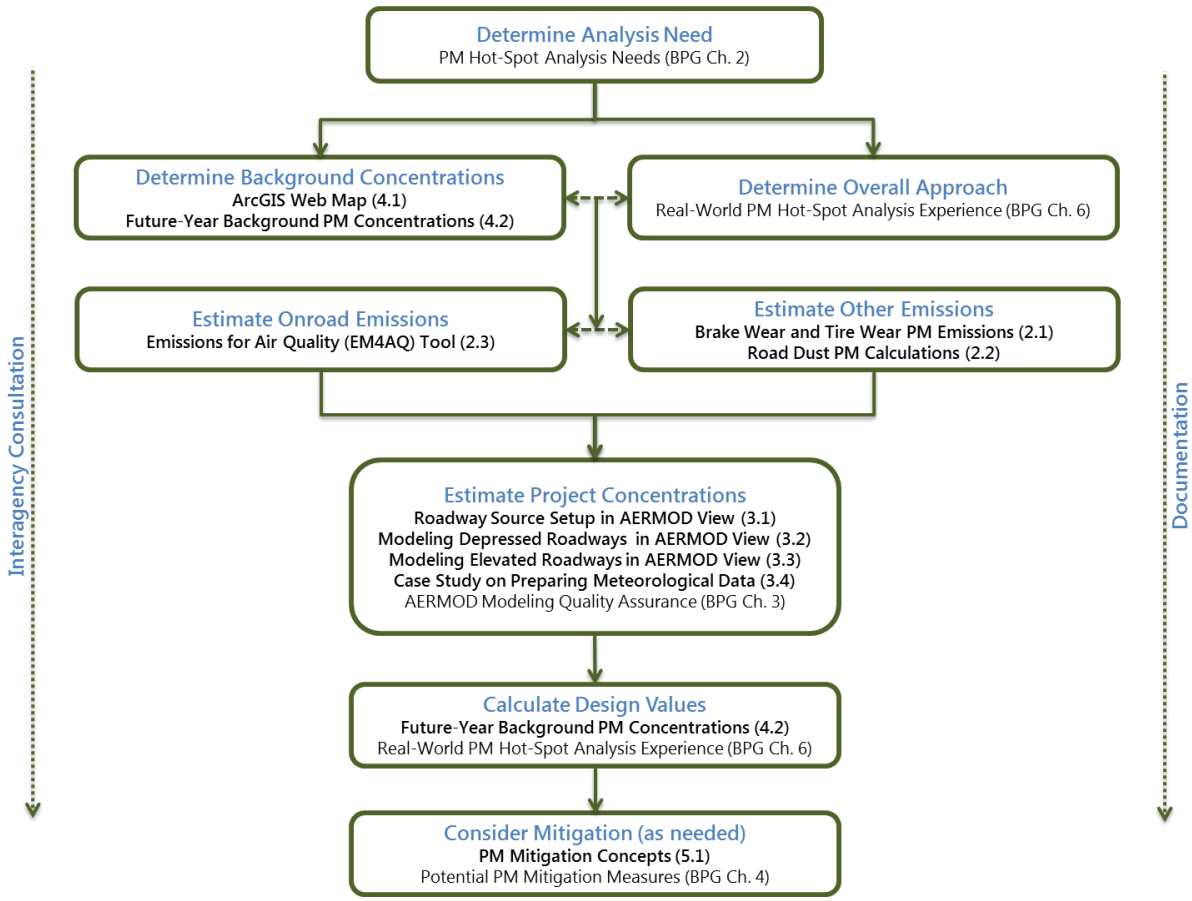


Figure 1-1. Precedence diagram for key work steps in a quantitative PM hot-spot analysis. Interagency consultation and documentation are required for all aspects of the analysis. Each work step contains relevant sections from this report (bold) and the *Best Practices Guidebook* (BPG) that provide information about the work step.

This report is organized into four main topic areas: emission modeling support (Chapter 2), dispersion modeling support (Chapter 3), background PM development (Chapter 4), and Project-Level PM Mitigation Concepts (Chapter 5). Chapter 2 explains brake and tire wear emission factors in the EMFAC and MOVES emissions models, identifies key parameters affecting road dust emissions, and prioritizes steps that can be taken to improve emissions modeling and road dust estimation for PM hot-spot analyses. The chapter also includes a description of the Emissions for Air Quality (EM4AQ) spreadsheet-based tool, which processes CT-EMFAC PM emission factors data and project-specific travel activity data to generate emissions input for AERMOD air quality modeling. Chapter 3 provides practical information and detailed instructions on configuring line-area and line-volume sources in AERMOD View, modeling scenario analyses of depressed and elevated roadways in AERMOD, and a case study illustrating how to prepare meteorological data for AERMOD use in PM hot-spot analyses. Chapter 4 focuses on tools and methods for developing background PM

concentrations; it contains a description of the PM Background ArcGIS Web Map and an introduction on the use of chemical transport model (CTM) data to develop future-year background PM concentrations. Finally, Chapter 5 contains a brief discussion of project-level mitigation concepts; practical mitigation measures that can be implemented at the project level and reduce near-road air quality impacts are still emerging.

2. Emissions Modeling Support

2.1 Assessment of Brake Wear and Tire Wear in Particulate Matter Emissions Modeling

2.1.1 Summary

With fleet turnover, exhaust particulate matter (PM) emissions are declining substantially; brake wear and, to a lesser extent, tire wear PM emissions are becoming a larger fraction of total on-road PM emissions. However, modeling of brake and tire wear emissions is based on limited literature, and much of it is old in comparison to recent work done to evaluate exhaust emissions. The two official models used to estimate on-road emissions—MOVES and EMFAC—treat brake and tire wear differently, with the result being that future-year EMFAC-based brake and tire wear estimates are higher than those produced by MOVES, especially for brake wear and for $PM_{2.5}$. Additionally, the vehicle fleet is evolving to include advanced technology vehicles (e.g., electric or hybrid vehicles with regenerative braking), and these vehicles are not represented in the data used to develop the brake and tire wear emissions factors included in current models. This section of Chapter 2 explains brake and tire wear emission factors in MOVES and EMFAC, and prioritizes steps that can be taken to improve emissions modeling. As a general observation, EMFAC brake wear emissions are far greater than tire wear emissions; therefore, it is a high priority to assess and improve brake-related emissions estimates. The work summarized here was motivated by the U.S. Environmental Protection Agency (EPA) mandate to model PM hot-spots; EPA's mandate requires quantification of brake and tire wear PM emissions. Major findings and recommendations include:

- **MOVES varies brake and tire wear emissions by travel speed; EMFAC does not**. At the project level, speed-based emission factors offer the opportunity to assess emissions differences among various project alternatives that modify forecasted travel volumes, fleet mix, and speeds. *Thus, the most important recommendation emerging from our assessment is to examine whether EMFAC-based emissions can be speed-adjusted using the technical information employed by EPA to develop MOVES speed-varying emissions factors*.

- **Electric and hybrid-electric vehicles employ regenerative braking systems to recharge batteries; qualitatively, these systems are expected to reduce the wear rate of brake pads**. Neither MOVES nor EMFAC takes into consideration how regenerative braking affects brake wear emissions. The importance of this issue increases over time, since the vehicle fleet is forecasted to include a greater fraction of advanced technology vehicles in coming years. *Thus, there is an important need to quantitatively adjust EMFAC-based brake-wear emissions rates to account for forecasted regenerative braking systems use*.

- **Numerous other factors can affect brake or tire wear emissions that are not fully characterized by either MOVES or EMFAC**. However, collectively these factors are lower priority issues because they are likely to account for only a small fraction of overall PM emissions or have minimal impact on build vs. no-build project comparisons. Examples include federal requirements to reduce the stopping distance of trucks and the growing use of lower rolling resistance tires. *Although various factors introduce uncertainty into the emissions modeling process, they are less important to address than brake wear emissions variation by travel speed and the impact from regenerative braking systems*.

2.1.2 Introduction

This purpose of Chapter 2.1 is to prioritize ways to improve how brake and tire wear PM emissions are estimated in California. This work was motivated by the EPA requirement to complete quantitative PM hot-spot analyses for selected transportation projects. PM hot-spot analysis results, particularly for analysis years of 2020 and beyond, reflect the growing importance of brake and tire wear as a fraction of total on-road vehicle PM emissions. However, there are important shortcomings in the way that brake wear and tire wear emissions are currently estimated, due in part to issues such as the introduction of advanced technology vehicles and the use of outdated emissions data. In addition, brake wear and tire wear modeling techniques were originally developed to support regional emissions analysis work and have important limitations (e.g., they are not sufficiently sensitive to reflect emissions variations by vehicle type and travel speed) when applied to transportation project-level assessment. Given these shortcomings, we developed this document to help Caltrans better understand how brake and tire wear emissions are estimated, and what steps can be taken to improve those estimates.

Following this introduction, the remainder of this document is organized to include

- Statewide on-road PM emissions over time, by emissions source
- An overview of brake and tire wear modeling by MOVES and EMFAC, focused on
  - Data sources used to create emission factors
  - Assumptions embedded in each model regarding brake and tire wear emissions
  - An illustration of MOVES and EMFAC output differences, using hypothetical cases
- Anticipated changes in future brake and tire wear emissions due to regulations and advances in vehicle technology
- Overall findings and recommendations to assess and improve emissions estimations

2.1.3 Statewide On-Road PM Emissions Over Time, by Emissions Source

On-road mobile source emissions are a major contributor to PM emissions in urban areas. Motor vehicles emit PM through combustion exhaust, brake wear, tire wear, and the suspension or

resuspension of road dust. PM exhaust emissions have historically dominated mobile source inventories. However, federal emissions standards have dramatically reduced exhaust emissions over time, while other forms of PM emissions have remained largely unregulated. Figure 2-1 illustrates these changes for two regulatory models: MOVES2014a and EMFAC2014 v1.0.7 (hereafter referred to as MOVES and EMFAC). As shown in Figure 2-1, in 2020 and beyond, brake wear and tire wear emissions will account for a much larger proportion than exhaust emissions in the California statewide on-road vehicle-based PM emissions; the modeled statewide total brake wear and tire wear emissions increase by year due to projected continuous growth in travel activities (i.e., vehicle miles traveled).

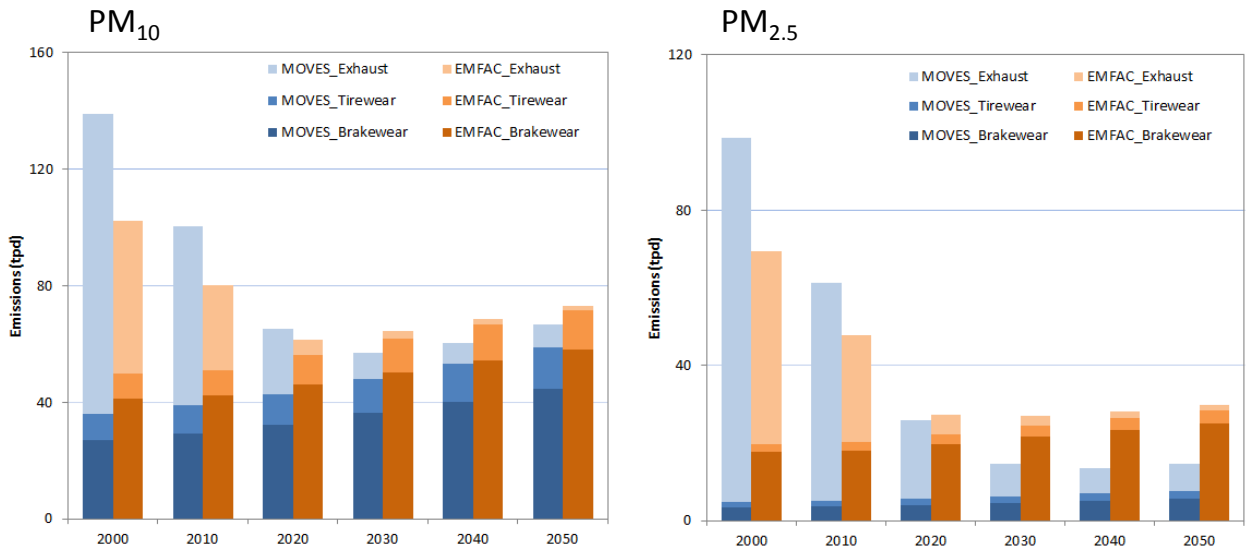


Figure 2-1. Comparison of MOVES and EMFAC emissions models for California statewide annual average daily emissions for PM_{10} and $PM_{2.5}$.

At the project level, quantitative PM hot-spot analyses rely on detailed PM modeling that includes brake wear and tire wear emissions as well as exhaust emissions (U.S. Environmental Protection Agency, 2015c). However, the modeling approaches and data used for estimating brake wear and tire wear emissions have not been as extensively researched and refined as exhaust emissions, especially in EMFAC. A recent study with modeled running exhaust, brake wear, and tire wear emissions for a hypothetical highway project suggested that brake wear and tire wear emissions from EMFAC were higher than those generated by MOVES; fleet turnover effects were found to sharply reduce project-level exhaust emissions with limited variation in brake wear and tire wear emissions by analysis year (Reid et al., 2016a). There is a growing need to assess brake wear and tire wear emissions modeling, evaluate how brake wear and tire wear emissions may change with future changes to the vehicle fleet, and identify and prioritize opportunities to improve brake wear and tire wear estimation.

2.1.4 Brake Wear and Tire Wear Modeling: MOVES vs. EMFAC

Both MOVES and EMFAC model brake wear and tire wear as two separate PM emission processes. However, MOVES and EMFAC emission rates for brake wear and tire wear are different, since they are based on different data sources, modeling assumptions, and calculation methods. Using light-duty vehicles (LDVs) and heavy-duty trucks (HDTs) as examples, this section illustrates MOVES and EMFAC differences. The discussion separately addresses brake and tire wear. In both discussions, the text refers to "base" emission rates. Base emission rates are specific to vehicle types and operations in MOVES, and only to vehicle types in EMFAC. For example, MOVES includes base brake wear emissions rates specific to LDVs operating in a moderate speed coasting mode with speed ranging from 25 mph to 50 mph. Overall, or composite emissions rates, are derived by weighting and aggregating base rates to appropriately reflect the fraction of vehicle types and operating modes that make up overall fleet travel activities.

Brake Wear Modeling Differences Between MOVES and EMFAC

1. Data Sources

The data sources used for developing the base brake wear emission rates in MOVES and EMFAC are limited in comparison to the many studies used to support exhaust emissions rate development. Table 2-1 summarizes the studies used to support brake wear emissions development; these studies derived data in several ways, such as through the use of dynamometers or wind tunnels to obtain PM measurements. Virtually all of these studies date from 1999 to 2004 (U.S. Environmental Protection Agency, 2014a; California Air Resources Board, 2011).

Two studies in particular were used to develop brake wear emissions for both MOVES and EMFAC: work completed by Garg et al. (2000) and Sanders et al. (2003). Although MOVES and EMFAC relied on the same studies, the two models produce different base brake wear emission rates (see sample data in Tables 2-2 and 2-3). Differences are due to varying assumptions and calculation methods. In MOVES, base brake wear emission rates are quantified as grams per hour and vary by vehicle type (i.e., regulatory class) and vehicle operating mode (e.g., vehicle speed, acceleration/deceleration modes). In EMFAC, base brake wear emission rates are quantified at the per-mile level and vary only by vehicle type and do not change by vehicle speed. Note that the lack of a speed-adjusted emission rate in EMFAC poses significant challenges for project-level PM hot-spot analysis, since EMFAC lacks the ability to assess emissions changes due to changes in congestion (travel speed). In both MOVES and EMFAC, the base brake wear emission rates are independent of fuel type, road type, calendar year, model year, and meteorology (e.g., temperature and relative humidity). One exception is urban buses in EMFAC; their base rates vary by fuel type as shown in Table 2-3. Both models suggest that the highest brake wear emission rates are associated with buses and heavy duty vehicles, based on

the assumption that use of these vehicles typically involves more braking applications and requires more brake friction to stop.[1]

Table 2-1. Data sources for brake wear emission rates in MOVES and EMFAC.

Data Source	MOVES	EMFAC
(Garg et al., 2000)	Used for developing base $PM_{2.5}$ brake wear emission rates (grams per hour) for LDV only.	Used for developing base total PM emission rates (grams per brake application) for all vehicle types.
(Sanders et al., 2003)		
(Luhana et al., 2004)	Used to scale LDV emission factors to produce brake wear emission rates for heavy-duty vehicles.	Not used.
(Abu-Allaban et al., 2003)		
(Westerlund, 2001)		
(Rauterberg-Wulff, 1999)		
(Carbotech, 1999)		
(California Air Resources Board, 2011)	Not used.	Used for estimating frequency and intensity of braking activities per vehicle mile for different vehicle types.

Table 2-2. Examples of MOVES base brake wear emission rates (g/hr) for $PM_{2.5}$ (U.S. Environmental Protection Agency, 2014a).

Operating Mode[a]	Braking	Idling	Low Speed Coasting	Moderate Speed Coasting	Cruise/ Acceleration
Light-duty vehicle (LDV), g/hr	0.55846	0.02447	0.54600	0.35896	0.06440
Medium heavy-duty truck (MHDT), g/hr	2.09000	0.06604	1.90190	1.51525	0.25289
Heavy heavy-duty truck (HHDT), g/hr	4.16000	0.06656	4.16000	2.66656	0.28288

[a]MOVES assumes some brake use in each of the operating modes listed; for example, the "idling" mode is assumed to include some fraction of time that involves brake use, and therefore idling results in 0.02447 g/hr of brake wear $PM_{2.5}$ emissions for light-duty vehicles.

[1] An interesting difference between MOVES and EMFAC involves medium heavy-duty trucks (MDHTs) vs. heavy heavy-duty trucks (HHDTs). Unlike MOVES, where emission rates of MDHTs are lower than the rates for HHDTs, EMFAC brake wear emission rates for MHDTs are higher than the rates for HHDTs. This is because EMFAC includes an assumption of more per-mile brake applications for MDHTs than for HHDTs (i.e., 3 vs. 1.2).

Table 2-3. Examples of base brake wear $PM_{2.5}$ emission rates in EMFAC (California Air Resources Board, 2015b).

Vehicle Type	Emission Rate (g/mile)
Light-duty vehicle (LDV), light-duty truck 1 (LDT1 or T1) and 2 (LDT2 or T2), medium-duty vehicle (MDV or T3)	0.01575
Light heavy-duty truck 1 (LHD1 or T4)	0.03276
Light heavy-duty truck 2 (LHD2 or T5)	0.03822
Medium heavy-duty truck (MHDT or T6), motor home, urban bus - gasoline, and other buses	0.05586
Heavy heavy-duty truck (HHDT or T7)	0.02646
Urban bus (UBUS) - diesel/natural gas	0.36078
School bus (SBUS)	0.31920
Motorcycle (MCY)	0.00504

2. Modeling Assumptions

A side-by-side comparison of key modeling assumptions between MOVES and EMFAC is presented in Table 2-4. The MOVES calculation approach for brake wear emissions is based on $PM_{2.5}$ measurements for LDVs for specific vehicle operations; these are then adjusted to estimate brake wear emissions for other vehicle types and for PM_{10}. In contrast, the EMFAC approach is based on total PM break wear data (representing PM_{30}) that are associated with an overall average trip; the PM_{30} data are then scaled to estimate brake wear emissions for PM_{10} and $PM_{2.5}$. MOVES and EMFAC involve different assumptions regarding brake pad materials, braking activities per vehicle, and brake types.

Table 2-4. MOVES and EMFAC modeling assumptions for base brake wear emission rates.

Components	MOVES	EMFAC
Base pollutant	$PM_{2.5}$	PM_{30}
Unit	Gram per hour	Gram per mile
Variation	By vehicle type and operating mode	By vehicle type
Testing drive cycles for braking activity	A single Federal Test Procedure (FTP) cycle	Multiple drive cycles for different vehicle types (e.g., for light-duty vehicles, heavy-duty trucks, and buses)
Brake pad materials	Assumed equal mix of three brake types (low-metallic, semi-metallic, non-asbestos organic)	Assumed vehicle type-specific mix of three brake types
Brake number & type	Assumed two front disc brakes and two rear drum brakes for LDVs	Varies by vehicle type: four disc brakes for LDVs and MDVs; two front discs, four tractor drums, and four trailer drums for HHDTs; two discs for motorcycles; and two front discs and two rear drums for other vehicle types
Airborne dust fraction	60%	50%
PM_{10} to $PM_{2.5}$ ratio[a]	8	2.333
Basic modeling method	Regression model between $PM_{2.5}$ rates and vehicle deceleration rates; distribution of braking activity for each deceleration bin based on real-world instrumented vehicle studies conducted in Los Angeles and Kansas City	Regression model between brake emission rates and wheel loads (varies by wheel type and vehicle gross weight) for different brake materials, brake types, and initial braking speeds (assumed one average speed specific to each vehicle type).
Aggregation of emission rates	Average brake emission rates (per hour) for different operating modes for LDVs; adjusted for other vehicle types (with different numbers of brakes and braking events) using scaling factors and linear interpolation	Average brake emission rates (per mile) based on different braking attributes (e.g., type of brake application, number of brakes, and braking frequency) for each vehicle type

[a]The MOVES PM_{10} to $PM_{2.5}$ ratio is based on more recent information (2003 data) than the information used to support the ratio in EMFAC (pre-2000 data) (Sanders et al., 2003; California Air Resources Board, 2010).

3. Illustration of Brake Wear Modeling Differences with a Hypothetical Case

To compare brake wear emissions generated from MOVES and EMFAC, we conducted a series of modeling scenarios based on a hypothetical road in Fresno, California. The test case included the following parameters:

- Geographic area: Fresno County, California

- Analysis years: 2000, 2005, 2010, 2015, 2020, 2025, 2030, 2035, 2040, 2045, and 2050
- Modeling period: January weekday
- Brake wear emissions unit: gram per mile (by average speed bin)
- Vehicle age distribution: EMFAC2014 default for Fresno County
- Vehicle type: different vehicle types in MOVES and EMFAC, mapped using vehicle class definition and weight information (see Table 2-5)

Table 2-5. MOVES and EMFAC vehicle types mapping.

EMFAC			MOVES		
Vehicle Type	**Definition**	**Weight Class (lb)**	**Vehicle Type**	**Definition**	**Weight Class (lb)**
LDV	Passenger cars	All	LDV	Light-duty Vehicles	All
LDT1	Light-duty trucks	0-3750	LDT	Light-duty Trucks	All
LDT2	Light-duty trucks	3751-5750			
MDV	Medium-duty trucks	5751-8500			
LHDT1	Light heavy-duty trucks	8501-10000	LHD1	Class 2b trucks with two axles and four tires	8501-10000
LHDT2	Light heavy-duty trucks	10001-14000	LHD2	Class 2b trucks with two axles and at least six tires or Class 3 trucks	8501-14000
MHDT	Medium heavy-duty trucks	14001-33000	LHD3	Class 4 and 5 trucks	14000-19500
			MHD	Class 6 and 7 trucks	19500-33000
HHDT	Heavy heavy-duty trucks	33001+	HHD	Class 8a and 8b trucks	33001+
OBUS	Other buses	All	N/A	N/A	N/A
UBUS	Urban buses	All	UB	Urban bus	All
MCY	Motorcycles	All	MC	Motorcycles	All
SBUS	School buses	All	N/A	N/A	N/A
MH	Motor homes	All	N/A	N/A	N/A

Using light-duty vehicles and heavy heavy-duty trucks as examples, Figures 2-2 and 2-3 present the PM_{10} and $PM_{2.5}$ brake wear emission rates from MOVES and EMFAC. Note that MOVES brake wear emission rates vary by speed. In effect, the MOVES model embeds assumptions that per-mile brake wear emissions are lower when vehicle speed is higher, due to some combination of fewer braking and/or deceleration mode activities at higher speeds.[2] In contrast, EMFAC brake wear emission rates are constant across all speeds for a specific vehicle type. The EMFAC speed-constant rate is within the range of the speed-variable rates from MOVES. For example, the EMFAC LDVs brake wear emission rates are similar to the MOVES rates associated with the 30 mph bin and 10 mph bin for PM_{10} and $PM_{2.5}$, respectively. Both MOVES and EMFAC show that heavy-duty vehicles have much larger g/mi brake wear emissions than light-duty vehicles.

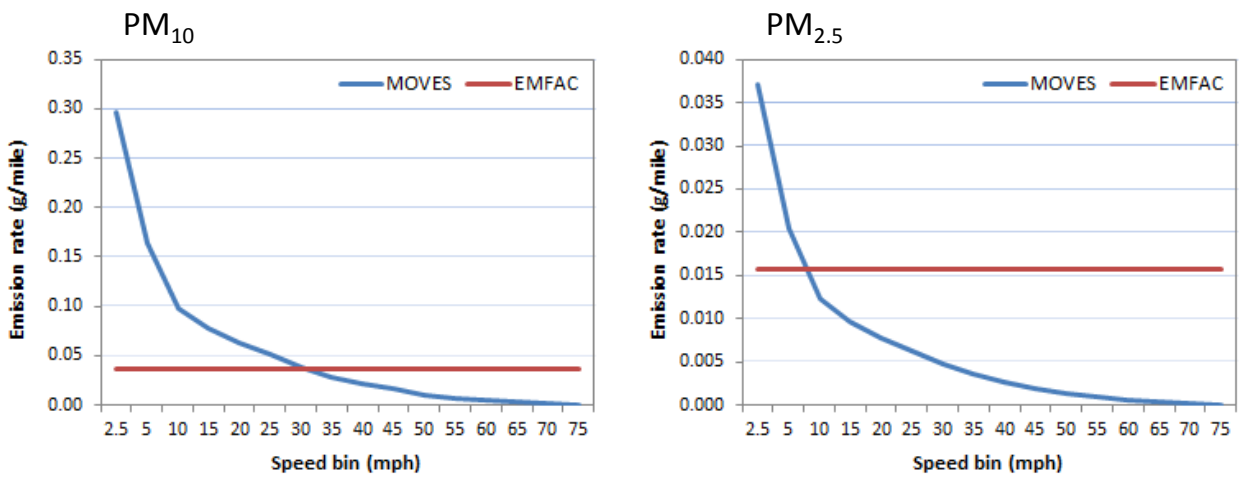


Figure 2-2. MOVES and EMFAC brake wear PM_{10} and $PM_{2.5}$ emission rates for light-duty vehicles.

[2] In general, MOVES brake wear emission rates decrease with increased vehicle speeds. However, for HHDTs, MOVES g/mi brake wear emission rates for the 2.5 mph speed bin appear lower than those for the 5 mph bin. EPA's technical staff confirmed that, for heavy-duty vehicles, MOVES incorporated idling activities (with lower brake wear emissions) within the 2.5 mph bin, which result in the lower average brake wear emission rates observed for this speed bin (personal communication with EPA's MOVES Team on February 9, 2016).

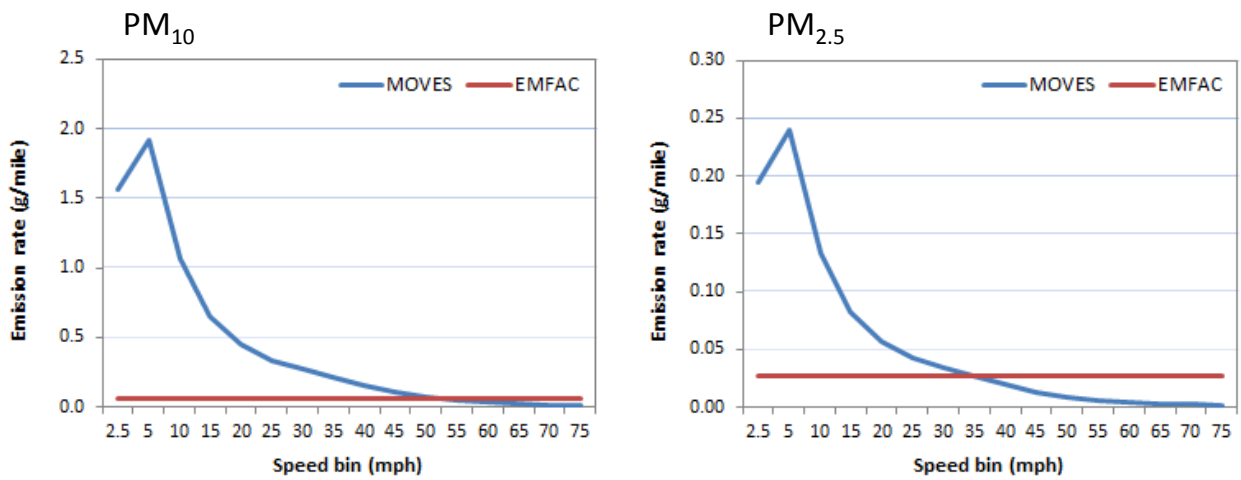


Figure 2-3. MOVES and EMFAC brake wear PM_{10} and $PM_{2.5}$ emission rates for heavy heavy-duty trucks.

For project-level emissions assessment, base emission rates have to be aggregated to high-level vehicle categories (such as non-trucks and trucks) typically used in project-level PM hot-spot work. Therefore, using MOVES and EMFAC brake wear emissions rates, we also calculated g/mi brake emission factors for three vehicle categories defined in EMFAC and CT-EMFAC: Non-Truck, Truck 1 (light heavy-duty trucks) and Truck 2 (medium heavy-duty trucks and heavy heavy-duty trucks), as well as for fleet average. Also, to make the case study more appropriate for PM hot-spot assessments, we assumed the vehicle fleet to be comprised of 8% trucks (consistent with the sample EPA benchmark of 8% trucks and 125,000 AADT for a PM Project of Air Quality Concern). The resulting case study brake wear emission factors are shown in Figures 2-4 and 2-5.

Major findings from this case study include:

- EMFAC g/mi brake wear emissions do not vary by speed; therefore project-level brake wear emissions are proportional to vehicle miles. Project analyses that involve congestion relief and travel speed changes (given that fleet mix is not changed) will not result in varying g/mi brake wear emission rates.

- At the per-mile level, EMFAC brake wear emissions are lower in low-speed bins but higher in high-speed bins than MOVES brake wear emissions.

- EMFAC brake wear emissions rate differences among the three vehicle categories are less substantial than the differences embedded in MOVES; for low-speed bins, MOVES Truck 2 brake wear emissions are much higher than Truck 1 and Non-Truck brake wear emissions.

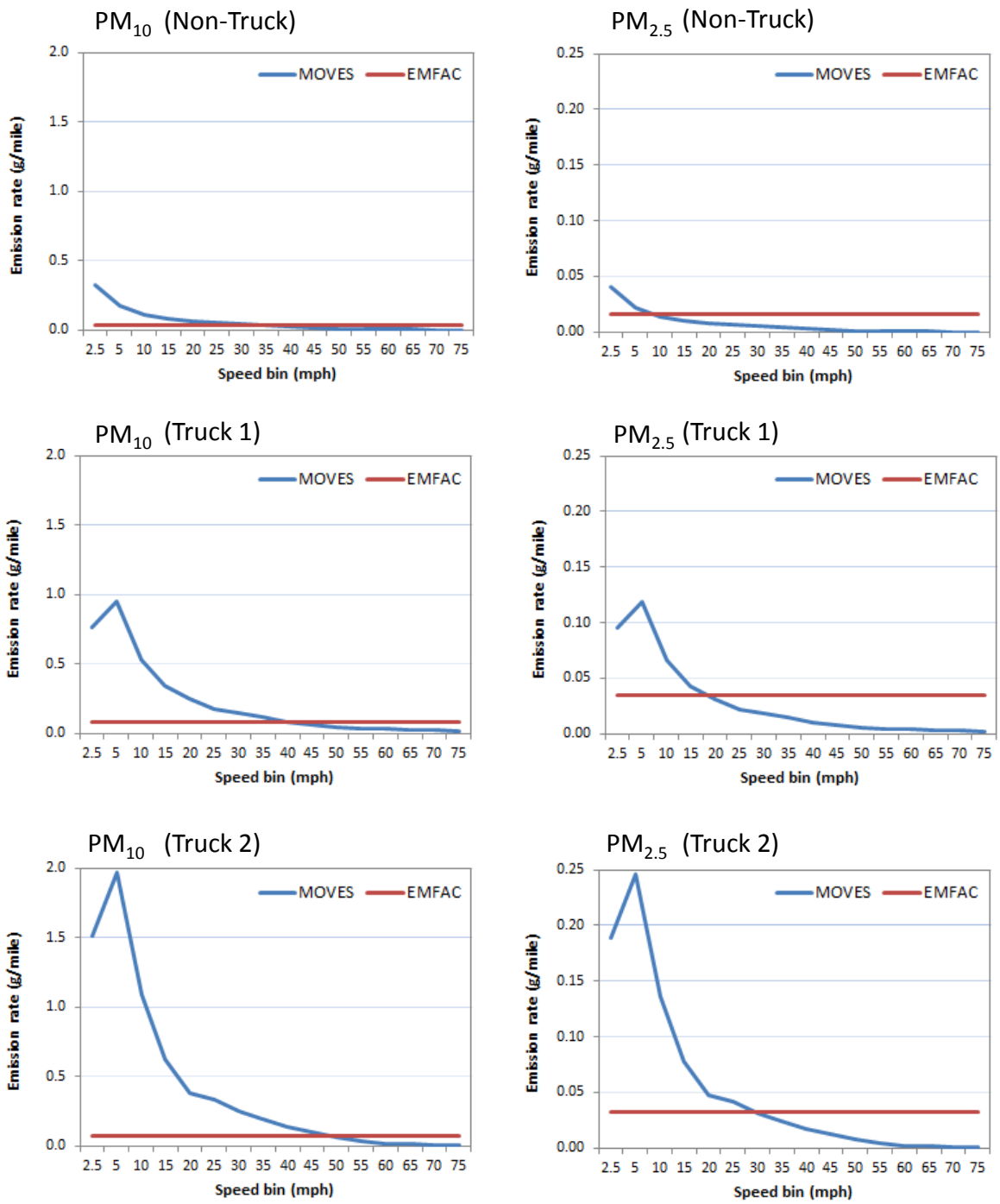


Figure 2-4. MOVES and EMFAC brake wear PM_{10} and $PM_{2.5}$ emission rates for Non-Truck, Truck 1 (light heavy-duty trucks) and Truck 2 (medium and heavy heavy-duty trucks).

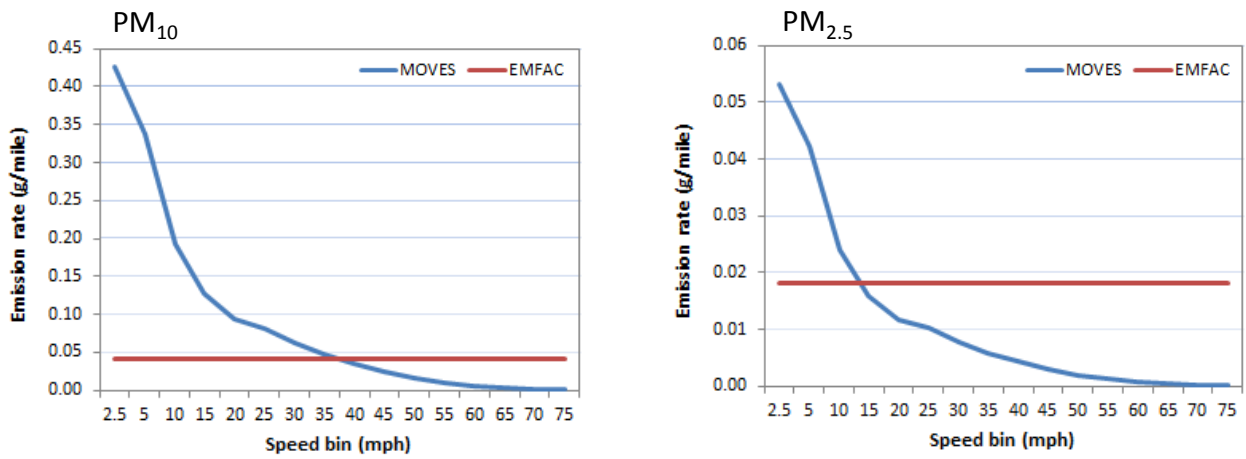


Figure 2-5. MOVES and EMFAC fleet-average brake wear PM_{10} and $PM_{2.5}$ emissions (assumes a hypothetical vehicle fleet with 8% trucks).

Tire Wear Modeling Differences Between MOVES and EMFAC

1. Data Sources

MOVES and EMFAC base emission rates for tire wear were derived from limited data sources. MOVES tire wear data is primarily from two studies that measured tire weight loss (Luhana et al., 2004; Kupiainen et al., 2005). EMFAC tire wear data is from a study published in 2000 based on data adopted from EPA's 1995 particulate emission factors model (PART5). Note that PART5 is an outdated model originally distributed by the Office of Transportation and Air Quality (OTAQ) of EPA in August 1995; to estimate PM emissions from highway vehicles, EPA replaced the PART5 model with the MOBILE model, which was later replaced with the MOVES model. Due to their different data sources, the base tire wear emission rates in MOVES and EMFAC are different, as illustrated by the sample data for LDVs and HHDTs shown in Tables 2-6 and 2-7. In both models, base tire wear emission rates are independent of road type, model year, and meteorology (e.g., temperature and relative humidity). In MOVES, base tire wear emission rates are quantified in units of g/hr and, as with brake wear emissions, tire wear emissions vary by vehicle speed. In EMFAC, base tire wear emission rates vary only by vehicle and fuel type. In both models, heavy-duty vehicles have higher per-mile tire wear emission rates than light-duty vehicles (mainly due to the assumptions that heavy-duty vehicles have more tires than light-duty vehicles).

Table 2-6. Base tire wear $PM_{2.5}$ emission rates (g/hr and g/mi) for LDVs and HHDTs in MOVES (U.S. Environmental Protection Agency, 2014a).

Speed Bin (mph)	LDV (g/hr)	LDV (g/mi)	HHDT (g/hr)	HHDT (g/mi)
2.5	0.006355	0.005084	0.023655	0.018924
5	0.012020	0.002404	0.044740	0.008948
10	0.022310	0.002231	0.083050	0.008305
15	0.031065	0.002071	0.115635	0.007709
20	0.038440	0.001922	0.143120	0.007156
25	0.044600	0.001784	0.166050	0.006642
30	0.049680	0.001656	0.184950	0.006165
35	0.053795	0.001537	0.200305	0.005723
40	0.057080	0.001427	0.212480	0.005312
45	0.059580	0.001324	0.221850	0.00493
50	0.061450	0.001229	0.228800	0.004576
55	0.062755	0.001141	0.233640	0.004248
60	0.063540	0.001059	0.236580	0.003943
65	0.063895	0.000983	0.237900	0.00366
70	0.063910	0.000913	0.237790	0.003397
75	0.063525	0.000847	0.236475	0.003153

Table 2-7. Base tire wear $PM_{2.5}$ emission rates in EMFAC (California Air Resources Board, 2015b).

Vehicle Type	Emission Rate (g/mi)
LDVs, LDTs, and MDVs	0.002
LHDT (Gas)	0.002
LHDT (Diesel)	0.003
MHDT (Gas)	0.003
MHDT, MH, OBUS (Diesel)	0.004
HHDT (Gas)	0.005
HHDT (Diesel & Natural Gas)	0.009
Urban Buses (Diesel)	0.003
School Buses (Gas)	0.002
Motorcycles	0.001

2. Modeling Assumptions

Table 2-8 summarizes the key assumptions made in MOVES and EMFAC for developing the base tire wear emission rates. The MOVES calculation approach for tire wear emissions is based on a regression model fitted with LDV tire weight loss rates (g/mile) against average vehicle speed (mph). MOVES also assumes zero tire wear emissions for vehicle idling. Tire wear emissions for other vehicle types are adjusted from LDV emission rates using scaling factors. The EMFAC approach is based on a simplified calculation of multiplying a constant per-wheel airborne PM emission rate by the average number of wheels.

Table 2-8. Comparison of modeling assumptions for base tire wear emission rates.

Components	MOVES	EMFAC
Base pollutant	$PM_{2.5}$	PM_{30}
Unit	Gram per hour	Gram per mile
Variation	Varies by vehicle type and operating mode (speed)	Varies by vehicle type and fuel type
Number of wheels	Assumed for different vehicle types	Assumed for different vehicle types and fuel types
PM_{10} to $PM_{2.5}$ factor[a]	6.667	4
Basic modeling method	Regression curve fitted with tire weight loss rates (g/mile) against average speed (mph) for LDVs; scaling factors applied for other vehicle types; assuming total tire wear per vehicle is a function of the number of tires per vehicle	Multiplying a constant per-wheel airborne PM emission rate (0.002 g/mile/wheel) by the average number of wheels for each vehicle/fuel type

[a]The MOVES PM_{10} to $PM_{2.5}$ ratio is based on more recent information (2005 data) than the information used to support the ratio in EMFAC (pre-2000 data) (Kupiainen et al., 2005; California Air Resources Board, 2010).

Comparisons of MOVES and EMFAC LDV and HHDT base PM_{10} and $PM_{2.5}$ tire wear emission rates are presented in Figures 2-6 and 2-7. Similar to what was shown earlier regarding brake wear emissions, g/mi MOVES base tire wear emission rates decrease by speed, while EMFAC base tire wear emission rates are constant across all travel speeds for specific vehicles and fuel types. EMFAC rates include higher tire wear emissions from diesel vehicles than gasoline vehicles (with the assumption that diesel vehicles typically have more tires than gasoline vehicles).

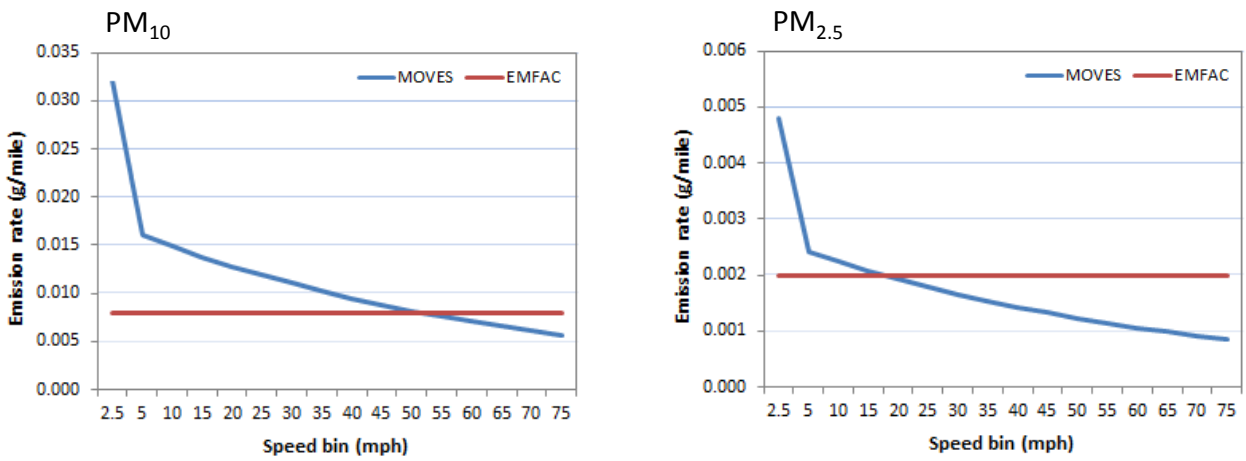


Figure 2-6. MOVES and EMFAC base tire wear PM_{10} and $PM_{2.5}$ emission rates for LDVs.

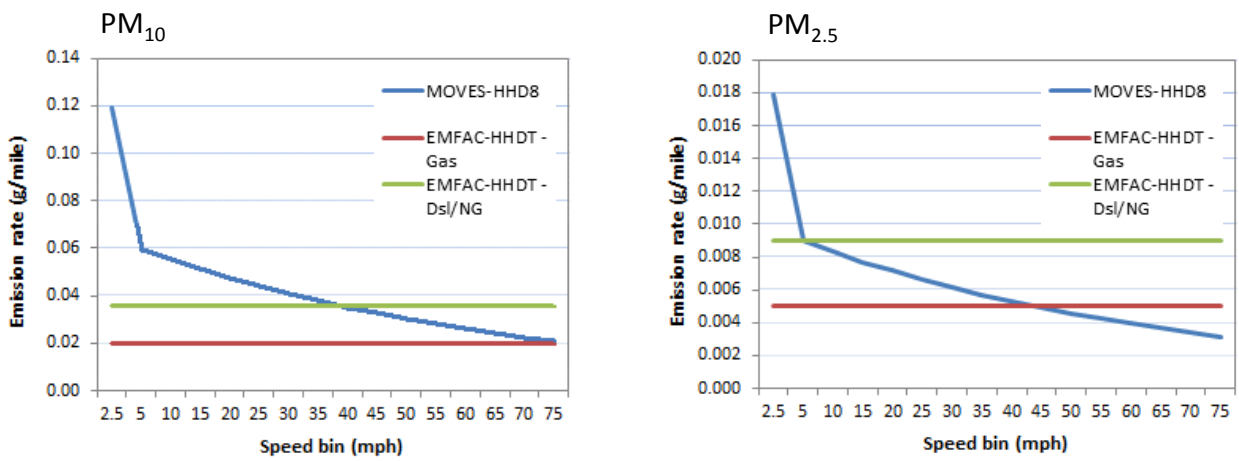


Figure 2-7. MOVES and EMFAC base tire wear PM_{10} and $PM_{2.5}$ emission rates for HHDTs.

3. Illustration of Tire Wear Modeling Differences with a Hypothetical Case

Average g/mi tire wear emission factors for three vehicle categories and a hypothetical fleet with 8% trucks are presented in Figures 2-8 and 2-9. Main findings include:

- EMFAC g/mi tire wear emissions do not vary by speed; therefore project-level tire wear emissions are proportional to vehicle miles. As with brake wear emissions, and absent changes to the fleet mix, project analyses that involve congestion relief and travel speed changes will not result in varying g/mi tire wear emission rates.
- Compared to MOVES emission rates, EMFAC g/mi tire wear emissions are lower in low-speed bins but higher in high-speed bins.

- The EMFAC fleet average tire wear PM_{10} emission factor (for the 8% fleet scenario) is similar to MOVES factors associated with 50-55 mph vehicle speeds; however, for $PM_{2.5}$, the EMFAC tire wear emissions factor is similar to MOVES factors for 15-20 mph vehicle speeds.

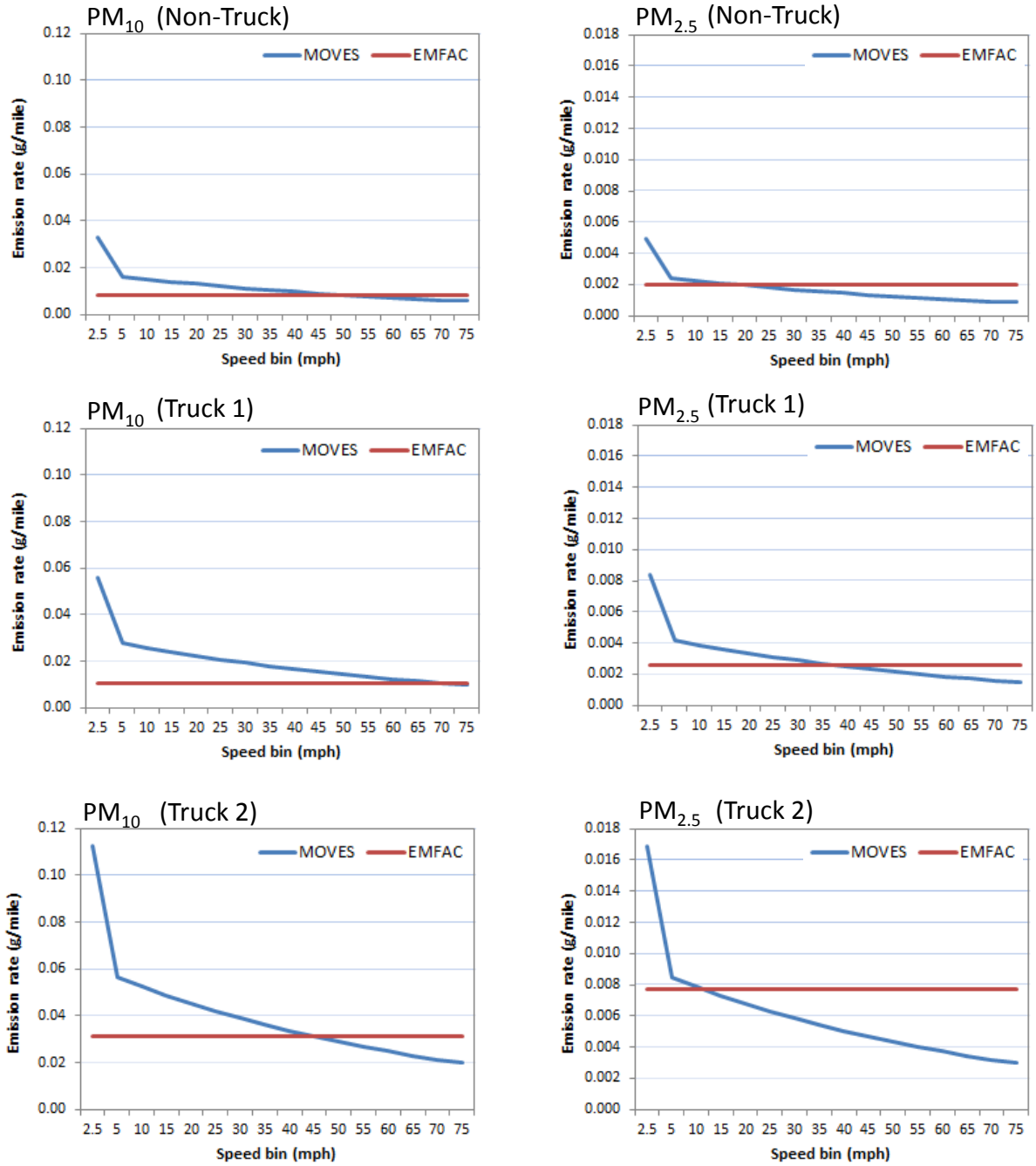


Figure 2-8. MOVES and EMFAC tire wear PM_{10} and $PM_{2.5}$ emission factors for Non-Truck, Truck 1 (light heavy-duty trucks) and Truck 2 (medium and heavy heavy-duty trucks).

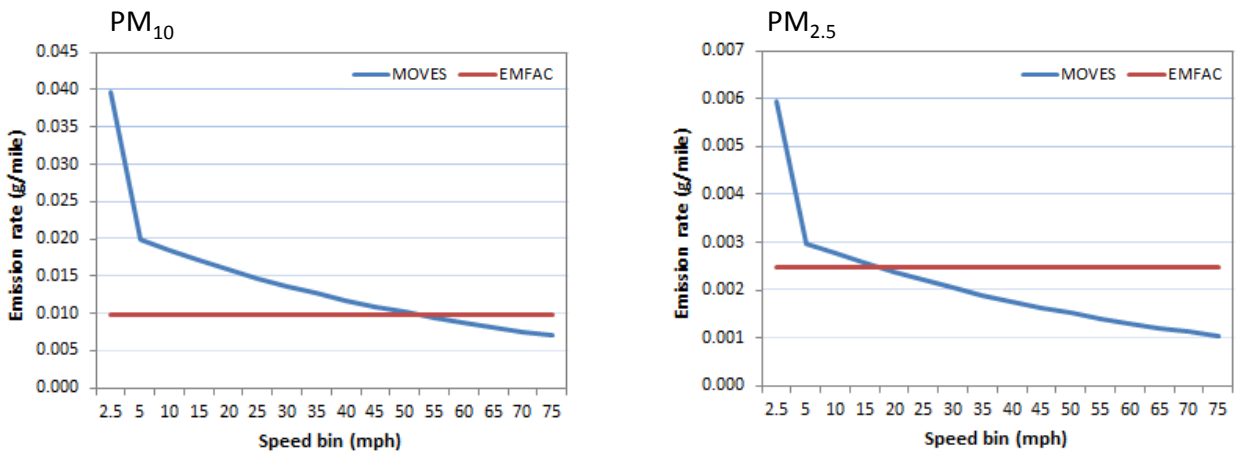


Figure 2-9. MOVES and EMFAC fleet-average tire wear PM_{10} and $PM_{2.5}$ emission factors.

2.1.5 Brake Wear and Tire Wear Data: Future Potential Changes

In this section, we discuss potential future changes in brake wear and tire wear emissions due to anticipated penetration of advanced technology vehicles and changes in response to recent regulations.

Brake Wear

1. Regenerative Braking

In recent years, alternative braking systems have been applied to advanced technology vehicles such as electric and hybrid light-duty vehicles and trucks. An important example of an alternative braking system (different from the traditional disc or drum braking) is regenerative braking. The regenerative brake is an energy recovery mechanism which slows a vehicle by converting kinetic energy into electricity and storing the power for later use (for example, in batteries). This contrasts with conventional braking systems, where the excess kinetic energy is converted to heat by friction in the brakes which causes brake wear dust emissions (California Air Resources Board, 2015a).[3]

Currently, neither EMFAC nor MOVES provides estimates of brake wear emissions from vehicles with regenerative braking. To evaluate the emission impacts from regenerative braking, we designed a set of test case scenarios and estimated fleet average emission rates with and without regenerative braking. For the test scenarios, the following assumptions were made.

[3]As noted by the California Air Resources Board (CARB) in a November 2015 report on heavy-duty hybrid vehicles, "Regenerative braking also extends the life of the brakes therefore reducing the operating and maintenance costs of the vehicle. Many fleets are reporting greatly extended brake maintenance intervals, especially in severe-duty, stop-and-go vocations such as refuse haulers and inner-city transit buses, which result in much fewer brake replacements over the hybrid vehicle's life. *Reduced brake wear also contributes to reduction of near-road exposure to brake dust emissions.*" [emphasis added]. See pp II-1 to II-2 in: http://www.arb.ca.gov/msprog/tech/techreport/hybrid_tech_report.pdf.

- Fresno, California was selected as the modeling area and 2015 and 2050 were selected as the modeling years.
- For the "Base" scenarios, no regenerative braking system was assumed in the fleet. In other words, the penetration rate of regenerative braking was assumed to be zero. For the scenarios called "EV30," we assumed 30% of the light-duty fleet to be electric or hybrid vehicles equipped with a regenerative braking system (i.e., a penetration rate of 30% for regenerative braking). The EV30 scenarios were based on a forecast by the California Energy Commission (CEC) that by 2050 up to 30% of the LDV California fleet will be electric or hybrid vehicles (Bahreinian, 2013).[4] We used a 30% regenerative braking penetration rate in both the 2015 and 2050 analysis years to test whether the analysis results were influenced by fleet composition shifts over time (meaning shifts in the percentage of the total vehicle fleet assumed to be LDVs).
- To test for the maximum impact of LDV regenerative braking use, the brake wear emission rate for the 30% of LDVs with regenerative braking was set to zero in both MOVES and EMFAC. One exception in MOVES involved emission rates at speeds lower than 10 mph. For the MOVES-based emissions, we applied gasoline-powered LDV emission rates for travel under 10 mph; this is because some literature indicates that conventional braking is still required during very low speed conditions (Cody et al., 2009).

Analysis results are shown in Figure 2-10. With 30% regenerative braking penetration, EMFAC estimated an emission benefit of approximately 30% in both 2015 and 2050, while MOVES estimated emission benefits ranging from 13% to 30% in 2015 and 10% to 28% in 2050 (MOVES results vary with varying speeds). MOVES data suggest that the largest absolute brake wear emission reduction benefits of regenerative braking occur at lower speeds of less than 30 mph.

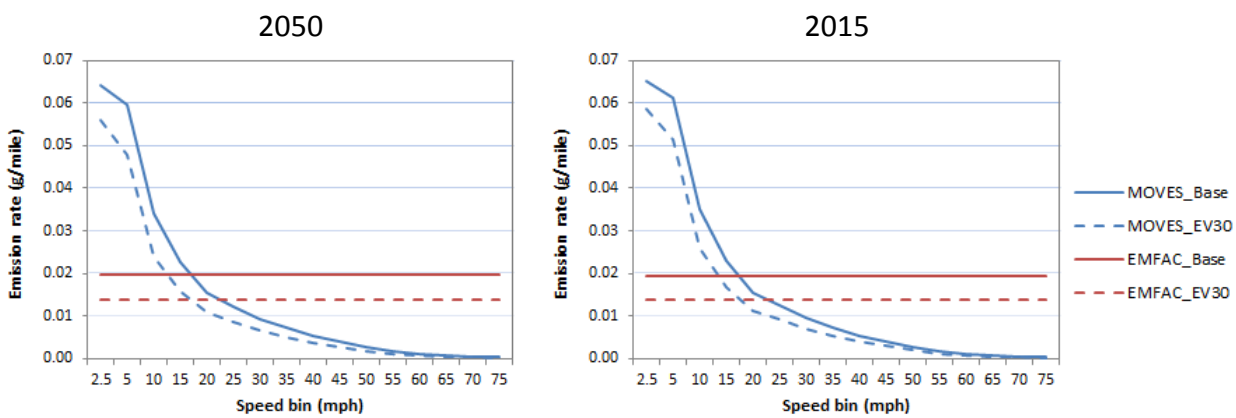


Figure 2-10. MOVES and EMFAC fleet-average brake wear $PM_{2.5}$ emission rates with and without considering regenerative braking technology for a Fresno, CA, hypothetical case.

[4] The CEC also forecasted that up to 17% of the heavy-duty fleet would be diesel-electric hybrids by 2050 (McBride, 2015); in this analysis, we did not evaluate scenarios with heavy-duty vehicles equipped with regenerative braking. For analysis purposes other than assessing break wear, current versions of MOVES and EMFAC assume penetration into the vehicle fleet of light-duty electric and hybrid vehicles; neither model currently includes heavy-duty electric and hybrid vehicles in future-year default vehicle fleets.

2. Reduced Stopping Distance Regulation

In 2009, the National Highway Traffic Safety Administration (NHTSA) announced Federal Motor Vehicle Safety Standard (FMVSS) 121, to require Reduced Stopping Distance (RSD) for heavy-duty trucks. The RSD regulation requires a 30 percent reduction in the maximum stopping distance for the vast majority of new heavy truck tractors—from 355 feet to 250 feet—phased-in over the 2011 to 2013 model years.[5] The RSD requirements have encouraged development of different brake materials and front axle brake configurations, as described below, that may influence brake wear emissions.

- *Brake materials*: Among some manufacturers, there is a trend to shift brake linings to semi-metallic materials to obtain better stopping power at high temperature (NUCAP Brakes, 2011). In the aftermarket sales of brake parts, increased use of semi-metallic brakes has also been observed for parts sales related to higher-end vehicles (Global Industry Analysts Inc., 2015). Use of semi-metallic brakes has been shown to result in the release of more airborne dust than other brake types such as metallic and ceramic brakes. Therefore if semi-metallic brake use increases in response to the RSD requirement, it is likely that brake wear emissions will increase for at least some vehicles. Further research is needed for quantifying the impact of brake materials on brake wear emissions at both regional and project levels.

- *Brake size*: In response to the RSD requirements, larger-sized brakes with more brake lining surface area have been phased into some of the truck fleet (e.g., 16.5x5-in. and 16.5x7-in brakes, in comparison to 15x4-in. brakes). The PM emissions impact from a shift to larger brake sizes is uncertain. Larger brakes likely mean larger brake pad surfaces that, when worn, may generate more brake wear PM than smaller brake pads; however, larger brake surfaces may also help dissipate heat generated from friction, and reduced heat might reduce brake pad wear (Sturgess, 2010; Skydel, 2014).

- *Hazardous material restrictions*: Effective January 1, 2014, California legislation (SB 346) regulated the hazardous material content in brake pads. The goal was to reduce the copper weight content of brake pads to 5% by 2021 and 0.5% by 2025. Other states are currently considering similar legislation (Centric Parts, 2012).[6] Potentially, the new requirement could change the chemical composition and size distribution of brake wear PM emissions (e.g., the $PM_{2.5}$ to PM_{10} mass ratio), although as of this writing there was no definitive data or information to help forecast the brake wear emissions implications.

[5] See: http://www.nhtsa.gov/Laws+&+Regulations/Brakes.

[6] Similar legislation took effect January 1, 2015, in the state of Washington.

Tire Wear

This discussion highlights technology and regulatory issues that likely have an impact on tire wear PM emissions. However, there is insufficient information to indicate the overall effect of these issues on fleet-average tire wear PM emissions.

1. Advanced Technology

A portion of tires sold either separately or as original vehicle equipment are designed to reduce rolling resistance and improve fuel economy. However, there is some evidence that low rolling resistance tires may wear more quickly, resulting in increased tire wear emissions rates. Rolling resistance consumes about 4% to 7% of the energy expended by a vehicle (Transportation Research Board, 2006). For passenger vehicles, a 10% reduction in rolling resistance has been estimated to lead to a 1% to 2% increase in fuel economy; this approximation has been included in studies of tire rolling resistance that date from the 1980s (Sandberg, 1997) to more recent work by NHTSA (Evans et al., 2009). A 2003 CEC study estimated that adoption of low rolling resistance tires could reduce gasoline consumption 1.5 to 4.5% (Larson et al., 2003). A 2009 NHTSA study found that if 2% of replacement tires reduced rolling resistance by 5%, there would be 7.9 million gallons of fuel and 76,000 metric tons of CO_2 saved annually (National Highway Traffic Safety Administration, 2009). Federal requirements to achieve higher Corporate Average Fuel Economy (CAFE) standards have led to greater use of reduced rolling resistance tires; low rolling resistance tires are frequently standard equipment for electric and hybrid vehicles. California mandates the use of low rolling resistance tires on heavy-duty trucks (California Air Resources Board, 2014). Notwithstanding their fuel economy and CO_2 emissions benefits, some studies have observed that low rolling resistance tires wear out more quickly (Witzenburg, 2014; Campbell, 2015), although earlier work by NHTSA found mixed results (Evans et al., 2009; National Highway Traffic Safety Administration, 2010). If all or some subset of low rolling resistance tires wear out more rapidly than conventional tires, then it would follow that their tire wear PM emission rates would be greater. The impact, if any, on fleet-average tire wear PM emissions would be a function of the penetration rate of low rolling resistance tires into the vehicle fleet.

In addition to changes in rolling resistance, tire size changes may be affecting PM emissions. Some industry professionals have observed that demand for larger wheel sizes is increasing for both cars and trucks (Campbell, 2014). This suggests the surface areas of tires might be increasing as well, although the impact on tire wear emissions would depend on several factors, such as rolling resistance. Overall, changes in tire technology and potential shifts in tire purchasing trends may be having an impact on tire wear PM emissions. However, these impacts are too uncertain to quantify at this time.

2. Standards/Regulations

Tire under-inflation results in more tread wear loss. For example, statistics from Firestone Tire and Rubber Company indicate that under-inflation of 25% could cause 40% more thread wear loss.[7] Various studies have shown that greater than 25% of in-use vehicles have underinflated tires (e.g., Waddell, 2008; Pearce and Hanlon, 2007; Ratrout, 2005; Thiriez and Boudy, 2001). However, neither EMFAC nor MOVES considers impacts from tire under-inflation on tire wear PM emissions. NHTSA's FMVSS Tire Pressure Monitoring Systems (TPMS) Rule required installation of a TPMS capable of detecting when one or more of the vehicle's tires is 25 percent or more below the manufacturer's recommended inflation pressure, or when a minimum activation pressure specified in the standard is reached, whichever is higher.[8] As of this writing, insufficient data were available to quantify to what extent fleet penetration of TPMS-equipped vehicles has reduced under-inflation, and how that relates, if at all, to actual and modeled fleet-average tire wear PM emissions.

2.1.6 Brake Wear and Tire Wear Modeling: Major Findings and Recommendations

The two official models used to estimate on-road emissions—MOVES and EMFAC—treat brake and tire wear differently, and apportion different amounts of brake and tire wear PM_{10} to the $PM_{2.5}$ size category. In general, for future analysis years EMFAC-based brake and tire wear estimates are higher than those produced by MOVES, especially for brake wear emissions and for $PM_{2.5}$.

Current brake and tire wear data are based on a limited number of studies, many of which were completed more than a decade ago prior to technology and regulatory changes affecting current and future vehicle fleets. As a result, modern vehicle, brake, and tire technologies are not effectively represented in the data used to develop MOVES and EMFAC brake and tire wear PM emissions.

As a general observation, EMFAC produces brake wear emissions that are far greater than tire wear emissions, and produces $PM_{2.5}$ emissions which are far greater than emissions produced by MOVES. Therefore it is a high priority to assess and improve EMFAC-based brake-related emissions estimates. Major findings and recommendations include

- **MOVES varies brake and tire wear emissions by travel speed; EMFAC does not**. EMFAC brake and tire wear emission factors were developed primarily to support regional emissions inventory development, for which average travel speeds were considered sufficient to characterize regionally-averaged conditions. At the project level, speed-based emission factors offer the opportunity to assess emissions differences among various project alternatives that modify forecasted travel volumes, fleet mix, and speeds. For example, assume a build-project alternative reduced peak-period congestion and improved traffic flow from 10-15 mph to 30-35 mph. As shown in Figures 2-2 and 2-3, use of MOVES-based

[7] See: http://www.tireqp.com/nahitrsaadn.html
[8] The requirement affects 2007 and later vehicles; see: http://www.nhtsa.gov/cars/rules/rulings/tpmsfinalrule.6/tpmsfinalrule.6.html.

emission factors, which adjust for speed changes, would result in build-scenario brake-wear g/mi PM emission rates about 50% less than no-build rates; EMFAC-based results would show no change in g/mi emissions. Note that speed-based emission factor differences included in MOVES apply to all analysis years. *Thus, the most important recommendation emerging from our assessment is to examine whether EMFAC-based emissions can be speed-adjusted using the technical information employed by EPA to develop MOVES speed-varying emissions factors. Given the overwhelming importance of brake wear compared to tire wear emissions (see Figure 2-1), this examination should focus on brake wear emissions*.

- **Electric and hybrid-electric vehicles employ regenerative braking systems to recharge batteries; qualitatively, these systems are expected to reduce the wear-rate of brake pads**. Neither MOVES nor EMFAC takes into consideration how regenerative braking affects brake wear emissions. The importance of this issue increases over time, since the vehicle fleet is forecasted to include a greater fraction of advanced technology vehicles in coming years. The CEC, for example, forecasts that up to 17% of the truck fleet and up to 30% of the light-duty fleet will be electric or hybrid vehicles by 2050. The impact of this issue is relatively small for current and near-term analysis years, and larger over time with fleet turnover. *Thus, there is an important need to quantitatively adjust EMFAC-based brake-wear emissions rates to account for forecasted regenerative braking systems use*.

- **Numerous other factors can affect brake or tire wear emissions that are not fully characterized by either MOVES or EMFAC**. However, collectively they are likely to account for only a small fraction of overall PM emissions, or are likely to have minimal impact on build vs. no-build project comparisons, and are therefore lower priority issues. For brake wear, factors include the federal requirements to reduce the stopping distance of trucks. For tire wear, factors include the growing use of lower rolling resistance tires, efforts to reduce under-inflation of tires in-use, and potential increase in the use of larger-sized tires over time. For both brake and tire wear, factors include the differences between the EPA and CARB assumptions about the fraction of PM_{10} that is $PM_{2.5}$ (EPA ratios are based on more recent data and result in reduced $PM_{2.5}$ values as a fraction of PM_{10}). *Although all of the factors discussed introduce uncertainty into the emissions modeling process, they are less important to address than brake wear emissions variation by travel speed and the emissions impact on brake wear from regenerative braking systems*. *It may be possible to update PM_{10} to $PM_{2.5}$ ratios rather easily to reflect more recent information; such an update may assist project analyses in build vs. no-build situations where background PM concentrations are not already above the PM NAAQS.*

2.2 Assessment of Road Dust Calculation in Particulate Matter Emissions Modeling

2.2.1 Introduction

This section of Chapter 2 helps Caltrans identify key parameters affecting road dust emissions and improve road dust emissions estimation for particulate matter (PM) hot-spot analyses. The following topics are covered:

- Existing U.S. Environmental Protection Agency (EPA) and California Air Resources Board (CARB) methods for road dust emissions estimation
- Key differences between EPA and CARB-based road dust emission estimates
- Discussion of key parameters and related issues
- Recommendations for next steps

Vehicle travel on roadways is a source of airborne dust, otherwise referred to as re-entrained road dust, fugitive dust, or simply road dust (the term primarily used here). Road dust becomes airborne when loose material on road surfaces becomes suspended in the air by traffic-induced turbulent air currents. EPA requires that emissions from "re-entrained road dust" be included in a quantitative PM_{10} hot-spot analysis (U.S. Environmental Protection Agency, 2015c). EPA also stated in the guidance document that road dust emissions must be included in a $PM_{2.5}$ hot-spot analysis if the applicable air quality management agencies determine that road dust is a significant contributor to the area's $PM_{2.5}$ nonattainment problem (U.S. Environmental Protection Agency, 2015c).[9]

Caltrans-funded case studies and related research have shown that, at the project level, road dust emissions are becoming an increasingly important component of total PM emissions (especially for PM_{10}) and are largely driven by vehicle miles traveled (VMT) over time (Bai et al., 2017). For example, **Figure 2-11** shows PM_{10} emissions for selected analysis years for a hypothetical freeway with annual average daily traffic (AADT) of 125,000 and 8% diesel truck traffic. In this hypothetical example, the contribution of re-entrained dust to the project-level PM_{10} inventory increases from 52% in 2006 to 67% in 2035 (Reid et al., 2016a).

[9] Per communication with Caltrans District 6 (Ken Romero) and District 7 (Andrew Yoon), as of April 2016, road dust emissions have been always considered and included in $PM_{2.5}$ hot-spot analyses in the San Joaquin Valley Air Basin and South Coast Air Basin.

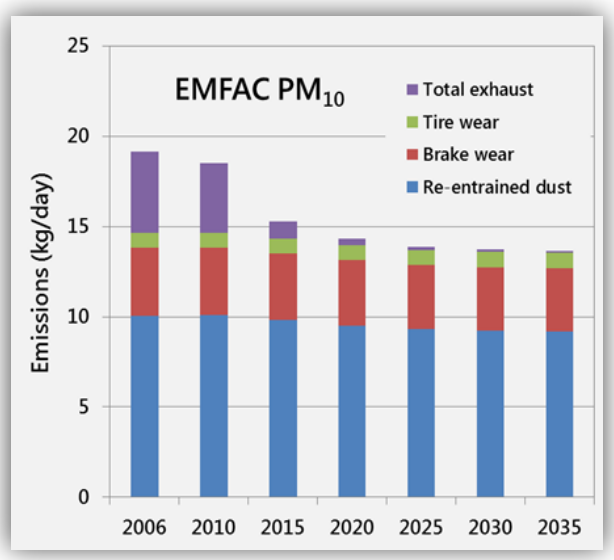


Figure 2-11. PM_{10} emissions for a hypothetical project for selected analysis years. Note that the total road dust emissions for this hypothetical project decreases slightly by year, because the fleet average vehicle weight decreases from 2015 to 2035 (lower vehicle weight is associated with lower road dust emissions at the per-mile level, according to EPA's AP-42 calculation approach).

According to EPA's quantitative PM hot-spot analysis guidance (U.S. Environmental Protection Agency, 2015c), road dust emissions need to be quantified using EPA's AP-42 method or an alternative locally developed method that is more appropriate for local project conditions. The AP-42 method defines equations to estimate road dust PM emissions; these equations use several key parameters, such as silt loading and vehicle weight (U.S. Environmental Protection Agency, 2011). Over the past three decades, EPA has updated the recommended values for these key parameters several times. However, road dust emissions estimation remains uncertain due to variability in key parameters (e.g., the amount of dust, or "silt load," on roads can vary widely in different geographic areas). There is ongoing work to improve the methods and parameters used for road dust emissions modeling, such as the development of California-specific silt loading factors for the AP-42 equation (California Air Resources Board, 2016), application of new mobile monitoring methods[10] to better measure silt loading factors (U.S. Environmental Protection Agency, 2014b), and analysis of mitigation effects of vegetation[11] cover surrounding the roadway (U.S. Environmental Protection Agency, 2005b).

This document assesses the AP-42 road dust emissions calculation method, summarizes the scientific understanding regarding changes in road dust emissions with key modeling parameters (e.g., silt

[10] The mobile monitoring methods were described in EPA's technical document as "Other Test Methods" for measurement of road dust PM emissions. The methods involve using a test vehicle with mobile measurement systems that can measure PM concentrations with high time resolution; the measured concentrations in the wake of the test vehicle are used to estimate road dust PM emissions.
[11] The mitigation effects of vegetation, as described in EPA's technical document, mainly reflect dust capture by vegetation at a regional scale, instead of removal of near-source particles at the highway project level.

loads), and identifies potential adjustments or further analysis needs for improving project-level road dust emissions estimation.

2.2.2 Existing Methods for Road Dust Emissions Estimation

Basic AP-42 Road Dust Equation for Paved Roads

As of the writing of this document, the most recent EPA-approved AP-42 method for road dust emissions estimation is in the 2011 version of the EPA AP-42 guidance document, Chapter 13.2.1, "Paved Roads" (U.S. Environmental Protection Agency, 2011). AP-42 defines the following equation (Equation 1) to estimate an average particulate emission factor:

$$E = k \times (sL)^{0.91} \times W^{1.02} \quad (1)$$

where E = particulate emission factor (lb/VMT)
k = particle size multiplier (lb/VMT), or "k factor"; see default values in Table 2-9 below
sL = road surface silt loading (g/m^2); see default values in Table 2-10 below
W = average weight (tons) of vehicles traveling the road

Table 2-9. AP-42 particle size multipliers for the paved road equation (EPA default values).

Size Range	Particle Size Multiplier k (lb/VMT)
PM_{10}	0.0022
$PM_{2.5}$	0.00054

Table 2-10. EPA (AP-42) silt loading national default values.

EPA Silt Loading Categories	Average Daily Traffic (ADT)			
	<500	500-5,000	5,000-10,000	>10,000
Normal Baseline sL Values (g/m^2)	0.6	0.2	0.06	0.015 for limited-access roads such as freeways; 0.03 for other roads
Winter Baseline Multiplier During Months with Frozen Precipitation	X4	X3	X2	X1

According to EPA's supporting documents (U.S. Environmental Protection Agency, 2011, 2003b, 2003a), the development of the AP-42 method for road dust emissions modeling has a long history. The basic form of the EPA emission factor model for road dust from paved roads was first published in a 1979 report, and a slightly revised version first appeared in a supplemental section to AP-42 in 1983. The AP-42 method used a regression analysis of PM_{10} data collected from paved roads, where most of the data collection involved free-flowing vehicles traveling at constant speed on level roads. The 1995 update revised the silt loading factors and particle size multipliers in the previous version of the AP-42 method, introduced a vehicle weight term, and made these parameters independent variables in the equation. From 2002-2003, the $PM_{2.5}$ k factor was reduced by about half and the default silt loading data were recommended for normal and worst-case conditions. A reduction in PM emissions due to precipitation was introduced as a mitigation effect (discussed below). Shortly thereafter, the exhaust, brake wear, and tire wear components were separated from the composite fugitive dust emission factor equation to avoid double-counting these emissions estimates obtained from other mobile source emissions models. In 2006, the $PM_{2.5}$ k factor was lowered again in EPA's guidance. An updated road dust emissions equation for paved roads was developed in 2010 using slow-moving and stop-and-go traffic test data from a Midwest Research Institute (MRI) study (U.S. Environmental Protection Agency, 2011). In summary, with additional data to support modeling parameters, road dust research and emissions estimation have evolved over the past 30 years. During that time, EPA has changed the road dust equation in AP-42 considerably in an effort to improve its accuracy and reflect emerging scientific understanding of road dust emissions.

AP-42 Road Dust Equation with Precipitation Correction

The road dust emissions calculated using Equation 1 represent conservative estimates, given that the impact of precipitation is not considered. AP-42 also includes two additional equations (**Equation 2** and **Equation 3**) with precipitation correction terms, based on the assumption that average road dust emissions decrease with increased frequency of measureable (>0.01 inches) precipitation (U.S. Environmental Protection Agency, 2011). These equations are most applicable at the regional scale when annual or average daily emissions are being estimated.

On a daily basis, Equation 1 is revised to:

$$E = k \times (sL)^{0.91} \times W^{1.02} \times (1 - \frac{P}{4N}) \qquad (2)$$

where E, k, sL, and W are the same as defined in Equation 1

P = number of "wet" days (with at least 0.01 inches of precipitation) during the averaging period

N = number of days in the averaging period (e.g., 365 for annual, 91 for seasonal, 30 for monthly)

On an hourly basis, Equation 1 is revised to:

$$E = k \times (sL)^{0.91} \times W^{1.02} \times (1 - \frac{1.2P}{N}) \quad (3)$$

where: E, k, sL, and W are the same as defined in Equation 1
P = number of hours with at least 0.01 inches for precipitation during the averaging period
N = number of hours in the averaging period (e.g., 8760 for annual, 2124 for seasonal, 720 for monthly)

Road dust emission factors generated using the 2011 AP-42 methods reflect estimates of PM emissions from resuspended road surface material only; this avoids potential double-counting of emissions when models (MOVES and EMFAC) are used for generating exhaust, tire wear, and brake wear PM emissions. AP-42 Chapter 13.2.1 highlights the importance of the silt loading factor, which refers to the mass of silt-size material (particulate equal to or less than 75 µm in diameter) per unit area on the travel surface (U.S. Environmental Protection Agency, 2011). EPA provides a list of parameters that may affect silt loadings (e.g., mean speed of vehicles traveling the road, average daily traffic (ADT), number of lanes, the fraction of heavy-duty vehicles, and local land use characteristics) and recommends collection and use of site-specific silt loading data.

California-Specific Parameters Developed by CARB

CARB also uses AP-42 (Equations 1 to 3) to estimate California road dust emissions. However, instead of using EPA's default values, CARB developed California-specific parameters and provided them in look-up tables in a guidance document (California Air Resources Board, 2016).

Key information regarding California-specific silt loading factors for road dust emissions calculation includes:

- California statewide and area-specific silt loading factors are provided for multiple roadway types (major roads, collector roads, and local roads), in addition to limited-access roads such as freeways.
- Area-specific silt loading factors are available for four counties in Southern California (Los Angeles, Orange, Riverside, and San Bernardino) and one air district (the San Joaquin Valley Air Pollution Control District).
- As shown in **Table 2-11**, the statewide silt loading value for freeways (0.015 g/m^2) is lower than the statewide values for major roads and collector roads (0.032 g/m^2) and local roads (0.32 g/m^2); differences reflect data collection and assumptions that more heavily traveled, limited-access roads such as freeways have less silt loading than roads with multiple access points (California Air Resources Board, 2016, pp. 5-6).

Table 2-11. CARB-recommended silt loading values for California.

Region	Silt Load by Roadway Type and Location (g/m^2)		
	Freeway	Major Road and Collector Road	Local Road
Statewide	0.015	0.032	0.32
Los Angeles and Orange Counties	--	0.013	0.135
Riverside and San Bernardino Counties	--	0.08	0.84
San Joaquin Valley Air Pollution Control District	--	--	1.6

For average vehicle weight, CARB recommends assuming a fleet-wide average weight of 2.4 tons per vehicle, while EPA provides default values of 20 tons for trucks and 2 tons for non-trucks. CARB noted the need for re-evaluating their 2.4 ton default value and recommended use of county-specific information when available (California Air Resources Board, 2016, pp. 5-6).

In addition, CARB recommends a $PM_{2.5}/PM_{10}$ ratio of 0.15 for paved road dust (i.e., using PM_{10} as the base for estimating road dust emissions and assuming that 15% of PM_{10} is considered $PM_{2.5}$ for road dust emissions calculation). CARB also provides county-specific precipitation information (the number of average days per year a county receives at least 0.01 inches of precipitation) based on data from the Western Regional Climate Center (WRCC).

2.2.3 Key Differences Between EPA and CARB Road Dust Emissions Estimates

EPA's and CARB's AP-42 methods generally apply the same concepts and key assumptions: road dust emissions are proportional to silt loadings and vehicle weights; freeways (limited access) have lower silt loadings and therefore reduced dust emission factors compared to arterial roads (multiple access/exit points); trucks and buses increase fleet-average vehicle weight, resulting in higher road dust emissions. Key differences between EPA defaults and CARB's California-specific parameters are summarized in Table 2-12.

Table 2-12. Key differences between EPA and CARB road dust estimation parameters.

Parameter	EPA AP-42	CARB
Roadway Type	Four categories based on ADT levels (<500, 500-5000, 5000-10000, >10000)	Four types (Freeway, Major Road, Collector Road, and Local Road)
Silt Loading	Baseline values by ADT level (see Table 2-10)	Baseline values by roadway type; statewide and area-specific factors available (for Los Angeles, Orange, Riverside, and San Bernardino counties and the San Joaquin Valley) (see Table 3)
$PM_{2.5}$ Particle Size Multiplier (k factor)	0.00054 lb/VMT (assuming a $PM_{2.5}/PM_{10}$ ratio of 0.25 and PM_{10} multiplier of 0.0022 lb/VMT)	0.00033 lb/VMT (assuming a $PM_{2.5}/PM_{10}$ ratio of 0.15 and PM_{10} multiplier of 0.0022 lb/VMT)
Vehicle Weight	User-defined	User-defined or use default 2.4 tons
Precipitation	User-defined; use nationwide contour map as reference for daily values	User-defined; use California county-specific precipitation data

To illustrate the difference between road dust emissions estimates using EPA- and CARB-based analysis parameters, we assumed a hypothetical 1-mile freeway project in Orange County, ADT of 125,000 vehicles, and a vehicle fleet with 8% heavy-duty trucks. We also assumed an average vehicle weight, W, of 3.44 tons, reflecting a weighted average vehicle weight for a 8% truck and 92% non-truck fleet with EPA AP-42 default values of 20 tons for trucks and 2 tons for non-trucks (i.e., average vehicle weight = 20 x 8% + 2 x 92% = 3.44 tons).

As shown in Table 2-13, the $PM_{2.5}$ particle size multiplier (k) used to assess the hypothetical project is different between the EPA- and CARB-based methods.

Table 2-13. Comparison of key road dust emissions parameters in EPA's and CARB's methods used for the hypothetical project.

Pollutant	EPA's Method		CARB's Method	
	k factor (lb/VMT)	sL factor (g/m^2)	k factor (lb/VMT)	sL factor (g/m^2)
PM_{10}	0.00220	0.015	0.00220	0.015
$PM_{2.5}$	0.00054	0.015	0.00033	0.015

Note: Silt load factors and particle size multipliers (k factors) are from Tables 2-9 to 2-12.

Daily PM_{10} and $PM_{2.5}$ road dust emissions can be estimated using Equation 1 (with no precipitation correction) for the hypothetical 1-mile freeway segment. For example, using EPA's method and parameters (note that the road dust emission factor is in the unit of mass per vehicle mile,

independent of time period):

E ($PM_{2.5}$ emission factor) = 0.00054 x 0.015 $^{0.91}$ x 3.44 $^{1.02}$= 4.17 x 10^{-5} lb/VMT
Daily emissions ($PM_{2.5}$) = 4.17 x 10^{-5} lb/VMT x 125,000 vehicles/day x 1 mile = 5.21 lb/day

A comparison of the road dust emission factors and daily total road dust emissions using EPA and CARB parameters is shown in Table 2-14.

Table 2-14. EPA- and CARB-based daily road dust emissions calculations for the hypothetical project.

Parameter	EPA-Based		CARB-Based	
	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$
Emission Factor (Pounds/VMT)	1.70 x 10^{-4}	4.17 x 10^{-5}	1.70 x 10^{-4}	2.55 x 10^{-5}
Emissions (Pounds/Day)	21.23	5.21	21.23	3.18

In this hypothetical case, using CARB's particle size multiplier (k) for $PM_{2.5}$ results in 39% lower daily $PM_{2.5}$ emissions compared to the EPA-based results (because of the different particle size multiplier values).

When calculating an annual PM_{10} or $PM_{2.5}$ road dust emission rate, the precipitation correction in Equation 2 or 3 may be used to account for the annual precipitation rate in the project area. For the same hypothetical project example used in the daily road dust calculation above, the annual road dust emission factor can be estimated using Equation 2. The number of days with at least 0.01 inches of precipitation per year for Orange County is 33 days of the year, which was found in Table 8 of the CARB emissions estimation guidance (California Air Resources Board, 2016). The number of days in the averaging annual period is 365 days. Using the EPA-based method and parameters with correction for precipitation,

E ($PM_{2.5}$ emission factor) = $[0.00054 \times 0.015^{0.91} \times 3.44^{1.02}] \times \left[1 - \frac{33}{4 \times 365}\right] = 4.07 \times 10^{-5}$ lb/VMT
Daily emissions ($PM_{2.5}$) = 4.07×10^{-5} lb/VMT x 125,000 vehicles/day x 1 mile = 5.09 lb/day

Correcting for precipitation reduced the EPA-based road dust emission results shown in Table 2-14 by 2% in this example (5.09 lb/day vs. 5.21 lb/day of $PM_{2.5}$).

For PM hot-spot analyses, precipitation corrections are best applied when evaluating annual average PM emissions; it will typically be inappropriate to correct for precipitation when doing 24-hr PM hot-spot analyses. This is explained further in the Discussion section later in this report.

A comparison of the annualized daily road dust emission factors using EPA- and CARB-based methods, corrected for precipitation, is shown in Table 2-15.

Table 2-15. EPA- and CARB-based daily road dust emissions for the hypothetical project, corrected for precipitation.

Parameter	EPA-Based		CARB-Based	
	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$
Emission Factor (Pounds/VMT)	1.66×10^{-4}	4.07×10^{-5}	1.66×10^{-4}	2.49×10^{-5}
Emission (Pounds/Day)	20.75	5.09	20.75	3.11

Note: Emissions are based on an average daily emission factor, accounting for precipitation over the entire year. In this example, , correcting for precipitation reduced $PM_{2.5}$ and PM_{10} emissions 2% compared to the values in Table 2-14 (results will vary by project).

2.2.4 Discussion of Key Parameters and Related Issues

For project-level emissions assessment, the AP-42 method is conceptually straightforward to use with EPA default or CARB inputs for key parameters; however, resulting road dust emissions estimates remain uncertain due to various analysis challenges. This section, based on a brief review of key literature and technical documents, identifies important gaps in understanding with respect to road dust emissions modeling, especially for project-level hot-spot analyses. We have identified these issues to help Caltrans determine whether there are potentially useful avenues that can be pursued to improve the AP-42 road dust calculation method and/or its associated input parameters.

Silt Loading

One of the essential parameters in calculating road dust emissions is the silt loading factor (sL), which is quantified as the mass of silt-size material (75 µm or less in physical diameter) per unit area of the travel surface. The dry-particle size distribution of exposed soil or surface material determines its susceptibility to mechanical entrainment. Silt loading factors are typically estimated through road surface sampling at multiple locations, using measurements of total road surface dust loading and proportions of particles that pass through a 200-mesh screen (U.S. Environmental Protection Agency, 2011). Because road dust emissions are sensitive to silt loading factors, it is important to use values that are representative of local silt loading conditions. However, making local silt measurements is time-consuming, costly, and a potentially hazardous undertaking (National Cooperative Highway Research Program, 2008).

The 2011 version of AP-42 includes default silt loading factors for normal baseline conditions and wintertime conditions in areas that apply antiskid material to roadways (see Table 2-10). These silt loading values are based on regression analyses of 83 tests for PM_{10} on public and industrial paved roads. CARB measured silt content in several California counties and published statewide silt factors for major, collector, and local roads. CARB's statewide silt loading value for freeways (0.015 g/m^2) is based on Section 13.2.1 of the EPA AP-42 manual (California Air Resources Board, 2016). Local silt loading values recommended by CARB vary by region and differ from statewide default values.

The default silt loading values published in both EPA's AP-42 and CARB documentation may not accurately represent spatial and temporal variation of re-entrained road dust emissions on a localized level. The EPA's national default silt loading values are based on a relatively small number of studies. As noted above, CARB developed county-specific silt loading factors for major, collector, and local roads using local samples, but they also included the following statement in the guidance document regarding data limitations (California Air Resources Board, 2016):

> *CARB assigned silt loadings to four roadway types (freeway, major, collector, local), assuming that more highly traveled roadways with fewer entrance and exit points (limited-access roadways such as freeways) have less silt loading compared to roadways with multiple access and exit points, and that roads with similar configurations and usage have similar silt loadings statewide. While ARB understands the limitations to this assumption, especially in computing localized emissions, our current strategy is to use the best available California roadway silt loading data to estimate regional entrained road dust emissions.*

The collection of silt loading data is typically based on road surface sampling and is logistically very difficult to conduct, especially for limited-access roads (U.S. Environmental Protection Agency, 2011). EPA recently recognized an alternative test method, submitted by the Center for the Study of Open Source Emissions (CSOSE) and the Desert Research Institute (DRI), to quantify road dust emission factors using vehicles traveling on paved roads (U.S. Environmental Protection Agency, 2014b). In this new method, a test vehicle is used to generate its own dust plume. Instruments attached to the vehicle monitor the dust concentration on a mass basis, where a calibration factor is used to relate relative dust emissions to equivalent silt loading or emission factors. The method relies on a comparison between increased PM concentration measurements and the ambient background levels at one or more locations that are directly influenced by dust originating from tire contact with the road surface at a known travel speed and fixed travel distance (U.S. Environmental Protection Agency, 2014b). This method can potentially provide a repeatable and improved approach to quantifying road dust PM emissions; therefore, it could be helpful for supporting development of site-specific silt loading and road dust emission factors. However, EPA clarified that this mobile monitoring test method does not yet have regulatory approval; it may be considered for use in federally enforceable state and local programs provided they are subject to an EPA Regional state implementation plan (SIP) approval process (U.S. Environmental Protection Agency, 2014b).

In summary, it may be useful to examine whether area-specific freeway silt loadings should be developed in cases where localized data are unavailable.

PM_{10} and $PM_{2.5}$ Particle Size Multiplier

The particle size multiplier (k) is in the unit of grams/VMT or pounds/VMT and varies with aerodynamic size range. EPA AP-42 and CARB methods use the same PM_{10} particle size multiplier but different $PM_{2.5}$ particle size multipliers. The EPA approach includes a particle size fraction of 25% for $PM_{2.5}$ based on data collected for heavy-duty vehicles traveling at very slow speeds at corn processing facilities in the Midwest (U.S. Environmental Protection Agency, 2011). CARB derived an updated $PM_{2.5}/PM_{10}$ fraction of 15% using a California particle speciation profile based on testing data collected from the San Joaquin Valley, and Imperial and Mono counties; this updated fraction reflects CARB's adjustment to potential over-estimation of $PM_{2.5}$ road dust emissions following CARB's review of several Western Regional Air Partnership (WRAP) studies (California Air Resources Board, 2016). However, CARB stated that the testing data from those counties may not fully reflect California statewide variability of particle size distributions.

It may be useful to revisit this issue and collect additional area-specific data, particularly for the South Coast (Los Angeles) area, where road dust has been included in $PM_{2.5}$ hot-spot analyses.

Vehicle Weight

When applying AP-42 (Equations 1-3), vehicle weight should reflect a fleet average across the different vehicle types using the road. Larger vehicles create more wake (i.e., the circulating flow immediately behind the vehicle), increasing resuspension of dust (Transport Research Laboratory, 2014). The AP-42 document used 2 tons per car/light truck and 20 tons per heavy-duty truck as default values for vehicle weight; CARB assumed a California statewide average vehicle fleet weight of 2.4 tons per vehicle. Vehicle weight varies substantially by vehicle type; for example, the EMFAC model specifies four vehicle types (light heavy-duty truck T4, light heavy-duty truck T5, medium heavy-duty truck T6, and heavy heavy-duty truck T7), as trucks and their weights range from 4.625 to 23.25 tons (see **Table 2-16** for assumed vehicle weights for various vehicle classifications). There is very limited discussion and guidance on how to estimate average vehicle weight for road dust emissions estimation. However, for analysts seeking to develop a project-specific average vehicle weight, EMFAC vehicle weights and county-specific data on VMT distributions by vehicle type could be used with project-specific vehicle fleet information (e.g., truck and non-truck percentages) to develop an average vehicle weight value that is representative of project conditions. For example, the EMFAC2014 data from the web database (see http://www.arb.ca.gov/emfac/2014) suggest that the Los Angeles County average fleet (excluding motorcycles, motor homes, and buses from this calculation example) in 2020 includes VMT proportions of:

55% LDV, 5% LDT1, 20% LDT2, 12% MDV, 2% LHDT1, 1% LHDT2, 2% MHDT, and 3% HHDT.

Using these VMT proportions and the weight by vehicle type from Table 2-16, the fleet average vehicle weight can be estimated:

$$0.55x1.479+0.05x1.688+0.2x2.375+0.12x3.563+0.02x4.625+0.01x6+0.02x11.75+0.03x23.25 \approx 2.89 \text{ tons.}$$

Table 2-16. Average weight by vehicle type from the EMFAC model.

Vehicle Type	Average Weight (tons)
Motorcycles (MC)	0.285[a]
Passenger Cars (LDV)	1.479[a]
Light-Duty Trucks T1 (LDT1)	1.688
Light-Duty Trucks T2 (LDT2)	2.375
Medium- Duty Trucks T3 (MDV)	3.563
Light-Heavy-Duty Trucks T4 (LHDT1)	4.625
Light-Heavy-Duty Trucks T5 (LHDT2)	6.000
Motor Homes (MH)	7.526[a]
School Buses (SBUS)	9.070[a]
Medium-Heavy-Duty Trucks T6 (MHDT)	11.750
Other Buses (OBUS)	19.594[a]
Urban Buses (UBUS)	16.556[a]
Heavy-Heavy-Duty Trucks T7 (HHDT)	23.250

[a] The average vehicle weights were obtained from EPA's MOVES2014a model database; vehicle weight data for these vehicle types are not available in EMFAC technical documents.

Traffic and Roadway Characteristics

Vehicle speed, road type, and other traffic and roadway characteristics are not specified in the AP-42 equations, but they may directly influence silt loading factors (U.S. Environmental Protection Agency, 2011). For example, one study documented a strong correlation between road surface silt loading and vehicle speed, and found road dust emissions are negligible when traffic speeds are below 10 mph; the study concluded that the VMT portion of stop-and-go traffic (associated with low speeds) should be excluded in emissions inventory development (National Cooperative Highway Research Program, 2008). A silt loading study in Clark County, Nevada, also found that the presence of curbs and gutters, stabilized shoulders, and good pavement conditions each reduce silt loading (National Cooperative Highway Research Program, 2008). In concept, improvements to default silt loading factors may include adjustments for these roadway characteristic factors.

Precipitation

The precipitation term in the AP-42 calculation equations is a correction applied to account for the residual mitigative effect of moisture (U.S. Environmental Protection Agency, 2011); its use can reduce dust emission estimates. Road moisture corrections can be made by determining the number of wet days or wet hours (those with at least 0.01 inches of precipitation) for the project area (e.g., see Table 8 in CARB's Paved Road Dust guidance document (California Air Resources Board, 2016) for the average days per year that California counties receive at least 0.01 inches of precipitation). However, considering precipitation impacts is most applicable when estimating annual average emissions. At the project scale, analysts will typically be concerned with maximum daily emissions for comparison with the daily (24-hour average) PM_{10} National Ambient Air Quality Standard (NAAQS). However, for projects in areas that are not in attainment of the annual $PM_{2.5}$ standard and for which road dust is being considered as part of project-level impacts, it may be appropriate to consider precipitation in the development of annual (based on average daily) $PM_{2.5}$ emissions estimates for road dust. This decision would need to be made as part of the interagency consultation process that is required for quantitative PM hot-spot analyses.

Transportable Fraction

EPA has recognized that some vegetation types capture low-level dust plumes. EPA published a conceptual method to account for near-source removal of particles in regional analyses, called Near Source Capture (NSC) (U.S. Environmental Protection Agency, 2005b). These removal mechanisms are not accounted for in the current emission inventories. The capture fraction is based on the simple idea that dust capture increases when density, leafiness, and the height of vegetation increase.[12] However, the effect of dust removal from land cover is considered highly variable (0% for barren landscapes, 25% for agricultural, scrub, sparse woodlands, and grasses to 100% for forest lands). The transportable fraction (TF) averages approximately 0.49 across all counties in the United States (U.S. Environmental Protection Agency, 2005b). EPA noted (in 2005, when it published its report), that the NSC fraction adjustment concept was valid tens to hundreds of meters from a roadway, and the percent reduction could be anywhere from 0% to 100% depending on the land use surrounding the roadway. However, EPA also noted that an NSC adjustment based on vegetation capture could not be used to adjust emission estimates where local-scale impacts were important, nor should the adjustment be applied to emissions input into Gaussian models (e.g., AERMOD) (U.S. Environmental Protection Agency, 2005b). Therefore, at this time, it appears the TF method cannot be applied to project-level transportation assessments. This may be an important adjustment concept in future emissions inventory development as the impact of roadside barriers is considered on project-level air

[12] The EPA report referenced in this discussion references a Western Regional Air Partnership (WRAP) study, which concluded that "ground level fugitive dust from soil disturbed by man's activities is likely to be removed close to the source…the low release height and turbulence leaves particles temporarily close to the ground where they are subject to removal by impact on nearby horizontal and vertical surfaces, including vegetation and structures." The referenced WRAP study goes on to say that a "forest" is considered a very good filter, both horizontally and vertically. If foliage is dense enough to block light, it also effectively filters particles. See http://www3.epa.gov/ttnchie1/emch/dustfractions/transportable_fraction_080305_rev.pdf.

quality impacts. Also, EPA's report is more than a decade old, and there is now interagency interest in further examination of the impact of near-road barriers, including vegetation.

2.2.5 Recommendations for Next Steps

The AP-42-based road dust emissions calculation methods were developed primarily to assist with regional-level analyses; for project-level emissions assessment, there are limitations and data gaps in calculating road dust emissions from localized roadway activities. In particular, silt loading values and average vehicle weights developed for statewide or regional emissions estimates may not be representative of conditions at the project scale. To improve emissions estimates for re-entrained road dust from transportation projects in California, we recommend the following steps:

- Work with CARB to determine an appropriate freeway silt loading for Los Angeles and Orange counties, where use of the statewide default (0.015 g/m^2) would result in a value that exceeds the recommended local silt loading for major and collector roads (0.013 g/m^2).
- Develop a long-term plan for collecting silt loading data for areas in California that are subject to PM hot-spot requirements.
- Develop guidance or recommended values for estimating average vehicle weights at the project scale. This is an important parameter for road dust emissions estimation and one that may vary significantly among project scenarios based on fleet composition. This work can leverage CT-EMFAC's characterization of the fleet into various truck and non-truck categories.
- Further evaluate the potential applicability of precipitation correction factors (daily vs. hourly) at the project scale.
- Investigate, with EPA, the ability to credit near-road barriers and vegetation with PM and road dust removal or reduction.

In addition, other sub-topics related to estimating re-entrained road dust emissions may warrant further research, including silt measurement technology and adjustment factors due to speed, roadway type, land use, or activity variability. As these topics become better understood, they may be incorporated into emission estimation methods to improve the accuracy of road dust emission estimations for project-level assessments.

2.3 Emissions Processing Tool Development

2.3.1 EM4AQ Information and User's Guide

Overview

EM4AQ (file "EM4AQ Tool v1.1 Beta.xlsm") is a Microsoft Excel spreadsheet-based tool, which processes CT-EMFAC particulate matter (PM) emission factors data and project-specific travel activity data to generate emissions input for AERMOD air quality modeling. EM4AQ calculates hourly PM emission rates for roadway sources defined in AERMOD View and includes automated features to generate an hourly emission rate file formatted for use in AERMOD View runs. The tool also reports the hourly emission rates in a format that can be directly copied and pasted into the AERMOD View graphical user interface (GUI).

As illustrated in Figure 2-12, EM4AQ builds the link between CT-EMFAC and AERMOD View with automated data processing functions to help reduce the tedious manual work of developing AERMOD View-ready PM emissions input. Before using EM4AQ, the user should have already determined the basic project scenario information (e.g., geographic area, analysis year and season), obtained the corresponding CT-EMFAC outputs for g/mi PM emission factors (including running exhaust, brake wear, and tire wear), and set up roadway sources in AERMOD View for the analyzed project.

EM4AQ requires the following inputs:

- CT-EMFAC2014 version 6.0 emission factor output files (in CSV format) by vehicle category (separate data files for non-trucks and trucks, or separate data files for Non-trucks, Truck 1, and Truck 2, obtained from CT-EMFAC2014 runs).
- The daily time periods used to characterize project-level travel activity data for 24 hours (e.g., overnight, morning peak, midday, afternoon peak, and evening).
- The SO Pathway Partial Input File for the project, which is exported from AERMOD View after specifying the project emission sources for roadway links using the AERMOD View user interface.
- Roadway type (freeway, arterial/collector road, or local road) and travel activity data (traffic volume and average speed) for each roadway source by time period.

EM4AQ generates hourly PM_{10} or $PM_{2.5}$ emission rate outputs for each roadway source created in AERMOD View. These output data represent emissions strength for the roadway sources and are ready for importing into AERMOD View to model near-road air pollutant concentrations.

Note: *For air quality modeling, volume or area sources can be used to represent roadway sources. There are several ways to represent a roadway with volume or area sources in AERMOD View, including*

use of a line volume source (a series of volumes), line area source (a series of areas), or line source (an individual area). This version of the EM4AQ tool processes hourly emission rates data for all three of those source types. However, the current version of AERMOD View (version 9.1) has an error that prevents users from using an external hourly emission rate file for modeling line area sources. ***As a best practice, it is recommended that users of the EM4AQ tool define roadway sources in AERMOD View as line volume sources for the analyzed project.***

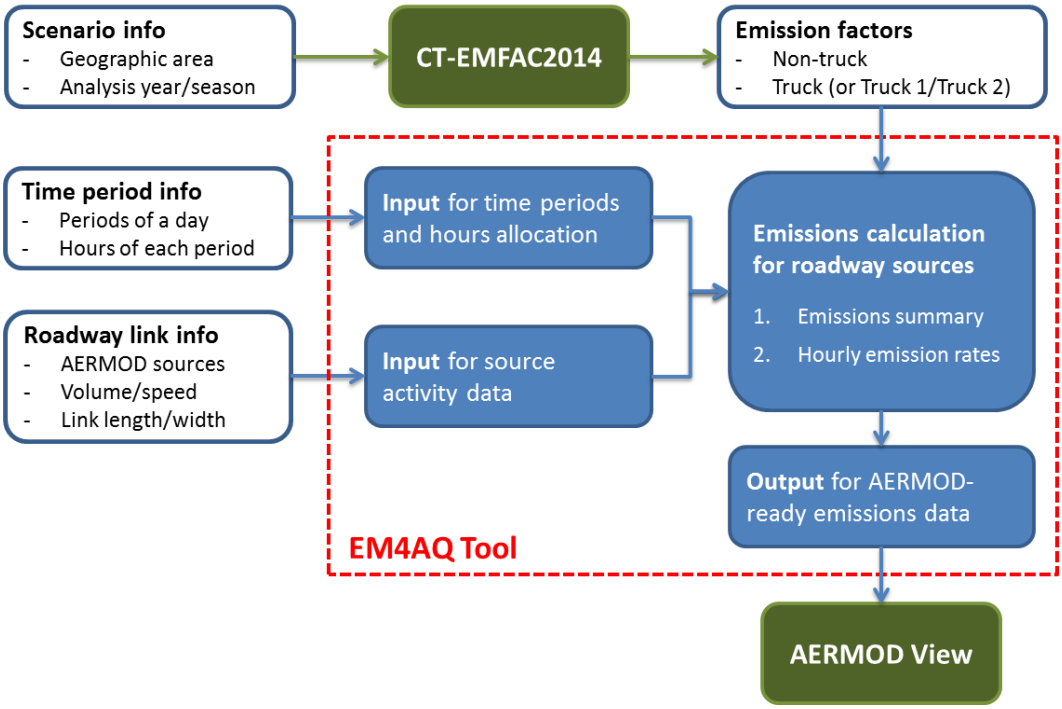


Figure 2-12. Illustration of the EM4AQ tool structure and data flow.

The EM4AQ tool contains several worksheets (or tabs):

- **ReadMe** holds the quick start guide.
- **Scenario Setup** is the worksheet where users provide inputs and execute tool functions.
- **Intermediate Data** stores CT-EMFAC emissions data, traffic time period inputs, and roadway type categories used for calculating hourly emissions rates.
- **Source Input** stores default and user-entered input data by roadway source.
- **Emissions Summary** contains the estimated emissions by emission process and vehicle category.
- **Source Output** contains the calculated hourly emission rates by roadway source.
- **Documentation Form** provides a standard Caltrans documentation form.

Using the EM4AQ Tool

It is recommended that users access the EM4AQ Tool (open the Excel spreadsheet file) from their local drive instead of a shared drive. The user follows seven work steps on the **Scenario Setup** worksheet to obtain hourly emission rates formatted for AERMOD View runs. These steps involve using drop-down menus, pop-up interfaces, or function buttons to specify and enter scenario input data (see Figures 2-13 and 2-14). It is recommended that a scenario name for the analyzed project be entered at the top of the **Scenario Setup** worksheet; it is good practice to create a concise scenario name that is consistent with the name used (if any) in an AERMOD View run. A green check mark appears to the left of the step number after each step is complete. The panels with gray backgrounds at the right of the function buttons summarize the input information the user has provided after the associated input files and data have been loaded or entered successfully.

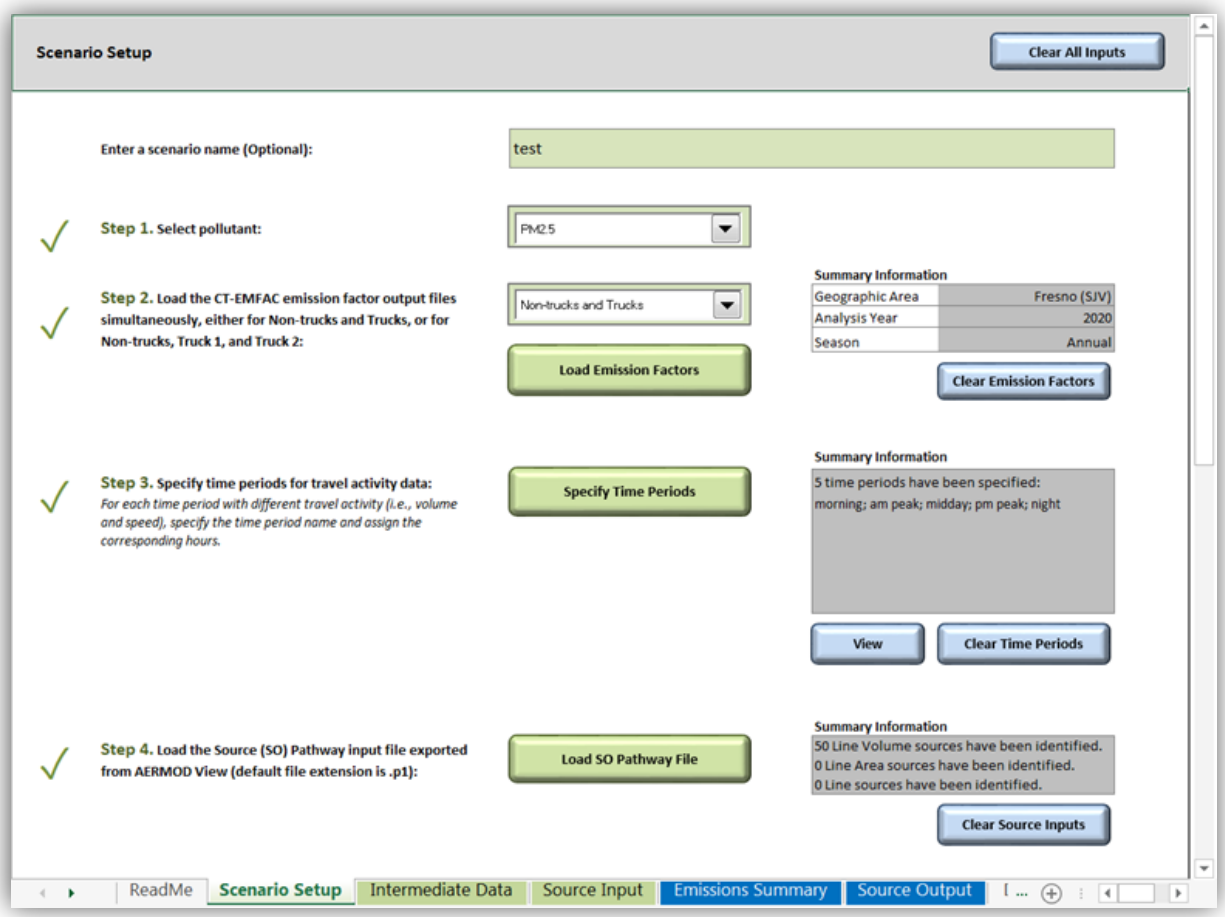


Figure 2-13. EM4AQ **Scenario Setup** worksheet for a hypothetical project after the inputs for Steps 1 through 4 have been specified.

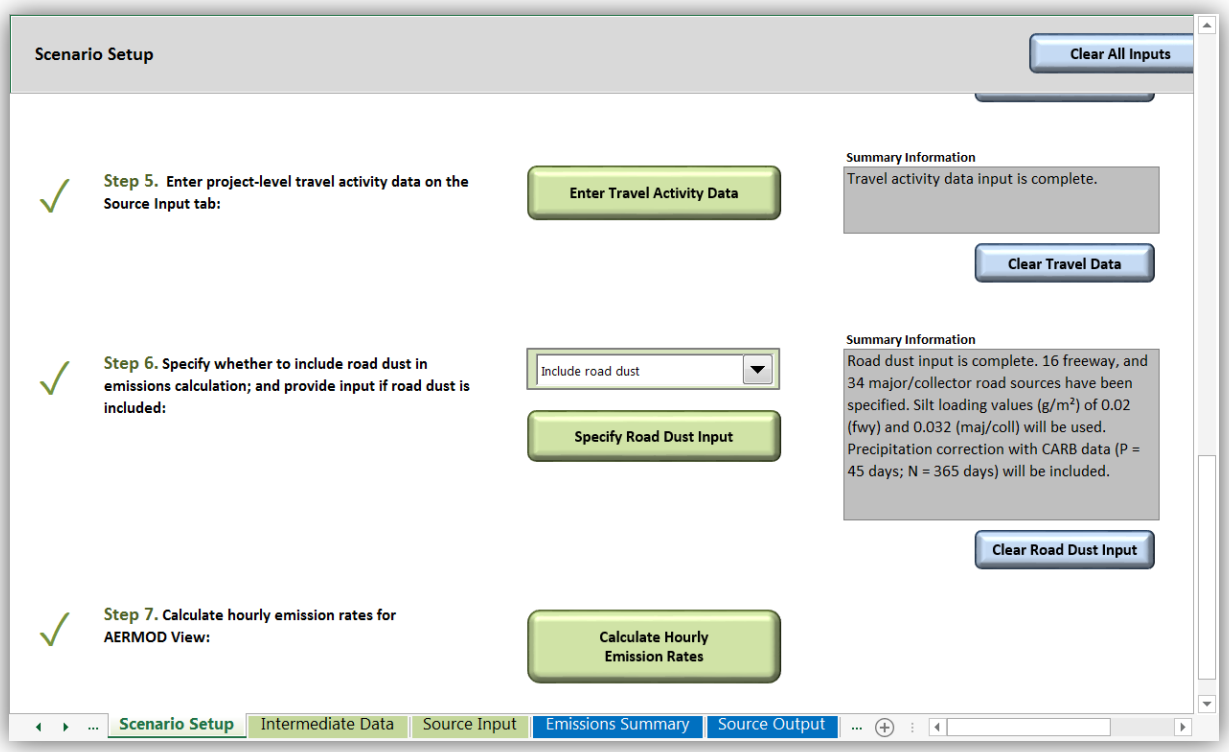


Figure 2-14. EM4AQ **Scenario Setup** worksheet for a hypothetical project after the inputs for Steps 5 and 6 have been specified and a calculation of hourly emission rates (Step 7) has been completed.

Step 1. Select pollutant of interest

Select the pollutant of interest (either PM_{10} or $PM_{2.5}$) using the drop-down menu. For both pollutants, the emissions processed in this tool include running exhaust, brake wear, and tire wear. The option to include estimates of road dust emissions is available (see Step 6 for details).

Step 2. Load CT-EMFAC emission factor output files

From the drop-down menu, select either "Non-trucks and Trucks" or "Non-trucks, Truck 1, and Truck 2," depending on which set of emission factor files have been obtained from CT-EMFAC2014. As shown in the two examples in Figure 2-15, CT-EMFAC2014 should be used to create pollutant g/mi emission factors for non-trucks (by specifying 100% "Non-Truck" category) and trucks (by specifying 100% "Truck" category with default Truck 1 and Truck 2 proportions). In this example, the corresponding emission factors files are saved as *Fresno (SJV) - 2020 - Annual - NonTruck.EF.csv* and *Fresno (SJV) - 2020 - Annual - Truck.EF.csv*. Regardless of the emission factor file name, the tool determines which vehicle type it represents and what pollutant data to import from the contents of each file. However, a best practice is to append the default CT-EMFAC file names with "Truck" and "NonTruck" (or "Truck1", "Truck2", and "NonTruck"), so that the file names are consistent with the emission factors data included in the files. These files are saved in the Input-Output folder under the

CT-EMFAC2014 model package; it is recommended that these emission factors files be moved to the folder where the EM4AQ spreadsheet is saved.

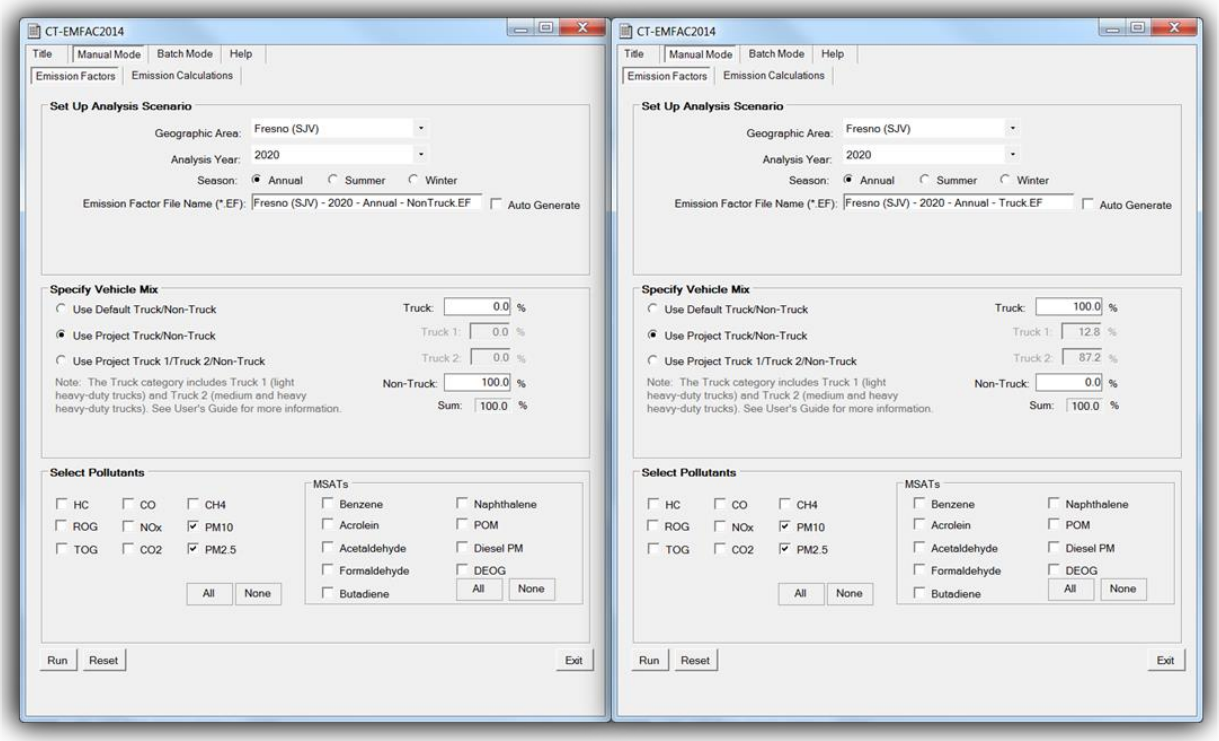


Figure 2-15. Screenshots of CT-EMFAC2014 runs used to generate PM emission factors files for Non-trucks and Trucks.

Once the correct option has been selected in the drop-down menu, choose **Load Emission Factors** and select and open the appropriate CT-EMFAC output files (use the **Shift** or **Control** keys to select the multiple files simultaneously) from the **Select Emission Factor Files** pop-up browser window. The set of two files (Non-trucks and Trucks) or the set of three files (Non-Trucks, Truck 1, and Truck 2) must be loaded simultaneously in this step. This browser window is illustrated in Figure 2-16, with files selected for non-trucks and trucks for a hypothetical project.

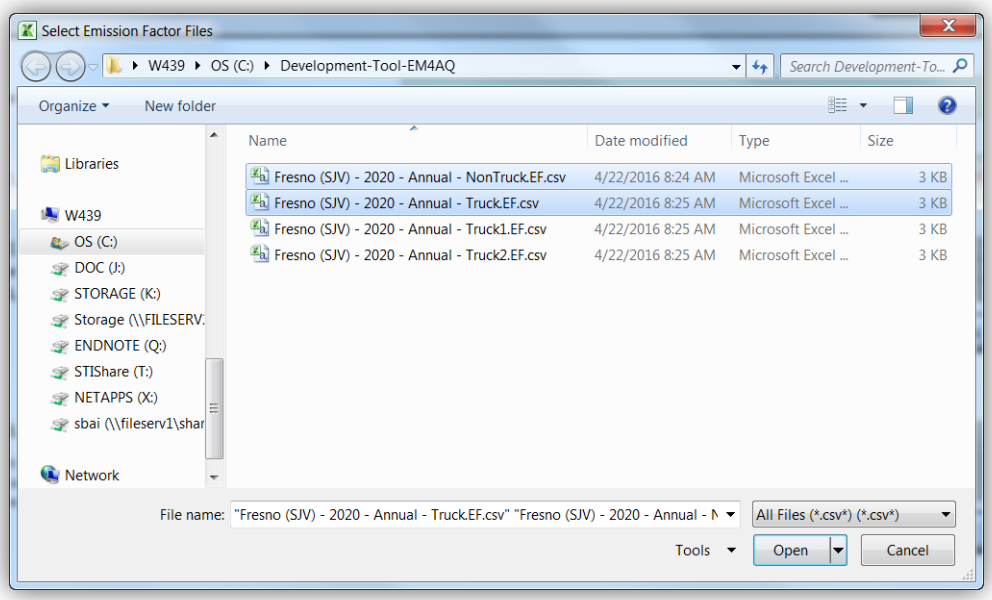


Figure 2-16. **Select Emission Factor Files** browser window used to load CT-EMFAC emission factor output files for non-trucks and trucks (or emission factor output files for non-trucks, truck 1, and truck 2, depending on the user's selection from the Step 2 drop-down menu).

Step 3. Specify Time Periods

Choose **Specify Time Periods** to open the **Specify Travel Activity Time Periods** user interface and assign hours to the time periods (see Figure 2-17 for an example). These time periods should correspond to those specified for the project-specific travel activity data (e.g., volume and speed), and should cover 24 hours. For each time period:

- Enter the name of the time period in the **Specify Time Period Name** text box. The names created for time periods are case sensitive.
- Select the corresponding hours from the **Available Hours** list, choose the right-arrow to move them to the **Selected Hours** list, and choose **Add Time**. Choose **Auto Generate 24 Periods** when specifying each hour as a single time period.
- As needed, choose **Clear** to reset all time periods that have been specified.
- After assigning all 24 hours to the traffic time periods, choose **Done**.

The **Summary Information** panel on the **Scenario Setup** worksheet summarizes the specified time periods. Choose **View** to review the time period names and corresponding hours.

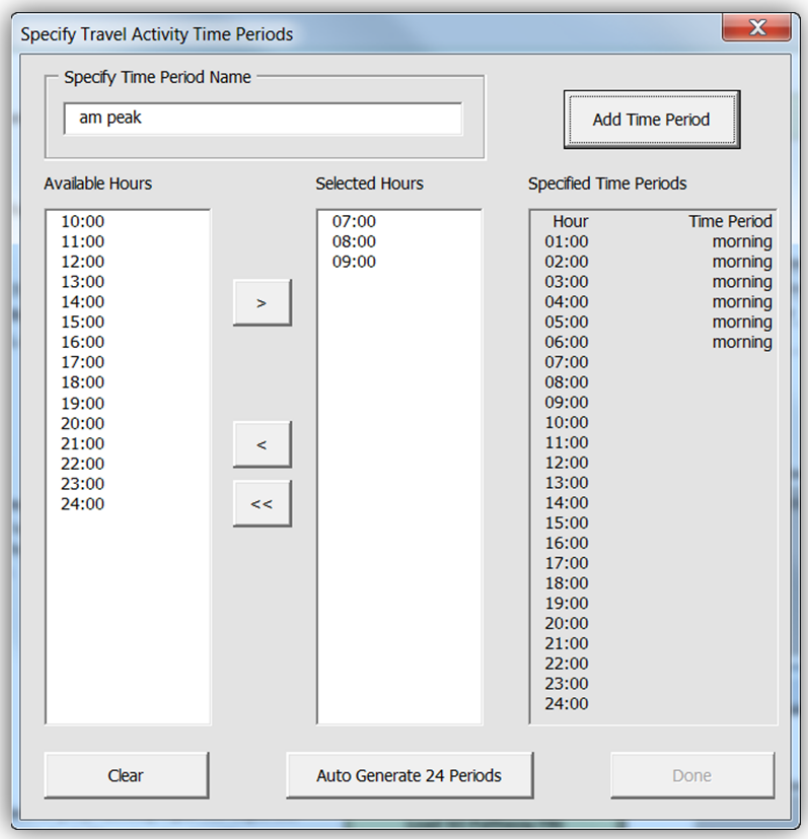


Figure 2-17. User interface for specifying time periods. The example shows that hours are selected from the "Available Hours" list on the left and assigned to time periods named by the user in the panel at the top of the interface.

Step 4. Load Source Pathway Partial Input File

This step requires input of the SO Pathway Partial Input file exported from AERMOD View after the roadway sources have been specified in AERMOD View. EM4AQ will directly use the source ID included in the SO Pathway Partial Input file to partially populate the **Source Input** tab, where users specify travel activity data. As a best practice, when creating sources in AERMOD View, users should match the source IDs used in AERMOD View and the roadway link IDs (corresponding to travel activity data).

To obtain the SO Pathway Partial Input file (with default file name extension of *.p1*), use the **Export** menu from the AERMOD View user interface, and select **Pathway to File ► SO Pathway** to File, as illustrated in Figure 2-18. Choose **Load SO Pathway File** on the **Scenario Setup** worksheet, and select and open the file from the pop-up browser window. A message box with a progress bar shows the status of file loading and will close when the file has been successfully loaded. The panel at the right of this step summarizes the number of line volume, line area, and/or line sources identified in the SO Pathway Partial Input file.

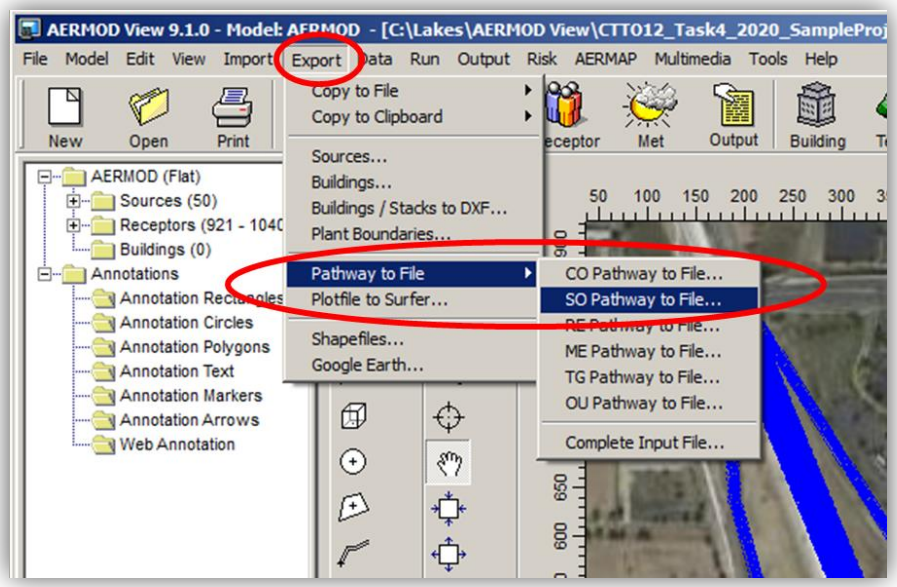
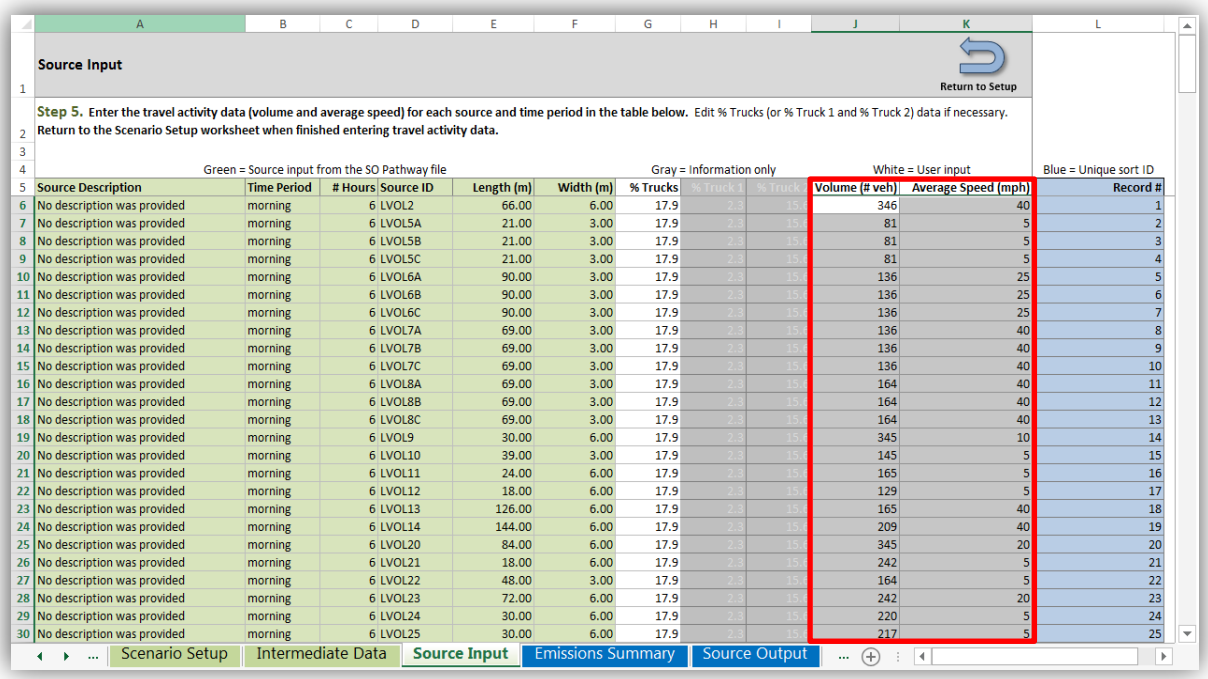


Figure 2-18. Exporting a SO Pathway Partial Input File from AERMOD View.

Step 5. Enter Travel Activity Data

Choose **Enter Travel Activity Data** or navigate to the **Source Input** worksheet to specify the traffic volumes (number of vehicles) and average speeds (mph), by time period, for each source identified in the SO Pathway Partial Input file. Figure 2-19 highlights the volume and speed data columns on the **Source Input** worksheet.

- The **% Truck** (or **% Truck 1** and **% Truck 2**, depending on which set of emission factor files was loaded) data are populated using the EMFAC2014 default values that reflect the county-wide average vehicle fleet mix; users may update these values (by link source and time period, e.g., for link sources that represent HOV lanes or mixed flow lanes) to reflect project-specific information, as needed.
- Traffic volume inputs must include positive numbers, and average speed values must be between 0 and 90 mph.
- The **Record #** column includes unique IDs for users to index each row of the data table; users may use these record numbers to facilitate preparation of travel activity data (e.g., sorting this input table externally to match the original travel activity data table records for the analyzed project).
- After specifying all source inputs, return to the **Scenario Setup** worksheet.



Source Input

Return to Setup

Step 5. **Enter the travel activity data (volume and average speed) for each source and time period in the table below.** Edit % Trucks (or % Truck 1 and % Truck 2) data if necessary. **Return to the Scenario Setup worksheet when finished entering travel activity data.**

Green = Source input from the SO Pathway file | Gray = Information only | White = User input | Blue = Unique sort ID

Source Description	Time Period	# Hours	Source ID	Length (m)	Width (m)	% Trucks	% Truck 1	% Truck 2	Volume (# veh)	Average Speed (mph)	Record #
No description was provided	morning	6	LVOL2	66.00	6.00	17.9	2.3	15.7	346	40	1
No description was provided	morning	6	LVOL5A	21.00	3.00	17.9	2.3	15.7	81	5	2
No description was provided	morning	6	LVOL5B	21.00	3.00	17.9	2.3	15.7	81	5	3
No description was provided	morning	6	LVOL5C	21.00	3.00	17.9	2.3	15.7	81	5	4
No description was provided	morning	6	LVOL6A	90.00	3.00	17.9	2.3	15.7	136	25	5
No description was provided	morning	6	LVOL6B	90.00	3.00	17.9	2.3	15.7	136	25	6
No description was provided	morning	6	LVOL6C	90.00	3.00	17.9	2.3	15.7	136	25	7
No description was provided	morning	6	LVOL7A	69.00	3.00	17.9	2.3	15.7	136	40	8
No description was provided	morning	6	LVOL7B	69.00	3.00	17.9	2.3	15.7	136	40	9
No description was provided	morning	6	LVOL7C	69.00	3.00	17.9	2.3	15.7	136	40	10
No description was provided	morning	6	LVOL8A	69.00	3.00	17.9	2.3	15.7	164	40	11
No description was provided	morning	6	LVOL8B	69.00	3.00	17.9	2.3	15.7	164	40	12
No description was provided	morning	6	LVOL8C	69.00	3.00	17.9	2.3	15.7	164	40	13
No description was provided	morning	6	LVOL9	30.00	6.00	17.9	2.3	15.7	345	10	14
No description was provided	morning	6	LVOL10	39.00	3.00	17.9	2.3	15.7	145	5	15
No description was provided	morning	6	LVOL11	24.00	6.00	17.9	2.3	15.7	165	5	16
No description was provided	morning	6	LVOL12	18.00	6.00	17.9	2.3	15.7	129	5	17
No description was provided	morning	6	LVOL13	126.00	6.00	17.9	2.3	15.7	165	40	18
No description was provided	morning	6	LVOL14	144.00	6.00	17.9	2.3	15.7	209	40	19
No description was provided	morning	6	LVOL20	84.00	6.00	17.9	2.3	15.7	345	20	20
No description was provided	morning	6	LVOL21	18.00	6.00	17.9	2.3	15.7	242	5	21
No description was provided	morning	6	LVOL22	48.00	3.00	17.9	2.3	15.7	164	5	22
No description was provided	morning	6	LVOL23	72.00	6.00	17.9	2.3	15.7	242	20	23
No description was provided	morning	6	LVOL24	30.00	6.00	17.9	2.3	15.7	220	5	24
No description was provided	morning	6	LVOL25	30.00	6.00	17.9	2.3	15.7	217	5	25

Scenario Setup | Intermediate Data | Source Input | Emissions Summary | Source Output

Figure 2-19. EM4AQ Tool **Source Input** worksheet, highlighting the columns with required user inputs of traffic volume and average speed for each roadway source and time period.

Step 6. Specify Road Dust Emissions Input

Specify whether to include road dust emissions by selecting either "Include road dust" or "Do not include road dust" from the drop-down menu. Road dust emissions are calculated using the EPA-approved AP-42 method and CARB default parameter values, which are summarized in Tables 2-17 and 2-18. If road dust is included in the calculation of hourly emission rates, choose **Specify Road Dust Input** to open the **Road Dust Inputs** user interface. Specify the road dust inputs as follows (illustrated in Figure 2-20 for a hypothetical project):

- In the **Select and Assign Sources to Road Type Categories** panel, assign each project roadway source to a road type category (i.e., freeway, major or collector road, or local road) by selecting the sources (using the **Shift** or **Control** keys to select multiple sources simultaneously) in the **Available Sources** list box and choosing **Assign** below the appropriate road type category list box. The number of sources assigned to each category will appear in parentheses next to the category name above the list boxes. If a source is assigned to the wrong category, select it and choose **Remove** under the category list box to move it back to the **Available Sources** list for reassignment.
- The **Road Surface Silt Loading (g/m^2)** panel shows the CARB default silt loading values. To provide project-specific silt loading values, deselect the **Use CARB defaults** check box and edit the relevant values. When using the CARB defaults, check the box for **San Joaquin Valley (SJV) Rural Area** if the project is in a rural area of the San Joaquin Valley (SJV) and includes

local roads. If that box is not checked, the tool will use the default CARB silt loading values that are appropriate for an SJV urban area.

- To include a precipitation correction, check the box in the **Precipitation Correction** panel, and choose either the **CARB data** or **User-defined inputs** option. The precipitation correction in EM4AQ uses the number of days with at least 0.01 inches of precipitation (**P**) during the averaging period (**N**) for the project geographic area. When the **CARB data** option is selected, EM4AQ will use the CARB default P and N values for an annual averaging period. When the **User-defined inputs** option is selected, specify whether the data provided is in units of days or hours by selecting the unit from the **Units** drop-down menu, and enter values for P and N.

Table 2-17. CARB data for particle size multipliers for the paved road equation.

Particle Size Multiplier, k (lb/VMT)	
PM_{10}	$PM_{2.5}$
0.0022	0.00033

Table 2-18. CARB silt loading values for California.

Region	Silt Load by Roadway Type and Location (g/m^2)		
	Freeway	Major Road / Collector Road	Local Road
Statewide	0.015	0.032	0.32
Los Angeles and Orange Counties	–	0.013	0.135
Riverside and San Bernardino Counties	–	0.08	0.84
San Joaquin Valley Air Pollution Control District	–	–	1.6

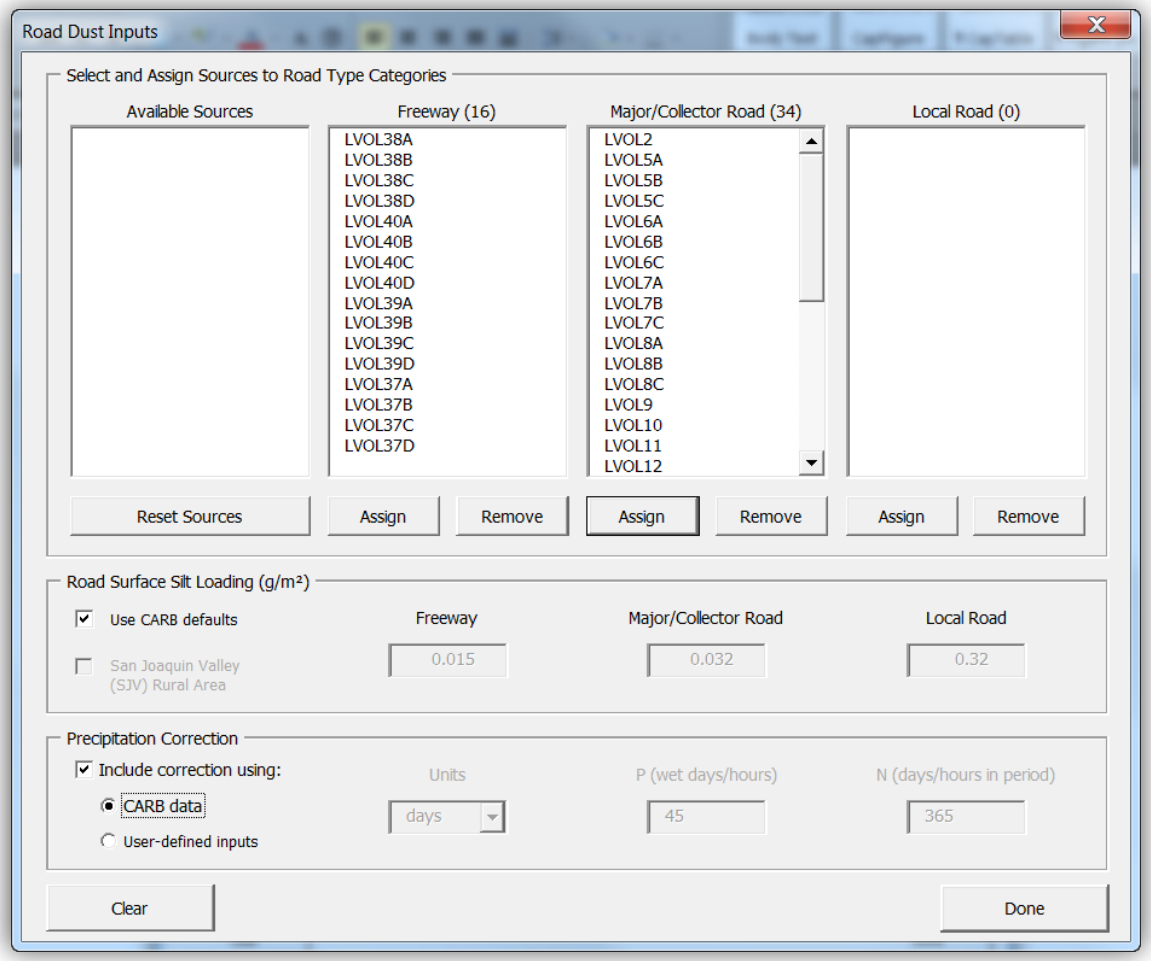
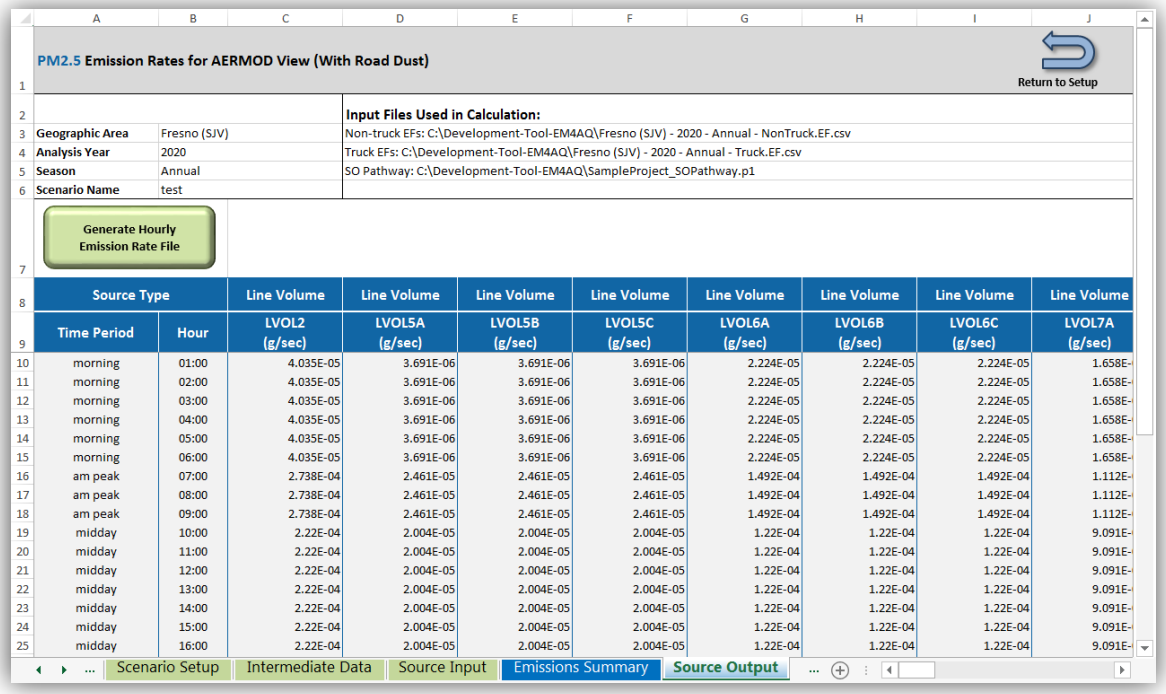


Figure 2-20. **Road Dust Inputs** user interface showing selections for a hypothetical project.

Step 7. Calculate Hourly Emission Rates

Choose **Calculate Hourly Emission Rates** to execute the calculation. The tool automatically navigates to the **Source Output** worksheet when the calculation is complete. The output data presented in this worksheet are AERMOD-ready hourly emission rates (e.g., g/s for each line volume source or g/s/m^2 for each line area and line source). Figure 2-21 shows the **Source Output** worksheet with sample data for a hypothetical project (with line volume sources defined in AERMOD View). From the **Source Output** worksheet, you may copy the columns of hourly emission rate values from the data table and paste them directly into the **Variable Emissions** screen of AERMOD View.

The total emissions (grams per day) for each individual roadway source are also summarized by process and vehicle category on the **Emissions Summary** worksheet, which is populated at the same time as the **Source Output** worksheet. As shown in Figure 2-22, the PM emissions by source are summarized for four emission processes: running exhaust, tire wear, brake wear, and road dust. The proportion of non-truck emissions and truck emissions for each source is also provided; these proportions can be used as needed for developing emissions-weighted average release heights and plume heights in further AERMOD modeling for the analyzed project.



PM2.5 Emission Rates for AERMOD View (With Road Dust)

Return to Setup

Geographic Area	Fresno (SJV)
Analysis Year	2020
Season	Annual
Scenario Name	test

Input Files Used in Calculation:

Non-truck EFs: C:\Development-Tool-EM4AQ\Fresno (SJV) - 2020 - Annual - NonTruck.EF.csv

Truck EFs: C:\Development-Tool-EM4AQ\Fresno (SJV) - 2020 - Annual - Truck.EF.csv

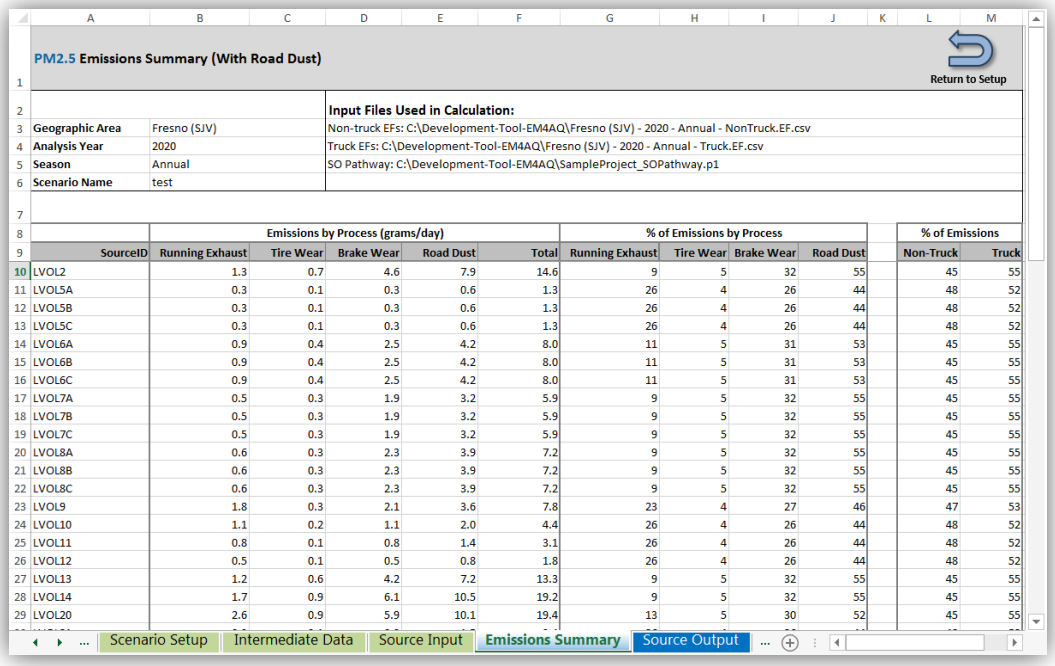
SO Pathway: C:\Development-Tool-EM4AQ\SampleProject_SOPathway.p1

Generate Hourly Emission Rate File

Source Type		Line Volume	Line Volume	Line Volume	Line Volume	Line Volume	Line Volume	Line Volume	Line Volume
Time Period	**Hour**	**LVOL2 (g/sec)**	**LVOL5A (g/sec)**	**LVOL5B (g/sec)**	**LVOL5C (g/sec)**	**LVOL6A (g/sec)**	**LVOL6B (g/sec)**	**LVOL6C (g/sec)**	**LVOL7A (g/sec)**
morning	01:00	4.035E-05	3.691E-06	3.691E-06	3.691E-06	2.224E-05	2.224E-05	2.224E-05	1.658E-
morning	02:00	4.035E-05	3.691E-06	3.691E-06	3.691E-06	2.224E-05	2.224E-05	2.224E-05	1.658E-
morning	03:00	4.035E-05	3.691E-06	3.691E-06	3.691E-06	2.224E-05	2.224E-05	2.224E-05	1.658E-
morning	04:00	4.035E-05	3.691E-06	3.691E-06	3.691E-06	2.224E-05	2.224E-05	2.224E-05	1.658E-
morning	05:00	4.035E-05	3.691E-06	3.691E-06	3.691E-06	2.224E-05	2.224E-05	2.224E-05	1.658E-
morning	06:00	4.035E-05	3.691E-06	3.691E-06	3.691E-06	2.224E-05	2.224E-05	2.224E-05	1.658E-
am peak	07:00	2.738E-04	2.461E-05	2.461E-05	2.461E-05	1.492E-04	1.492E-04	1.492E-04	1.112E-
am peak	08:00	2.738E-04	2.461E-05	2.461E-05	2.461E-05	1.492E-04	1.492E-04	1.492E-04	1.112E-
am peak	09:00	2.738E-04	2.461E-05	2.461E-05	2.461E-05	1.492E-04	1.492E-04	1.492E-04	1.112E-
midday	10:00	2.22E-04	2.004E-05	2.004E-05	2.004E-05	1.22E-04	1.22E-04	1.22E-04	9.091E-
midday	11:00	2.22E-04	2.004E-05	2.004E-05	2.004E-05	1.22E-04	1.22E-04	1.22E-04	9.091E-
midday	12:00	2.22E-04	2.004E-05	2.004E-05	2.004E-05	1.22E-04	1.22E-04	1.22E-04	9.091E-
midday	13:00	2.22E-04	2.004E-05	2.004E-05	2.004E-05	1.22E-04	1.22E-04	1.22E-04	9.091E-
midday	14:00	2.22E-04	2.004E-05	2.004E-05	2.004E-05	1.22E-04	1.22E-04	1.22E-04	9.091E-
midday	15:00	2.22E-04	2.004E-05	2.004E-05	2.004E-05	1.22E-04	1.22E-04	1.22E-04	9.091E-
midday	16:00	2.22E-04	2.004E-05	2.004E-05	2.004E-05	1.22E-04	1.22E-04	1.22E-04	9.091E-

Scenario Setup | Intermediate Data | Source Input | Emissions Summary | Source Output

Figure 2-21. EM4AQ Tool **Source Output** worksheet showing calculated hourly emission rates for sources in a hypothetical project.



PM2.5 Emissions Summary (With Road Dust)

Return to Setup

Geographic Area	Fresno (SJV)
Analysis Year	2020
Season	Annual
Scenario Name	test

Input Files Used in Calculation:

Non-truck EFs: C:\Development-Tool-EM4AQ\Fresno (SJV) - 2020 - Annual - NonTruck.EF.csv

Truck EFs: C:\Development-Tool-EM4AQ\Fresno (SJV) - 2020 - Annual - Truck.EF.csv

SO Pathway: C:\Development-Tool-EM4AQ\SampleProject_SOPathway.p1

	Emissions by Process (grams/day)					% of Emissions by Process				% of Emissions	
SourceID	Running Exhaust	Tire Wear	Brake Wear	Road Dust	Total	Running Exhaust	Tire Wear	Brake Wear	Road Dust	Non-Truck	Truck
LVOL2	1.3	0.7	4.6	7.9	14.6	9	5	32	55	45	55
LVOL5A	0.3	0.1	0.3	0.6	1.3	26	4	26	44	48	52
LVOL5B	0.3	0.1	0.3	0.6	1.3	26	4	26	44	48	52
LVOL5C	0.3	0.1	0.3	0.6	1.3	26	4	26	44	48	52
LVOL6A	0.9	0.4	2.5	4.2	8.0	11	5	31	53	45	55
LVOL6B	0.9	0.4	2.5	4.2	8.0	11	5	31	53	45	55
LVOL6C	0.9	0.4	2.5	4.2	8.0	11	5	31	53	45	55
LVOL7A	0.5	0.3	1.9	3.2	5.9	9	5	32	55	45	55
LVOL7B	0.5	0.3	1.9	3.2	5.9	9	5	32	55	45	55
LVOL7C	0.5	0.3	1.9	3.2	5.9	9	5	32	55	45	55
LVOL8A	0.6	0.3	2.3	3.9	7.2	9	5	32	55	45	55
LVOL8B	0.6	0.3	2.3	3.9	7.2	9	5	32	55	45	55
LVOL8C	0.6	0.3	2.3	3.9	7.2	9	5	32	55	45	55
LVOL9	1.8	0.3	2.1	3.6	7.8	23	4	27	46	47	53
LVOL10	1.1	0.2	1.1	2.0	4.4	26	4	26	44	48	52
LVOL11	0.8	0.1	0.8	1.4	3.1	26	4	26	44	48	52
LVOL12	0.5	0.1	0.5	0.8	1.8	26	4	26	44	48	52
LVOL13	1.2	0.6	4.2	7.2	13.3	9	5	32	55	45	55
LVOL14	1.7	0.9	6.1	10.5	19.2	9	5	32	55	45	55
LVOL20	2.6	0.9	5.9	10.1	19.4	13	5	30	52	45	55

Scenario Setup | Intermediate Data | Source Input | Emissions Summary | Source Output

Figure 2-22. EM4AQ Tool **Emissions Summary** worksheet showing calculated emissions by emission process and vehicle category for sources in a hypothetical project.

Optional Step. Create and Use Hourly Emission Rate File

For scenarios that involve many roadway sources, manually copying and pasting hourly emission rates data into AERMOD View is very time-consuming. As an alternative to manually entering AERMOD-ready hourly emission rates data into AERMOD View, the EM4AQ tool provides an automated function to generate a large data file (the hourly emission rate file) with variable emission rates for AERMOD View use:

- Choose **Generate Hourly Emission Rate File** on the **Source Output** worksheet.
- In the **Hourly Emissions File Specifications** window, select or enter the ending year and number of years in the meteorological data period. For example, if the meteorological data set used for AERMOD View runs cover a five-year range from 2011 to 2015, the input in this tool should be "2015" for the ending year and "5" for number of years.
- Edit the name of the file as needed, or use the default file name. Figure 2-23 shows the **Hourly Emission Rate File Specifications** window with selections made for a hypothetical project.
- After making these selections, choose **Create File**. This hourly emission rate file can be very large (e.g., several gigabytes) and may take several minutes or longer to write (depending on the number of sources for the scenario). A **File Creation in Progress** window (shown in Figure 2-24) appears while the tool is writing the file; do not close this window until the tool has finished.

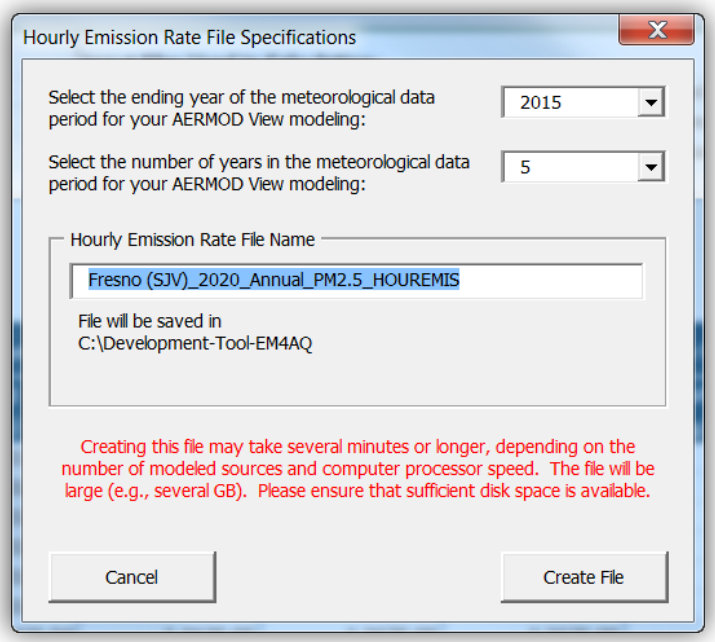


Figure 2-23. **Hourly Emission Rate File Specifications** window with sample data for a hypothetical project.

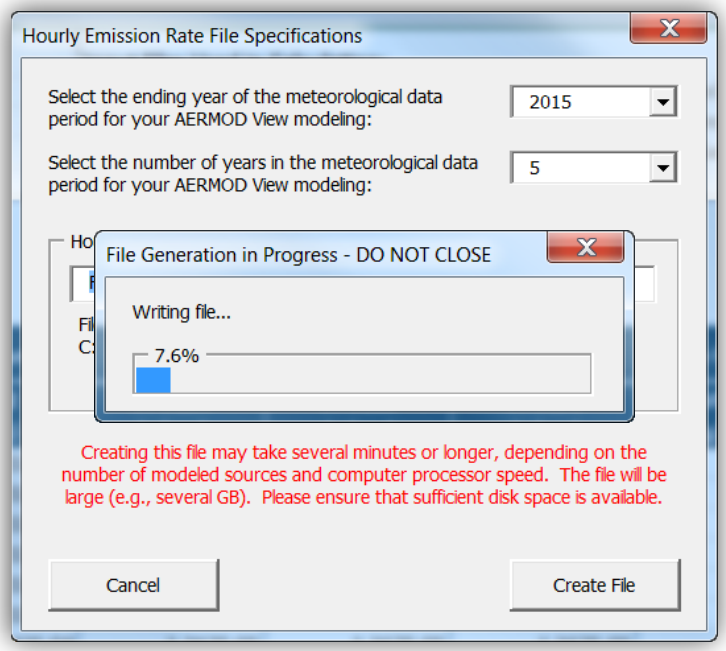


Figure 2-24. **File Generation in Progress** window during the creation of the hourly emission rate file showing the percentage of the file that has been written.

- Once the file creation is complete, a large .txt data file is saved in the same folder where the EM4AQ tool is stored (see Figures 2-25 and 2-26). This data file has a large file size because, as required by AERMOD modeling, it includes hourly emissions data for all link sources defined for the project across the entire data period consistent with the meteorological data. For example, the test case shown here includes 50 line volume sources and a 5-year meteorological data period; this hourly emission rate file ready for AERMOD View runs is approximately 8 gigabytes in size.

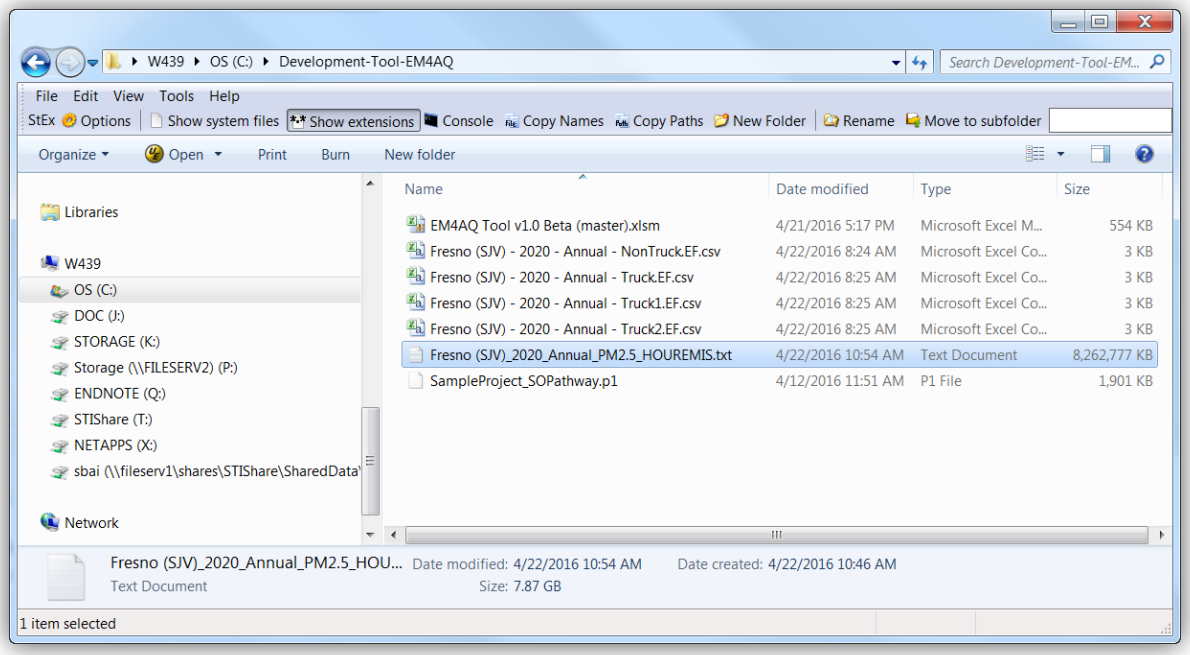
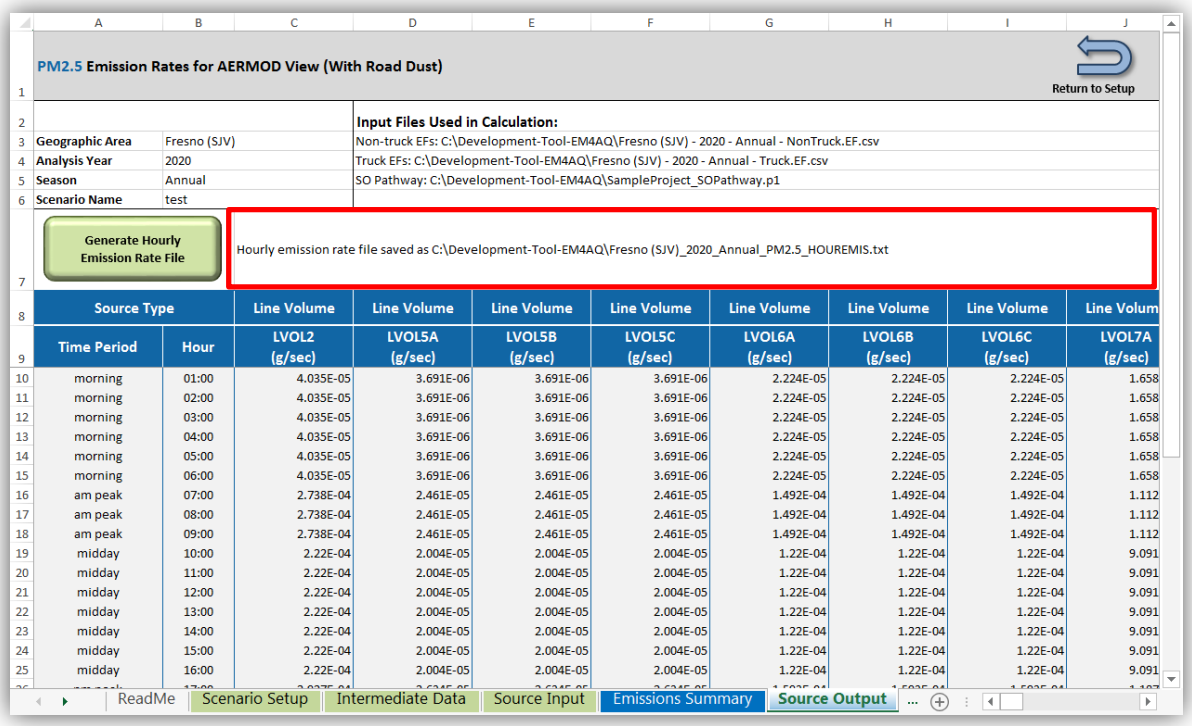


Figure 2-25. Hourly emission rates file created and saved in the folder.



PM2.5 Emission Rates for AERMOD View (With Road Dust)

Return to Setup

Geographic Area	Fresno (SJV)
Analysis Year	2020
Season	Annual
Scenario Name	test

Input Files Used in Calculation:
Non-truck EFs: C:\Development-Tool-EM4AQ\Fresno (SJV) - 2020 - Annual - NonTruck.EF.csv
Truck EFs: C:\Development-Tool-EM4AQ\Fresno (SJV) - 2020 - Annual - Truck.EF.csv
SO Pathway: C:\Development-Tool-EM4AQ\SampleProject_SOPathway.p1

Generate Hourly Emission Rate File

Hourly emission rate file saved as C:\Development-Tool-EM4AQ\Fresno (SJV)_2020_Annual_PM2.5_HOUREMIS.txt

Source Type		Line Volume	Line Volume	Line Volume	Line Volume	Line Volume	Line Volume	Line Volume	Line Volum
Time Period	Hour	LVOL2 (g/sec)	LVOL5A (g/sec)	LVOL5B (g/sec)	LVOL5C (g/sec)	LVOL6A (g/sec)	LVOL6B (g/sec)	LVOL6C (g/sec)	LVOL7A (g/sec)
morning	01:00	4.035E-05	3.691E-06	3.691E-06	3.691E-06	2.224E-05	2.224E-05	2.224E-05	1.658
morning	02:00	4.035E-05	3.691E-06	3.691E-06	3.691E-06	2.224E-05	2.224E-05	2.224E-05	1.658
morning	03:00	4.035E-05	3.691E-06	3.691E-06	3.691E-06	2.224E-05	2.224E-05	2.224E-05	1.658
morning	04:00	4.035E-05	3.691E-06	3.691E-06	3.691E-06	2.224E-05	2.224E-05	2.224E-05	1.658
morning	05:00	4.035E-05	3.691E-06	3.691E-06	3.691E-06	2.224E-05	2.224E-05	2.224E-05	1.658
morning	06:00	4.035E-05	3.691E-06	3.691E-06	3.691E-06	2.224E-05	2.224E-05	2.224E-05	1.658
am peak	07:00	2.738E-04	2.461E-05	2.461E-05	2.461E-05	1.492E-04	1.492E-04	1.492E-04	1.112
am peak	08:00	2.738E-04	2.461E-05	2.461E-05	2.461E-05	1.492E-04	1.492E-04	1.492E-04	1.112
am peak	09:00	2.738E-04	2.461E-05	2.461E-05	2.461E-05	1.492E-04	1.492E-04	1.492E-04	1.112
midday	10:00	2.22E-04	2.004E-05	2.004E-05	2.004E-05	1.22E-04	1.22E-04	1.22E-04	9.091
midday	11:00	2.22E-04	2.004E-05	2.004E-05	2.004E-05	1.22E-04	1.22E-04	1.22E-04	9.091
midday	12:00	2.22E-04	2.004E-05	2.004E-05	2.004E-05	1.22E-04	1.22E-04	1.22E-04	9.091
midday	13:00	2.22E-04	2.004E-05	2.004E-05	2.004E-05	1.22E-04	1.22E-04	1.22E-04	9.091
midday	14:00	2.22E-04	2.004E-05	2.004E-05	2.004E-05	1.22E-04	1.22E-04	1.22E-04	9.091
midday	15:00	2.22E-04	2.004E-05	2.004E-05	2.004E-05	1.22E-04	1.22E-04	1.22E-04	9.091
midday	16:00	2.22E-04	2.004E-05	2.004E-05	2.004E-05	1.22E-04	1.22E-04	1.22E-04	9.091

ReadMe | Scenario Setup | Intermediate Data | Source Input | Emissions Summary | Source Output

Figure 2-26. EM4AQ Tool **Source Output** worksheet showing the location of the hourly emission rates file for the hypothetical project.

To use the hourly emission rate file in AERMOD View, open the **Source Pathway** dialog window and select the **Hourly Emission File** screen. Complete the following three steps below, illustrated in Figure 2-27.

1. Checkmark the **Hourly Emission Rate File** box in the upper panel.
2. Choose **Specify File**, and browse for and select the hourly emission rate file.
3. In the **Available Sources** panel, select all the sources that are in the file, and use the move buttons in the center of the screen to assign the sources.

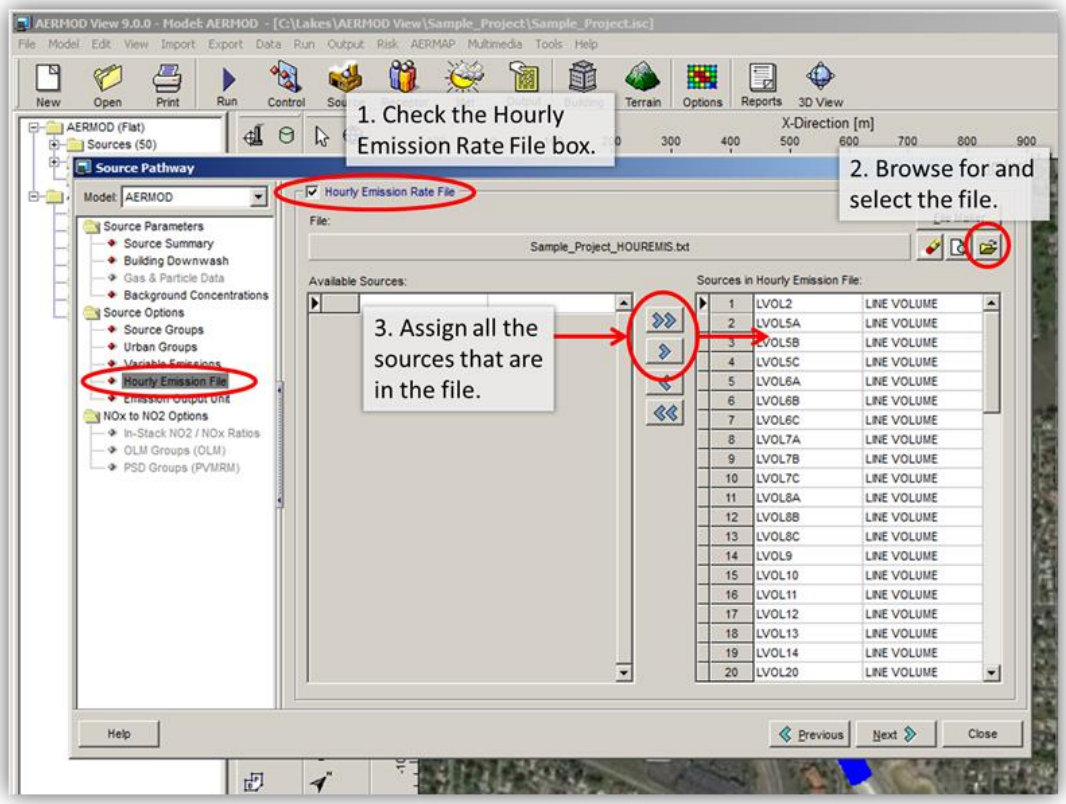


Figure 2-27. Using the hourly emission rate file in AERMOD View.

3. Dispersion Modeling Support

3.1 Illustration of Roadway Source Setup in AERMOD View for PM Hot-Spot Analyses

3.1.1 Introduction

The purpose of Chapter 3.1 is to help analysts set up a transportation project when using AERMOD View to complete dispersion modeling for a particulate matter (PM) hot-spot analysis. In Chapter 3.1, project traffic-related emissions are referred to as "roadway sources." Accurate specification of the locations and characteristics of roadway sources for AERMOD dispersion modeling is a critical part of a PM hot-spot analysis. In addition, AERMOD dispersion modeling requires specification of roadway sources as either area or volume sources (U.S. Environmental Protection Agency, 2015c).

The setup of roadway sources in AERMOD View is accomplished with application tools that allow analysts to draw their project sources in the AERMOD View graphical user interface (GUI) using geospatial project data and satellite imagery as visual guides. Using illustrations with a hypothetical transportation project, Chapter 3.1 provides step-by-step instructions for analysts to

- Import geospatial project design data into AERMOD View;
- Specify line area sources in AERMOD View to represent roadway emissions; and
- Specify line volume sources in AERMOD View to represent roadway emissions.

It also describes attributes of and differences between area and volume sources, and summarizes best practices for setting up sources in transportation project scenarios within reasonable computing constraints. Source attributes and computing constraints are important factors for consideration when deciding whether to use area or volume sources to represent roadway emissions. This is one of several key modeling decisions that project analysts must make when conducting a quantitative PM hot-spot analysis.[13] Prior case studies showed that area source-based model-predicted $PM_{2.5}$ concentrations are higher than volume source-based concentrations (Erdakos and Craig, 2015a). While this chapter provides information for consideration when choosing between area and volume sources, it does not suggest which type to use for any particular transportation project. Transportation conformity practice involves working with interagency partners when making key decisions related to project analysis methods.

[13] Analysts must seek consensus on this decision with interagency partners.

This chapter synthesizes and expands upon earlier Caltrans guidance and training material for PM hot-spot analyses:

- Guidance for using AERMOD View in PM hot-spot analyses (Erdakos et al., 2013);
- Webinars: Representing Roadway Emission Sources in AERMOD (Erdakos and Craig, 2015a, 2015b);
- Introduction to Air Quality Modeling Tools: Two-Day Training Workshop (Craig and Reid, 2015).

3.1.2 Regulatory Background

The U.S. Environmental Protection Agency (EPA) transportation conformity rule requires a PM hot-spot analysis for certain transportation projects located in federal $PM_{2.5}$ and PM_{10} nonattainment or maintenance areas. In December 2010, EPA published guidance for completing a quantitative PM hot-spot analysis: *Transportation Conformity Guidance for Quantitative Hot-Spot Analyses in $PM_{2.5}$ and PM_{10} Nonattainment and Maintenance Areas* (U.S. Environmental Protection Agency, 2010); updated versions of the guidance were released in November 2013 (U.S. Environmental Protection Agency, 2013) and November 2015 (U.S. Environmental Protection Agency, 2015c). The guidance describes three overall steps for completing a PM hot-spot analysis: (1) estimate the incremental PM contribution of the proposed project; (2) add the increment to a representative background concentration; and (3) determine whether the combination (increment plus background) meets conformity requirements. Section 7.4 and Appendix J of EPA's PM hot-spot guidance describe the characterization of roadway emissions for modeling the incremental PM contribution with AERMOD, but do not provide detailed instructions on how to specify sources in AERMOD View.

3.1.3 Importing Geospatial Project Data

Base maps in AERMOD View are useful guides for specifying the location of roadway emission sources. They simplify the process of drawing sources in the GUI using the application tools. AERMOD View supports several formats of base maps, which include project design files that contain project-specific information. Several pre-programmed tile map servers (e.g., OpenStreetMap and MapQuest) are also available to users whose AERMOD View license is in current maintenance.

In most cases, Caltrans analysts use MicroStation software for project design applications, and therefore would generate a Drawing Interchange Format (DXF) file containing project design data for import into AERMOD View. A DXF file is a standard computer-aided design (CAD) system file. Table 3-1 summarizes information about DXF base maps and tile map options in AERMOD View Version 9.0.0.[14] The following section describes and illustrates the procedure for importing a DXF file into AERMOD View for a hypothetical transportation project.

[14] Refer to the AERMOD View Help documentation for information about other base map options.

Table 3-1. Summary of DXF base maps and tile map options supported in AERMOD View 9.0.0.

Map Type	Description	Supported Formats
DXF base maps	Import a DXF file, which is a standard format for exchanging data between CAD systems. Use MicroStation CAD software to convert the design file into a DXF format base map. The base map will be placed on the same coordinates defined for the model domain.	DXF (Release 12 or earlier)
Tile maps	Import a map from a pre-programmed or custom tile map server. Not all tile map server formats are available. If adding a custom map server, verify copyright requirements.	Pre-programmed formats: OpenStreetMap; MapQuest Streets; MapQuest Satellite; MapQuest Aerial; OpenCycleMap; CloudMade Maps

Procedure to Import DXF Base Maps into AERMOD View

Before a base map can be imported, the model domain and map projection for the project must be defined in AERMOD View, and the DXF file must be available. Model domain specifications correspond with the geographic extents of the project, and the map projection will be in Universal Transverse Mercator (UTM) coordinates with a WGS84 datum.[15] Caltrans analysts create the project DXF file using MicroStation. A design file based on the California State Plane Coordinate System must be converted in MicroStation to be consistent with the map projection defined in AERMOD View (i.e., UTM coordinates with a WGS84 datum).

Once the model domain and map projection for the transportation project are specified in AERMOD View, and the DXF file is available, import the DXF file into AERMOD View as illustrated in Figure 3-1:

Creating a DXF File

Create a DXF file by converting the original design file for a transportation project in MircroStation: (1) if necessary, change the working units in the file to metric by selecting the Working Units screen of the Design File Settings window and modify the Master Unit; (2) change the map projection by selecting a UTM coordinate system, WGS84 datum, and UTM zone from the Geographic Coordinate System Library; and (3) export the file to DXF format from the File menu.

[15] WGS84 is the latest revision of the World Geodetic System established in 1984 and revised in 2004. The UTM zone will be 10 or 11 North depending on where in California the project is located. In general, for project locations west of -120° longitude, use a UTM zone of 10; for project locations east of -120° longitude, use a UTM zone of 11. Consult with interagency partners for project locations that span the two zones.

1. From the **Import** menu, select **Base Maps**, then **DXF**.
2. Select **Specify File** to open the **Import DXF Base Map** browser window, then select and **Open** the appropriate DXF project design file.
3. If the units in the DXF file are *not* metric, select **Feet to Meters** in the **Unit Conversion** panel.
4. Select **Import All Layers** in the **Specify Layers to Import** panel.
5. Select **OK** to finish importing the file and close the import window.

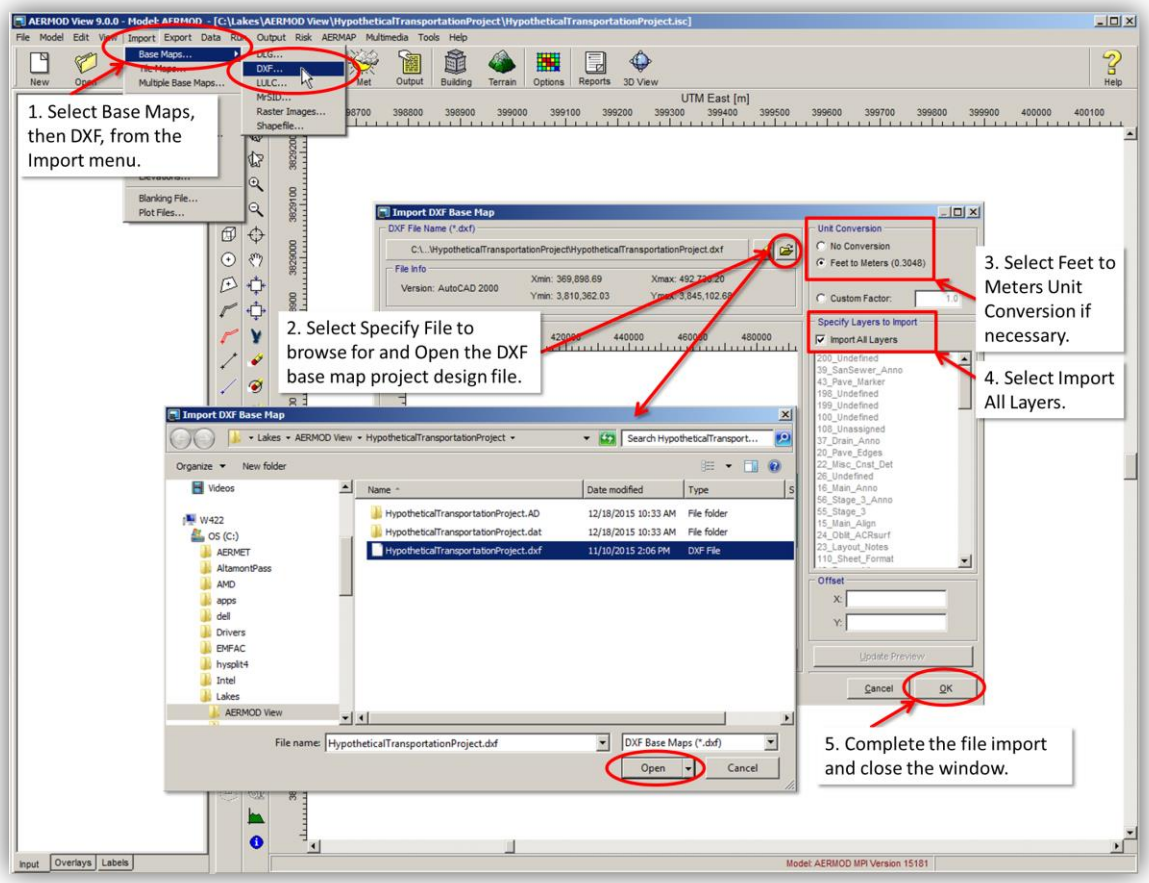


Figure 3-1. Procedure to import a DXF project design file as a base map layer in AERMOD View.

Figure 3-2 shows a section of the DXF design file for the hypothetical project in the AERMOD View GUI. The partial view is of a freeway interchange. For real-world projects, project design files display project elements with Caltrans standard colors (see the Caltrans CADD Users Manual at http://www.dot.ca.gov/hq/oppd/cadd/usta/caddman/metric/toc.htm).

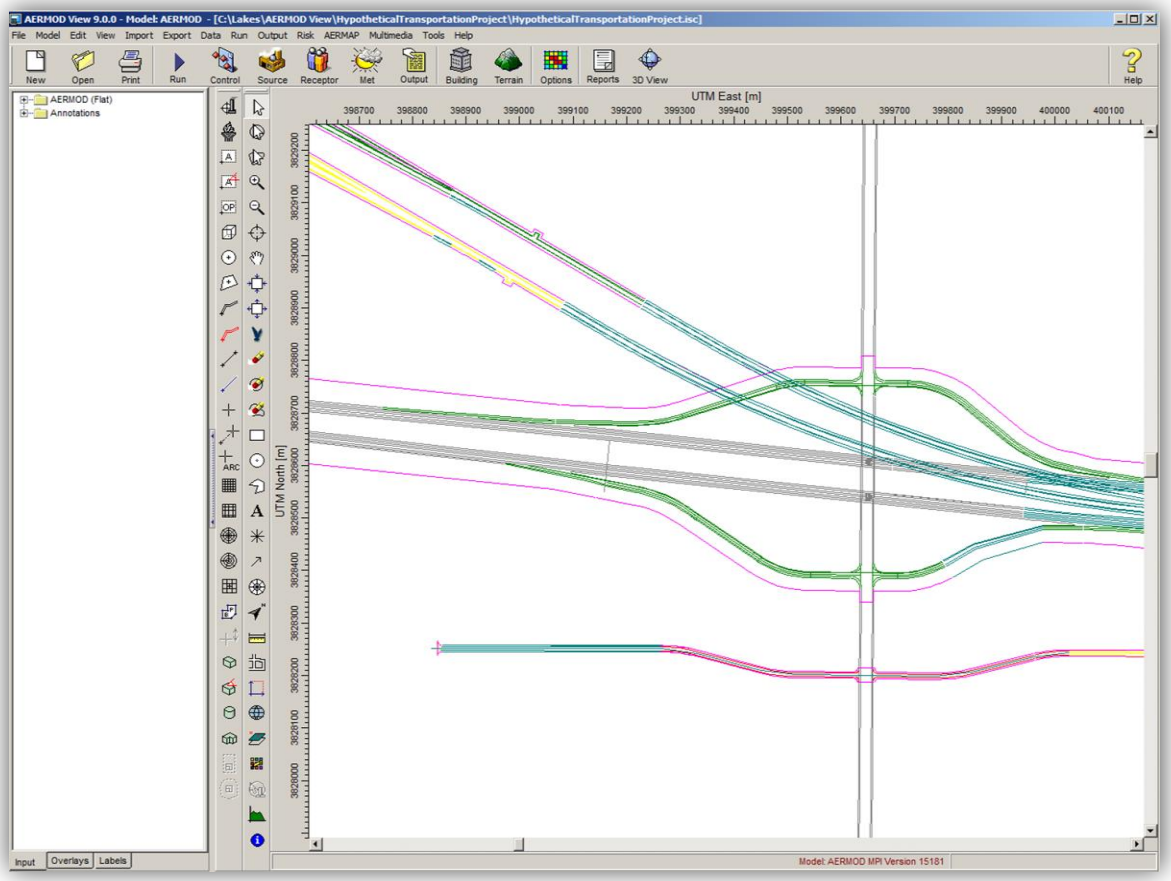


Figure 3-2. Partial view of a DXF file base map layer for a hypothetical transportation project displayed in the AERMOD View GUI drawing area. Color lines in the base map represent project design elements.

Next, import a tile map that will provide a visual display of geographical imagery. From the **Import** menu highlighted in Figure 3-1, select **Tile Maps**. The **Import Tile Maps** window, which is shown in Figure 3-3, will open automatically; select **MapQuest Satellite** from the **Map Server** drop-down menu, then select **OK**. AERMOD View will display the tile map for the model domain as a layer in the drawing area. Figure 3-4 shows the AERMOD View GUI with the satellite map layer and the DXF project design file layer displayed in the drawing area.

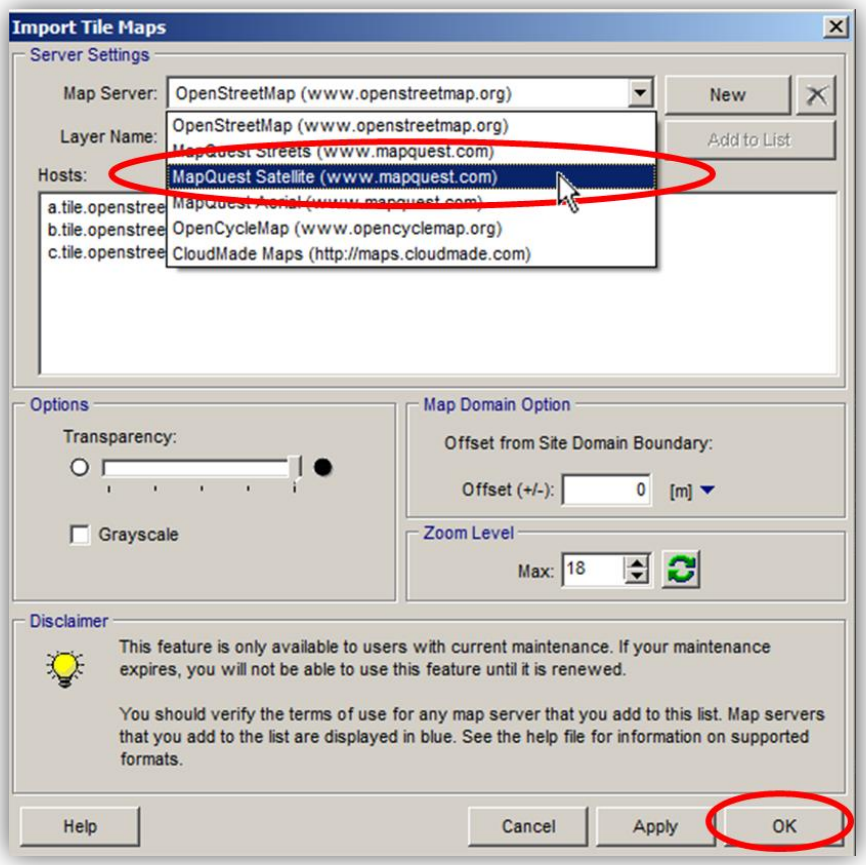


Figure 3-3. Selecting MapQuest satellite imagery from the **Import Tile Maps** window in AERMOD View.

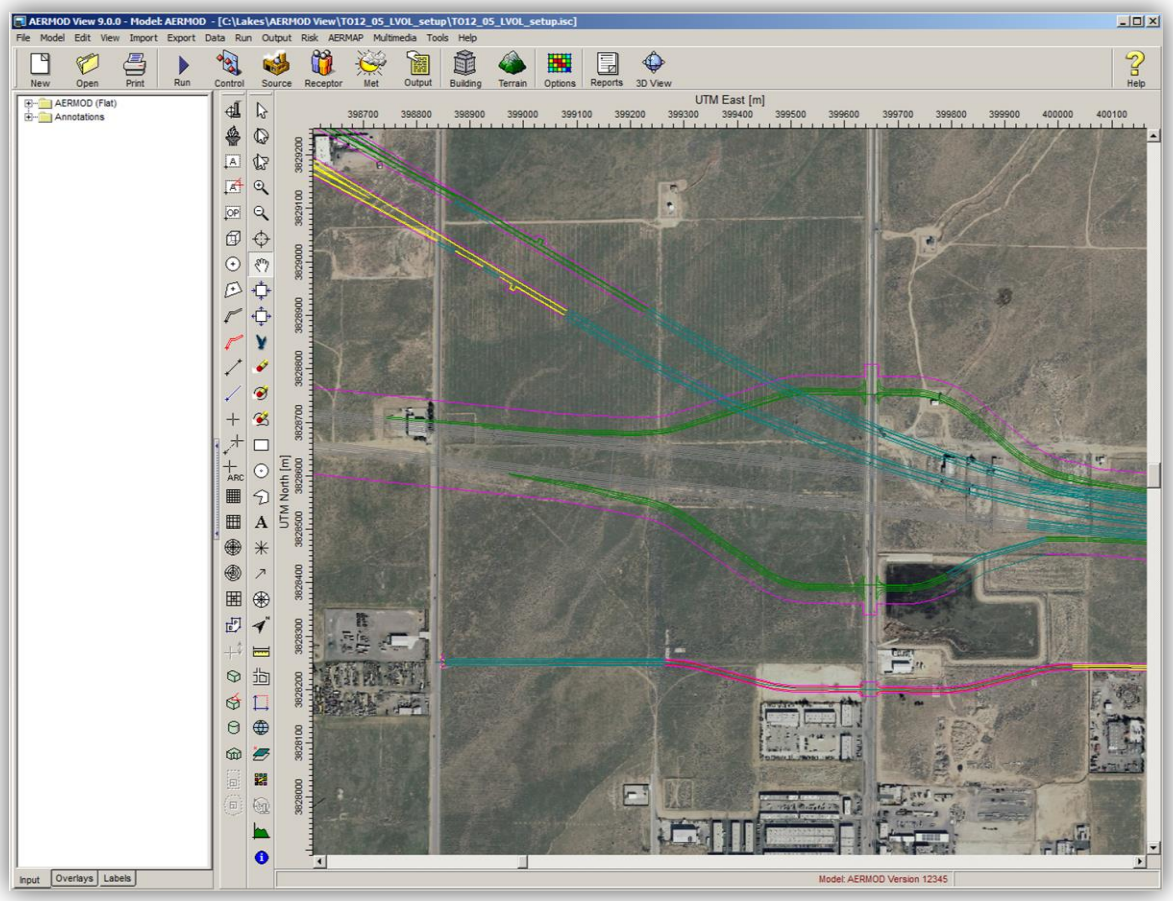


Figure 3-4. Screenshot of the AERMOD View GUI showing a partial view of the DXF project design file base map overlaid with a MapQuest satellite tile map in the drawing area for a hypothetical transportation project. Color lines in the base map represent project design elements.

3.1.4 Configuring Roadway Sources in AERMOD View

After the model domain and map projection have been specified in AERMOD View and a base map and tile map have been imported, specify emission source locations using AERMOD View application tools to draw the sources in the drawing area. Either area or volume sources can be used to represent roadway emissions, although they may result in different modeled concentrations. Analysts should carefully consider differences between the attributes of these two types of sources and how they are configured to represent roadway emissions when deciding which source type to use.

Attributes of Area and Volume Sources in AERMOD Dispersion Modeling

In general, when specifying sources in AERMOD View, the effort required to represent roadway links with area or volume sources is similar. However, when used in quantitative PM hot-spot analyses,

volume sources have features that require more consideration than area sources. Figure 3-5 illustrates the representation of a roadway link by an elongated area source and as a series of adjacent volume sources. While a single rectangular area source represents the individual link shown in Figure 3-5, several adjacent volume sources are necessary to represent the same link. Since an area source is rectangular, more than one would be required to represent a curved roadway link.

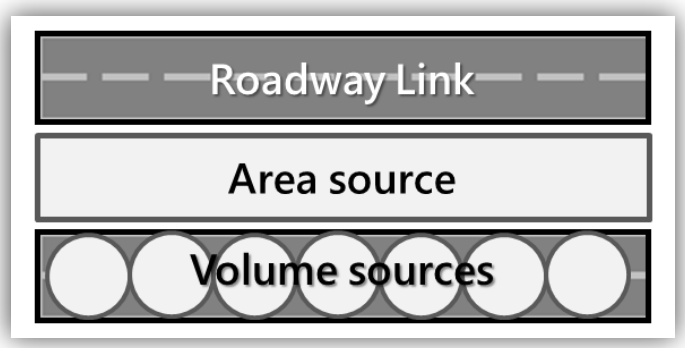
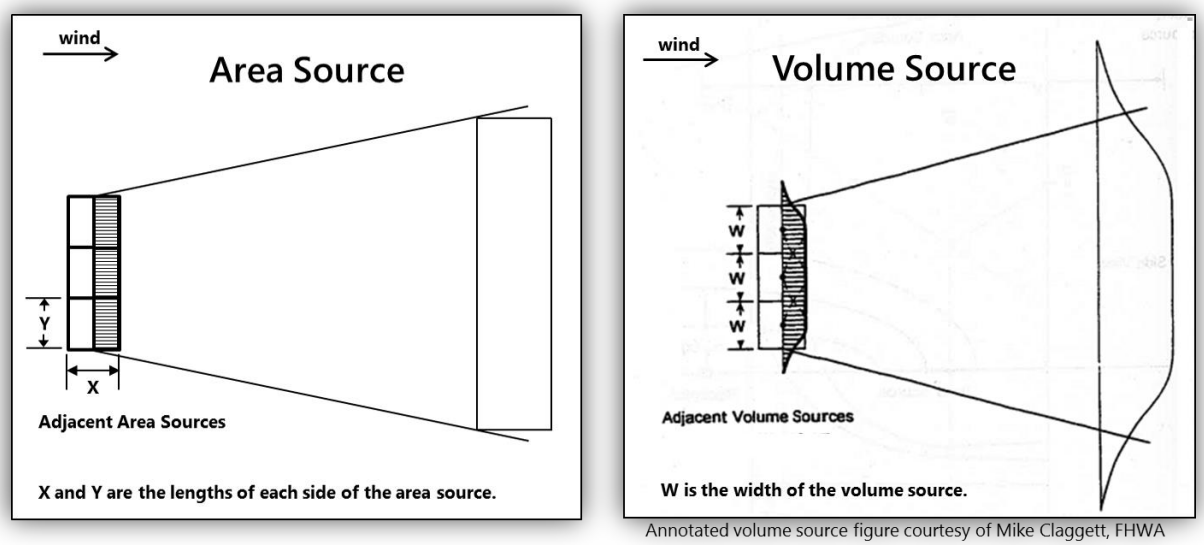


Figure 3-5. Representation of a roadway link with area or volume sources.

In AERMOD dispersion modeling, an area source has a uniform emissions distribution across a rectangular area, and a volume source has an emissions distribution in the shape of a Gaussian curve with "tails" that extend beyond the specified width of the volume source. Figure 3-6 illustrates area and volume source emissions distributions. A volume source emissions distribution may provide a better representation of roadway emissions, which are impacted by vehicle-induced turbulence. However, the tails of the volume source emissions distribution produce a volume source "exclusion zone" within which AERMOD does not calculate PM concentrations. Therefore, volume sources must be specified appropriately, so that an exclusion zone does not contain model receptors necessary for PM concentration estimates in sensitive areas.

Figure 3-7 illustrates volume source exclusion zones and considerations for receptor placement. The figure illustrates that the width of a volume source corresponds to the size of the exclusion zone. The roadway link in the figure is comprised of three separate traffic lanes. When the link is represented with a single series of adjacent volume sources with width equal to the width of the link (top panel), one of the exclusion zones overlaps the nearest receptor, Receptor A. When the roadway link is represented with three series of adjacent volume sources, where each series represents a single lane of traffic (bottom panel), that exclusion zone no longer encompasses Receptor A. EPA guidance for PM hot-spot analyses suggests placement of receptors as near as 5 meters from a source (e.g., from the edge of the roadway or right-of-way). Analysts must carefully consider receptor placement requirements when using volume sources to represent roadway emissions.



Annotated volume source figure courtesy of Mike Claggett, FHWA

Figure 3-6. Simplified illustration of AERMOD area and volume source emissions distributions.

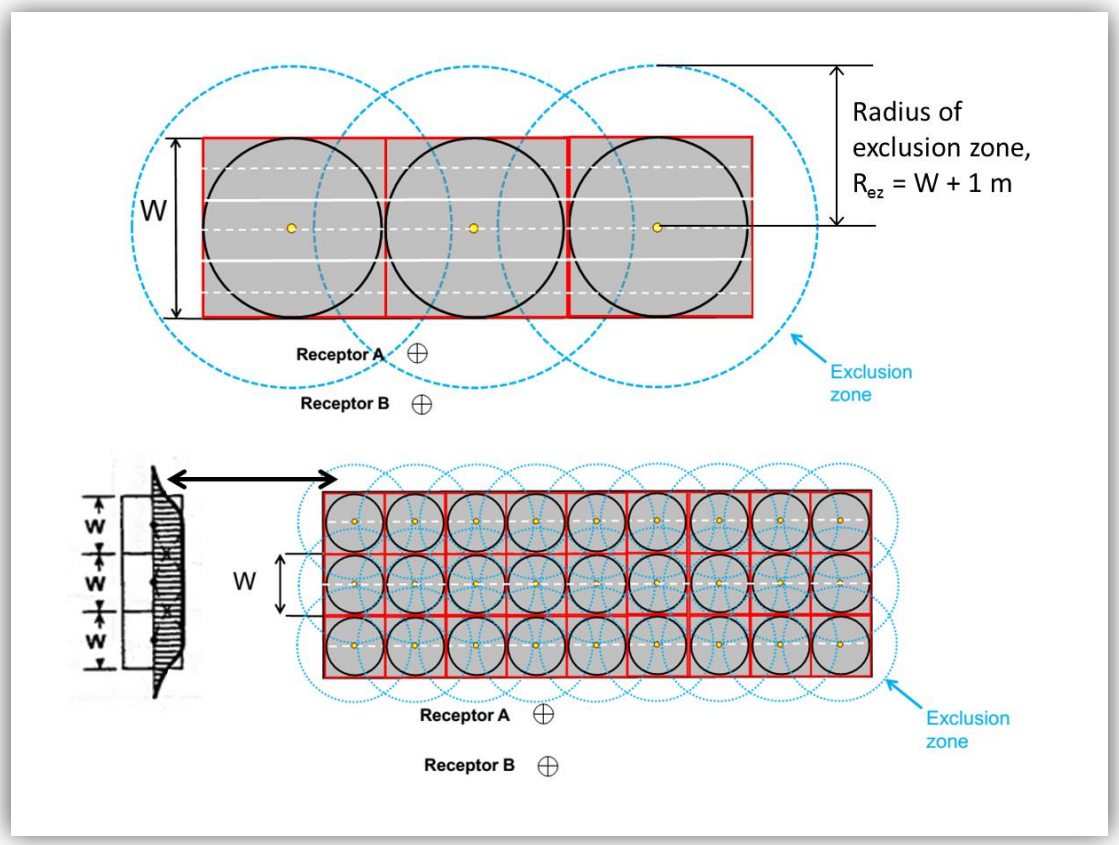


Figure 3-7. Volume source exclusion zones and corresponding receptor placement limitations. W is the volume source width. The graphics in the figure are adapted from EPA PM Hot-Spot 3-Day Course material (U.S. Environmental Protection Agency, 2014d).

Since an area source has a uniform emissions distribution, it is specified in AERMOD View with dimensions that span the dimensions of a given roadway link. The Gaussian distribution of volume source emissions and the corresponding exclusion zone results in multiple options for specifying the volume width. For example, the width of a volume source may span the width of a roadway link if the exclusion zone does not encompass required receptors, or the width may be specified such that the exclusion zone, and therefore the tails of the emissions distribution, extends to the edges of the road. Analysts must ensure that the chosen volume source configuration adequately represents the roadway emissions.

Application tools in AERMOD View simplify the specification of source location and type by allowing users to draw sources in the GUI. The AERMOD View **Line Area Source** tool is used to draw an elongated area source to represent a roadway link, or a series of adjacent area sources for curved roadway links. The **Line Volume Source** tool is used to draw a series of volume sources to represent a straight or curved roadway link. Both tools generate the appropriate constituent sources after the analyst specifies endpoints of the roadway link, or multiple "node" points for curved roadway links.

Procedure to Specify Line Area Sources in AERMOD View

Figure 3-8 illustrates how to draw a line area source and specify source input parameters in AERMOD View. The illustration focuses on drawing multiple nodes to represent a curved roadway link (for a straight roadway link, analysts would only draw nodes at the ends of the link). The constituent area sources extend to the edges of the roadway. To create a line area source representation of a curved roadway link, follow the steps shown in Figure 3-8 for the hypothetical project:

1. Select the **Line Area Source** tool on the Application toolbar.
2. Click in the drawing area of the AERMOD View GUI to define the first node at the center of one end of the roadway using the base map as a guide.
3. Continue to click at additional points along the center of the curved roadway to define the placement of the line area source. Right-click at the last node to finish drawing the line area source. The **Source Inputs** dialog window for the source will then open automatically.
4. Enter a meaningful name in the **Source ID** text box (e.g., "LAREA1").
5. Enter a meaningful description in the **Description** text box (e.g., "Hypothetical Roadway Link").
6. Enter the values for the line area source parameters (length of side, initial vertical dimension, and emission rate). For the hypothetical roadway link, the input parameters corresponding to a vehicle fleet mix of 8% trucks and 92% non-trucks are

   Length of side (representing the source width) = 7.32 m
   Initial vertical dimension = 1.21 m
   Emission rate = 1 g/s-m^2

For the hypothetical project, the length to width ratio (**Ratio 1**) of the constituent area sources has been left as the default value of 10.[16]

AERMOD View will multiply the unit emission rate by the variable emission factors entered in the Variable Emissions screen of the Source Pathway window (not shown here).

7. In the **Line Source Nodes** panel of the **Source Inputs** window, enter the **Release Height** (1.47 m, a weighted average for a fleet with 8% trucks and 92% non-trucks) for each node.
8. **Close** the **Source Inputs** window.

The line area source representation of the roadway link then appears in the AERMOD View drawing area as shown for the hypothetical roadway in Figure 3-9.

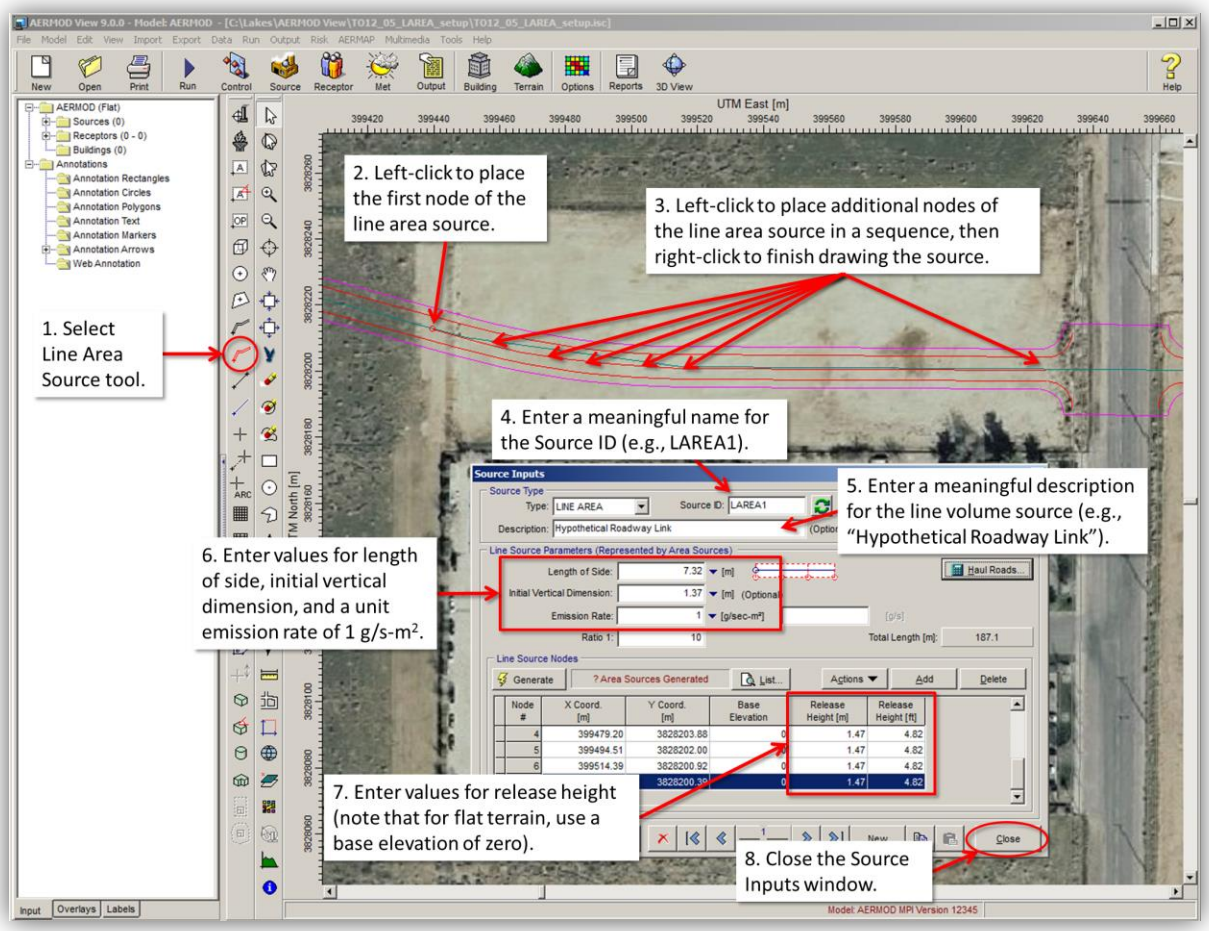


Figure 3-8. Procedure to specify a line area source in AERMOD View for a curved roadway link in a hypothetical transportation project.

[16] AERMOD will produce a warning message for area source length to width ratios greater than 100 (U.S. Environmental Protection Agency, 2015b). While this does not affect the model run, it suggests that the length to width ratio should be limited to 100.

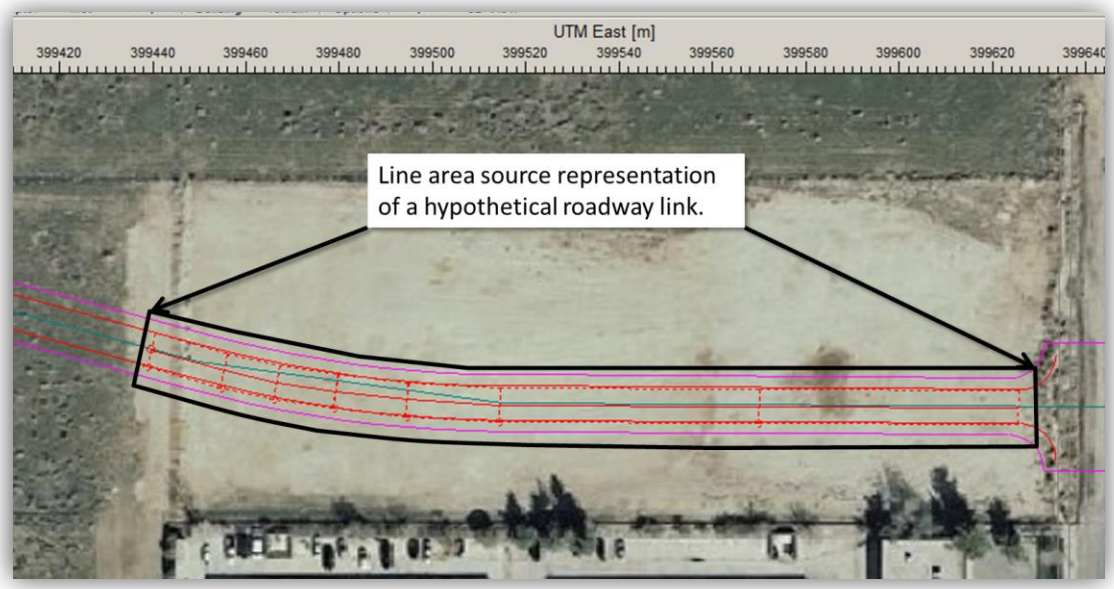


Figure 3-9. Completed line area source representation of a curved roadway link in AERMOD View for the hypothetical transportation project. Adjacent red dashed-line rectangles, encompassed by the black outline, represent the constituent area sources. All of these features are overlaid on the satellite tile map.

Procedure to Specify Line Volume Sources in AERMOD View

Figure 3-10 illustrates how to draw a line volume source and specify source input parameters in AERMOD View for a curved roadway link using the hypothetical transportation project. Analysts need to create multiple nodes to represent a curved link; for straight roadway links, analysts need to draw only the nodes at the ends of the link. The process is similar to that for defining a line area source, except for the exclusion zone considerations discussed earlier. In this example, the line volume source for the hypothetical project is specified such that the widths of the constituent volumes extend to the edges of the roadway. The exclusion zone of each volume source in this configuration, therefore, extends less than 5 meters beyond the edge of the roadway. To create a line volume source representation of a roadway link, follow the steps below as shown in Figure 3-10 for the hypothetical project:

1. Select the **Line Volume Source** tool on the **Application** toolbar.
2. Click in the drawing area of the AERMOD View GUI to define the first node at the center of one end of the roadway using the base map as a guide.
3. Continue to click at additional points along the center of the curved roadway to place a sequence of nodes that define the placement of the line volume source. Right-click at the last node to finish drawing the line volume source. The **Source Inputs** dialog window for the source will then open automatically.
4. Enter a meaningful name in the **Source ID** text box (e.g., “LVOL1”).

5. Enter a meaningful description in the **Description** text box (e.g., "Hypothetical Roadway Link").
6. Select **Adjacent** from the **Configuration** drop-down menu.
7. Enter values for the line volume source parameters (plume height, plume width, and emission rate). For the hypothetical roadway link, the input parameters corresponding to a vehicle fleet mix of 8% trucks and 92% non-trucks are

   Plume height = 2.94 m
   Plume width = 7.32 m
   Emission rate = 1 g/s

   AERMOD View will multiply the unit emission rate by the variable emission factors entered in the Variable Emissions screen of the Source Pathway window (not shown here).
8. In the **Line Source Nodes** panel of the **Source Inputs** window, enter the **Release Height** (1.47 m, a weighted average for a fleet with 8% trucks and 92% non-trucks) for each node.
9. **Close** the **Source Inputs** window.

The line volume source representation of the roadway link then appears in the AERMOD View drawing area as shown for the hypothetical roadway in Figure 3-11.

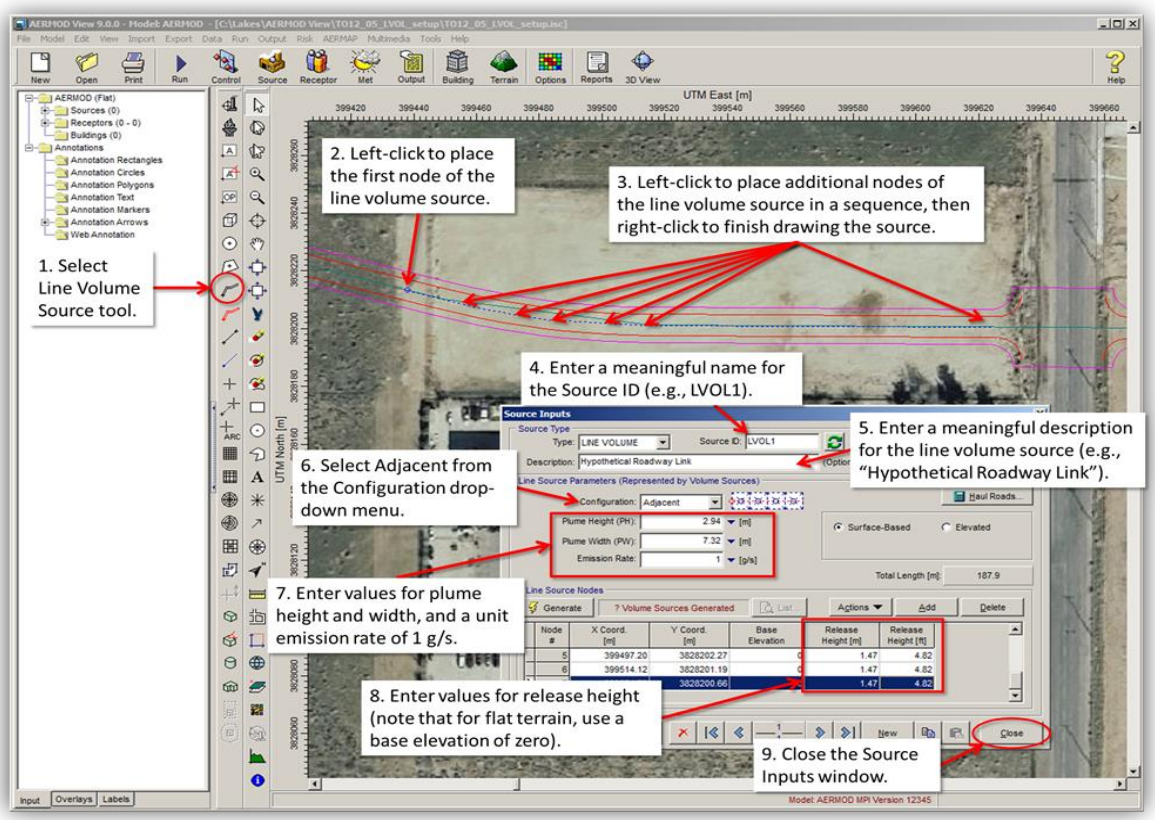


Figure 3-10. Procedure to specify a line volume source in AERMOD View for a hypothetical transportation project.

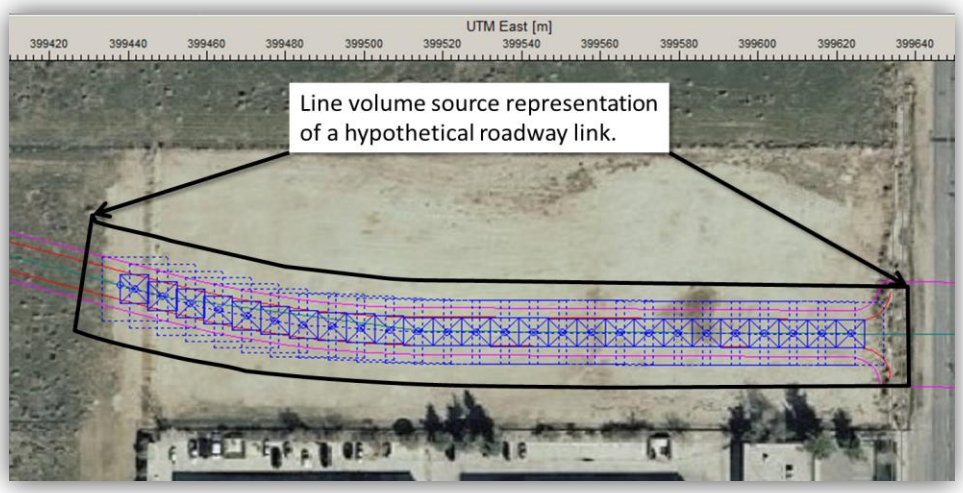


Figure 3-11. Completed line volume source representation of a curved roadway link in AERMOD View for a hypothetical transportation project. Adjacent blue squares, encompassed by the black outline, represent constituent volume sources.[17] Blue dashed-line squares represent the volume source exclusion zones. All of these features are overlaid on the satellite tile map.

3.1.5 Best Practices for Minimizing Model Runtime

Two major factors related to the setup of roadway sources in AERMOD View have a significant effect on simulation runtime: (1) whether the roadways are represented by area or volume sources; and (2) the number of area or volume sources required to adequately represent roadway emissions. The number of sources required depends on the type of source and the size, number, and complexity of roadway links. When volume sources are used, the number of sources required also depends on the source configuration (e.g., whether the volume width or exclusion zone extends to the roadway edges). For a real-world transportation project, hundreds to thousands of individual sources may be needed in AERMOD dispersion modeling.

To examine the effect of the number of modeled sources and source type on model runtime, we performed eight test simulations in AERMOD View for a 100-meter roadway link. Figure 3-12 shows our hypothetical link represented by a series of adjacent volume sources in AERMOD View. The volume source configuration in Figure 3-12 is one of eight configurations (four area source configurations, and four volume source configurations) that correspond with the eight test simulations. The call-out box following Figure 3-12 summarizes key results from the test simulations and considerations for minimizing model runtime. The remainder of this section discusses the test results, and Appendix A (Section 3.2.7) provides details about the simulation source configurations.

[17] Volume sources are represented by circles beginning with AERMOD View Version 9.1.

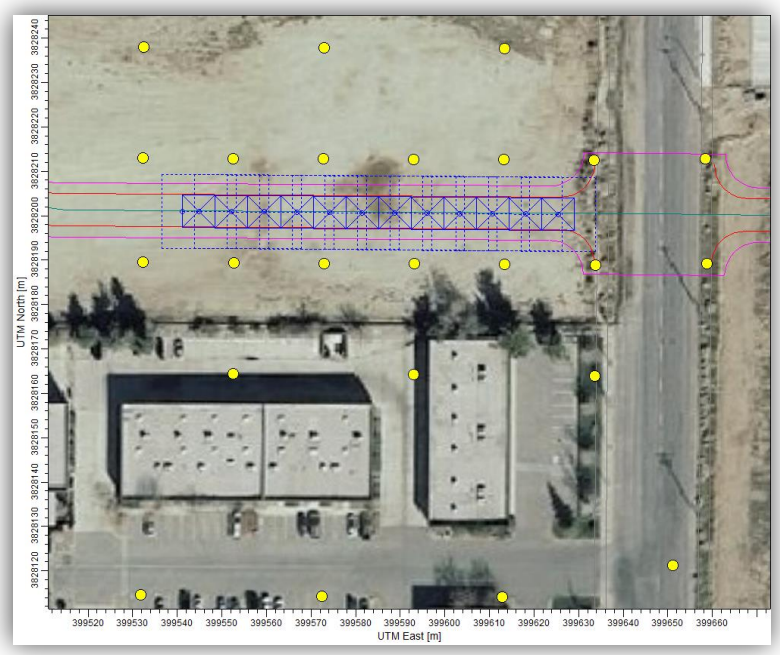


Figure 3-12. AERMOD View display of a hypothetical 100-meter roadway link represented by a volume source configuration corresponding to one of eight test simulations. Blue squares with solid and dashed lines represent modeled volume sources and corresponding exclusion zones; yellow circles represent model receptors.[18] Project design elements are shown in Caltrans standard colors. All of these features are overlaid on the satellite tile map.

Considerations for Minimizing Model Runtime

- Fewer area sources are required to represent a typical roadway link than volume sources.
- Given equal numbers of modeled sources, model runtimes are longer for area sources than volume sources.
- Model runtime increases linearly with the number of modeled sources, although the rate of increase is greater for area sources than for volume sources.
- For a given source type, model-estimated PM concentrations vary by ≤2% when using different roadway source configurations.
- PM hot-spots are likely to occur in specific locations (e.g., interchanges); limiting the model domain to a localized area of the project will limit model runtime.
- Dividing the project into multiple model domains and distributing simulations across separate computers will reduce overall model runtime.

[18] Volume sources are represented by circles beginning with AERMOD View Version 9.1.

Results of the test simulations show that model runtime increases linearly with the number of modeled sources, although the rate of increase is greater for area sources than for volume sources (see Figure 3-13). Therefore, minimizing the number of sources used to represent roadway emissions for a given source type limits model simulation runtime. Figure 3-13 also shows that, while the different area source representations of the roadway required fewer individual sources than each of the volume source representations, they resulted in relatively longer model runtimes in these test cases.

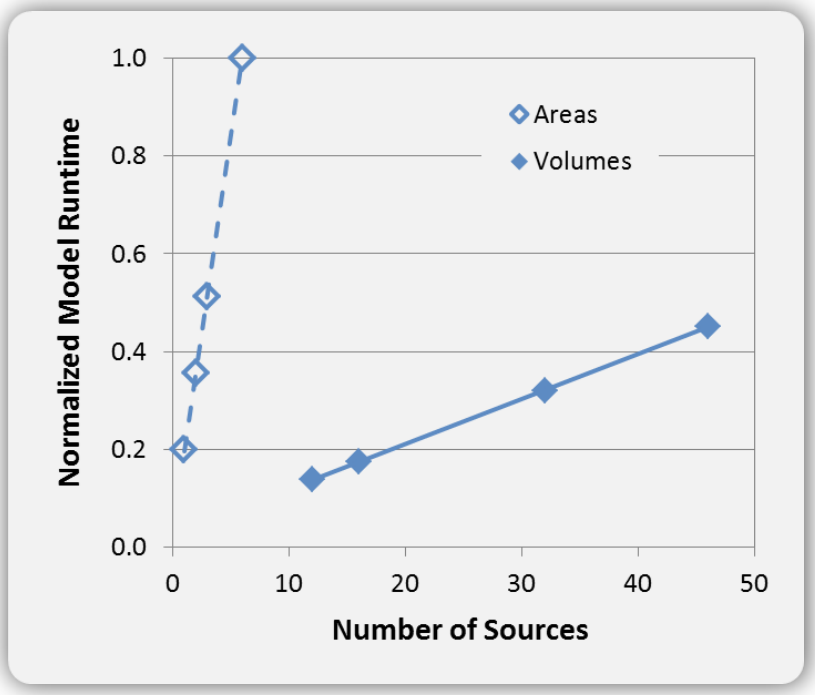


Figure 3-13. Variability of model runtime by number of sources when used on a highly simplified hypothetical 100-meter roadway link.

Model-estimated PM concentrations across the test simulations for a given source type varied by ≤2%. A similar result was reported in earlier Caltrans PM hot-spot training material (Erdakos and Craig, 2015b). However, the test simulations are insufficient to determine whether area or volume sources are preferable for real-world projects when considering strictly the limitation of model runtime. The size and complexity of real-world projects influence how many area or volume sources are necessary to adequately represent roadway emissions. For a real-world project, it may take hundreds or thousands more volume sources than area sources to represent the project roadway sources. In some cases, the number of volume sources required may be too large to result in less runtime compared to an area source configuration.

For very large transportation projects (e.g., those extending many miles in length) that require thousands of sources, analysts should consider additional options for reducing model runtime. For

example, overall runtime can be minimized by dividing the project area into multiple model domains, and distributing the simulations across separate computers. Other options include using the message passing interface (MPI) version of AERMOD available in AERMOD View, and limiting the model domain to one or more localized regions of a project where PM hot-spots are likely to occur.

Table 3-2 lists details about the source configurations used in test simulations to evaluate variability of model runtime for a 100-meter roadway link in a hypothetical transportation project (see Figure 3-12). The test simulations form two sets: simulations 1-4 comprise the area source set, and simulations 5-8 comprise the volume source set. In both sets of simulations, we used the same receptor network and varied the number of sources that represent the roadway link. In each simulation, the line area or the line volume source contains one or more individual sources.

Table 3-2. Source configurations for a hypothetical roadway link in simulations to test model runtime variability.

ID	Source Configuration[a]	Area Dimensions or Volume Width	Extent of Exclusion Zone	Number of Constituent Sources	Model Runtime[b]
1	Two line areas (ratio = 9)	3.66 m × 28 m	N/A	6	02:40
2	One line area (ratio = 4)	7.32 m × 28 m	N/A	3	01:22
3	One line area (ratio = 6)	7.32 m × 42 m	N/A	2	00:57
4	One line area (ratio = 12)	7.32 m × 84 m	N/A	1	00:32
5	Two line volumes	3.66 m	2.8 m beyond edge of road	46	01:12
6	One line volume	2.66 m	Edge of road	32	00:51
7	One line volume	5.16 m	2.5 m beyond edge of road	16	00:28
8	One line volume	7.32 m	4.7 m beyond edge of road	12	00:22

[a] In AERMOD View, a line area source is a series of adjacent area sources that have a specified length to width ratio. A line volume source is a series of separated or adjacent volume sources. For these test simulations, we used adjacent volume sources.
[b] The runtimes (MM:SS) correspond with using the AERMOD View MPI executable with 8 CPUs at 3.6 GHz.

3.2 Modeling Depressed Roadways in AERMOD View Using the AERMOD OPENPIT Source Type

3.2.1 Introduction

The purpose of Section 3.2 is to (1) help analysts understand the implications of modeling depressed roadways in a transportation project with the AERMOD OPENPIT source type, (2) support interagency consultation on the use of the OPENPIT source type as an option for modeling depressed roadways in a particulate matter (PM) hot-spot analysis, and (3) illustrate how to define input parameters of OPENPIT sources for depressed roadways in AERMOD View.

Peer-reviewed research published by EPA scientists suggests that, under some conditions, pollutant concentrations near depressed roadways are approximately 50% lower than concentrations near at-grade roadways (Heist et al., 2009; Steffens et al., 2014). Three major factors present challenges to modeling depressed roadways in a PM hot-spot analysis:

- AERMOD, one of the recommended dispersion models for PM hot-spot analyses, does not contain algorithms designed to represent the effects of roadway depressions on pollutant dispersion.
- EPA's quantitative PM hot-spot analysis guidance does not include recommendations on how to model depressed roadway emission sources in AERMOD.
- Typically, at-grade area or volume sources are used to model all roadway emissions in a PM hot-spot context.

For the recent Colorado I-70 East PM environmental impact statement, EPA recommended that depressed roadway sections in the project be modeled using AERMOD's OPENPIT emission source type (Colorado Department of Transportation, 2016). EPA commented that using AERMOD's OPENPIT source for depressed roadways in CDOT's project was a viable and better option than modeling the sources as being at grade (Colorado Department of Transportation, 2016). This represents perhaps the first major effort to apply the OPENPIT source to model PM emissions from a depressed roadway. This approach, compared to modeling depressed roadway sources at grade, may result in a more realistic representation of real-world conditions.

Because the model formulation of the OPENPIT source in AERMOD was developed for large open pit sources such as rock quarries and surface coal mines, using the OPENPIT source to represent depressed roadways in a transportation context is a novel approach. Therefore, the approach has not been studied or tested in a variety of transportation project scenarios. In particular, testing is needed to understand the implications of using different OPENPIT source parameters to represent different roadway configurations. We performed sensitivity tests on an approximately 0.7-mile straight

depressed roadway segment with four traffic lanes in each direction, a median, and a vehicle fleet with 8% trucks.

For the sensitivity tests, we performed a total of 60 simulations in AERMOD View to evaluate the impact of varying model inputs on peak 24-hour average PM_{10}, 24-hour average $PM_{2.5}$, and annual average $PM_{2.5}$ concentrations. We modeled a hypothetical transportation project that includes a depressed freeway link, at-grade on- and off-ramp links, and at-grade connecting arterial links. Considering the typical approach of using at-grade area or volume sources to represent roadway emissions, we used four basic representations (line area source is referred to as "LA"; line volume source is referred to as "LV"; OPENPIT is referred to as "OP") of the roadway links in AERMOD View:

1. All links represented by at-grade line area sources (LA representation).
2. Depressed freeway link represented by an OPENPIT source, and all other links represented by at-grade line area sources (OPLA representation).
3. All links represented by at-grade line volume sources (LV representation).
4. Depressed freeway link represented by an OPENPIT source, and all other links represented by at-grade line volume sources (OPLV representation).

Section 3.2 focuses on evaluating the overall peak concentrations, rather than, for example, the 98th percentile values that would be relevant to a specific design value calculation required in a PM hot-spot assessment. A full PM hot-spot analysis, including design value calculations, is not addressed here.

3.2.2 Key Aspects of the OPENPIT Source Model Formulation

Users will generally not need to know the details of how an OPENPIT source is used to model emissions and estimate concentrations. However, this section provides a brief discussion of key aspects of the model formulation for those interested in technical details.

Helpful User Information

The model formulation for the OPENPIT source is described in the 1995 publication of the "User's Guide for the Industrial Source Complex (ISC3) Dispersion Models: Volume II – Description of Model Algorithms" (U.S. Environmental Protection Agency, 1995). The ISC model is the predecessor of AERMOD for regulatory applications, and the model formulation for the OPENPIT source in AERMOD is consistent with that in the ISC model. Briefly, the OPENPIT source is modeled as an area source that has dimensions (i.e., effective area) based on the footprint of the OPENPIT source, and an emission rate (i.e., effective emission rate) based on that of the OPENPIT source and the so-called "escape fraction" of PM from the pit.

Model Formulation Details

Figure 3-14 illustrates the "effective area" of an OPENPIT source, which is equal to the effective length (L_{eff}) times the effective width (W_{eff}) of the pit. The effective length and width of the OPENPIT source are functions of the

- Pit length (L_{OP}),
- Pit width (W_{OP}),
- Pit depth,
- Emissions release height,
- Wind direction,
- Angle between the wind vector and the upwind side of the pit (θ), and
- Along-wind length ($\ell = L_{OP} \times (1 - \theta/90) + W_{OP} \times \theta/90$).

Based on fluid modeling, for each hour, the effective area is positioned along the upwind side of the pit. (See the ISC User's Guide for more details.) The effective emission rate is a function of the effective area and escape fraction, which depends on wind speed at a given hour and the gravitational settling velocity of the emitted PM. Because an OPENPIT source is modeled as an area source (after adjusting its size, location, and emission rate), the width of the OPENPIT source can only realistically represent a depressed roadway with vertical walls along its edges. In other words, it cannot account for characteristics of sloped embankments on the sides of a depressed roadway, where the width of the below-grade roadway is less than the distance between the at-grade edges of the embankments. In a PM hot-spot analysis, valid receptors are located as near as 5 m from the edge of the emission source (i.e., an at-grade roadway). Therefore, for the depressed roadway case with sloped embankments on the sides, using the distance between the top edges of the embankments is a realistic specification of the OPENPIT source width to allow for appropriate receptor siting.

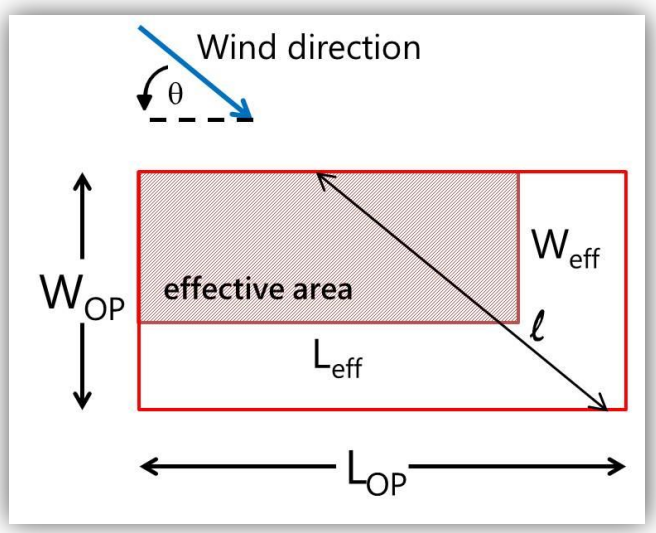


Figure 3-14. Illustration of the effective area of an OPENPIT source.

The dependence of the OPENPIT escape fraction on settling velocity, calculated as a function of particle size and density, has an important implication for using OPENPIT in a PM hot-spot context: this formulation requires enabling the particle deposition algorithms in AERMOD, not only for the OPENPIT source, but for all modeled PM sources (area or volume sources). EPA's guidance for PM hot-spot analyses makes no recommendations regarding the use of AERMOD deposition algorithms. Moreover, the Guideline on Air Quality Models (U.S. Environmental Protection Agency, 2005a, 2015a) requires coordination with and approval from the reviewing agency when applying deposition algorithms for modeling primary PM. Therefore, consensus through the interagency consultation process must be attained when using OPENPIT sources to represent depressed roadways in a PM hot-spot analysis.

There are important limitations that need to be considered when project analysts define an OPENPIT source to model depressed roadways. In the AERMOD user guide (U.S. Environmental Protection Agency, 2015b), EPA states[19]:

> *"The aspect ratio (i.e., length/width) of open pit sources should be less than 10 to 1. However, since the pit algorithm generates an effective area for modeling emissions from the pit, and the size, shape and location of the effective area is a function of wind direction, an open pit cannot be subdivided into a series of smaller sources."*

These limitations regarding the maximum aspect ratio and the use of a series of smaller sources are significant when using the OPENPIT source to represent a depressed roadway that is curved and a depressed roadway with a length-to-width ratio greater than 10:1. When the OPENPIT source aspect

[19] See section 2.3 on page 44 of the User's Guide for the AMS/EPA Regulatory Model – AERMOD Addendum (https://www3.epa.gov/scram001/dispersion_prefrec.htm).

ratio of 10:1 is exceeded, AERMOD issues a warning message but continues with the model processing. However, it should be noted that the OPENPIT source is modeled in AERMOD using the model's area source algorithms, and in AERMOD version 09292, the criterion for issuing a warning message about the aspect ratio of an area source was updated from 10:1 to 100:1.[20] This increased aspect ratio criterion of 100:1 may be applicable to both area and OPENPIT source types, though a similar update has not yet been implemented for the OPENPIT option.

3.2.3 Hypothetical Transportation Project

We used a hypothetical transportation project to evaluate the impacts that different OPENPIT source parameters have on modeled near-road PM concentrations, and to illustrate how to define an OPENPIT source in AERMOD View. This hypothetical project was created using materials previously developed for Caltrans regarding AERMOD View use for a PM hot-spot analysis. Here, the hypothetical project has been simplified to include only freeway lanes, on- and off-ramps, and some of the connecting arterial road links. The following sections describe a case study using the hypothetical project, comprised of a set of sensitivity tests for analyzing the impact of using the OPENPIT source to represent a depressed roadway as compared to modeling the depressed roadway at grade with area or volume sources. In this case study, the freeway lanes and freeway median of the hypothetical project are assumed to be depressed.

The hypothetical project consists of 34 road links (including the on- and off-ramps and the connecting arterial links) plus a freeway link with four northbound and southbound lanes. Each lane in the freeway link is 12 feet (3.66 m) wide, and the northbound and southbound lanes are separated by a median that is approximately 26 feet (8 m) wide. Since the freeway link is approximately 0.7 miles (1062 m) long, the length-to-width ratio is approximately 30:1. To model the depressed freeway link with the OPENPIT source appropriately, we referred to the OPENPIT source modeling performed for the CDOT I-70 East project. Although the initial modeling for the CDOT I-70 East used adjacent OPENPIT sources in 100 m segments to represent the depressed roadway portion of the project, the final documentation for the project does not include technical details for modeling with the OPENPIT source type.[21] Rather than subdividing the depressed freeway link in the hypothetical project into multiple OPENPIT sources with length-to-width ratios of 10:1, we used a single OPENPIT source to represent the entire depressed freeway link. As discussed in the next section, we chose to use a single OPENPIT source for the hypothetical project because testing of scenarios with adjacent OPENPIT sources showed some unrealistic model-estimated concentrations. For real-world depressed roadway projects, analysts may need to consider using a single OPENPIT source with a length-to-width ratio greater than 10:1.

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[20] The upper limit is set to maintain numerical stability but has not been thoroughly tested for all potential project scenarios.

[21] Initial modeling for the CDOT I-70 East project used adjacent OPENPIT sources in 100 m segments for the depressed roadway portion of the project (per communication with Sabrina Williams, formerly with CDOT, and now at Pinyon Environmental, Inc.). However, the Final Environmental Impact Statement (FEIS) and Record of Decision (ROD) Document for the CDOT project do not include any technical details for the use of the OPENPIT source type to model the depressed roadway portion of the project (e.g., dimensions or aspect ratio of OPENPIT source(s) used in the modeling).

The receptor network for the hypothetical project includes more than one thousand discrete receptors with spacing varying from 25 m near the roadways to 100 m farther from the roadways, and extends out to 500 m from the roadway edges. Figure 3-15 shows two representations of the hypothetical project in AERMOD View.

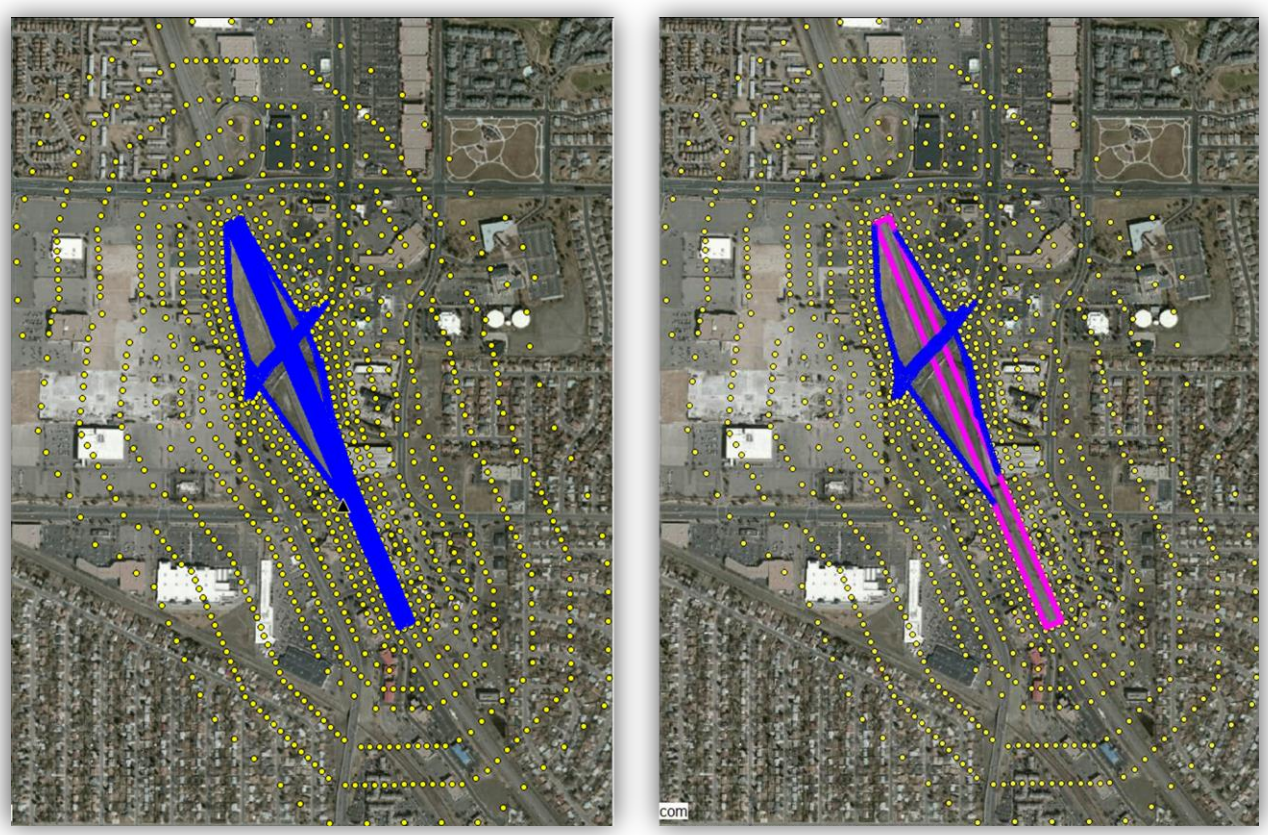


Figure 3-15. Hypothetical transportation project in AERMOD View. Image on the left shows all road links represented by line volume sources (blue lines); image on the right shows the ramps and arterials represented by line volume sources (blue lines), and the freeway link and median represented by a single OPENPIT source (pink rectangle). The yellow circles represent model receptors.

3.2.4 Modeling OPENPIT Sources with Aspect Ratio Greater than 10:1

Using the hypothetical project as a starting point, we ran three sample simulations for only a 0.5-mile portion of the freeway link, which is 37.37 m wide (including the median), depressed by 6 m, and has a length-to-width ratio equal of 20:1. Other simulation features include

- A vehicle fleet with (1) 8% trucks with an emissions release height of 1.47 m, and (2) year 2035 emissions for an overall freeway traffic volume of 125,000 AADT (Bai et al., 2017).

- Meteorological data from Santa Monica Municipal Airport corresponding to "base-case" wind speeds and a predominant southwesterly wind direction over the five-year period from 2007 through 2011. This wind direction is approximately perpendicular to the freeway link.

The three simulations use

1. A single at-grade area source;
2. A single OPENPIT source; and
3. Two smaller adjacent OPENPIT sources that each had a length-to-width ratio of 10:1.

Results for these simulations are shown in Figure 3-16, and the overall peak 24-hour PM_{10} concentration in each case is indicated by a black star. In Case 1, which used a single at-grade area source, the overall peak 24-hour PM_{10} concentration was 6.2 µg/m^3. The overall peak concentration for both cases using the single OPENPIT source (Cases 1 and 2) was 4.8 µg/m^3, with the peak impact locations differing slightly between the two Cases. In case 3, which used two smaller OPENPIT sources, unrealistic model-estimated concentrations occur at locations near the adjacent edges of the sources. When using the single larger OPENPIT source, concentrations are more realistic throughout the modeling domain. Therefore, in an AERMOD simulation, we suggest that exceeding the criterion of an OPENPIT length-to-width ratio of no greater than 10:1 is a more reasonable approach than using multiple smaller OPENPIT sources.

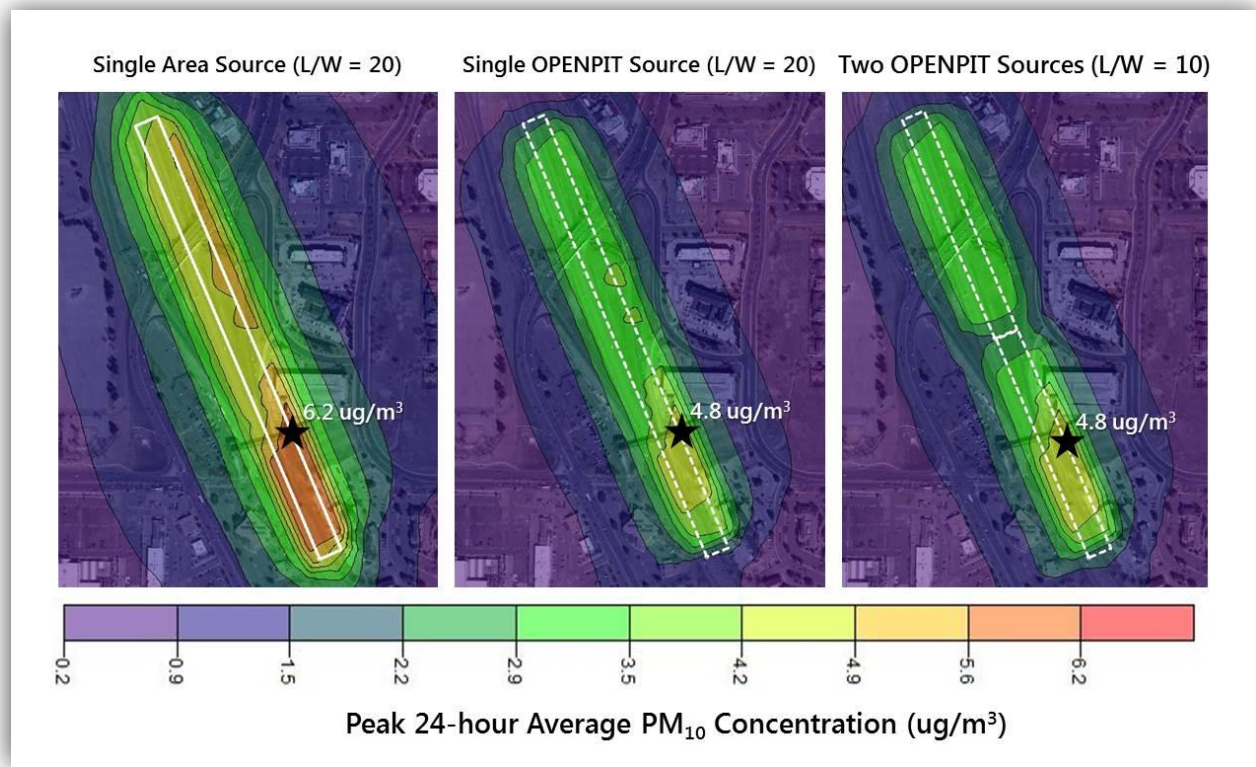


Figure 3-16. Contour plots of peak 24-hour average PM_{10} concentrations in test simulations for only a depressed freeway link with an aspect ratio of 20:1, using (1) a single at-grade area source, (2) a single OPENPIT source, and (3) two adjacent OPENPIT sources, each having an aspect ratio of 10:1. The black stars indicate the locations of the overall peak concentrations, and the magnitudes of the overall peaks are displayed on the contour plots.

We also ran sample simulations to evaluate differences in peak PM concentrations when a roadway link depressed by 6 m in between two at-grade roadway segments is modeled in AERMOD View. We modeled this roadway using several configurations:

1. All depressed and at-grade segments as line area sources, without using any OPENPIT sources;
2. All depressed and at-grade segments as line volume sources, without using any OPENPIT sources;
3. The depressed segment as an OPENPIT source, and the at-grade segments as line area sources;
4. The depressed segment as an OPENPIT source, and the at-grade segments as line volume sources; and
5. The entire roadway length as a single OPENPIT source.

Modeled peak PM_{10} concentrations in these modeling scenarios are illustrated by the contour plots in Figure 3-17. The results show that the at-grade roadway segments dominate the overall peak modeled concentration, and that modeled concentrations are substantially reduced only at receptors along the edges of the depressed roadway segment.

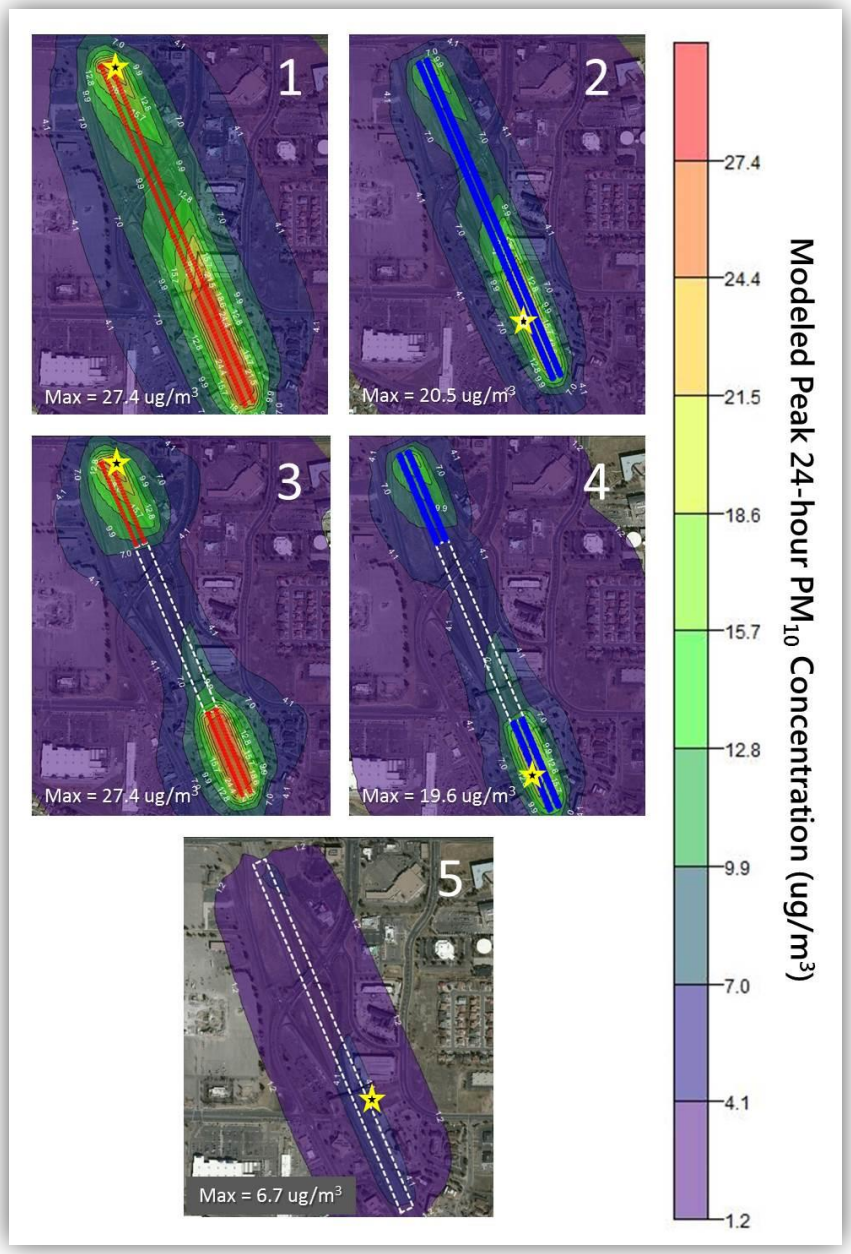


Figure 3-17. Contour plots of peak 24-hour average PM_{10} concentrations in sample simulations for a depressed freeway link (modeled with an OPENPIT source) between two at-grade roadway segments (modeled with line area and line volume sources). The yellow stars indicate the locations of the overall peak concentrations, and the magnitudes of the overall peaks are displayed on the contour plots.

It is important to keep in mind that a depressed and curved roadway cannot be represented by a single OPENPIT source, regardless of the length-to-width ratio. A series of OPENPIT sources would need to be used to represent a curved roadway; however, as mentioned earlier, multiple OPENPIT sources should not be used to represent a single emissions source. A roadway bordered by soundwalls is another roadway configuration that could theoretically be represented by an OPENPIT source. However, that scenario would require modeling complex terrain because the OPENPIT emissions would be released at a height above the ground-level elevation of receptors adjacent to the soundwall. Modeling with complex terrain would likely result in underestimation of concentrations near the roadway due to limitations in the AERMOD complex terrain algorithms for low-level, non-buoyant sources such as those from vehicle emissions. EPA provides no definitive guidance on using the OPENPIT source for modeling depressed roadways, and interagency consultation must be used in determining the appropriate configuration of OPENPIT sources used to model depressed roadways in a PM hot-spot analysis.

3.2.5 Case Study

Overview of Sensitivity Tests

Using the hypothetical project described above, we developed 60 AERMOD modeling scenarios to compare concentration estimates with and without the OPENPIT source, and to evaluate the sensitivity of peak modeled concentrations of 24-hour average PM_{10}, 24-hour average $PM_{2.5}$, and annual average $PM_{2.5}$ to different OPENPIT source and meteorological data inputs. In this case study, we evaluated multiple scenarios, each of which was based on a hypothetical project with the following features:

- An 8 lane freeway link that is 0.7 miles (1,062 m) long and 37.37 m wide (including the median).
- A vehicle fleet with (1) 8% trucks with an emissions release height of 1.47 m, and (2) year 2035 emissions for an overall freeway traffic volume of 125,000 AADT (Bai et al., 2017).
- Meteorological data from Santa Monica Municipal Airport corresponding to “base-case” wind speeds and a predominant southwesterly wind direction over the five-year period from 2007 through 2011. This wind direction is approximately perpendicular to the freeway link.

Using this starting point, we modeled four base case scenarios: two scenarios using all at-grade sources, and two scenarios using the OPENPIT source to represent the freeway link in the hypothetical project:

- **Base LA** is the base case scenario using all at-grade line area sources to represent all the roadways
- **Base LV** is the base case scenario using all at-grade line volume sources to represent all the roadways.
- **Base OPLA** is the base case scenario using the OPENPIT source to represent the freeway link and at-grade line area sources to represent all other roads.

- **Base OPLV** is the base case scenario using the OPENPIT source to represent the freeway link and at-grade line volume sources to represent all other roads.

In the two OPENPIT base-case scenarios, the OPENPIT source is used to represent only the freeway link, which is assumed to be depressed by 6 m. Table 3-3 summarizes the parameters varied in the sensitivity tests and the methods by which they were varied. Note that for the wind direction parameter, different real-world meteorological data sets were used to represent different predominant wind directions, as wind direction can vary by hour and the predominant wind direction for a given meteorological site applies only to the multi-year period of data used in the model simulations. Therefore, sensitivity to wind direction was examined only for peak annual average $PM_{2.5}$ concentration. Additionally, both PM_{10} and $PM_{2.5}$ were modeled in this case study.

Details of the model scenarios and travel activity data used in the sensitivity tests are provided in Appendix A (Section 3.2.7).

Table 3-3. Summary of sensitivity test parameters and the methods by which they were varied.

Parameter	Values	Method
Pit Depth	3 m, 6 m, 9 m	Vary depth of OPENPIT source
Pit Width[a]	24.92 m, 31.55 m, 37.37 m	Vary width of OPENPIT source, or number of line area or line volume sources, by varying the number of lanes (4, 6, and 8) in the freeway link
Release Height[b]	1.47 m, 1.72 m, 2.14 m	Vary emissions release height by varying the freeway link fleet mix (8%, 20%, and 40% trucks)
Wind Speed	½ base, base, 2 × base	Vary magnitude of wind speed for each hour by applying a factor of ½ or 2 to the base-case wind speed in the Santa Monica meteorological data
Wind Direction	Northwesterly, Westerly, Southwesterly, Southerly	Vary predominant wind direction by using meteorological data from different met stations (Fresno, Banning, Santa Monica, and Tahoe)

[a] The strength of emissions from the freeway link changes with the number of lanes in the freeway link (i.e., fewer lanes means lower emissions for the link).
[b] The strength of emissions from the freeway link changes with release height, since the release height is a function of the percentage of trucks in the vehicle fleet (i.e., greater release height means more trucks and higher emissions for the freeway link).

Case Study Results

The results of this case study are complex, due to the number of variables considered and their combined impacts on peak PM concentrations. Furthermore, the hypothetical project is not simply a single straight depressed roadway segment; rather, it is representative of a simplified real-world example with both depressed and at-grade roadways. The locations of peak concentration differ

between scenarios tested, primarily when considering the use of either line area or line volume sources to model at-grade roadway links. The peak concentration at a given location is a function of the depressed roadway as well as the other roadways that are at-grade. We found that the at-grade roadways contribute more to the total concentration when modeled with line area sources compared to line volume sources.

The set of model sensitivity tests for the hypothetical project showed that

- Using an OPENPIT source to represent a depressed roadway resulted in lower peak concentration estimates compared to using at-grade sources.
- Peak concentration estimates for OPENPIT scenarios were more sensitive to some input parameters compared to others; for example, on average, reduction in peak concentration relative to using all at-grade sources was greater when increasing the emissions release height (which also resulted in an overall increase in freeway source emissions[22]), than when changing the predominant wind direction.
- Across all model scenarios, absolute peak concentrations were (1) 6.6 $\mu g/m^3$ to 59 $\mu g/m^3$ for 24-hour average PM_{10}; (2) 1.3 $\mu g/m^3$ to 5.6 $\mu g/m^3$ for 24-hour average $PM_{2.5}$; and (3) 0.4 $\mu g/m^3$ to 2.3 $\mu g/m^3$ for annual average $PM_{2.5}$.
- Sensitivity of peak concentrations when using an OPENPIT source varied by model input parameter (pit depth, pit width, emissions release height, wind speed, and wind direction).
- The percent reductions in modeled peak PM concentrations ranged from 19% to 64% when using an OPENPIT source to represent a depressed roadway compared to modeling the roadway with at-grade line area or line volume sources for the hypothetical freeway project in this case study.
- The approximate 50% reduction in PM concentrations near depressed roadways, as reported in published literature, falls within the range quantified from the testing scenarios in this case study.

If only the depressed freeway link were modeled, the percent reduction in peak PM concentration would be greatest when comparing OPENPIT-based results to at-grade area source modeling as opposed to at-grade volume source modeling. This is illustrated by the findings in Table 3-4. However, the peak concentrations for the three configurations (i.e., modeling with line area, line volume, or OPENPIT sources) occurred on different days and at different locations.

[22] The release height is a function of fleet mix, so raising the release height was accomplished by increasing the fleet truck percentage, which also resulted in higher overall emissions.

Table 3-4. Modeled peak PM concentrations for only the depressed freeway link in the hypothetical project.

Source Type Used When Modeling Only the Depressed Freeway Link	Peak Concentration ($\mu g/m^3$)	Reduction (%) Modeled with OPENPIT
24-hour Average PM_{10}		
Line Area	27.4	76
Line Volume	20.5	67
OPENPIT	6.7	N/A
24-hour Average $PM_{2.5}$		
Line Area	3.7	65
Line Volume	2.8	54
OPENPIT	1.3	N/A
Annual Average $PM_{2.5}$		
Line Area	1.6	68
Line Volume	1.6	68
OPENPIT	0.5	N/A

Users familiar with AERMOD and PM hot-spot analysis modeling will find the Table 3-4 results intuitively understandable, since AERMOD generally produces higher peak near-road PM concentrations with area sources than with volume sources. Therefore, when looking just at a single road segment, it is reasonable to expect that use of OPENPIT would reduce concentrations more when compared to using at-grade area sources rather than at-grade volume sources. Furthermore, the reductions of peak modeled $PM_{2.5}$ average concentrations are less than those of PM_{10}, because the escape fraction of $PM_{2.5}$ from the OPENPIT is much greater than that of PM_{10}.

One of the complexities of the illustration modeled here is that the modeled peak concentrations were a function not just of the single depressed road segment, but also of the other arterial and ramp sources. When the entire project site was modeled, the greatest concentration reductions resulting from the use of OPENPIT were in comparison to the at-grade *volume source* scenario (not the at-grade area source scenario). This finding, which is counter-intuitive and different from the simplified result shown in Table 3-4, is due to the contribution of the arterial roadways and intersections on peak concentrations. Across the three scenarios modeled (OPENPIT, at-grade volume, and at-grade area), peak concentration absolute values were different and were also

modeled to occur in different locations depending on the importance of the arterial and ramp source contributions.

Reductions in peak concentrations, when using an OPENPIT source instead of at-grade sources, varied among the standards evaluated (i.e., annual average $PM_{2.5}$, 24-hour average $PM_{2.5}$, and 24-hour PM_{10}):

- For scenarios using line volume sources, the largest average reduction in peak concentration occurred for annual average $PM_{2.5}$.
- For scenarios using line area sources, the largest average reduction in peak concentration occurred for 24-hour average PM_{10}.

When considering only the scenarios using the OPENPIT source, estimated peak concentrations (normalized to the "Base Case OPLA" or "Base Case OPLV" scenarios) varied substantially with different test parameters; the largest variations in normalized concentrations occurred when the pit width, release height, and wind speed inputs were varied.

Appendix B (Section 3.2.8) includes a detailed summary of the overall results of the sensitivity test simulations, detailed plots of the percent reductions in PM concentrations, as well as the normalized concentrations for only scenarios using the OPENPIT source, by pollutant, averaging period, and by parameter varied.

3.2.6 Conclusion

For the CDOT I-70 East project, EPA recommended using the OPENPIT source in AERMOD to model a section of depressed roadway. However, analysts should understand that using OPENPIT for a depressed roadway is a novel approach. Analysts should seek consensus on the approach with interagency consultation partners before completing PM hot-spot analyses for a depressed roadway with the OPENPIT source function. Important limitations need to be considered and discussed through interagency consultation when using OPENPIT sources to model roadways that have an aspect ratio greater than 10:1, are curved, or are bordered by soundwalls. If interagency agreement is reached to use the OPENPIT source function, users can refer to the step-by-step illustration provided in Appendix C (Section 3.2.9) to see how to define an OPENPIT source in AERMOD View. When an OPENPIT source is used to represent a depressed roadway, we recommend using the OPENPIT source to model the entire length of the roadway, including both ends that transition to at-grade roadway elevation. This approach will avoid complicating factors, such as modeling with complex terrain to represent varying elevation from the elevation of greatest depression to the elevation at grade, which is necessary to represent transition segments with line area or line volume sources.

The sensitivity tests summarized in this section (Section 3.2) show that many of the trends observed for scenarios with an OPENPIT source are similar to those for scenarios with at-grade sources. The impact of wind direction on modeled peak PM concentration is the most difficult to anticipate, since

it depends on the roadway configuration and orientation relative to predominant wind direction, and the occurrence of low wind speeds.

When considering modeling options in AERMOD View for a depressed roadway, analysts can use these sensitivity testing results as reference information to support discussion with interagency consultation partners.

3.2.7 Appendix A: Details of Modeled Case Study Scenarios

Tables 3-5 and 3-6 provide detailed lists of all the model parameters tested, the corresponding model scenario IDs, and the number of unique model simulations associated with those IDs. When considering the percent reduction in modeled peak PM concentrations, the OPENPIT model simulations in the tables are compared with the corresponding simulations using all at-grade line area sources and all at-grade line volume sources listed in the tables. Note that scenarios with varying pit depth correspond only with those using the OPENPIT source, which are compared to the "base-case" scenarios with all at-grade line volumes and all at-grade line areas, as described in Section 3.2.5 (i.e., an 8-lane freeway that is 37.37 m wide, an 8% truck fleet mix with corresponding emissions and release height of 1.47 m, and 2007-2011 meteorological data for the Santa Monica Municipal Airport).

The parameters listed in Tables 3-5 and 3-6 were selected for the sensitivity tests based on the OPENPIT model formulation and their expected impacts on modeled PM concentrations. Key considerations:

- Pit width and emissions release height were expected to similarly impact the peak concentrations of PM_{10} and $PM_{2.5}$.
- Sensitivity of peak concentrations to pit depth and wind speed was anticipated to differ between PM_{10} and $PM_{2.5}$ because of the dependence of the effective emission rate on the OPENPIT escape fraction (i.e., particle size and density). Therefore, 24-hour $PM_{2.5}$ concentrations were tested only with the pit depth and wind speed parameters.
- Annual $PM_{2.5}$ concentrations were tested with pit depth, wind speed, and wind direction. Wind direction was expected to primarily impact the spatial distribution of peak PM concentrations.

Table 3-7 summarizes the travel activity data by roadway link in the hypothetical project.

Table 3-5. Summary of sensitivity test scenarios for 24-hour average PM_{10} concentrations. Each scenario ID is associated with two or four model simulations, including simulations for all roadways modeled as line area (LA) or line volume (LV) sources, and simulations with the depressed roadway modeled as an OPENPIT source and all other sources modeled as line area (OPLA) or line volume (OPLV) sources. Scenario IDs in bold represent the same base-case scenario.

Test Parameter	Scenario ID	Description	Number of Unique Simulations (Source Type)
24-hour Average PM_{10}			
Pit Depth	N/A[a]	Base case scenario without OPENPIT	2 (LA, LV)
	PitDepth3m	Pit depth = 3 m	2 (OPLA, OPLV)
	PitDepth6m	Pit depth = 6 m	2 (OPLA, OPLV)
	PitDepth9m	Pit depth = 9 m	2 (OPLA, OPLV)
Pit Width	**PitWidth8lane**	Pit width = 37.37 m (8 lane freeway)	0 (same as **PitDepth6m**)
	PitWidth6lane	Pit width = 31.55 m (6 lane freeway)	4 (LA, LV, OPLA, OPLV)
	PitWidth4lane	Pit width = 24.92 m (4 lane freeway)	4 (LA, LV, OPLA, OPLV)
Release Height	**RelHt8%truck**	Emissions release height = 1.47 m (8% truck fleet mix)	0 (same as **PitDepth6m**)
	RelHt20%truck	Emissions release height = 1.72 m (20% truck fleet mix)	4 (LA, LV, OPLA, OPLV)
	RelHt40%truck	Emissions release height = 2.14 m (40% truck fleet mix)	4 (LA, LV, OPLA, OPLV)
Wind Speed	WSPDdouble	Wind speed doubled across all hours	4 (LA, LV, OPLA, OPLV)
	WSPDbase	Wind speed in base case (Santa Monica)	0 (same as **PitDepth6m**)
	WSPDhalf	Wind speed halved across all hours	4 (LA, LV, OPLA, OPLV)

[a] Simulations with all at-grade line area (LA) and all at-grade line volume (LV) sources have no corresponding pit depth. These simulations are compared in the analysis with the base-case OPENPIT scenario with a pit depth of 6 m (i.e., scenario ID PitDepth6m).

Table 3-6. Summary of sensitivity test scenarios for 24-hour and annual average $PM_{2.5}$ concentrations. Each scenario ID is associated with two or four model simulations, including simulations for all roadways modeled as line area (LA) or line volume (LV) sources, and simulations with the depressed roadway modeled as an OPENPIT source and all other sources modeled as line area (OPLA) or line volume (OPLV) sources. Scenario IDs in bold represent the same base-case scenario.

Test Parameter	Scenario ID	Description	Number of Unique Simulations (Source Type)[a]
24-hour and Annual Average $PM_{2.5}$			
Pit Depth	N/A[a]	Base case scenario without OPENPIT	2 (LA, LV)
	PitDepth3mPM2.5	Pit depth = 3 m	2 (OPLA, OPLV)
	PitDepth6mPM2.5	Pit depth = 6 m	2 (OPLA, OPLV)
	PitDepth9mPM2.5	Pit depth = 9 m	2 (OPLA, OPLV)
Wind Speed	WSPDdoublePM2.5	Wind speed doubled across all hours	4 (LA, LV, OPLA, OPLV)
	WSPDbasePM2.5	Wind speed in base case (Santa Monica)	0 (same as **PitDepth6mPM2.5**)
	WSPDhalfPM2.5	Wind speed halved across all hours	4 (LA, LV, OPLA, OPLV)
Annual Average $PM_{2.5}$			
Wind Direction	WDIRNW	Fresno meteorological data	4 (LA, LV, OPLA, OPLV)
	WDIRW	Banning meteorological data	4 (LA, LV, OPLA, OPLV)
	WDIRSW	Santa Monica meteorological data	0 (same as **PitDepth6mPM2.5**)
	WDIRS	Tahoe meteorological data	4 (LA, LV, OPLA, OPLV)

[a] Simulations with all at-grade line area (LA) and all at-grade line volume (LV) sources have no corresponding pit depth. These simulations are compared in the analysis with the base-case OPENPIT scenario with a pit depth of 6 m (i.e., scenario ID PitDepth6mPM2.5).

Table 3-7. Summary of travel activity for modeled roadway links.

Link ID[a]	Link Type[b]	Length (m)	Width (m)	AADT[c]	Average Speed (mph)	
					Peak	Off-Peak
1	accel	259	6	4,549	20	20
2	cruise	61.7	6	5,782	40	40
3	cruise	52.1	3	1,249	40	40
5	queue	22.1	9	4,001	5	5
6	accel	90.5	9	6,768	25	25
7	cruise	68.9	9	6,768	40	40
8	cruise	68.6	9	8,160	40	40
9	queue	27.4	6	5,751	5	10
10	queue	39.6	3	2,398	5	5
11	queue	21.3	6	2,757	5	5
12	queue	17.5	6	2,151	5	5
13	cruise	127.9	6	2,757	40	40
14	cruise	142.7	6	3,495	40	40
20	accel	85.1	6	5,751	20	20
21	queue	17.5	6	4,038	5	5
22	queue	48	3	2,720	5	5
23	accel	73.1	6	4,038	20	20
24	queue	30.5	6	3,653	5	5
25	queue	30.5	6	3,626	5	5
26	decel	70.9	3	2,730	30	30
30	accel	102.1	6	6,330	20	20
31	queue	30.5	6	4,501	5	5
32	accel	75.3	6	8,149	20	20
33	cruise	342	6	10,004	40	40
63	accel	257	3	8,370	25	25
65	cruise	140.7	3	5,287	50	50
HWYN	cruise	1061.7	14.6	105,378	55	60
HWYS	cruise	1061.7	14.6	129,477	55	60

[a] The northbound and southbound freeway links correspond with link IDs HWYN and HWYS. In the model configurations using the OPENPIT source, these two links are combined into a single link which includes the median between them.

[b] In this hypothetical project case, the links were specified to different types, including acceleration (accel), cruise, deceleration (decel), and queue links, to ensure appropriate emissions modeling. Each link was assigned with a type to represent a roadway segment for which activity parameters and emissions processes are generally consistent. For example, accel and decel links represent segments departing from and approaching to an intersection; cruise links represent segments with constant travel speed; and queue links reflect short segments with vehicle idling activities (e.g., at the intersection signal).

[c] AADT is annual average daily traffic; the values are presented to show the general vehicle activity levels. In this project case, the emissions calculation for each link was based on hourly activity estimates (vehicle miles traveled). The EMFAC2014 default distribution of vehicle miles traveled (VMT) by hour (i.e., proportion of hourly VMT in daily total VMT) for Fresno County were used to distribute the AADT across the hours during peak time (6:00–9:00 a.m. and 4:00–7:00 p.m.) and off-peak time (all other 16 hours). Those hourly traffic activity estimates were then used to calculate hourly emission rates for AERMOD View simulations.

3.2.8 Appendix B: Detailed Results of the Case Study Sensitivity Tests

This appendix to Section 3.2 is divided into four parts:

1. A summary of the overall results of the sensitivity tests;
2. Summaries of the sensitivity of percent reduction in modeled peak concentrations using the OPENPIT source relative to using at-grade sources as a function of the OPENPIT input parameter;
3. Summaries of the sensitivity of modeled peak concentrations using the OPENPIT source as a function of OPENPIT input parameter (i.e., the variation in estimated concentrations using OPENPIT normalized to the base-case OPENPIT scenario);
4. A summary of the ratios of modeled peak concentrations using line volume sources to those using line area sources with and without use of the OPENPIT source to represent the depressed freeway link.

Overall Results

In all of the model sensitivity tests, using an OPENPIT source to represent a depressed roadway resulted in lower modeled peak PM concentrations than when modeling the roadway at-grade with either line area or line volume sources. Absolute modeled peak concentrations across all scenarios were (1) 6.6 µg/m^3 to 59 µg/m^3 for 24-hour average PM_{10}; (2) 1.3 µg/m^3 to 5.6 µg/m^3 for 24-hour average $PM_{2.5}$; and (3) 0.4 µg/m^3 to 2.3 µg/m^3 for annual average $PM_{2.5}$. The percent reduction of modeled peak concentration when using an OPENPIT source instead of at-grade line area sources across all three pollutant-averaging periods ranged from 19% to 48%, while the percent reduction when using an OPENPIT source instead of at-grade line volume sources ranged from 38% to 64%. When considering only the scenarios using the OPENPIT source, the estimated peak concentration normalized to the OPENPIT base-case scenario ranged from approximately 0% to 95%, with the largest normalized concentrations occurring when the release height, wind speed, and wind direction inputs were varied.

Table 3-8 summarizes the source input parameters that were varied, the expected impact of varying those parameters as based on the OPENPIT model formulation, and the impacts observed in the sensitivity tests; Tables 3-9 through 3-11 summarize the total emissions and AERMOD-estimated peak PM concentrations for each test simulation; Table 3-12 lists the hourly emission rates for the OPENPIT source representing the freeway link; and Table 3-13 summarizes the range of model runtimes for the sensitivity test simulations.

Table 3-8. Summary of parameters varied in the sensitivity tests and their impacts on model-estimated peak concentrations. All concentrations in this table refer to near-road concentrations at receptors shown in Figure 3-15.

Parameter Change	Expected Impact (Based on OPENPIT Model Formulation)[a]	Observed Impact in Sensitivity Tests	
		Description	Numerical Change
Increasing Pit Depth	• More trapping of total emissions • Decrease in effective area • Increase in effective emission rate per unit area • Lower estimated peak concentrations with greater pit depth	**Change in peak concentration:** • Negligible decrease **Change in percent reduction:** • Small increase	**Change in peak concentration:** • Up to 0.4 µg/m^3 (PM_{10}) **Change in percent reduction:** • Up to 2% (PM_{10})
Decreasing Pit Width	• Decrease in effective area • Increase in effective emission rate per unit area • Increase in distance between source and receptor • Unknown impact on estimated peak concentrations	**Change in peak concentration:** • Small decrease **Change in percent reduction:** • Moderate decrease using line area sources or line volume sources for at-grade road links	**Change in peak concentration:** • Up to 2 µg/m^3 (PM_{10}) **Change in percent reduction:** • Up to 10% using line area sources for at-grade road links (PM_{10}) • Up to 22% using line volume sources for at-grade road links (PM_{10})
Increasing Release Height	• Increase in effective area • Decrease in effective emission rate per unit area • Decrease in distance between source and receptor • Unknown impact on estimated peak concentrations	**Change in peak concentration:** • Substantial increase **Change in percent reduction:** • Moderate increase using line area sources for at-grade road links • Small increase using line volume sources for at-grade road links	**Change in peak concentration:** • Up to 9 µg/m^3 (PM_{10}) **Change in percent reduction:** • Up to 19% using line area sources for at-grade road links (PM_{10}) • Up to 2% using line volume sources for at-grade road links (PM_{10})

Parameter Change	Expected Impact (Based on OPENPIT Model Formulation)[a]	Observed Impact in Sensitivity Tests	
		Description	Numerical Change
Increasing Wind Speed	• Increase in OPENPIT emissions escape fraction • Increase in plume dispersion • Unknown impact on estimated peak concentrations	**Change in peak concentration:** • Substantial decrease **Change in percent reduction:** • Moderate increase using line area sources for at-grade road links • Small increase using line volume sources for at-grade road links	**Change in peak concentration:** • Up to 17 µg/m^3 (PM_{10}) decrease **Change in percent reduction:** • Up to 8% using line area sources for at-grade road links ($PM_{2.5}$) • Up to 3% using line volume sources for at-grade road links (PM_{10} and $PM_{2.5}$)
Range of Prevailing Wind Directions Relative to Freeway Link Alignment	• Smaller effective area and larger emission rate per unit area for perpendicular winds • Larger effective area and smaller emission rate per unit area for parallel winds • Higher estimated peak concentrations with perpendicular winds	**Change in peak concentration:** • Higher estimated peak annual average $PM_{2.5}$ concentrations with near perpendicular wind **Change in percent reduction:** • Moderate range in percent reductions of estimated peak annual average $PM_{2.5}$ concentration	**Change in peak concentration:** • Up to 0.3 µg/m^3 using line area sources for at-grade road links • Up to 0.2 µg/m^3 using line volume sources for at-grade road links **Change in percent reduction:** • Range of 9% using line area sources for at-grade road links • Range of 11% using line volume sources for at-grade road links

[a] The OPENPIT model formulation was described in the 1995 publication of the User's Guide for the Industrial Source Complex (ISC3) Dispersion Models: Volume II – Description of Model Algorithms (U.S. Environmental Protection Agency, 1995).

Table 3-9. Total PM_{10} EMFAC2014-based vehicle emissions for the year 2035 and maximum modeled 24-hour average peak concentrations for simulations in the case study.

Scenario ID[a]	Emissions (kg/day)			Maximum Modeled Peak Concentration ($\mu g/m^3$)			
	Arterial Links	Freeway Link	Total	All Line Areas (LA)	All Line Volumes (LV)	Line Areas and OPENPIT (OPLA)	Line Volumes and OPENPIT (OPLV)
24-hour Average PM_{10}							
N/A (base case w/out OPENPIT)	1.80	11.76	13.56	38.2	21.7	N/A	N/A
PitDepth3m	1.80	11.76	13.56	N/A	N/A	27.2	8.7
PitDepth6m				N/A	N/A	27.1	8.5
PitDepth9m				N/A	N/A	27.1	8.3
PitWidth8lane	1.80	11.76	13,56	38.2	21.7	27.1	8.5
PitWidth6lane	1.80	8.82	10.62	35.0	16.0	26.5	7.3
PitWidth4lane	1.80	5.88	7.68	32.0	10.7	25.8	6.6
RelHt8%truck	1.80	11.76	13.56	38.2	21.7	27.1	8.5
RelHt20%truck	2.73	17.33	20.07	43.9	30.6	28.4	11.4
RelHt40%truck	4.30	26.70	31.00	59.2	43.9	30.6	16.6
WSPDdouble	1.80	11.76	13.56	26.0	19.5	18.1	8.0
WSPDbase				38.2	21.7	27.1	8.5
WSPDhalf				49.6	25.8	35.4	10.9

[a] The scenario IDs in bold represent the same base-case model scenario.

Table 3-10. Total $PM_{2.5}$ EMFAC2014-based vehicle emissions for the year 2035 and maximum modeled 24-hour average peak concentrations for simulations in the case study.

Scenario ID[a]	Emissions (kg)			Maximum Modeled Peak Concentration (µg/m^3)			
	Arterial Links	Freeway Link	Total	Line Areas Only (LA)	Line Volumes Only (LV)	Line Areas and OPENPIT (OPLA)	Line Volumes and OPENPIT (OPLV)
24-hour Average $PM_{2.5}$							
N/A (base case w/out OPENPIT)	0.19	1.61	1.80	3.4	2.9	N/A	N/A
PitDepth3mPM2.5	0.19	1.61	1.80	N/A	N/A	3.2	1.4
PitDepth6mPM2.5				N/A	N/A	3.2	1.4
PitDepth9mPM2.5				N/A	N/A	3.2	1.4
WSPDdoublePM2.5	0.19	1.61	1.80	3.2	2.6	2.2	1.3
WSPDbasePM2.5				3.4	2.9	3.2	1.4
WSPDhalfPM2.5				5.6	3.5	4.2	1.8

[a] The scenario IDs in bold represent the same base-case model scenario.

Table 3-11. Total $PM_{2.5}$ EMFAC2014-based vehicle emissions for the year 2035 and maximum modeled annual average peak concentrations for simulations in the case study.

Scenario ID[a]	Emissions (kg)			Maximum Modeled Peak Concentration ($\mu g/m^3$)			
	Arterial Links	Freeway Link	Total	Line Areas Only (LA)	Line Volumes Only (LV)	Line Areas and OPENPIT (OPLA)	Line Volumes and OPENPIT (OPLV)
Annual Average $PM_{2.5}$							
N/A (base case w/out OPENPIT)	0.19	1.61	1.80	1.7	1.6	N/A	N/A
PitDepth3mPM2.5	0.19	1.61	1.80	N/A	N/A	1.2	0.6
PitDepth6mPM2.5				N/A	N/A	1.2	0.6
PitDepth9mPM2.5				N/A	N/A	1.2	0.6
WSPDdoublePM2.5	0.19	1.61	1.80	1.0	1.0	0.7	0.4
WSPDbasePM2.5				1.7	1.6	1.2	0.6
WSPDhalfPM2.5				2.3	2.1	1.7	0.8
WDIRNW	0.19	1.61	1.80	1.5	1.3	0.9	0.6
WDIRW				1.3	1.1	0.9	0.4
WDIRSW				1.7	1.6	1.2	0.6
WDIRS				1.3	0.9	0.9	0.4

[a] The scenario IDs in bold represent the same base-case model scenario.

Table 3-12. OPENPIT emission rates used in the case study sensitivity simulations.

Hour	Emission Rate ($g/s/m^2$)
1	5.76×10^{-8}
2	2.96×10^{-8}
3	4.44×10^{-8}
4	3.79×10^{-8}
5	3.31×10^{-8}
6	5.05×10^{-8}
7	1.69×10^{-7}
8	3.00×10^{-7}
9	2.90×10^{-7}
10	1.70×10^{-7}
11	1.76×10^{-7}
12	2.12×10^{-7}
13	2.13×10^{-7}
14	2.12×10^{-7}
15	2.32×10^{-7}
16	2.30×10^{-7}
17	2.92×10^{-7}
18	3.05×10^{-7}
19	2.15×10^{-7}
20	1.33×10^{-7}
21	1.13×10^{-7}
22	1.15×10^{-7}
23	8.39×10^{-8}
24	6.22×10^{-8}

Table 3-13. Summary of runtimes for AERMOD View simulations in the case study.

Source Type(s)	Number of Individual Sources	Range of Simulation Runtimes[a]
All Line Areas (LA)	69 areas	2 to 4 hours
All Line Volumes (LV)	3,525 volumes	5 to 10 hours
Line Areas and OPENPIT (OPLA)	37 areas and 1 OPENPIT	2 to 4 hours
Line Volumes and OPENPIT (OPLV)	693 volumes and 1 OPENPIT	3 to 6 hours

[a] Model runtimes are dependent on the number and type of sources, the number of model receptors, computer processor speed, and whether or not the MPI (message passing interface) version of AERMOD in AERMOD View is used. For the simulations in this case study, we used the MPI version of AERMOD with eight processors.

Sensitivity of Peak Concentration Reductions to OPENPIT Source Parameters

In this section, we summarize sensitivity test results in terms of percent reduction of peak PM concentrations when using OPENPIT instead of at-grade line area or line volume sources. Tables 3-14 through 3-16 show the modeled reductions in peak concentration by source input parameter and pollutant-averaging period. The same results are also shown in Figures 3-18 through 3-24. In all cases, the concentration reduction when using the OPENPIT source with line volume sources is greater than that when using the OPENPIT source with line area sources. As explained in Section 3.2.5, these results were a function not just of the modeled depressed roadway segment, but also the arterial and ramp sources contributing to peak concentrations.

Table 3-14. Percent reduction of peak 24-hour average PM_{10} concentrations using the OPENPIT source relative to at-grade sources (either line area or line volume sources).

Scenario ID[a]	Line Area	Line Volume
PitDepth3m	29	60
PitDepth6m	29	61
PitDepth9m	29	62
PitWidth8lane	29	61
PitWidth6lane	25	55
PitWidth4lane	19	38
RelHt8%truck	29	61
RelHt20%truck	35	63
RelHt40%truck	48	62
WSPDhalf	29	58
WSPDbase	29	61
WSPDdouble	30	59

[a] Scenario IDs in bold represent the base-case scenarios with and without use of the OPENPIT source, so the values are identical in each of the corresponding rows.

Table 3-15. Percent reduction of peak 24-hour average $PM_{2.5}$ concentrations using the OPENPIT source relative to at-grade sources (either line area or line volume sources).

Scenario ID[a]	Line Area	Line Volume
PitDepth3mPM2.5	26	52
PitDepth6mPM2.5	26	52
PitDepth9mPM2.5	27	53
WSPDhalfPM2.5	25	49
WSPDbasePM2.5	26	52
WSPDdoublePM2.5	33	49

[a] Scenario IDs in bold represent the base-case scenarios with and without use of the OPENPIT source, so the values are identical in each of the corresponding rows.

Table 3-16. Percent reduction of peak annual average $PM_{2.5}$ concentrations using the OPENPIT source relative to at-grade sources (either line area or line volume sources).

Scenario ID[a]	Line Area	Line Volume
PitDepth3mPM2.5	27	62
PitDepth6mPM2.5	27	63
PitDepth9mPM2.5	27	64
WSPDhalfPM2.5	25	63
WSPDbasePM2.5	27	63
WSPDdoublePM2.5	28	62
WDIRNW	36	56
WDIRW	29	60
WDIRSW	27	63
WDIRS	34	52

[a] Scenario IDs in bold represent the base-case scenarios with and without use of the OPENPIT source, so the values are identical in each of the corresponding rows.

Sensitivity of Percent Concentration Reduction to Pit Depth

Figure 3-18 shows that the percent concentration reduction is somewhat insensitive to pit depth for all scenarios tested, although reductions do increase by a small amount as pit depth increases. Upon further review of the OPENPIT model formulation, we found that, in general, the effective area of the pit is weakly dependent on pit depth, particularly for the relatively large aspect ratio of the pit and the small depths used in this PM hot-spot context. As described in the ISC User's Guide, the effective area decreases as the pit depth increases (U.S. Environmental Protection Agency, 1995). Also note the location of the effective area is along the upwind side of the pit; therefore, the emission source is farther from the nearest downwind receptors as the pit depth increases.

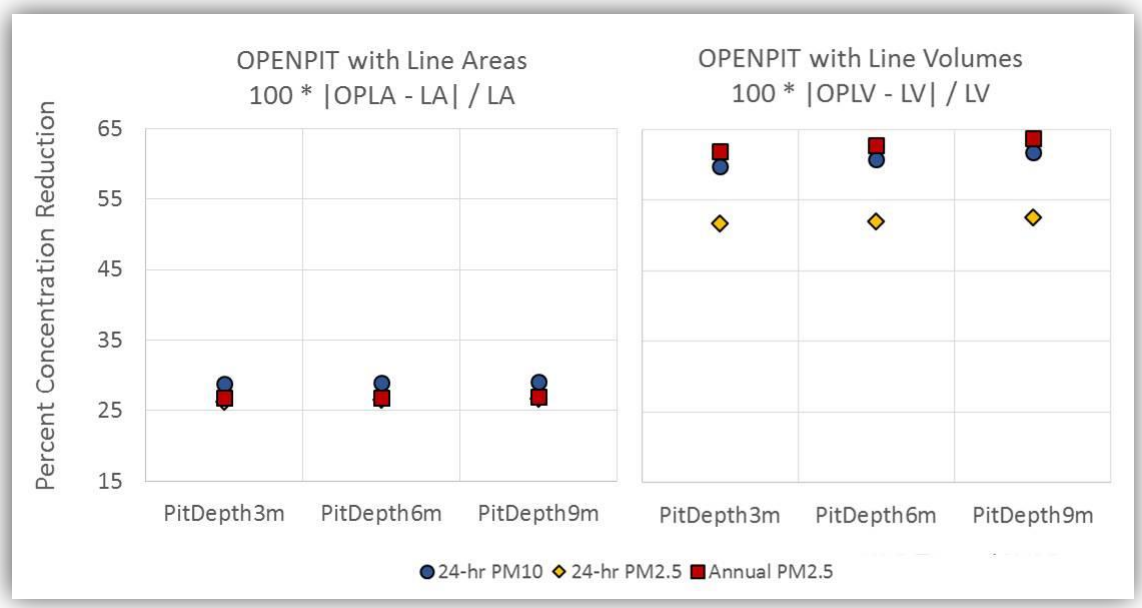


Figure 3-18. Percent reduction in modeled peak concentration using the OPENPIT source relative to at-grade line area or line volume sources as a function of pit depth.

Sensitivity of Percent Concentration Reduction to Pit Width

Sensitivity to pit width was tested only for 24-hour average PM_{10} because it was assumed that varying pit width would similarly affect concentrations of 24-hour and annual average $PM_{2.5}$. As Figure 3-19 shows,

- The sensitivity of percent concentration reduction is significant regardless of whether the at-grade scenarios were modeled with line area or with line volume sources.
- As pit width decreases, the reduction in concentration relative to modeling the freeway at grade decreases as well.
- The sensitivity to pit width is greater in the scenarios where at-grade line volume sources were used.

The higher rate of decrease in peak concentration for the at-grade line volume scenarios compared to that for the OPENPIT scenarios (illustrated by the greater range of reductions for line volume scenarios) is likely due to the effect of plume meander. Plume meander accounts for the back and forth shifting of the emissions plume, and it decreases the likelihood of a coherent plume reaching a receptor after long travel times (Cimorelli et al., 2004). Plume meander is modeled for line volume sources, and not for OPENPIT or area sources. Note that in this hypothetical case study, the same receptor network was used for each model scenario, and the nearest receptors are farther from the freeway source as the width of the freeway link, or the number of lanes, decreases. Therefore, the effect of plume meander becomes more pronounced in these scenarios as the distance to the nearest receptors increases.

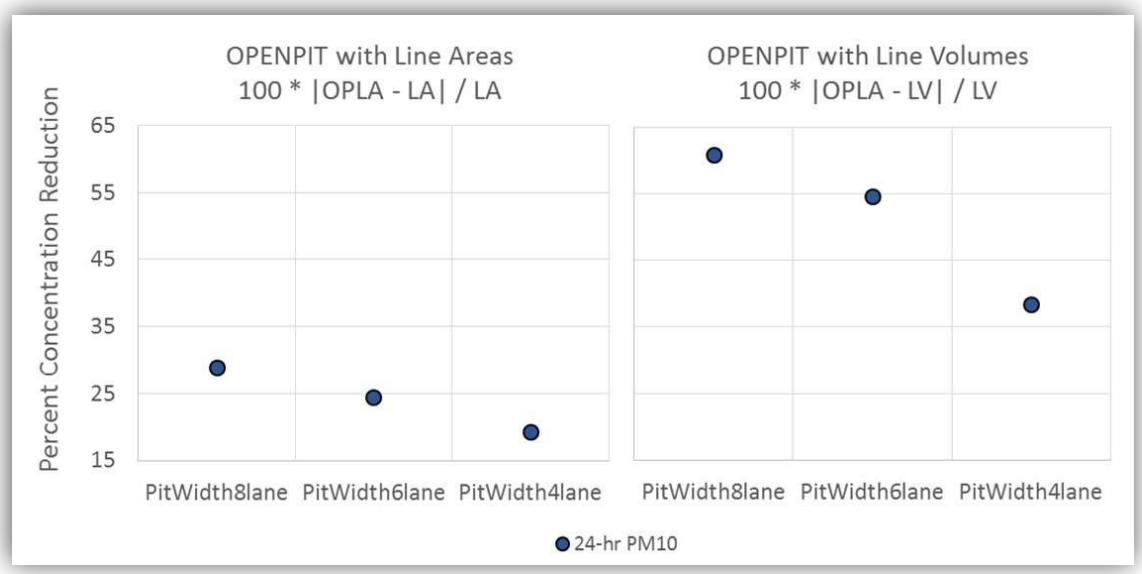


Figure 3-19. Percent reduction in modeled peak concentration using the OPENPIT source relative to at-grade line area or line volume sources as a function of pit width. Note that as the width of the depressed roadway decreases, so does the emission rate, due to the corresponding reduction in traffic on the freeway link.

Sensitivity of Percent Concentration Reduction to Emissions Release Height

Sensitivity of the percent reduction in peak PM concentration to emission source release height was also tested only for 24-hour average PM_{10}. As seen in Figure 3-20, the sensitivity was significant only in the modeling scenarios using OPENPIT and line area sources. The increase in release height was achieved by increasing the percentage of trucks in the fleet mix for the hypothetical project, which increased the amount of emissions. The scenarios using line area sources to represent all roadway links are more sensitive to changes in release height and emissions increases than the scenarios with OPENPIT and line area sources. On the other hand, the figure shows that scenarios using all line volume sources are equally sensitive to those changes as the scenarios using OPENPIT and line volume sources.

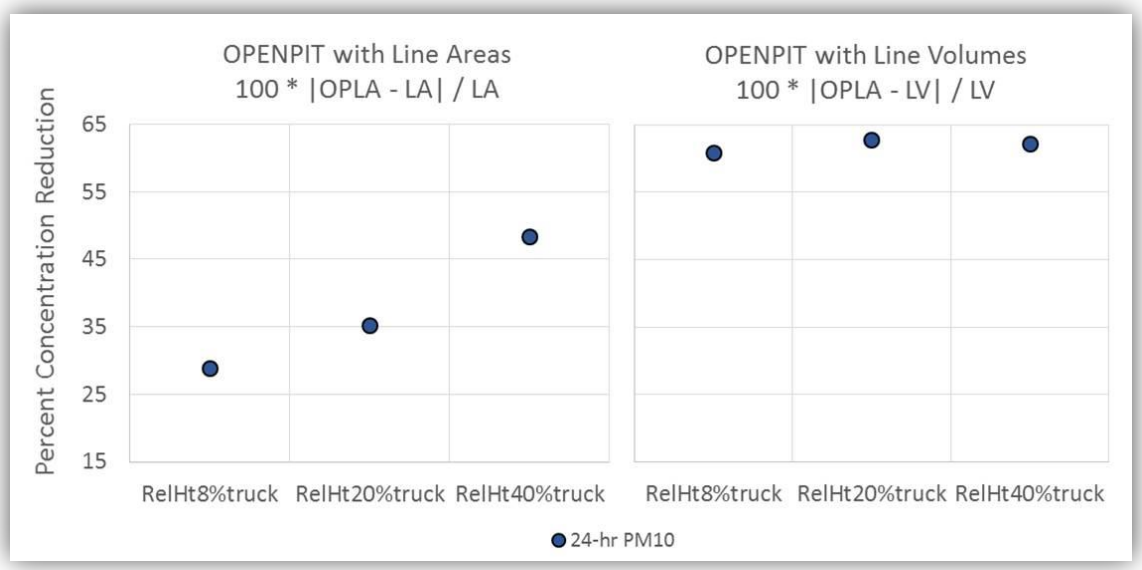


Figure 3-20. Percent reduction in peak concentration using the OPENPIT source relative to at-grade line area or line volume sources as a function of release height. Note that as release height increases, so does the emission rate, due to increasing truck percentage.

Sensitivity of Percent Concentration Reduction to Wind Speed

As shown in Figure 3-21, the variations of modeled peak concentrations with wind speed in scenarios with the OPENPIT source and those without are similar. The figure shows a slight increase in concentration reduction with increasing wind speed for the scenarios with OPENPIT and line area sources. The greatest variability in concentration reduction is seen for 24-hour $PM_{2.5}$ concentrations in the scenarios with OPENPIT and line area sources, which shows a slight trend towards greater reduction as the wind speed increases. In general, peak PM concentrations are expected to decrease as wind speed increases. The results in Figure 3-21 suggest that the concentrations in the scenarios with OPENPIT decrease as wind speed increases more than they do in the scenarios with all road links modeled with at-grade line area sources.

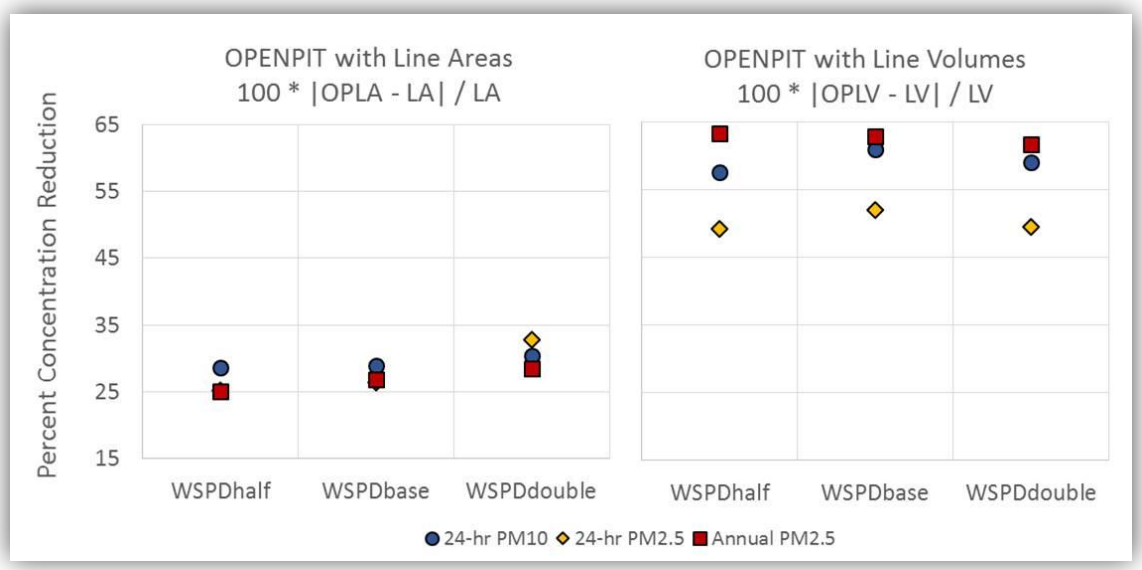


Figure 3-21. Percent reduction in peak concentration using the OPENPIT source relative to at-grade line area or line volume sources as a function of wind speed.

Sensitivity of Percent Concentration Reduction to Wind Direction

The freeway in the hypothetical project is oriented in the northwest to southeast direction, as shown in Figures 3-22 and 3-23. These figures illustrate the overall reductions in peak annual average $PM_{2.5}$ concentration when using the OPENPIT source in both the line area and line volume source scenarios. The plots show that the extent of the contours decreases when the OPENPIT source is used to represent the freeway link. In the scenarios with line area sources (Figure 3-22), the change in shape of the contours appears to follow the shape of the arterial roadway links, indicating that the relative contributions from those sources increases when the OPENPIT source is used. This effect is less pronounced in the scenarios with line volume sources (Figure 3-23).

In the scenarios tested, the predominant wind directions in the WDIRNW and WDIRS scenarios are near parallel to the freeway link, and those in the WDIRW and WDIRSW scenarios are near perpendicular to the freeway link. In the scenarios with line area sources shown in Figure 3-22,

- The maximum peak concentration indicated by the yellow star shifts with the predominant wind direction when only line area sources are used.
- In the near perpendicular wind direction cases, when only line area sources are used, the location of the maximum peak is roughly the same as in all the scenarios using OPENPIT with line area sources.

The shifting of maximum peak concentration location with predominant wind direction does not occur for the scenarios with only line volume sources (Figure 3-23), which is likely a result of the plume meander treatment for volume sources.

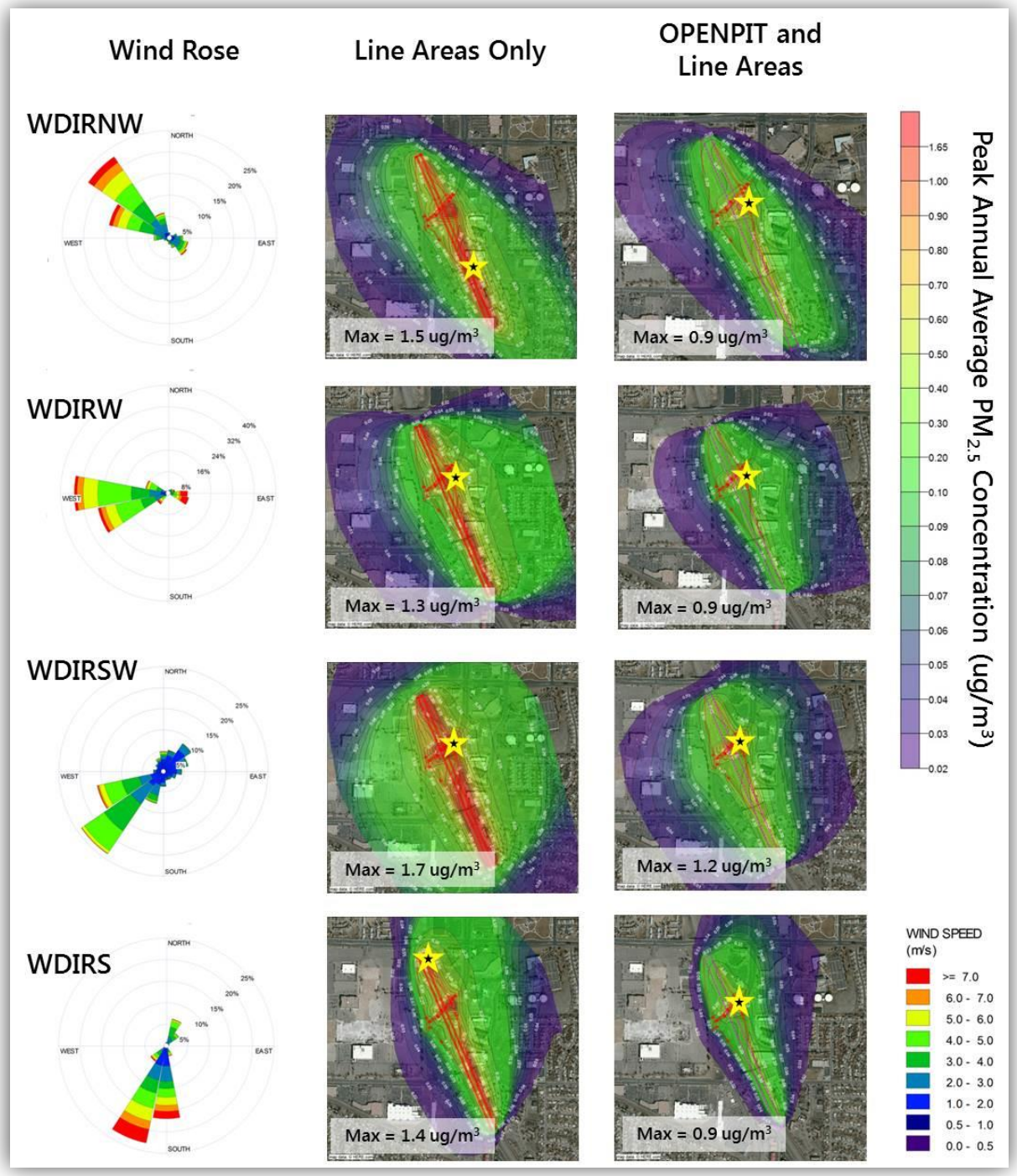


Figure 3-22. Contour plots (middle, right) of peak annual average $PM_{2.5}$ concentrations with wind roses (left) for the wind direction scenarios with line area and OPENPIT sources testing the sensitivity to predominant wind direction. The location of the maximum peak concentration (Max) is indicated by the yellow star.

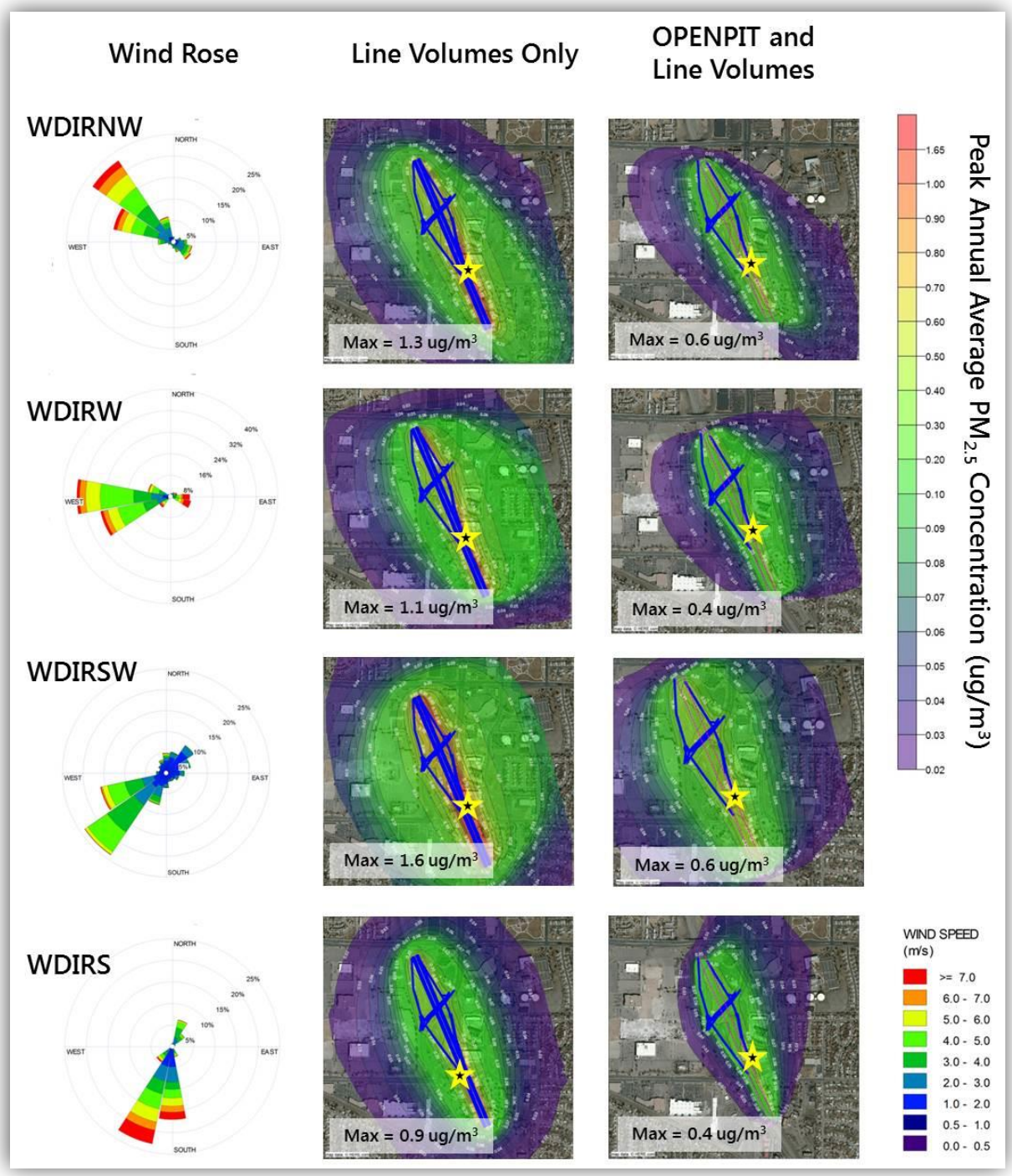


Figure 3-23. Contour plots (right, middle) of peak annual average $PM_{2.5}$ concentrations with wind roses (left) for the wind direction scenarios with line volume and OPENPIT sources testing the sensitivity to predominant wind direction. The location of the maximum peak concentration (Max) is indicated by the yellow star.

Figure 3-24 shows that the sensitivity to predominant wind direction was substantial when comparing the use of OPENPIT sources with both at-grade line area and at-grade line volume sources. The OPENPIT model formulation indicates that, in general,

- The effective area and emission rate of an OPENPIT source will be largest for winds parallel to the source and smallest for winds perpendicular to the source.
- Concentration reductions when using the OPENPIT source to represent the freeway link would be smallest for parallel winds and largest for perpendicular winds.

The reduction in peak annual average $PM_{2.5}$ concentration for the scenarios with line volume sources is consistent with this expectation. However, in the scenarios with line area sources, the reductions in concentration when using the OPENPIT source are less for the perpendicular winds than for the parallel winds. This may indicate that, when using line area sources, the arterial links' contribution to the maximum peak concentration is greatest with perpendicular winds. The result may also be influenced by the absence of plume meander treatment for line area sources.

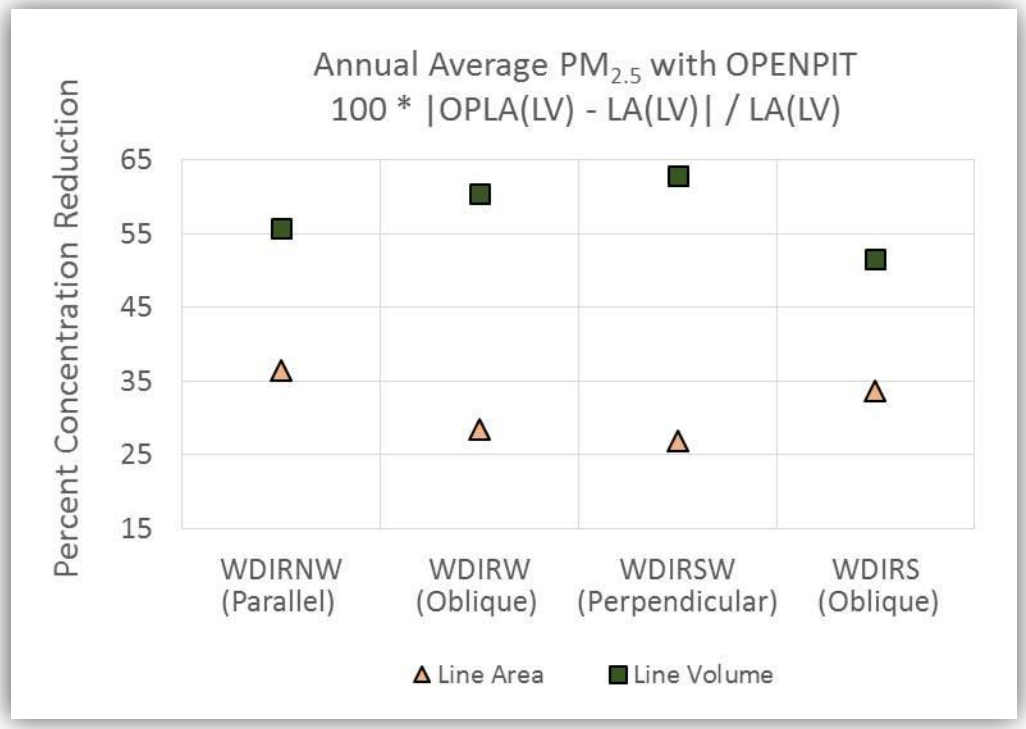


Figure 3-24. Percent reduction in peak concentration using the OPENPIT source relative to at-grade line area or line volume sources as a function of wind direction.

Sensitivity of Peak Concentrations to OPENPIT Source Parameters

In this section we consider the results of only the scenarios using the OPENPIT source to represent the depressed roadway in the hypothetical transportation project in terms of the sensitivity of modeled concentrations to source input parameters. Here we focus on the sensitivity of OPENPIT results, and not the reduction of concentrations compared to using all at-grade sources. In Figures 3-25 through 3-28, we show the concentrations modeled using the OPENPIT source normalized to those of the base-case OPENPIT source scenario. Therefore, values in the plots that are greater than 1 indicate a modeled concentration greater than that for the base case, and values less than 1 indicate a modeled concentration less than that for the base case. The base-case parameters include a pit depth equal to 6 m, a pit width equal to 37.37 m (corresponding with an 8-lane freeway with median), an emissions release height of 1.47 m (corresponding with a fleet mix with 8% trucks), and wind speed and direction information from the Santa Monica (WDIRSW scenario) meteorological data.

Sensitivity of Modeled Peak Concentrations to Pit Depth

Figure 3-25 shows that the modeled peak concentrations for all three pollutant and averaging periods are relatively insensitive to pit depth. There is only a slight reduction in concentration as pit depth increases for both the scenarios with OPENPIT and line area sources and the scenarios with OPENPIT and line volume sources. The change in concentration across the three pit depths considered is slightly greater when line volume sources are used.

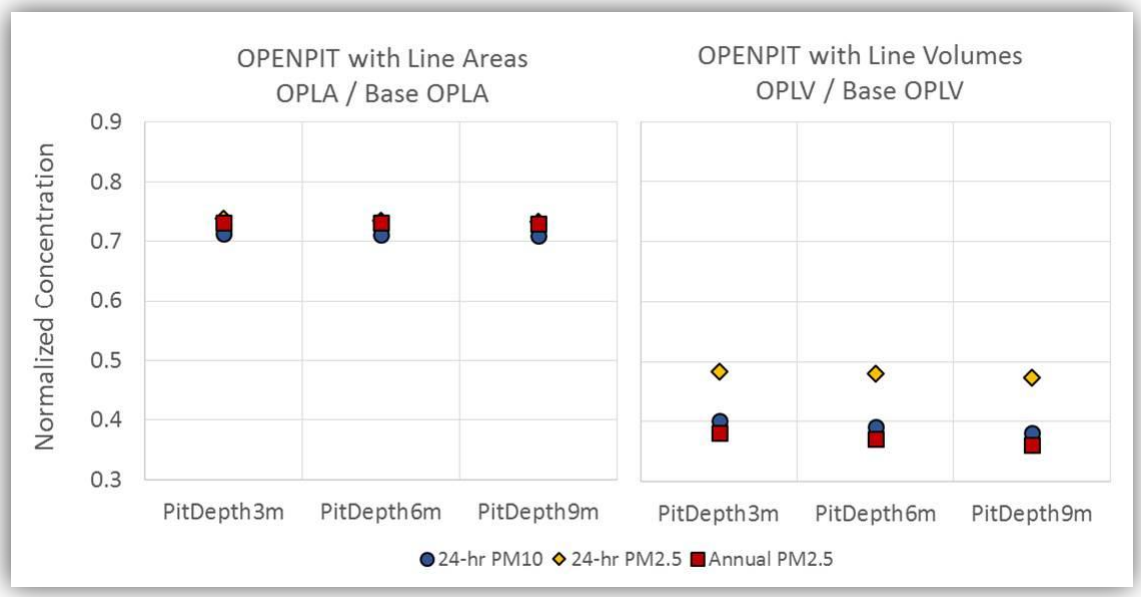


Figure 3-25. Sensitivity of peak average concentration to pit depth, showing peak average concentrations for scenarios with the OPENPIT source normalized to concentrations in the base-case OPENPIT scenario (PitDepth6m).

Sensitivity of Modeled Peak Concentrations to Pit Width

Figure 3-26 shows that the modeled peak 24-hour average PM_{10} concentration using the OPENPIT source is relatively insensitive to plume width when OPENPIT is modeled along with line area sources, while it is more sensitive to plume width when OPENPIT is modeled along with line volume sources. As discussed earlier, plume meander, which is treated for line volume sources and not line area sources, accounts for the back and forth shifting of the emissions plume and decreases the likelihood of a coherent plume reaching a receptor after long travel times. Considering the effect of plume meander, the results shown in Figure 3-26 suggest that the decrease in modeled concentration with pit width in the scenarios using the OPENPIT source with line volume sources is likely due more to the use of line volume sources than the use of the OPENPIT source.

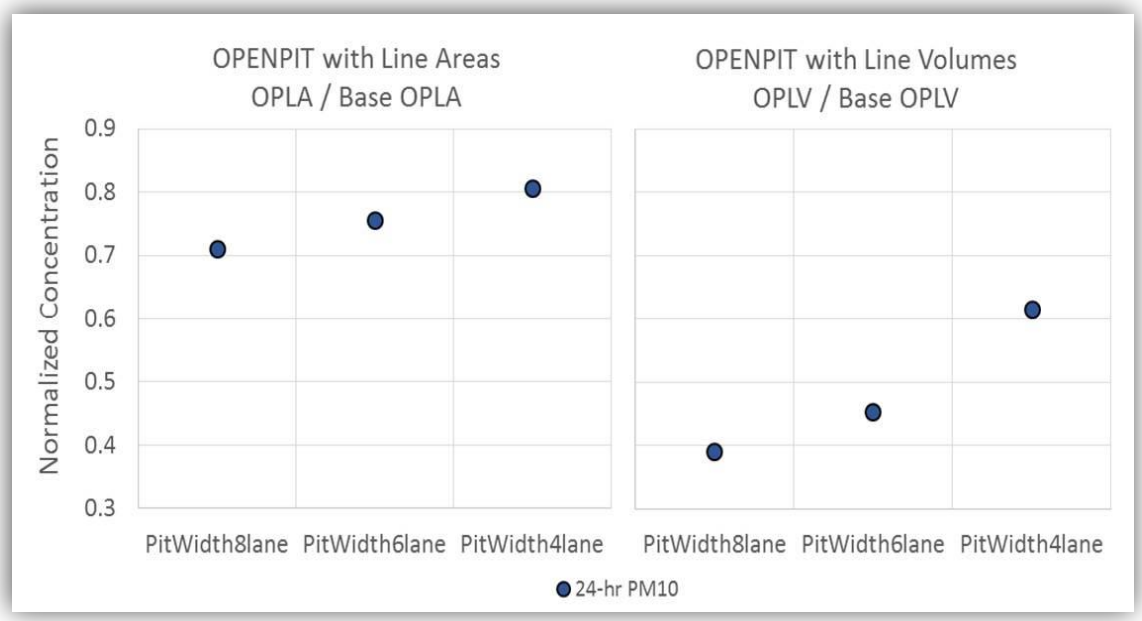


Figure 3-26. Sensitivity of peak average concentration to pit width for scenarios with the OPENPIT source normalized to the base-case OPENPIT scenario (PitWidth8lane).

Sensitivity of Modeled Peak Concentrations to Release Height

Figure 3-27 shows that the modeled PM_{10} concentration when using the OPENPIT source is slightly sensitive to emissions release height when the arterial roadway links are modeled with at-grade line area sources, and much more sensitive when the arterial links are modeled with at-grade line volume sources. While the results in this figure may appear inconsistent with the results that were shown earlier in Figure 3-20, when considered together the two figures indicate that the peak concentrations resulting from using at-grade line area sources for the freeway link increase at a lower rate with increasing emissions than those resulting from using at-grade line volume sources.

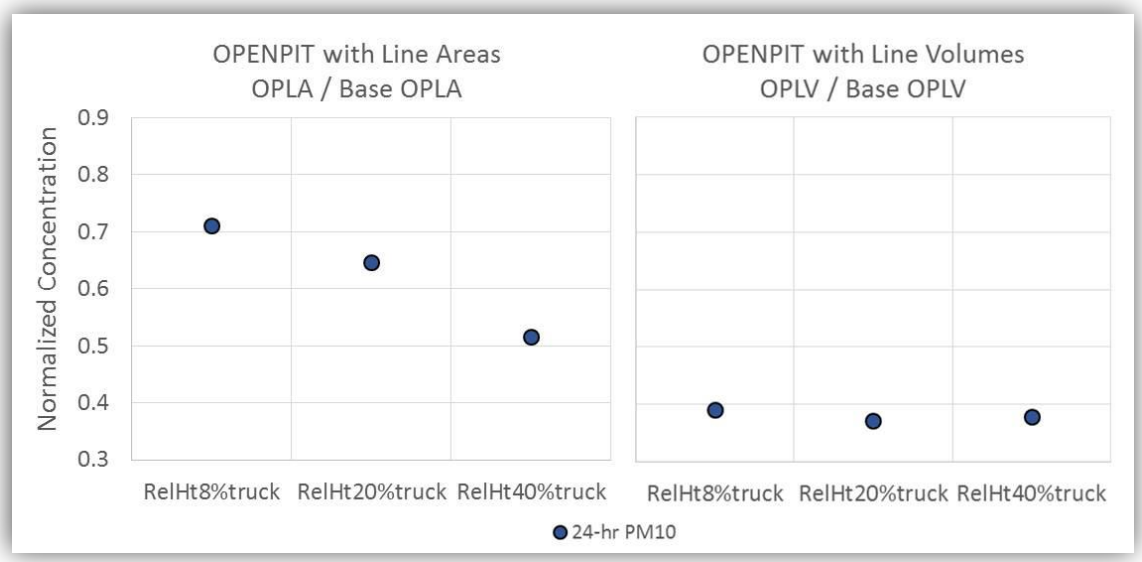


Figure 3-27. Sensitivity of peak average concentration to emissions release height (corresponding with different fleet mixes), showing peak average concentrations for scenarios with the OPENPIT source normalized to the base-case OPENPIT scenario (RelHt8%truck). Note that as release height increases, so does the emission rate due to increasing truck percentage.

Sensitivity of Modeled Peak Concentrations to Wind Speed

As shown in Figure 3-28, the sensitivity of modeled peak concentrations to wind speed is relatively large. This is expected, as increasing the wind speed results in greater dispersion and lower near-road concentrations; this is the case whether or not the OPENPIT source is used to represent the freeway link. Similar sensitivity for scenarios with either all line area sources or all line volume sources can be expected, and is supported by the weak dependence of concentration reduction shown earlier in Figure 3-21. The difference in reduced 24-hour PM_{10} and 24-hour $PM_{2.5}$ concentrations between the scenarios using OPENPIT with line area sources and scenarios using OPENPIT with line volume sources can be explained by considering plume meander and the relatively frequent occurrence of low wind speeds in the base-case WDIRSW scenario. When low wind speeds in the base case are doubled, the resulting wind speeds can still be relatively low in terms of their impact on modeled concentrations when accounting for the effect of plume meander. This results in a smaller reduction of peak concentration in the scenarios with OPENPIT and line volume sources as the wind speed increases. The same trend is not observed for the annual average $PM_{2.5}$ scenarios because the effect of plume meander, which occurs during hours of low wind speed, is averaged out over the entire modeling period.

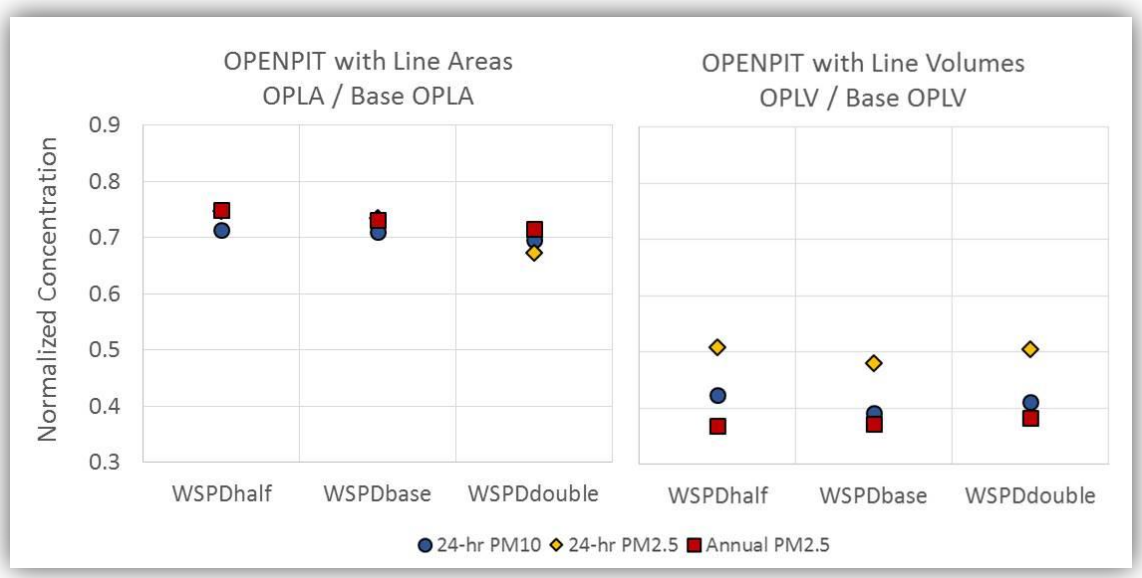


Figure 3-28. Sensitivity of peak average concentration to wind speed, showing peak average concentrations for scenarios with the OPENPIT source normalized to the base-case OPENPIT scenario (WSPDbase).

Ratios of Peak Concentrations in Scenarios with Line Volume Sources to Those with Line Area Sources

In this final part of the case study sensitivity summaries, **Figures 3-29 through 3-31** show the ratio of modeled peak PM concentrations using line volume sources to those using line area sources, with and without the use of the OPENPIT source to model the depressed freeway link. Previous Caltrans work comparing area and volume source representations of roadway sources showed that modeled peak PM concentrations were consistently lower when using volume sources (Erdakos and Craig, 2015a, 2015b). The figures below show that this is also the case when the OPENPIT source is used to model the depressed freeway link. The figures also show that the trends across sensitivity test parameters using the OPENPIT source are similar to those using all at-grade sources. For projects with a depressed roadway link modeled as an OPENPIT source that also includes at-grade roadway links, lower peak modeled PM concentrations can be expected when the at-grade roadway links are modeled with line volume sources rather than line area sources.

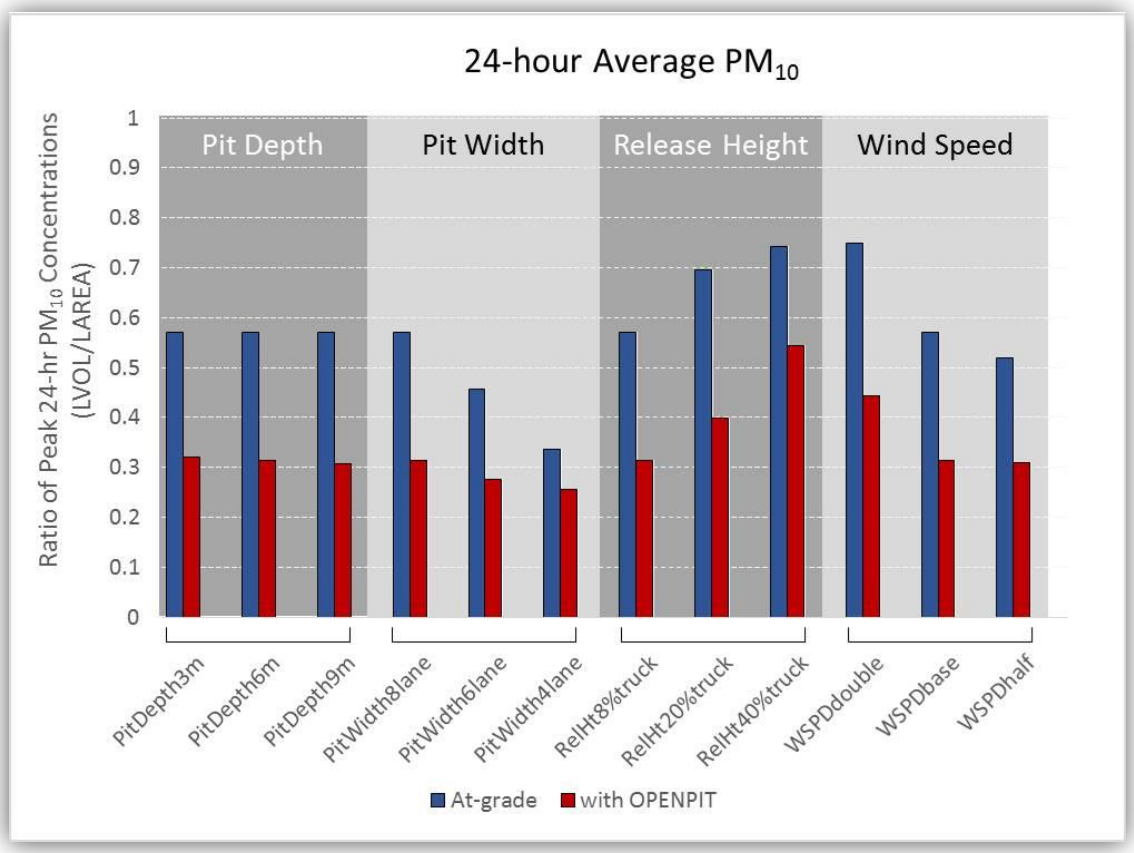


Figure 3-29. Ratios of peak 24-hour average PM_{10} concentrations using at-grade line volume sources to those using at-grade line area sources across sensitivity test scenarios. Blue bars are for the scenarios using at-grade sources for all roadway links. Red bars are for scenarios using the OPENPIT source for the freeway link and at-grade line area or line volume sources for all other links.

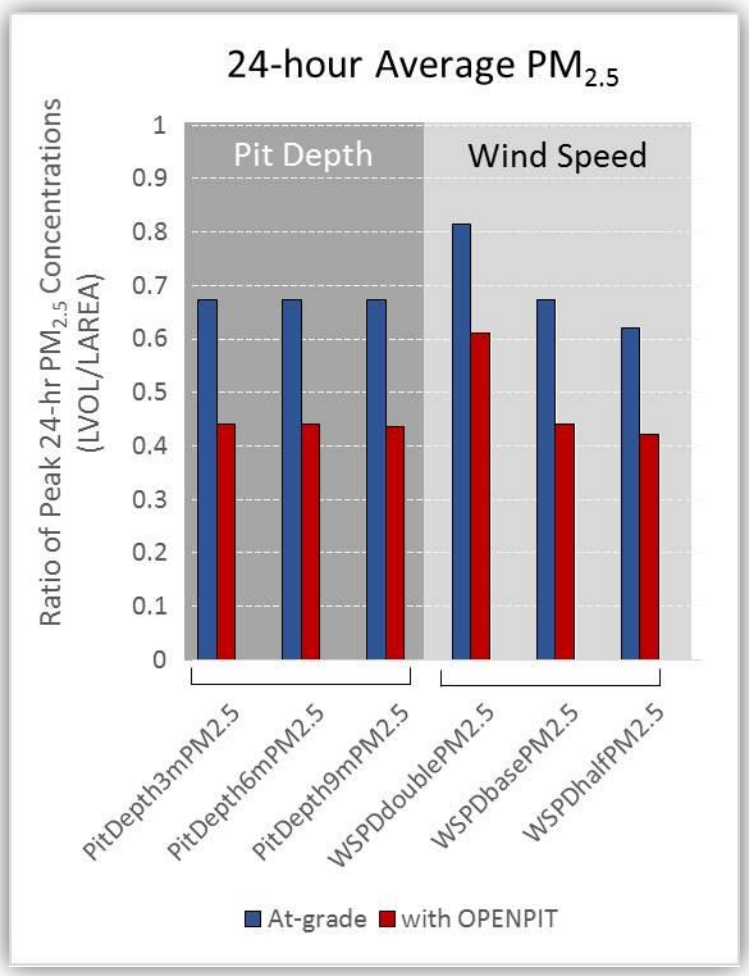


Figure 3-30. Ratios of peak 24-hour average $PM_{2.5}$ concentrations using at-grade line volume sources to those using at-grade line area sources across sensitivity test scenarios. Blue bars are for the scenarios using at-grade sources for all roadway links. Red bars are for scenarios using the OPENPIT source for the freeway link and at-grade line area or line volume sources for all other links.

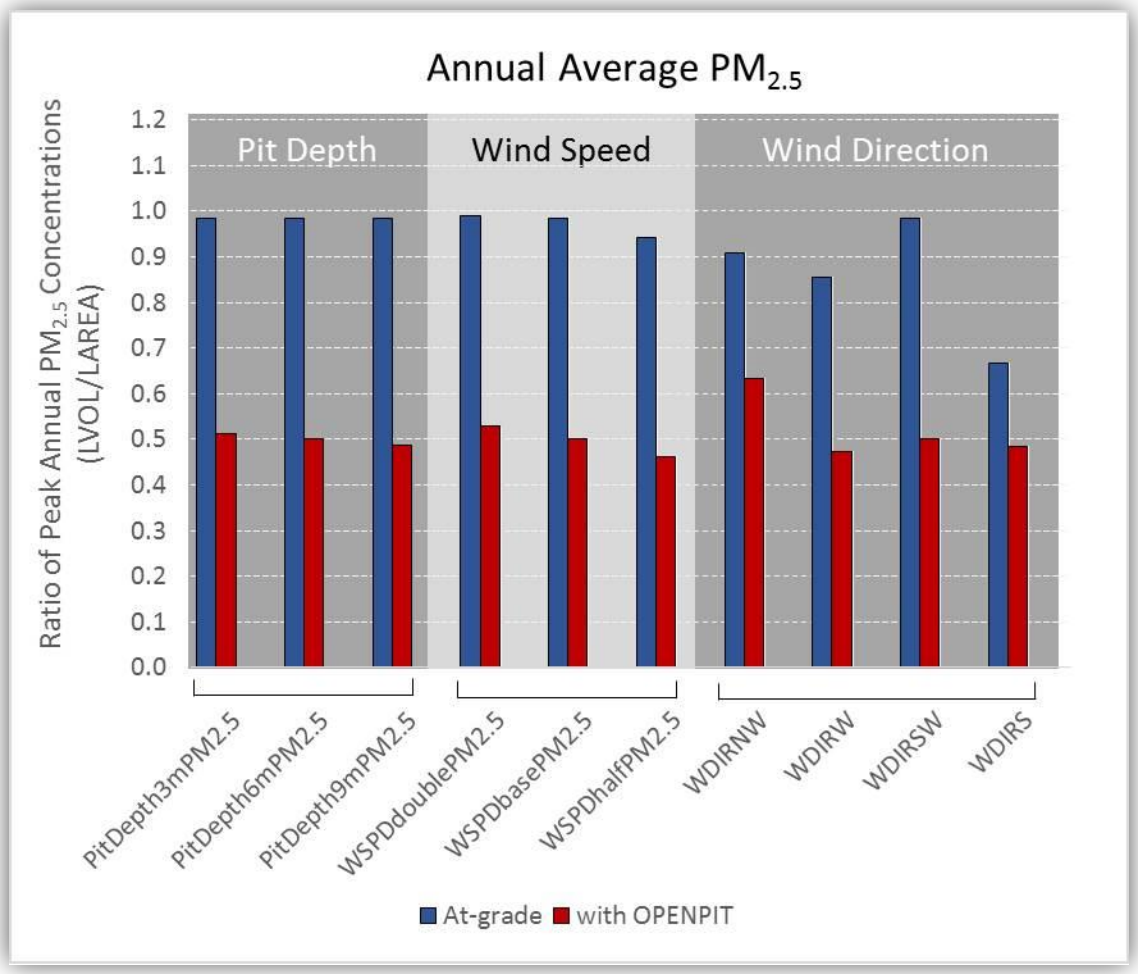


Figure 3-31. Ratios of peak annual average $PM_{2.5}$ concentrations using at-grade line volume sources to those using at-grade line area sources across sensitivity test scenarios. Blue bars are for the scenarios using at-grade sources for all roadway links. Red bars are for scenarios using the OPENPIT source for the freeway link and at-grade line area or line volume sources for all other links.

3.2.9 Appendix C: Defining an OPENPIT Source in AERMOD View

If determined through interagency consultation that the OPENPIT source type should be used in a PM hot-spot analysis to model a depressed roadway, analysts will need to define the source in AERMOD View. Using the hypothetical project as an example, **Figures 3-32 through 3-34** illustrate how to define an OPENPIT source and its input parameters in AERMOD View. In this example, the OPENPIT source represents the freeway link in the hypothetical project; a 0.7 mile straight depressed roadway segment with four southbound and northbound freeway lanes and the median between the two. The other road links in the project have already been drawn as line volume sources (shown by the blue symbols in the figures). After following the steps listed, the AERMOD View layout of the hypothetical project would resemble the right image of Figure 3-15. Note that the graphical options for the color mapping of the OPENPIT source type in this hypothetical project have been modified from the defaults, and the OPENPIT source has been set to display as a pink dashed rectangle. In addition, note that a rectangular OPENPIT source can be drawn in AERMOD View only vertically or horizontally, and the orientation angle from the north must be applied after the source is drawn by either rotating the source in the AERMOD View drawing area or by specifying the angle in the Source Inputs window.

To add an OPENPIT source in AERMOD View to represent a straight segment of road

1. Select the **OPENPIT** source tool from the application toolbar.
2. Click one corner of the depressed road link in the AERMOD View drawing area, drag the cursor to draw a rectangle of roughly the same width and length of the road link, and release to finish drawing the OPENPIT source. The **Source Inputs** dialog window will open automatically.
3. After the **Source Inputs** window opens, fill in the blank fields, except for *Orientation Angle from North* (unless you know the value). Note that the OPENPIT volume is the product of its width, length, and depth.
4. Close the **Source Inputs** window.
5. Click on the **OPENPIT** source in the AERMOD View drawing area and select **Rotate.**
6. Hover over the selected source, click on the source when the **Rotate** cursor appears, drag the cursor to rotate the source, and release when the source is parallel to the road link.
7. When you are finished rotating the source, right-click on the source and choose **Unselect.**
8. Click on the **OPENPIT** source in the AERMOD View drawing area and choose **Move.**
9. Hover over the selected source, click on it when the **Move** cursor appears, drag the source to align it with the roadway link, and release.
10. When you are finished moving the source, right-click on it and choose **Unselect**.

Make any adjustments to the OPENPIT source parameters (e.g., width, length, volume, and/or orientation angle) by editing the values through the Source Inputs window, which can be opened from within the Source Pathway dialog window.

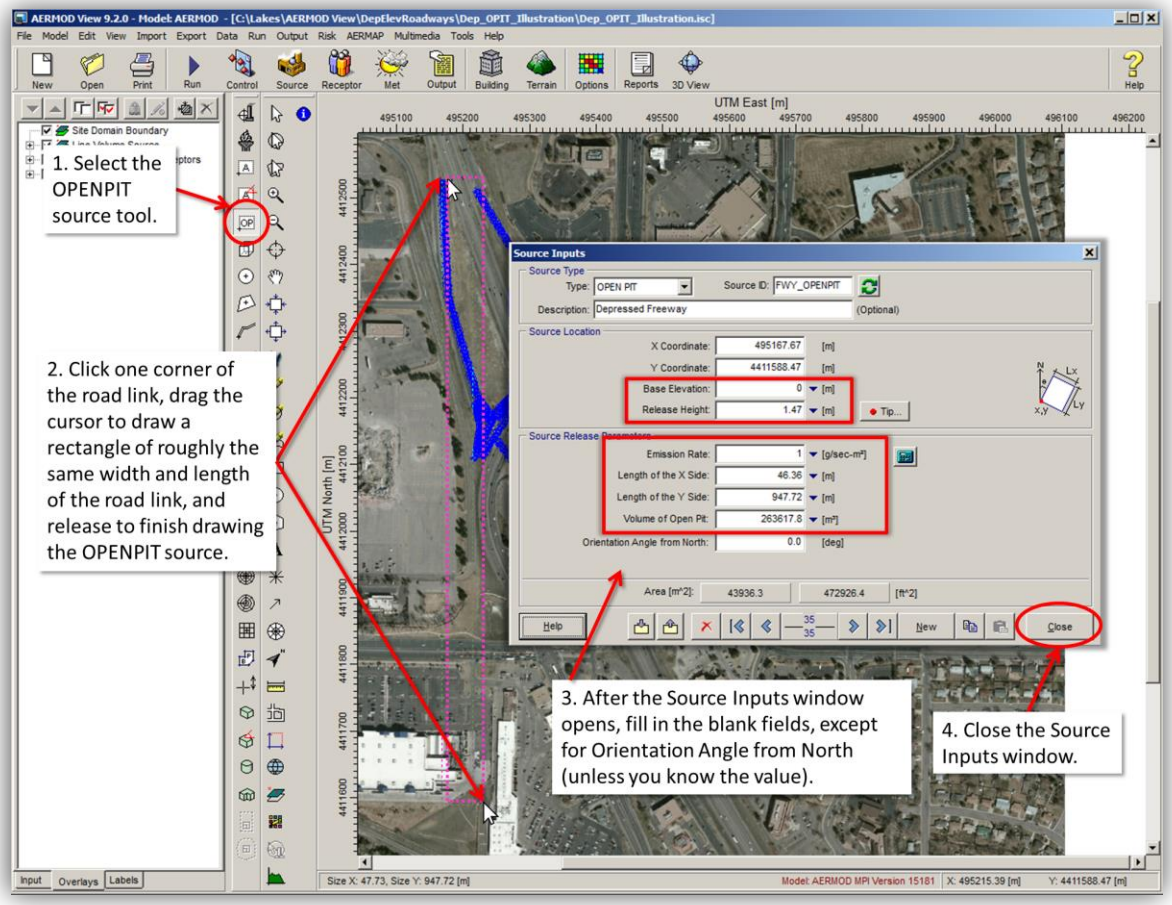


Figure 3-32. Adding an OPENPIT source in AERMOD View to represent a depressed roadway link.

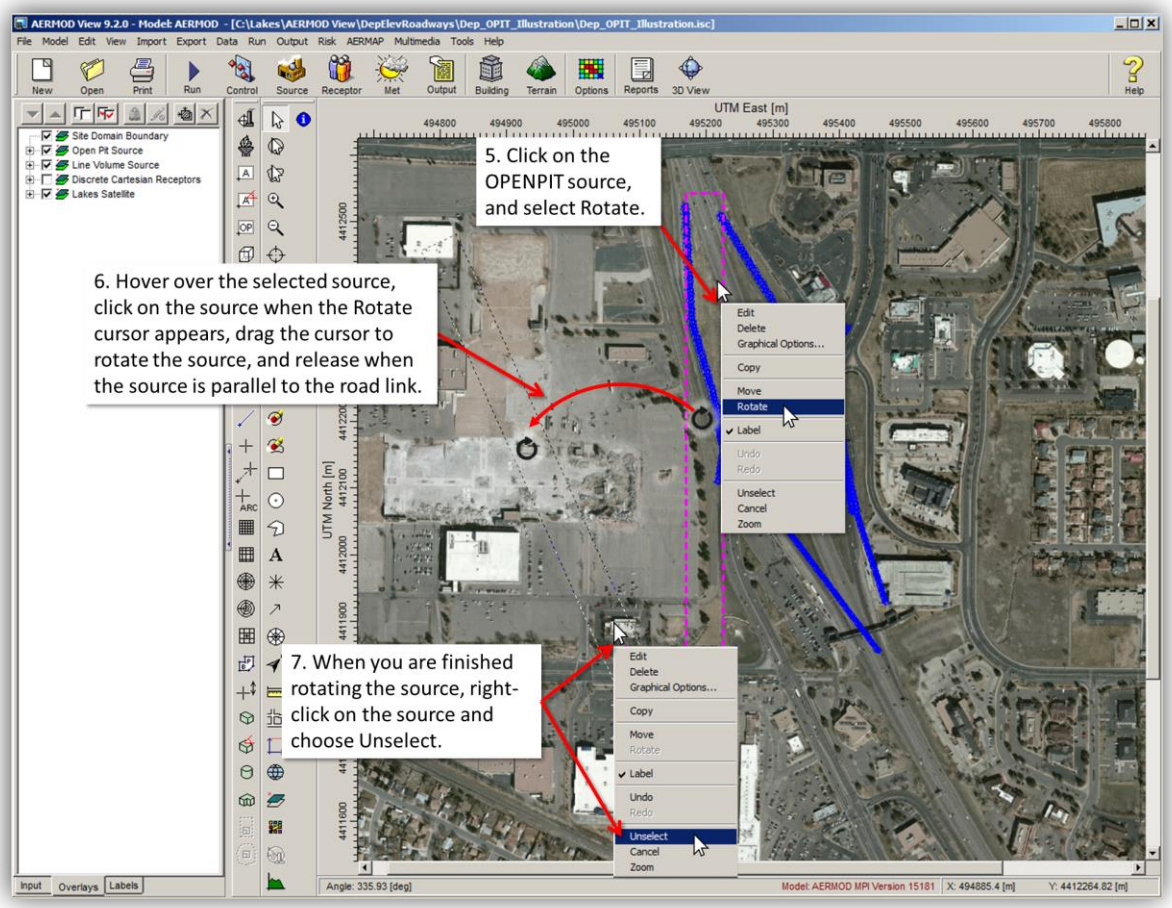


Figure 3-33. Rotating an OPENPIT source in the AERMOD View drawing area.

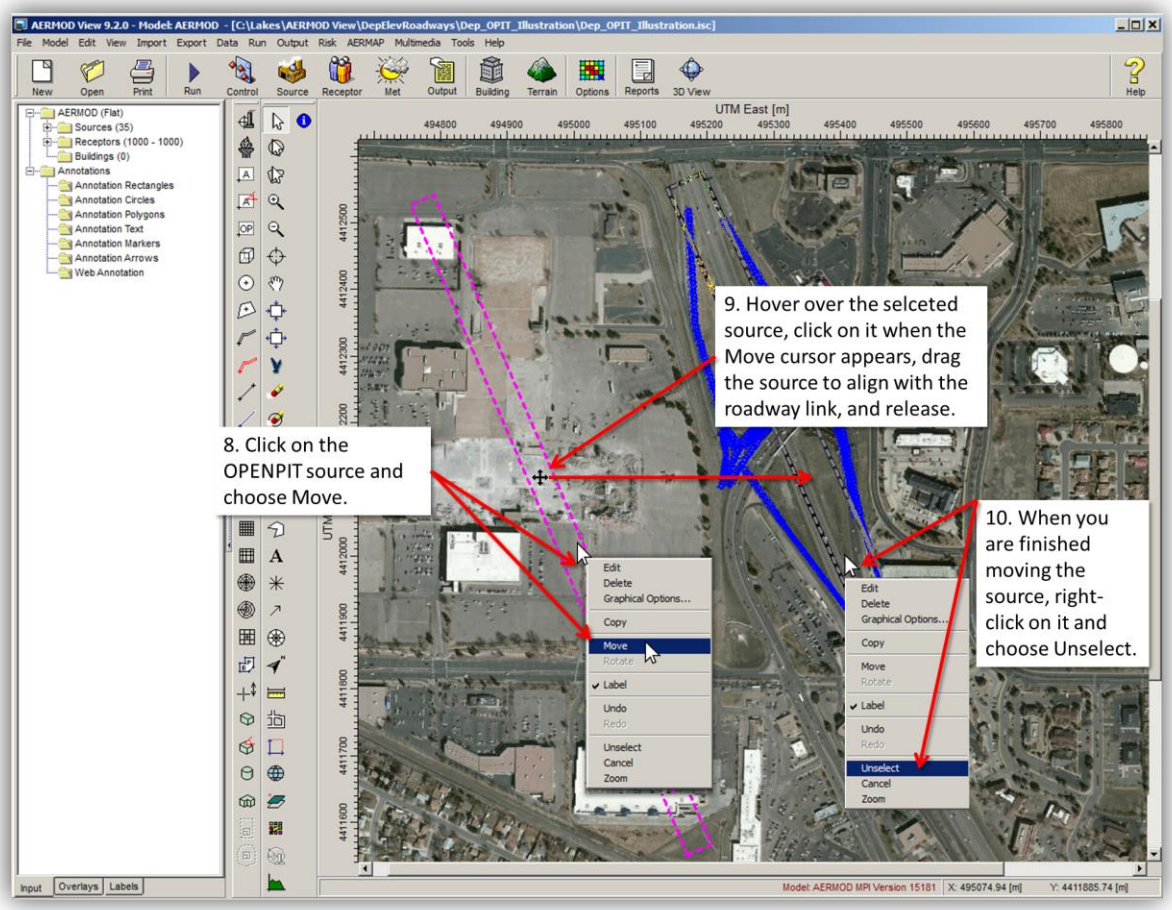


Figure 3-34. Moving an OPENPIT source in the AERMOD View drawing area to align it with a depressed roadway.

3.3 Modeling Elevated Roadways in AERMOD View

3.3.1 Introduction

The purpose of Section 3.3 is to (1) help analysts understand the implications of modeling elevated roadways in a transportation project, (2) support interagency consultation when modeling elevated roadways in a particulate matter (PM) hot-spot analysis, and (3) illustrate how to define key input parameters for modeling elevated roadway sources in AERMOD View.

Elevation of a roadway above grade increases both the height at which emissions are released from the roadway source and the distance between the roadway emissions source and near-road at-grade receptors. Therefore, an elevated roadway will likely result in lower near-road PM concentrations compared to an at-grade roadway. For example, recent wind tunnel studies and fluid dynamics modeling have shown approximately 10-25% lower near-road concentrations for a 6 meter elevated fill section of roadway relative to a level, at-grade roadway (Heist et al., 2009; Steffens et al., 2014).

Section 3.3 discusses 16 simulations we performed in AERMOD View to evaluate the impact of varying roadway elevation on peak 24-hour average and annual average $PM_{2.5}$ concentrations. Because deposition in AERMOD is not modeled in a PM hot-spot context, only $PM_{2.5}$ was modeled for this case study. Therefore, the trend in modeled impacts of varying roadway elevation on peak 24-hour average PM_{10} concentrations would be the same as for 24-hour average $PM_{2.5}$ concentrations. The simulations discussed here involved a hypothetical transportation project with

- an approximately 0.7-mile straight freeway segment with four traffic lanes in each direction,
- a median, and
- a vehicle fleet with 8% trucks.

The modeled project includes the freeway link (with different elevations above grade), at-grade on- and off-ramp links, and at-grade connecting arterial links. The term "grade" here refers to the ground-level elevation of the terrain above sea level. We considered three different elevations above grade (5 m, 10 m, and 15 m) for the freeway link. We also used two different source configurations—one using line area sources, and one using line volume sources

3.3.2 Key Aspects of Modeling Elevated Roadways in AERMOD View

EPA's quantitative PM hot-spot analysis guidance does not include recommendations on how to model elevated roadway emission sources in AERMOD. In a PM hot-spot context,

- At-grade area sources or at-grade volume sources are typically used to model all roadway emissions, and
- The project area should be modeled as having flat terrain in most situations.

However, if elevation of a roadway above grade is not accounted for, modeled PM concentrations may be overestimated. Analysts have two options for modeling elevated roadways in AERMOD View: representing the roadway elevation with

1. an adjusted release height parameter, or
2. an adjusted base elevation parameter.

These approaches are described in Section 3.3.4. The configuration of an elevated roadway should be considered when determining the appropriate approach for modeling the roadway in AERMOD View.

Using an adjusted release height that includes the magnitude of the roadway elevation above grade is an appropriate approach for modeling an elevated roadway such as a viaduct or bridge where air is able to flow underneath the roadway structure. The User's Guide for the Industrial Source Complex (ISC3) Dispersion Model, which is the predecessor to AERMOD, discusses the use of elevated volume sources to model an elevated line source (U.S. Environmental Protection Agency, 1995). When using a series of elevated volume sources to represent an elevated emissions line source, the elevation of the source is accounted for in its release height input parameter. In other words, the source elevation is represented by an adjusted source release height. This adjusted release height is the sum of the actual release height (above the roadway surface) and the elevation of the roadway source above grade. As described in the EPA PM hot-spot guidance (U.S. Environmental Protection Agency, 2015c), the actual release height of the source is related to the average vehicle height.

If the elevated roadway is an elevated fill section where air is not able to flow underneath the roadway like a viaduct or bridge, analysts may consider modeling the project with complex terrain and adding the roadway elevation above grade to the source's at-grade base elevation. However, as recommended in EPA's PM hot-spot guidance, interagency consultation is required to determine whether terrain effects should be included in air quality modeling for a PM hot-spot analysis.

When modeling complex terrain, the PM concentrations resulting from an elevated roadway will highly depend on the modeled terrain in the project area and the differences between elevations of the roadway and model receptors. For example, in the complex terrain simulations modeled for this case study, terrain elevation varied by up to 45 m across the project domain, and increasing the base elevation of the roadway source decreased, rather than increased, the distance to some nearby receptors. This result is specific to this hypothetical project, and is discussed in the Case Study Results section (Section 3.3.5). A similar result did not occur in the "Adjusted Release Height" simulations, because those were modeled with flat terrain, and all model receptors had a base elevation of 0 m.

3.3.3 Hypothetical Transportation Project

We used a hypothetical transportation project to evaluate the impacts that different roadway elevations have on modeled near-road PM concentrations and to illustrate how to specify inputs for an elevated roadway source in AERMOD View. The project included freeway lanes, on- and off-ramps, and connecting arterial road links. The following sections describe case study results comparing modeled concentration impacts when modeling an elevated roadway and an at-grade roadway. For the elevated roadway simulations, we assumed that the freeway lanes and freeway median of the hypothetical project were elevated.

The hypothetical project consists of

- 34 road links (including the on- and off-ramps and the connecting arterial links)
- A freeway link with four northbound and southbound lanes
    - Each lane in the freeway link is 12 feet (3.66 m) wide.
    - The northbound and southbound freeway lanes are separated by a median that is approximately 26 feet (8 m) wide.
    - The freeway link is approximately 0.7 miles (1,062 m) long.

The receptor network for the hypothetical project includes more than one thousand discrete receptors extending out to 500 m from the roadway, with spacing varying from 25 m near the roadways to 100 m farther from the roadways.

Figure 3-35 represents the hypothetical project in AERMOD View for the two sets of sensitivity tests.

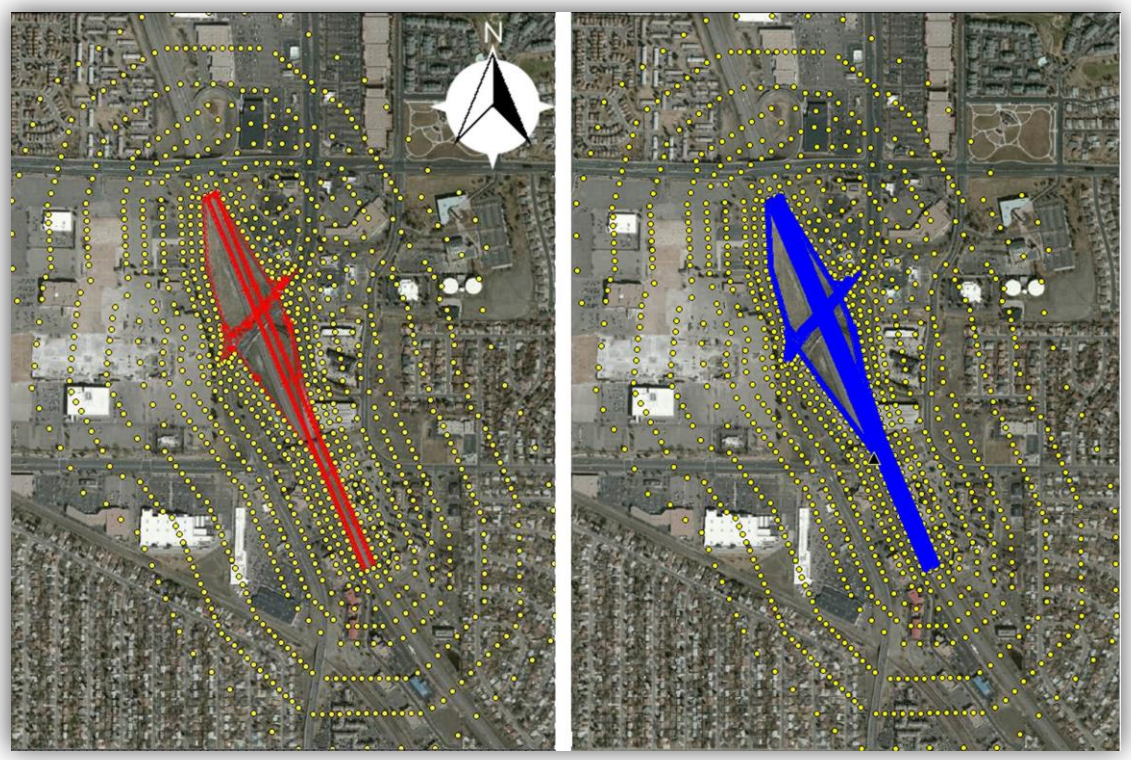


Figure 3-35. Hypothetical transportation project in AERMOD View. Image on the left shows all road links represented by line area sources (red symbols); image on the right shows all road links represented by line volume sources (blue symbols). The yellow circles represent model receptors.

3.3.4 Case Study: Overview of Sensitivity Tests

Using the hypothetical project described above, we developed 16 simulations in AERMOD View to evaluate the impact of varying roadway elevation on peak 24-hour average and annual average $PM_{2.5}$ concentrations. These are summarized in Table 3-17. Two key source inputs are required in each model simulation: (1) the "base elevation," which defines the elevation of the source above sea level, and is equal to zero when modeling in AERMOD with flat terrain; and (2) the emissions "release height," which is the height above the base elevation at which the emissions are released from the source. The 16 simulations comprise two sets of eight simulations each:

- "Adjusted Release Height" simulations
  - Use the flat terrain modeling option, and represent the elevation of the freeway link with an adjusted release height, which is obtained by adding its elevation above grade to its initial emissions release height input parameter.
  - In this approach, the initial release height is determined as a weighted average for the vehicle fleet mix (equal to 1.47 m for a vehicle fleet with 8% trucks), and the

elevation of the freeway link above grade is modeled with the adjusted release height parameter.
  - The base elevations of the elevated freeway link, all other roadway sources, and model receptors are equal to 0 m.

- "Adjusted Base Elevation" simulations
  - Use complex terrain, and represent the elevation of the freeway link by adding its elevation above grade to its base elevation input parameter.
  - In this approach, the initial at-grade base elevation is determined from terrain data using AERMAP[23], and the elevation of the freeway link above grade is then modeled with the adjusted base elevation parameter.
  - The base elevations of the at-grade sources and the model receptors are also determined from terrain data using AERMAP.
  - The release heights of the elevated freeway link and all other roadway sources are equal to 1.47 m.

Table 3-17. Summary of sensitivity test simulations for the hypothetical transportation project.

Modeling Approach	Base Elevation[a]	Release Height	Roadway Source Type
Adjusted Release Height (model flat terrain and add freeway elevation to release height parameter)	• 0 m • 0 m • 0 m • 0 m	• 1.47 m (1.47 m + 0 m) • 6.47 m (1.47 m + 5 m) • 11.47 m (1.47 m + 10 m) • 16.47 m (1.47 m + 15 m)	• Line area • Line volume
Adjusted Base Elevation (model complex terrain and add freeway elevation to base elevation parameter)	• At-grade + 0 m • At-grade + 5 m • At-grade + 10 m • At-grade + 15 m	• 1.47 m • 1.47 m • 1.47 m • 1.47 m	• Line area • Line volume

[a] For the Adjusted Base Elevation simulations, the at-grade elevation portion of the modeled base elevation varies for the individual area or volume sources that comprise the freeway link line area or line volume sources.

Sample source inputs used in the two sets of simulations are shown in Appendix A (Section 3.3.7). In each simulation set, we ran the model using two separate roadway source configurations: one using line area sources to represent the roadways, and one using line volume sources to represent the roadways. Each of the simulations corresponds to the hypothetical project that has:

[23] AERMAP is a terrain preprocessor for AERMOD. AERMAP processes commercially available Digital Elevation Data and creates a file suitable for use within an AERMOD control file. The output file from AERMAP containing source and receptor elevation data is provided as input in AERMOD View through the Control Pathway dialog window.

- An 8-lane freeway link that is 0.7 miles (1,062 m) long and 37.37 m wide (including the median).
- A vehicle fleet with 8% trucks with an emissions release height of 1.47 m, and year 2035 emissions (Bai et al., 2017).
- Meteorological data from the Santa Monica Municipal Airport corresponding to "base-case" wind speeds and a predominant southwesterly wind direction over the five-year period from 2007 through 2011 (this wind direction is approximately perpendicular to the freeway link). Figure 3-36 shows a wind rose for this meteorological data set.

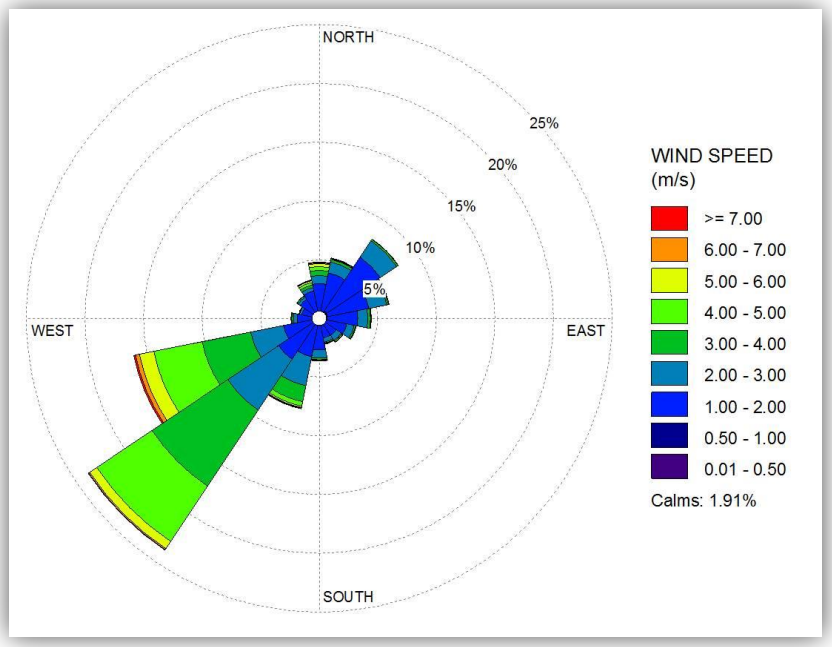


Figure 3-36. Wind rose for the Santa Monica meteorological data used in the model simulations.

3.3.5 Case Study Results

The results of the two sets of simulations conducted in this case study show that, in all cases, modeling the freeway as elevated above grade resulted in the same or lower peak PM concentrations than modeling the freeway link at grade (no elevation above grade) with flat terrain. However, some differences exist in the results of the Adjusted Release Height simulations compared to the Adjusted Base Elevation simulations. For the former cases, modeling the elevation of the freeway link above grade reduced the peak PM concentrations in a linear manner (i.e., as the release height increased, peak concentrations decreased). However, in the Adjusted Base Elevation simulations, the modeled peak concentration does not necessarily decrease as the elevation of the freeway increases, as described below (in "Adjusted Base Elevation Simulation Results"). For both 24-hour average and

annual average $PM_{2.5}$, the largest reductions in peak concentrations resulted from modeling the freeway link as elevated in the Adjusted Release Height simulations using line volume sources.

Adjusted Release Height Simulation Results

For the simulation set using flat terrain and modeling the freeway link elevation using an adjusted release height parameter, the modeled peak concentrations and reductions in peak concentrations are summarized in **Table 3-18**. The reduction in peak concentration is determined relative to the simulation with the freeway link at grade (0 m elevation). In this simulation set,

- As the modeled adjustment to the freeway link release height increased to 15 m, reductions in modeled peak 24-hour average $PM_{2.5}$ concentration ranged from 10% to 36% when using line area sources, and from 45% to 72% when using line volume sources.
- Reductions in modeled peak annual average $PM_{2.5}$ concentration ranged from 12% to 29% when using line area sources, and from 50% to 75% when using line volume sources.

The locations of the modeled peak concentrations in each simulation are presented in Appendix B (Section 3.3.8), along with a summary of model results that shows increases in modeled concentration at receptors farther from the roadway sources.

Table 3-18. Modeled peak $PM_{2.5}$ concentrations and reductions in peak concentrations when modeling an elevated roadway with flat terrain and adjusted release height.

Freeway Link Adjusted Release Height	Line Area Sources	% Reduction[a]	Line Volume Sources	% Reduction[a]
24-hour Average $PM_{2.5}$ ($\mu g/m^3$)				
1.47 m + 0 m	4.2	N/A	2.9	N/A
1.47 m + 5 m	3.8	10%	1.6	45%
1.47 m + 10 m	3.0	29%	1.1	62%
1.47 m + 15 m	2.7	36%	0.8	72%
Annual Average $PM_{2.5}$ ($\mu g/m^3$)				
1.47 m + 0 m	1.6	N/A	1.6	N/A
1.47 m + 5 m	1.4	12%	0.8	50%
1.47 m + 10 m	1.2	25%	0.6	62%
1.47 m + 15 m	1.0	29%	0.4	75%

[a] The percent reduction of modeled concentration is calculated relative to the simulation for the freeway link at grade, or 0 m elevation above grade (i.e., freeway link release height equal to 1.47 m + 0 m).

Adjusted Base Elevation Simulation Results

For the simulation set using complex terrain and modeling the freeway link elevation using an adjusted base elevation parameter, the modeled peak concentrations and reductions in peak concentrations are summarized in Table 3-19. In this simulation set,

- The peak concentrations when modeling the freeway link as elevated above grade are always the same or less than those when modeling the freeway link with no elevation in the Adjusted Release Height simulations with flat terrain.
- When using line area sources, the modeled peak 24-hour average $PM_{2.5}$ concentration is greater when the freeway link is elevated to 15 m above grade than it is when the freeway link is at grade.
- When using line area sources, the reduction in modeled peak annual average $PM_{2.5}$ concentration is greater when the freeway link is elevated to 10 m above grade than when it is elevated to 15 m above grade.
- The reductions in modeled peak concentration are generally less than when modeling the project with flat terrain and an adjusted release height.

- As in the first simulation set, greater reductions (up to 21%) are modeled when using line volume sources, compared to using line area sources (up to 13%).

As illustrated in Appendix B (Section 3.3.8), there is more variation in the location of the peak modeled concentrations in the Adjusted Base Elevation simulation set than in the Adjusted Release Height simulation set.

Results from the second simulation set using complex terrain and adjusted base elevation are complicated by the fact that the freeway link emissions source in the hypothetical transportation project impacts some near-road receptors more when the freeway is elevated than when it is at grade. Therefore, the modeled peak concentration does not necessarily decrease with increasing elevation of the freeway. **Figure 3-37** shows an example of this for a straight-line transect of terrain that intersects receptors along the northeastern perimeter of the roadway sources in the hypothetical project. The plot on the right in Figure 3-37 shows the terrain elevation along the transect, which is 300 m long and indicated by the solid black line in the image on the left. The solid blue line represents the elevation of the freeway link when the link is modeled at grade, while the dashed blue line represents the elevation when the link is modeled at 15 m above grade. The labels A and B in the plot represent the locations of the two receptors at the ends of the transect, and are the locations of the overall peak modeled annual average $PM_{2.5}$ concentrations when modeling the freeway link at grade (receptor A) and at both 10 m and 15 m above grade (receptor B) with line area sources. The elevation of receptor A is closer to that of the freeway source when the freeway is modeled at grade, and the elevation of receptor B is closer to that of the freeway source when the freeway is modeled at either 10 m or 15 m above grade.

Table 3-19. Modeled peak $PM_{2.5}$ concentrations and reductions in peak concentrations when modeling an elevated roadway with complex terrain and adjusted base elevation.

Freeway Link Base Elevation[a]	Line Area Sources	% Reduction[b]	Line Volume Sources	% Reduction[b]
24-hour Average $PM_{2.5}$ ($\mu g/m^3$)				
0 m (flat terrain)[c]	4.2	N/A	2.9	N/A
At-grade + 0 m	3.9	N/A	2.9	N/A
At-grade + 5 m	3.7	5%	2.8	3%
At-grade + 10 m	3.8	3%	2.4	17%
At-grade + 15 m	4.0	-3%	2.3	21%
Annual Average $PM_{2.5}$ ($\mu g/m^3$)				
0 m (flat terrain)[c]	1.6	N/A	1.6	N/A
At-grade + 0 m	1.6	N/A	1.6	N/A
At-grade + 5 m	1.6	0%	1.6	0%
At-grade + 10 m	1.4	13%	1.3	19%
At-grade + 15 m	1.5	6%	1.3	19%

[a] The at-grade elevation in the Adjusted Base Elevation simulations is determined from the terrain data using AERMAP, and varies along the length of the freeway link.

[b] The percent reduction of modeled concentration is calculated relative to the simulation for the freeway link at grade, or 0 m elevation above grade (i.e., freeway link base elevation equal to At-grade + 0 m).

[c] The model results from the Adjusted Release Height simulations with flat terrain are shown in this table to illustrate that modeling the freeway link as elevated in the Adjusted Base Elevation simulations always results in the same or lower concentrations than when modeling the freeway at grade with flat terrain.

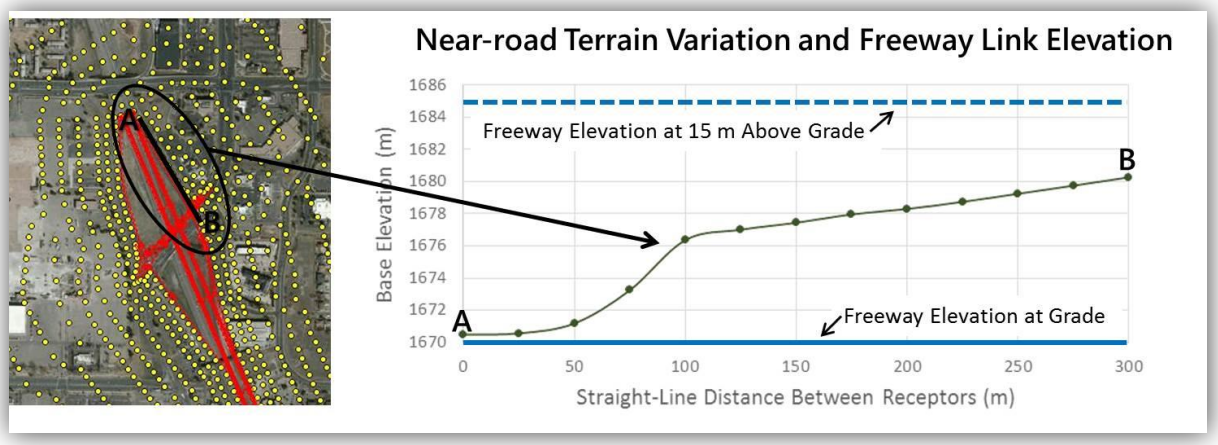


Figure 3-37. Sample illustration of terrain variation in the hypothetical project. The plot on the right shows terrain base elevations along a transect bordering roadway sources in the hypothetical project (black line from receptor A to receptor B in the image on the left), and the freeway link elevation when modeled at grade and 15 m above grade. Receptor A is the receptor where the overall peak modeled annual average $PM_{2.5}$ concentration occurs when modeling the freeway at grade; receptor B is the receptor where the overall peak modeled annual average $PM_{2.5}$ concentration occurs when modeling the freeway at both 10 m and 15 m above grade with line area sources.

3.3.6 Conclusion

To account for reduced near-road PM concentration due to above-grade elevation of a roadway, two modeling options can be considered:

1. Modeling the project with flat terrain and representing roadway elevation above grade with an adjusted source release height parameter.
    - This modeling approach is straightforward, and applies directly to an elevated roadway configured as a viaduct or bridge where air is able to flow underneath the roadway structure.
    - The ISC user guide suggests this approach when modeling an elevated line source, and EPA's PM hot-spot guidance suggests that projects should be modeled as having flat terrain in most situations.
2. Modeling the project with complex terrain and representing roadway elevation above grade with an adjusted source base elevation parameter.
    - This modeling approach may be more suitable when modeling an elevated fill section of roadway where air is not able to flow underneath the roadway.
    - This approach is more complicated, and requires additional modeling work to process terrain data for the project area through AERMAP.

- EPA's PM hot-spot guidance recommends determining whether to include terrain effects through interagency consultation in cases where significant concentrations result from nearby elevated sources.
  - Such cases may include a nearby elevated source that is not part of the project, but is affected by the project (e.g., a highway project whose primary purpose is to accommodate future growth in freight and goods movement).
  - These sources would not typically include an elevated roadway source that is part of a project.
- Impacts on modeled near-road concentrations may be unexpected as a result of the combined effects of roadway elevation and terrain, as was demonstrated by the Adjusted Base Elevation simulations presented in Section 3.3.5, and will vary on a case-by-case basis.

Analysts should seek consensus with interagency consultation partners on the best approach to use before completing PM hot-spot analyses for projects with an elevated roadway.

For the Adjusted Release Height simulations summarized in Sections 3.3.4 and 3.3.5

- Modeling an elevated roadway using flat terrain and an adjusted source release height resulted in greater reduction of modeled near-road PM concentrations as the modeled roadway elevation increases; this is because increasing the release height of the emissions source increases the distance between the source and all model receptors.
- When modeling the roadway with line area sources in these simulations, the results show consistency with wind tunnel study data and Large Eddy Simulation (LES) model results published by Heist et al. (2009) and Steffens et al. (2014) for a 6-m elevated fill section of roadway (10-25% reduction in near-road PM concentration).
- When modeling with line volume sources in these simulations, reductions in near-road peak PM concentrations were somewhat greater than those in published data. This is likely due to the fact that the wind tunnel study and LES modeling were conducted for an elevated fill section, while the Adjusted Release Height simulations effectively model a viaduct or bridge. Dispersion of PM emissions downwind of a viaduct would be expected to be greater than dispersion downwind of an elevated fill section.

For the Adjusted Base Elevation simulations summarized in Sections 3.3.4 and 3.3.5

- Modeled peak concentrations were the same or less than those when modeling the freeway link with no elevation in the Adjusted Release Height simulations with flat terrain.
- Not all of the Adjusted Base Elevation simulations resulted in reduction of near-road PM concentrations when comparing peak concentrations across the different modeled elevations of the freeway link.
- In some cases, the modeled near-road PM concentrations increased when the roadway elevation increased. This increase was due to terrain variations specific to the hypothetical project that resulted in the distance between the roadway source and some nearby receptors to be less when the roadway was elevated than when the roadway was at grade.

When considering modeling options in AERMOD View for an elevated roadway, analysts can use the sensitivity simulation results presented in Section 3.3.5 as reference information to support discussion with interagency consultation partners. However, project-specific outcomes will be highly dependent on the site variables specific to each project.

3.3.7 Appendix A: Sample Source Inputs for the Sensitivity Simulations

This appendix to Section 3.3 is divided into two parts:

1. Sample inputs for the simulation set modeling flat terrain and representing roadway elevation with an adjusted emissions source release height;
2. Sample inputs for the simulation set modeling complex terrain and representing roadway elevation with an adjusted emissions source base elevation.

Sample Inputs for the Simulation Set Modeling Flat Terrain and Adjusted Emissions Source Release Height

In this section, we present examples of two key source input parameters required for modeling an elevated roadway in AERMOD View using flat terrain and representing the roadway elevation with an adjusted emissions source release height. These two parameters are referred to as the initial vertical dimension and release height in AERMOD and AERMOD View modeling terminology. It is important to keep in mind that the initial vertical dimension described in EPA's PM hot-spot guidance differs from the initial vertical dimension defined in EPA's AERMOD user guide and AERMOD View.

In AERMOD, the initial vertical dimension (σ_{zo}, or Szinit) represents the initial dispersion of the emission source plume. In EPA's PM hot-spot guidance, this term is referred to as the initial vertical dispersion coefficient, and is calculated from what the guidance refers to as the initial vertical dimension. That initial vertical dimension is referred to as "plume height" for line volume sources in AERMOD View. According to EPA's PM hot-spot guidance, AERMOD View's plume height parameter is calculated as 1.7 times the average vehicle height to account for the effects of vehicle-induced turbulence. For surface-based sources, the initial vertical dimension (in AERMOD and AERMOD View) is calculated by dividing the plume height by 2.15. As described in the ISC User Guide, the initial vertical dimension (in AERMOD and AERMOD View) for elevated volume sources is calculated by dividing the plume height by 4.3.

For the hypothetical project used in this case study, the fleet mix is 8% trucks. Following EPA's PM hot-spot guidance, the average height of light-duty vehicles is 1.53 m and that of heavy-duty vehicles is 4.0 m. Using those values for the hypothetical project, the plume height parameter to be used in AERMOD View is

$$\text{Plume Height} = 1.7 \times (92\% \times 1.53\ \text{m} + 8\% \times 4.0\ \text{m}) = 2.94\ \text{m}$$

Then, for surface-based sources, the initial vertical dimension to be used in AERMOD View is

$$\text{Initial Vertical Dimension (surface-based source)} = 2.94\ \text{m} / 2.15 = 1.37\ \text{m}$$

and for elevated sources, the initial vertical dimension to be used in AERMOD View is

$$\text{Initial Vertical Dimension (elevated source)} = 2.94\ \text{m} / 4.3 = 0.68\ \text{m}$$

The second input parameter of interest here is the source release height. According to EPA's PM hot-spot guidance, the release height is the plume height in AERMOD View multiplied by 0.5. Therefore, before making any adjustments to account for elevation of a roadway source above grade, the release height for the roadway sources in the hypothetical project is

$$\text{Release Height (surface-based source)} = 2.94\ \text{m} \times 0.5 = 1.47\ \text{m}$$

For a surface-based (or at-grade) roadway, the release height input to AERMOD View would simply be the calculated value of 1.47 m. For elevated roadways, the elevation of the roadway above grade would be added to the surface-based value, e.g., for a roadway elevated 10 m above grade,

$$\text{Adjusted Release Height (elevated source, 10 m above grade)} = 1.47\ \text{m} + 10\ \text{m} = 11.47\ \text{m}$$

While the release height input parameter is provided to AERMOD View in the same way whether modeling line volume or line area sources, the initial vertical dimension is not. For line volume sources, the plume height is the input parameter, and AERMOD View calculates the initial vertical dimension automatically. In order for AERMOD View to calculate the correct initial vertical dimension for either a surface-based or elevated source, the user must specify this option in the Source Inputs window.

For line area sources, the initial vertical dimension is input manually.

Figures 3-38 and 3-39 show AERMOD View **Source Inputs** windows for one of the freeway lane sources in the hypothetical project modeled with flat terrain and adjusted release height. Figure 3-38 shows inputs for a line volume source, and Figure 3-39 shows inputs for a line area source. The inputs in the top panel of each figure correspond to modeling the freeway link at grade (0 m elevation), and those in the bottom panel of each figure correspond to modeling the freeway link at 10 m above grade. Note that in each sample **Source Inputs** window, the inputs for **Base Elevation** equal 0 m since these simulations are modeled with flat terrain, and the elevation of the roadway is accounted for in the adjusted release height parameter.

For line volume sources, the **Plume Height** and **Release Height** inputs are highlighted in Figure 3-38. Additionally, the option for a **Surface-Based** source is selected in the top panel of Figure 3-38, and

the option for an **Elevated** source is selected in the bottom panel of Figure 3-38. For line area sources, the **Initial Vertical Dimension** and **Release Height** inputs are highlighted in Figure 3-39.

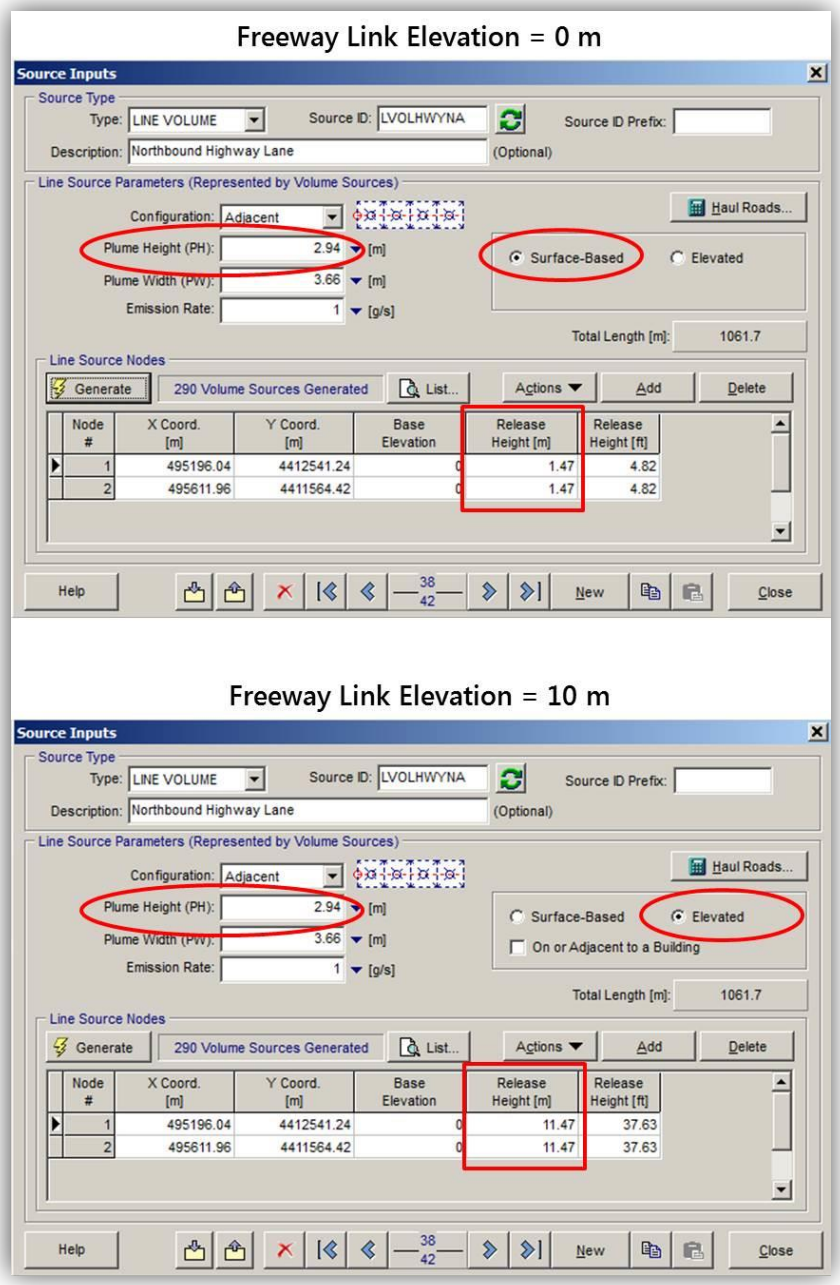


Figure 3-38. Sample line volume source inputs for one lane of the freeway link in the hypothetical project when modeling flat terrain and representing roadway elevation with an adjusted release height. Top panel shows inputs for modeling the roadway at grade (0 m elevation); bottom panel shows inputs for modeling the roadway at 10 m above grade.

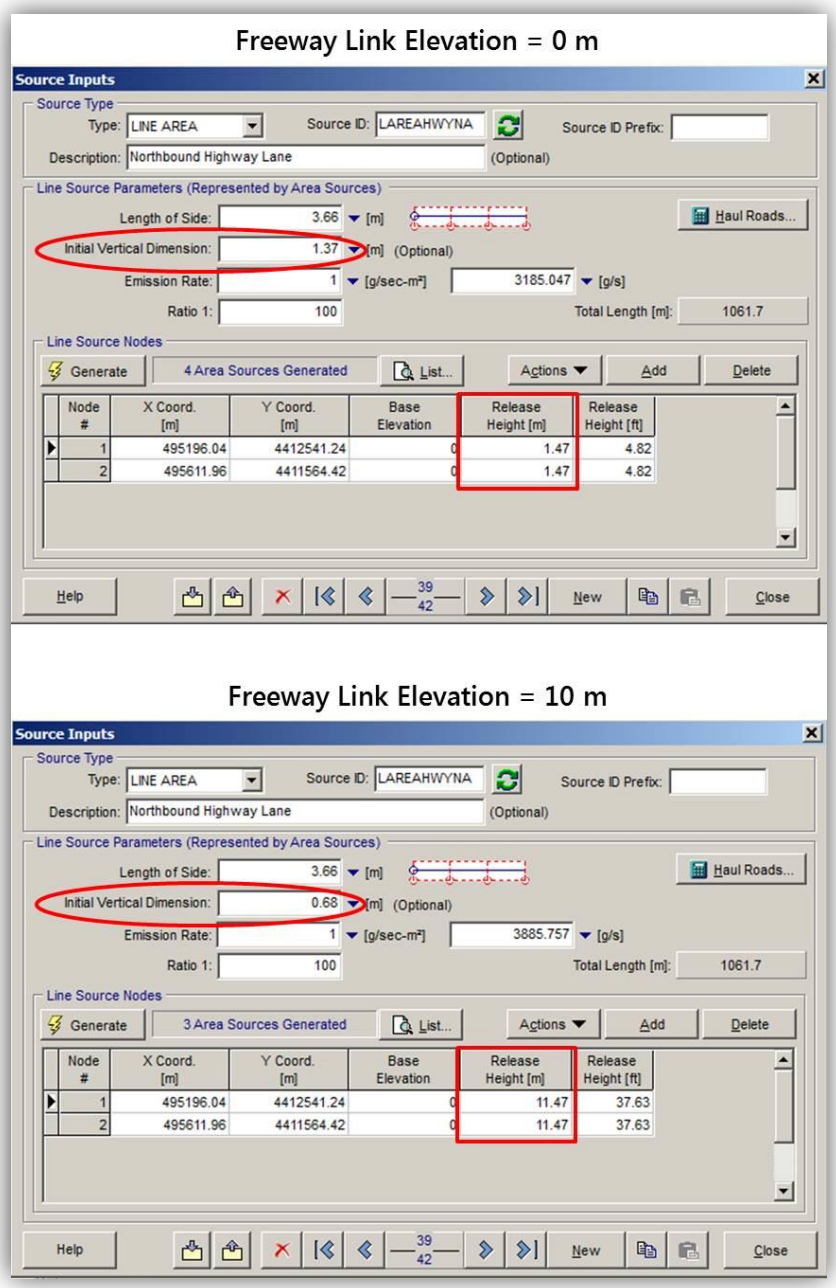


Figure 3-39. Sample line area source inputs for one lane of the freeway link in the hypothetical project when modeling flat terrain and representing roadway elevation with an adjusted release height. Top panel shows inputs for modeling the roadway at grade (0 m elevation); bottom panel shows inputs for modeling the roadway at 10 m above grade.

Sample Inputs for the Simulation Set Modeling Complex Terrain and Adjusted Emissions Source Base Elevation

In this section, we present examples of two key source input parameters required for modeling an elevated roadway in AERMOD View using complex terrain and representing the roadway elevation with an adjusted emissions source base elevation. Those two parameters are referred to as the initial vertical dimension and base elevation in AERMOD modeling terminology. As explained in the previous section, the initial vertical dimension described in EPA's PM hot-spot guidance is different than the initial vertical dimension defined in EPA's AERMOD user guide and AERMOD View.

When modeling an elevated roadway using complex terrain, we assume that the roadway is an elevated fill section, and that the source can be considered as surface-based regardless of the elevation of the roadway. As shown in the previous section for the hypothetical project with an 8% truck fleet mix, the initial vertical dimension of the roadway source is 1.37 m. When using line volume sources, AERMOD View will automatically calculate the initial vertical dimension from the plume height input parameter of 2.94 m for the hypothetical project. When using line area sources, users must manually input the initial vertical dimension.

To model complex terrain, users must run the terrain processor AERMAP to obtain the appropriate base elevations of all modeled sources and receptors. Digital elevation terrain data used to run AERMAP may account for existing (no-build scenario) roadway elevations above grade, but will not account for roadway elevations in future design scenarios. Therefore, to model an elevated roadway in the project area for a build scenario with roadway elevation that differs from the no-build scenario, users would add the roadway elevation to the base elevation produced by AERMAP for the source locations.

Figures 3-40 and 3-41 show AERMOD View **Source Inputs** windows for one of the freeway lane sources in the hypothetical project modeled with complex terrain and adjusted base elevation. Figure 3-40 shows inputs for a line volume source, and Figure 3-41 shows inputs for a line area source. The inputs in the top panel of each figure correspond to modeling the freeway link at grade (base elevation produced by AERMAP), and those in the bottom panel of each figure correspond to modeling the freeway link at 10 m above grade.

For line volume sources, the **Plume Height** and **Base Elevation** inputs are highlighted in Figure 3-40. Note that the **Surface-Based** option is selected so that AERMOD View will calculate the appropriate initial vertical dimension. In the top panel, the **Base Elevation** inputs for the two nodes of the line volume source are the elevations produced by AERMAP. In the bottom panel, the elevation of the roadway above grade (10 m) has been added to the values produced by AERMAP.

For line area sources, the **Initial Vertical Dimension** and **Base Elevation** inputs are highlighted in Figure 3-41. The pairs of **Base Elevation** inputs used for the roadway at grade and at 10 m above grade are the same as those used for the line volume sources.

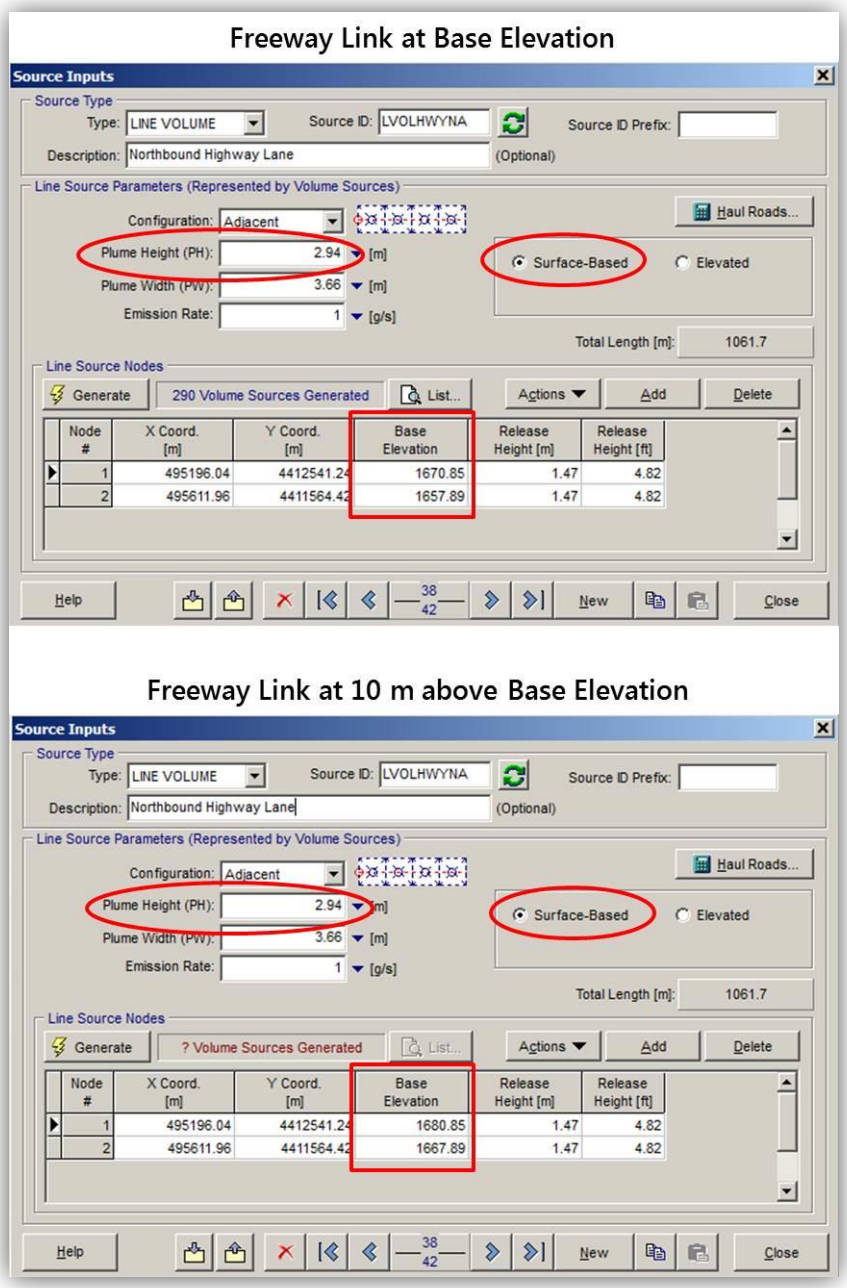


Figure 3-40. Sample line volume source inputs for one lane of the freeway link in the hypothetical project when modeling complex terrain and representing roadway elevation with an adjusted base elevation. Top panel shows inputs for modeling the roadway at grade; bottom panel shows inputs for modeling the roadway at 10 m above grade.

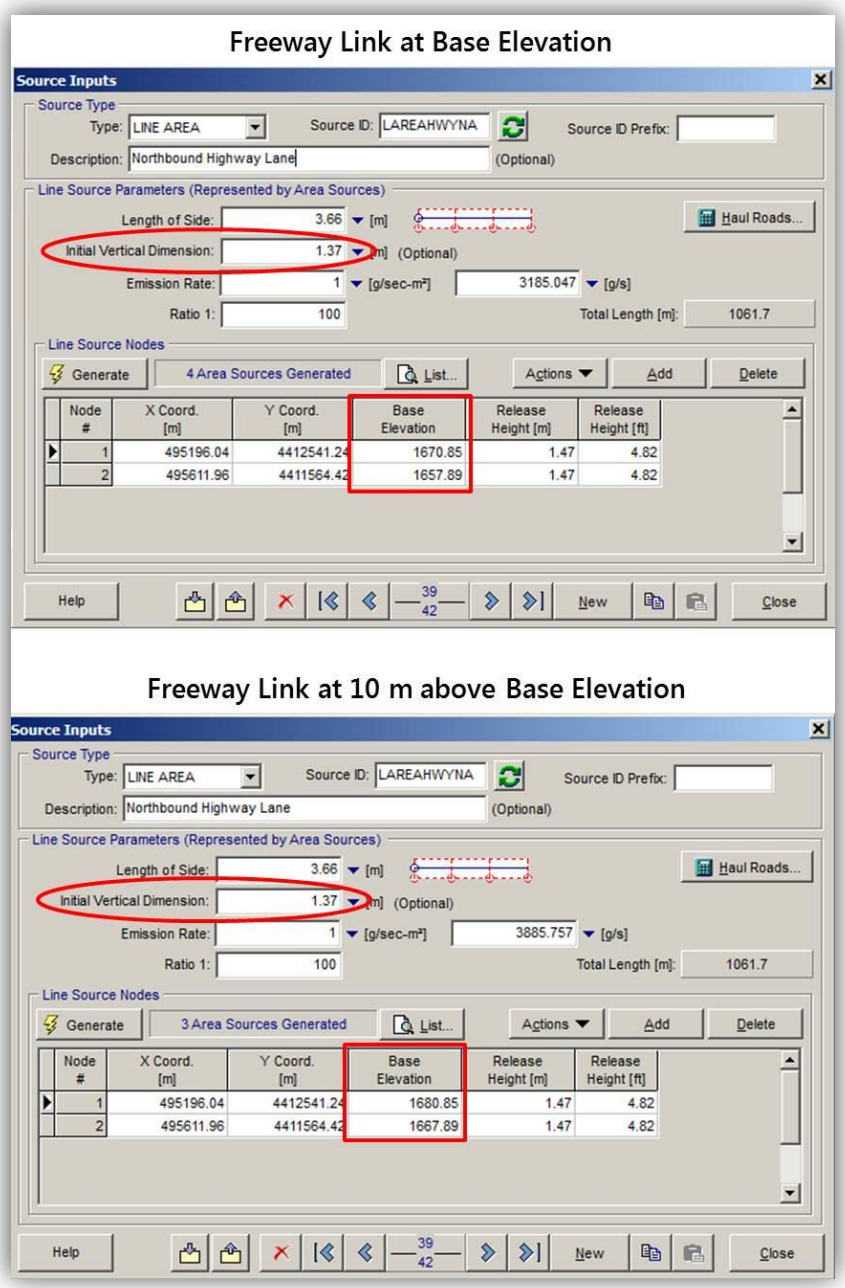


Figure 3-41. Sample line area source inputs for one lane of the freeway link in the hypothetical project when modeling complex terrain and representing roadway elevation with an adjusted base elevation. Top panel shows inputs for modeling the roadway at grade; bottom panel shows inputs for modeling the roadway at 10 m above grade.

3.3.8 Appendix B: Detailed Results of the Case Study Sensitivity Simulations

This appendix to Section 3.3 is divided into two parts:

1. Results from the Adjusted Release Height simulation set (modeling flat terrain and representing roadway elevation with an adjusted emissions source release height);
2. Results from the Adjusted Base Elevation simulation set (modeling complex terrain and representing roadway elevation with an adjusted emissions source base elevation).

Results from the Adjusted Release Height Simulation Set Modeling Flat Terrain and Adjusted Emissions Source Release Height

In this section, we present contour plots of the modeled peak PM concentrations. We also show an example of increased peak PM concentrations with increased emissions source release height. Those increases occur at receptors located more than 100 m from the roadways. The maximum modeled peak PM concentrations, and the corresponding reductions in maximum near-road peak concentration with increasing emissions source release height, were presented in Section 3.3.5.

Figure 3-42 shows contour plots of the modeled peak 24-hour average $PM_{2.5}$ concentrations using line area sources for simulations with the freeway link modeled at grade (release height = 1.47 m + 0 m), and three different elevations above grade (release height = 1.47 m + 5 m + 10 m + 15 m) using flat terrain and adjusted source release height. Figure 3-43 shows results when using line volume sources. The extents of the contours in these two figures illustrate that the peak concentrations at near-road receptors decrease with increasing release height of the freeway link, and that lower peak concentrations are modeled when using line volume sources compared to line area sources. When using line area sources, the maximum peak concentration (indicated by the yellow stars in Figure 3-42) occurs at the same model receptor for each simulation. The location of the maximum peak concentration (indicated by the yellow stars in Figure 3-43) is the same when using line volume sources and line area sources except for the simulation of the freeway link at grade using line volume sources.

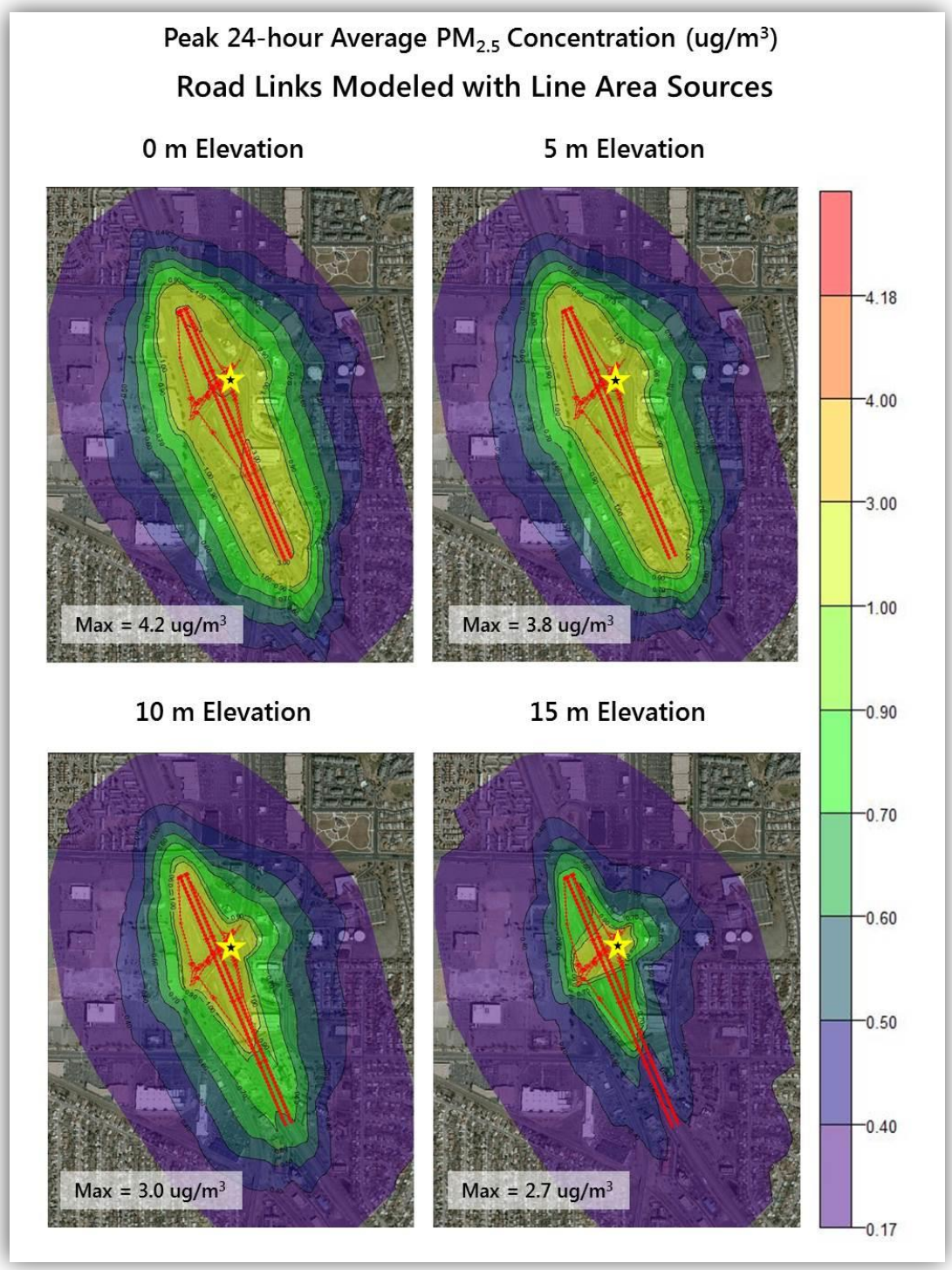


Figure 3-42. Contour plots for the hypothetical project showing peak 24-hour average $PM_{2.5}$ concentrations modeled with line area sources, with the freeway link modeled at grade (0 m) and three elevations (5 m, 10 m, and 15 m) above grade. Modeling was performed with flat terrain and adjusted release height for the elevated freeway. The location of the maximum peak concentration (Max) is indicated by the yellow star.

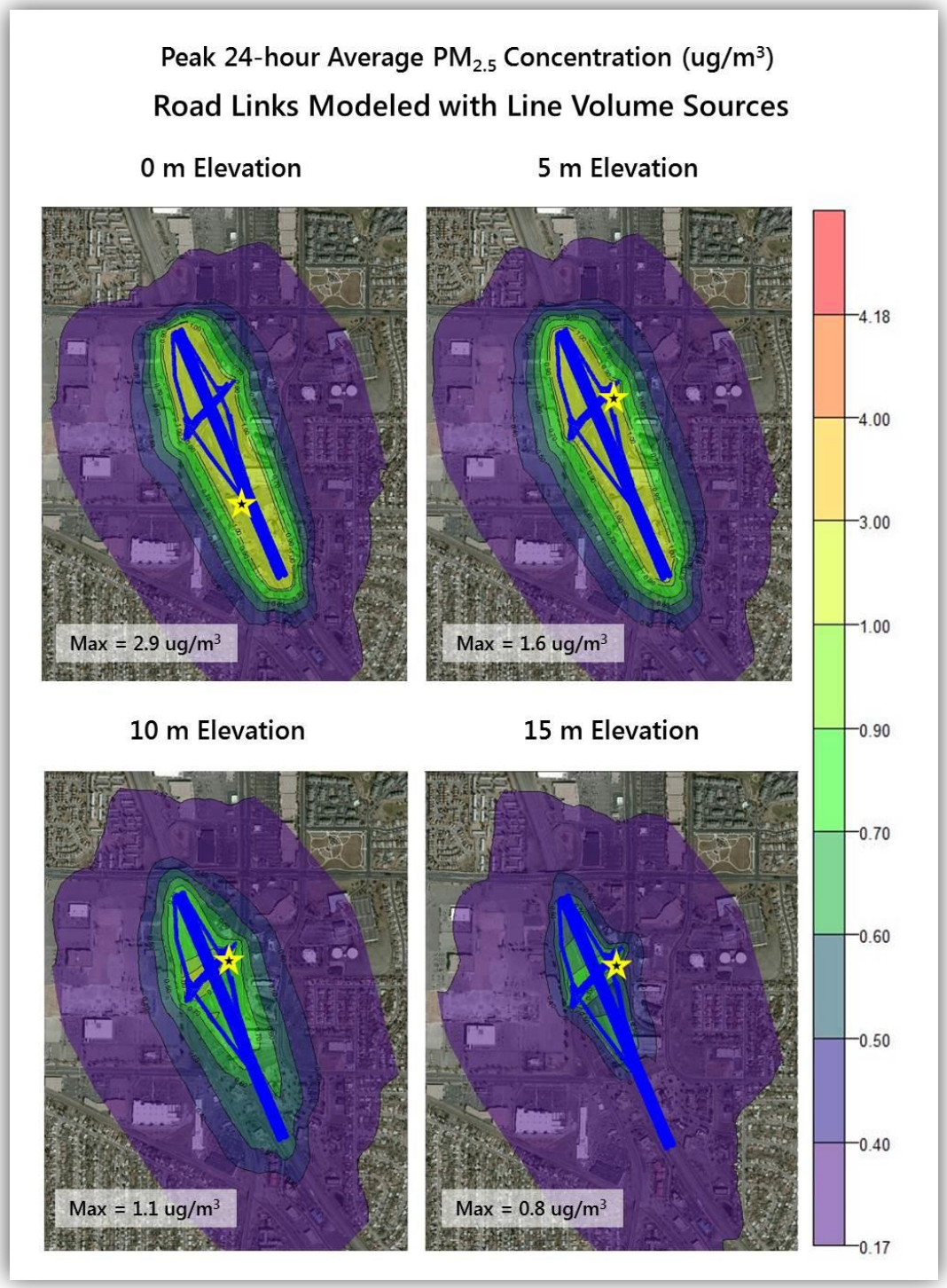


Figure 3-43. Contour plots for the hypothetical project showing peak 24-hour average $PM_{2.5}$ concentrations modeled with line volume sources, with the freeway link modeled at grade (0 m) and three elevations (5 m, 10 m, and 15 m) above grade. Modeling was performed with flat terrain and adjusted release height for the elevated freeway. The location of the maximum peak concentration (Max) is indicated by the yellow star.

Figure 3-44 shows contour plots of the modeled peak annual average $PM_{2.5}$ concentrations using line area sources for simulations with the freeway link modeled at grade (base elevation, or 0 m), and three different elevations (5 m, 10 m, and 15 m) above grade using flat terrain and adjusted source release height. Figure 3-45 shows results when using line volume sources.

The extents of the contours in these figures illustrate that the peak concentrations at near-road receptors decrease with increasing elevation of the freeway link modeled with an adjusted release height, and that lower peak concentrations are modeled when using line volume sources compared to line area sources. However, in the simulation modeling the freeway at grade, the overall maximum peak concentration is the same (1.6 $\mu g/m^3$) whether using line area or line volume sources. For annual average $PM_{2.5}$, the location of the maximum peak modeled concentration differs between the simulations modeling the freeway at grade and the simulations modeling the freeway above grade whether using line area or line volume sources. However, for each of the Adjusted Release Height simulations, the maximum peak concentration when using line area sources occurs at the same location as when using line volume sources.

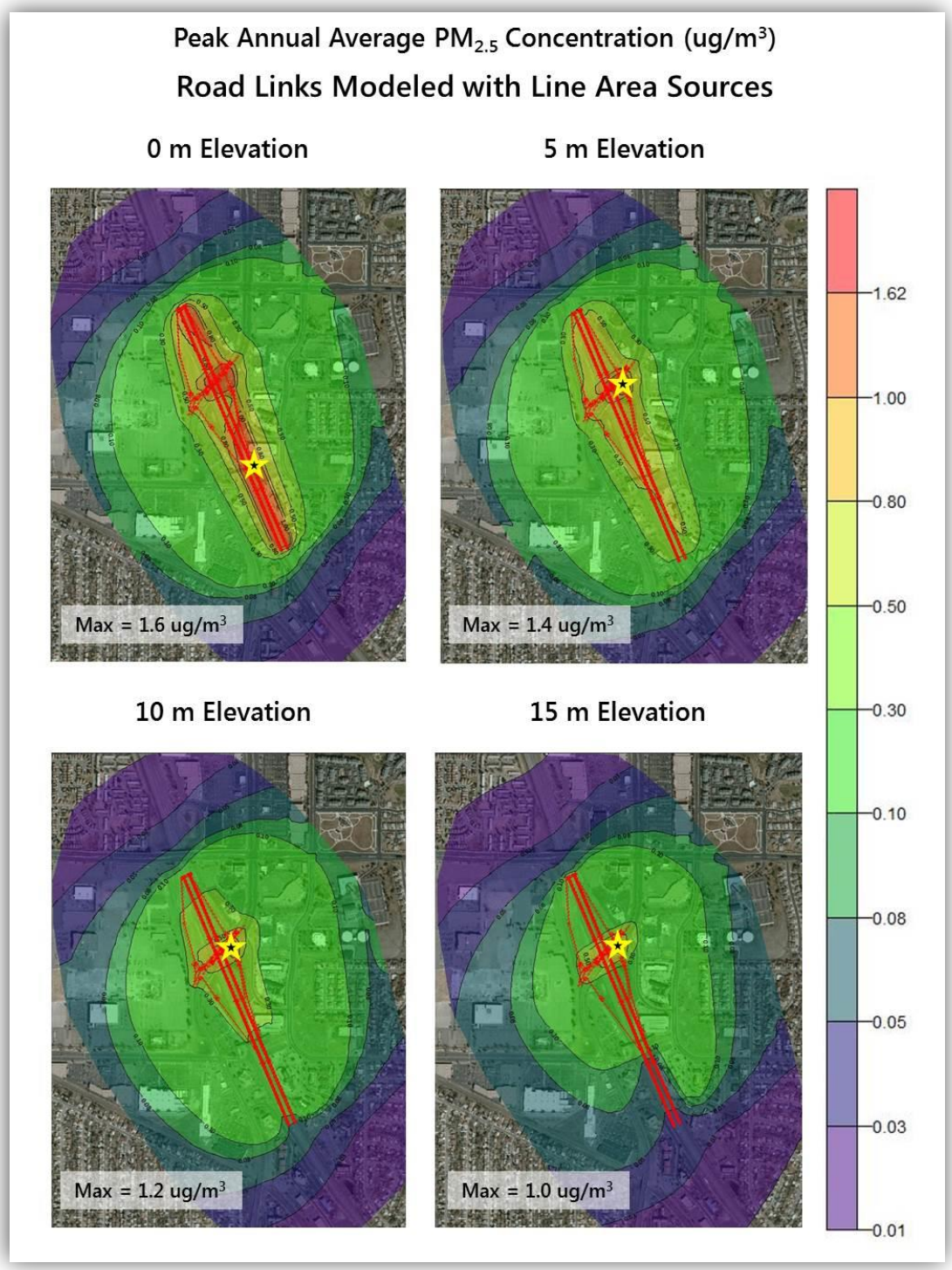


Figure 3-44. Contour plots for the hypothetical project showing peak annual average $PM_{2.5}$ concentrations modeled with line area sources, with the freeway link modeled at grade (0 m) and three elevations (5 m, 10 m, and 15 m) above grade. Modeling was performed with flat terrain and adjusted release height for the elevated freeway. The location of the maximum peak concentration (Max) is indicated by the yellow star.

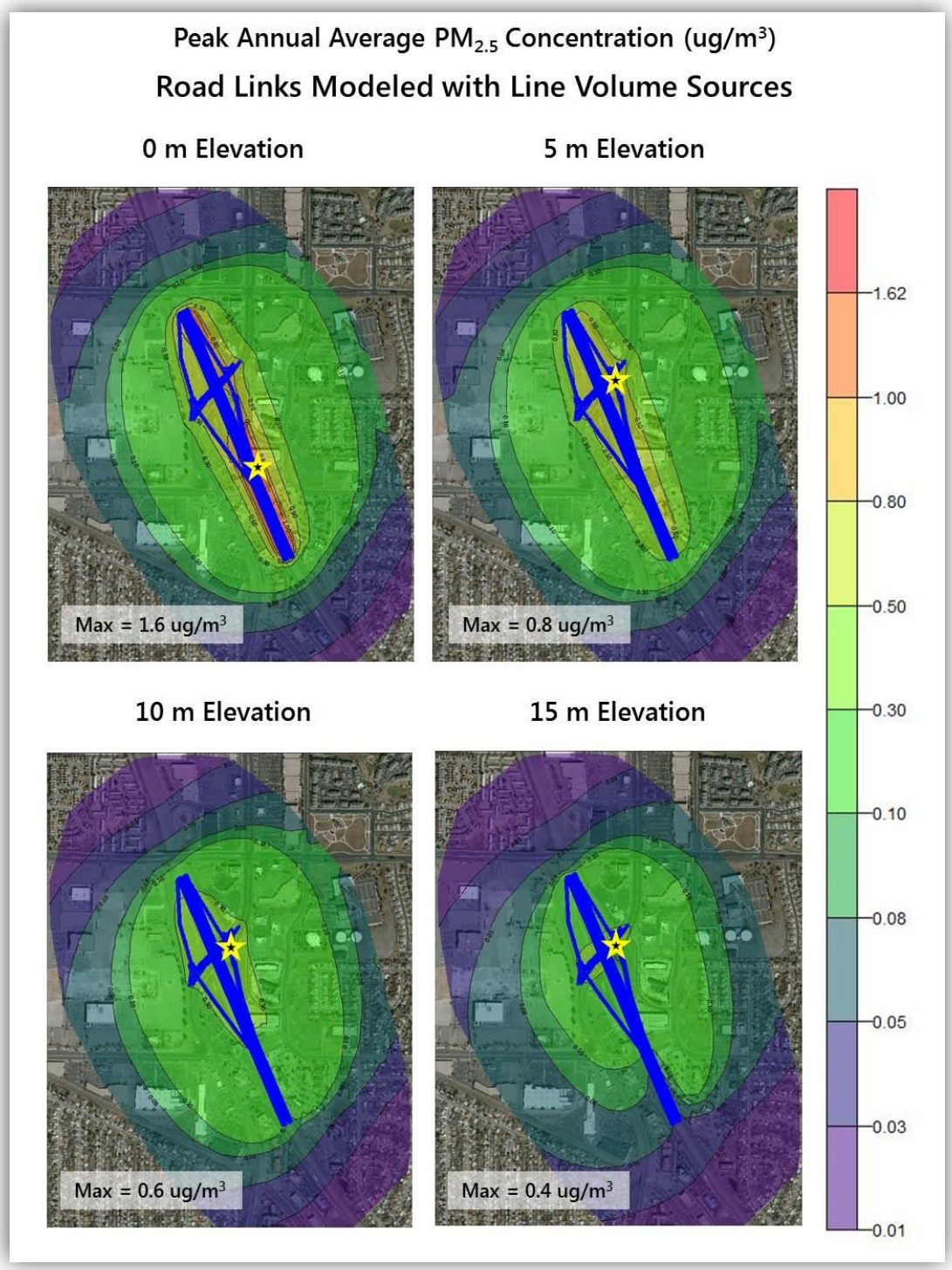


Figure 3-45. Contour plots for the hypothetical project showing peak annual average $PM_{2.5}$ concentrations modeled with line volume sources, with the freeway link modeled at grade (0 m) and three elevations (5 m, 10 m, and 15 m) above grade. Modeling was performed with flat terrain and adjusted release height for the elevated freeway. The location of the maximum peak concentration (Max) is indicated by the yellow star.

As mentioned in Section 3.3.1, some studies have shown lower near-road concentrations for an elevated fill section of roadway relative to an at-grade roadway. Field measurement data also suggest complexity of concentration changes near elevated roadways; for example, concentrations increase several hundred feet downwind of a 6-m elevated fill section of roadway in Los Angeles relative to an at-grade roadway (Cahill et al., 1973). Increased modeled peak concentrations for an elevated roadway were observed at downwind receptors in some of the Adjusted Release Height simulations performed in this case study. **Tables 3-20 and 3-21** summarize this result and compare modeled peak $PM_{2.5}$ concentrations in simulations using flat terrain and line volume sources for the freeway link modeled at grade (release height = 1.47 m + 0 m) and at 10 m above grade (release height = 1.47 m + 10 m).

As shown in Tables 3-20 and 3-21, the maximum increase in modeled peak 24-hour average concentrations is 38% (with an average increase of 12%), while the maximum increase in modeled peak annual average $PM_{2.5}$ is 2% (with an average increase of 1%). When modeling the roadway at 10 m above grade, increased concentrations occur at 38% of all model receptors for 24-hour average, and 1% of all model receptors for annual average $PM_{2.5}$ (see Table 3-21). In the context of a PM hot-spot analysis, this effect would not be important for the determination of conformity, because the modeled peak 24-hour and annual average $PM_{2.5}$ concentrations at these receptors when modeling the roadway at 10 m above grade are 10% or less of the maximum modeled peak concentrations at near-road receptors when modeling the roadway at grade. In other words, the higher modeled peak concentrations at downwind receptors are only a fraction of the peak concentrations modeled at near-road receptors. The locations where the increased concentrations are modeled are at receptors more than 100 m from the roadway sources in the hypothetical project. All receptor locations where the modeled peak concentrations occurred in this example are shown by the black dots in **Figure 3-46**. The locations of the maximum increases in concentration are indicated with yellow stars.

Although modeled concentrations may increase at some downwind receptors, the highest concentration impacts will generally occur near roadway emissions sources, and near-road receptors will be of greatest concern in transportation conformity analyses. In other words, increases in modeled concentrations at downwind receptors will not likely correspond with violations of the National Ambient Air Quality Standards (NAAQS) in a conformity analysis. However, the results presented here provide an example of the kind of results analysts may obtain when modeling elevated roadways in a PM hot-spot analysis.

Table 3-20. Summary of increases in peak PM concentration when modeling an elevated roadway compared to modeling the roadway at grade.

Averaging Time	Maximum Increase in Concentration		Location of Maximum Increase	Average Increase	
	μg/m^3	%		μg/m^3	%
24-hour	0.183	38%	109 m north of highway	0.031	12%
Annual	0.001	2%	600 m west of highway	0.001	1%

Table 3-21. Summary of the number of receptors where higher peak PM concentrations occur when modeling an elevated roadway compared to modeling the roadway at grade.

Averaging Time	No. of Receptors	Percentage of Total No. of Receptors
24-hour	395	38%
Annual	15	1%

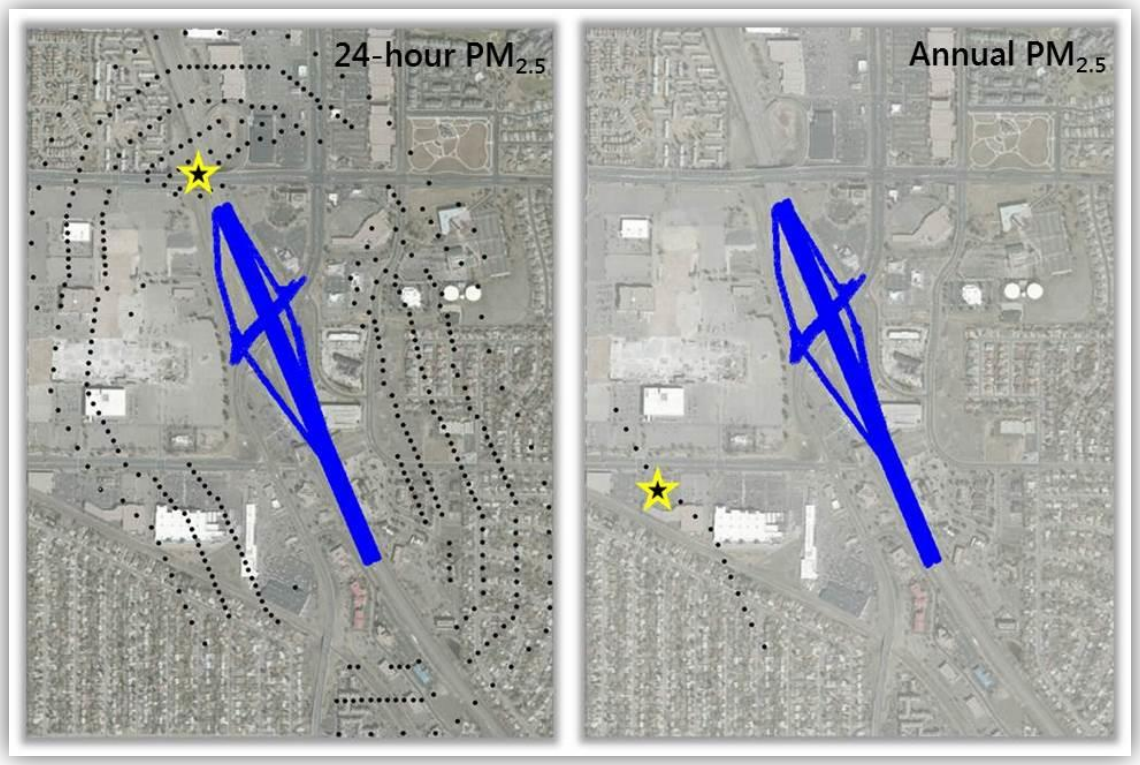


Figure 3-46. Illustration of receptor locations (black dots) in the hypothetical transportation project where peak PM concentrations increase when modeling the freeway link at 10 m elevation relative to modeling the freeway link at base elevation (0 m). The receptor location where the maximum increase in modeled concentration occurs is indicated by the yellow star. Results for 24-hour average $PM_{2.5}$ concentrations are shown on the left, while results for annual average $PM_{2.5}$ concentrations are shown on the right.

Results from the Adjusted Base Elevation Simulation Set Modeling Complex Terrain and Adjusted Emissions Source Base Elevation

In this section, we present the modeled peak PM concentrations, reductions in peak concentrations, and contour plots of the modeled peak PM concentrations in the Adjusted Base Elevation simulation set using complex terrain and representing roadway elevation with an adjusted emissions source base elevation.

Table 3-19 summarizes the overall modeled peak $PM_{2.5}$ concentrations in the hypothetical project when using complex terrain, as well as the reductions in peak concentration when modeling the freeway link at elevations of 5 m, 10 m, and 15 m above grade (or base elevation) relative to at grade. As described in Section 3.3.5, results from the simulation set using complex terrain and adjusted base elevation are complicated by the fact that, in the hypothetical transportation project, the freeway link emissions source is closer to some near-road receptors when the freeway is elevated than when it is at grade. Therefore, as shown in Table 3-19, the modeled peak concentration does not necessarily

decrease with increasing elevation of the freeway. In fact, when modeling the roadways with line area sources, there is less reduction in modeled peak 24-hour average $PM_{2.5}$ concentration when the roadway is elevated at 10 m above base elevation than at 5 m above grade. Moreover, the modeled peak 24-hour average $PM_{2.5}$ concentration is higher when the roadway is elevated at 15 m above grade than when it is modeled at grade. Similarly, the reduction in modeled peak annual average $PM_{2.5}$ concentration is less when the roadway is modeled at 15 m above grade than at 10 m above grade. On the other hand, when modeling the roadways with line volume sources in the Adjusted Base Elevation simulations, the modeled reduction in peak 24-hour average $PM_{2.5}$ concentration is continuously greater as the roadway elevation above grade increases. For annual average $PM_{2.5}$ concentrations, when modeling with line volume sources, there was no change in the modeled peak concentration between base elevation and 5 m above grade, and the reduction in peak concentration was the same when modeling at 10 m and 15 m above grade.

Figure 3-47 shows contour plots of the modeled peak 24-hour average $PM_{2.5}$ concentrations using line area sources for simulations with the freeway link modeled at grade (base elevation), and at 5 m, 10 m, and 15 m elevations above grade using complex terrain and adjusted source base elevation. Figure 3-48 shows results when using line volume sources. In general, the contour plots show that reductions in modeled peak concentrations when modeling the road at elevations above grade relative to at grade are much lower than those modeled using flat terrain and adjusted source release height. Furthermore, as shown by the yellow stars in the contour plots, the location of the overall peak concentration differs more between these simulations than it did when modeling with flat terrain and adjusted source release height in Figures 3-42 and 3-43.

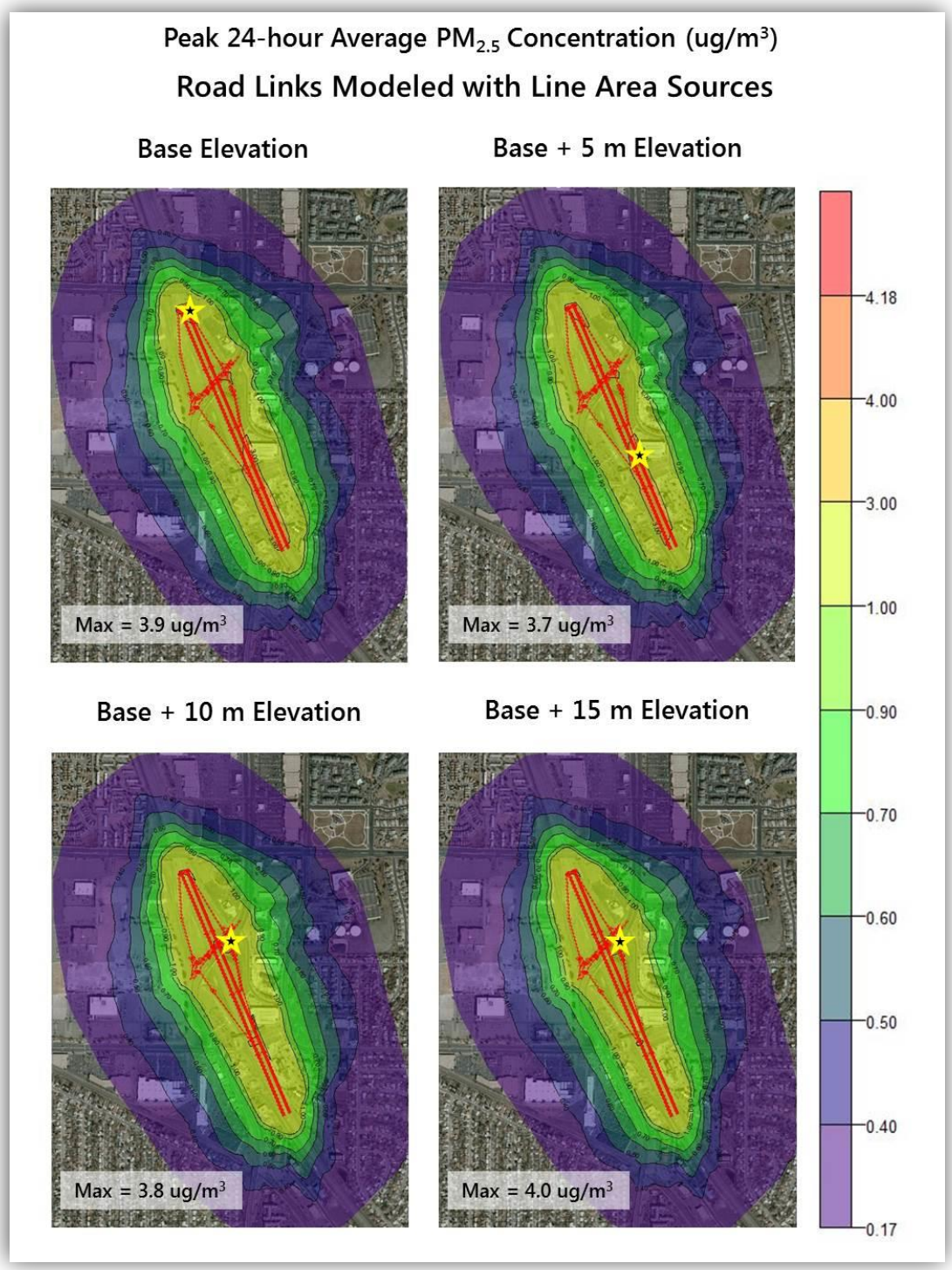


Figure 3-47. Contour plots for the hypothetical project showing peak 24-hour average $PM_{2.5}$ concentrations modeled with line area sources, with the freeway link modeled at grade (base elevation) and three elevations (5 m, 10 m, and 15 m) above grade. Modeling was performed with complex terrain and adjusted base elevation for the elevated freeway. All roadway sources modeled with line area sources. The location of the maximum peak concentration (Max) is indicated by the yellow star.

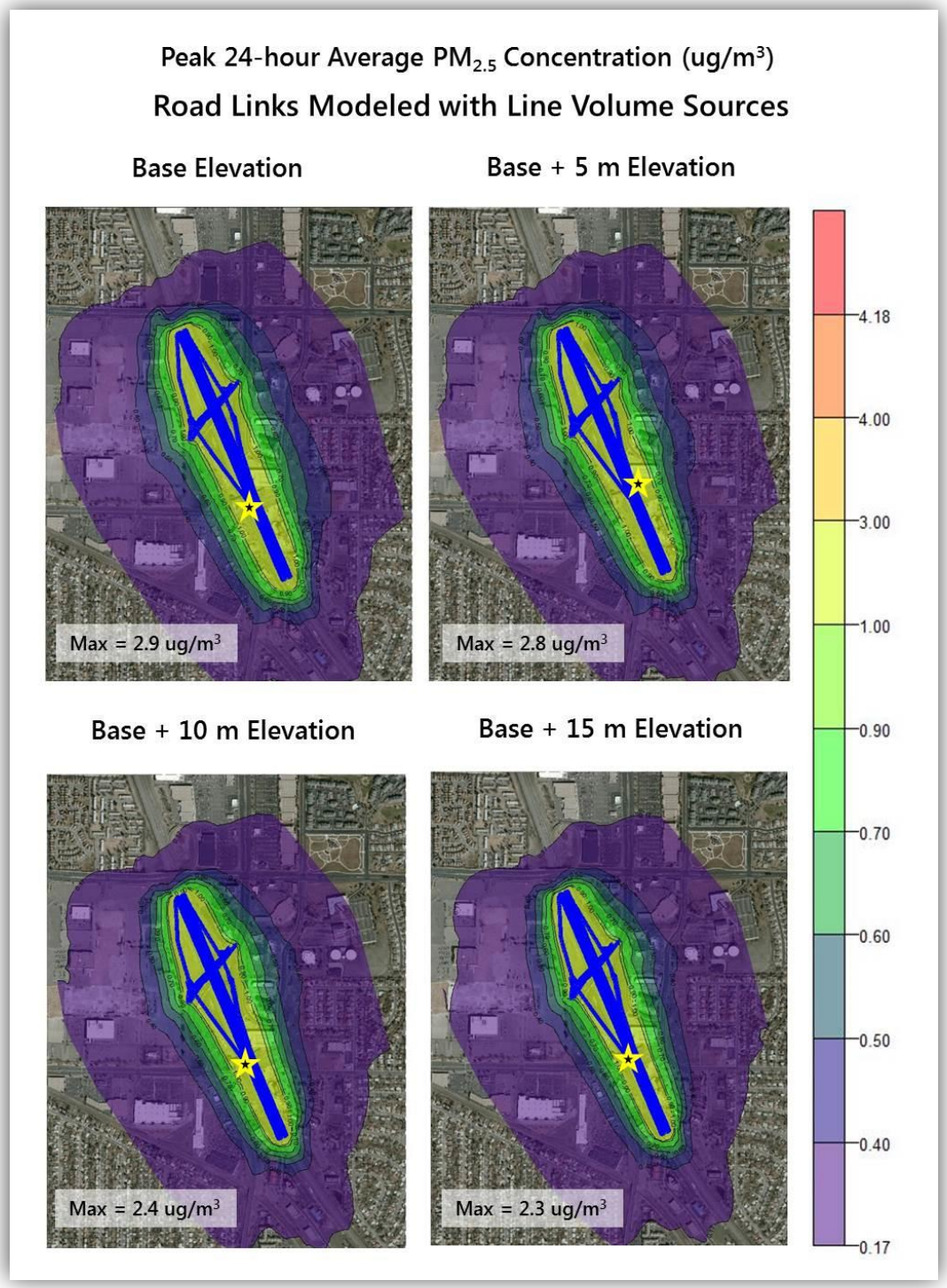


Figure 3-48. Contour plots for the hypothetical project showing peak 24-hour average $PM_{2.5}$ concentrations modeled with line volume sources, with the freeway link modeled at grade (base elevation) and three elevations (5 m, 10 m, and 15 m) above grade. Modeling was performed with complex terrain and adjusted base elevation for the elevated freeway. The location of the maximum peak concentration (Max) is indicated by the yellow star.

Figure 3-49 shows contour plots of the modeled peak annual average $PM_{2.5}$ concentrations using line area sources for simulations with the freeway link modeled at grade (base elevation), and at 5 m, 10 m, and 15 m elevations above grade using complex terrain and adjusted source base elevation. Figure 3-50 shows results when using line volume sources. As for 24-hour average $PM_{2.5}$ concentrations, in general these contour plots show that reductions in modeled peak concentrations when modeling the road at elevations above grade relative to at grade are much lower than those modeled using flat terrain and adjusted source release height. Similarly, the location of the overall peak concentration differs more between simulations when using line area sources than it did when modeling with flat terrain and adjusted source release height in Figures 3-44 and 3-45.

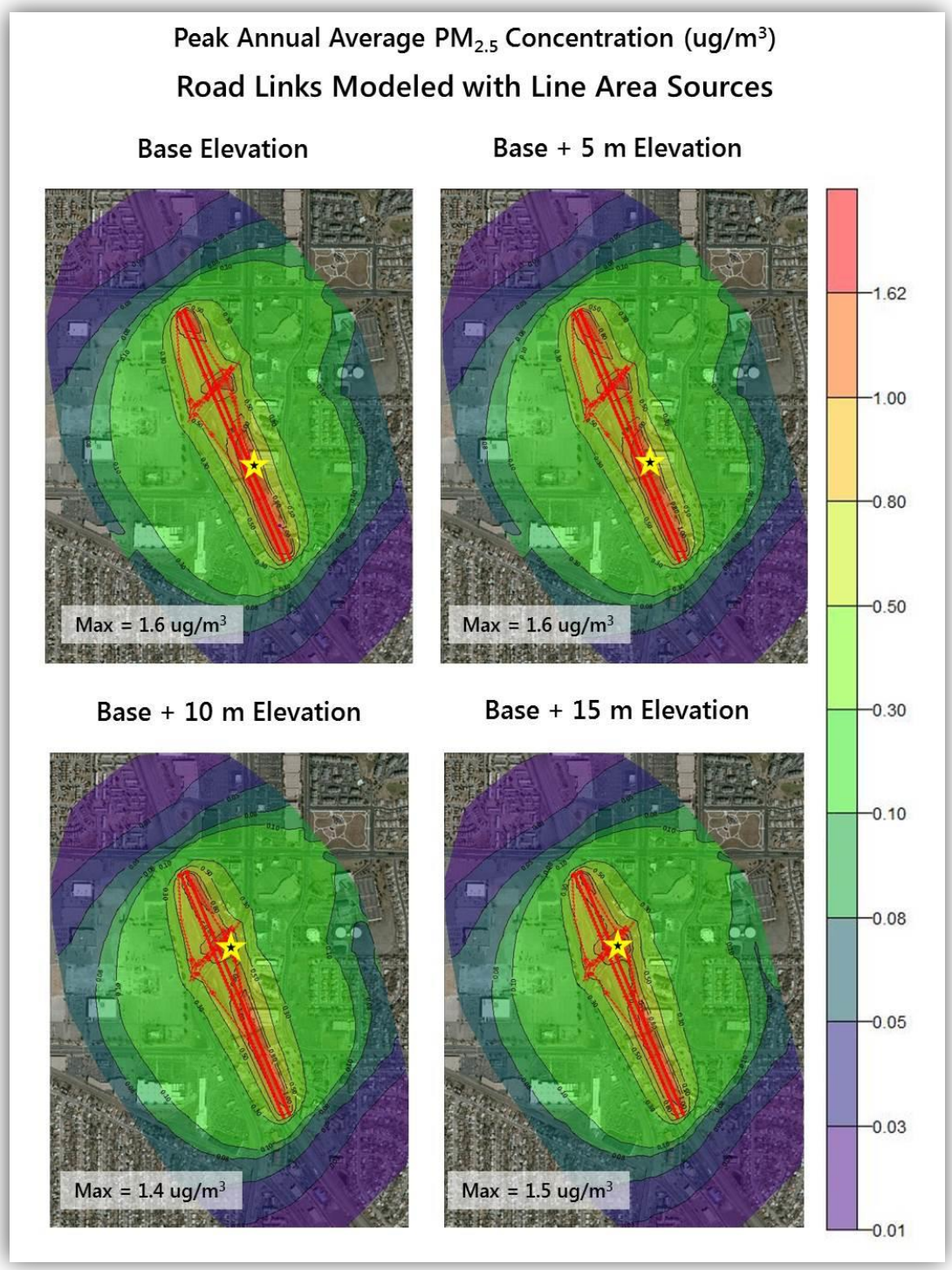


Figure 3-49. Contour plots for the hypothetical project showing peak annual average $PM_{2.5}$ concentrations modeled with line area sources, with the freeway link modeled at grade (base elevation) and three elevations (5 m, 10 m, and 15 m) above grade. Modeling was performed with complex terrain and adjusted base elevation for the elevated freeway. The location of the maximum peak concentration (Max) is indicated by the yellow star.

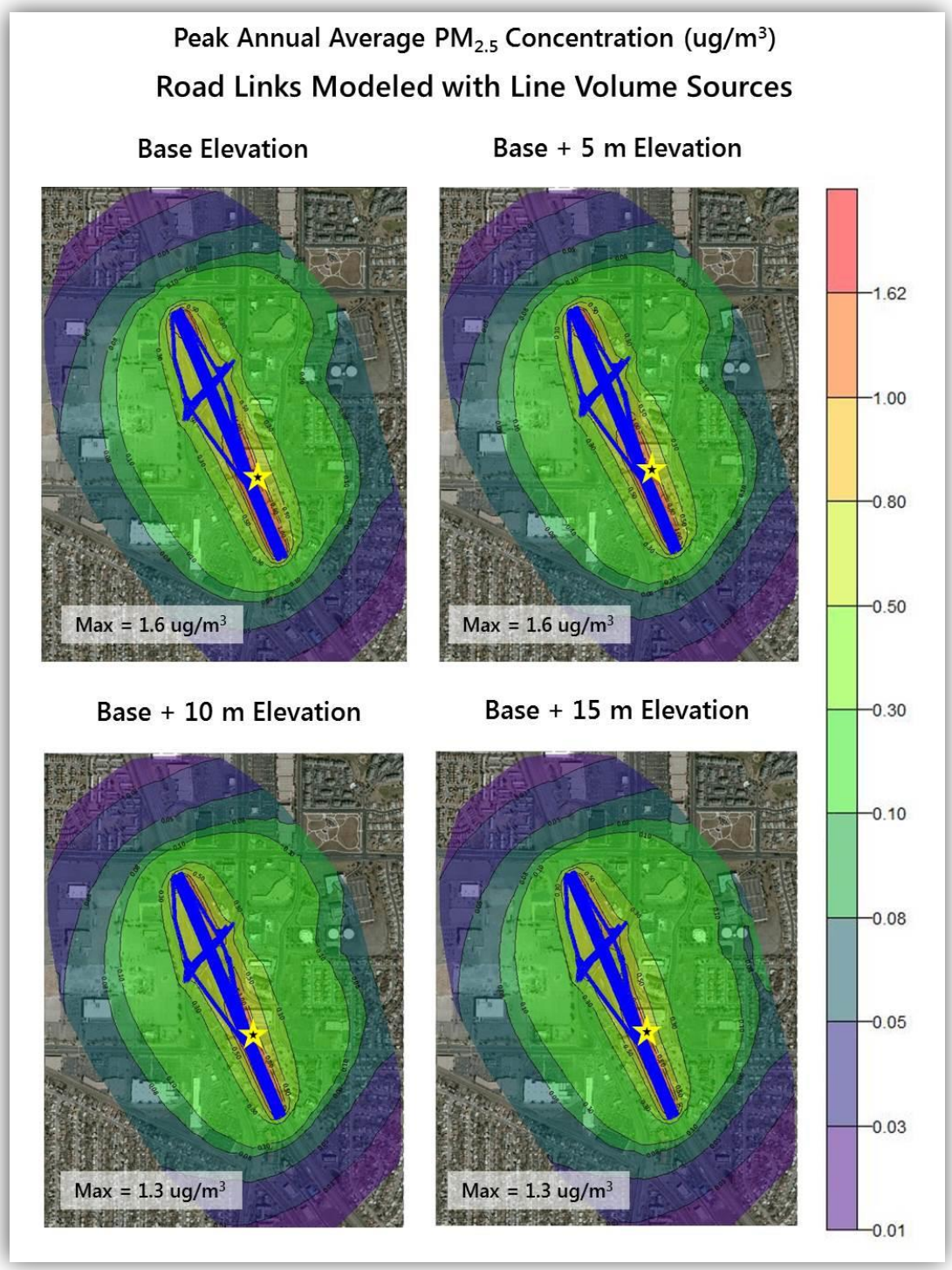


Figure 3-50. Contour plots for the hypothetical project showing peak annual average $PM_{2.5}$ concentrations modeled with line volume sources, with the freeway link modeled at grade (base elevation) and three elevations (5 m, 10 m, and 15 m) above grade. Modeling was performed with complex terrain and adjusted base elevation for the elevated freeway. The location of the maximum peak concentration (Max) is indicated by the yellow star.

3.4 Case Study on Preparing Meteorological Data for Use in PM Hot-Spot Analyses

3.4.1 Introduction

This case study illustrates how to prepare meteorological data for use in particulate matter (PM) hot-spot analyses. The AERMOD dispersion model needs meteorological data to calculate the incremental PM contribution of a transportation project. The information provided here supplements previously prepared guidance (Bai et al., 2014), which focused on using the command-line version of AERMET to process meteorological data for AERMOD. Chapter 3.4 focuses on using the AERMET View graphical user interface (GUI), which is developed by Lakes Environmental and bundled with the AERMOD View license that Caltrans purchased.

The U.S. Environmental Protection Agency's (EPA) transportation conformity rule requires a PM hot-spot analysis for certain transportation projects located in federal $PM_{2.5}$ or PM_{10} nonattainment or maintenance areas. In December 2010, EPA published guidance for completing a quantitative PM hot-spot analysis, *Transportation Conformity Guidance for Quantitative Hot-Spot Analyses in $PM_{2.5}$ and PM_{10} Nonattainment and Maintenance Areas* (Transportation Conformity Guidance); updated versions of the guidance were released in November 2013 and November 2015 (U.S. Environmental Protection Agency, 2015c). The guidance describes three major steps for completing a PM hot-spot analysis: (1) estimate the incremental PM contribution of the proposed project; (2) add the increment to a representative background concentration; and (3) determine whether the combination (increment plus background) meets conformity requirements.

AERMOD is used to estimate the incremental PM contribution from a transportation project. AERMOD needs detailed meteorological data because meteorology (i.e., wind, temperature, clouds, and atmospheric stability) affect how PM is dispersed in the atmosphere. For most PM hot-spot analyses, AERMOD requires five years of surface and upper-air meteorological data. Preparing meteorological data for use by AERMOD is a significant work effort that involves multiple processing steps and the use of additional EPA software tools such as AERMET[24] and, in some cases, AERSURFACE[25] and AERMINUTE.[26]

When pre-packaged AERMOD-ready meteorological data files are not available, project analysts must (a) select representative meteorological monitoring sites; (b) acquire raw meteorological data in the proper formats; (c) process the meteorological data with AERMET View; (d) quality-assure the data before it is used in AERMOD; and (e) load the processed data into AERMOD View. EPA's Transportation Conformity Guidance describes the general use of representative meteorological data

[24] AERMET is the meteorological data pre-processor for AERMOD.
[25] AERSURFACE uses land cover and precipitation data to calculate albedo, Bowen Ratio, and roughness length. These land surface characteristics are needed by AERMET.
[26] AERMINUTE is an optional tool that processes 1-min and 5-min meteorological data for AERMET.

for PM hot-spot analyses, but does not provide detailed instructions on how to complete these work steps. Section 3.4 guides project analysts through these work steps and provides a detailed end-to-end case study to illustrate how to prepare meteorological data for a PM hot-spot analysis using the AERMET View GUI.

This document builds upon EPA guidance and other Caltrans resources, including

- *Caltrans Quantitative Particulate Matter Hot-Spot Analysis Guidance* version 3.2, Supplement 2: Meteorological Data. AERMOD Particulate Matter Hot-Spot Analyses: Selecting and Processing Representative Meteorological Data, November, 2014 (Bai et al., 2014);
- *Guidance and Resources for Developing AERMOD-Ready Meteorological Data using AERMET View*, August, 2014 (Craig and Bai, 2014); and
- *Quantitative Particulate Matter Hot-Spot Analysis Best Practices Guidebook* (Bai et al., 2017).

Analysts should consult interagency partners to determine whether any state or local air quality agencies have already developed AERMOD-ready meteorological data files that are suitable for a PM hot-spot analysis that needs to be done. The work steps described in this document are not needed when representative AERMOD-ready data are available for the analyzed transportation project. Using pre-packaged AERMOD-ready data will reduce the time and resources needed to complete a PM hot-spot analysis. AERMOD-ready data for California are available from several sources, shown in Table 3-22.

Table 3-22. Sources of AERMOD-ready meteorological data files in California.

Agency	Data Website
California Air Resources Board	http://www.arb.ca.gov/toxics/harp/metfiles2.htm
San Joaquin Valley Air Pollution Control District	http://www.valleyair.org/busind/pto/Tox_Resources/AirQualityMonitoring.htm
Santa Barbara County Air Pollution Control District	http://www.ourair.org/metdata
South Coast Air Quality Management District	http://www.aqmd.gov/home/library/air-quality-data-studies/meteorological-data

3.4.2 Case Study

We use a detailed case study of a hypothetical transportation project to illustrate the preparation of meteorological data for use in PM hot-spot analyses. The project, assumed to be located in an urban area in Fresno, California, is based on a sample project developed by the EPA to facilitate PM hot-spot analysis training.

Assuming that AERMOD-ready meteorological data are not available for this hypothetical project, we follow the work steps outlined in Figure 3-51 to create AERMOD-ready meteorological data files. The remaining sections of this document describe in detail how to complete each work step. In particular, Step 4 contains detailed instructions on using the AERMET View GUI to prepare meteorological data for use in AERMOD. Step 4 also includes best practices for quality-assuring meteorological data, and common issues that analysts may encounter when using AERMET View.

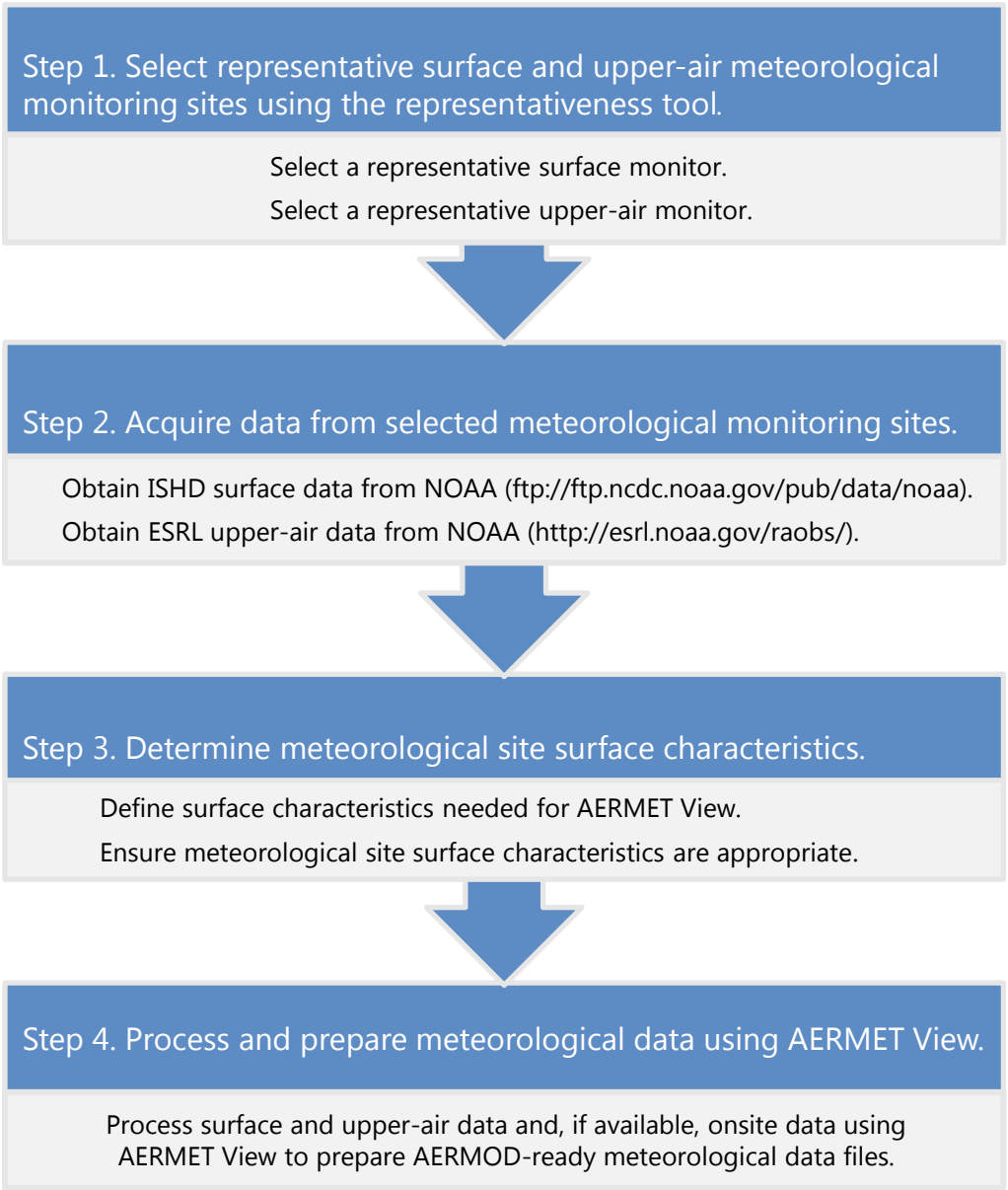


Figure 3-51. Major work steps for preparing AERMOD-ready meteorological data. Acronyms are explained in the main text, where work steps are described in more detail.

3.4.3 Step 1: Select Representative Meteorological Monitoring Sites

The first major work step of preparing meteorological data for AERMOD is to select representative surface and upper-air monitoring sites. According to EPA, meteorological monitoring data should be selected based on spatial and climatological (temporal) representativeness, and on whether the data adequately characterize the transport and dispersion in the project area. Representativeness depends on several factors summarized in EPA's PM hot-spot guidance (U.S. Environmental Protection Agency, 2015c):

- proximity of the meteorological monitoring site to the project area;
- similarity of surface characteristics at the meteorological monitoring site and project area;
- complexity of the terrain;
- exposure of the meteorological monitoring site,[27] and
- period of time over which data are collected.

To assist project analysts with selecting representative meteorological data, Caltrans developed GIS-based maps that show the locations of National Weather Service (NWS) measurement sites throughout California, and the spatial extent of the representativeness of those sites. A sample map is presented in Figure 3-52. The spatial extent of representativeness for a particular site depends on many factors, including distance, elevation, terrain slope, proximity to the ocean, time of day, season, and prevailing winds. The analysis procedure for developing the representativeness maps is described in the Caltrans PM hot-spot guidance (Bai et al., 2014).[28]

These GIS-based representativeness maps are available as a set of GIS shapefiles via the Caltrans Intranet,[29] and can be used as a guide for selecting representative meteorological sites. In some cases, a meteorological data site identified through the GIS-based maps may not be appropriate for a hot-spot analysis. For example:

- Data (particularly upper-air data) from a neighboring state may be more appropriate for projects located near state boundaries;
- Interagency partners may recommend a site that is farther from the project, but more representative of the meteorology at the project site; and
- An air quality management district (AQMD) may recommend the use of data collected through its own monitoring network.

[27] Exposure refers to proper placement of the meteorological monitoring site to avoid interference from nearby land features or obstacles (such as, trees, buildings, etc.).
[28] See the appendix of Supplement 2 of the Caltrans Quantitative Particulate Matter Hot-Spot Analysis Guidance for methodology details for estimating the spatial representativeness of data collected at the meteorological measurement sites.
[29] Contact Caltrans Division of Environmental Analysis to determine the appropriate Intranet page from which to access the GIS map resources.

Final site selection must be concurred through interagency consultation prior to using the data in a PM hot-spot analysis. Use of the Caltrans GIS-based representativeness maps is illustrated below for the hypothetical Fresno project.

Selecting a Representative Surface Site

Figure 3-52 is a sample representativeness map for surface meteorological data sites, with the case study project in Fresno denoted by the black star. Each meteorological data site (shown as a blue dot with a corresponding four-letter identifier) is mapped in an area surrounded by a site allocation boundary (shown with black lines). The site allocation boundary marks the region where a particular site's influence (or representativeness) is high, compared to neighboring meteorological sites. Each area marked by allocation boundaries is divided into color-coded regions that reflect areas where those particular monitoring data are most representative (green), less representative (yellow), and not representative (red).

The hypothetical project area is located in a green area within the Fresno Air Terminal (KFAT) site allocation boundary shown in Figure 3-52 (the KFAT site allocation boundary is outlined in blue), suggesting that surface meteorological data from KFAT may be most representative of the project area. Analysts should perform additional evaluation[30] based on EPA's guidance on data representativeness to corroborate the information provided by the GIS-based maps. In this example, KFAT is the closest NWS site to the project area. Also, the area around KFAT is topographically similar to the project area (both are at low elevation and located within the central San Joaquin Valley), and both KFAT and the project area are located within suburban areas with similar surface characteristics.

[30] Satellite imagery is useful for evaluating representativeness.

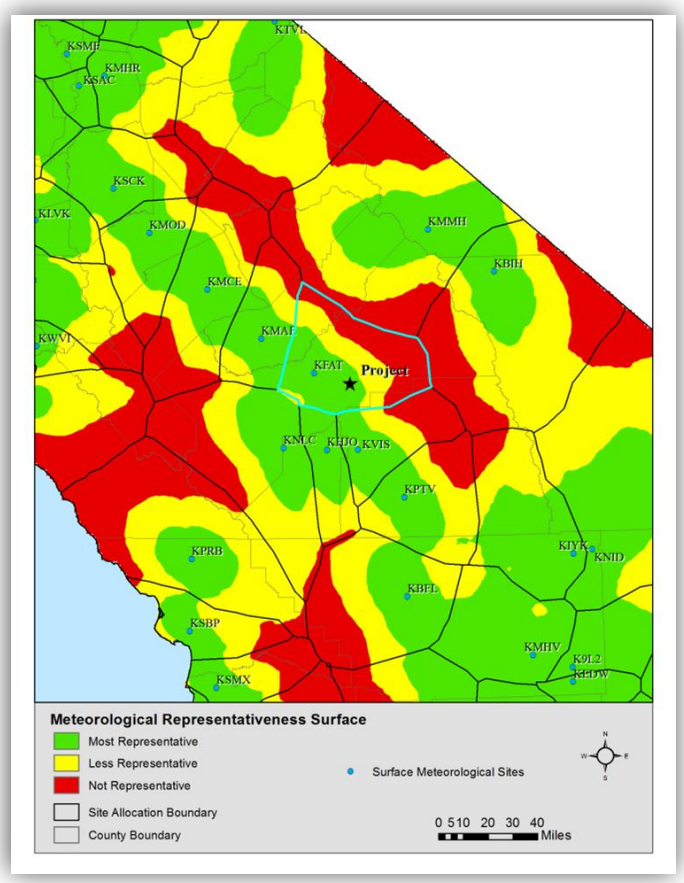


Figure 3-52. Sample surface meteorological representativeness map. The black star labeled "Project" represents the hypothetical project location, and the blue line indicates the region represented by the KFAT site.

Selecting a Representative Upper-Air Site

Figure 3-53 shows a sample representativeness map for upper-air meteorological data sites, with the Fresno case study project location denoted by the black star that is labeled "Project". Stars with four-letter identifiers indicate the upper-air site locations and black lines represent the site allocation boundaries for each data site. The regions are color-coded to reflect areas where those particular monitoring data are most representative (green), less representative (yellow), and not representative (red) of the monitoring site. Since there are only four upper-air sites in California, upper-air sites in neighboring states may be needed for projects located near state boundaries.

As shown in Figure 3-53, the case study project is located in an area that is well represented by the Vandenberg Air Force Base (KVBG) upper-air site. However, it was determined that data from the Oakland International Airport (KOAK) site better represents the upper-air meteorology at the project location. Two primary factors indicate that KOAK is the most representative site for the hypothetical project: topography and surface characteristics. The immediate vicinity of the hypothetical Fresno

project site is a flat urban area, much more similar to the area surrounding the KOAK site than the KVBG site. In this case study, interagency consultation is important and necessary to determine the most representative upper-air meteorological site.

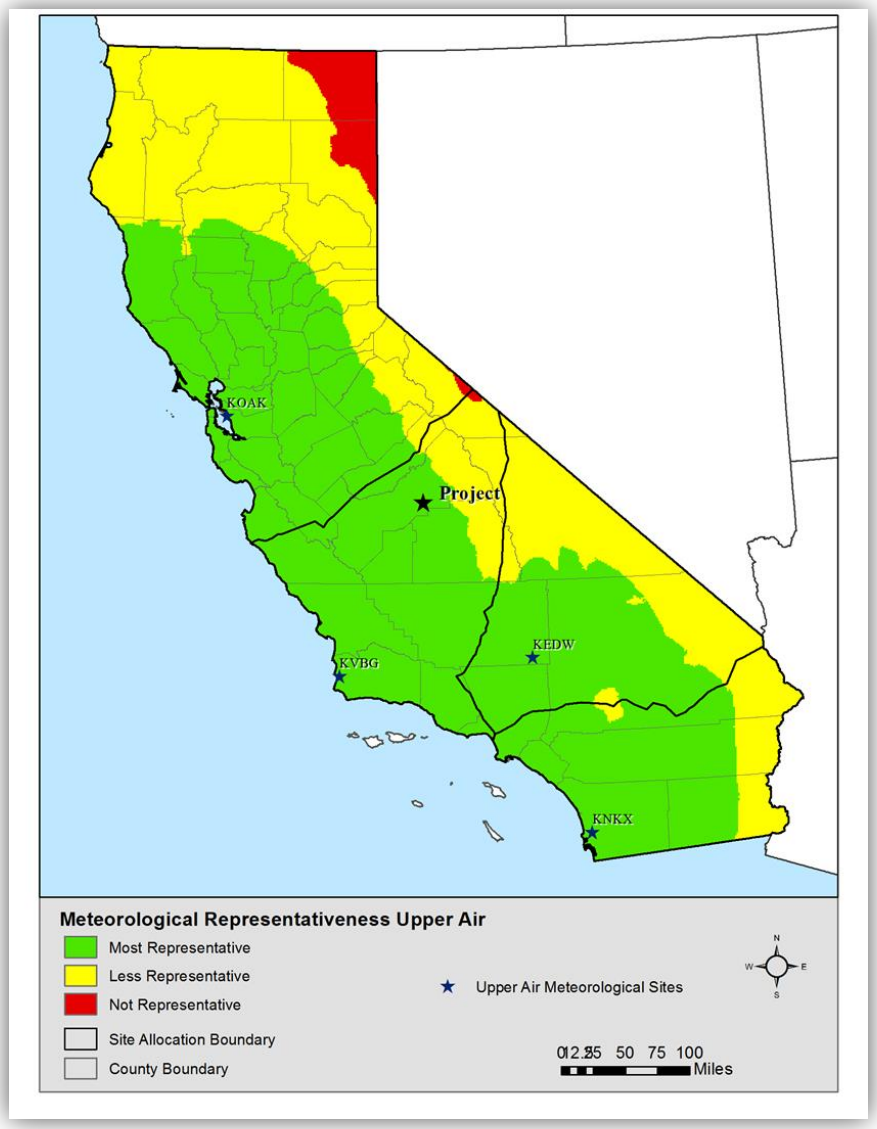


Figure 3-53. Sample upper-air meteorological representativeness map. The black star that is labeled "Project" represents the hypothetical project location; the black boundary enclosing that star describes the region represented by the Vandenburg Air Force Base (KVBG) site. For the case study, we determined that the Oakland International Airport (KOAK) site is more representative of the project location.

3.4.4 Step 2: Acquire Meteorological Data

AERMOD requires wind, temperature, humidity, and cloud cover data. These measurements are routinely collected by the NWS, and the data are made freely available by the National Oceanic and Atmospheric Administration's (NOAA) National Centers for Environmental Information (NCEI)[31], and the Earth System Research Laboratory (ESRL). Quantitative PM hot-spot modeling with AERMOD View requires the use of five consecutive years of representative meteorological data.

Acquiring NWS Surface Data

The NCEI Integrated Surface Hourly Database (ISHD) is a quality-controlled archive of hourly NWS surface weather observations collected from thousands of observation stations worldwide. The ISHD archive includes NWS Automated Surface Observing System (ASOS) observations collected at airports throughout the United States. Analysts can acquire ISHD data in TD-3505 format from the ISHD file transfer protocol (FTP) site.[32] Individual annual files downloaded from this site can be imported directly into AERMET View.

Figure 3-54 shows the ISHD website and illustrates the process for downloading one year (2011) of ISHD data for the case study. Repeat this process for each year of meteorological data needed. Since the data are archived in UTC, analysts should also acquire the data file for the year following the five-year modeling period. Analysts should use the page's search feature to find the station ID of interest, as indicated in Figure 3-54. Each ISHD station is identified by an 11-digit code: a six-digit U.S. Air Force (USAF) Air Weather Service (AWS) identifier, followed by a five-digit Weather-Bureau-Army-Navy (WBAN) identifier. These identifiers and the corresponding site names and call letters are available electronically in the Caltrans GIS data representativeness data layer from Step 1, and in the *isd-history.txt* file on the ISHD FTP site. The USAF and WBAN numbers for Fresno Air Terminal are 723890 and 93193, respectively, and therefore the appropriate data ISHD file for 2011 is *723890-93193-2011.ish*.

[31] Formerly the National Climatic Data Center (NCDC)
[32] ftp://ftp.ncdc.noaa.gov/pub/data/noaa/

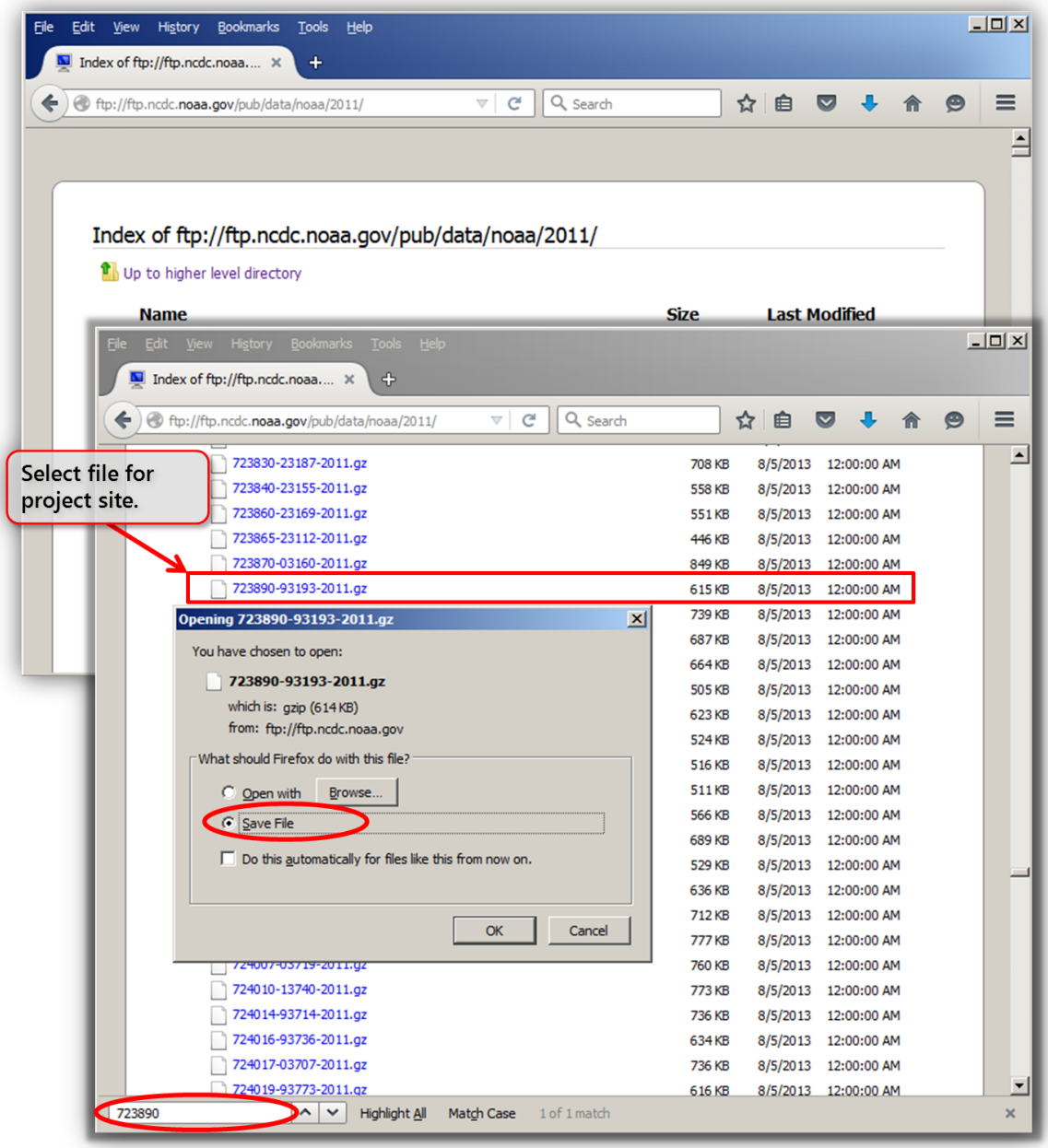


Figure 3-54. Downloading ISHD surface meteorological data from the NCEI ISHD data FTP site for the case study KFAT monitoring site.

AERMET View provides the option to augment the standard hourly surface data with 1-minute ASOS wind data using the EPA AERMINUTE tool, which can be accessed through the AERMET View GUI. The need for 1-minute wind ASOS data should be discussed through interagency consultation. If the use of AERMINUTE is required, analysts can use the AERMINUTE tool to download the data directly from NCEI.

Acquiring Non-NWS Surface Data

In most cases, analysts will not need to use non-NWS surface data in their analysis. However, if a non-NWS meteorological data site is recommended through interagency consultation, the local AQMD or other interagency partners will likely provide the raw data. AERMET View does not require non-NWS data (referred to as "onsite" data in AERMET View) to be in a specific pre-defined file format (the way it does for NWS data sets); instead, AERMET View provides a flexible interface for analysts to define a custom ASCII text file format and specify the included meteorological parameters. Unless the data are collected directly from the project site, five years of non-NWS surface data are needed.

Acquiring NWS Upper-Air Data

The NOAA ESRL Radiosonde Database is a quality-controlled archive of worldwide upper-air weather observations collected from radiosondes (balloon-based observing platforms). The ESRL radiosonde archive includes NWS radiosonde observations collected throughout the United States, including at four sites in California.

Upper-air data are available in a text format known as the Forecast Systems Laboratory (FSL) format, which can be imported directly into AERMET View. The upper-air data in FSL format are available at http://esrl.noaa.gov/raobs/. Users are led through a sequence of pages on this website to request data. **Figures 3-55 through 3-57** illustrate the process of acquiring Oakland (KOAK) upper-air data for the case study. Highlighted selections in these figures are necessary to conform to AERMET View requirements.

Once all of the selections are made, the requested data will load into the web browser and will appear on the screen. The data file can be saved to the local disk using the web browser's **Save As** function. Analysts should rename the file appropriately and change the file extension from .tmp to .txt or .fsl. Because ESRL upper-air data are in the UTC time zone, analysts should acquire data for the five consecutive years of interest, plus at least one day into the next year to cover the full five-year period in the local time zone.

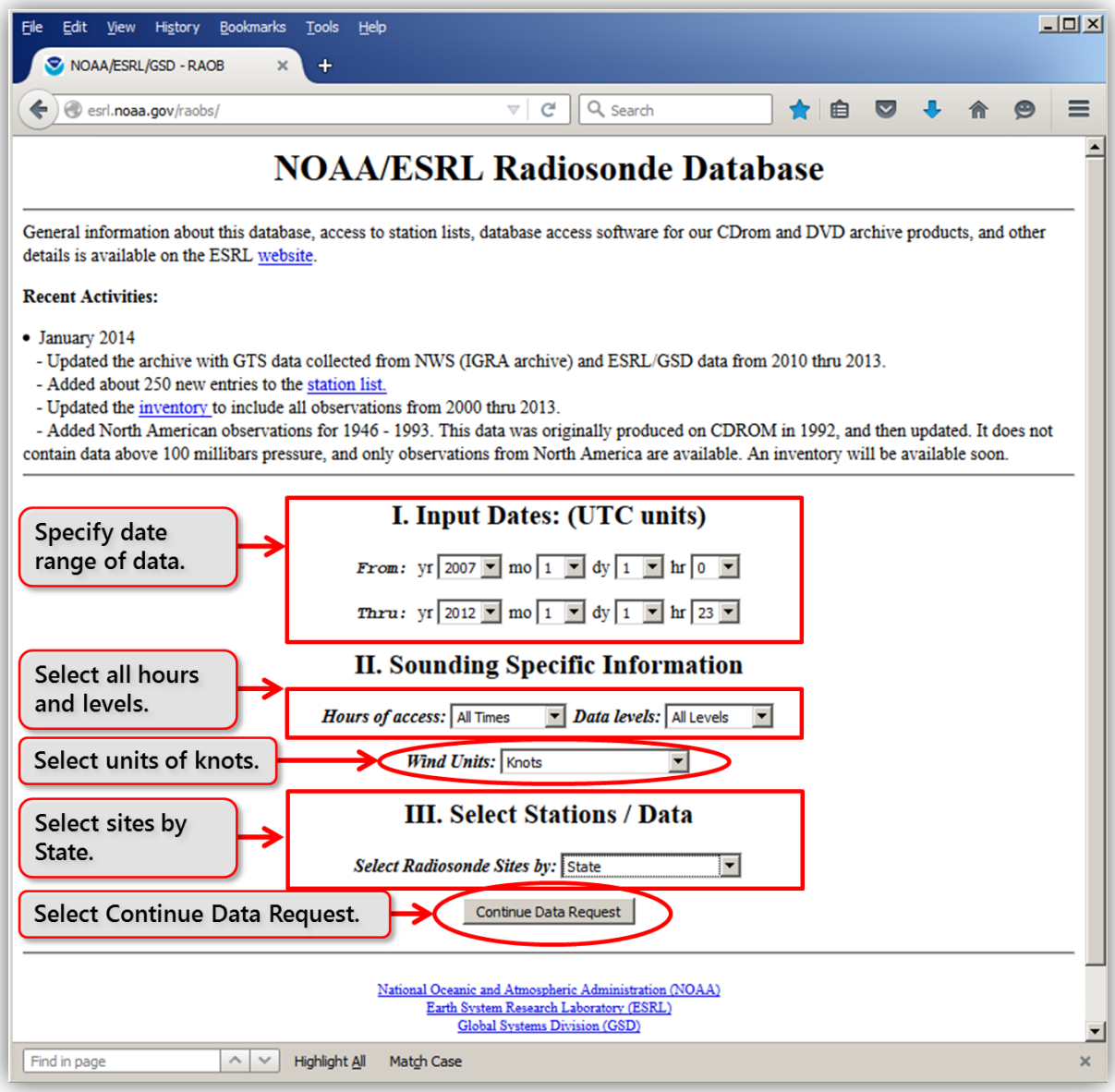


Figure 3-55. The main ESRL upper-air data access webpage, with selections made for the case study.

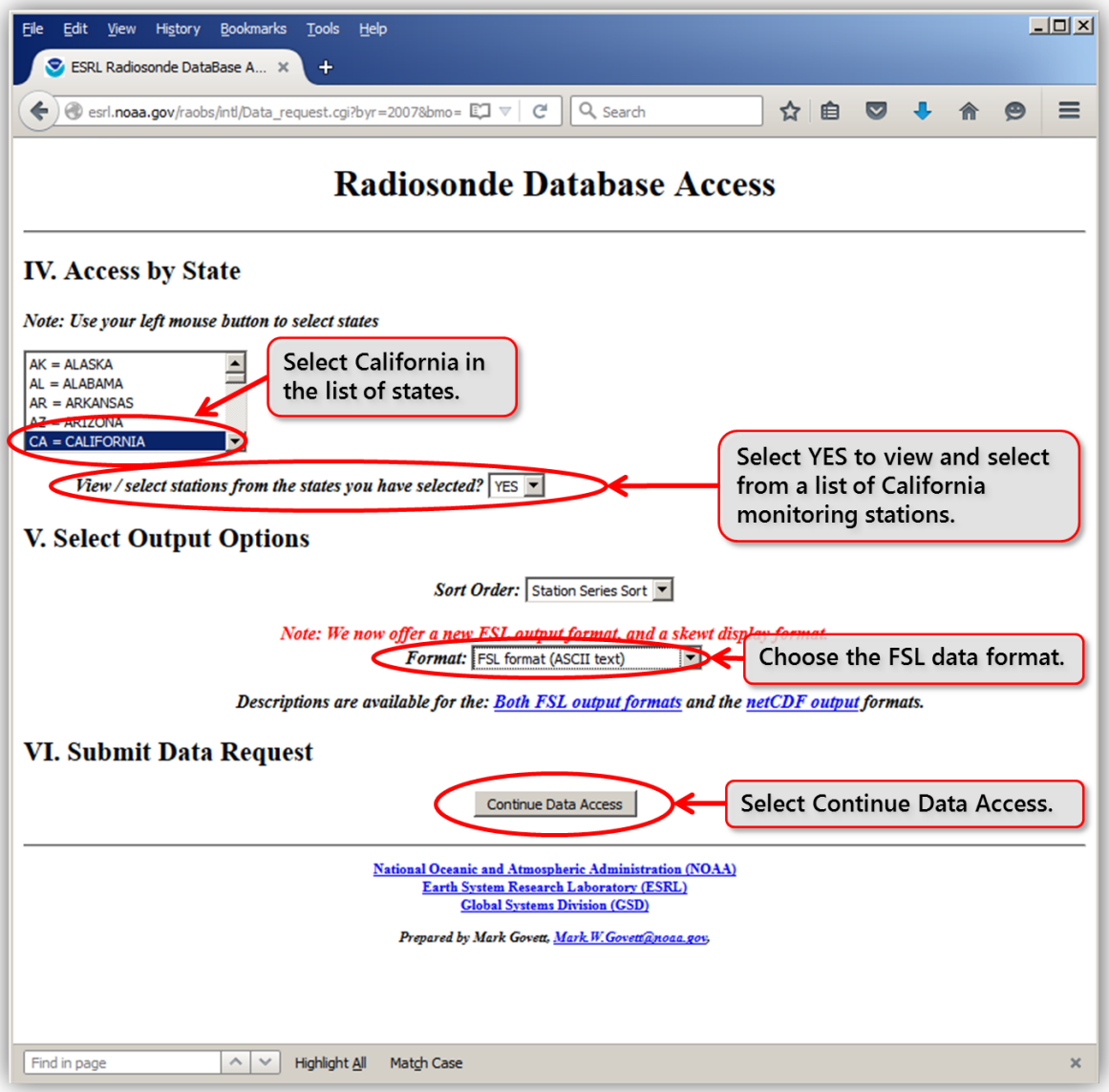


Figure 3-56. Selecting a site by state on the ESRL upper-air data access webpage.

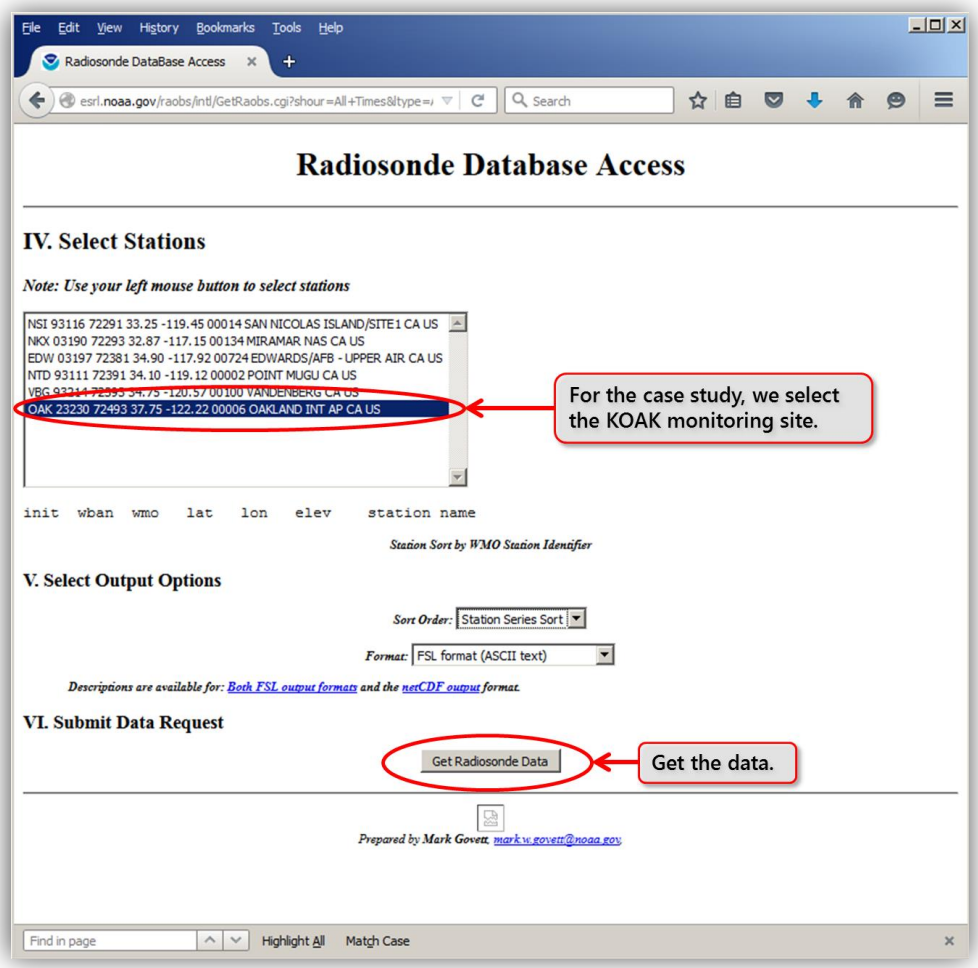


Figure 3-57. The ESRL upper-air data access webpage, with the KOAK monitoring station selected for the case study.

3.4.5 Step 3: Determine Meteorological Site Surface Characteristics

In addition to representative surface and upper-air meteorological data, AERMET View also requires the specification of three land surface characteristics for the surface meteorological site:

- **Roughness Length** – A measure of the height of obstacles to wind flow
- **Albedo** – A measure of midday surface reflectivity
- **Bowen Ratio** – A measure of midday surface moisture

In many cases, local air agencies have developed guidance for determining appropriate surface characteristics for regulatory AERMOD modeling applications. Project analysts should inquire through interagency consultation to determine if appropriate surface characteristic data already exist,

as this could reduce the time and resources needed to develop meteorological data for AERMOD modeling. If necessary, analysts can use EPA's AERSURFACE tool, which uses land use data, precipitation, and other inputs to calculate surface characteristics for a meteorological site.

3.4.6 Step 4: Process and Prepare Meteorological Data Using AERMET View

This section uses real-world data and examples from the case study to provide detailed instructions on how to process meteorological data with AERMET View. These instructions cover both NWS data processing and the special cases when non-NWS (or onsite) surface data from an AQMD need to be processed. To process the meteorological data, first configure AERMET View's data import and quality assurance (QA) assessment settings. Once the data imports and QA assessments are configured, provide surface characteristics and configure the AERMET View processing options. Finally, once the AERMET View run is complete, review the run logs, QA assessments, and output data to confirm that AERMET View ran properly and that the results are suitable for subsequent use in AERMOD. Common issues that analysts may encounter when using AERMET View are highlighted and discussed throughout this section.

NWS Surface Data

Once representative data have been acquired, they can be processed through AERMET View. To begin processing, start the AERMET View program and create a new project.

Import NWS Surface Data

Use the AERMET View Surface pathway to import NWS surface meteorological data. The Surface pathway allows the user to identify the data file, data format, and station information, and to specify QA variables. Figure 3-58 shows the screen that appears when **Surface** is selected from the button bar and the **Hourly Surface Data** tab is selected.

For the Fresno case study, data were acquired from the NOAA ISHD in TD-3505 format. In AERMOD View, select the **NCDC TD-3505 (ISHD – Full archival)** option from the **Format** drop-down box, and then click on the folder icon to locate the ISHD data file (see Step 2: Acquire Meteorological Data to learn how to select the correct files from NCEI). In most cases, AERMOD View populates the station information, such as the station name, identifier, location, and base elevation. However, if the NWS station is not recognized by AERMET View, you will need to enter these station properties manually. A list of ISHD weather stations with site locations and base elevations can be found in the *isd-history.txt* file on the ISHD FTP site (ftp://ftp.ncdc.noaa.gov/pub/data/noaa/isd-history.txt). Typically, the five-digit WBAN number is used as the station ID in AERMET View. Set the **Met Data Reported Time** to **No** to indicate that the ISHD data are not reported in Local Standard Time, and set the **Adjustment to Local Standard Time** to **+8 hours** to adjust the data to Pacific Standard Time.

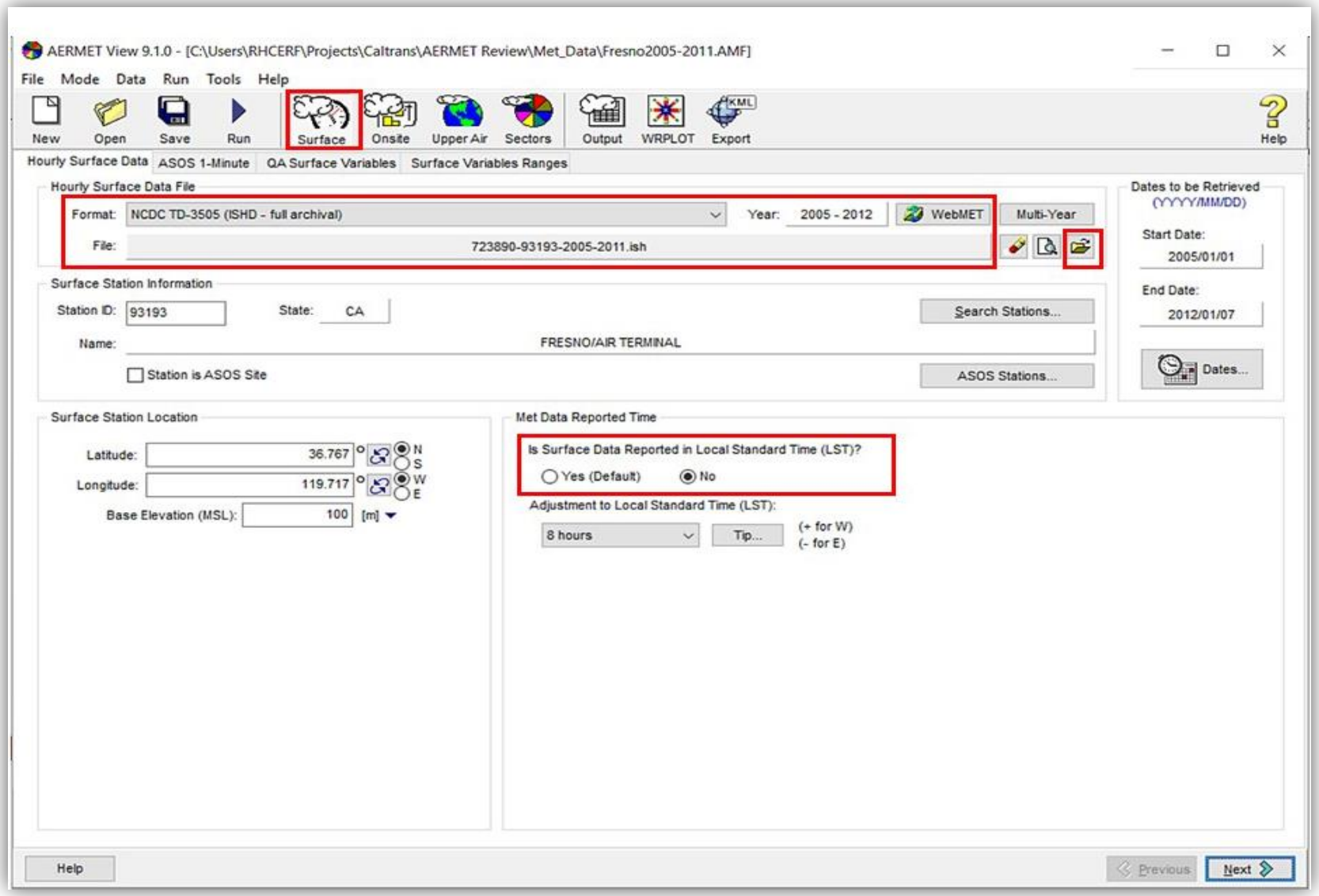


Figure 3-58. The AERMET View hourly surface information page.

AERMET View provides the option to augment the standard hourly surface data with 1-minute wind data through the **ASOS 1-Minute** input screen (Figure 3-59), using the EPA AERMINUTE software that is incorporated into AERMET View. Because 1-minute data were not used in this case study, this option is bypassed by setting the **Include 1-Minute ASOS Wind Data File** option to **No**. Use interagency consultation to determine whether the use of 1-minute data is appropriate or necessary.

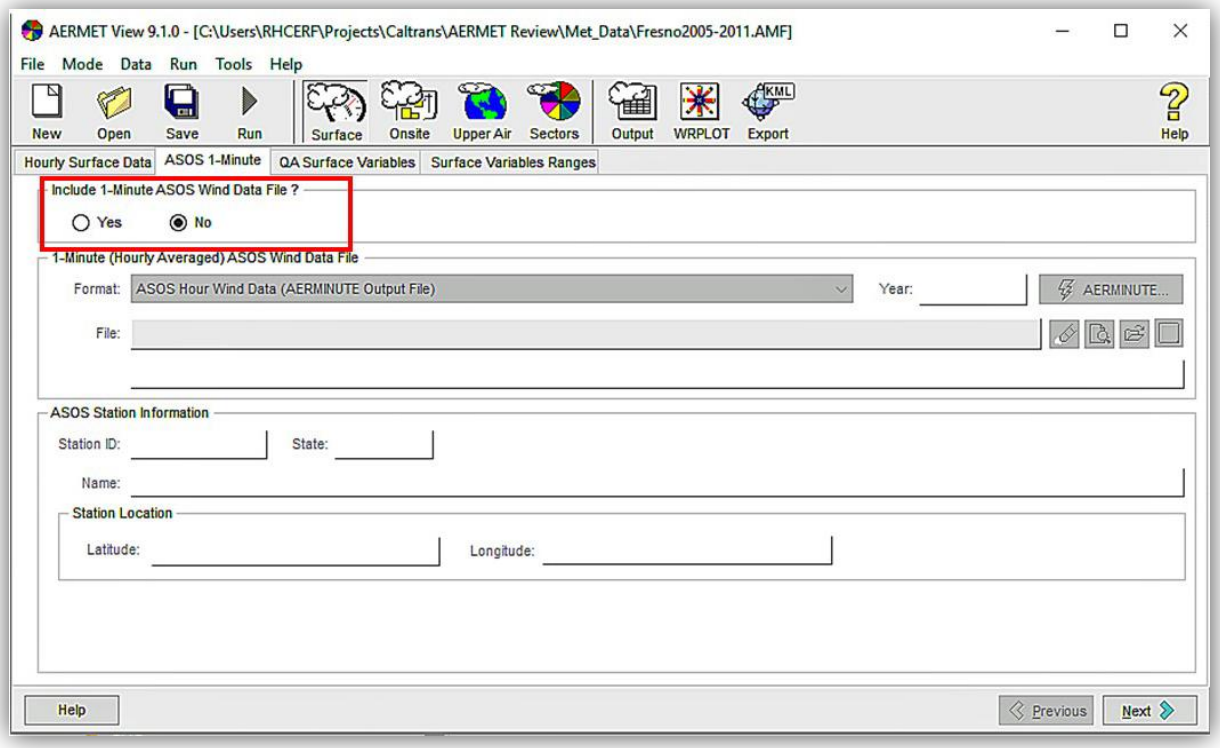


Figure 3-59. The AERMET View ASOS 1-minute input screen in the Surface input pathway.

Configuring the QA Assessment

The **QA Surface Variables** and **Surface Variables Ranges** tabs are used to configure the QA assessment in AERMET View. The QA assessment checks for missing and unreasonable data. Select the **QA Surface Variables** tab and choose the variables to be included in the QA assessment. This assessment is optional, but it is recommended to identify any potential problems in the data. The default list of variables can be accepted, but for most applications certain variables can be excluded to streamline the review process. Figure 3-60 illustrates the variables that are often included in the QA assessment.

Once the variables for the QA assessment have been selected, click the **Surface Variables Ranges** tab and select the **Modify Ranges** check box to edit the lower and upper bounds for each variable included in the QA assessment, as shown in Figure 3-61. AERMET View will generate a warning message for data values that fall outside the indicated ranges. The default ranges are reasonable for

most variables, but consider adjusting the data ranges for temperature (TMPD) and wind speed (WSPD). When adjusting these data ranges, note the units of the variable. For instance TMPD is listed in units of Celsius (°C) multiplied by 10 (i.e., a temperature value of 25°C in the data file is actually indicated as 250). The default maximum range for TMPD is 360 (36°C, or 96.8°F). Since typical temperatures in the summertime at the Fresno project location may exceed this value, an upper-bound temperature value of 400 (40°C, or 104°F) may be more reasonable and will result in fewer warning messages.

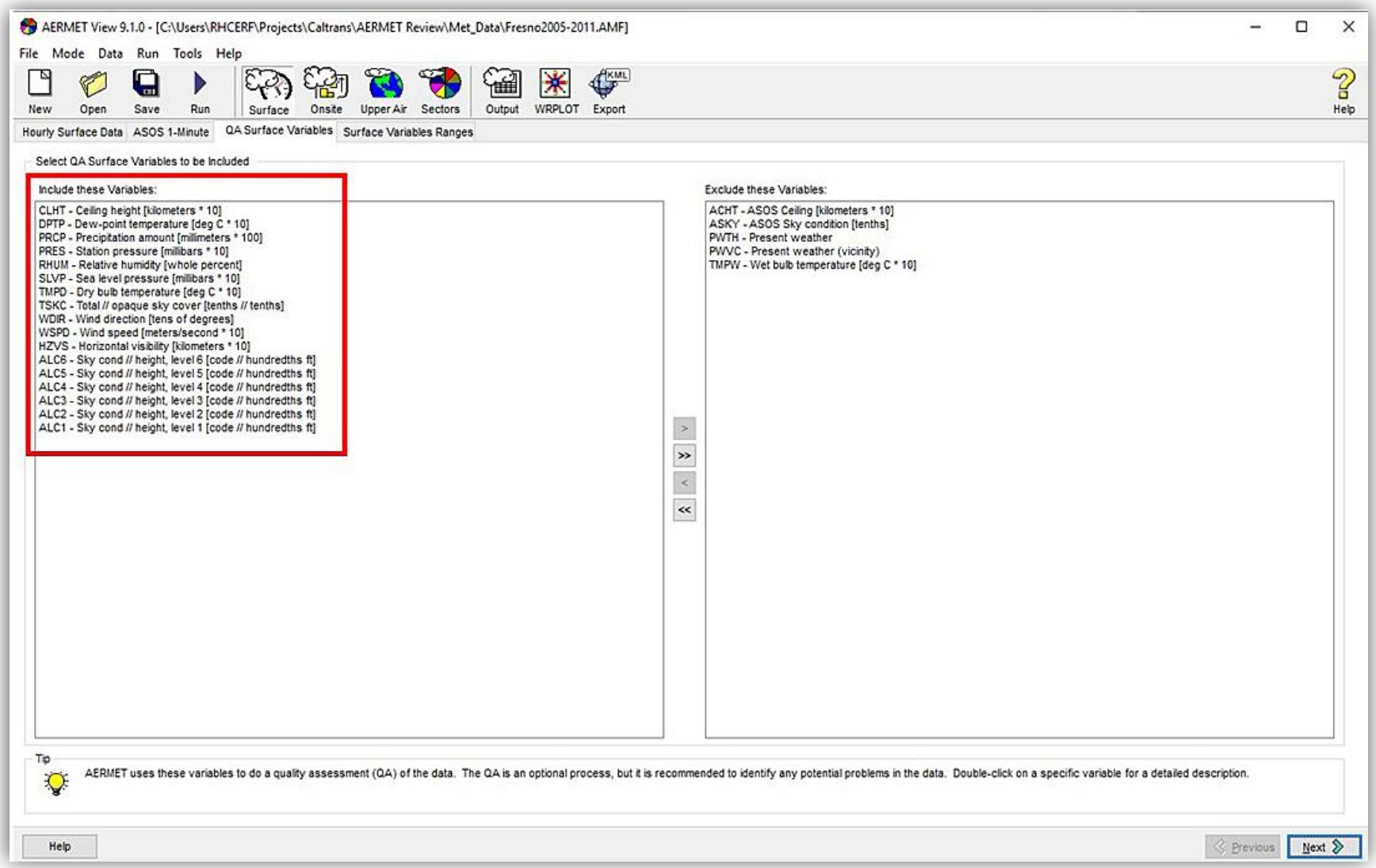
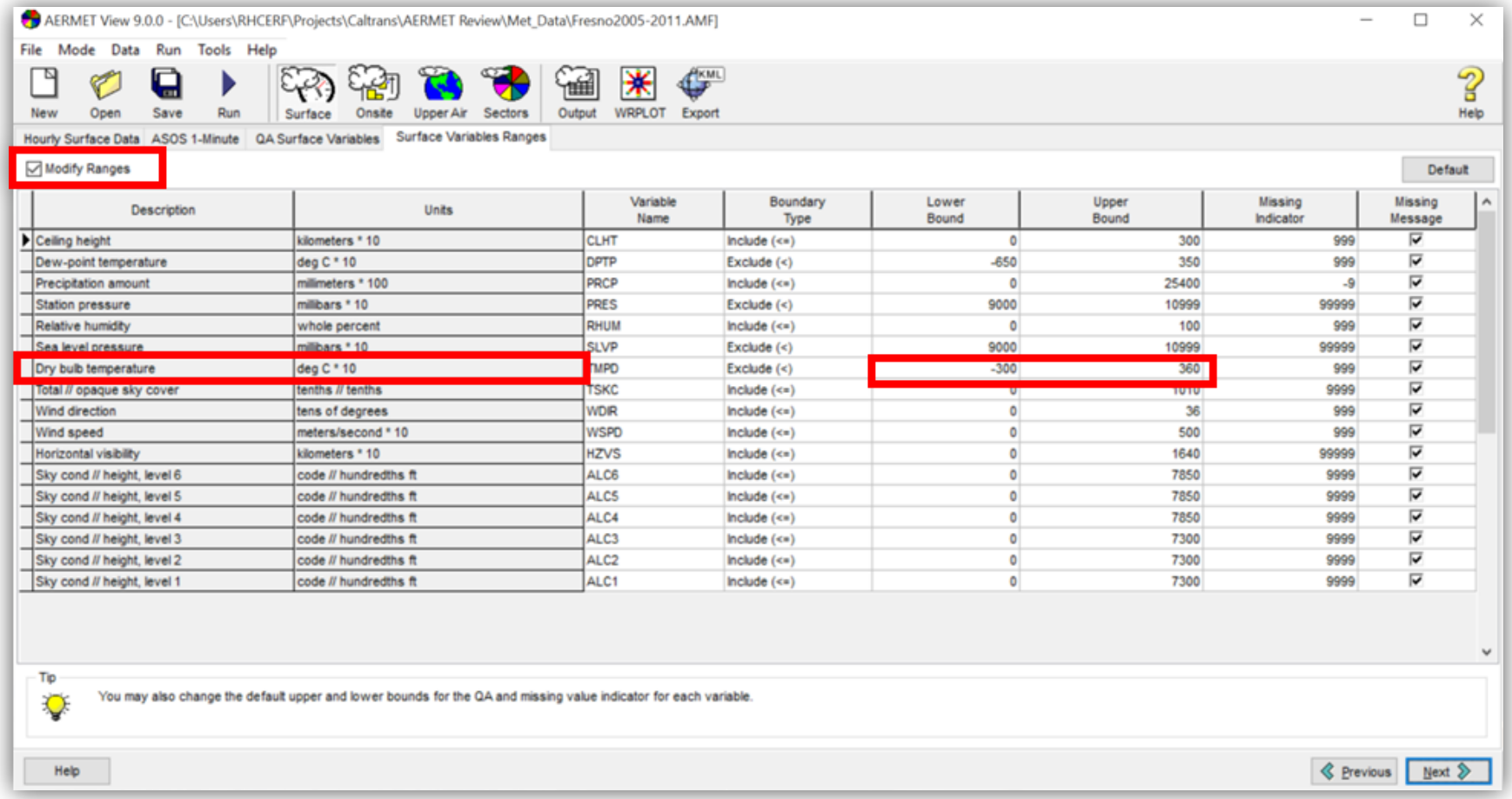


Figure 3-60. The AERMET View input screen for selecting variables for the QA assessment.



Description	Units	Variable Name	Boundary Type	Lower Bound	Upper Bound	Missing Indicator	Missing Message
Ceiling height	kilometers * 10	CLHT	Include (<=)	0	300	999	☑
Dew-point temperature	deg C * 10	DPTP	Exclude (<)	-650	350	999	☑
Precipitation amount	millimeters * 100	PRCP	Include (<=)	0	25400	-9	☑
Station pressure	millibars * 10	PRES	Exclude (<)	9000	10999	99999	☑
Relative humidity	whole percent	RHUM	Include (<=)	0	100	999	☑
Sea level pressure	millibars * 10	SLVP	Exclude (<)	9000	10999	99999	☑
Dry bulb temperature	deg C * 10	TMPD	Exclude (<)	-300	360	999	☑
Total // opaque sky cover	tenths // tenths	TSKC	Include (<=)	0	1010	9999	☑
Wind direction	tens of degrees	WDIR	Include (<=)	0	36	999	☑
Wind speed	meters/second * 10	WSPD	Include (<=)	0	500	999	☑
Horizontal visibility	kilometers * 10	HZVS	Include (<=)	0	1640	99999	☑
Sky cond // height, level 6	code // hundredths ft	ALC6	Include (<=)	0	7850	9999	☑
Sky cond // height, level 5	code // hundredths ft	ALC5	Include (<=)	0	7850	9999	☑
Sky cond // height, level 4	code // hundredths ft	ALC4	Include (<=)	0	7850	9999	☑
Sky cond // height, level 3	code // hundredths ft	ALC3	Include (<=)	0	7300	9999	☑
Sky cond // height, level 2	code // hundredths ft	ALC2	Include (<=)	0	7300	9999	☑
Sky cond // height, level 1	code // hundredths ft	ALC1	Include (<=)	0	7300	9999	☑

Figure 3-61. The AERMET View Surface Variables Ranges screen for selecting data bounds for the QA assessment.

Non-NWS Surface Data

In some cases, you may need to use meteorological data from a non-NWS station (i.e., not an airport) recommended by an AQMD through interagency consultation.[33] For example, an AQMD might recommend the use of non-NWS data when a project is far from an airport and available NWS data may not be representative of the project area. Use the AERMET View "Onsite" input pathway to process data from an AQMD.[34] Because AQMD sites typically provide only wind and temperature data (but not cloud data), be sure to also import NWS surface data through the AERMET View Surface pathway. AERMET View will use the cloud cover data from the NWS data file for atmospheric stability calculations.

To process non-NWS data through the Onsite pathway, (1) import the data file and specify the site information; (2) define the data variables and file format; and (3) configure the QA assessment. These three steps are described below. Additional discussion on handling non-standard meteorological data can be found in *Guidance and Resources for Developing AERMOD-Ready Meteorological Data Using AERMET View* (Craig and Bai, 2014). If you're not using non-NWS data from an AQMD, skip ahead to the NWS Upper-Air data section.

Base Elevation in AERMET View

Base elevation refers to the elevation above mean sea level (MSL) of the surface meteorological data site, and is used to estimate barometric pressure when that data is unavailable. The site elevation is included in NWS ISHD surface data, but typically not in other datasets. If a base elevation is not provided to AERMET View and is not included in the raw data, AERMET View will erroneously assume the site is at sea level.

Project analysts should confirm that the correct base elevation is provided to AERMET View, particularly when non-NWS data are imported through the Onsite pathway.

Import Surface Data and Specify Site Information

Use the AERMET View Onsite pathway to import non-NWS surface meteorological data. Figure 3-62 shows the screen that appears when **Onsite** is selected from the button bar and the **Onsite Data** tab is selected. Use this input screen to identify the data file and station information for the non-NWS surface data. Select **Yes** for the **Include Onsite Data** radio button to activate the page, and then click on the folder icon to locate the data file.

Ensure that the **Dates to be Retrieved** are set properly and match the date period for the NWS surface data included in the project. For the case study, data for Fresno were acquired from the local AQMD.

[33] In this context, raw meteorological data from an AQMD should not be confused with AERMOD-ready data files that may also be available from an AQMD.

[34] Meteorological data from an AQMD are not site-specific because the data are not collected at the project site. Therefore, five years of data are still needed for the PM hot-spot analysis, even though AERMET View considers these data as "onsite."

After selecting the data file and setting the data period, enter a station ID, as well as the latitude, longitude, and base elevation of the measurement site.[35] Select **Yes** on the **Surface Data Reported in Local Standard Time** option if the AQMD data were reported in Local Standard Time rather than UTC. After all data are entered into the screen, click the **Next** button.

Define Data Variables and File Format

The **Data Records** tab provides the interface for defining the variables included in the non-NWS data file, and how the data are formatted within the file. Note that the order and format of the variables in the onsite file is very important. Project analysts are encouraged to seek guidance through interagency consultation as needed.

For the case study, the onsite file provides wind and temperature data from a single height, and each line of data (i.e., each data record) contains data for one hour. As a result, select **1** for both **No. of Data Records per Observation Period** and **No. of Measurement Heights in Multi-Level Data**. The first row of data as it appears in the data file should be visible in the **Data Records** box, as shown in Figure 3-63.

To define the variables contained in the data file, click the **Edit** button next to the **Variable to Read for Current Record** line (see Figure 3-63). There are eight variables in this sample file: year, month, day, hour, pressure, wind speed, wind direction, and temperature. Select the **Fortran Format** option and enter a Fortran-formatted read statement[36] that is consistent with how the data are formatted in the file. Figure 3-63 has been annotated to illustrate how the data format statement was constructed. You may also click the **Suggested** button to populate the **Fortran Format** line with suggested values. If using this option, check the suggested values to verify they properly match the input data format.

Click **Next** to advance to the **Additional Parameters** tab. Figure 3-64 illustrates the important options on this input screen. Because the onsite file contains one data record for each hour, choose **1** for the **Number of Observations per Hour** option. Since temperature-difference measurements were not collected, do not check the **Temperature Difference Measurements** option. Many anemometers have a threshold wind speed of 0.5 m/s.[37] Confirm the appropriate value for the particular measurement site through interagency consultation before entering it in the **Threshold Wind Speed** text box. For this example, 0.5 m/s was used. Check the **Height Levels in Multi-Level Input Data** option. Since the anemometer level parameter was not explicitly contained in the onsite data file, a height value must be entered on this screen; for this example, a data collection height of 10 meters was used.

[35] Obtain geographic coordinates to at least four decimal places to ensure proper accuracy in AERMET View.
[36] For more information about Fortran-formatted read statements, see https://software.intel.com/en-us/node/525637 or any Fortran language reference document.
[37] The threshold wind speed is the minimum reliable wind speed that can be measured by the anemometer. AERMET View translates wind speeds below this threshold as "calm."

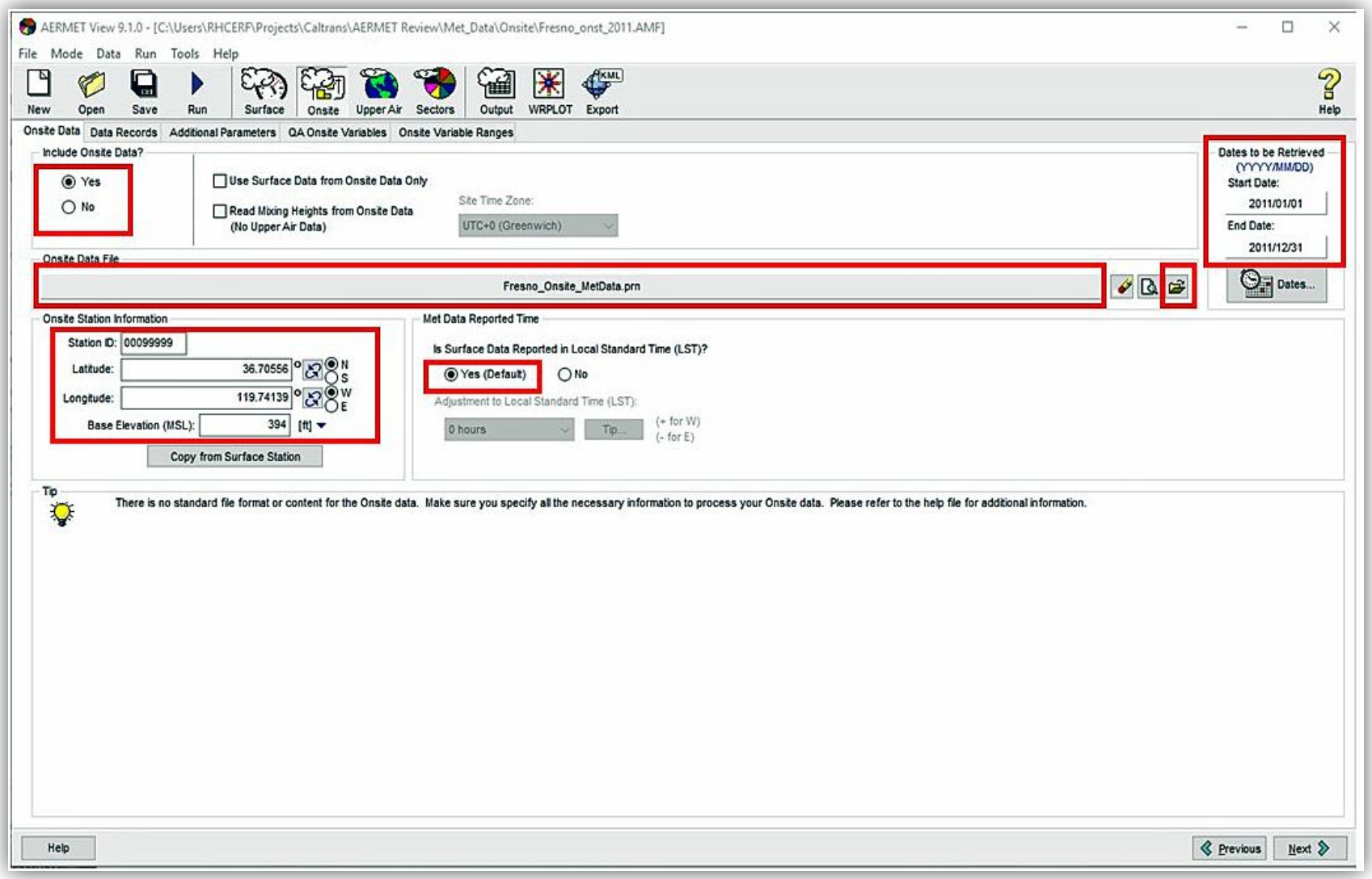


Figure 3-62. The AERMET View Onsite pathway Onsite Data information screen.

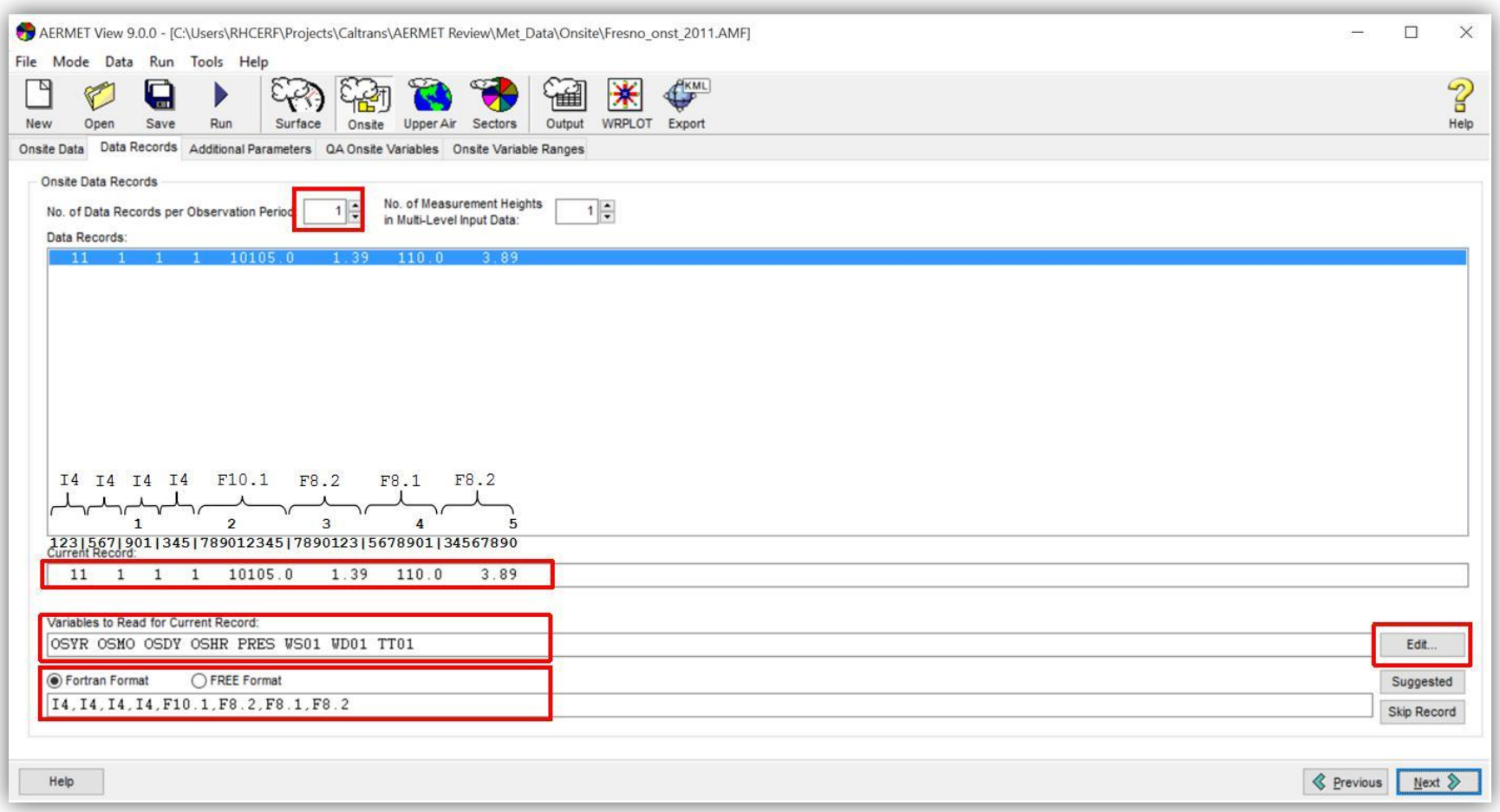


Figure 3-63. The AERMET View Onsite pathway Data Records input screen for specifying onsite data file variables and file format.

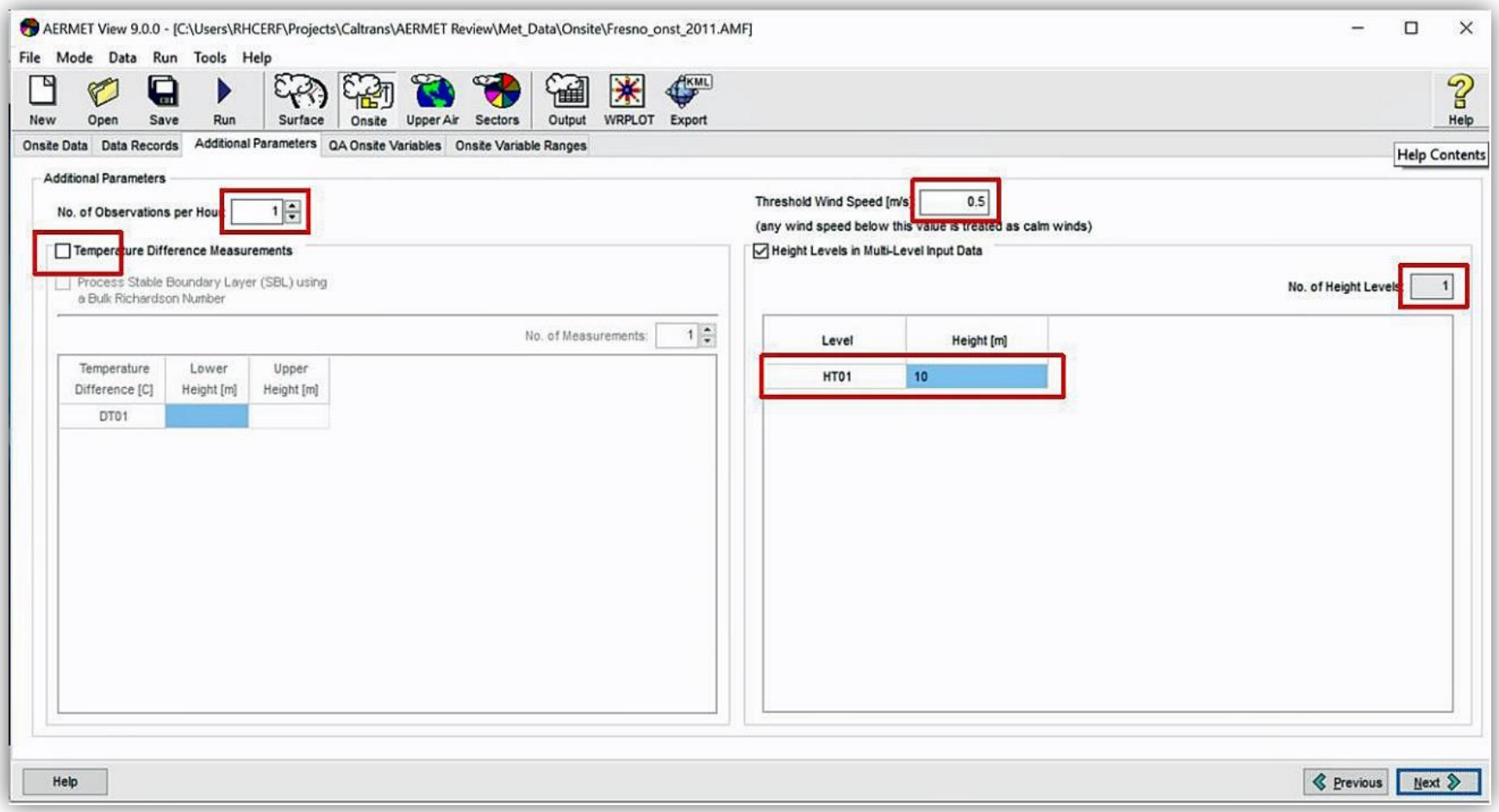


Figure 3-64. The AERMET View Onsite pathway Additional Parameters input screen.

Configure the QA Assessment

The **QA Onsite Variables** and **Onsite Variable Ranges** tabs are used to configure the QA assessment in AERMET View for onsite data. The QA assessment is optional, but is recommended to identify any potential problems in the data. To select variables for the QA assessment, select the **QA Onsite Variables** tab and choose the variables indicated in Figure 3-65. Ensure that the units for each variable are the same in the input file. AERMET View does not perform unit conversions for non-NWS data. The units may not be conventional. For instance, AERMET View requires station pressure in units of millibars*10.

Once the QA variables are chosen, click the **Onsite Variable Ranges** tab and select the **Modify Ranges** check box to edit the lower and upper bounds for the QA assessment, as shown in Figure 3-66. AERMET will generate a warning message for data values that fall outside the indicated ranges. The default ranges are reasonable for most variables. When using data from an AQMD, verify that the data ranges for temperature (TTnn) and wind speed (WSnn) are reasonable, and make sure the missing value indicators match those used in the data file.

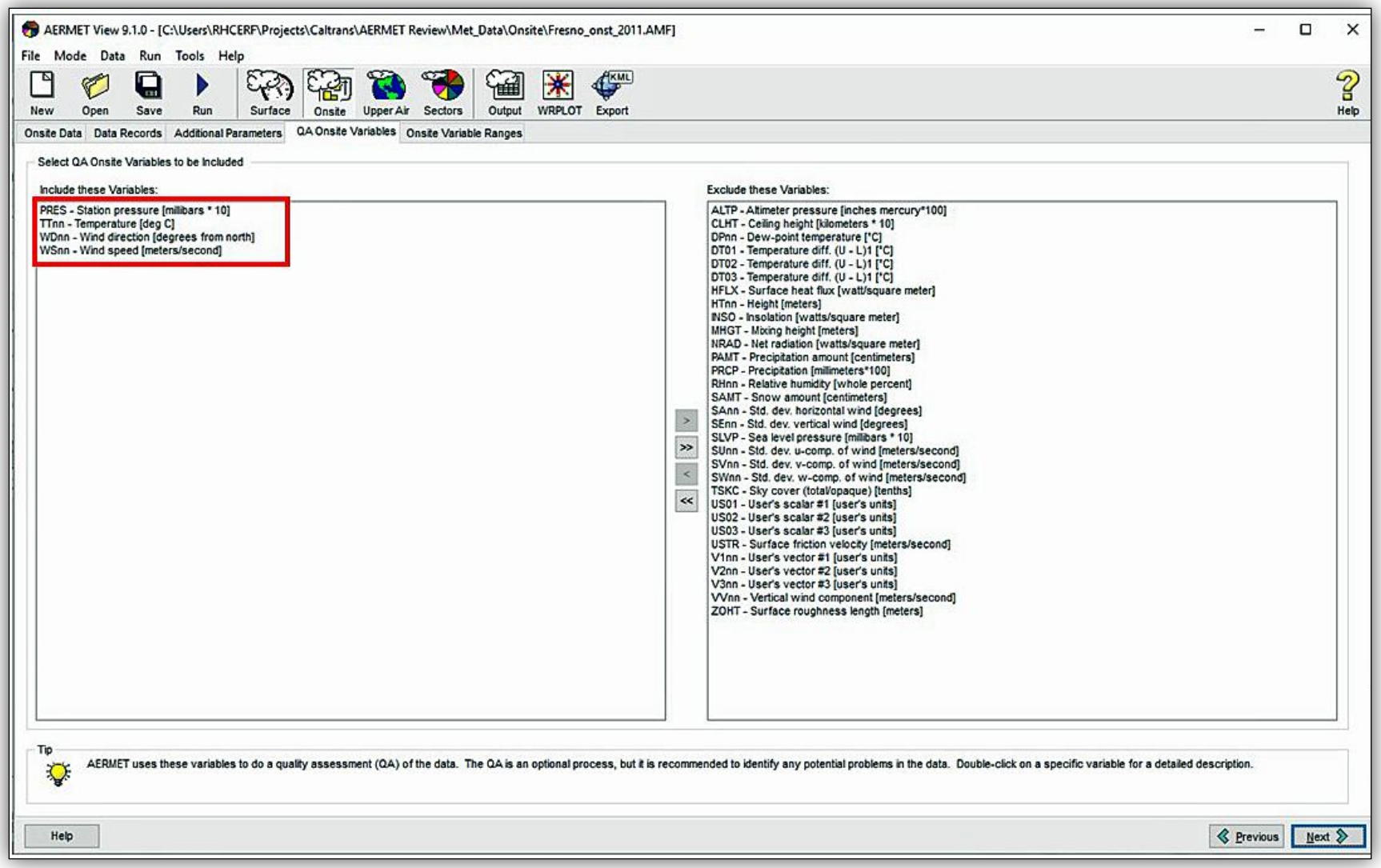


Figure 3-65. The AERMET View Onsite pathway QA Onsite Variables input screen for selecting variables for the onsite QA assessment.

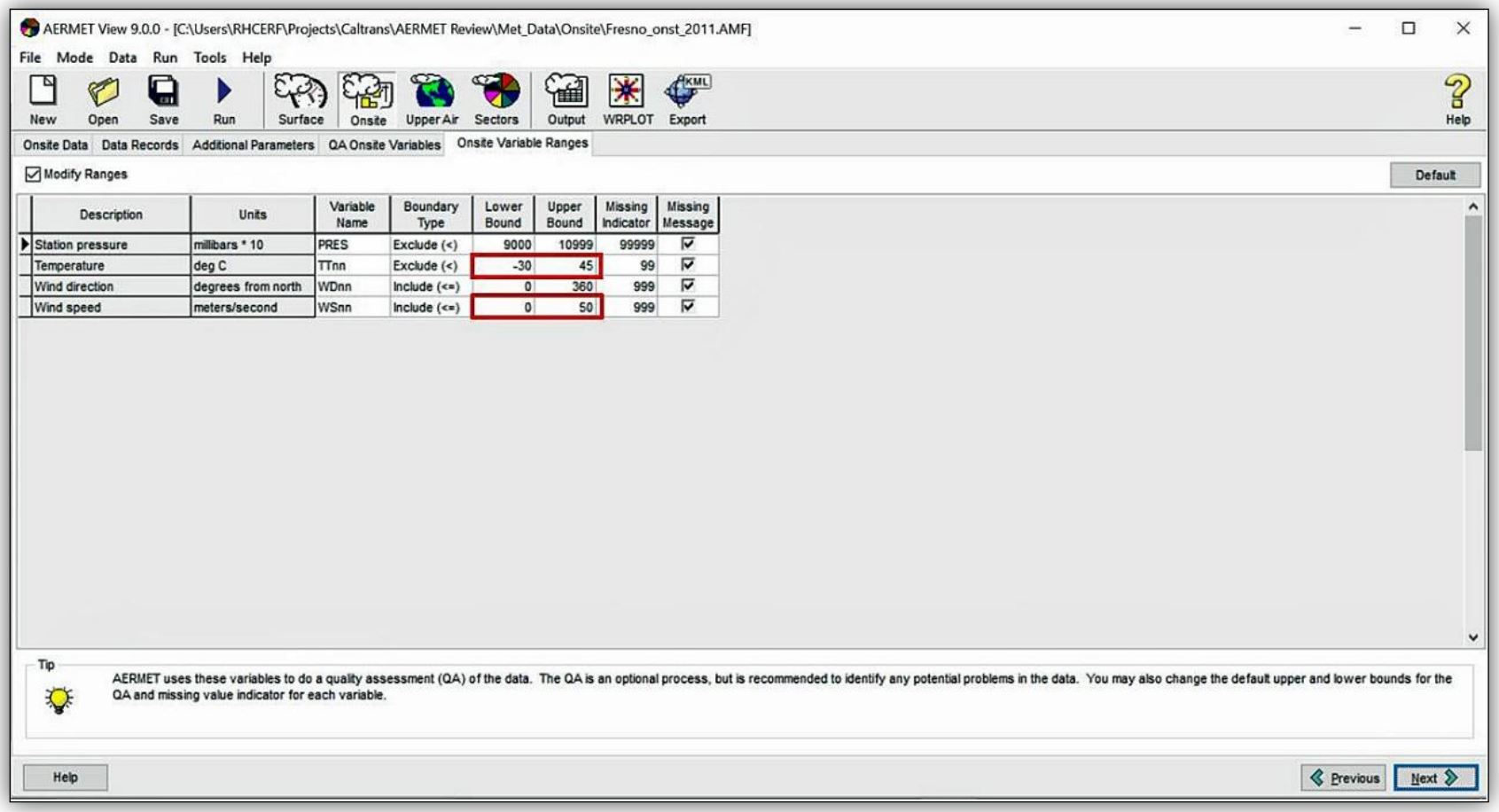


Figure 3-66. The AERMET View Onsite pathway Onsite Variable Ranges input screen.

NWS Upper-Air Data

Use the Upper Air pathway in AERMET View to import NWS upper-air meteorological sounding data. As with the Surface pathway, the Upper Air pathway allows you to identify the data file, data format, and station information, and configure the QA assessment.

Import Upper-Air Data

Figure 3-67 shows the screen that appears when **Upper Air** is selected from the button bar and the **Upper Air Data** tab is selected. Choose the **Standard AERMET** processing mode to make use of upper-air observations. For this case study, data were acquired from the NOAA ESRL Radiosonde archive in FSL format. In AERMET View, select FSL from the format drop-down menu, then click on the folder icon to locate the FSL data file (in this example, the file is 22230-*2005-2011.fsl*). AERMET View reads the data file and populates the **Upper Air Station Information** and **Location** data. Select **No** for the **Adjust Sounding Information**. Finally, set the **Met Data Reported in GMT** to **Yes** to indicate that the upper-air data are reported in UTC, and set the **Adjustment from GMT to Local Time** to **+8 hours** to adjust the data to Pacific Standard Time. The data period for the upper-air data should match the surface data period. For this case study, the surface data period is for calendar years 2005–2011 and the upper-air station is Oakland International Airport (station ID 23230).

Configure the QA Assessment

The **QA Upper Air Variables** and **Upper Air Variables Ranges** tabs are used to configure the QA assessment for the upper-air data. Select the **QA Upper Air Variables** tab and choose the variables to be included in the QA assessment. The default list of variables can be accepted, but for most applications some variables can be excluded to streamline the review process. Figure 3-68 shows the variables that are typically included in the QA assessment.

Once the variables for the QA assessment have been selected, click the **Upper Air Variables Ranges** tab and select the **Modify Ranges** check box to edit the lower and upper bounds for each variable included in the QA assessment, as shown in Figure 3-69. AERMET View will generate a warning message for data values that fall outside the indicated ranges. The default ranges are reasonable for most variables, but consider adjusting the data ranges for temperature (UATT) and wind speed (UAWS) to reduce the number of warning messages that AERMET View generates. When adjusting the data ranges, note the units of the variable.

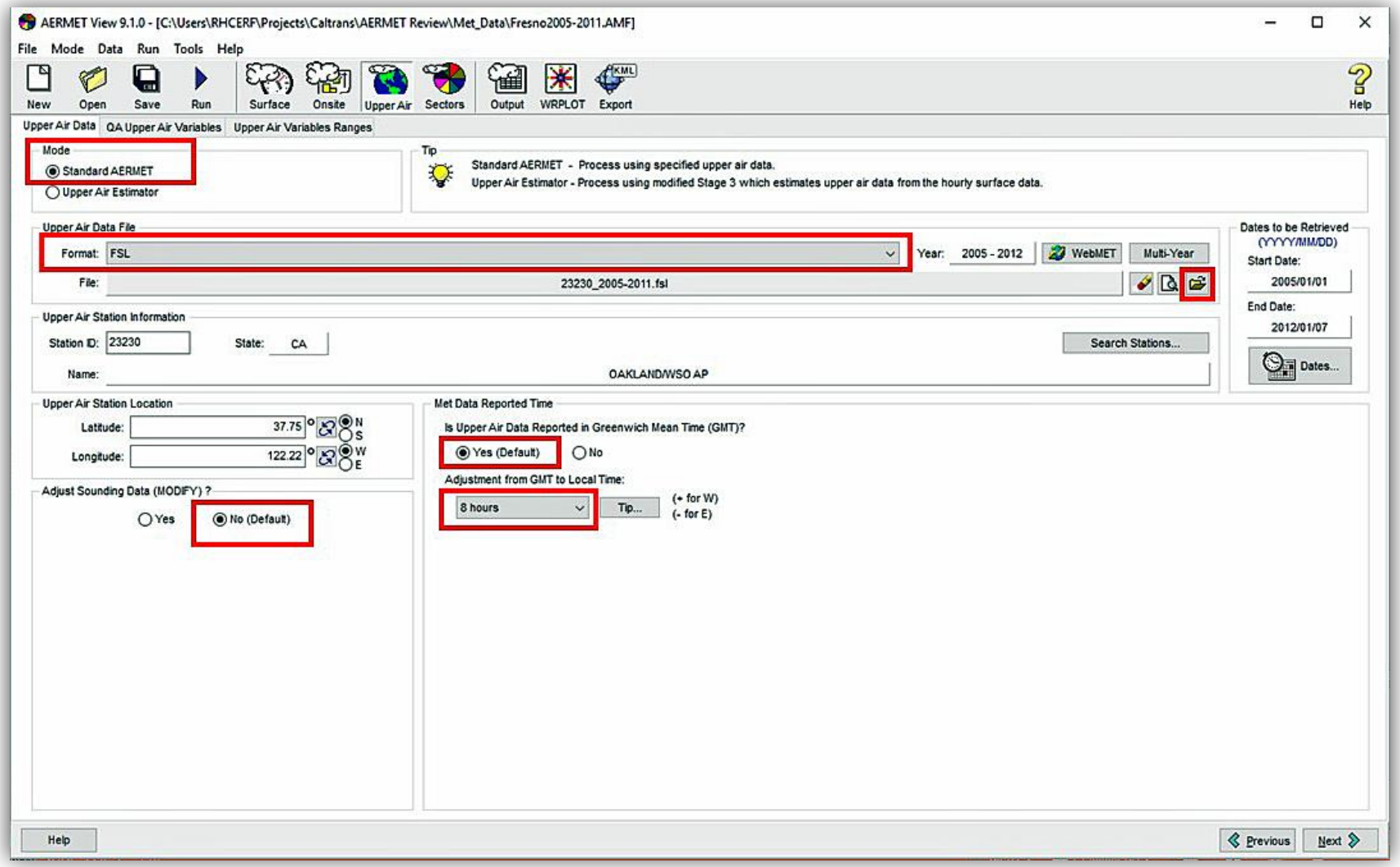


Figure 3-67. The AERMET View Upper Air pathway Upper Air Data input screen for selecting upper-air data variables and formats.

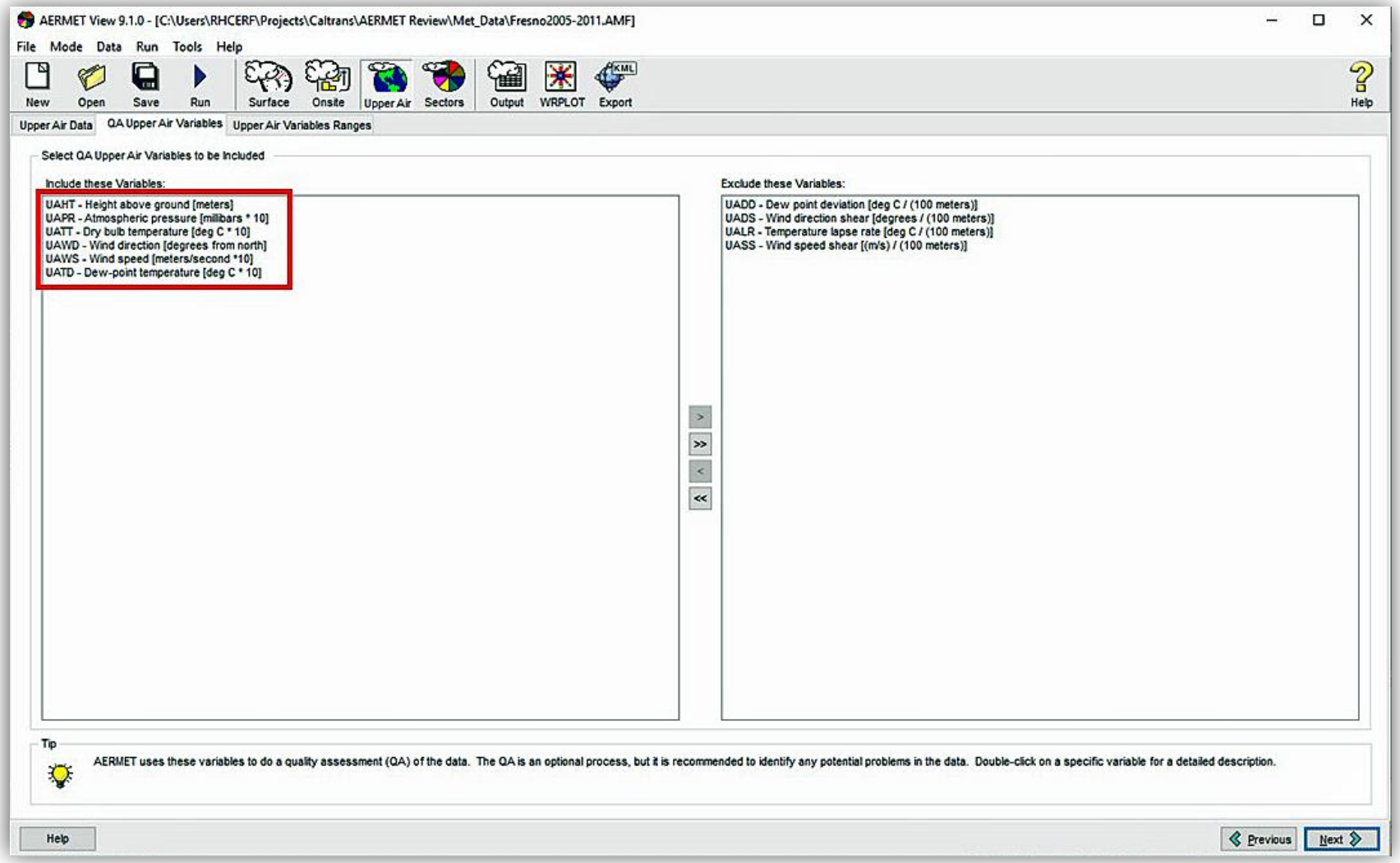
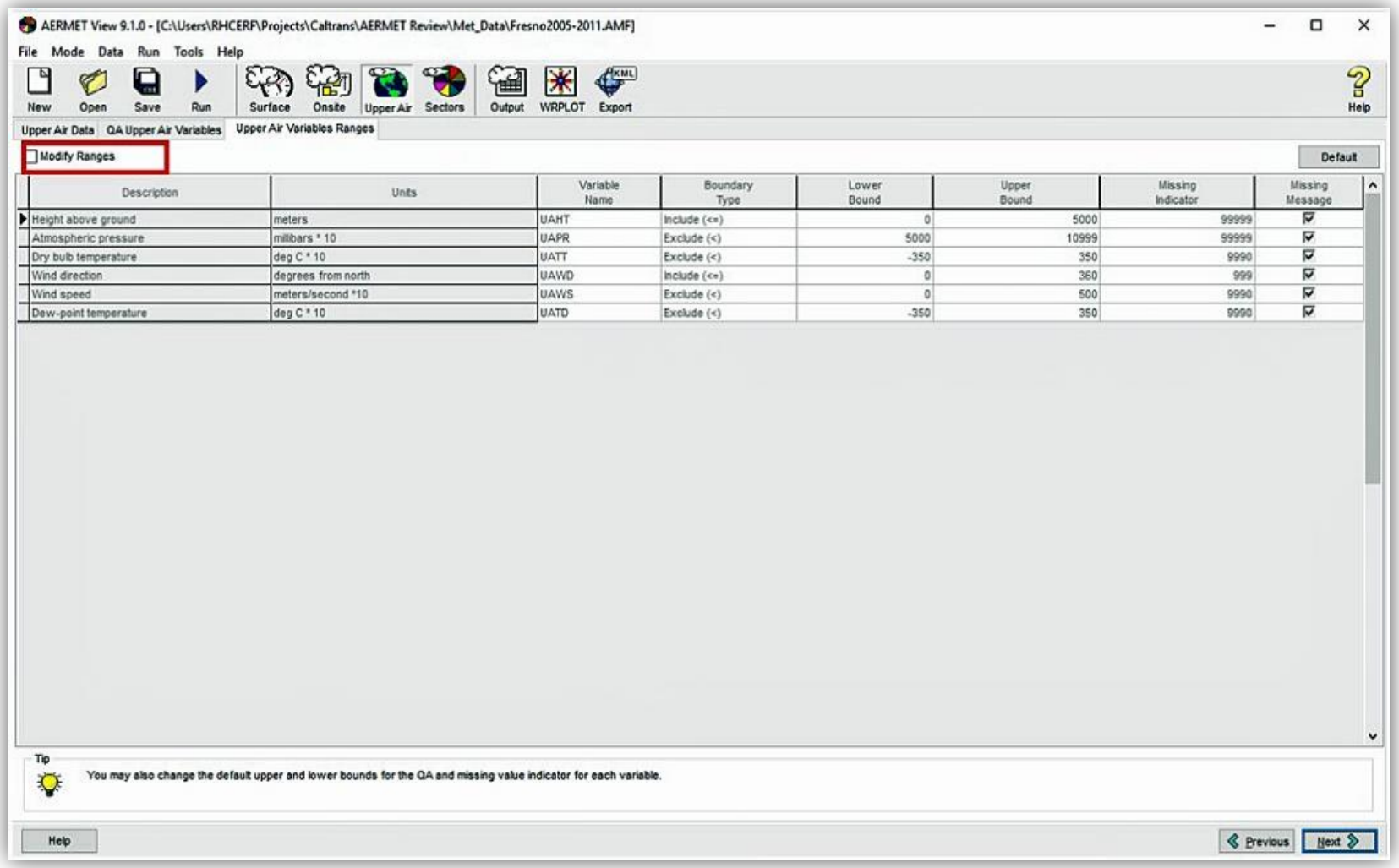


Figure 3-68. The AERMET View Upper Air pathway QA Upper Air Variables screen for selecting variables for the upper-air QA assessment.



Description	Units	Variable Name	Boundary Type	Lower Bound	Upper Bound	Missing Indicator	Missing Message
Height above ground	meters	UAHT	Include (<=)	0	5000	99999	☑
Atmospheric pressure	millibars * 10	UAPR	Exclude (<)	5000	10999	99999	☑
Dry bulb temperature	deg C * 10	UATT	Exclude (<)	-350	350	9990	☑
Wind direction	degrees from north	UAWD	Include (<=)	0	360	999	☑
Wind speed	meters/second *10	UAWS	Exclude (<)	0	500	9990	☑
Dew-point temperature	deg C * 10	UATD	Exclude (<)	-350	350	9990	☑

Figure 3-69. The AERMET View Upper Air pathway Upper Air Variable Ranges input screen.

AERMET View Options

The AERMET View **Sectors** pathway provides the interface to set the AERMET processing options, surface characteristics data, and output files. These groups of inputs correspond to the three tabs (four tabs if onsite data were included) that appear when the **Sectors** button is chosen, and are discussed in the subsections below.

Processing Options

Table 3-23 summarizes the recommended AERMET View processing options. The figures in this section also show the appropriate processing options for the typical case when only NWS data are used (Figure 3-70), and the special case when additional onsite data from an AQMD are used (Figure 3-71). After selecting **Sectors** from the button bar, choose the **Processing Options** tab to view the AERMET View processing options. Some options depend on whether onsite data from an AQMD were imported.

Table 3-23. Recommended AERMET View processing options.

Option	Only NWS Data	NWS Plus Onsite Data[a]
Substitute Missing Onsite Data by NWS Data	Inactive	Selected
Randomize Wind Directions[b]	Yes	No
Anemometer Height	Height of the NWS anemometer	Height of the NWS anemometer
Apply Missing Cloud Cover Substitution	All Hours	All Hours
Apply Missing Ambient Temperature Substitution	All Hours	All Hours
Adjust ASOS Wind Speeds for Truncation	Inactive	Inactive
Upper Air Sounding Options	Not selected	Not selected
Adjust Surface Friction Velocity	Not selected	Not selected

[a] In most cases, onsite data are not needed for the PM hot-spot analyses.
[b] Wind directions in hourly NWS data are recorded to the nearest 10 degrees. Randomizing wind directions provides a higher-resolution input for AERMET View. This option is not needed when onsite wind data are used, and has no effect on any 1-minute ASOS data that were incorporated via AERMINUTE.

Analysts should determine the appropriate **Anemometer Height** of the NWS wind data and provide that value to AERMET View. When onsite data are used in conjunction with NWS data, select **Substitute Missing Onsite Data by NWS Data**, and set the cloud cover and ambient temperature substitution options **All Hours** so AERMET View can fill data gaps using EPA-approved interpolation methods.

If 1-minute ASOS data were incorporated into AERMET View using AERMINUTE, set **Adjust ASOS Wind Speeds for Truncation** to **Yes** and enter a **Threshold Wind Speed** of 0.5 m/s, consistent with EPA guidance (U.S. Environmental Protection Agency, 2015c).

Anemometer Height in AERMET View

The anemometer height refers to the height above ground level (AGL) of the wind measurements. On the Processing Options input screen, AERMET View expects input of the anemometer height of the NWS data site. The anemometer height for any onsite data is set through the AERMET View Onsite pathway.

The anemometer height is typically between 6 and 10 meters for NWS sites, and can be highly variable for non-NWS sites. Be sure to input the correct anemometer height. Anemometer heights for most NWS stations can be found at http://www.nws.noaa.gov/ops2/Surface/asosimplementation.htm.

Finally, do not select the **Non-Default Option (BETA) Adjust Surface Friction Velocity** (ADJ_U*), as beta options are not accepted for use in regulatory modeling applications without further justification.

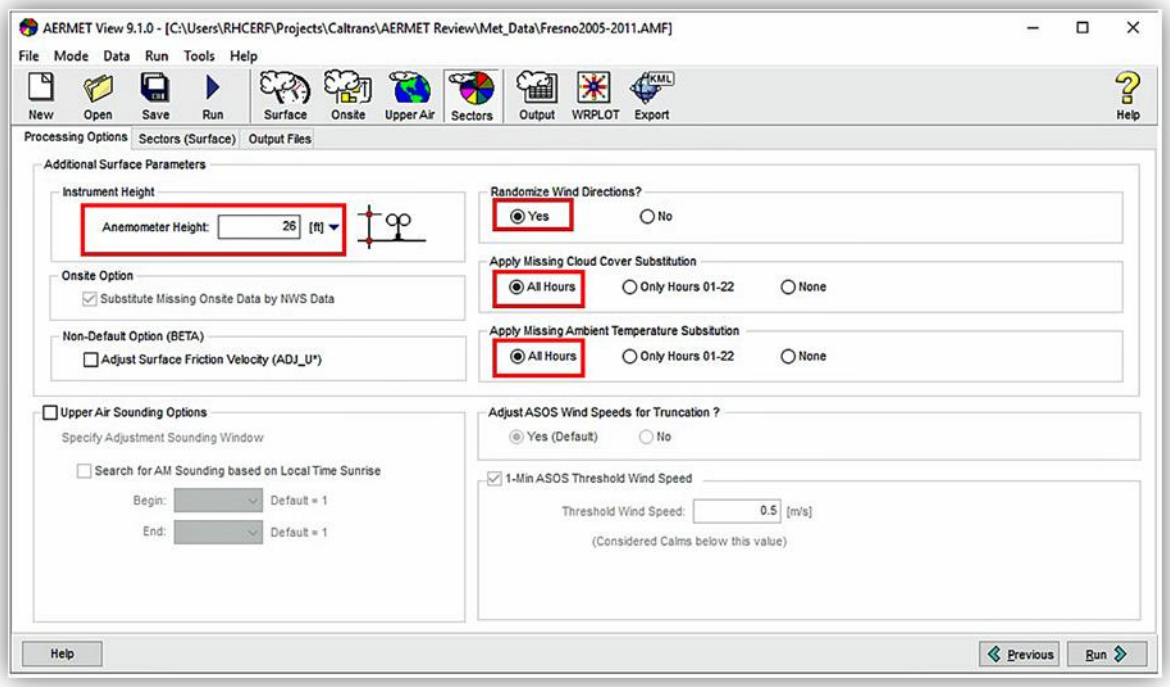


Figure 3-70. The AERMET View processing options screen for selecting how AERMET will process NWS input meteorological data.

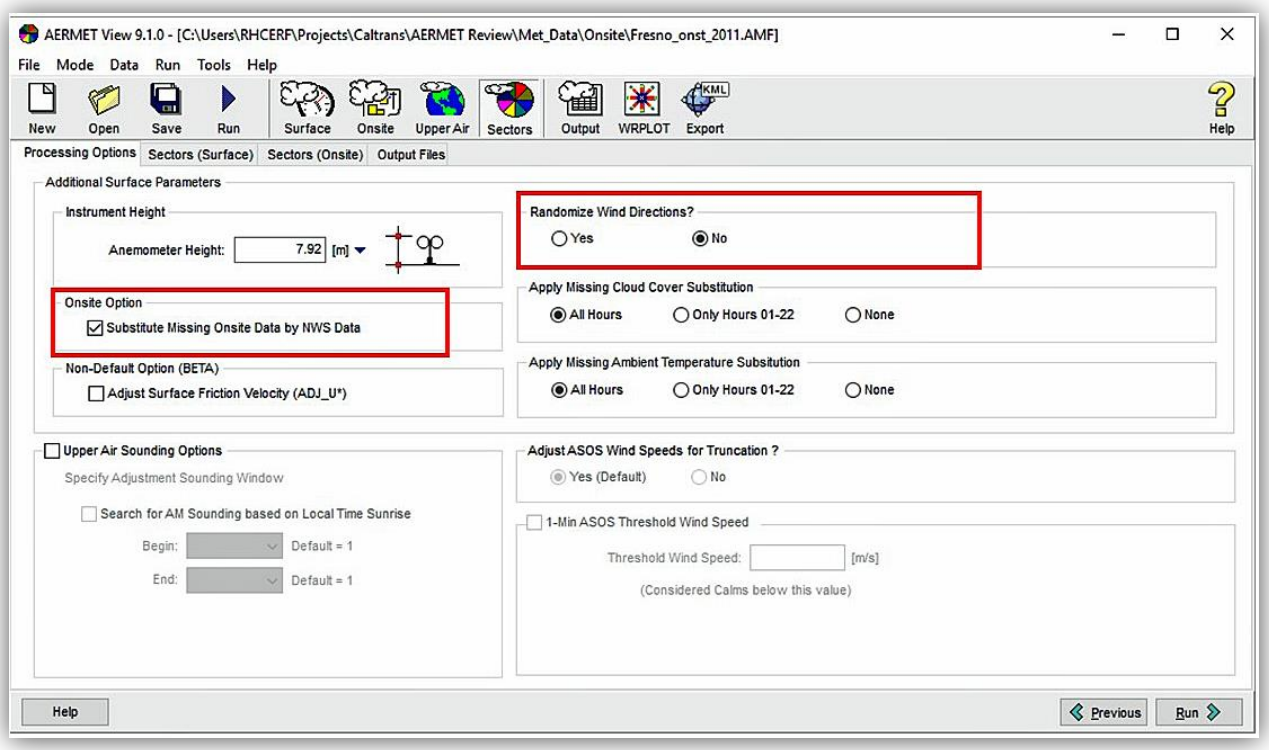


Figure 3-71. The AERMET View processing options screen for selecting how AERMET will process non-NWS input meteorological data.

Surface Characteristics

In addition to meteorological data, AERMET View also needs inputs for surface characteristics that represent land surface conditions where the meteorological data were collected (not the project site). The EPA pre-processor AERSURFACE can calculate surface characteristics from land use data, precipitation data, and other inputs. AERSURFACE is included with the AERMET View software and can be invoked in the **Sectors (Surface)** tab. Alternatively, if the surface characteristics have been provided, they can be entered manually into AERMET View.

Surface Characteristics in AERMET View

- Surface characteristic inputs required by AERMET View include roughness length, albedo, and Bowen Ratio.
- If non-NWS data were included in the Onsite pathway, unique surface characteristics must be entered in both the Sectors (Surface) and Sectors (Onsite) tabs.
- Project analysts should solicit surface characteristics through interagency consultation, as these inputs can significantly impact AERMOD concentrations.

Enter the surface characteristics of the NWS surface observation site in the AERMET View **Sectors (Surface)** tab. For this case study, we selected **Seasonal** from the drop-down box and selected the **MAX** button to automatically set the number of wind direction sectors to the maximum value of 12. Figure 3-72 shows the selected surface characteristics data, which are defined for each of the 12 sectors. To manually enter these data, select the desired sector on the left (the figure shows Sector 0) and enter the surface data in the table in the **Specify Surface Parameters for Each Sector** panel on the right (enclosed in a red box in the figure). If non-NWS data from an AQMD were imported through the Onsite pathway, a **Sector (Onsite)** tab will appear and analysts must also provide the surface characteristics for the non-NWS site.

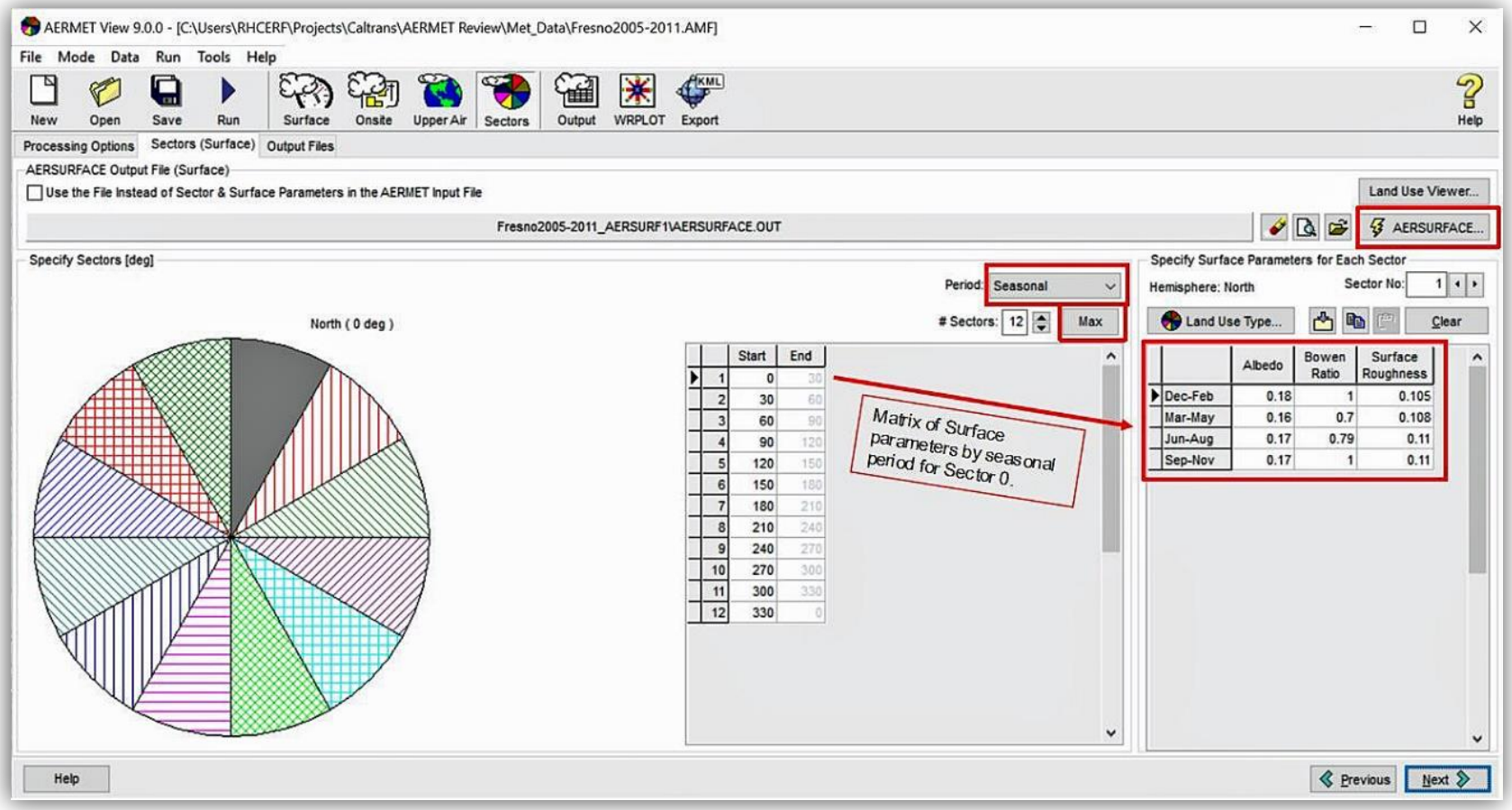


Figure 3-72. The AERMET View Sectors (Surface) screen for selecting the surface characteristics that will be processed through AERMET.

Output Files

The **Output Files** tab (Figure 3-73) contains the file names for the two output files that AERMET View will produce: the surface file (*.SFC) and the profile file (*.PFL). These files will become the meteorological data inputs for AERMOD View. Verify that the files are being written to the project directory and that the start and end dates are correct. If no output information is provided, it will be created in the project folder automatically when AERMET runs the first time. To execute the AERMET model, select **Run** on the AERMET View button bar.

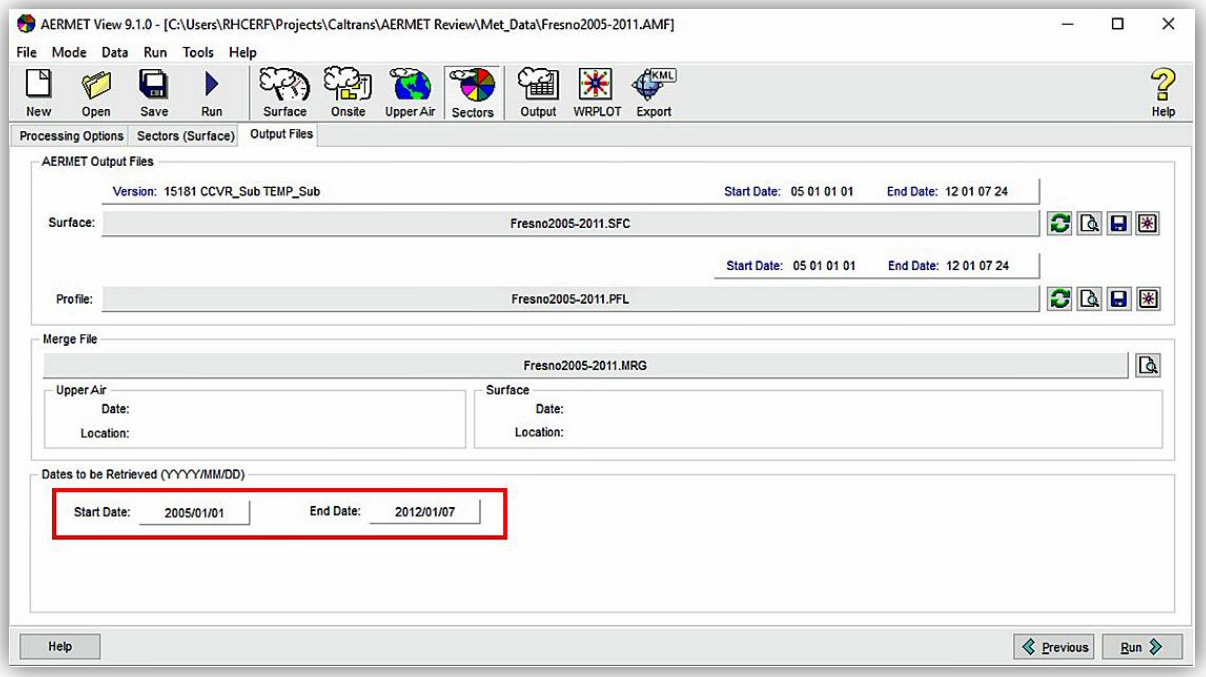


Figure 3-73. The AERMET View Sectors pathway Output Files screen.

Quality Assurance Best Practices

After the meteorological data have been processed through AERMET View, project analysts should review the quality of the meteorological data and make sure that AERMET View ran properly. Using consistent procedures to review the processed data will improve data quality and reduce the uncertainty of AERMOD model results. AERMET View produces several files and incorporates tools that are designed to help analysts QA the meteorological data and verify data completeness. This section outlines steps for quality-assuring the meteorological data.

Reviewing Log Files and QA Assessment

After running AERMET View, examine the report and message files (i.e., the log files) that AERMET View produces. These log files report any errors or warnings encountered by AERMET View, and provide summaries of the QA assessments. Internally, AERMET View runs in three stages (Table 3-24), and produces log files for each stage. Log files are accessed within AERMET View by selecting **Run** on the menu bar then **Message File** or **Report File**, as shown in Figure 3-74.

Table 3-24. Summary of AERMET View's internal processing stages.

AERMET View Processing Stage	Description
Stage 1	Extract raw meteorological data and perform QA assessment
Stage 2	Merge surface and upper-air data
Stage 3	Calculate boundary layer parameters and prepare AERMOD-ready input

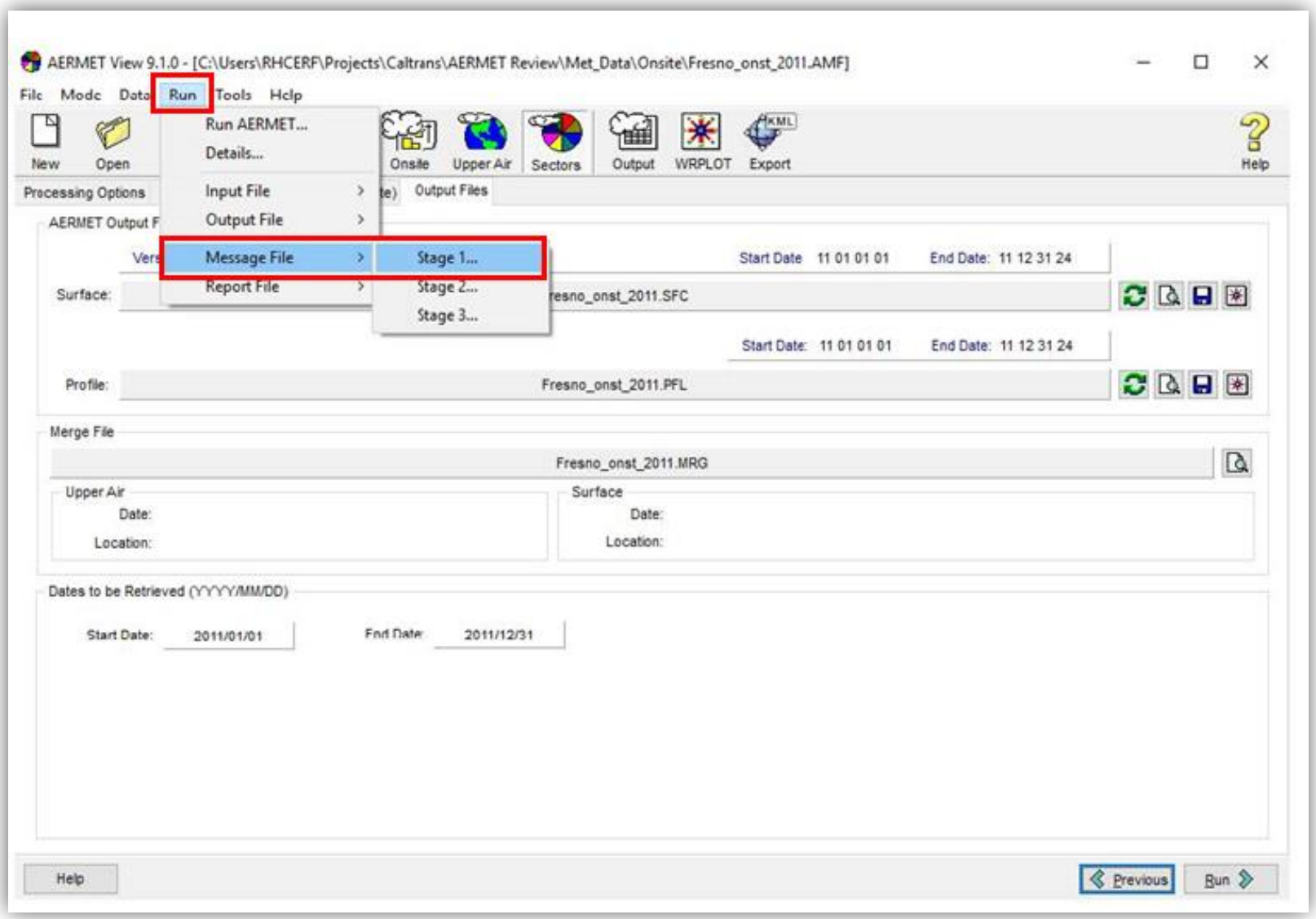


Figure 3-74. Access path for AERMET View log files.

The report files in each stage summarize the data inputs, configurations, and messages produced by AERMET View. Review these files to confirm there were no problems with the AERMET View run, and verify the proper data files and number of observations were processed. For example, AERMET View should process around 43,800 hours of surface data during a five-year period.

The Stage 1 report file also contains the data quality and completeness statistics from the QA assessment (or QA audit). Pay careful attention to these results. Generally, data acceptance should be above 90%. If the acceptance percentage is near or below 90%,[38] discuss the suitability of the meteorological data with interagency partners. AERMET View does not change any data that violate bound checks in the QA assessment.

For surface data, the variables listed in Table 3-25 are most important for the QA assessment. Some variables, such as opaque sky cover (KC, which AERMET View assesses automatically when TSKC is included in the QA assessment) are always 100% missing because they are not available from the NWS ASOS data. Figure 3-75 shows the QA assessment results for the NWS surface data from the case study. The data acceptance rate for all important variables is over 90%. As mentioned previously, summer temperatures in Fresno often exceed AERMET View's default upper bound for temperature (96.8°F). The QA assessment flagged over two thousand observations that violated this upper bound test. Adjusting the upper bound to 104°F (a reasonable upper bound value for Fresno) eliminates most of the upper bound violations and increases the data acceptance rate.

Table 3-25. Surface data variables to include in the QA assessment.

Surface Variable Name	Description
TMPD	Temperature
WDIR	Wind Direction
WSPD	Wind Speed
PRES	Station Pressure
TSKC	Total // Opaque Sky Cover
ALC1 – ALC6	Sky Condition // Height Level

[38] EPA's completeness requirement for meteorological data is 90% for temperature, wind speed, and wind direction, determined by quarter. The QA assessment in AERMET View is a screening tool and does not calculate data completeness on a quarterly basis. If AERMET View reports data completeness near or below 90%, additional analysis is needed to determine whether EPA's quarterly data completeness criteria are met.

SURFACE DATA	TOTAL # OBS	|------VIOLATION SUMMARY------| # MISSING	LOWER BOUND	UPPER BOUND	% ACCEPTED	|-----TEST VALUES-----| MISSING FLAG	LOWER BOUND	UPPER BOUND
PRCP	61362	0	0	0	100.00	-9.0,	0.0,	25400.0
SLVP	61362	101	0	0	99.84	99999.0,	9000.0,	10999.0
PRES	61362	628	0	0	98.98	99999.0,	9000.0,	10999.0
CLHT	61362	2904	0	0	95.27	999.0,	0.0,	300.0
TS	61362	395	0	0	99.36	99.0,	0.0,	10.0
KC	61362	61362	0	0	0.00	99.0,	0.0,	10.0
AL	61362	61362	0	0	0.00	9.0,	0.0,	7.0
C1	61362	61362	0	0	0.00	999.0,	0.0,	300.0
AL	61362	0	0	0	100.00	9.0,	0.0,	7.0
C2	61362	0	0	0	100.00	999.0,	0.0,	300.0
AL	61362	0	0	0	100.00	9.0,	0.0,	7.0
C3	61362	0	0	0	100.00	999.0,	0.0,	300.0
AL	61362	0	0	0	100.00	9.0,	0.0,	7.0
C4	61362	0	0	0	100.00	999.0,	0.0,	850.0
AL	61362	0	0	0	100.00	9.0,	0.0,	7.0
C5	61362	0	0	0	100.00	999.0,	0.0,	850.0
AL	61362	0	0	0	100.00	9.0,	0.0,	7.0
C6	61362	0	0	0	100.00	999.0,	0.0,	850.0
HZVS	61362	3	0	0	100.00	99999.0,	0.0,	1640.0
TMPD	61362	5	0	2056	96.64	999.0,	-300.0,	360.0
DPTP	61362	7	0	0	99.99	999.0,	-650.0,	350.0
RHUM	61362	8	0	0	99.99	999.0,	0.0,	100.0
WDIR	61362	3439	0	0	94.40	999.0,	0.0,	36.0
WSPD	61362	13	0	0	99.98	999.0,	0.0,	500.0

SURFACE DATA	TOTAL # OBS	|------VIOLATION SUMMARY------| # MISSING	LOWER BOUND	UPPER BOUND	% ACCEPTED	|-----TEST VALUES-----| MISSING FLAG	LOWER BOUND	UPPER BOUND
PRCP	61362	0	0	0	100.00	-9.0,	0.0,	25400.0
SLVP	61362	101	0	0	99.84	99999.0,	9000.0,	10999.0
PRES	61362	628	0	0	98.98	99999.0,	9000.0,	10999.0
CLHT	61362	2904	0	0	95.27	999.0,	0.0,	300.0
TS	61362	395	0	0	99.36	99.0,	0.0,	10.0
KC	61362	61362	0	0	0.00	99.0,	0.0,	10.0
AL	61362	61362	0	0	0.00	9.0,	0.0,	7.0
C1	61362	61362	0	0	0.00	999.0,	0.0,	300.0
AL	61362	0	0	0	100.00	9.0,	0.0,	7.0
C2	61362	0	0	0	100.00	999.0,	0.0,	300.0
AL	61362	0	0	0	100.00	9.0,	0.0,	7.0
C3	61362	0	0	0	100.00	999.0,	0.0,	300.0
AL	61362	0	0	0	100.00	9.0,	0.0,	7.0
C4	61362	0	0	0	100.00	999.0,	0.0,	850.0
AL	61362	0	0	0	100.00	9.0,	0.0,	7.0
C5	61362	0	0	0	100.00	999.0,	0.0,	850.0
AL	61362	0	0	0	100.00	9.0,	0.0,	7.0
C6	61362	0	0	0	100.00	999.0,	0.0,	850.0
HZVS	61362	3	0	0	100.00	99999.0,	0.0,	1640.0
TMPD	61362	5	0	300	99.50	999.0,	-300.0,	400.0
DPTP	61362	7	0	0	99.99	999.0,	-650.0,	350.0
RHUM	61362	8	0	0	99.99	999.0,	0.0,	100.0
WDIR	61362	3439	0	0	94.40	999.0,	0.0,	36.0
WSPD	61362	13	0	0	99.98	999.0,	0.0,	500.0

Figure 3-75. AERMET View QA assessment results for NWS surface data. Data on the left show 2056 bounds violations for temperature. Data on the right show a reduction of these violations when the upper bound is increased. Because AERMET View internally represents sea level pressure (SLVP) and station pressure (PRES) in units of Pascals/10, 9000 and 10999 are appropriate data bounds for meteorological sites below an altitude of 3000 ft. AERMET View uses different missing data flags for each variable.

Figure 3-76 shows QA assessment results for one year of non-NWS (onsite) data from the case study. In this second example, the data acceptance rates for temperature, wind speed, and wind direction are above 95%, but the data acceptance for wind direction is only 90% due to 836 missing values (compared with 268 missing wind speeds). This lower acceptance rate may signal a problem with the data completeness. Carefully review the log files to understand why the values were identified as missing. In this particular case, whenever the wind speed was less than the threshold wind speed value of 0.5 m/s, AERMET View flagged the corresponding wind direction observation as "missing." This is a misleading statistic that commonly occurs in the QA assessment and it should be carefully examined if the wind data completeness is in question. In this case, the data completeness for wind direction is higher than was reported by AERMET View.

```
                    **** SUMMARY OF THE QA AUDIT, CONTINUED ****


SITE SCALARS          |------VIOLATION SUMMARY------|   |-----TEST VALUES-----|
               TOTAL     #     LOWER  UPPER      %      MISSING   LOWER   UPPER
               # OBS  MISSING  BOUND  BOUND  ACCEPTED     FLAG    BOUND   BOUND
      PRES     8760      290      0      0     96.69    99999.0, 9000.0,10999.0


SITE VECTORS          |------VIOLATION SUMMARY------|   |-----TEST VALUES-----|
               TOTAL     #     LOWER  UPPER      %      MISSING   LOWER   UPPER
               # OBS  MISSING  BOUND  BOUND  ACCEPTED     FLAG    BOUND   BOUND
    10.00 M
      TT       8760      361      0      0     95.88       99.0,  -30.0,   45.0
      WD       8760      836      0      0     90.46      999.0,    0.0,  360.0
      WS       8760      268      0      0     96.94      999.0,    0.0,   50.0

    THIS CONCLUDES THE AUDIT TRAIL

       AERMET, A Meteorological Processor for the AERMOD Dispersion Model
                                  Version  15181
```

Figure 3-76. AERMET View QA assessment results for surface pressure (PRES), temperature (TT), wind direction (WD), and wind speed (WS).

For upper-air data, pressure (UAPR), geopotential height (UAHT), temperature (UATT), and dew point temperature (UATD) are most important for the QA assessment. AERMET View does not use upper-air wind data (UAWD, UAWS), and therefore the QA assessment for those variables can be ignored. Figure 3-77 shows QA assessment results for the upper-air sounding data from the case study. AERMET View summarizes these results by height above ground level. Data acceptance rates are above 90% for all variables except wind data up to 2500 meters. Above 2500 meters, more dew point temperature readings fail the lower bound check, causing the acceptance rate for UATD to fall below 90%. However, the atmosphere can be extremely dry above 2500 m, and dew point temperatures at higher altitudes may frequently fall below -350 (-35°C).

```
SOUNDINGS          |------VIOLATION SUMMARY------|   |-----TEST VALUES-----|
            TOTAL     #     LOWER  UPPER      %     MISSING   LOWER   UPPER
            # OBS  MISSING  BOUND  BOUND  ACCEPTED    FLAG    BOUND   BOUND
          SURFACE
   UAPR     5115       0      6      0     99.88    99999.0, 5000.0,10999.0
   UAHT     5115       0      0      6     99.88   -99999.0,    0.0, 5000.0
   UATT     5115       0      6      3     99.82    -9990.0, -350.0,  350.0
   UATD     5115       0      6      0     99.88    -9990.0, -350.0,  350.0
   UAWD     5115       1      0      0     99.98      999.0,    0.0,  360.0
   UAWS     5115       1    399      0     92.18     9990.0,    0.0,  500.0
       0 -  500M
   UAPR    12570       0      0      0    100.00    99999.0, 5000.0,10999.0
   UAHT    12570       0      0      0    100.00   -99999.0,    0.0, 5000.0
   UATT    12570       0      0      6     99.95    -9990.0, -350.0,  350.0
   UATD    12570      45      0      0     99.64    -9990.0, -350.0,  350.0
   UAWD    12570    8007      0      0     36.30      999.0,    0.0,  360.0
   UAWS    12570    8007     15      0     36.18     9990.0,    0.0,  500.0
     500 - 1000M
   UAPR    13717       0      0      0    100.00    99999.0, 5000.0,10999.0
   UAHT    13717       0      0      0    100.00   -99999.0,    0.0, 5000.0
   UATT    13717       0      0      0    100.00    -9990.0, -350.0,  350.0
   UATD    13717     189     39      0     98.34    -9990.0, -350.0,  350.0
   UAWD    13717    8885      0      0     35.23      999.0,    0.0,  360.0
   UAWS    13717    8885      1      0     35.22     9990.0,    0.0,  500.0
    1000 - 1500M
   UAPR     9216       0      0      0    100.00    99999.0, 5000.0,10999.0
   UAHT     9216       0      0      0    100.00   -99999.0,    0.0, 5000.0
   UATT     9216       0      0      0    100.00    -9990.0, -350.0,  350.0
   UATD     9216     126    162      0     96.88    -9990.0, -350.0,  350.0
   UAWD     9216    6788      0      0     26.35      999.0,    0.0,  360.0
   UAWS     9216    6788      1      0     26.33     9990.0,    0.0,  500.0
    1500 - 2000M
   UAPR     8621       0      0      0    100.00    99999.0, 5000.0,10999.0
   UAHT     8621       0      0      0    100.00   -99999.0,    0.0, 5000.0
   UATT     8621       0      0      0    100.00    -9990.0, -350.0,  350.0
   UATD     8621     135    384      0     93.98    -9990.0, -350.0,  350.0
   UAWD     8621    6070      0      0     29.59      999.0,    0.0,  360.0
   UAWS     8621    6070      2      0     29.57     9990.0,    0.0,  500.0
```

Figure 3-77. AERMET View QA assessment results for upper-air data.

The message files in each stage contain a detailed listing of informational, warning, and error messages produced by AERMET View. Review these message files to determine if any warnings or errors need to be addressed. Understanding the various messages that AERMET View can generate takes considerable experience. A description of these messages can be found in the AERMET User's Guide Addendum (U.S. Environmental Protection Agency, 2015d). In addition, commonly encountered messages and message descriptions for the case study can be found in Section 3.4.8.

Viewing Processed Meteorological Data

AERMET View produces two output files: the surface file (.SFC) and the profile file (.PFL). These files can be viewed by selecting **Output** on the AERMET View button bar. Review these files to make sure the data are complete and the ranges of data are reasonable (minimum to maximum ranges are listed in the first two lines of the screen when viewing within AERMET View).

Wind data from the output files can also be viewed as a wind rose plot using the WRPLOT tool that is incorporated into AERMET View. Wind rose show predominant wind directions and associated wind

speeds. Figure 3-78 shows a wind rose plot of the Fresno (KFAT) NWS data. The plot is thought of as a rose, where each petal represents a specific wind direction and the size of the petal represents the frequency of winds from that direction. Each color represents a wind speed category so the viewer can see the distribution of wind speeds for each wind direction. The wind directions are read by visualizing the wind blowing from the edge to the center of the plot for each wind direction. In Figure 3-78, a predominant northwest wind component is observed in the data, with a less frequent southeasterly wind component. This wind pattern is expected for Fresno due to the strong channeling effect of the mountains surrounding the San Joaquin Valley. A review of wind rose plots is an important part of the QA process.

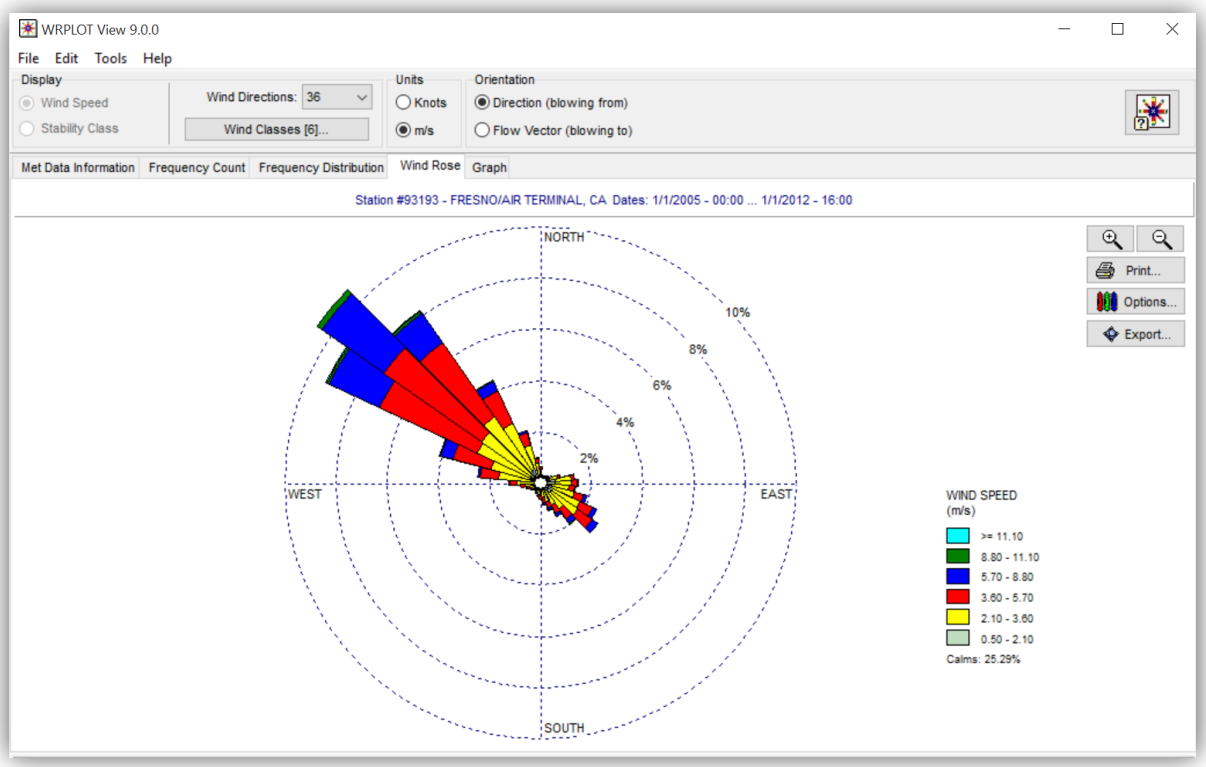


Figure 3-78. Wind rose plot of the Fresno KFAT NWS data from the case study.

3.4.7 Loading Meteorological Data into AERMOD View

Once the meteorological data files have been generated with AERMET View, copy them to the AERMOD View project folder, and specify them as inputs to AERMOD View on the Met Input Data screen of the Meteorology pathway window. Open the Meteorology pathway dialog window by selecting **Met** on the AERMOD View toolbar (see Figure 3-79). The pathway window will open to the Met Input Data screen.

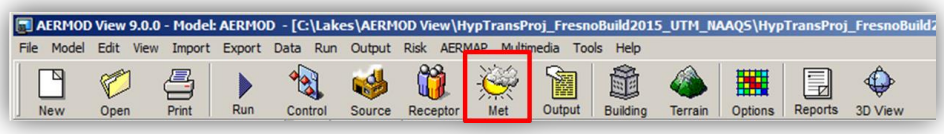


Figure 3-79. AERMOD View main toolbar, with the Met pathway button highlighted.

Figure 3-80 shows the input data screen for the AERMOD View Meteorology Pathway, and illustrates steps for loading the AERMOD-ready data files, and for specifying the base elevation of the surface meteorological data site. Browse for and open the surface data file. AERMOD View will automatically specify the corresponding profile data file if it is in the same directory. If the data are not concatenated into a single file for the five-year modeling period, load the annual files individually into AERMOD View using the **Multi-Year Files Utility**. Once the data files are loaded, AERMOD View will automatically populate fields in the **Met Stations** panel. Enter a base elevation; since the FLAT terrain option in AERMOD is recommended for PM hot-spot applications, enter a base elevation of 0 meters, as all sources and receptors in the hypothetical project will be at this same base elevation. By default, AERMOD will process all hours in the meteorological data files unless the setting is changed in the **Data Period** screen.

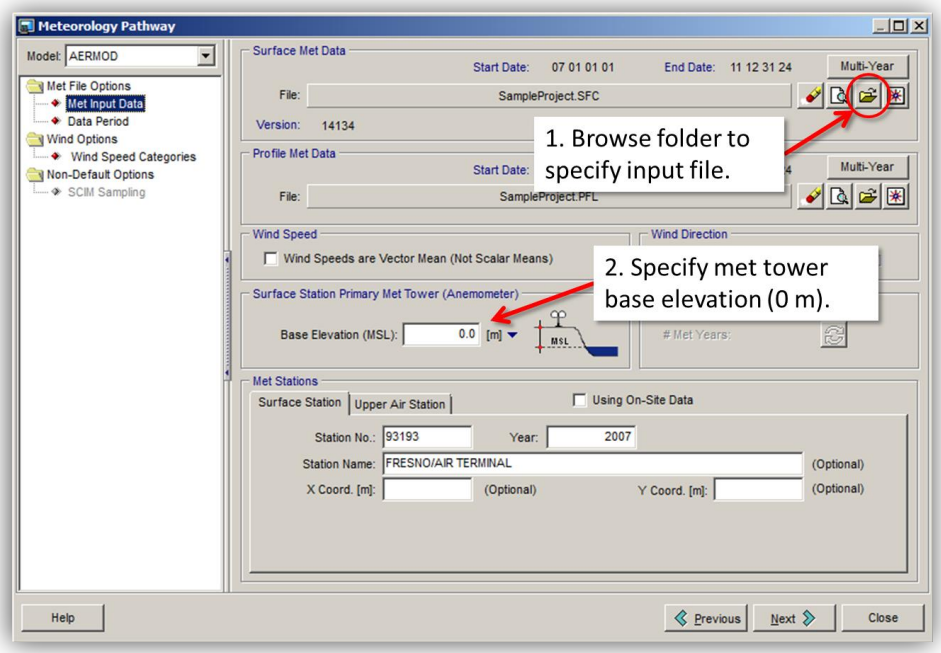


Figure 3-80. Specifying surface and upper-air meteorological data inputs in AERMOD View.

3.4.8 AERMET Data Processing – Explanation of Common Log Messages, As Seen in Case Study Output

Tables 3-26 and 3-27 show AERMET log messages that were encountered for the case study. For a full list of AERMET log messages, see the AERMET User's Guide Addendum (U.S. Environmental Protection Agency, 2015b).

Table 3-26. AERMET log messages encountered in Stage 1 processing for the the case study.

Stage 1:

Data Type	Message Code	Message Content	Description
Upper Air	W36	SDG SKIPPED: 1st LEVEL NOT TYPE 9, SDG # 358	The first level of FSL format upper air data is not the correct type and was therefore skipped. This warning can occur when a portion of the sounding data is missing.
Upper Air	Q37	LB: UATT= -401 <= -350 FOR HR 04	The lower bound (LB) threshold was violated in the upper air data. In this example, the temperature (TT) is slightly lower than the LB for hour 4.
Upper Air	Q38	UB: UAHT= 5524 > 5000 FOR HR 16	The upper bound (UB) threshold was violated in the upper air data. In this example, the height value (HT) exceeded the default UB for hour 16.
Upper Air	Q39	UAWS MISSING FOR HR 04 AT LEVEL 3	The wind speed (WS) is missing in the upper air (UA) data for the given hour and level. These warnings for wind speed and wind direction are not important for the upper air data processing.
Upper Air	CLM	Calm Winds for HR 16 at Level 1	This is an informational message that indicates the wind was calm for hour 16 at Level 1.
Surface	W48	The # of discarded records is: 12457	The W48 messages are associated with ISHD format surface data and provide statistics of the data extracted from the raw file(s).
Surface	CLM	CALM WINDS FOR HR 18	Calm wind condition existed for the specified hour.
Surface	Q48	UB: TMPD= 406 >= 400 FOR HR 15	The value exceeded the specified data range. In this example, the temperature exceeded the upper bound limit of 400.
Surface	Q49	TSKC Missing for HR 17	The data value for the listed hour is missing.
Surface	CLM	Calm Winds for HR 10	This is an informational message that indicates the wind was calm for hour 10.
Onsite	W51	Recommend specifying station elevation	This warning message would be listed if the onsite station elevation were not specified.
Onsite	Q57	LB: TT01= -31.0 < -30 FOR HR 11	This warning message would be listed if a temperature value of -31.0 were in the dataset. The lowerbound (LB) threshold would be violated in the onsite data because the temperature was less than the LB threshold for hour 11.
Onsite	Q58	UB: WS01 = 52.00 > 50.00 FOR HR 23	This warning message would be listed if a wind speed value of 52.0 were in the dataset. The upper bound (UB) threshold would be violated in the onsite air data beause the wind speed value exceeded the UB for hour 23.
Onsite	Q59	WD missing for HR: 10; LEVEL : 1	Missing wind direction data was identified in the onsite record for the given hour and level.

Table 3-27. AERMET log messages encountered in Stage 2 and Stage 3 processing for the the case study.

Stage 2:

Data Type	Message Code	Message Content	Description
All	MRPATH	MERGING UPPER AIR SDGS. AND ON-SITE DATA ONLY	The merging operation is being performed only for upper air and onsite data.
All	E??	Various	Most error messages in this stage relate to errors reading the data properly which would indicate the Stage 1 processing did not run properly.
All	W66	Various	W66 warning messages relate to processing issues with 1-minute ASOS wind data.

Stage 3:

Data Type	Message Code	Message Content	Description
Metprep	W73	No ZICONV - No UA sounding - Julian day: 3	The convective boundary layer parameters could not be calculated for this hour because the sounding (12Z) was missing.
Metprep	W79	No ZICONV; HFLUX msg on 1st CBL hr JDAY: 185	No convective mixing heights were calculated for the given day due to missing heatflux values. In this case, the warning message is due to a block of missing onsite data during all daytime hours on Julian day 185. AERMET will calculate the mixing height.
Metprep	I71	Calm wind - No BL calculations for hour: 01	Not all boundary layer calculations could not be made because of calm wind conditions for the given hour.
Metprep	I71	No estimate for insolation due to missing sky cover for hour: 07	Because the cloud cover data is missing for the hour, no calculations of insolation could be made.
Metprep	I77	Suspect (neg) heat flux (0.0) for CBL - reset to +0.1 for hour: 10	The net radiation calculation has either a negative value during a daytime hour or positive value during nighttime. AERMET resets the value to 0.1 for daytime or -0.1 for nighttime.
Metprep	I78	CCVR missing - no SBL estimates for hour: 02	The cloud cover was missing for the specified hour; therefore no stable boundary layer estimates could be calculated.
Metprep	I83	Anem height found in ASOS list for station 93193: Height from ASOS list (m) is: 7.92	Indicates that AERMET-View identified the anemometer height from an ASOS station list. If this differs from the entered value, a warning will be generated.
Metprep	I84	Upper air sounding selected for this day: 12 Z	AERMET selects the best sounding each day to represent the morning conditions, preferrably before sunrise. In this example, the 12Z sounding was selected for the given day.

Additional Messages with Onsite Data Processing

Metprep	I71	No ref wind (w/ SUBNWS option) for hour: 19	No reference wind was identified because all winds were listed as calm.
Metprep	I81	NWS winds used as reference winds for hour: 10	No onsite wind data meeting the criteria for the reference wind existed for the specified hour; therefore NWS winds were substituted.
Metprep	I82	NWS temperature used as reference winds for hour: 14	No onsite temperature data meeting the criteria for a reference temperature existed for the specified hour; therefore NWS temperature was substituted.

4. Background PM Development

4.1 PM Background ArcGIS Web Map User Guide (Version 1.2)

4.1.1 Introduction

Chapter 4.1 describes the availability of an updated online resource to support particulate matter (PM) hot-spot analysis work in California. The ArcGIS Web Map (available to Caltrans users logged in at http://www.arcgis.com/home/index.html) is designed to help transportation analysts identify one or more PM monitoring sites that are representative of background concentrations at a proposed project site, to assess how background concentrations at monitors near the project compare with the National Ambient Air Quality Standards (NAAQS), and to identify a representative meteorological monitoring site for a proposed project. The ArcGIS Web Map Version 1.2 contains all map layers from previous versions, including map layers to quickly visualize how concentrations at monitors compare with the NAAQS.[39] Additionally, Version 1.2 includes files for PM background values and site metadata, wind roses for meteorological monitoring sites in California and neighboring states, and meteorological representativeness layers to help project analysts identify a meteorological monitoring site that is potentially representative of a proposed project location.[40] Combined, these mapping resources will expedite the completion of the hot-spot analysis process described in U.S. Environmental Protection Agency (EPA) guidance (U.S. Environmental Protection Agency, 2015c), including the identification of representative PM and meteorological monitors. This document briefly describes the data sets included in the ArcGIS Web Map, provides directions for their use, and includes examples of maps that can be visualized within the resource.

4.1.2 Data Sets

Several data sets are included in the PM Background ArcGIS Web Map to help transportation analysts examine monitoring locations, background concentrations relative to the NAAQS, pollutant sources, and terrain characteristics near a proposed California transportation project site. **Table 4-1** lists data parameters, sources, and data sets included in the Web Map. Data are organized into two groups: (1) data for assessing PM site representativeness, and (2) data for assessing meteorological

[39] The background concentrations used in the ArcGIS Web Map Version 1.2 reflect the air quality status at the monitor locations. They are determined according to the methods described in the Clean Air Act, 40 CFR Part 50, which are consistent with the methods for calculating project-level design values for 24-hour PM_{10}, 24-hour $PM_{2.5}$ (Tier 1 approach), and annual $PM_{2.5}$ in PM hot-spot analyses.

[40] Meteorological representativeness layers were originally developed in May 2012 under an earlier PM Hot-Spot AERMOD Support task order.

site representativeness. All data sets are publicly available online, and data sources are listed in table footnotes.

Table 4-1. Data parameters, sources, and data sets included in the Web Map.

Parameter	Source	Data Set
PM Site Representativeness		
PM_{10} 24-hr Background Concentration vs NAAQS (150 µg/m^3)	Computed using data from AirData[a]	2012–2014 PM_{10} 24-hr background concentrations and site information; background concentrations are computed following EPA's November 2015 PM hot-spot guidance using Annual Summary Data from AirData[41]
$PM_{2.5}$ 24-hr Background Concentration vs NAAQS (35 µg/m^3)	EPA 2014 Design Value Report[b]	2012–2014 $PM_{2.5}$ 24-hr background concentrations and site information are identical to those included in the EPA's 2014 Design Value Report
$PM_{2.5}$ Annual Background Concentration vs NAAQS (12.0 µg/m^3)	EPA 2014 Design Value Report	2012–2014 $PM_{2.5}$ annual background concentrations and site information are identical to those included in the EPA's 2014 Design Value Report
Monitors	AirData	CSV spreadsheet versions of map layers (for PM_{10} and $PM_{2.5}$, respectively)
PM Emissions (tons/year)	EPA website[c]	2011 National Emissions Inventory (NEI) point source PM_{10} and $PM_{2.5}$ emissions
Population (census block)	U.S. Census[d]	2010 Census Population
Land Use	U.S. Geological Survey (USGS) website[e]	Enhanced Historical Land-Use and Land-Cover Data Set
Elevation (meters)	USGS website[f]	National Elevation Data Set (NED), 1 arc-second (~30-meter) resolution

[41] The 24-hr PM_{10} background concentration is calculated at each monitor using three years of monitoring data, based on the number of valid measurements from the monitor (see Exhibit 9-6 in EPA's November 2015 PM hot-spot guidance).

Parameter	Source	Data Set
Meteorological Site Representativeness		
Surface Meteorological Monitors	National Oceanic and Atmospheric Administration (NOAA) National Centers for Environmental Information website[g]	Metadata are from the Enhanced Master Station History Report
	NOAA National Climatic Data Center (NCDC)[h]	Integrated Surface Hourly (ISH) database
Surface Site Allocation Boundary	Caltrans meteorological representativeness layers	Surface Site Allocation Boundary
Surface Representativeness Index	Caltrans meteorological representativeness layers	Surface Representativeness Index (options include "most representative," "less representative," and "not representative")
Upper-Air Meteorological Monitors	NOAA National Centers for Environmental Information website[g]	Metadata are from the Enhanced Master Station History Report
Upper-Air Site Allocation Boundary	Caltrans meteorological representativeness layers	Upper-Air Site Allocation Boundary
Upper-Air Representativeness Index	Caltrans meteorological representativeness layers	Upper-Air Representativeness Index (options include "most representative," "less representative," and "not representative")

[a] www.epa.gov/airdata/ad_maps.html
[b] https://www.epa.gov/air-trends/air-quality-design-values#previous; the method for determining background concentrations for 24-hour average $PM_{2.5}$ in this report is consistent with the Tier 1 approach for calculating 24-hour average $PM_{2.5}$ design values in a PM hot-spot analysis.
[c] https://www.epa.gov/air-emissions-inventories
[d] http://www.census.gov/2010census/
[e] http://water.usgs.gov/GIS/dsdl/ds240/
[f] https://nationalmap.gov/viewer.html
[g] www.ncdc.noaa.gov/homr/reports/mshr
[h] https://www1.ncdc.noaa.gov/pub/data/noaa/

PM Site Representativeness

Three PM site representativeness layers have been included in the ArcGIS Web Map to offer comparisons between 2012–2014 24-hr PM_{10}, 24-hr $PM_{2.5}$, and annual $PM_{2.5}$ background concentrations at each monitor with the applicable NAAQS[42] (for example, see **Figure 4-1**). These layers offer transportation analysts a quick and easy way to identify monitors near a project site where PM concentrations are below the NAAQS, and to visualize the corresponding project increment that would allow a project build scenario to result in a total PM concentration (modeled concentration from the project plus background concentration) that falls at or below the NAAQS (for example, see **Figure 4-2**). PM_{10} background concentrations were calculated using methods consistent with EPA's November 2015 PM hot-spot guidance (U.S. Environmental Protection Agency, 2015c). $PM_{2.5}$ values are from EPA's 2014 Design Value Report,[43] which includes values that are typically used to designate and classify nonattainment areas and that are consistent with the Tier 1 calculation approach (for 24-hr $PM_{2.5}$ design values)[44] described in EPA's November 2015 PM hot-spot guidance. PM_{10} values are calculated on a per-monitor basis, while $PM_{2.5}$ values are calculated on a per-site basis (certain sites may have multiple monitors and the calculation of $PM_{2.5}$ background concentrations may involve using data from multiple monitors).[45] PM background concentrations and comparisons with the NAAQS are documented in a companion spreadsheet; **Figure 4-3** shows a screen capture of the PM Background Concentrations vs NAAQS spreadsheet, which can be downloaded from the landing page of the Web Map on the Overview tab.

All other necessary parameters are included in the map to help analysts identify a representative PM monitor for a hot-spot analysis. The relevance of these parameters for identifying a representative PM monitor is briefly discussed in the EPA guidance for completing a PM hot-spot analysis, and in a guidance document developed for Caltrans for determining representative background concentrations (Graham et al., 2014).

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[42] Comparisons are made with the following NAAQS: PM_{10} NAAQS: 150 µg/m^3; 24-hr $PM_{2.5}$ NAAQS: 35 µg/m^3; Annual $PM_{2.5}$ NAAQS: 12 µg/m^3.

[43] EPA's Design Value Reports are available at www3.epa.gov/airtrends/values.html.

[44] The Tier 1 approach involves directly adding the five-year average 98th percentile modeled concentrations to the three-year average 98th percentile background concentrations for a given receptor. Design values computed with the Tier 1 approach may potentially be conservative for certain project cases when emissions are highest in one season, and are not temporally correlated with background $PM_{2.5}$ levels that are highest during a different season.

[45] Personal communication, Brett Gantt, U.S. EPA Office of Research and Development, November 20, 2015.

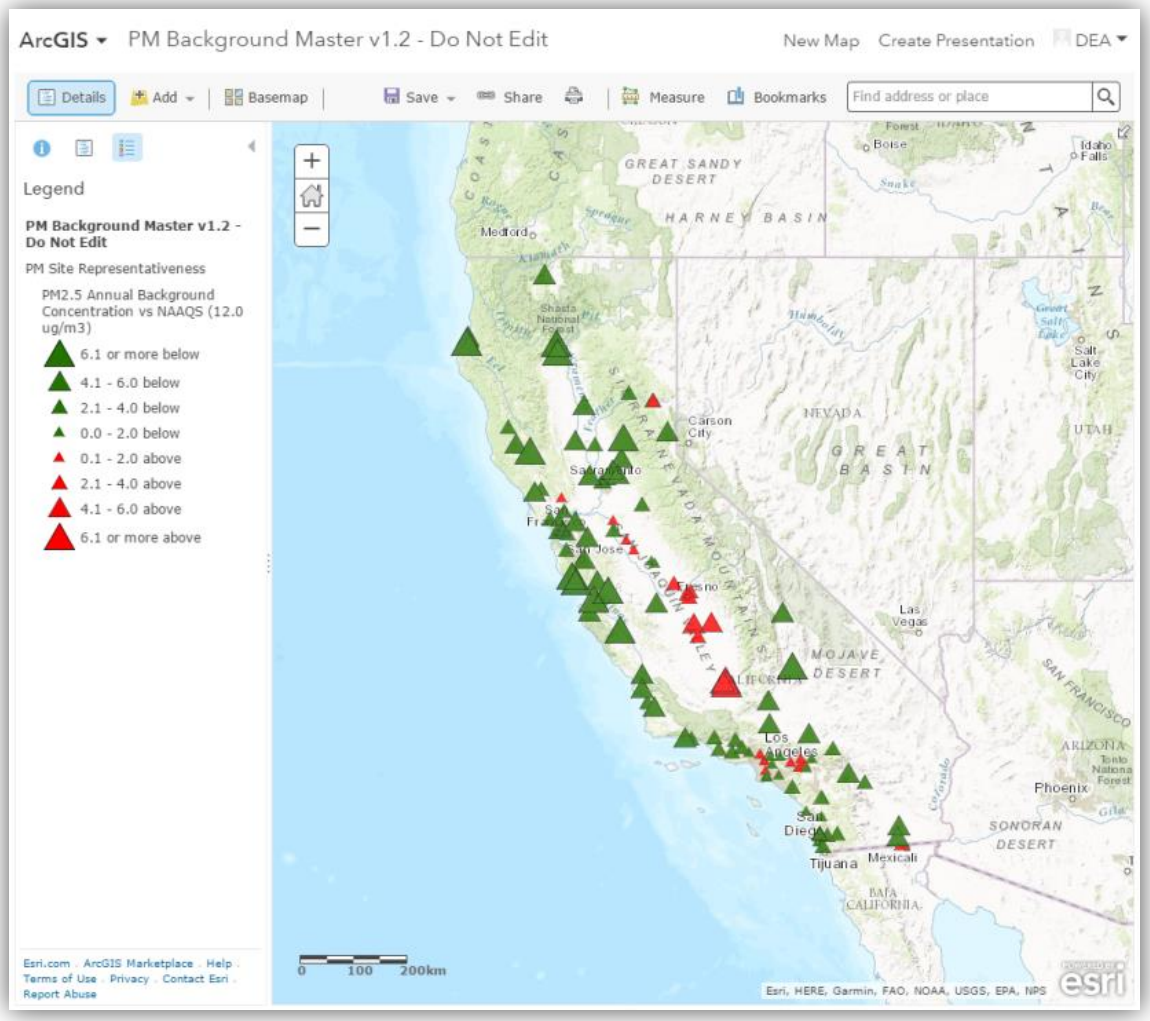


Figure 4-1. The PM Background ArcGIS Web Map showing annual $PM_{2.5}$ background concentrations compared to the NAAQS. Red triangles depict $PM_{2.5}$ sites where the annual background concentration for 2012–2014 exceeds the NAAQS; green triangles show $PM_{2.5}$ sites where the background concentration is below the NAAQS.

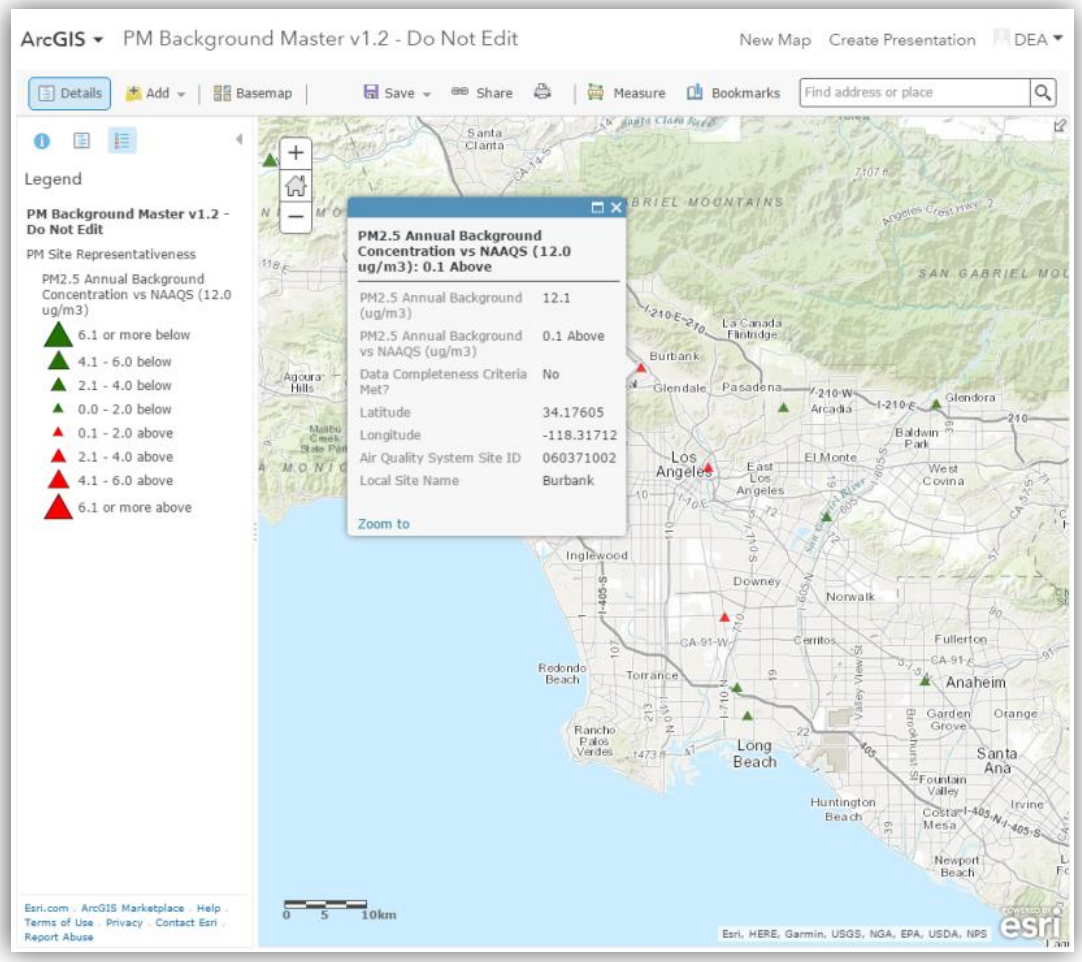
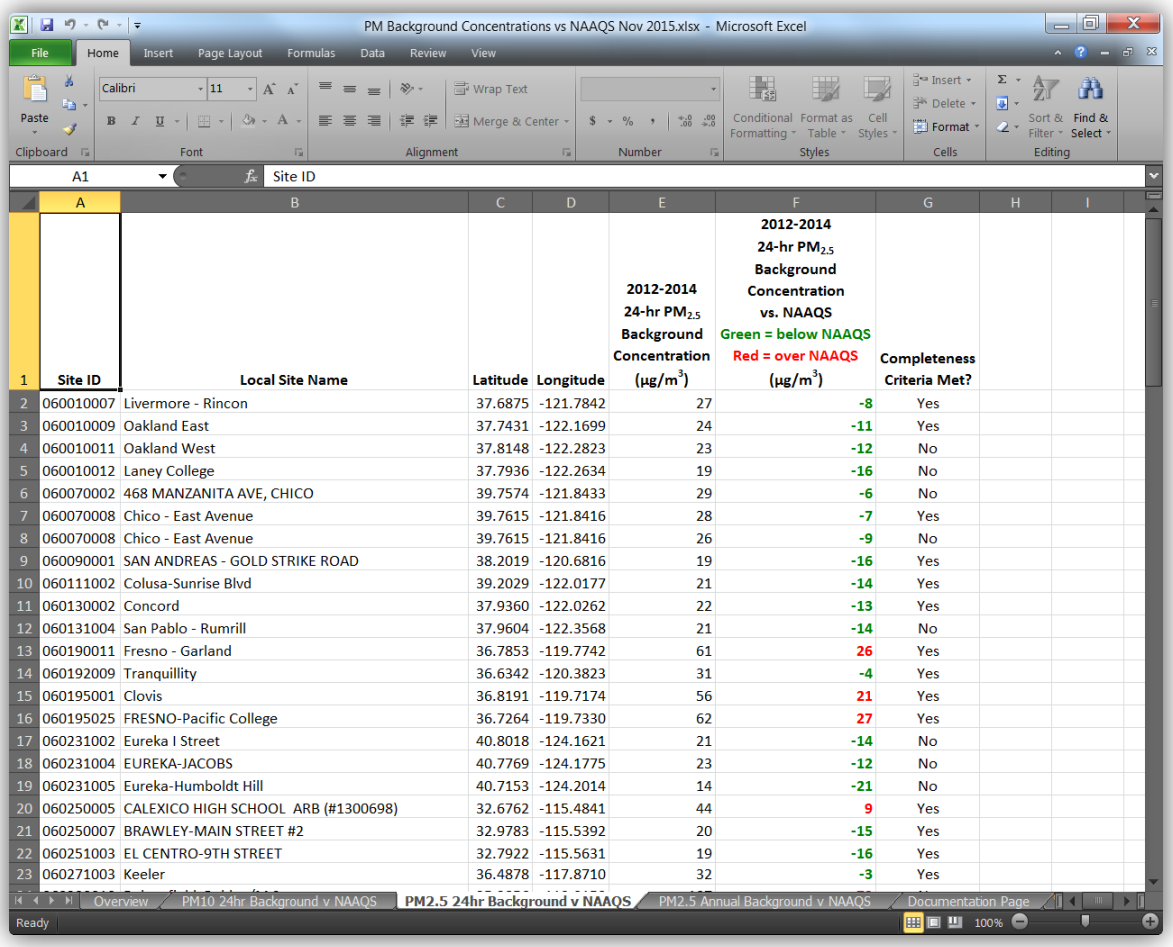


Figure 4-2. The PM Background ArcGIS Web Map showing a sample pop-up information window, including the background concentration, the background concentration relative to the NAAQS, and site information. The information also includes an indicator that the monitored data meet or do not meet EPA's data completeness criteria, in the context of comparing background concentrations to the NAAQS (see Table 8-1 on page 15 of the EPA's guidance document at https://www3.epa.gov/ttn/caaa/t1/memoranda/pmfinal.pdf). For PM hot-spot analysis, data completeness is also a requirement when monitoring data are used for calculating representative background concentrations; interagency consultation is needed prior to using any ambient monitoring data that does not meet the data completeness criteria.



Site ID	Local Site Name	Latitude	Longitude	2012-2014 24-hr $PM_{2.5}$ Background Concentration ($\mu g/m^3$)	2012-2014 24-hr $PM_{2.5}$ Background Concentration vs. NAAQS Green = below NAAQS Red = over NAAQS ($\mu g/m^3$)	Completeness Criteria Met?
060010007	Livermore - Rincon	37.6875	-121.7842	27	-8	Yes
060010009	Oakland East	37.7431	-122.1699	24	-11	Yes
060010011	Oakland West	37.8148	-122.2823	23	-12	No
060010012	Laney College	37.7936	-122.2634	19	-16	No
060070002	468 MANZANITA AVE, CHICO	39.7574	-121.8433	29	-6	No
060070008	Chico - East Avenue	39.7615	-121.8416	28	-7	Yes
060070008	Chico - East Avenue	39.7615	-121.8416	26	-9	No
060090001	SAN ANDREAS - GOLD STRIKE ROAD	38.2019	-120.6816	19	-16	Yes
060111002	Colusa-Sunrise Blvd	39.2029	-122.0177	21	-14	Yes
060130002	Concord	37.9360	-122.0262	22	-13	Yes
060131004	San Pablo - Rumrill	37.9604	-122.3568	21	-14	No
060190011	Fresno - Garland	36.7853	-119.7742	61	26	Yes
060192009	Tranquillity	36.6342	-120.3823	31	-4	Yes
060195001	Clovis	36.8191	-119.7174	56	21	Yes
060195025	FRESNO-Pacific College	36.7264	-119.7330	62	27	Yes
060231002	Eureka I Street	40.8018	-124.1621	21	-14	No
060231004	EUREKA-JACOBS	40.7769	-124.1775	23	-12	No
060231005	Eureka-Humboldt Hill	40.7153	-124.2014	14	-21	No
060250005	CALEXICO HIGH SCHOOL ARB (#1300698)	32.6762	-115.4841	44	9	Yes
060250007	BRAWLEY-MAIN STREET #2	32.9783	-115.5392	20	-15	Yes
060251003	EL CENTRO-9TH STREET	32.7922	-115.5631	19	-16	Yes
060271003	Keeler	36.4878	-117.8710	32	-3	Yes

Figure 4-3. Screen capture of the PM Background Concentrations vs NAAQS Excel spreadsheet containing monitor information, background concentrations, and comparisons between background concentrations and the NAAQS.

Meteorological Site Representativeness

The ArcGIS Web Map includes features and layers to help analysts (1) visualize predominant wind patterns at California meteorological monitors, and (2) determine which monitoring site may be most representative of the meteorology within the modeling domain for their project. The Web Map features include wind roses for selected meteorological monitoring sites in California and neighboring states, and meteorological representativeness layers.

Wind Roses

Wind roses were generated using meteorological data archived by site and by year in Integrated Surface Data (ISD) format, which are obtained from the National Centers for Environmental

Information (NCEI)[46] ISH database.[47,48] To account for interannual meteorological variability, and to follow requirements for Meteorological Input Data in Appendix W (Section 8.4.2e),[49] the most recent five years of meteorological data should be used to create wind roses. For each site, this set of data was obtained using the following steps:

1. Download meteorological data (starting from the most recent year available) from the NCEI ISH database.
2. Use the meteorological data preprocessor for AERMOD (AERMET) to obtain an hourly time series of wind speed and wind direction.[50]
3. Determine if the wind data are complete. A year of data is considered complete if 90% of concurrent wind speed and wind direction data by quarter are available.[51]
4. Download data from the preceding year (following steps 1-3) and continue to download data until either (1) five years of complete data or (2) data from the year 2000 are obtained. The data used for creating wind roses may not always represent five consecutive years.

For sites where less than five complete years of data were available, wind roses were generated using all available years of data (back to year 2000). Because the data are not complete, in some cases, these wind roses may not be representative of the predominant wind patterns at the site; in addition, incomplete meteorological data cannot be used for AERMOD dispersion modeling in a quantitative PM hot-spot analysis.

The wind roses included in the ArcGIS Web Map are annotated with the following information:

- The meteorological station's NCDC identification number and full station name;
- A statement of whether the completeness criteria (i.e., five complete years of wind data) were met or not;
- The years of data used to generate the wind rose (individual years are noted if completeness criteria are met; otherwise, the range of years is noted);
- The total number of records in the data set (where approximately 43,800 records are expected for five complete years of data);
- The percentage of data by quarter out of the total number of records[52];

[46] Formerly the National Climatic Data Center (NCDC).
[47] The database and data are also referred to as the Integrated Surface Data or Integrated Surface Database (ISD).
[48] See: https://www1.ncdc.noaa.gov/pub/data/noaa/.
[49] See: https://www3.epa.gov/ttn/scram/appendix_w/2016/AppendixW_2017.pdf (updated January 17, 2017)
[50] Only wind speed values between 0 and 50 m/s, and wind direction values between 0 and 360 degrees, were considered valid.
[51] Only concurrent wind speed and wind direction were considered for the 90% completeness criteria used to generate the wind roses, while EPA's "Meteorological Monitoring Guidance for Regulatory Modeling Applications" (https://www3.epa.gov/scram001/guidance/met/mmgrma.pdf) and "Quality Assurance Handbook for Air Pollution Measurement Systems" (https://www3.epa.gov/ttnamti1/files/ambient/pm25/qa/QA-Handbook-Vol-II.pdf) base data completeness on wind speed, wind direction, stability, and temperature..
[52] Quarters are defined as: "Q1" = January, February, March; "Q2" = April, May, June; "Q3" = July, August, September; "Q4" = October, November, December.

- The percentage of data by time period out of the total number of records, where "day" hours are from 7 AM to 6 PM, inclusive, in Local Standard Time (LST), and "night" hours are the remaining hours;
- The mean wind speed of the total data set (including calms which are treated as 0 m/s); and
- The percentage of calm winds (as diagnosed by AERMET).[53]

An example of a wind rose included in the ArcGIS Web Map is shown in Figure 4-4.

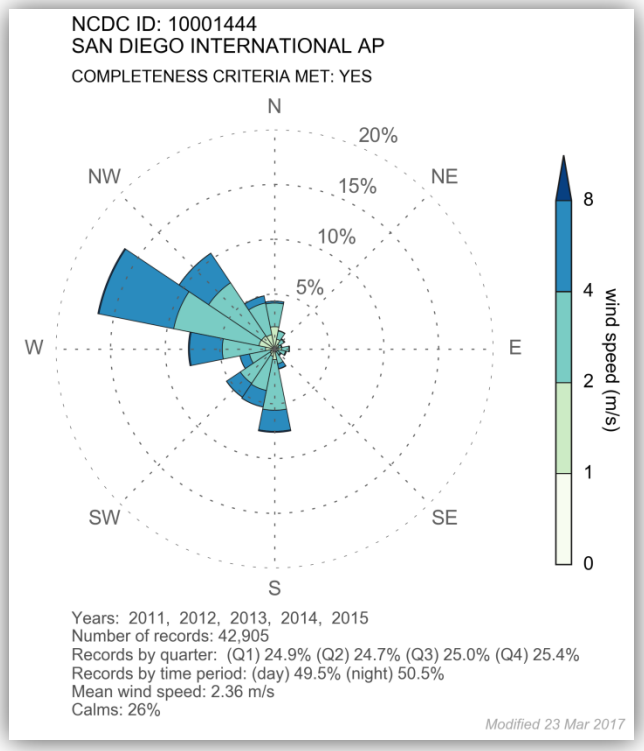


Figure 4-4. Wind rose generated for the ArcGIS Web Map for the San Diego International Airport. Wind roses are displayed in the surface meteorological site layer pop-ups.

How to Interpret a Wind Rose

A wind rose is a graphical representation of the joint distribution of wind speed and direction at a particular location over a given time period. The wind direction is depicted as the angle around the circle and corresponds to the direction where the wind is blowing **from**. Wind directions are binned into general cardinal directions which are drawn as "wedges." The total radial length of each wedge represents the percentage of records (i.e., time) when wind is blowing from that direction. Each directional wedge is then divided into wind speed bins, where the color corresponds to the range

[53] AERMET diagnoses calm winds when either the given wind speed value has passed all quality control checks and the wind speed is zero, or when the wind speed value is marked as calm.

identified by a color scale. The sum of the percentage of records from each wedge plus the percentage of calm winds equals 100%.

In the wind rose example shown in Figure 4-4, the completeness criteria were met (i.e., within each quarter, there are at least 90% concurrent wind speed and direction data available), thus the percentage of data by quarter out of the total number of records is approximately 25% across all quarters. Wind directions are binned into the 16 cardinal directions (e.g., N, NNE, NE, and ENE), and wind speeds are binned from greater than 0 m/s to 1 m/s, 1-2 m/s, 2-4 m/s, 4-8 m/s, and greater than 8 m/s. This wind rose was generated using five years of data (2011-2015) at the San Diego International Airport. The dominant wind direction at the site is from the WNW; winds blow from this direction approximately 16% of the time and the wind speeds are mainly in the range of 2 to 8 m/s. Winds are calm at the site 26% of the time within the period of record.

Meteorological Representativeness Layers

Meteorological representativeness layers included in Version 1.2 of the ArcGIS Web Map were developed to assist project analysts who must obtain and process meteorological data required by AERMOD to complete PM hot-spot analyses. Processing meteorological data for use in AERMOD requires four major steps. In summary, project analysts

1. Select representative surface and upper-air meteorological sites.
2. Acquire surface and upper-air meteorological data from the representative sites.
3. Determine surface characteristics at the surface meteorological site by qualitatively comparing the surface characteristics of the site with those of the project location and then calculating the surface characteristics to be used for the meteorological data processing.
4. Use AERMET to prepare meteorological data.

The meteorological representativeness layers were designed to assist project analysts with Step 1, selecting representative surface and upper-air meteorological sites. The map layers spatially illustrate the areas represented by data collected at meteorological monitors throughout California (for example, see **Figure 4-5**). The representativeness map layers can be used as a guide for selecting a representative meteorological monitoring site from which to obtain data for AERMET processing.[54] The methodology used to develop the maps and an illustration of obtaining and processing meteorological data required by AERMOD is discussed elsewhere (Pasch et al., 2012).

[54] It is recommended that, before data are selected and used in AERMET, site selection be discussed with the appropriate agencies involved with the transportation conformity interagency consultation process. In some cases, there may be alternative data sources that are superior to the site or sites mapped as most representative for a given project area. For example, project analysts whose projects are located near the state borders of California may want to consider using data from other states. The meteorological representativeness maps included in the ArcGIS Web Map are based solely on meteorological monitors located in California.

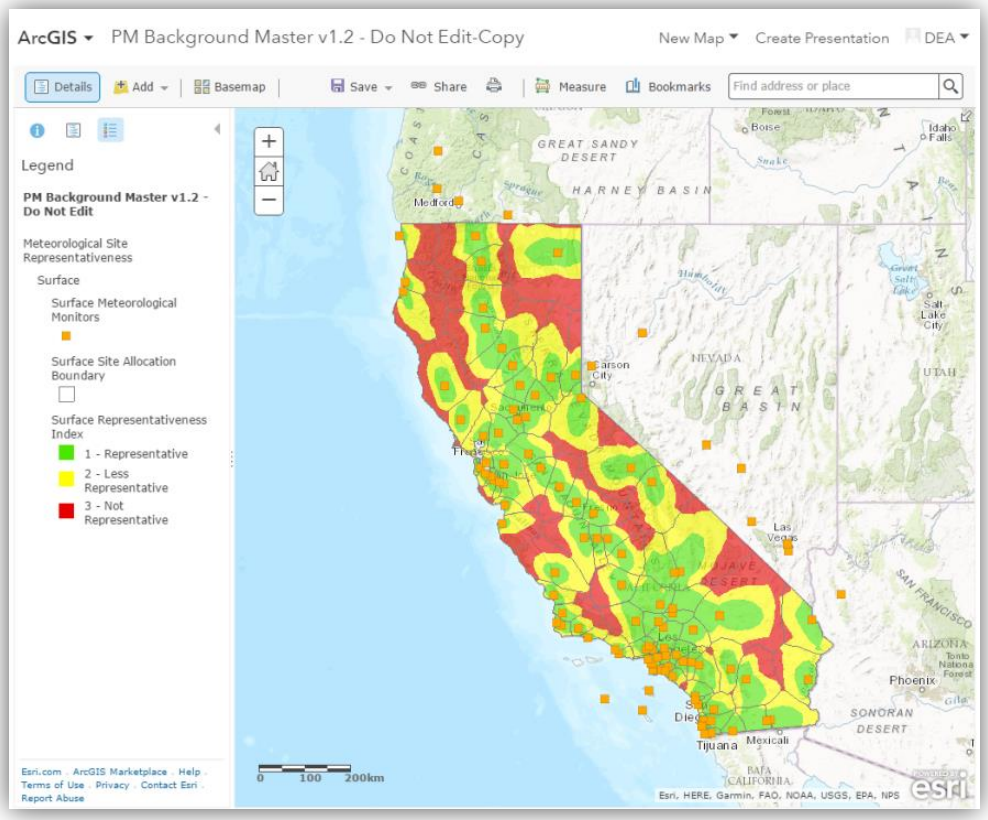


Figure 4-5. The PM Background ArcGIS Web Map showing surface meteorological site representativeness layers, including surface meteorological monitors, allocation boundaries, and representativeness indices.

4.1.3 Using the ArcGIS Web Map

To access the PM Background ArcGIS Web Map, visit www.arcgis.com, click **Sign In** in the top right corner of the web page, and log in to the Caltrans ArcGIS account using the user name **CaltransDEA** and password **Welcome1GIS**. Once logged in, select **My Content**, and then select the **PM Background Master v1.2 – Do Not Edit** link to access the Web Map. A description of the tool is also provided on the Overview tab of the landing page, along with download links for the PM Background values and site metadata files. Open the Web Map either by clicking on the map image or by selecting **Open** > **Open in map viewer** from the right-hand menu.

Figure 4-6 shows the initial map display. Before exploring the map layers, the user should save a copy of the map to work in so that the master copy is not modified inadvertently. To save a new version of the map, use the floppy disk icon to open the **Save** drop-down menu. Subfolders for each Caltrans district office have been created to help organize map copies. Select **Save As**, specify a new title for your map, and use the drop-down menu under **Save in folder** to save the map to a Caltrans district subfolder. Saving a copy of the map is especially useful if external data will be added to the

map (see the section below on how to add external data). If data are added to a map and the map is not saved, the data will be lost when the user exits the map.

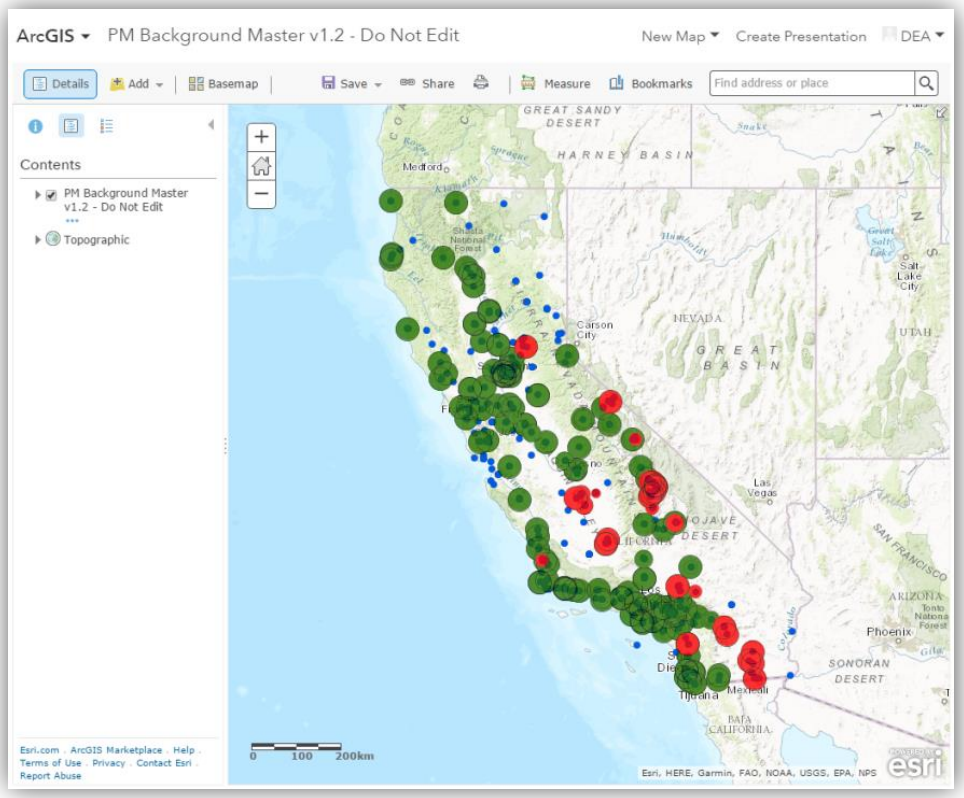


Figure 4-6. The initial display of the PM Background ArcGIS Web Map.

Once a copy of the map has been saved, the user may explore the data included in the Web Map. Under the **Contents** heading on the left of the screen, click on the map name to expand the Contents menu and view all map layers. Click on each layer (e.g., **PM10 Monitors**) to view the symbols associated with the layer (see Figure 4-7). Note that some layers may take longer to load than others due to a large volume of data. Also note that groups of layers appear under different headings, and the parent heading must be enabled to view the layers contained within the group. Click on a site or area of interest within the map to open a pop-up window showing layer information. Be careful not to disable or modify pop-ups by inadvertently clicking the arrow next to a layer and selecting **Remove Pop-up** or **Configure Pop-up**. A backup copy of the resource is saved in the **Administrator** folder in case a change is made to the master copy inadvertently. Table 4-2 lists data associated with each map layer. Click **Basemap** to select from several underlying map options, including satellite imagery as shown in Figure 4-8.

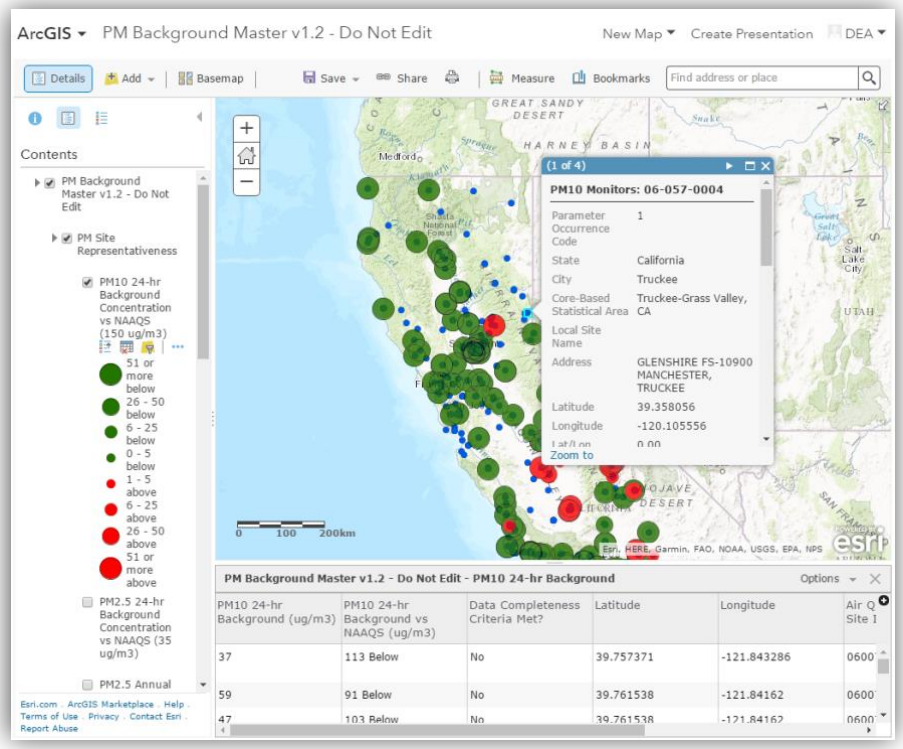


Figure 4-7. The PM Background ArcGIS Web Map showing the **Contents** section expanded to show symbols for the map layers and a sample pop-up and table of metadata.

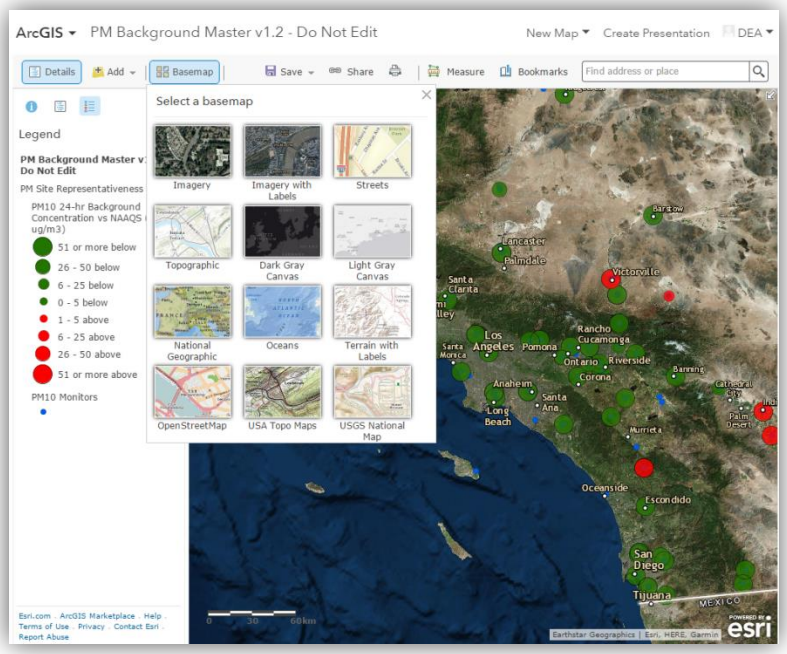


Figure 4-8. The PM Background ArcGIS Web Map showing how the **Basemap** can be changed.

In addition to the map layers contained within the PM Background ArcGIS Web Map, several tools within ArcGIS Online may be useful to transportation project analysts. For example, click **Measure Area and Distance** to access tools for calculating the area of a polygon; the distance between two points, such as the project site and a monitor (see Figure 4-9); or the latitude and longitude of a point of interest. Other data layers from the web or from a file can also be added to the map by clicking **Add** and can be saved to the Web Map if desired.

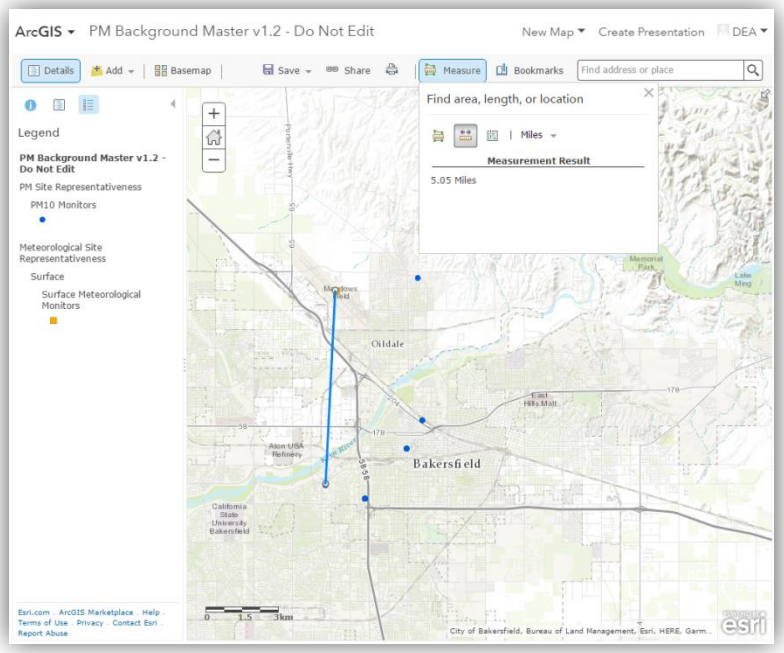


Figure 4-9. The PM Background ArcGIS Web Map illustrating how the **Measure Area and Distance** tool can be used to determine the distance between two locations.

To save the current view of the Web Map, click **Print**; this will open a new tab in the web browser. Once the image has loaded, right click the area and select either **Save image as...** to export the image as a PNG file, or **Copy image** to paste the image into a document or other program.

Table 4-2. Data available for each map layer in the pop-up that appears after selecting a point or shape of interest.

Layer	Data Available in Pop-Up
PM Site Representativeness	
PM_{10} 24-hr Background Concentration vs NAAQS (150 µg/m^3)	PM_{10} 24-hr Background (µg/m^3), PM_{10} 24-hr Background vs NAAQS (µg/m^3), Data Completeness Criteria Met?, Latitude, Longitude, Air Quality System Site ID, Parameter Occurrence Code, Local Site Name
$PM_{2.5}$ 24-hr Background Concentration vs NAAQS (35 µg/m^3)	$PM_{2.5}$ 24-hr Background (µg/m^3), $PM_{2.5}$ 24-hr Background vs NAAQS (µg/m^3), Data Completeness Criteria Met?, Latitude, Longitude, Air Quality System Site ID, Local Site Name
$PM_{2.5}$ Annual Background Concentration vs NAAQS (12.0 µg/m^3)	$PM_{2.5}$ Annual Background (µg/m^3), $PM_{2.5}$ Annual Background vs NAAQS (µg/m^3), Data Completeness Criteria Met?, Latitude, Longitude, Air Quality System Site ID, Local Site Name
$PM_{2.5}$ Monitors, PM_{10} Monitors	Air Quality System Site ID, Parameter Occurrence Code, State, City, Core-Based Statistical Area, Local Site Name, Address, Latitude, Longitude, Lat/Lon Accuracy (meters), Elevation (meters above mean sea level), Parameter Name, Monitor Start Date, Measurement Scale, Measurement Scale Definition, Sample Duration, Sample Collection Frequency, Sample Collection Method, Sample Analysis Method, Method Reference ID, Federal Reference Method/Federal Equivalent Method?, Monitor Objective, Monitor Type, Reporting Agency
PM Emissions (tons/year)	Emission Inventory System Facility Site ID, Program System Code, Alternate Agency ID, Region Code, State, County Name, State and County Federal Information Processing Standard Code, Tribal Name, Facility Site Name, North American Industrial Classification System Code, Facility Source Description, Facility Site Status Code, Latitude, Longitude, Location Address, Locality, Address State Code, Address Postal Code, Emissions Op Type Code, Pollutant Code, Description, Total Emissions, Units of Measure
Population (census block)	State Code, County Code, 2010 Census Tract, 2010 Census Block, 2010 Census Block ID, Part Flag, 2010 Housing Units, 2010 Census Population
Land Use	Land Use Code, Land Use
Meteorological Site Representativeness	
Surface Meteorological Monitors	Wind Rose, National Climatic Data Center ID, Weather Bureau Army Navy Number, Cooperative Observation ID, Call Sign, Name, State, County, Latitude, Longitude, Elevation, Coordinated Universal Time adjustment factor, Station Type
Upper-Air Meteorological Monitors	Wind Rose, National Climatic Data Center ID, Weather Bureau Army Navy Number, Cooperative Observation ID, Call Sign, Name, State, County, Latitude, Longitude, Elevation, Coordinated Universal Time adjustment factor, Station Type

4.1.4 Sample Maps

This section provides examples of the map layers that can be visualized using the PM Background ArcGIS Web Map to help transportation analysts identify a representative PM monitor. The following illustrations show sites in Bakersfield as an example, but the tool can be applied throughout California. In summary, Figures 4-10 through 4-18 illustrate that the Web Map can facilitate identification of nearby PM and meteorological monitors and the assessment of various site characteristics, including the density and mix of emissions sources, land use, and terrain.

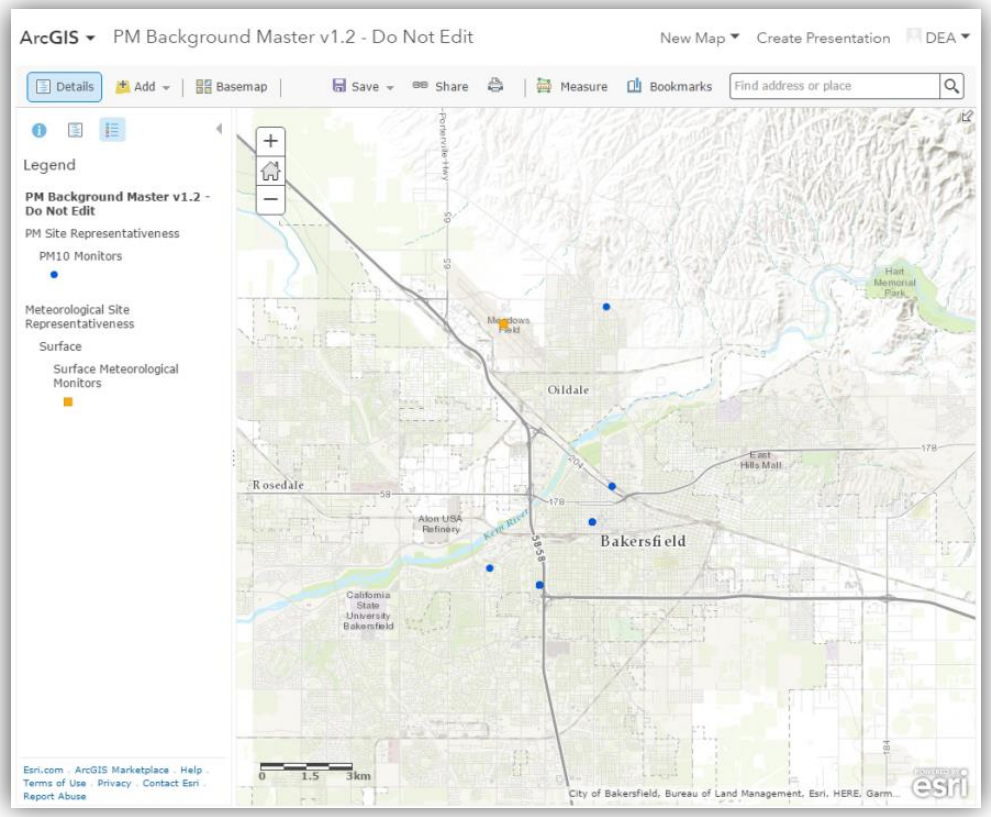


Figure 4-10. The PM Background ArcGIS Web Map showing ASOS (Automated Surface Observing System) meteorological monitors and PM_{10} monitors in the Bakersfield, California, area.

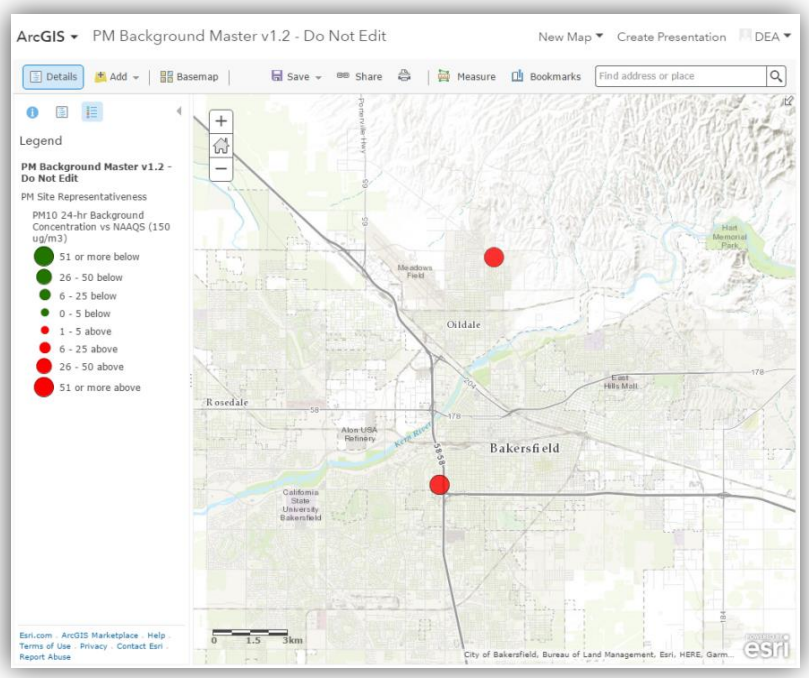


Figure 4-11. The PM Background ArcGIS Web Map showing 2012–2014 PM_{10} background concentrations compared to the NAAQS for monitors in the Bakersfield, California, area.

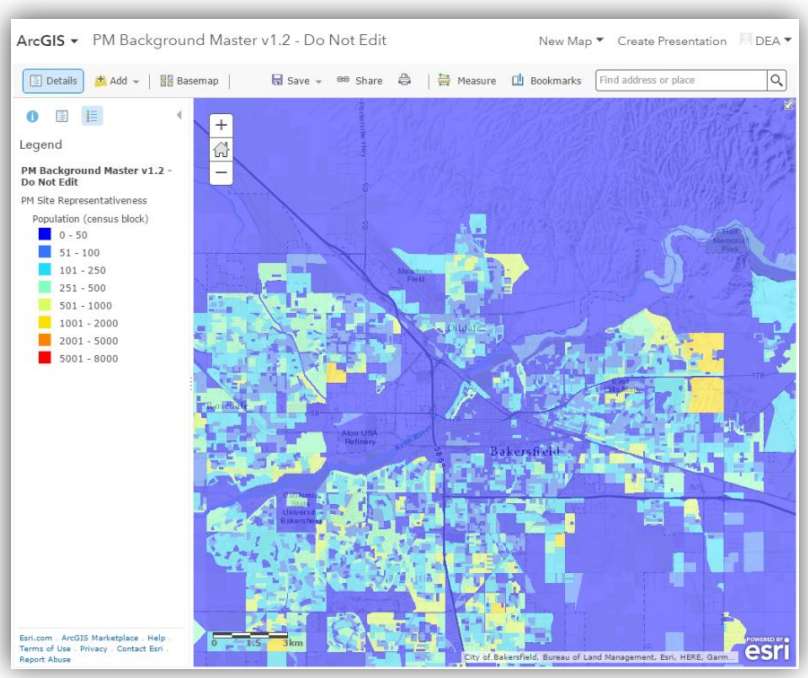


Figure 4-12. The PM Background ArcGIS Web Map showing population density in the Bakersfield, California, area.

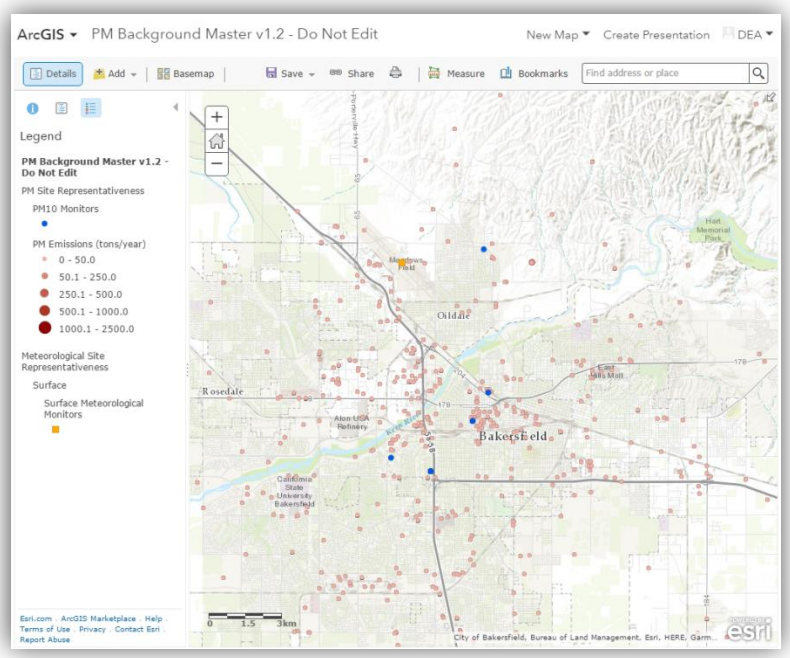


Figure 4-13. The PM Background ArcGIS Web Map showing ASOS meteorological monitors, PM_{10} monitors, and PM_{10} and $PM_{2.5}$ point sources in the Bakersfield, California, area.

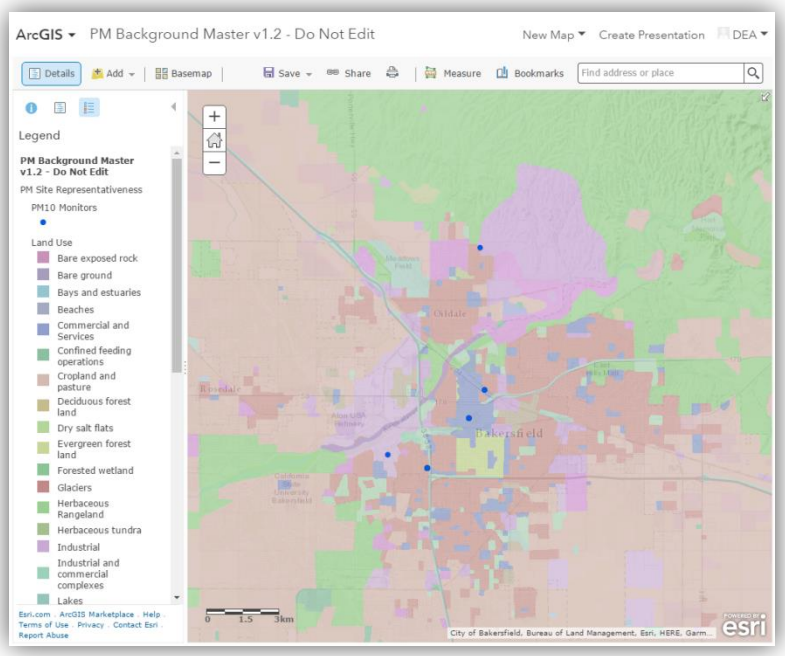


Figure 4-14. The PM Background ArcGIS Web Map showing PM_{10} monitors and land use in the Bakersfield, California, area.

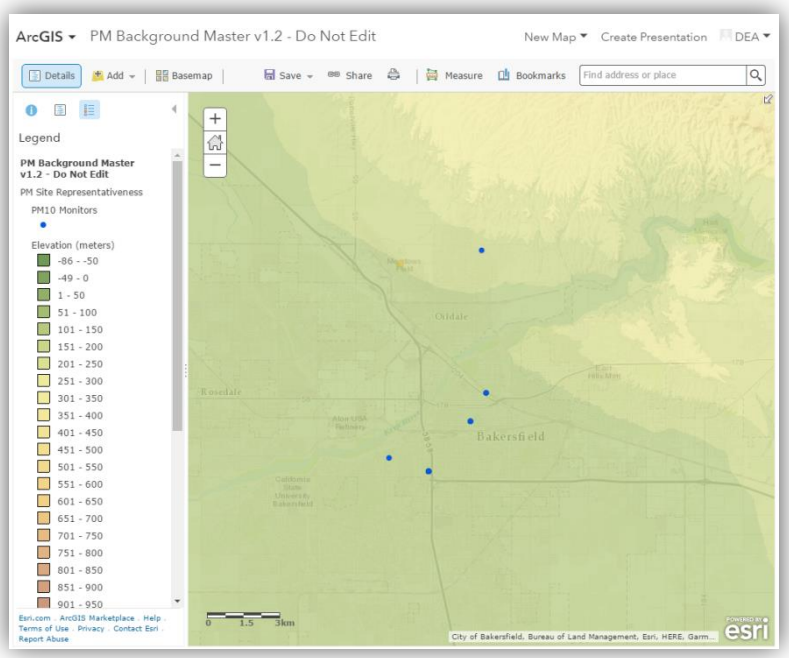


Figure 4-15. The PM Background ArcGIS Web Map showing ASOS meteorological monitors, PM_{10} monitors, and elevation in the Bakersfield, California, area.

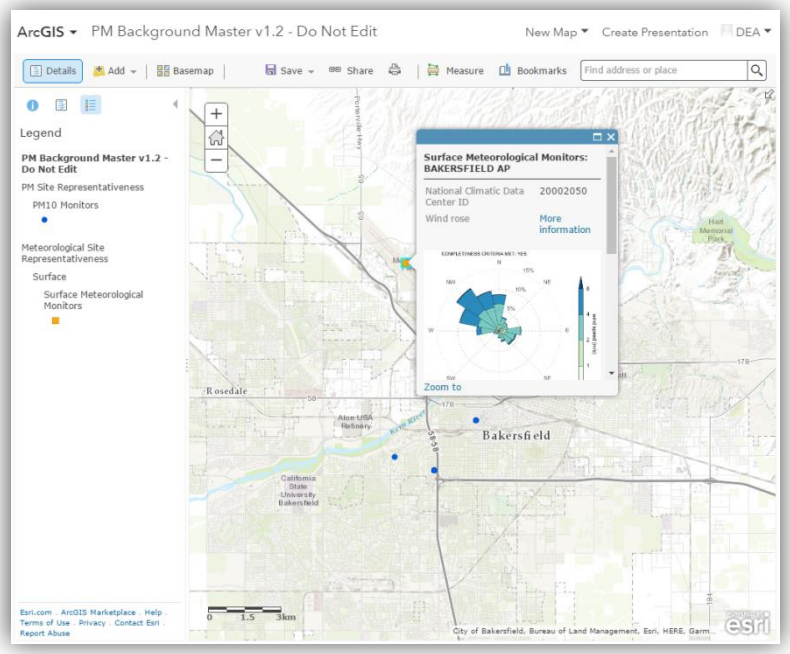


Figure 4-16. The PM Background ArcGIS Web Map showing PM_{10} monitors, ASOS meteorological monitors, and a wind rose inside the pop-up for the ASOS meteorological monitor at Bakersfield Airport.

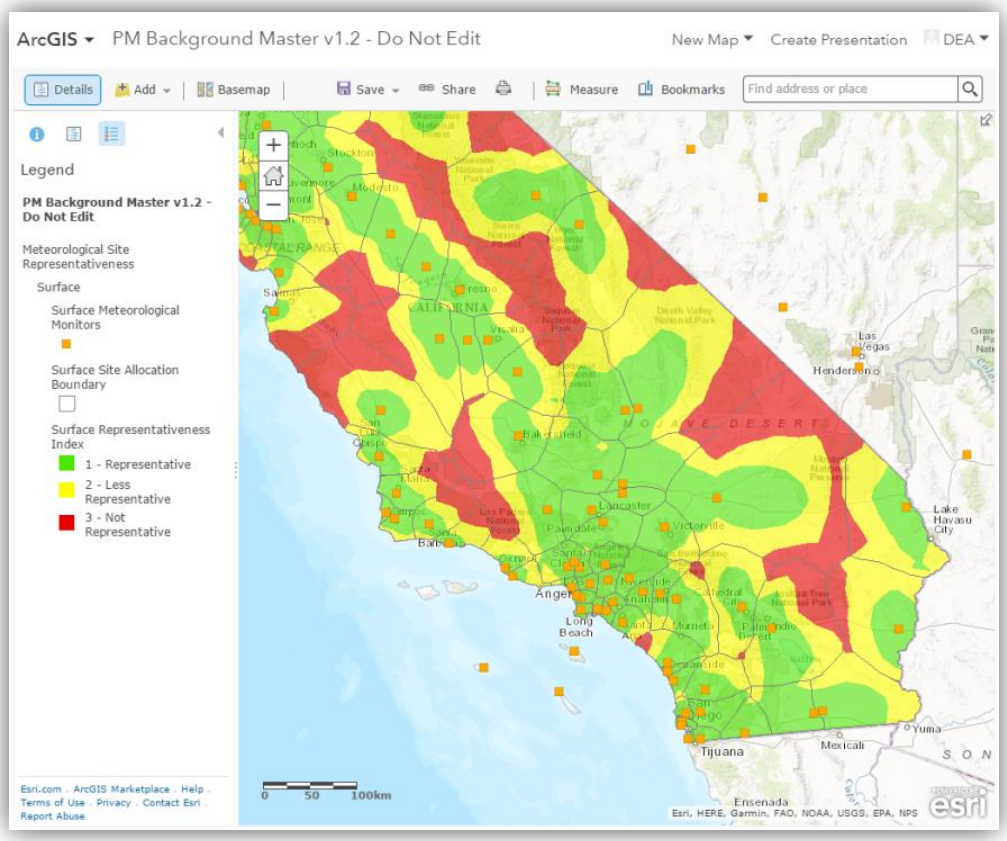


Figure 4-17. The PM Background ArcGIS Web Map showing surface meteorological site representativeness information, including surface meteorological monitors, surface site allocation boundaries, and representativeness indices.

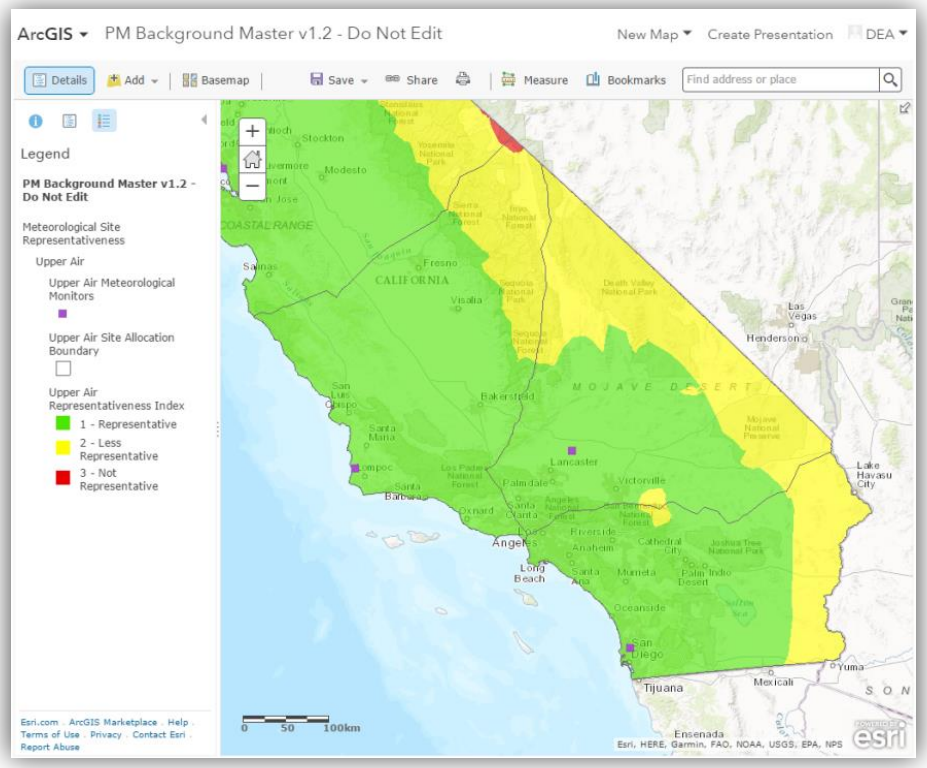


Figure 4-18. The PM Background ArcGIS Web Map showing upper-air meteorological site representativeness information, including upper-air meteorological monitors, upper-air site allocation boundaries, and representativeness indices.

4.1.5 Summary

The ArcGIS Web Map contains site characteristics data and tools to help project analysts identify representative PM and meteorological monitors for quantitative PM hot-spot analyses.

Follow these five simple steps to get started:

3. Visit www.arcgis.com.
4. Click **Sign In** in the top right corner of the web page.
5. Log in using the user name **CaltransDEA** and password **Welcome1GIS**.
6. Click **My Content**, select **PM Background Master v1.2 – Do Not Edit**, and click the map image to enter the map.
7. Save a new version by selecting **Save As**, specifying a new title for your map, and using the drop-down menu under **Save in folder** to save the map to a Caltrans district subfolder.

Once these steps have been completed, users can explore the map layers to identify one or more representative monitors near a proposed California project site.

4.2 Future-Year Background PM Concentrations

4.2.1 Introduction

Chapter 4.2 suggests approaches and resources to help estimate "background" particulate matter (PM) concentrations for future years. Generally, background concentrations refer to the pollutant concentrations in a project area before a transportation project is built. The information presented here supplements previously prepared guidance, *Establishing Representative Background Concentrations for Quantitative PM Hot-Spot Analyses in California* (Graham et al., 2014), which summarized data sources and methods for establishing background concentrations and presented a hypothetical case study for calculating background concentrations using ambient air quality data.

The U.S. Environmental Protection Agency's (EPA) transportation conformity rule requires a PM hot-spot analysis for certain transportation projects located in federal $PM_{2.5}$ or PM_{10} nonattainment or maintenance areas. In December 2010, EPA published guidance for completing a quantitative PM hot-spot analysis, *Transportation Conformity Guidance for Quantitative Hot-Spot Analyses in $PM_{2.5}$ and PM_{10} Nonattainment and Maintenance Areas*; an updated version of the guidance was released in November 2015 (U.S. Environmental Protection Agency, 2015c). The guidance describes three major steps for completing a PM hot-spot analysis: (1) estimate the incremental PM contribution of the proposed project; (2) add the increment to a representative background concentration; and (3) determine whether the combination (increment plus background) meets conformity requirements. The analysis years of a hot-spot analysis may extend 20 years or more into the future.[55]

EPA guidance describes two main approaches for determining representative background PM concentrations. First, background concentrations can be determined using ambient monitoring data, either from a single representative monitor or by interpolating data from several monitors in cases where no single monitor is appropriate for the project area. Alternatively, future-year background concentrations can be estimated using results from a chemical transport model (CTM).[56]

A typical approach for PM hot-spot analyses is to use historical ambient monitoring data to represent future-year background concentrations; however, monitoring data do not account for future changes in background concentrations. In California's PM non-attainment areas, legally enforceable commitments for reducing PM emissions through vehicle fleet turnover, transportation control measures (TCMs), and other emission control programs are expected to decrease background PM concentrations over time. These emission control measures are documented in state implementation plans (SIP) that state and local air quality management agencies submit to EPA for approval. The SIP development process may include the use of CTMs to quantify the expected impact

[55] Transportation projects must show conformity within the time frame of an area's Regional Transportation Plan (RTP), which, as of 2015, extends to 2035 or beyond in California.

[56] CTMs are photochemical models that are routinely used in regulatory analyses at the regional or national scale. CTMs are substantially more complex and data-intensive than Gaussian plume models such as AERMOD, making CTM modeling impractical for most project-level analyses.

of the emission control measures and demonstrate future attainment of the National Ambient Air Quality Standards (NAAQS). Unlike ambient monitoring data, the CTM results account for anticipated future changes in background concentrations. The South Coast Air Quality Management District (SCAQMD) and the San Joaquin Valley Air Pollution Control District (SJVAPCD) have completed CTM modeling for $PM_{2.5}$ attainment demonstrations in recent SIPs for the South Coast and San Joaquin Valley areas. However, SIPs for PM_{10} nonattainment and maintenance areas in California did not include CTM modeling as of 2015.

Although EPA guidance allows for the use of CTM results to estimate future-year background PM concentrations, this approach has not been used in a PM hot-spot analysis at the time of this writing. EPA's *Transportation Conformity Guidance* provides few details on how to apply CTM results in a project-level assessment, and uncertainties exist regarding the availability and suitability of CTM data for such assessments. To help address these issues, this document:

1. Provides project analysts with information on potential sources of CTM data for California.
2. Highlights issues and challenges that project analysts may encounter when considering the use of CTM data to determine background concentrations for a PM hot-spot analysis.
3. Assesses potential technical approaches and proposes a case study illustrating how to use CTM results to calculate background PM concentrations. This work complements previous case studies developed for Caltrans that illustrated how to use ambient monitoring data to determine background concentrations.

This information will help project analysts to have informed conversations with interagency partners regarding the availability, suitability, and application of CTM data for determining future-year background PM concentrations for a particular PM hot-spot project.

4.2.2 Sources of CTM Data

CTM modeling is routinely performed by EPA, the California Air Resources Board (CARB), and regional air quality management districts (AQMDs) to support regulatory rulemaking and SIP attainment demonstrations. The level of documentation for these modeling analyses varies, and analysts may need to contact EPA, CARB, or the AQMD to request additional modeling results.

Table 4-3 summarizes modeling results that could be used to calculate future-year background concentrations for PM hot-spot analyses in California. The table contains both EPA rulemakings and SIP submissions and is current as of early 2016; analysts should check with interagency partners about whether these results are suitable for use with a particular project and whether additional CTM results have become available. For example, California is scheduled to submit $PM_{2.5}$ SIPs to EPA in October 2016; related CTM SIP modeling may help project-level PM hot-spot work.[57]

[57] See the Executive Summary of the CARB 2016 Mobile Source Strategy Discussion Draft, available at arb.ca.gov/planning/sip/2016sip/2016mobsrc.htm.

Table 4-3. Summary of EPA rulemakings and SIPs with CTM-based projections that could be used to determine future-year background concentrations for PM hot-spot analyses in California.[a]

EPA Rulemaking/ SIP	Prepared By	Date Prepared[a]	EPA Approval Status	Air Quality Model	Air Quality Model Domain (Primary)	Base Year	Analysis Year(s)	Format/Availability of Future-Year PM Background Values[b]
Regulatory Impact Analysis (RIA) for the Final Revisions to the NAAQS for PM (U.S. Environmental Protection Agency, 2012a)	EPA	December 2012	N/A	Community Multi-scale Air Quality modeling system (CMAQ)	U.S. Lower 48 States; 12 km grid	2007	2020	Background values for 2020 analytical baseline[c] are provided in www.epa.gov/pm/2012/2020table.pdf and in Appendix F of the EPA technical support document (U.S. Environmental Protection Agency, 2012b). Background values account for emissions reductions from existing federal and state programs ("on-the-books" controls) and estimated emissions reductions needed to attain the $PM_{2.5}$ standards of 15/35 μg/m^3. Additional background values from the adjusted 2020 base case[d] (existing programs only) are provided in Appendix B of the EPA technical support document (U.S. Environmental Protection Agency, 2012b).
2012 $PM_{2.5}$ Plan	San Joaquin Valley Air Pollution Control District	December 2012	Approval pending[e]	CMAQ	San Joaquin Valley; 4 km grid	2007	2019	24-hr $PM_{2.5}$ background values for selected monitors are reported in Table 4-1 of SJVAPCD's SIP (San Joaquin Valley Air Pollution Control District, 2012).
Final 2012 Air Quality Management Plan	South Coast Air Quality Management District	February 2013	Approval pending[e]	CMAQ	Southern California; 4 km grid	2008	2014, 2019, 2023, and 2030	Annual and 24-hr $PM_{2.5}$ background values for selected monitors are reported in Appendix V of SCAQMD's SIP (South Coast Air Quality Management District, 2013).

[a] EPA-approved or EPA-generated CTM results are the best candidate materials for use in a PM hot-spot assessment; however, there are limited EPA-approved or generated results available, and this table includes other CTM-based projections. Project analysts will need to use interagency consultation to assess the suitability of using any of the CTM-based results shown here. Also, note that SIPs prepared prior to 2012 are not included in this table, as earlier plans include analysis years prior to 2015, and are therefore outdated for use in upcoming hot-spot analyses.

[b] The current SIPs for PM_{10} nonattainment and maintenance areas in California do not include CTM modeling. For a list of nonattainment/maintenance areas in California for all pollutants, see: http://www3.epa.gov/airquality/urbanair/sipstatus/reports/ca_areabypoll.html.

[c] This future-year CTM projection accounts for 2025 mobile NO_x emission adjustments in the San Joaquin Valley and South Coast Air Basin.

[d] This future-year CTM projection includes emission controls due to existing state and federal programs, and also accounts for episodic wood burning curtailments and atypical events.

[e] As of February 2016, EPA approval was pending. Follow the established interagency consultation process to determine the validity of using CTM data from SIPs that have not yet been approved by EPA.

4.2.3 Requirements for Using CTM Data

EPA guidance lists the following criteria for using CTM-based methods to estimate future-year background concentrations (U.S. Environmental Protection Agency, 2015c).

- The CTM has demonstrated acceptable performance for the project area using standard statistical indicators of model performance.[58] Assessments of operational model performance compare modeled concentrations of various $PM_{2.5}$ species to monitored concentrations, paired in time and space.
- The results of CTM runs are appropriate for the project and future analysis year(s) covered by the PM hot-spot analysis (e.g., the CTM modeling must include the project area, and must be completed for the analysis year or a year earlier than the analysis year).
- Any future emissions reductions for sources within the CTM modeling demonstration are based on enforceable commitments in the SIP and/or are consistent with the conformity rule's latest planning assumptions requirements (40 CFR 93.110).
- CTM modeling that includes future emissions reductions from a proposed rule, or hypothetical emissions reductions that are not associated with enforceable SIP commitments or state or Federal rules, should not be used.
- Any future emissions reductions for sources within the CTM modeling demonstration should take effect prior to the year(s) for which the PM hot-spot analysis is conducted.

The PM hot-spot analysis year(s) will often be after the CTM modeling years. In this case, the future-year background concentration should come from the last available year of CTM data; future-year background concentrations should not be extrapolated beyond the year for which CTM modeling is performed. Project analysts need to work with interagency partners to ensure that the CTM data meet EPA's requirements and are suitable for use in a PM hot-spot analysis.

4.2.4 Technical Approach for Applying CTM Data

Assuming that CTM results are available that meet the criteria described above, EPA guidance provides two general approaches for using CTM data to develop future-year background concentrations (U.S. Environmental Protection Agency, 2015c):

1. Using processed CTM data with PM background concentrations already calculated; and
2. Using unprocessed (gridded) CTM output data to calculate PM background concentrations.

These approaches are discussed in more detail in the sub-sections that follow. For SIP demonstrations, the modeled attainment test focuses on whether future-year modeling results lead

[58] More information on evaluating model performance is available in Chapter 3 of EPA's *Draft Modeling Guidance for Demonstrating Attainment of Air Quality Goals for Ozone, $PM_{2.5}$, and Regional Haze* (U.S. Environmental Protection Agency, 2014c).

to a demonstration of attainment at locations where existing monitors are placed. Generally, attainment tests focus on monitors with baseline measurement values that exceed the NAAQS. For these monitors, future-year estimates are based on CTM results and documented in the SIP. If such a monitor is selected as the single representative monitor for a given transportation project, the future-year background concentration will already have been calculated for the SIP, and the first approach listed above applies ("Using Processed CTM Data"). However, if a transportation project's representative monitor has a baseline value that is below the NAAQS, its future-year background value may not have been evaluated during the SIP process; in this case, the second approach applies ("Using Unprocessed CTM Data").

Using Processed CTM Data

To support SIP development, an AQMD will use the Model Attainment Test Software (MATS) or other EPA-approved methods to process CTM data and develop future-year background values for selected monitors. Because the detailed calculations have been performed, the processed background value for the representative monitor near a transportation project could potentially be used directly as the future background concentration for a PM hot-spot analysis. **Table 4-4** shows an example of monitor-specific future-year 24-hour $PM_{2.5}$ background values from the SCAQMD 2012 $PM_{2.5}$ SIP (South Coast Air Quality Management District, 2013).[59] In some cases, CTM analyses provide background values from multiple analysis years. In this example, the SIP includes $PM_{2.5}$ background values for seven southern California monitors for analysis years 2019, 2023, and 2030. The appropriate values that would be used in a particular PM hot-spot analysis would depend on the location of the transportation project, the representative monitor for that project, and the project analysis years.

[59] CARB makes SIP documents available via the web; see SCAQMD example here: arb.ca.gov/planning/sip/planarea/scabsip/scabsip.htm#2012_plan.

Table 4-4. 24-hour $PM_{2.5}$ background values (µg/m^3) for the 2008 baseline year and the 2019, 2023, and 2030 future years from the SCAQMD 2012 $PM_{2.5}$ SIP (South Coast Air Quality Management District, 2013) based on CTM results. These data were compiled from Tables V-5-19 through V-5-23 of the SCAQMD SIP.

Locations	2008 Base Year Background Value	2019 Background Value	2023 Background Value	2030 Background Value[a]
Anaheim	35.0	30.2	29.7	29.7
South Long Beach	33.4	25.9	25.5	26.2
Fontana	45.6	33.9	32.0	31.7
North Long Beach	34.4	30.3	30.0	30.3
Los Angeles	40.1	31.9	31.3	31.0
Mira Loma	47.9	35.4	33.7	33.4
Rubidoux	44.1	32.5	30.6	30.3

[a] Background values at some locations indicate increased concentrations in future years (e.g., 2030 vs. 2023 at the South Long Beach and North Long Beach sites). As long as the SIP demonstrates sustained compliance with the NAAQS beyond the target attainment date, background values from SIPs may increase due to activity growth and other emissions changes projected to occur in the area.

CTM analyses may also provide multiple background values for the same horizon year using different emission scenarios. For example, the EPA 2012 RIA (see Table 4-3) includes several CTM projections for 2020 using various emissions assumptions.

Using Unprocessed CTM Data

If future-year background values have not been processed for the representative monitor near a transportation project, then the background values must be calculated from unprocessed CTM results. This process is complex and data-intensive and requires a substantial level of effort and expertise; as a result, it is usually impractical for transportation hot-spot analyses. Conceptually, future-year background values are calculated from unprocessed CTM results by the following process:

1. Determine the representative PM monitor for the transportation project.
2. Determine the base year (e.g., 2007) background value based on the most recent three years of PM monitoring data.
3. Determine the modeled concentration for the base year.
4. Determine the modeled concentration for the future year (e.g., 2020).

5. Calculate a relative response factor (RRF)[60] from the modeled base-year and future-year concentrations by

$$RRF = \frac{Modeled\ future\ year\ concentration}{Modeled\ base\ year\ concentration}$$

6. Estimate the future-year background value by multiplying the RRF by the base-year background value

Future-year background value = RRF * Base-year monitoring value

For NAAQS attainment demonstrations, absolute concentrations from the CTM are not used directly because of uncertainties in the meteorological and emissions data inputs, as well as uncertainties in the chemistry and other physical processes represented in the CTM. Instead, EPA recommends using CTM data in a "relative" rather than "absolute" sense to estimate future-year background values, using the RRF as described above.

Although the process for calculating future-year background values from gridded CTM output is conceptually straightforward, the calculation is data- and labor-intensive and involves numerous subtleties. Much of the complexity arises from the fact that separate RRFs must be calculated individually for each $PM_{2.5}$ species[61] to accurately estimate how emission controls will affect total $PM_{2.5}$ concentrations. This affects how both CTM and monitored PM data are processed when calculating future-year background values. Calculations involving PM_{10} are somewhat less complex, but are still data- and labor-intensive.

Some of the calculation steps to derive future-year background values from CTM output include

- Hourly CTM output must be post-processed to develop the necessary speciated PM concentrations with the required daily and quarterly averaging.

Model Attainment Test Software (MATS)

- EPA and AQMDs post-process their CTM data using EPA's MATS (Abt Associates, 2014).
- MATS includes a set of default analysis methods consistent with EPA guidance for calculating RRFs and future-year design values from CTM results.
- MATS can be found on EPA's Support Center for Regulatory Atmospheric Modeling, at epa.gov/scram001/modelingapps_mats.htm.

[60] The RRF is a fractional change between modeled concentrations due to emissions changes between a base year and a future year.
[61] $PM_{2.5}$ consists of multiple species, including sulfate, nitrate, ammonium, organic carbon, elemental carbon, particle-bound water, fine soil, and sea salt.

- Data from multiple CTM grid cells near a monitoring site may be considered in the RRF calculations[62] to mitigate limitations in the data inputs and model physics that affect CTM precision at the grid cell level.
- Data from both filter-based and speciated $PM_{2.5}$ measurements are needed for developing RRFs. Filter-based measurements and speciation samplers measure particle mass differently and have unique measurement artifacts that must be accounted for.[63]
- Additional analysis is necessary to determine the high PM concentration days for which RRFs will be most meaningful.

4.2.5 Challenges for Project Analysts

Given the technical approaches described above, project analysts are likely to encounter the following key challenges in regard to finding suitable CTM data that meets EPA's requirements:

- **Availability of CTM data.** For California, the availability of CTM datasets is somewhat limited. Some EPA modeling results exist in addition to the 2012 PM NAAQS RIA listed in Table 4-3; however, many of these assessments focus on the eastern United States, focus on just the ozone season, or are outdated. With regard to California SIPs, the two recent SIPs listed in Table 4-3 had not been approved by EPA as of February 2016. Other California SIPs with CTM analyses developed during the last decade are outdated because the CTM analysis years are prior to 2015.
- **Analysis years in the PM hot-spot assessment that differ from those covered by available CTM results.** The time horizon for EPA regulatory analyses and SIP demonstrations is typically shorter than the planning horizon for transportation projects. The potential benefits of using future-year background concentrations diminish as the CTM analysis year(s) get closer in time to the present. For example, for a CTM analysis year of 2015, it may be more appropriate to use monitored 2012-2014 PM data for determining the background concentration than to use a modeled 2015 background value.
- **Time lag between a SIP submission and EPA approval.** As of early 2016, completing PM hot-spot analyses was still a relatively new requirement, and many of the interagency consultation decision practices had yet to be firmly established. Therefore, it is unclear whether, through interagency consultation, EPA will agree to allow CTM results to be used for hot-spot analyses if the CTM results are not already part of an EPA-approved SIP or regulatory action. Analysts wishing to use CTM results should gain interagency support before proceeding to complete analysis work.

[62] Instead of calculating the RRF for the single CTM grid cell containing the monitor, the RRF can be based on a 3-by-3 array of grid cells centered on the CTM grid cell containing the monitor.
[63] EPA recommends a method for reconstructing the measured $PM_{2.5}$ species so they add up to the total $PM_{2.5}$ mass measured by the filter-based monitor. This method includes various empirical adjustments to account for measurement artifacts and uncertainties. This reconstruction method is included in MATS (see the text box on the previous page).

- **Enforceability of future emissions reductions.** In some cases, particularly in EPA regulatory impact analyses, certain CTM modeling scenarios include future emissions reductions from a *proposed* rule or *hypothetical emissions reductions* that are not associated with enforceable SIP commitments or state or Federal rules. Interagency consultation is necessary to ensure that any future-year CTM results were based on enforceable emissions reductions, and that the emission reductions and associated assumptions are valid for a project-level PM hot-spot analysis.

4.2.6 Summary

Two technical approaches can be used to determine background PM concentrations from CTM data. The first approach uses future-year background values that have already been calculated from the CTM results at specific PM monitoring locations and have been published in documents that are readily available from EPA, CARB, a local AQMD, or are otherwise in the public domain. The second approach involves processing gridded CTM outputs from at least two CTM modeling simulations (a base-year and future-year simulation) and using EPA's MATS software to calculate future-year background values. This second approach is much more resource-intensive and requires additional coordination with EPA, CARB, or a local AQMD to acquire and process the gridded CTM data, and is likely not practical for Caltrans transportation hot-spot analyses.

Processed future-year background values are readily available for a number of selected monitors in California from the three regulatory CTM analyses listed in Table 4-3. The analysis years with CTM results range from 2019 to 2030 and are sufficiently far into the future to be relevant for PM hot-spot analyses.

The development of future-year PM background concentrations is a relatively new process for conformity hot-spot work. Project analysts are strongly encouraged to engage interagency consultation partners earlier in their project work, and to ensure that the interagency conformity working group supports the planned background concentration calculation methods before these methods are applied.

5. Project-Level PM Mitigation Concepts

5.1 Introduction

Mitigation measures to reduce transportation project impacts may be needed if a project fails to pass the conformity test in a quantitative PM hot-spot analysis. We identified potential PM mitigation measures and conducted a preliminary assessment of their applicability at the project scale. This preliminary assessment provides a basis for determining which mitigation options will be evaluated further.

5.2 Identification of Potential Measures

In general, mitigating PM hot-spot impacts requires modifying project features to reduce PM emissions (exhaust, tire wear, brake wear, and road dust) and thus to reduce PM concentrations at the project site. Vehicle fleet characteristics and travel activities directly influence PM emissions, and project infrastructure characteristics may also have an influence.

Some limited information identifies potential project mitigation options. For example, in its quantitative PM hot-spot analysis guidance, the U.S. Environmental Protection Agency (EPA) identified several categories of mitigation measures, such as retrofitting vehicles, replacing vehicles/engines, using cleaner fuels, reducing truck and bus idling, redesigning the project, controlling fugitive dust, and controlling other sources of emissions (U.S. Environmental Protection Agency, 2013). Also, Caltrans has sponsored development of a PM hot-spot analysis guidebook (Bai et al., 2017), which explains the emissions and air quality implications of fleet turnover, fleet mix changes, travel speed changes, and distance variations between emission sources and receptors. However, real-world examples of PM mitigation measures implemented at the project level have not been available. Project sponsors and analysts are still in the process of gaining practical experience in hot-spot analyses and exploring new ideas for mitigation measures.

5.3 Framework to Consider Mitigation

Figure 5-1 shows a framework for identifying and organizing mitigation options in the context of transportation projects. As shown in the following discussion, project analysts may consider four broad factors when developing mitigation approaches.

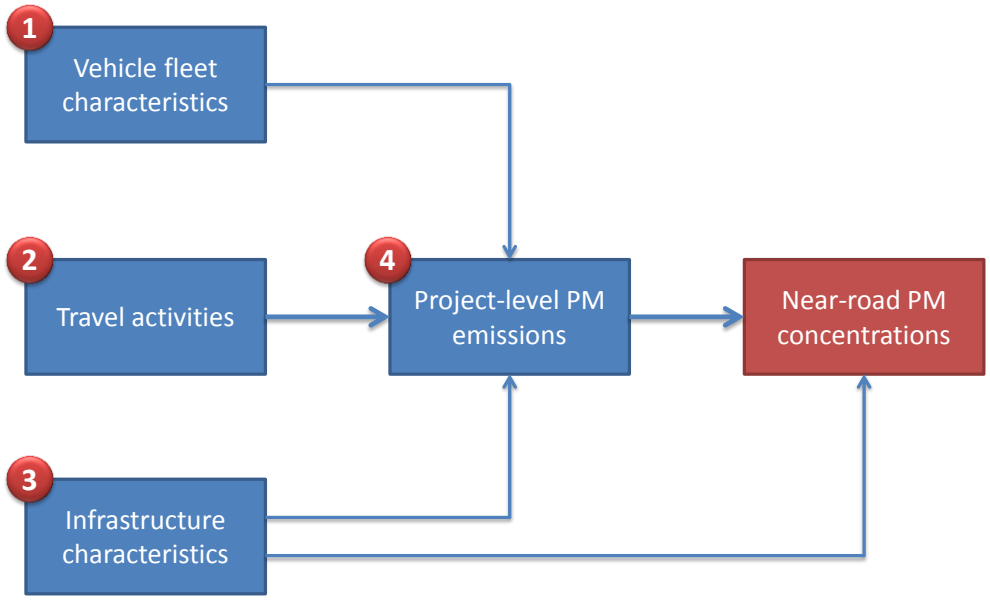


Figure 5-1. Framework for considering PM mitigation measures in a project context.

1. **Changing vehicle fleet characteristics (e.g., vehicle age and technology) to reduce PM emissions.** The basic concept for this mitigation approach is to change the vehicle fleet by replacing older, higher-emitting vehicles with newer, lower-emitting vehicles. This approach includes benefits from fleet turnover and from retrofitting or replacing older diesel trucks/buses. Because these measures do not change travel activities (i.e., vehicle miles traveled), they only affect exhaust PM emissions and do not reduce tire wear, brake wear, and road dust PM emissions.

2. **Changing travel activities (e.g., volume, speed, and idle time) to reduce PM emissions.** This category of mitigation measure typically involves removing or relocating traffic volumes, optimizing travel speed, and reducing idle time (especially for diesel traffic) at the project site. In addition to changing exhaust emissions, certain mitigation measures in this category may reduce road dust emissions by moving vehicle activities from high silt loading facilities (e.g., local streets) to low silt loading facilities (e.g., freeway segments).

3. **Changing project infrastructure (e.g., design changes, paved shoulders, and roadside barriers) to reduce PM emissions and concentrations.** Some measures in this category, such as paving unpaved shoulders and roads at the project site, can directly reduce PM emissions. Other mitigation concepts in this category, such as adding roadside barriers or elevating the roadway above grade, have the potential to mitigate PM concentrations at nearby receptors. The measures related to infrastructure changes usually require design changes and may substantially increase project cost.

4. **Controlling non-vehicular PM emissions directly from the project site.** Instead of changing project features, mitigation measures under certain project conditions (e.g., street sweeping) can be applied to directly reduce road dust emissions.

5.4 Assessment and Prioritization

Using the framework and categories described above, we identified 12 potential PM mitigation measures; these are summarized in Tables 5-1 through 5-4. For each mitigation measure, we discuss the basic approach, assess the limitations and potential project impacts expected on the basis of previous studies (if available), and assign an overall level (high, medium, low) of applicability at the project scale.

Table 5-1. Summary of potential PM mitigation through changing vehicle fleet characteristics.

Potential Measures	Mitigation Concepts	Assessment	Overall Applicability
Fleet turnover	Postponing projects to take advantage of additional fleet turnover benefits may reduce PM exhaust impacts.	More feasible at the regional level, instead of project level; applicable only to exhaust emissions; prior studies showed larger reduction in $PM_{2.5}$ during the near term (2015–2025) and minor impact on PM_{10} (Bai et al., 2017; Reid et al., 2016b).	Low
Truck retrofit or replacement	Retrofitting or replacing older diesel trucks/buses can reduce PM exhaust emissions and near-road impacts.	More feasible at the regional level or special areas such as port-related facilities; applicable only to exhaust emissions and certain infrastructure projects involving a special vehicle fleet (e.g., trucks at an intermodal terminal or buses at a transit terminal).	Low

Table 5-2. Summary of potential PM mitigation through changing travel activities.

Potential Measures	Mitigation Concepts	Assessment	Overall Applicability
Relocate and reduce traffic	Relocating general vehicle traffic or truck traffic from an existing, heavily congested, high silt loading facility (e.g., local street) to the project (e.g., freeway) may result in a net PM benefit.	May be more widely applicable to PM exhaust and fugitive dust emissions; may require project design changes; modeling and case studies to estimate potential project impacts and ensure interagency support are lacking.	High
Idle time reduction	Limiting vehicle idle time can reduce a portion of PM exhaust impacts.	Applicable to idle exhaust emissions only (a small portion of total project PM emissions); limited to certain terminal or special infrastructure projects that involve vehicle idle activities (e.g., bus transit terminal).	Low
Speed limit management	Restricting speed limit to an emission-optimized level may reduce PM exhaust impacts.	Applicable to exhaust emissions only; previous modeling analyses showed minimal impact on overall PM emissions and near-road PM concentrations, particularly in future years (Bai et al., 2017).	Low

Table 5-3. Summary of potential PM mitigation through changing project infrastructure.

Potential Measures	Mitigation Concepts	Assessment	Overall Applicability
Roadside barriers	Building barriers along the freeway can reduce near-road PM concentrations.	Applicable to freeway projects only and limited to areas without existing roadside barriers (no-build); some modeling and case study analyses exist, but additional research and interagency consultation is required; mitigation benefits are likely greatest for solid barriers as opposed to vegetative screens.	High
Buffer zone	Moving near-road receptors farther from the project (e.g., through purchasing additional right-of-way) may reduce the project impact.	Applicable to projects where physical spaces are available for creating buffer zones (increasing distance between the road and receptors such as schools and residences); may require design changes and involve substantial project costs.	Medium
Improvement of unpaved shoulders or unpaved roads	Paving unpaved shoulders and roads can reduce fugitive dust emissions and PM impacts.	Applicable to dust (mainly PM_{10}) emissions only; limited to projects that involve previously unpaved shoulders or unpaved roads in the no-build scenario.	Low
Designated truck lane	Moving truck traffic to a dedicated inner lane, farther from near-road receptors, may reduce overall project PM impacts.	Requires design and configuration changes and may substantially increase project cost; previous modeling analyses showed minor near-road PM impacts (Bai et al., 2017).	Low
Elevated or depressed roadway	Building the roadway above or below grade may affect pollutant dispersion and reduce near-road PM impacts.	Requires design and configuration changes; more expensive to build than at-grade highways; requires additional research, modeling evaluations, and interagency consultation.	Low

Table 5-4. Summary of potential PM mitigation through controlling emissions directly.

Potential Measures	Mitigation Concepts	Assessment	Overall Applicability
Street sweeping	Sweeping streets can reduce fugitive dust emissions and near-road PM impacts.	Applicable to dust (mainly PM_{10}) emissions only; limited to arterials and local roads; sweepers have long been used to reduce PM, but studies have showed mixed results (Nanzetta et al., 2005).	Medium
Control of additional emissions	Control of additional (non-project-related) emissions sources in the project area can reduce background PM concentrations.	Applicable to rare cases where a separate major emission source is identified and has impact on the project site; may substantially increase project cost and the need for additional modeling analyses to quantify reduction impacts.	Low

5.5 Recommendation for Further In-Depth Analysis

As documented in Tables 5-1 through 5-4, current PM hot-spot analysis experiences suggest that, for most transportation projects, practical options for mitigating project-level PM impacts are very limited. Several major challenges exist, including:

(a) Many options are more feasible at the regional scale and are difficult to directly incorporate into a highway project;

(b) Many options impact only exhaust emissions, which are expected to sharply decrease in importance compared to tire wear, brake wear, and dust emissions in future years (Bai et al., 2017; Reid et al., 2016b); and

(c) The implementation of individual mitigation measures or groups of measures may substantially increase project costs and hot-spot analysis time (e.g., redesign of the project, additional modeling, and interagency consultation).

Given these challenges, we recommend that the analysis phase of this task focus on the mitigation options identified in Tables 5-1 through 5-4 as having high applicability at the project level, rather than expending resources on mitigation options that are likely applicable to a very limited range of transportation projects. Specifically, we identified roadside barriers and the “relocate and reduce” concept as mitigation options that are most likely applicable at the project level.

Also, because the air quality benefits of roadside barriers are being evaluated in another research effort with which Caltrans is involved, we recommend that the analysis phase of this task focus on developing a case study illustrating conditions under which the "relocate and reduce" concept would be relevant and effective. EPA's quantitative PM hot-spot analysis guidance discusses this concept in the context of a build/no-build analysis, stating that, in some cases, a "new" violation of the National Ambient Air Quality Standards (NAAQS) in the build scenario could actually be the relocation of a violation that was already present in the no-build scenario. The guidance notes that this interpretation has been made in limited cases with CO hot-spot analyses, and that relocated violations in a PM hot-spot analysis would have to be evaluated through the interagency consultation process (U.S. Environmental Protection Agency, 2013).

Through personal communication, EPA staff expressed interest in seeing a "relocate and reduce" PM hot-spot case study that could be used to help interagency partners evaluate this mitigation option. In the PM hot-spot context, the relocation and reduction of a NAAQS violation would likely be accomplished by shifting traffic from a congested arterial road with high silt loading to a less congested freeway with lower silt loading. Developing a case study with a range of modeling scenarios (e.g., traffic volumes, truck traffic, and speeds) would provide insights into the conditions under which the "relocate and reduce" measure may have greatest applicability.

6. References

Abt Associates, Inc. (2014) Modeled Attainment Test Software user's manual. Prepared for the Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC, by Abt Associates, Inc., Bethesda, MD, April.

Abu-Allaban M., Gillies J.A., Gertler A.W., Clayton R., and Proffitt D. (2003) Tailpipe, resuspended road dust, and brake-wear emission factors from on-road vehicles. *Atmos. Environ.*, 37(37), 5283-5293, Dec.

Bahreinian A. (2013) Transportation energy demand forecast. Presented at the *California Energy Commission FTD Transportation Public Workshop, Sacramento, CA, August 21,* by the California Transportation Energy Office Fuels and Transportation Division, Sacramento, CA. Available at http://www.energy.ca.gov/2013_energypolicy/documents/2013-08-21_workshop/presentations/01_Bahreinian_Transportation_Energy_Forecast.pdf.

Bai S., Pasch A.N., Craig K.J., Eisinger D.S., Niemeier D., Graham A.R., and Brown S.G. (2014) Quantitative particulate matter hot-spot analysis guidance, v3.2. Final revised report prepared for the California Department of Transportation (Caltrans), Sacramento, CA, by Sonoma Technology, Inc., Petaluma, CA, CTAQ-RT-14-317.02.01; STI 909116-5518-FR, November 26.

Bai S., Craig K., Reid S., Eisinger D., Farstad E., Erdakos G., Du Y., and Baringer L. (2017) Quantitative particulate matter hot-spot analysis best practices guidebook. Prepared for the California Department of Transportation, Sacramento, CA, CTAQ-RT-17-317.02.6, May.

Cahill T.A., Feeney P.J., Flocchini R.J., and Dunn T. (1973) Contribution of freeway traffic to airborne particulate matter. Final report prepared for the California Air Resources Board, June 15. Available at https://www.arb.ca.gov/research/apr/past/arb-502.pdf.

California Air Resources Board (2010) Total particulate matter emission factors. Section 4.12 in On-road emission model methodology documentation, April. Available at http://www.arb.ca.gov/msei/onroad/doctable_test.htm.

California Air Resources Board (2011) EMFAC2011: technical documentation. September 29.

California Air Resources Board (2014) Multi-regulation summary (MRS): requirements for diesel truck and equipment owners. Website prepared by the California Air Resources Board, Sacramento, CA. Available at http://www.arb.ca.gov/msprog/onrdiesel/documents/multirule.pdf. November.

California Air Resources Board (2015a) Technology assessment: heavy-duty hybrid vehicles. Draft report, November. Available at http://www.arb.ca.gov/msprog/tech/techreport/hybrid_tech_report.pdf.

California Air Resources Board (2015b) EMFAC2014 Volume III: technical documentation, v1.0.7. May 12. Available at http://www.arb.ca.gov/msei/downloads/emfac2014/emfac2014-vol3-technical-documentation-052015.pdf.

California Air Resources Board (2016) Miscellaneous process methodology 7.9. November. Available at https://www.arb.ca.gov/ei/areasrc/fullpdf/full7-9_2016.pdf.

Campbell S. (2014) Tire and wheel trends update. Website prepared by the Specialty Equipment Market Association, Diamond Bar, CA. Available at https://www.sema.org/sema-news/2014/02/tire-and-wheel-trends-update. February.

Campbell S. (2015) 2015 tire & wheel trends. Website prepared by the Specialty Equipment Market Association, Diamond Bar, CA. Available at https://www.sema.org/sema-news/2014/02/tire-and-wheel-trends-update. February.

Carbotech (1999) PM_{10} - emissionsfaktoren: mechanischer abrieb im offroad-bereich (PM10 - emission factors: mechanical abrasion in the offroad segment). *Arbeitsunterlage 17 im Aftrag des BUWAL, Basel*, December. Cited in U.S. Environmental Protection Agency, 2014.

Centric Parts (2012) Brake friction material legislation. Website prepared by Centric Parts, Industry, CA. Available at http://www.centricparts.com/tech-support/brake-pad-material-legislation.

Cimorelli A.J., Perry S.G., Venkatram A., Weil J.C., Paine R.J., Wilson R.B., Lee R.F., Peters W.D., Brode R.W., and Paumier J.O. (2004) AERMOD: description of model formulation. Report by the U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Emissions Monitoring and Analysis Division, Research Triangle Park, NC, EPA-454/R-03-004, September. Available at http://www.epa.gov/scram001/7thconf/aermod/aermod_mfd.pdf.

Cody J., Göl Ö., Nedic Z., Nafalski A., and Mohtar A. (2009) Regenerative braking in an electric vehicle. *Zeszyty Problemowe – Maszyny Elektryczne*, 81, 113-118. Available at http://www.komel.katowice.pl/ZRODLA/FULL/81/ref_20.pdf.

Colorado Department of Transportation (2016) Air quality technical report: I-70 East final environmental impact statement. January. Available at http://www.i-70east.com/FinalEIS/chapters/I-70EastFEIS_Vol2AttJ_Air-Quality.pdf.

Craig K. and Bai S. (2014) Guidance and resources for developing AERMOD-ready meteorological data using AERMET View. Technical memorandum prepared for California Department of Transportation, District 7, Los Angeles, CA, by Sonoma Technology, Inc., Petaluma, CA, STI-914102-6048-TM, August 27.

Craig K.J. and Reid S.B. (2015) Introduction to air quality modeling tools: two-day hands-on workshop. Training course presented to the California Department of Transportation, Sacramento, CA, November 3-4, by Sonoma Technology, Inc., Petaluma, CA. STI-914103-6383.

Erdakos G. and Craig K. (2015a) Representing roadway emission sources in AERMOD (webinar 1 of 2). Webinar presented to the California Department of Transportation, Sacramento, CA, February 17, by Sonoma Technology, Inc., Petaluma, CA. STI-914103-6107.

Erdakos G. and Craig K. (2015b) Representing roadway emission sources in AERMOD (webinar 2 of 2). Webinar presented to the California Department of Transportation, Sacramento, CA, February 19, by Sonoma Technology, Inc., Petaluma, CA. STI-914103-6108.

Erdakos G.B., Pasch A.N., Bai S., and Eisinger D.S. (2013) Guidance for using AERMOD View in particulate matter hot-spot analyses. Training materials prepared for the California Department of

Transportation, Sacramento, CA, September 27, by Sonoma Technology, Inc., Petaluma, CA. CTAQ-OT-13-270.19.1, STI-909119-5769.

Evans L., MacIsaac J., Jr., Harris J., Yates K., Dudek W., Holmes J., Popio J., Rice D., and Salaani M.K. (2009) NHTSA tire fuel efficiency consumer information program development, Phase 2: effects of tire rolling resistance levels on traction, treadwear, and vehicle fuel economy. Prepared for the National Highway Traffic Safety Administration, U.S. Department of Transportation, Washington, D.C., DOT HS 811 154, August.

Garg B.D., Cadle S.H., Mulawa P.A., Groblicki P.J., Laroo C., and Parr G.A. (2000) Brake wear particulate matter emissions. *Environ. Sci. Technol.*, 34(21), 4463-4469, doi: 10.1021/es001108h.

Global Industry Analysts Inc. (2015) The global automotive aftermarket brake friction parts market - trends, drivers and projections. Website prepared by Global Industry Analysts, Inc., San Jose, CA. Available at http://www.strategyr.com/MarketResearch/Automotive_Aftermarket_Brake_Friction_Parts_Market_Trends.asp. January.

Graham A., Bai S., and Eisinger D. (2014) Establishing representative background concentrations for quantitative PM hot-spot analyses in California. Final report prepared for California Department of Transportation, Sacramento, CA by Sonoma Technology, Inc., Petaluma, CA,, STI-914102-6151, December 30.

Heist D.K., Perry S.G., and Brixey L.A. (2009) A wind tunnel study of the effect of roadway configurations on the dispersion of traffic-related pollution. *Atmos. Environ.*, 43, 5101-5111. Available at https://cfpub.epa.gov/si/si_public_file_download.cfm?p_download_id=490009.

Kupiainen K.J., Tervahattu H., Räisänen M., Mäkelä T., Aurela M., and Hillamo R. (2005) Size and composition of airborne particles from pavement wear, tyres, and traction sanding. *Environ. Sci. Technol.*, 39(3), 699–706, doi: 10.1021/es035419e.

Larson S., Calwell C., Ton M., Gordon D., Reeder T., Olson M., Foster S., Blackburn B., Koyama K., Ridgley K., and Treanton B.G. (2003) California state fuel-efficient tire report: volume II. Consultant report prepared for the California Energy Commission, Sacramento, CA, by TIAX LLC, Cupertino, CA, 600-03-011CR. Available at http://www.energy.ca.gov/reports/2003-01-31_600-03-001CRVOL2.PDF.

Luhana L., Sokhi R., Warner L., Mao H., Boulter P., McCrae I., Wright J., and Osborn D. (2004) Measurement of non-exhaust particulate matter, version 2.0. Report sponsored by the European Commission Directorate General Transport and Environment, Brussels, Belgium, deliverable No. 8 (revised), October. Available at http://ec.europa.eu/transport/roadsafety_library/publications/particulates_d8.pdf.

McBride B. (2015) Forecast of medium and heavy duty vehicle fleet. Presented at the *California Energy Commission IEPR Commissioner Workshop on the Revised Transportation Energy Demand Forecasts, Sacramento, CA, November 24,* by the California Energy Commission Energy Assessments Division, Sacramento, CA. Available at http://docketpublic.energy.ca.gov/PublicDocuments/15-IEPR-10/TN206743_20151124T085912_Forecast_of_California's_Medium_and_Heavy_Duty_Fleet.ppt.

Nanzetta K., Eisinger D., Kear T., O'Loughlin R., Brady M.J., and Niemeier D. (2005) Particulate matter and transportation projects, an analysis protocol. Final technical report prepared for the California Department of Transportation Environmental Program and the U.S. Federal Highway Administration Western Resource Center by U.C. Davis, the U.S. Federal Highway Administration, and the California Department of Transportation, February. Available at http://aqp.engr.ucdavis.edu/Documents/Qual%20PM%20Feb%202005%20Final%20Report.pdf.

National Cooperative Highway Research Program (2008) Alternative methods for determining emissions for re-entrained road dust on transportation projects. Final report prepared by the Midwest Research Institute and Parsons Brinckerhoff, December. Available at http://environment.transportation.org/pdf/research_news/nchrp25-25_task42finalreport.pdf.

National Highway Traffic Safety Administration (2009) Notice of proposed rulemaking replacement tire consumer information program, part 575.106. Preliminary regulatory impact analysis, June. Available at http://www.nhtsa.gov/DOT/NHTSA/Rulemaking/Rules/Associated%20Files/PRIA-RollingResistance.pdf.

National Highway Traffic Safety Administration (2010) Replacement tire consumer information program, part 575.106. Final regulatory impact analysis, March. Available at http://www.nhtsa.gov/staticfiles/rulemaking/pdf/Rolling_Resistance_FRIA.pdf.

NUCAP Brakes (2011) What are the latest trends in brake friction materials? Website prepared by NUCAP Inc., Toronto, Ontario, Canada. Available at http://nucapbrakes.com/blog/2011/09/what-are-the-latest-trends-in-brake-friction-materials/. September 20.

Pasch A., Craig K., Bai S., Pollard E., Eisinger D., and Du Y. (2012) Selecting and processing representative meteorological data for use in AERMOD to complete quantitative PM hot-spot analyses. Technical memorandum prepared for California Department of Transportation, Sacramento, CA, by Sonoma Technology, Inc., Petaluma, CA, STI-909116-5380-TM, May 21.

Pearce J.M. and Hanlon J.T. (2007) Energy conservation from systematic tire pressure regulation. *Energy Policy*, (35), 2673-2677, doi: 10.1016/j.enpol.2006.07.006.

Ratrout N.T. (2005) Tire condition and drivers' practice in maintaining tires in Saudi Arabia. *Accident Analysis & Prevention*, 37, 201-206, doi: 10.1016/j.aap.2003.03.001.

Rauterberg-Wulff A. (1999) Determination of emission factors for tyre wear particles up to 10µm by tunnel measurements. *Proceedings of 8th International Symposium 'Transport and Air Pollution', Graz, Austria, May 31 - June 2*.

Reid S., Bai S., Du Y., Craig K., Erdakos G., Baringer L., Eisinger D., McCarthy M., and Landsberg K. (2016a) Emissions modeling with MOVES and EMFAC to assess the potential for a transportation project to create particulate matter hot spots. *Transportation Research Record: Journal of the Transportation Research Board*, 2570, 12-20, doi: 10.3141/2570-02 (STI-6330).

Reid S.B., Bai S., Eisinger D.S., Erdakos G.B., Du Y., and Baringer L. (2016b) Scoping study to identify potential project types and situations that will not create PM hot spots. Final report prepared for the Washington State Department of Transportation, Seattle, WA, by Sonoma Technology, Inc., Petaluma, CA, STI-914202-6259-FR, February.

San Joaquin Valley Air Pollution Control District (2012) 2012 $PM_{2.5}$ plan. State Implementation Plan developed by the San Joaquin Valley Air Pollution Control District, Fresno, CA, December 20. Available at http://www.valleyair.org/Air_Quality_Plans/PM25Plans2012.htm.

Sandberg U. (1997) Influence of road surface texture on traffic characteristics related to environment, economy and safety: a state of the art study regarding measures and measuring methods. Study by the Swedish National Road and Transport Research Institute (VTI), Linköping, Sweden, VTI notat 53A-1997.

Sanders P.G., Xu N., Dalka T.M., and Maricq M.M. (2003) Airborne brake wear debris: size distributions, composition, and a comparison of dynamometer and vehicle tests. *Environ. Sci. Technol.*, 37(18), 4060-4069, doi: 10.1021/es034145s, September 15.

Skydel S. (2014) Report card: FMVSS 121 reduced stoping distance regulation. *Fleet Equipment Magazine*, website prepared by Babcox Media, Inc., Akron, OH, August 13. Available at http://www.fleetequipmentmag.com/reduced-stopping-distance-regulation-report-card/.

South Coast Air Quality Management District (2013) Final 2012 air quality management plan. State Implementation Plan developed by the South Coast Air Quality Management District, Diamond Bar, CA, February. Available at http://www.aqmd.gov/home/library/clean-air-plans/air-quality-mgt-plan/final-2012-air-quality-management-plan.

Steffens J., Heist D., Perry S., Isakov V., Baldauf R., and Zhang K.M. (2014) Effects of roadway configurations on near-road air quality and the implications on roadway designs. *Atmos. Environ.*, 94, 74-85, doi: http://dx.doi.org/10.1016/j.atmosenv.2014.05.015, September. Available at http://www.sciencedirect.com/science/article/pii/S1352231014003628.

Sturgess S. (2010) Friction in focus: trends in brake friction manufacturing. *HDT Trucking Magazine*, website prepared by Bobit Business Media, Torrance, CA, July. Available at http://www.truckinginfo.com/article/story/2010/07/friction-in-focus-trends-in-brake-friction-manufacturing.aspx.

Thiriez K. and Boudy N. (2001) NHTSA's tire pressure special study. Prepared by the National Highway Traffic Safety Administration, U.S. Department of Transportation, Paper Number 256, February.

Transport Research Laboratory (2014) Briefing paper on non-exhaust particulate emissions from road transport. Prepared for the Low Emission Partnership, Woolwich, Greater London, United Kingdom, by Tim Barlow, Transport Research Laboratory, Wokingham, Berkshire, United Kingdom, Client project report CPR1976. Available at http://www.lowemissionstrategies.org/downloads/Jan15/Non_Exhaust_Particles11.pdf.

Transportation Research Board (2006) Tires and passenger vehicle fuel economy: informing consumers, improving performance. Prepared by the Committee for the National Tire Efficiency Study, Transportation Research Board, National Research Council of the National Academies, Washington, D.C., TRB Special Report 286.

U.S. Environmental Protection Agency (1995) User's guide for the Industrial Source Complex (ISC3) dispersion models, volume II – description of model algorithms. EPA-454/B-95-003b, September. Available at https://www3.epa.gov/scram001/userg/regmod/isc3v2.pdf.

U.S. Environmental Protection Agency (2003a) Compilation of air pollutant emission factors, AP-42. Vol. 1: stationary point and area sources. Section 13.2.2, unpaved roads. December. Available at http://www.epa.gov/ttn/chief/ap42/ch13/.

U.S. Environmental Protection Agency (2003b) Compilation of air pollutant emission factors, AP-42. Vol. 1: stationary point and area sources. Section 13.2.1, paved roads. December. Available at http://www.epa.gov/ttn/chief/ap42/ch13/.

U.S. Environmental Protection Agency (2005a) Revision to the guideline on air quality models: adoption of a preferred general purpose (flat and complex terrain) dispersion model and other revisions; Final Rule (40 CFR Part 51). *Federal Register*, 70(216), November 9. Available at http://www.epa.gov/ttn/scram/guidance/guide/appw_05.pdf.

U.S. Environmental Protection Agency (2005b) Methodology to estimate the transportable fraction (TF) of fugitive dust emissions for regional and urban scale air quality analyses. Prepared by Thompson G. Pace, U.S. Environmental Protection Agency, Washington, DC. Available at http://www3.epa.gov/ttnchie1/emch/dustfractions/transportable_fraction_080305_rev.pdf. August 3.

U.S. Environmental Protection Agency (2010) Transportation conformity guidance for quantitative hot-spot analyses in $PM_{2.5}$ and PM_{10} nonattainment and maintenance areas: Appendices. Guidance document prepared by the Transportation and Regional Programs Division, Office of Transportation and Air Quality, EPA-420-B-10-040, December. Available at http://www.epa.gov/otaq/stateresources/transconf/policy/420b10040-appx.pdf.

U.S. Environmental Protection Agency (2011) Chapter 13: miscellaneous sources, 13.2.1 paved roads. In *Emissions Factors & AP 42, Compilation of Air Pollutant Emissions Factors*, 5th edition. Available at http://www3.epa.gov/ttn/chief/ap42/ch13/final/c13s0201.pdf.

U.S. Environmental Protection Agency (2012a) Regulatory impact analysis for the final revisions to the National Ambient Air Quality Standards for particulate matter. EPA-452/R-12-005, December. Available at http://www3.epa.gov/ttnecas1/regdata/RIAs/finalria.pdf.

U.S. Environmental Protection Agency (2012b) Air quality modeling technical support document for the regulatory impact analysis for the revisions to the national ambient air quality standards for particulate matter. December. Available at http://www3.epa.gov/ttn/naaqs/standards/pm/data/201212aqm.pdf.

U.S. Environmental Protection Agency (2013) Transportation conformity guidance for quantitative hot-spot analyses in $PM_{2.5}$ and PM_{10} nonattainment and maintenance areas. Prepared by the EPA Office of Transportation and Air Quality, Transportation and Climate Division, EPA-420-B-13-053, November. Available at http://www.epa.gov/omswww/stateresources/transconf/policy/420b13053-sec.pdf.

U.S. Environmental Protection Agency (2014a) Brake and tire wear emissions from on-road vehicles in MOVES2014. Technical report by the Office of Transportation and Air Quality, Assessment and Standards Division, EPA-420-R-14-013, December. Available at http://www.epa.gov/oms/models/moves/documents/420r14013.pdf.

U.S. Environmental Protection Agency (2014b) Other Test Method – 34: Method to quantify road dust particulate matter emissions (PM_{10} and/or $PM_{2.5}$) from vehicular travel on paved and unpaved roads. January 15. Available at http://www3.epa.gov/ttn/emc/prelim/otm34.pdf.

U.S. Environmental Protection Agency (2014c) Draft modeling guidance for demonstrating attainment of air quality goals for ozone, $PM_{2.5}$, and regional haze. Technical memorandum prepared for Regional Air Division Directors, Regions 1-10, U.S. Environmental Protection Agency, December 3.

U.S. Environmental Protection Agency (2014d) Project level training for quantitative PM hot-spot analyses. Available at http://www3.epa.gov/otaq/stateresources/transconf/training3day.htm#download.

U.S. Environmental Protection Agency (2015a) Revision to the guideline on air quality models: enhancements to the AERMOD dispersion modeling system and incorporation of approaches to address ozone and fine particulate matter; proposed rule. *Federal Register*, 80(145), 45340-45387, (EPA–HQ–OAR–2015–0310; FRL–9930–11–OAR), July. Available at https://www3.epa.gov/ttn/scram/11thmodconf/EPA-HQ-OAR-2015-0310-0001.pdf.

U.S. Environmental Protection Agency (2015b) Addendum: user's guide for the AMS/EPA regulatory model - AERMOD (EPA-454/B-03-001, September 2004). Updated user instructions by the Office of Air Quality Planning and Standards, Research Triangle Park, NC, EPA-454/B-03-001, June. Available at http://www.epa.gov/ttn/scram/models/aermod/aermod_userguide.zip.

U.S. Environmental Protection Agency (2015c) Transportation conformity guidance for quantitative hot-spot analyses in $PM_{2.5}$ and PM_{10} nonattainment and maintenance areas. Prepared by the EPA Office of Transportation and Air Quality, Transportation and Climate Division, Washington, DC, EPA-420-B-15-084, November. Available at https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100NMXM.pdf, appendix available at https://nepis.epa.gov/Exe/ZyPdf.cgi?Dockey=P100NN22.pdf.

U.S. Environmental Protection Agency (2015d) Addendum: User's guide for the AERMOD meteorological preprocessor (AERMET). June.

Waddell W.H. (2008) Summary: inflation pressure retention effects on tire rolling resistance, vehicle fuel economy and CO_2 emissions. Presented to the California Air Resources Board, Sacramento, CA, by ExxonMobil Chemical, Houston, TX, June 4.

Westerlund K.-G. (2001) Metal emissions from Stockholm traffic - wear of brake linings. Report by the Stockholm Air Quality and Noise Analysis, Stockholm, Sweden, Analysis No. 3:2001. Available at http://www.slb.mf.stockholm.se/slb/rapporter/pdf/metal_emissions2001.pdf.

Witzenburg G. (2014) A look at low-rolling resistance tires. Website by AutoBlog.com, Birmingham, MI. Available at http://www.autoblog.com/2014/06/05/looking-at-low-rolling-resistance-tires/. June 5.