Technical Support Document (TSD) for Replacement of CALINE3 with AERMOD for Transportation Related Air Quality Analyses

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Preface

This document provides a comparison of CALINE3 and AERMOD, including an analysis of the scientific merit of each dispersion model, a summary of existing model evaluations, and the presentation of additional testing by EPA.

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1. Introduction

The proposed revisions to EPA's *Guideline on Air Quality Models*, published as Appendix W to 40 CFR Part 51, include the proposal to remove CALINE3 for mobile source applications from Appendix A and replace it with AERMOD (80 FR 45340- 45387, July 29, 2015). This document provides the technical details supporting this proposed change, including the scientific merit of each dispersion model, summary of existing model evaluations, and presentation of additional testing by EPA used to determine appropriate application of these options as part of the proposal for AERMOD to be the required refined model for mobile source dispersion modeling.

2. Background

The version of Appendix W that was published in 2005 (70 FR 68218- 68261, Nov. 9, 2005), addresses modeling mobile sources, with specific recommendations for each criteria pollutant. AERMOD is currently EPA's recommended near-field dispersion model for regulatory applications. In addition, for carbon monoxide (CO), CAL3QHC is recommended for screening and CALINE3 for free flow situations. For lead (Pb), CALINE3 and CAL3QHCR are identified for highway emissions, while for nitrogen dioxide (NO2), CAL3QHCR is listed as an option. No models for mobile emissions are explicitly identified for coarse particulate matter (PM10), fine particulate matter (PM2.5), or sulfur dioxide (SO2), though CALINE3 is listed in Appendix A as appropriate for highway sources for averaging times of 1-24 hours.

2.1 CALINE3 history and status

The first CALINE line model was initially developed in 1972, with a focus on predicting CO concentrations near roadways (Benson, 1992). CALINE2 was developed in 1975, porting CALINE to FORTRAN and adding formulations for depressed roadways (Benson, 1992). CALINE3, which was developed in 1979 (Benson, 1979), updated the vertical and horizontal dispersion curves, reducing, but not eliminating, the over-predictions occasionally seen in CALINE2 (Benson, 1992). CALINE3 also updated the available averaging time, parameterized vehicle-induced turbulence, replaced the virtual point source with a finite line source, and increased the number of links capable in the model. CALINE3 was replaced by CALINE4 in 1984 (Benson, 1984), with further modifications to the lateral plume spread and vehicle induced turbulence, the addition of intersections, and limited chemistry for NO2 and PM. Unlike CALINE3, CALINE4 is not open source, such that the model code is not publically available, and thus does not meet the requirements in Appendix W for consideration as a preferred model. The CALINE models are Gaussian plume models, and though changes were made to the dispersion curves with each version, the dispersion curves are based on the Pasquill-Gifford (P-G) stability classes. The P-G stability classes do not reflect state of the science: the ISC dispersion model was also based on the P-G stability classes, and EPA replaced the ISC model with AERMOD in EPA's 2005 revision to Appendix W. Section 2.2 includes additional detail about how stability is defined in AERMOD.

In the late 1980s, CALINE3 was modified to automate estimates of vehicle queue lengths at intersections, resulting in the CAL3QHC screening model (U. S. EPA, 1995). In the early 1990s, further modifications were made to CAL3QHC to update traffic queuing and signaling based on the 1985 Highway Capacity Manual, increasing the number of links and receptors, and to add multiple wind directions to facilitate screening analyses (U. S. EPA, 1995). CAL3QHC was developed primarily for CO hot-spot analyses, computing hourly concentrations using "worse case" meteorology, which can then be

scaled to an 8-hour average to estimate compliance with the CO National Ambient Air Quality Standard (NAAQS).

Shortly after the development of CAL3QHC, additional work was done with the model to allow more refined estimates (rather than screening estimates) of emissions from roadways. The CAL3QHCR model is based on CAL3QHC, but has several modifications, including the ability to run 1 year of hourly meteorology, additional capabilities related to queuing and signalization, the addition of PM to the hard-coded pollutant options, incorporation of the mixing height algorithms from ISCST2, the ability to vary emissions by hour of the week, and the ability to calculate averages longer than 1 hour (Eckhoff & Braverman, 1995). The model was developed for situations when the screening, worst-case estimates from CAL3QHC indicated potential exceedances of the standard and more refined estimates were required. It should be noted that with the incorporation of the ISCST2 mixing height algorithms, CAL3QHCR has undergone modifications from the dispersion in CALINE3 and CAL3QHC that have not been reviewed with the same rigor and detail that was conducted for the other two models (Eckhoff & Braverman, 1995). As a result, there is some question as to the equivalency of CAL3QHCR to CALINE3 and CAL3QHC for identical model scenarios. Even so, until this final rule, CAL3QHCR has been listed in text of Appendix W, but not as a preferred model in Appendix A. CALINE3 was originally developed jointly by the Federal Highway Administration (FHWA) and the CA Department of Transportation (Caltrans). EPA sponsored much of the work to develop CAL3QHC and CAL3QHCR in the 1990s. The model codes have been hosted on EPA's dispersion model website.

The CALINE3-based models present some challenges when used for mobile source modeling. Current pre-processed meteorological data cannot be used with these models; the most recent pre-processed meteorological data available for them is from the 1990s. Furthermore, applying the CAL3QHCR model for the 24-hour and annual PM NAAQS requires multiple runs to represent a sufficiently long meteorological data period. For example, where a project-sponsor has off-site meteorological data, one AERMOD run is needed, in contrast to 20 CAL3QHCR runs. The CALINE models can model line sources only, which limit their application to highways and intersections.[1] They cannot be used for any other type of mobile source modeling, such as modeling a project that involves a parking lot or a freight or transit terminal. The use of the queuing algorithm for intersection idle queues is no longer recommended as EPA's MOVES emission factor model now accounts for changes in such activity. In the final rule, CALINE3 has been delisted from Appendix W as a preferred model for refined analyses, but CAL3QHC is available for CO screening until guidance has been developed for CO screening with AERMOD.

2.2 AERMOD history and status

The AMS-EPA Regulatory MODel (AERMOD) was developed over a 10-year period jointly by the American Meteorological Society (AMS) and EPA through the AERMOD Model Improvement Committee (AERMIC). In 2005, AERMOD was promulgated as EPA's preferred dispersion model for most inert pollutants (plus NO2) as part of revisions to Appendix W. The model reflects state of the science formulation for Gaussian Plume dispersion models (Cimorelli, et al., 2005). One of the major updates in AERMOD versus the previous preferred dispersion model, ISCST3, was the transition from the usage of

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[1] Based on implementation since 2010, some PM hot-spot analyses have been completed with CAL3QHCR, although the majority of such analyses have been based on AERMOD.

P-G stability class based parameterizations of dispersion coefficients. As detailed in (Cimorelli, et al., 2005), state of the science models like AERMOD use a planetary boundary layer (PBL) scaling parameter to characterize stability and determine dispersion rates based on Monin-Obukhov (M-O) similarity profiling of winds near the surface. AERMOD's performance was evaluated with 17 field study databases that represent a large variety of source types, local terrain, and meteorology (Perry, et al, 2005). AERMOD was found to be superior to ISCST3 for the majority of the situations modeled.

AERMOD includes options for modeling emissions from volume, area, and point sources and can therefore model the impacts of many different source types, including highways, intersections, intermodal terminals, and transit projects. In addition, EPA conducted a study to evaluate AERMOD and other air quality models in preparation for developing EPA's quantitative PM hot-spot guidance, and the study supported AERMOD's use (Hartley, Carr, & Bailey, 2006). To date, AERMOD has already been used to model air quality near roadways, other transportation sources, and other ground-level sources for regulatory applications by EPA and other federal and state agencies. For example, EPA used AERMOD to model NO2 concentrations as part of the 2008 Risk and Exposure Assessment for revision of the primary NO2 NAAQS (U. S. EPA, 2008). Also, other agencies have used AERMOD to model PM and other concentrations from roadways (represented as a series of volume or area sources) for regulatory purposes, including Clean Air Act transportation conformity analyses. Current pre-processed meteorological data based on AERMET is available for AERMOD from state air agencies, and the model offers efficiencies in calculations needed for the 24-hour and annual PM NAAQS (only one run is needed with site-specific meteorological data in contrast to four runs for CAL3QHCR; one run would be needed with data from off-site, in contrast to 20 runs for CAL3QHCR, (U.S. EPA, 2015)).

As EPA's preferred model, AERMOD has undergone continuous updates and developments in order to improve its performance for particular source types, meteorological conditions, and terrain features as well as to keep the model up to date with state of the science parameterizations for dispersion modeling. One of the major actions of the EPA's revisions to Appendix W is to formally adopt many enhancements made over the past 10 years into AERMOD (version 15181). EPA is committed to continuing to update the AERMOD modeling system to keep it a state of the science dispersion model and to incorporate updates and advancements, as scientifically appropriate, in accordance with the needs of regulatory stakeholders and the broader modeling community. The preamble for the final revised Appendix W and the supporting technical support documents describe the numerous modifications that have been made to AERMOD over the last decade as well as provide details on the scientific basis and model evaluations that have been conducted to continually improve the AERMOD modeling system.

3. Model selection

Section 3.1.1 of the current Appendix W (also section 3.1.1 of the proposed Appendix W) states, "When a single model is found to perform better than others, it is recommended for application as a preferred model and listed in Appendix A." Appendix A lists the models that EPA has determined can be used without any further justification for the particular application they have been identified. There are several requirements for a "preferred model" to be listed in Appendix A (section 3.1.1 of Appendix W),

including that the model is written in a common programming language; the model is well documented; test datasets are available for model evaluation; the model is useful to typical users; there are robust model-to-monitor comparisons; and the source code is freely available. In 2005 when Appendix W was promulgated, there had been no inter-comparisons between AERMOD and CALINE3 with sufficient merit to modify the status of CALINE3 as the preferred model for mobile source applications. However, since 2005, there have been notable model inter-comparisons for AERMOD and CALINE3, as described below, that provided justification for removing CALINE3 from the list in Appendix A in the 2016 Appendix W final rule.

3.1 Model inter-comparison studies

There are several types of model inter-comparison studies that are applicable for mobile source modeling. There are model sensitivity tests that compare model simulations for matching meteorological and emissions scenarios, but lack the ambient monitoring data to evaluate model performance. Alternatively there are studies for which ambient concentration measurements are available along with meteorological data for the measurement site, but emissions are parameterized in some fashion. Typically, traffic counts are used, and an emissions model is applied to estimate vehicular emissions. There can be significant uncertainties for model evaluation in these studies based on errors in the traffic counts, uncertainty in the emission profiles, and estimates that must be made to distribute emissions among different vehicles types, ages, etc. The best studies for model evaluation, however, are field studies based on metered emissions, usually the release of a passive tracer, with little or no background concentrations. These studies generally eliminate uncertainties and allow for the best evaluation of model performance.

When dealing with inert pollutants, a Gaussian dispersion model will operate in the same way regardless of pollutant. While CAL3QHC and CAL3QHCR are hard-coded to convert the input emissions to mixing ratios of CO (or concentrations of PM for CAL3QHCR), the dispersion parameterizations in these models would apply for any pollutant. Therefore, the models' performance can be examined accurately using another inert pollutant such as a passive tracer, as is done in the field studies discussed here.

In (Heist, et al., 2013), a model inter-comparison was conducted, based on data from two field studies that had known, metered emissions of inert SF6 tracers. SF6 is an inert pollutant used as the passive tracer in the studies. The first field study, CALTRANS 99, was conducted along Highway 99 outside Sacramento, CA. CALTRANS 99 used eight automobiles outfitted with SF6 emission units. The automobiles completed circuits of a section of highway during periods when meteorological conditions were favorable, i.e., winds were blowing from the highway to the monitors. SF6 monitors were placed perpendicular to the roadway at 50, 100, and 200 meters (m), with monitors along the roadway median. A total of 14 days of samples were collected for CALTRANS 99. The second field study, carried out in Idaho Falls, ID, was conducted in an open field with SF6 released uniformly along a 54 m long source meant to replicate emissions from a roadway. A grid of 56 monitors were placed downwind of the source at distances ranging from 15-180 m. Data was collected on a total of four days, representing a range of atmospheric stabilities and wind speeds. Both field studies had on-site meteorological measurements.

(Heist, et al., 2013) used these two field studies to evaluate model performance for several dispersion models to determine their ability to model concentrations from roadway emissions in the near-field. The models included AERMOD, CALINE3 and CALINE4, the Atmospheric Dispersion Modelling System (ADMS), which is the UK's preferred dispersion model for regulatory purposes, and RLINE, a research model specifically for roadway sources that is being developed by EPA's Office of Research and Development (ORD). Four statistical measures were computed to benchmark each model's ability to replicate the monitored concentrations. These measures were the fractional bias (FB), normalized mean square error (NMSE), the correlation (R), and the fraction of estimates within a factor of two of the measured value (FAC2). These results are summarized in Table 1 - Model Performance Statistics from the Idaho Falls Study and Table 2.

Table 1 - Model Performance Statistics from the Idaho Falls Study. Source: (Heist, et al., 2013).

Model	FB (0 is best)	NMSE (0 is best)	R (1 is best)	FAC2 (1 is best)
CALINE4	0.42	1.94	0.76	0.59
AERMOD - volume	0.38	1.26	0.84	0.59
AERMOD - area	0.32	1.25	0.82	0.59
ADMS	0.36	1.14	0.88	0.70
RLINE	0.23	0.96	0.85	0.73

Table 2 - Model Performance Statistics from the CALTRANS 99 Study. Source: (Heist, et al., 2013).

Model	FB (0 is best)	NMSE (0 is best)	R (1 is best)	FAC2 (1 is best)
CALINE3	0.25	2.26	0.29	0.45
CALINE4	0.19	0.86	0.47	0.68
AERMOD - volume	0.15	0.28	0.77	0.78
AERMOD - area	0.13	0.31	0.72	0.76
ADMS	0.09	0.20	0.78	0.85
RLINE	0.05	0.34	0.75	0.78

In general, the performance statistics indicate that the CALINE models are the worst performing for both field studies (also see Figure 5 and Figure 9 in (Heist, et al., 2013)). However, it should be noted that these metrics were computed for all modeled concentrations, rather than for the highest concentrations only. Regulatory models are generally needed to replicate the highest concentrations and, as a result, model evaluations for regulatory models typically focus on statistics for the highest concentrations (the

highest 25 is the most common, (Cox & Tikvart, 1990)). The need to replicate only the highest concentrations also means that performance of regulatory models is generally not based on pairing modeled concentrations in time and space. Instead, all concentrations are ranked from highest to lowest and compared independent on the timing and location. Figure 1 and Figure 3 show the quantiles plot, or QQ-plot, typically used to show model performance for ranked concentrations. From these plots, it can be seen that CALINE has the worst performance at the highest concentrations for both field studies and severely underestimates concentrations in Idaho Falls and overestimating concentrations in CALTRANS 99. Based on these results, AERMOD performed the best of all the dispersion models, being closest to the 1:1 line for the highest concentrations. When only the top 25 concentrations are considered, the FB and RHC are clearly better for AERMOD than CALINE. Figure 2 and Figure 4 show the ratios of modeled RHC to observed RHC vs FB for the field studies for the highest 25 concentrations only. A perfect model would have a FB of 0 and a ratio of modeled RHC to observed RHC of 1. For Idaho Falls, RLINE and AERMOD with both volume and area sources have virtually identical performance. For CALTRANS99, ADMS and AERMOD with both volume and area sources have very similar performance, with AERMOD volume sources performing best.

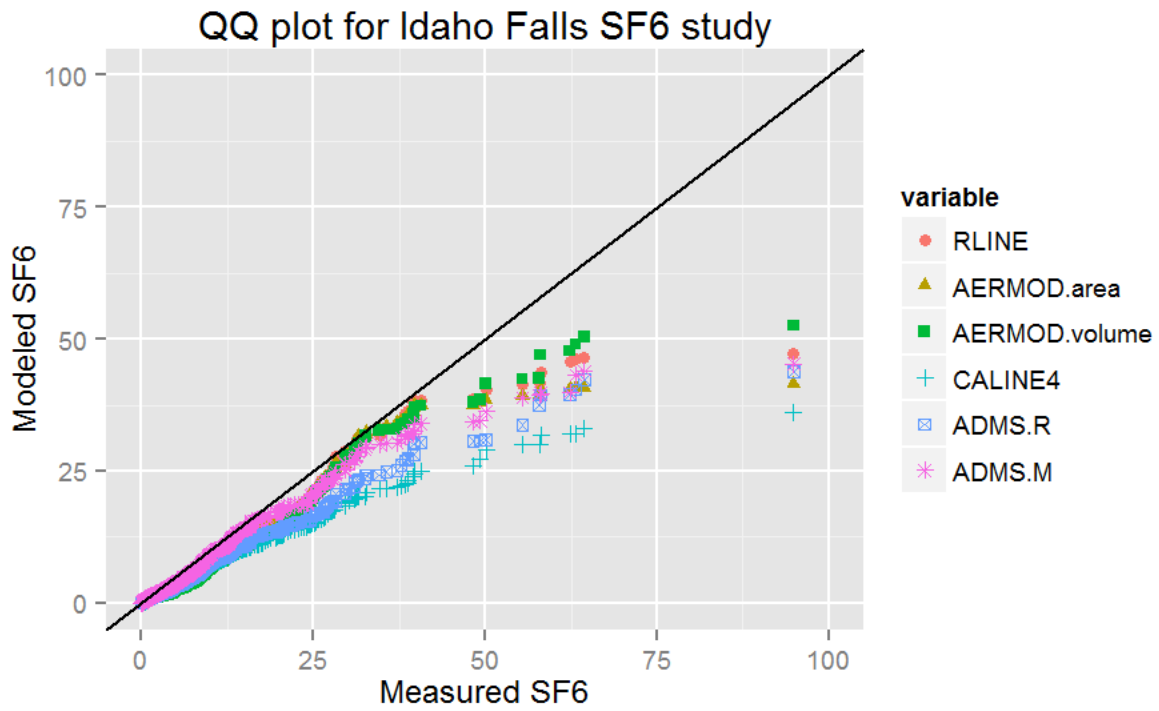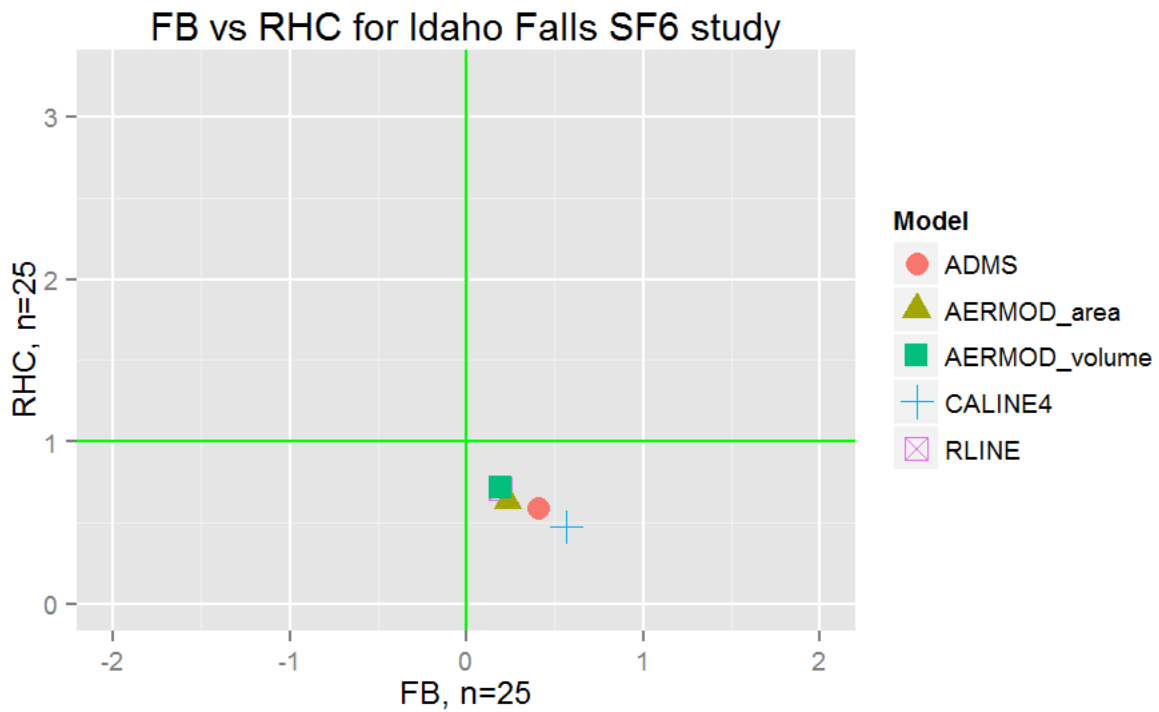**Figure 1 - QQ plot of Model Performance for Idaho Falls Study, based on (Heist, et al., 2013).**

Figure 2 - RHC vs FB Model Performance Statistics for Idaho Falls Study, based on (Heist, et al., 2013).
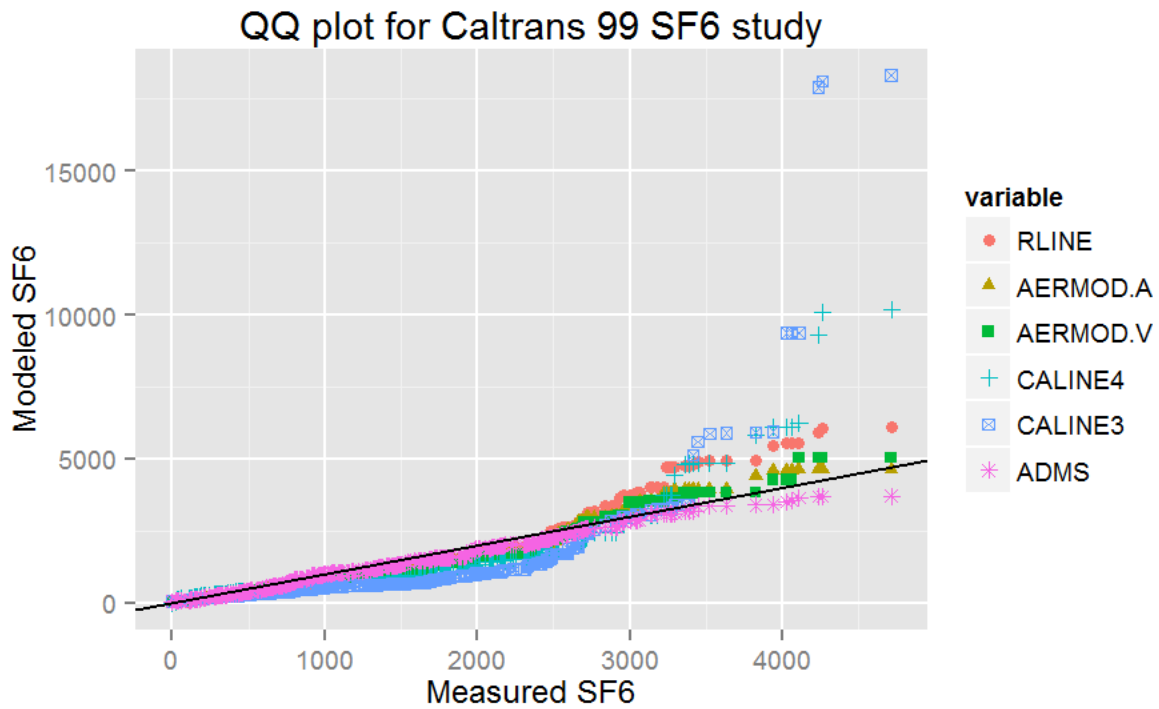
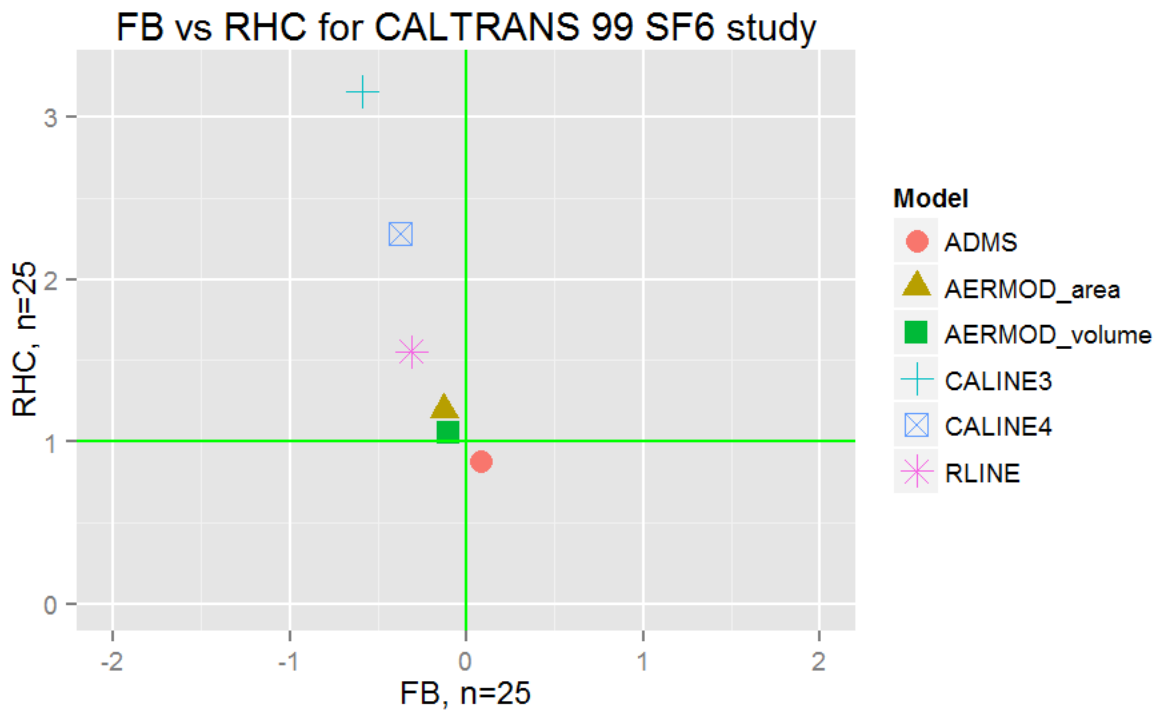**Figure 3 - QQ plot of Model Performance for CALTRANS 99 Study, based (Heist, et al., 2013).**

Figure 4 - RHC vs FB Model Performance Statistics for CALTRANS 99 Study, based (Heist, et al., 2013).

3.2 Regulatory applications for mobile sources

The current and future needs for mobile source modeling have evolved beyond the uses outlined in the 2005 version of Appendix W. For example, Pb modeling for mobile sources is no longer needed, as leaded gasoline is no longer used in the U.S. Currently, mobile source modeling for regulatory needs occurs primarily for CO, PM10, and PM2.5 hot-spot modeling for mobile source conformity analyses. Due to the background levels, emissions factors, types of projects modeled, and the shorter time period covered by the CO NAAQS, screening modeling involving conservative, worst-case modeling is exclusively done for CO analyses. Refined analyses involving actual meteorology with best estimates of emissions are conducted for PM10 and PM2.5. Because of the complex nature of PM emissions, the statistical form of each NAAQS, and the need to consider temperature effects throughout the time period of a year, EPA believes that quantitative PM hot-spot analyses need to be completed using the refined analysis procedures described in EPA's quantitative PM hot-spot guidance (U.S. EPA, 2015).

For CO screening analyses, CAL3QHC has been exclusively used for the past several decades with refined CO hot-spot modeling being completed in limited cases. Currently, EPA's MOVES emission model is used to estimate vehicular emissions for CO modeling (except in California, where EMFAC, short for EMission FACtor, is used). These emission models can be used to determine emission rates for free-flow traffic and rates for idle traffic (i.e., traffic in a queue at an intersection). Emissions from free-flow and idle traffic are input to CAL3QHC, along with the signalization and geometries of the intersection.

For PM10 and PM2.5, prior to the 2016 Appendix W final rule, AERMOD and CAL3QHCR had both been allowed for refined analyses. Note that having the capability to internally parameterize queuing emissions, like CAL3QHCR has, is not needed because queuing emissions are already accounted for by MOVES (and EMFAC in California). As noted in EPA's quantitative PM hot-spot guidance, CAL3QHCR's queuing algorithm should not be used in PM hot-spot analyses. These emissions, along with the geometries of the project, and meteorological data are input into AERMOD and CAL3QHCR to determine ambient impacts.

3.3 Summary of findings and recommended model

As discussed in section 3.1.1 of Appendix W, EPA should only list a preferred model in Appendix A when it is "found to perform better than others." In the 2005 update to Appendix W, no comparison was made between AERMOD and CALINE3 to assess which model actually performed better for mobile source applications. However, since that time, model inter-comparison studies now provide strong evidence that AERMOD is the best performing model relative to CALINE3 (and CALINE4) for mobile source applications. Specifically, EPA has found that:

- The dispersion modeling science used in CALINE3 is very outdated (30 years old) as compared to AERMOD, RLINE and other state-of-the-science dispersion models. CALINE3 is based on the same dispersion science underlying the ISCTS3 model, which EPA replaced with AERMOD in 2005 as the preferred regulatory dispersion model for inert pollutants.
- The model performance evaluations presented by (Heist, et al., 2013) represent the best model comparison for AERMOD, CALINE3 and CALINE4 to date. This study used metered emissions of an SF6 tracer and concurrent near-road measurements to serve explicitly as a platform for

evaluating mobile source models. The results showed that CALINE3 and CALINE4 were the worst performing models of the 5-model comparison for the two available field studies (Idaho Falls and CALTRANS 99) when considering all modeled and monitored concentrations, paired in time and space.

- Additional analysis of the data from (Heist, et al., 2013) was conducted by EPA in the context of regulatory use of models. This analysis focused on the highest concentrations (i.e., top 25 concentrations), which are most relevant for regulatory purposes, and typically the focus of performance evaluations of regulatory models. This additional analysis showed that not only were CALINE3 and CALINE4 the worst performers, but that AERMOD was the best performing model of the group.

- As described in more detail in Appendix A below, CALINE3 is insensitive to changes in mixing height which provides further support for the replacement of this model with AERMOD. For surface releases like roadways, low winds, stable conditions and a low mixing height are expected to result in the worst case concentrations because they are kept close to the ground. The recommendations in the 1995 CAL3QHC User's Guide result in assumptions that are somewhat contradictory and unrealistic.

In addition to the evidence about model performance, CALINE3, CAL3QHC, and CAL3QHCR have several limitations related to the model input that make them more difficult than AERMOD to use for refined modeling:

- Meteorological pre-processors for the CALINE3 models are only available for older meteorological data sets. As a result, newer, higher resolution meteorological data, that is more representative of actual wind conditions cannot readily be used. In contrast, pre-processed meteorological data from AERMET is available from state air agencies for use in AERMOD.

- For CAL3QHCR, only 1 year of meteorological data can be used in each model run. For refined PM10 and PM2.5 analyses, this requires multiple model runs to cover a 5-year modeling period with resulting model output data from up to 20 model runs that must be separately post-processed to obtain the necessary results.

Based on the data available, AERMOD is the best performing model for mobile source applications. Additionally, AERMOD is not limited by the practical usability issues especially in terms of most recent and improved model inputs data inputs that are not available with the CALINE3 models. As a result of these factors, EPA has replaced CALINE3 with AERMOD for all mobile source applications. This change also promotes greater commonality and consistency in air quality modeling analyses for EPA regulatory applications. For mobile sources, regulatory situations in which AERMOD would be used now and in future for refined modeling include:

- PM hot-spot analyses
- CO hot-spot analyses
- PM SIP attainment demonstrations
- PSD applications (PM, SO2, NO2, Pb, CO)

- NO2 near-road monitor siting and other potential future applications

4. Acknowledgements

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5. Additional information

Data for the analyses presented in this TSD can be obtained by contacting:

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Appendix A

AERMOD and CAL3QHC for CO hot-spot screening example

As noted in the main document, AERMOD is already used for PM10 and PM2.5 hot-spot analyses. However, for CO hot-spot analyses, CAL3QHC is currently the primary air quality model used. Therefore, a comparison of CO screening scenarios are presented here to illustrate the differences between AERMOD and CAL3QHC for these types of analyses and to illustrate how AERMOD can be used for CO screening purposes in hot-spot analyses. Version 15181 of AERMOD and version 04244 of CAL3QHC were used for this model-to-model comparison.

The basis for these comparisons is modeled emissions for a two-way timed signalized intersection (under capacity), adapted from Example 1 in the CAL3QHC User's Guide (U. S. EPA, 1995). The example consists of a 4-lane, two-way main street intersecting a 2-lane, one-way local street. The main street runs north and south with two northbound lanes and two southbound lanes. The local street runs from west to east. The configuration of the intersection and receptor placement is illustrated in Figure 5, taken from the CAL3QHC User's Guide. Traffic lanes were modeled as both LINE[2] sources and lines of adjacent VOLUME sources in AERMOD, for comparison to CAL3QHC.

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[2] The LINE source option in AERMOD uses the same dispersion parameterization as the AREA source option, but with simplified inputs for rectangular area sources and was specifically added to AERMOD to aid in modeling for transportation projects.
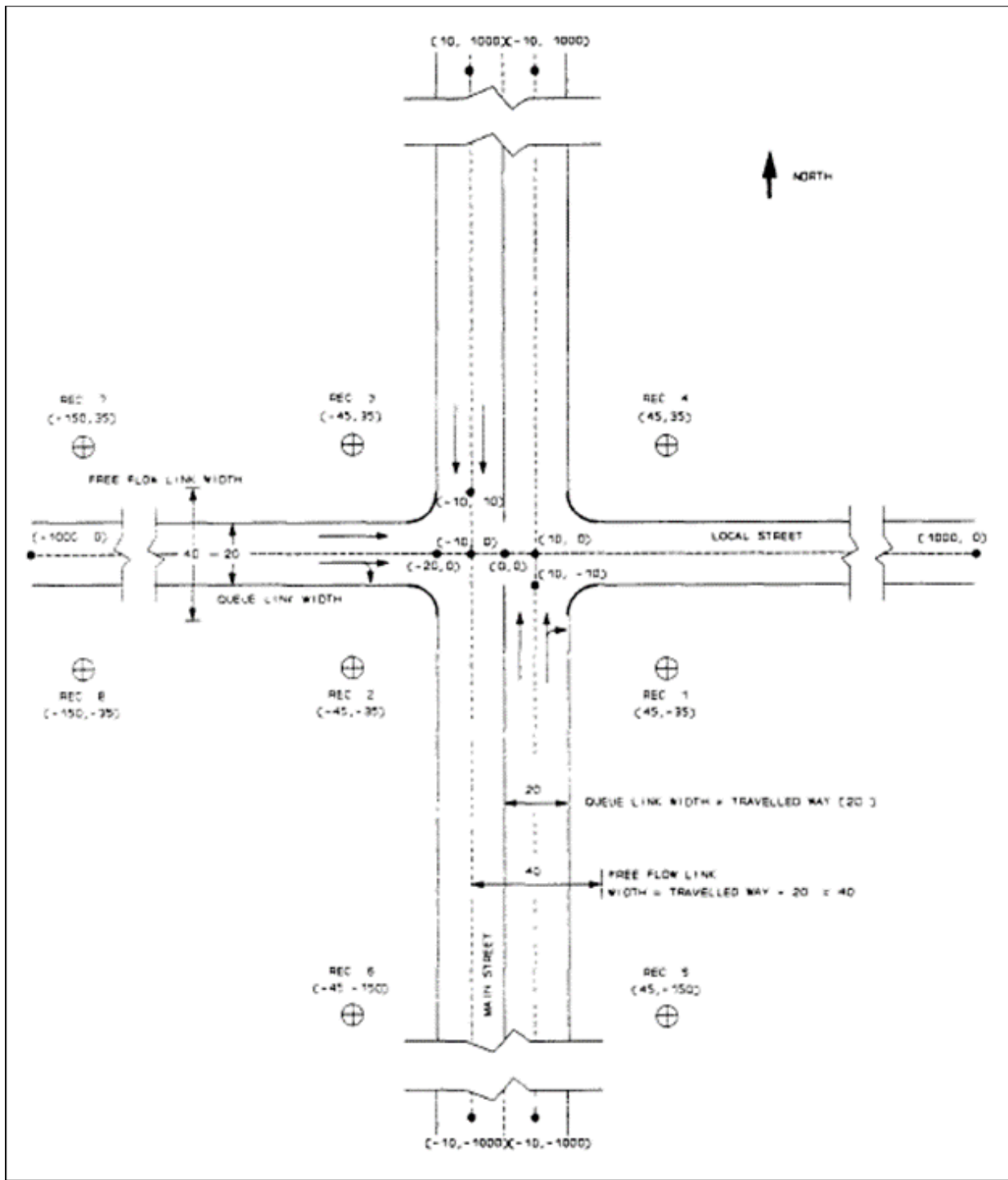
Figure 5 - Intersection Configuration and Receptor Placement (U. S. EPA, 1995)

Emissions Modeling

MOVES2014a was used at the project scale to estimate emissions from this roadway configuration for a single hour during 2016. MOVES runs were performed in the Inventory mode to produce total CO emissions for the hour, then post-processed using the MySQL script, "CO_CAL3QHC_EF.sql" to generate emissions in units of grams/vehicle-mile (g/veh-mi) for free-flow links and grams/vehicle-hour (g/veh-hr) for queue links. The MySQL script is available in the MOVES post-processing pull-down menu. The MOVES run specifications for this example include the following:

- *Scale: Project* scale, *Inventory* mode;
- *Time Span*: One hour: 2016, January, 7am-8am, Weekday;
- *Geographic Bounds:* Washtenaw County, MI;
- *Vehicle/Equipment:* All valid fuel/vehicle combinations included;
- *Pollutants/Processes:* All running CO processes;
- *Road Type:* Urban Unrestricted (i.e., representing urban arterial roads); and
- *Output:* By link and hour.

Local inputs provided to the Project Data Manager include:

- *Links:* Vehicle volume and average speed are consistent with those published for Example 1 in the CAL3QHC users' guide. Each intersection approach was modeled as two links: one link with an average speed representing free-flow traffic, and one link with an average speed of 0 miles per hour (mph) representing idling traffic (queue link). Each intersection departure was modeled as single link. Thus, three links in each direction were modeled for a total of nine links representing 6 approach lanes (3 links), 6 departure lanes (3 links), and 6 queue lanes (3 links). All links were modeled at 0% grade. Vehicle volume in vehicles per hour (veh/hr) and average speed for each road link are listed in Table 3.

Table 3 - Vehicle Volume and Average Vehicle Speed by Roadway Link

Street	Link	Vehicle Volume (veh/hr)	Average Speed (mph)
Main St. Northbound (2 lanes)	Approach	1500	20
	Queue	1500	0
	Departure	1500	20
Main St. Southbound (2 lanes)	Approach	1200	20
	Queue	1200	0
	Departure	1200	20
Local St. Eastbound (2 lanes)	Approach	1000	20
	Queue	1000	0
	Departure	1000	20

- *Link Source:* For all links, the national default distribution of VMT was used as a representative fleet mix, generated from a separate 2016 national scale run.

  Fleet mix: 8.6% Light Duty, 91.4% Heavy Duty.

- *Source Type Age Distribution:* The 2016 national default age distribution was used for all vehicle types.

- *Meteorology:* A temperature of 30 degrees F and 70% humidity was used.[3]

- *I/M:* No I/M program.

Using the input specifications above, MOVES2014a produced the following emission rates for the example intersection:

- *Free-flow rate, for approach and departure links (at 20 mph):* **5.11 g/veh-mi**
- *Idle rate, for queue links:* **20.45 g/veh/hr**.

Table 4 lists the total CO emissions, by vehicle type (Light Duty vs Heavy Duty), for the intersection.

Table 4 - CO Emissions by Vehicle Type

Vehicle type	CO Emissions (g/hr)
Heavy duty vehicles (8.6 %)	659
Light duty vehicles (91.4%)	7,004
Total	**7,663**

Air Quality Modeling

For the air quality modeling, the following combinations of source characteristics were included:

- Urban Dispersion (urban population of 1,000,000 used in AERMOD)
- All lanes at grade, flat terrain
- 6 Free Flow Lanes, (2 north bound lanes, 2 south bound lanes, and 2 east bound lanes with each pair of lanes further divided into approach lanes and departure lanes with respect to the intersection)

  Each pair of free flow approach lanes was modeled as a single link in CAL3QHC, as were each pair of departure lanes. Similarly, each pair of free flow approach lanes was modeled as a single LINE source in AERMOD, as were each pair of departure lanes. Each individual approach lane was modeled as a single line of adjacent VOLUME sources in AERMOD, as was each individual departure lane.

- 6 Queue Lanes (2 north bound lanes, 2 south bound lanes, 2 east bound lanes)

  Each pair of queue lanes was modeled as a single link in CAL3QHC, a single LINE source in AERMOD, and a single line of adjacent VOLUME sources in AERMOD.

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[3] This input does not affect CO emission rates for running emission processes, which are the only processes occurring in this intersection example.

- Lane Width = 10 feet (3.05 meters, m)
- Lane Length (approach + departure) = 2000 ft (610 m)
- Receptor Height = 6 ft (1.83 m)
- Surface Roughness = 1.25 m
- 36 wind directions, modeled every 10 degrees (10-360 degrees)

Source Characterization

There are several settings that are unique to each model, in particular AERMOD has more source-characterizations options than CAL3QHC. The model-specific settings are summarized as follows:

- CAL3QHC:
  - Link Type = At Grade (AG)
  - 6 Free Flow Links (1 approach and 1 departure link in each of 3 directions)
    - Link Width = (# lanes X 10 ft) + 20 ft, i.e. 2 x 10 ft +20 ft = 40 ft.
    - Link Length = 1000 ft
  - 3 Queue Links (1 in each of 3 directions)
    - Link Width = # lanes x 10 ft, i.e., 2 x 10 ft = 20 ft
    - Link Length = 1000 ft
    - Saturation Flow Rate = 1600 veh/hr/lane (default)
    - Signal Type = pre-timed (default)
    - Arrival Type = average progression (default)
  - Link Height = 0 ft
  - Release Height: *based on weighted emissions by vehicle mix (discussed below)*
  - Initial Vertical Dimension: *based on weighted emissions by vehicle mix (discussed below)*

- AERMOD:
  - Flat terrain, source elevation = 0 m
  - Each link in CAL3QHC modeled as a single LINE source in AERMOD
  - Each free flow link in CAL3QHC modeled as two lines of VOLUME sources in AERMOD (one per lane)
  - Each queue link in CAL3QHC modeled as a single line of *adjacent* VOLUME sources in AERMOD (one per pair of lanes)

  LINE Sources

  - 6 Free Flow LINE Sources (1 approach and 1 departure LINE in each of 3 directions)
    - LINE Source Width = (# lanes X 10 ft) + 20 ft, i.e. 2 x 10 +20 ft = 40 ft (12.2 m)
    - LINE source Length = 1000 ft (304.8 m)
  - 3 Queue LINE Sources (1 LINE in each of 3 directions)
    - LINE Source Width = (# lanes X 10 ft), i.e. 2 x 10 ft = 20 ft (6.1 m)
    - LINE Source Length: *based on traffic volume and capacity of approach (discussed below)*

  VOLUME Sources

Individual VOLUME sources have an equal length and width, and the size of all volume sources that comprise a lane are equal. The number of VOLUME sources that comprise a lane is dependent on the user specified width of the VOLUME source and the length of the lane.

- o 12 Free Flow Lines of VOLUME Sources (2 approach and 2 departure lines of VOLUME sources in each of 3 directions, see Figures 6-8))
    - VOLUME Source Width = lane width X 2, i.e., 10 ft (3.05 m) X 2 = 20 ft (6.1 m)
    - Total Length of Line of VOLUME Sources = 1000 ft (304.8 m)
- o 3 Queue Lines of VOLUME Sources (1 line of VOLUME sources in each of 3 directions)
    - VOLUME Source Width = (# lanes X 10 ft), i.e. 2 x 10 ft = 20 ft (6.1 m)
    - Total Length of Line of VOLUME Sources: *based on traffic volume and capacity of approach (discussed below)*

Some of the input requirements for AERMOD are not directly known from the information provided for Example 1 in the CAL3QHC user's guide, including: the calculated length of the queue lanes represented as LINE or VOLUME sources in AERMOD, the release height, the initial vertical dispersion of the release, and the initial lateral dimension and dispersion of the release (VOLUME sources). In CAL3QHC, the queue length entered is the actual lane length, and the emission rate for queue links is specified in units of g/veh-hr; whereas, the emission rates for free flow links are specified in g/veh-mi. In AERMOD, LINE source emission rates are specified in units of grams/second-sq. meter (g/s-m^2) and VOLUME source emission rates are specified in grams/second (g/s). For queue links, CAL3QHC adjusts the queue lane length and traffic volume based on the approach volume specified and the capacity of the approach. With those adjusted parameters, CAL3QHC derives an equivalent emission factor expressed in g/veh-mi, consistent with free flow links, and computes total emissions for each link in g/hr. The queue link lengths calculated by CAL3QHC were then used in AERMOD to define the queue link geometry in order to have equivalent emissions between the two model runs (see Tables 6 and 7 for more details).

AERMOD LINE Source : Emission Rate Conversions

To convert CAL3QHC emission rates for free flow links, expressed in g/veh-mi, to equivalent emission rates for AERMOD LINE sources in g/s/m^2, CAL3QHC emission rates were multiplied by the vehicle traffic volume (# vehicles/hour) and link length (mi) to get g/hr. The product was then divided by 3600 s/hr and the area of the LINE source to get an emission rate in units of g/s-m^2. This is demonstrated in equations 1 and 2.

Free Flow Vehicle Emission Rate:
[grams/vehicle-mile] * [# vehicles per hour] * [link length in miles] = [grams/hour]   *(Eq. 1)*

Free Flow LINE Source Emission Rate:
[grams/hour] ÷ [3600 seconds/hour] ÷ [link area in sq. meters] = [grams/second/sq. meters](Eq. 2)

To facilitate consistency for this comparison of CAL3QHC with AERMOD, the length of the LINE sources that represent queue links were obtained from the CAL3QHC output. The emission rates for the CAL3QHC queue links, in g/veh-hr, were converted for AERMOD LINE sources by multiplying the rate by

the number of vehicles per hour (adjusted by CAL3QHC) and the fraction of red light time. This product was then divided by 3600 s/hr and by the link area. These calculations are shown in equations 3 and 4.

Queue Vehicle Emission Rate:
[grams/vehicle-hour] * [# vehicles] * [red light fraction] = [grams/hour]   (Eq. 3)

Queue LINE Source Emission Rate:
[grams/hour] ÷ [3600 seconds/hour] ÷ [link area in sq. meters] = [grams/second/sq. meters](Eq. 4)

AERMOD VOLUME Source: Emission Rate Conversions

To convert CAL3QHC emission rates for to equivalent emission rates for individual AERMOD VOLUME sources in g/s, the product of Equation 1 (for free flow links) or Equation 3 (for queue links) was divided by 3600 s/hr to get the total emission rate for the link in g/s (Equation 5). For free flow links (approach and departure lanes), the quotient from Equation 5 was then divided by 2 to get the total emissions for a single approach or departure lane (i.e., the line of VOLUME sources that comprise a lane) since the CAL3QHC free flow links each represent a pair of lanes (Equation 6). The emission rate for each individual VOLUME source that comprises a free flow approach or departure lane or a pair of queue lanes was obtained by dividing the total emission rate for the line of VOLUME sources (Equation 5 or Equation 6) by the number of individual VOLUME sources that make up the lane as shown in Equation 7.

Link Emission Rate: [grams/hour] ÷ [3600 seconds/hour] = [grams/second]   (Eq. 5)

Free Flow Lane Emission Rate: [grams/second] ÷ 2 = [grams/second]   (Eq. 6)

VOLUME Source Emission Rate: [grams/second] ÷ # volume sources = [grams/second]   (Eq. 7)

AERMOD LINE and VOLUME Source: Initial Vertical Dimension (Szinit)

When defining a LINE or VOLUME sources in AERMOD, the user has the option for LINE sources to specify the initial vertical dimension (Szinit), in meters. This input is required for VOLUME sources. This value was calculated as 1.7 multiplied by the average vehicle height (light duty = 1.53 m, heavy duty = 4.0 m), weighted by the contribution of emissions from light duty (91.4%) and heavy duty (8.6%) vehicles. The weighted vehicle height for this example is 2.96 meters. The weighted height was then divided by 2.15, per the AERMOD user's guide for elevated releases. The final value for the Szinit is 1.38 meters. These calculations are demonstrated in equations 8 through 11.

Light Duty: 1.53 m * 1.7 = 2.6 m   (Eq. 8)

Heavy Duty: 4.0 m * 1.7 = 6.8 m   (Eq. 9)

Weighted Vehicle Height: (0.914 * 2.6 m) + (0.86 * 6.8 m) = 2.96 m   (Eq. 10)

Initial Vertical Dimension (Szinit): 2.96 m ÷ 2.15 = 1.38 m   (Eq. 11)

AERMOD LINE and VOLUME Source: Release Height

The release height, per hot-spot guidance, was computed as 1/2 of the weighted vehicle height (equations 8 through 10) as shown in equation 9.

$$\textbf{\textit{Release Height:}} \textit{ 0.5 * 2.96 m = 1.48 m} \qquad\qquad \textit{(Eq. 9)}$$

AERMOD VOLUME Source: Initial Lateral Dimension (Syinit)

Another required input for VOLUME sources is the initial lateral dimension (Syinit), in meters. Syinit for adjacent volume sources, per the AERMOD user's guide, is calculated as the VOLUME width divided by 2.15 as in Equation 10.

$$\textbf{\textit{Initial Lateral Dimension (Syinit):}} \textit{ VOLUME source width (m)} \div \textit{2.15 = m} \qquad \textit{(Eq. 11)}$$

The full details of the source characteristics for CAL3QHC and AERMOD are provided in Table 5, Table 6, Table 7, and Table 8. The receptor locations, as defined in Example 1 of the CAL3QHC user's guide are provided in Table 9. Table 5 and Table 6 show the differences in the values input into CAL3QHC (Table 5) and how the model adjusts several of the input values for the queue links (Table 6), as discussed above, such as the link length and traffic volume and derives an emission factor. Figure 6 through Figure 8 illustrate the intersection represented as LINE and VOLUME sources in AERMOD. The eastbound free-flow link/lanes and queue link/lanes are shaded in these two figures for reference.

Table 5 - CAL3QHC Initial Input Values

Link	XL(1) (ft)	YL(1) (ft)	XL(2) (ft)	YL(2) (ft)	Link Length (ft)	Link Length (mi)	Link Width (ft)	VPHL (veh/hr)	EFL (g/veh-mi) (g/veh-hr)	Avg. Signal Cycle Length (s)	Avg. Red Time Length (s)	Clearance Lost Time (s)
NB Approach	10	-1000	10	0	1000	0.1894	40	1500	5.11	--	--	--
NB Queue	10	-10	10	-1000	1000	0.1894	20	1500	20.45	90	40	3
NB Depart	10	0	10	1000	1000	0.1894	40	1500	5.11	--	--	--
SB Approach	-10	1000	-10	0	1000	0.1894	40	1200	5.11	--	--	--
SB Queue	-10	10	-10	1000	1000	0.1894	20	1200	20.45	90	40	3
SB Depart	-10	0	-10	-1000	1000	0.1894	40	1200	5.11	--	--	--
EB Approach	-1000	0	0	0	1000	0.1894	40	1000	5.11	--	--	--
EB Queue	-20	0	-1000	0	1000	0.1894	20	1000	20.45	90	50	3
EB Depart	0	0	1000	0	1000	0.1894	40	1000	5.11	--	--	--

Table 6 - CAL3QHC Derived Values for Queue Links

Link	XL(1) (ft)	YL(1) (ft)	XL(2) (ft)	YL(2) (ft)	Link Length (ft)	Link Length (mi)	Link Width (ft)	VPHL (veh/hr)	EFL (g/veh-mi)	Total Emissions (g/hr)
NB Approach	10	-1000	10	0	1000	0.1894	40	1500	5.11	1,451.70
NB Queue	10	-10	10	-238.5	228.5	0.0433	20	49	100	212.05
NB Depart	10	0	10	1000	1000	0.1894	40	1500	5.11	1,451.70
SB Approach	-10	1000	-10	0	1000	0.1894	40	1200	5.11	1,161.36
SB Queue	-10	10	-10	141.2	131.2	0.0248	20	49	100	121.76
SB Depart	-10	0	-10	-1000	1000	0.1894	40	1200	5.11	1,161.36
EB Approach	-1000	0	0	0	1000	0.1894	40	1000	5.11	967.80
EB Queue	-20	0	-165.4	0	145.4	0.0275	20	61	100	167.98
EB Depart	0	0	1000	0	1000	0.1894	40	1000	5.11	967.80
Values altered or derived by CAL3QHC are highlighted in yellow.									**Total:**	**7,663.54**

Table 7 - AERMOD LINE Source Input Values

LINE	Xs(1) (m)	Ys(1) (m)	XL(2) (m)	Ys(2) (m)	Zs (m)	LINE Length (m)	LINE Width (m)	Release Height (m)	Szinit (m)	Emission Rate (g/s-m²)	Total Emissions (g/hr)
NB Approach	3.0	-304.8	3.0	0.0	0.0	304.8	12.2	1.48	1.38	1.085E-04	1,451.70
NB Queue	3.0	-3.0	3.0	-72.7	0.0	69.6	6.1	1.48	1.38	1.387E-04	212.05
NB Depart	3.0	0.0	3.0	304.8	0.0	304.8	12.2	1.48	1.38	1.085E-04	1,451.70
SB Approach	-3.0	304.8	-3.0	0.0	0.0	304.8	12.2	1.48	1.38	8.681E-05	1,161.36
SB Queue	-3.0	3.0	-3.0	43.0	0.0	40.0	6.1	1.48	1.38	1.387E-04	121.76
SB Depart	-3.0	0.0	-3.0	-304.8	0.0	304.8	12.2	1.48	1.38	8.681E-05	1,161.36
EB Approach	-304.8	0.0	0.0	0.0	0.0	304.8	12.2	1.48	1.38	7.234E-05	967.80
EB Queue	-6.1	0.0	-50.4	0.0	0.0	44.3	6.1	1.48	1.38	1.727E-04	167.98
EB Depart	0.0	0.0	304.8	0.0	0.0	304.8	12.2	1.48	1.38	7.234E-05	967.80
										Total:	7,663.54

Table 8 - AERMOD VOLUME Source Input Values

VOLUME Line	Xs(1) (m)	Ys(1) (m)	XL(2) (m)	Ys(2) (m)	Zs (m)	VOL Line Length (m)	# of VOLUME Sources	Source Width (m)	Release Height (m)	Szinit (m)	Syinit (m)	Emission Rate (g/s-m²)	Total Emissions (g/hr)
NB Approach-1	3.0	-304.8	3.0	0.0	0.0	304.8	50	6.1	1.48	1.38	2.84	0.20163	725.85
NB Approach-2	1.5	-304.8	1.5	0.0	0.0	304.8	50	6.1	1.48	1.38	2.84	0.20163	725.85
NB Queue	3.0	-3.0	3.0	-72.7	0.0	69.6	11	6.1	1.48	1.38	2.84	0.05890	212.05
NB Depart-1	4.6	0.0	4.6	304.8	0.0	304.8	50	6.1	1.48	1.38	2.84	0.20163	725.85
NB Depart-2	1.5	0.0	1.5	304.8	0.0	304.8	50	6.1	1.48	1.38	2.84	0.20163	725.85
SB Approach-1	-4.6	304.8	-4.5	0.0	0.0	304.8	50	6.1	1.48	1.38	2.84	0.16130	580.68
SB Approach-2	-1.5	304.8	-1.5	0.0	0.0	304.8	50	6.1	1.48	1.38	2.84	0.16130	580.68
SB Queue	-3.0	3.0	-3.0	43.0	0.0	40.0	7	6.1	1.48	1.38	2.84	0.03382	121.76
SB Depart-1	-4.6	0.0	-4.6	-304.8	0.0	304.8	50	6.1	1.48	1.38	2.84	0.16130	580.68
SB Depart-2	-1.5	0.0	-1.5	-304.8	0.0	304.8	50	6.1	1.48	1.38	2.84	0.16130	580.68
EB Approach-1	-304.8	-1.5	0.0	-1.5	0.0	304.8	50	6.1	1.48	1.38	2.84	0.13442	483.90
EB Approach-2	-304.8	1.5	0.0	1.5	0.0	304.8	50	6.1	1.48	1.38	2.84	0.13442	483.90
EB Queue	-6.1	0.0	-50.4	0.0	0.0	44.3	7	6.1	1.48	1.38	2.84	0.04666	167.98
EB Depart-1	0.0	-1.5	304.8	-1.5	0.0	304.8	50	6.1	1.48	1.38	2.84	0.13442	483.90
EB Depart-2	0.0	1.5	304.8	1.5	0.0	304.8	50	6.1	1.48	1.38	2.84	0.13442	483.90
												Total:	7,663.54

Table 9 - Receptor locations for CO screening runs

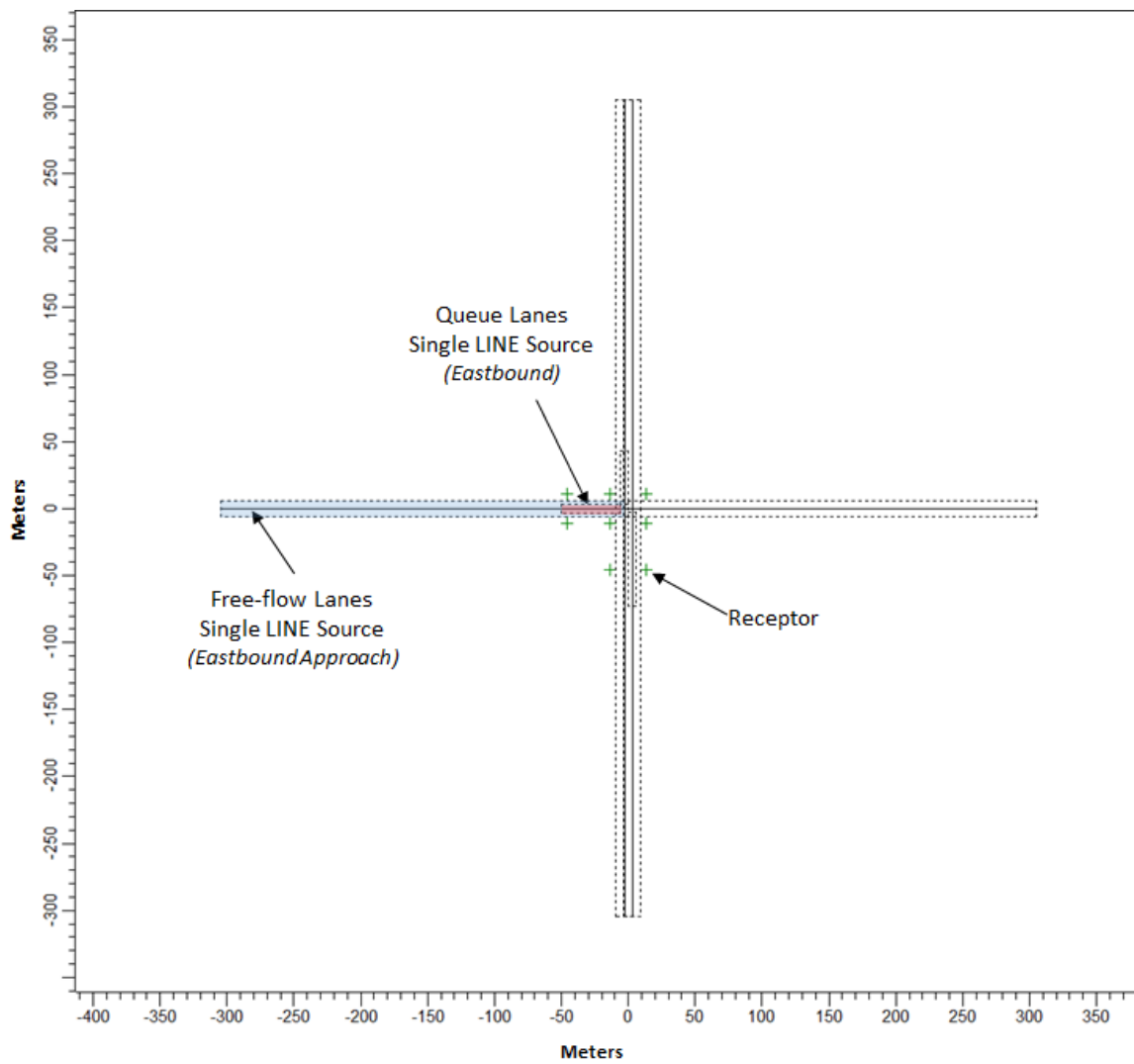| Receptor Name	X (ft)	Y (ft)	Z (ft)	X (m)	Y (m)	Z (m)
REC 1 (SE CORNER)	45.	-35.	6.00	13.72	-10.67	1.83
REC 2 (SW CORNER)	-45.	-35.	6.00	-13.72	-10.67	1.83
REC 3 (NW CORNER)	-45.	35.	6.00	-13.72	10.67	1.83
REC 4 (NE CORNER)	45.	35.	6.00	13.72	10.67	1.83
REC 5 (E MID-MAIN)	45.	150.	6.00	13.72	-45.72	1.83
REC 6 (W MID-MAIN)	-45.	150.	6.00	-13.72	-45.72	1.83
REC 7 (N MID-LOCAL)	-150.	35.	6.00	-45.72	10.67	1.83
REC 8 (S MID-LOCAL)	-150.	-35.	6.00	-45.72	-10.67	1.83

Figure 6 - Representation of Intersection in AERMOD (Links defined as LINE sources)
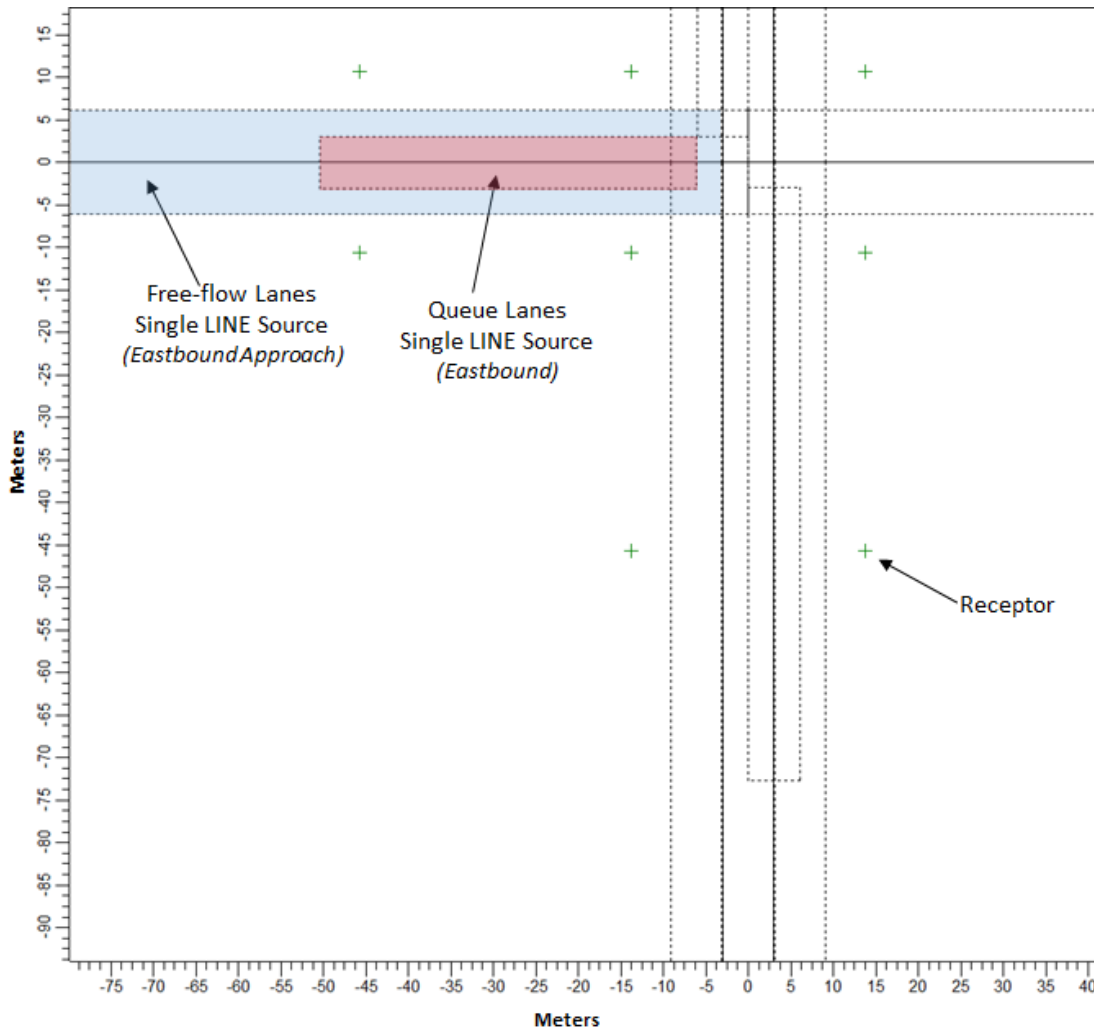
Figure 7 - Close-up of Eastbound Approach and Queue Lanes as LINE Sources in AERMOD

Meteorology

The meteorological parameters accepted by CAL3QHC are minimal and include wind speed, wind direction, mixing height, and Pasquill-Gifford (P-G) stability class (1-6). CAL3QHC also requires an estimate of the surface roughness length, independent of wind direction. The surface roughness length was set to 1.25 m for both CAL3QHC and AERMOD to represent an urban setting.

CAL3QHC is used for screening analyses which focuses on using "worst-case" meteorology to estimate the worst possible 1-hour concentrations. The example in the CAL3QHC User's Guide, which is consistent with EPA's current guidance for CO screening analyses (U. S. EPA, 1992), consists of a 1000 m mixing height, a 1 m/s wind speed, a stable atmosphere (P-G stability class 5). However, these assumptions are somewhat unrealistic. For near surface releases like roadways, low winds, stable conditions, and a low mixing height are expected to result in the worst case concentrations because emissions are kept close to the ground. These conditions typically occur during nighttime, as mixing

heights and turbulence are generally higher and during the day due to solar heating of the surface. Thus, a mixing height of 1000 m could not physically occur in the atmosphere with the accompanying low wind and stable conditions. Nonetheless, the 1000 m mixing height is recommended in the 1995 CAL3QHC User's Guide:

> "Mixing height should be generally set at 1000 m. CALINE-3 sensitivity to mixing height is significant only for extremely low values (much less than 100 m)."

(As noted above, the fact that CALINE3 is insensitive to changes to the mixing height provides further support for the replacement of this model with AERMOD.) In contrast, AERMOD is sensitive to mixing height, as well as other boundary layer parameters, and it is important that the boundary layer parameters are consistent with the measured meteorological conditions.

For these examples, a range of meteorological conditions were modeled. One hour of representative meteorology was developed for each of the six stability classes and replicated for 36 wind directions by varying the wind direction every 10 degrees from 10 to 360 degrees. Separate model runs were performed for each of the stability classes. The meteorology was created using the MAKEMET tool provided with AERSCREEN (U. S. EPA, 2011). MAKEMET generates an array of realistic meteorological conditions for physical parameters that are typically observed (e.g. wind speed, temperature, and cloud cover) and computes the boundary layer parameters required by AERMOD (e.g., mixing height, Monin-Obukhov length (L), and surface friction velocity) from the physical parameters for each set of conditions. Because MAKEMET does not derive or report the stability class required by CAL3QHC, Golder's[4] method for relating L to stability class was used to assign a stability class to each unique set of meteorological conditions generated by MAKEMET. For all but stability class 4, a single set of conditions was selected from the MAKEMET as representative of the stability category. Two sets of conditions were selected for stability class 4 as explained below.

Within each stability class, a combination of the value of L and the mixing height, if needed, was used as the basis for selecting representative meteorology. With the exception of stability class 4, the selection was made by taking the set of conditions for which the value of L is closest to the computed median value of L within the stability class. If this resulted in more than one set of conditions, then from that subset the selection was made by taking the set of conditions for which the mixing height is closest to the computed median mixing height within the stability class.

For all stability classes except 4, the values of L, by definition, are either all positive or all negative. However, neutral stability is characterized by either large positive values of L or large negative values of L (i.e., as L gets farther from zero). Because L in neutral conditions can be both positive and negative, the median value of L across all neutral conditions would likely be close to zero which does not represent neutral conditions. Therefore, two sets of neutral conditions were selected, one for which L is positive and one for which L is negative. Rather than using the median value of L as the criteria for selection, the 10th percentile was used for negative values of L and the 90th percentile was used for positive values of L. Subsequently, if this resulted in more than one unique set of conditions, then the median value of the mixing height was applied as described before. In addition to the seven CAL3QHC

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[4] Golder, D., 1972. Relations among stability parameters in the surface layer. Boundary Layer Meteorology 3, 47-58.

and AERMOD model runs for a single stability category, an eighth AERMOD run was performed using all of the meteorology generated with MAKEMET.

Modeling results

The results from these comparisons are shown in Table 10. For the model-to-model comparisons, the worst-case conditions of those modeled proved to be stability class 6 with a wind speed of 0.5 m/s and a mixing height of 156 meters (i.e., stable, low wind speed, and low mixing height). In this case, AERMOD predicted a concentration that is about half the concentration predicted by CAL3QHC. The lowest concentrations occurred under neutral stability with a high wind speed (6.0 m/s) and high mixing height (2874 m). In this case, AERMOD predicted a higher concentration. For the other conditions, there is a mix of results. In some cases, AERMOD predicted a higher concentration than CAL3QHC and in others, a lower concentration. The modeled concentrations for stability class 3 (slightly unstable) are nearly identical. Note that the mixing height for each of these model runs is greater than 100 meters, where CAL3QHC's sensitivity to mixing height is not significant. Modifying the mixing height in the CAL3QHC control file for any of these cases is expected to have little if any effect on the maximum modeled concentration, whereas AERMOD is more sensitive to the mixing height but also takes into account other boundary layer parameters whose values reflect the measured physical parameters from which they are computed.

Table 10 - Modeled Concentrations of CO (CAL3QHC vs. AERMOD)

Wind Speed (m/s)	Mixing Height (m)	P-G Stability Class	Monin-Obukhov Length (m)	CAL3QHC (ppm)	CAL3QHC ($\mu g/m^3$)	AERMOD LINE ($\mu g/m^3$)	AERMOD VOLUME (g/m^3)	Ratio AERMOD LINE/CAL3	Ratio AERMOD VOL/CAL3
0.5	766.	1	-5.8	0.90	1030.5	945.2	578.6	0.92	0.56
2.0	803.	2	-33.2	0.20	229.0	378.4	287.4	1.65	1.26
2.0	1439.	3	-153.5	0.40	458.0	458.7	397.0	1.00	0.87
6.0	2874.	4	-3257.1	0.10	114.5	171.1	156.1	1.49	1.36
2.5	1993.	4	6748.5	0.40	458.0	292.6	210.2	0.64	0.46
1.0	470.	5	114.1	0.90	1030.5	815.6	495.3	0.79	0.48
0.5	156.	6	27.9	2.20	2519.0	1279.9	732.6	0.51	0.29
All Meteorology						1713.8	1012.2		