A SURVEY OF AIR QUALITY DISPERSION MODELS FOR PROJECT-LEVEL CONFORMITY ANALYSIS

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A Caltrans request to provide guidance on how to quantitatively evaluate transportation project air quality impacts for purposes of meeting the federal transportation conformity requirements, and for preparing environmental impact assessments documents in compliance with the National Environmental Policy Act (NEPA) and the California Environmental Quality Act (CEQA).

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List of Acronyms

AERMOD- A dispersion model developed by AERMIC
AERMIC- The EPA Regulatory Model Improvement Committee
BEEST- A Model Manager and Graphic User Interface for ISC
CAAA- California Air Act Amendments
CALINE3- California Line Source Dispersion Model (Version 3)
CALINE4- California Line Source Dispersion Model (Version 4)
CAL3QHC- CALINE3 with Queuing and Hot-spot Calculations
CAL3QHCR- CALINE3 with Queuing and Hot-spot Calculations (Refined)
CAR- California Air Resources Board
CO- carbon monoxide
EMFAC- CARB's Mobile Emissions Factor Model
EPA- Environmental Protection Agency
FDM- Fugitive Dust Model
HYROAD- Hybrid Roadway Intersection Model
I/M- Inspection and Maintenance
ISC3 (LT/ST) - Industrial Source Complex Version 3 (Long-Term/Short-Term)
ISTEA- Intermodal Surface Transportation Efficiency Act
MOBILE- EPA Mobile Emissions Factor Model
NAAQS- National Ambient Air Quality Standards
NO_x- Nitrogen Oxides
PM- Particulate Matter
$PM_{2.5}$- Particulate Matter with a diameter less than 2.5 micrometers
PM_{10}- Particulate Matter with a diameter less than 10 micrometers
SMAQMD- Sacramento Municipal Air Quality Management District
UC Davis- University of California at Davis

1 Introduction

This report is intended to serve as a general primer on the use of air quality models for environmental documentation on transportation projects. The impacts of emission sources are usually predicted using computer-aided modeling. There are many air quality analysis models currently available for purchase or free download from both public and private organizations. These models vary widely in their intended applications, methodologies, sophistication and required user input. This report helps familiarize Caltrans project engineers with air quality modeling tools appropriate for specific project-level emissions analyses.

The report begins with a framework for analysis of project-specific emissions and discusses some of the basic data requirements. We then provide short descriptions of some of the most useful emission dispersion models currently available for analyzing mobile emissions. Where appropriate, we have annotated the descriptions with additional information to assist the reader.

All of the models considered for this analysis are applicable for short-range (< 100 m) and short-term (< 24 hours) analyses, which is generally sufficient for most project-level air quality analyses (i.e., use of micro-scale dispersion models for short distance dispersion of non-reactive pollutants). Models for measuring pollutant dispersion and interaction at the area or regional level have not been included in this report. Although each model is described in detail in the "Model Descriptions" section of this report, the following bullets provide a brief overview of the models covered.

- *AERMOD* is the U.S. EPA-approved dispersion model for nearly all applications where its use is reasonable (e.g. industrial source emissions modeling), and can be used for mobile source modeling in some cases.
- *CALINE3* and *CALINE4* are two line-source models developed by Caltrans and are used mostly in California for modeling roadway emissions.

- *CAL3QHC* and *CAL3QHCR* are both based on the *CALINE3* dispersion algorithm, but also include additional calculations for approximating emissions near roadway intersections.
- *HYROAD* is a relatively new emissions model that was also developed specifically to monitor pollutant dispersion near roadway intersections.
- The Industrial Source Complex (*ISC3*) is capable of modeling the dispersion of both stationary and mobile source emissions. *ISC3* has a screening version called *SCREEN3* that uses a "worst case" scenario approach for modeling emissions.
- The Point Area Line (*PAL*) model is capable of analyzing those three source types and was developed for modeling many different source locations simultaneously.

2 Modeling Framework

Project assessments typically involve some combination of the following: (1) estimating expected emissions associated with the project; (2) estimating ambient pollutant concentrations in the vicinity of the project; and (3) comparing resulting numbers to a baseline (e.g., the emissions from the current year, future emissions without the project, or a threshold value). Each of these analyses builds upon those before it; in other words, you need the emissions before dispersion can be addressed.

There are two spatial scales at which analysis can be performed: the local, or project-level, and regional studies (project-level studies are also referred to as hotspot analysis). Local studies are used to assess potential impacts adjacent to the roadway, typically for pollutants directly emitted by vehicles. The project-level carbon monoxide (CO) studies common to the last 30 years are an example of local, or project-level studies. Other pollutants, including respirable particulate mater (e.g., PM_{10} and $PM_{2.5}$), also require project-level studies under some conditions.

Some pollutants result from precursor pollutants undergoing chemical reactions in the atmosphere, such as the formation of ozone from hydrocarbons and oxides of nitrogen. These atmospheric reactions typically require time scales on the order of hours to days to occur, and therefore the air mass will be transported away from the original source before the pollutant of concern has formed. Such pollutants are addressed looking at all of the emissions in an air basin rather than project-by-project contributions. An example regional analysis includes conformity determinations for transportation plans, where regional precursor emissions are estimated and compared to allowable emission budgets from the region's air quality plan.

There are a series of steps that all analyses will have in common. The fist thing is an administrative check; confirmation should be obtained that an air quality analysis is in fact necessary. For example, under the transportation conformity rule many projects are exempt from some or all air quality analysis. That exemption is often extended to NEPA and CEQA analysis as well. Regional analysis is seldom necessary for individual projects because those projects are addressed at the regional transportation plan (RTP) and transportation improvement program (TIP) level. If a project does not come from a transportation plan and program with positive conformity findings and approved NEPA/CEQA studies, it might be appropriate to delay the project-level studies until the regional assessments are complete. Note that for transportation corridor studies, analysts should consider discrete locations that might be affected by the project; regional considerations are typically addressed during the transportation plan or TIP assessment.

Before starting a quantitative project analysis it is often a good idea to check whether qualitative screening approaches are available and sufficient. Screening protocols exist for CO [1] and for particulates (PM_{10}) [2]. When proceeding with quantitative assessments, a considerable degree of technical detail about the project needs to be described and analyzed. The remainder of this framework discussion focuses on completing these steps.

Typically, the analysis goal is to determine if the worst-case air quality scenario for the project is likely to exceed some threshold value, such as the National Ambient Air Quality Standards (NAAQS) or a target emissions level. Usually, it cannot be known with certainty when the worst-case scenario will occur, therefore several different points in time are typically analyzed in an attempt to "bound" the problem. For on-road emissions, this typically means that the opening year of the project, the design year, and the planning horizon year are all studied. For project construction, emissions are often estimated for each of the construction phases and the worst-case scenario is then used. (Note that there is less experience with the estimation of construction impacts because construction activity lasting less than five years is exempt from conformity analyses.) The technical data required to assess project-level impacts can be characterized as:

- <u>Emission rates will be required for the vehicle or equipment activity associated with the project</u>. The emission rates are generated from a model such as EMFAC, for on-road vehicles, or OFFROAD, for construction equipment; the California Air Resources Board developed both EMFAC and OFFROAD. In some instances, simplified results from these models have been incorporated into spreadsheet tools that may be available for screening projects.

- The activity that will occur at the project site needs to be determined. This may entail estimating the traffic volume, speeds, and vehicle mix that will occur on the project during future milestone years. The amount, type, and operating schedule for construction equipment may also be needed.
- The basic geometry of the project needs to be defined. Many screening procedures assess if emission sources are being moved closer to potential receptors (places where the public may be exposed). For example, adding an auxiliary lane to the right hand shoulder of a freeway might be viewed quite differently than adding an HOV lane to the center island. Geometry is also important as the precise location of the pollutant sources relative to the receptors is key. Some models also look at the effect of nearby buildings and topography that would be expected to influence local wind patterns.
- Interagency Consultation Should be Considered. In situations where the project analyst intends to take a non-traditional approach to completing qualitative or quantitative analyses, interagency consultation is recommended. The purpose of interagency consultation is two-fold: it helps meet the requirements called for by the conformity regulations, and it facilitates project approvals by developing interagency consensus prior to preparing the environmental impact assessment.

These information categories form the core of the modeling framework; the framework is relatively consistent regardless of the type of analysis that is to be performed. For transportation projects, “hot spot” or localized studies for directly emitted pollutants are the norm; results from regional RTP and TIP analyses are also referenced, assuming the project was included in the regional assessments.

One goal of this report is to identify the data input requirements of each of the dispersion models under review. This should assist the practitioner in choosing a model based upon the availability of existing data or the resources necessary to obtain such data. Additionally, some models are more “refined” than others, which may yield more accurate results but may or may not be appropriate or necessary for certain projects. This report qualitatively assesses the degree of sophistication of each dispersion model and identifies the resources required for implementing the model.

The U.S. EPA maintains a “Guideline on Air Quality Models” [3, 4], or Appendix W to 40 CFR Part 51 (referred to hereafter as “The Guideline”), which has been implemented and supported through the Support Center for Regulatory Atmospheric Modeling (SCRAM) [5]. SCRAM acts as the “final word” on the status of EPA-recommended air quality models. Any deviations in model selection or application from the recommendations outlined in the Guideline should be well documented; that documentation is typically developed during the drafting of an analysis protocol in consultation with other stakeholders such as the local air district and CARB. SCRAM can be accessed via the World Wide Web by visiting http://www.epa.gov/ttn/scram/. SCRAM was updated in 2005 to provide practitioners with access to emission dispersion models (http://www.epa.gov/scram001/ dispersionindex.htm), meteorological data and processors (http://www.epa.gov/scram001/ metobsdata.htm), and modeling guidance and support (http://www.epa.gov/scram001/guidance index.htm). Much of the content on the SCRAM website has been developed for stationary sources and is not applicable for mobile source emissions; however, there is still a great deal of information for mobile source modelers. Section 5 of this report provides information about U.S. EPA model designations and how this might affect the model practitioner.

2.1 Emission Rates

Emission rates fit into two different categories; on-road emission rates, typically from the EMFAC model, are used for the operational phase of a project, and emission rates for off-road equipment are typically applicable for the construction activity from a project. Emission rates from both of these categories can come from a variety of sources and each has their own caveats and limitations.

On-road emission rates are most commonly generated by the EMFAC [6] portion of California's motor vehicle emission inventory program. Both CARB [7] and Caltrans [8] offer guidance on how to apply the model and we refer the user to those documents for detailed directions. EMFAC estimates emission rates for CO; hydrocarbons (as NMOG, TOG, and ROG), oxides of nitrogen; and particulates (both PM_{10} and $PM_{2.5}$), along with other outputs. These emission rates are developed from trip-based dynamometer test cycles that include both trip origination and termination on local roads, freeway driving, arterials and other facilities. The resulting emission rates cannot be disaggregated to represent a single facility type and therefore there is typically a mismatch between the special scale of the activity data and the special scale of the emission factor [9]. Despite this incompatibility, regulation and guidance still require the use of EMFAC [10, 11]. Another option which occasionally comes up is the EPA on-road emission factor model MOBILE [12]. MOBILE is routinely applied everywhere in the United States except California. The current version of MOBILE produces emission rates for air toxics compounds that EMFAC would require post processing to obtain.

Emissions for construction equipment have traditionally come from a procedure documented in an EPA publication referred to as AP-42 [13]. AP-42 contains tabulated emission data by equipment type and engine power. AP-42 procedures have been updated and incorporated into a CARB model, called OFFROAD [14], and the EPA model "NONROAD" [15]. There is generally less experience with the application of these models than there is with their on-road counterparts. Several spreadsheet tools have evolved to aid analysts (see for example [16]); however, none of these have been developed with the transportation community in mind as an end-user.

2.2 Activity Data

Appropriate emission rates are combined with activity forecasts to generate project-level emission estimates. Activity during the operation of the project will generally consist of vehicle flows (ADT or peak-hour) and their corresponding speeds, the timing of traffic control devices, and an understanding of the vehicle fleet. By fleet, we mean the ages and types of vehicles on the road and their characteristics such as the fuel used and whether they are subject to the Smog Check program. In practice, the assumptions embedded in the emission factor model are typically used to represent the fleet, unless there is a reason to use tailored, site-specific data. For example, a truck lane project would likely require the user to alter the default assumptions in the emission model, but analysis of a new mixed-flow arterial lane would probably employ default fleet information included in the model tool.

For project construction, an estimate of the equipment types and their schedules of operation will be needed. For dust emissions, the amount of disturbed ground and volume of excavation or fill may be required; for exhaust emissions some knowledge about the fleet age, maintenance and fuel will be required. Heavy-duty off-road diesel-powered engines have been largely unregulated until recent years. Early generation emission controls were first required beginning with model year 1996 equipment and engines; California-certified engines had to meet more stringent requirements starting in 2001; similar federal requirements followed in 2003 [17]; engines and fuel will become cleaner yet starting in 2008 [18]. Notwithstanding the implementation of emission controls, off-road equipment can have a long useful life. Consequently, one of the most pressing analytical questions will be to estimate the age of the equipment on the job site; newer engines will be substantially lower emitting.

2.3 Project Geometry

Project geometry describes the relative location of emissions and receptors (locations at which a person could be exposed) in the vicinity of the project. The consideration of project geometry differs somewhat between qualitative and quantitative analysis. The concept of receptor siting is consistent for both analysis types. EPA guidelines [3] generally require that receptors be placed at locations where the public has access, but not closer than 3m from the edge of the traveled way. The 3m buffer between the road and a receptor is a technical limitation of the dispersion models; it is assumed that due to the initial mixing/dilution of the pollutants from the vehicle wake, the concentration at 3m and that over the center of the roadway are identical [19]. Most analyses will also require that receptors be placed at sensitive receptors such as nursing homes, preschools, and hospitals.

For qualitative analysis, it will typically be sufficient to identify if the emission sources are being moved closer to receptors, or if there are receptors within 100m of the project [1, 2, 20]. For quantitative assessments, sources are generally described in simple terms on a Cartesian coordinate system. For example, a roadway link would typically be described as a line with an associated link width.

2.4 Interagency Consultation

If an analysis will differ in approach from the standard modeling or screening approaches discussed here, it is usually important to discuss the methodology first through an interagency consultation process, and to receive interagency concurrence on the methodology. For carbon monoxide studies, use of the CO protocol [1] has already received interagency approval; the Protocol was developed with input from various agencies and was approved for use by EPA. Similarly, the PM_{10} Protocol was developed with input from Caltrans, CARB, and FHWA, and will typically require little further interagency consultation. In situations where interagency consultation makes sense, the consultative process will involve a review of the modeling approach selected and the input data and assumptions to be used. The information in this report should aid Caltrans staff during the development of analysis methods that might differ from standard qualitative or quantitative approaches.

3 Brief Model Descriptions

This section provides basic descriptions and background information for tools that are commonly used for project-level assessment. In addition, the report covers some lesser-used models. The lesser-used tools have been included to illustrate the range of modeling options available; they may seldom (if ever) be encountered in routine project analyses. This section has been divided into three categories: *Screening Tools*, *Refined Tools* and a *Summary*. Each of the individual modeling tool discussions covers five topic categories: *Description*, *Strengths*, *Limitations*, *Applications* and *Data Requirements*. An **Appendix** includes additional supporting information.

3.1 Screening Tools

CAL3QHC

<u>*Description*</u>

CAL3QHC is a multi-source model developed by the U.S. EPA in 1990. *CAL3QHC* was intended to be used for estimating vehicle emissions near roadway intersections. This model can be used to identify potential exceedances of the NAAQS, specifically for CO, although it can also be used for analyzing other inert pollutants such as some types of particulate matter (PM). *CAL3QHC* is based on the same line-source dispersion algorithm used in *CALINE3* (discussed below), with an added algorithm to provide simple vehicle queuing estimates. According to the *CAL3QHC* user's guide, *CALINE3* was designed to predict emissions from vehicles under free-flow conditions but does not account for emissions from idling vehicles [21]. The queuing theory added to *CALINE3* to produce *CAL3QHC* reportedly allows for the consideration of idling vehicle emissions by estimating queue lengths. The model is relatively insensitive to traffic speed, reducing the need for extensive on-site data collection [21]. As with each of the modeling tools discussed in this report, *CAL3QHC* is based on Gaussian dispersion principles.[1]

Strengths

CAL3QHC is intended for use as a screening tool for assessing worst-case impacts of inert pollutants (such as CO and some types of PM) near intersections. *CAL3QHC* can accommodate up to 120 roadway links, each of which can be specified as either a free-flow or queued link. The program allows for 60 receptor sites and automatically sums the contribution of all links to each receptor site. Link widths should include 10 feet on either side of the traveled roadway to include vehicle plume/wake interactions.

Limitations

In some comparison studies, it has been shown that the queuing theory in *CAL3QHC* and resulting emission predictions can be unrealistic under certain traffic scenarios, including times when intersection traffic is less than saturated [22]. The model also does not allow the link width to be greater than the link length, and wind speed must be greater than 1 m/s. *CAL3QHC* is not intended for modeling sites with complex geometries, topography or atmospheric instability. Additionally, *CAL3QHC* is not valid for analysis of link heights greater than 30 feet (since *CALINE3* has not been validated outside of this range) [22]. CAL3QHC can predict unrealistically long queues as the volume-to-capacity ratio (v/c) approaches 1. Intersections with high v/c ratios are of concern with regard to CO, therefore the model is quite limited in its ability to accurately predict near-field CO concentrations under travel conditions likely to be explored during most project-level assessments. In applications involving receptors at greater distances, this limitation is less of a concern. Once a source is more than a few hundred yards away, it has relatively trivial impacts on any given receptor.

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[1] Gaussian models use the Gaussian equation, which treats pollutant emissions as dispersing from a given source as a plume, traveling downwind and spreading horizontally and vertically according to the release height and wind speed/direction. The Gaussian distribution describes the stratification of emissions across the plume, more concentrated near the center line and less toward the edges (also referred to as a "normal" distribution). Some Gaussian models incorporate advanced equations for simulating mixing near the edges.

Applications

CAL3QHC is intended for analysis of inert pollutants (such as CO and certain types of PM) at or near roadway intersections. The model can include in the analysis up to 1,000 feet of roadway leading to the intersection. The U.S. EPA recommends that *CAL3QHC* be used as a screening tool for modeling the worst-case CO concentrations at receptor sites near the intersection. For a more refined analysis (incorporating site-specific meteorological data), it is necessary to use *CAL3QHCR*.

Data Requirements

CAL3QHC requires data inputs for roadway geometries, receptor locations, meteorological conditions, vehicular emission rates (including idling emission rates), signal timing, intersection configuration, number of 'moving' lanes, saturation flow rate, signal type and arrival type.

SCREEN3

Description

SCREEN3 is a single-source dispersion model developed by the U.S. EPA to estimate the worst-case dispersion (maximum concentration) for various pollutants. This model is the screening version of *ISC3* (a dispersion model typically used to model stationary, or "point" source impacts). This model was previously the EPA-preferred screening tool for point and area source emissions in regions with relatively non-complex terrain, but has since been replaced by *AERSCREEN*. The model is based on an EPA screening procedure document entitled "Screening Procedures for Estimating the Air Quality Impact of Stationary Sources" [23]. *SCREEN3* incorporates features from other existing screening models, including the *VALLEY* model. Because it is relatively simple, and does not require detailed meteorological data input files, SCREEN3 is often used to complete initial screening assessments for point and area sources.

Strengths

Although *SCREEN3* was only developed for flat or elevated simple terrain, it was equipped with several sophisticated algorithms to account for shoreline fumigation, inversion break-up, building downwash and long- and short-range transport and for determining plume rise for flare releases [24]. *SCREEN3* determines the combination of stability class and wind speed that represent the worst-case meteorological conditions.

Limitations

SCREEN3 is a single-source analysis tool. If the practitioner requires the analysis of multiple sources, they will require the use of *ISC3*. Since computer operating times are generally not a significantly limiting factor for air quality modeling, practitioners such as those at the Sacramento Metropolitan Air Quality Management District (SMAQMD) are reported to rarely (if ever) use screening tools for air quality analysis [25]. SMAQMD reportedly uses an *ISC*-based modeling package called BEEST for nearly all of their emissions analyses, including analysis for both stationary and mobile sources. BEEST and similar software packages are described in greater detail in Section 5.

Applications

SCREEN3 is applicable for all of the same projects that can be analyzed using *ISC*, but it is limited to analyzing emissions from a single source. This includes pollutant emissions from point, area and line sources where local terrain is relatively flat and simple.

Data Requirements

SCREEN3 requires data input for emission rates, source release height, dimensions of area and volume, receptor height, urban/rural specification, and wind direction.

3.2 Refined Analysis Tools

AERMOD

<u>Description</u>

AERMOD is a multi-source, steady-state Gaussian dispersion model developed by the U.S. EPA and American Meteorological Society. *AERMOD* is currently one of the most sophisticated dispersion models available, and it is the EPA-recommended model for evaluating the dispersion of inert pollutants from point, area and line sources under short-range, steady-state conditions. For long-range (> 100m) and/or non-steady-state conditions, the EPA recommends the use of *CALPUFF*, which will not be discussed in this report but can be found at http://www.epa.gov/ scram001/dispersion_prefrec.htm. Like *ISC3*, *AERMOD* was developed more with stationary-source applications in mind, but it can be applied to mobile source emissions from roadways by combining multiple volume or area sources joined consecutively (see the **Appendix** for supporting information).

<u>Strengths</u>

According to the most recent findings by the U.S. EPA [3], *AERMOD* is the most accurate dispersion model available for regulatory applications. A number of tests have been performed by the U.S. EPA and others [26] to compare *AERMOD* to other dispersion models, such as the Industrial Source Complex (*ISC3*) and the Complex Terrain Dispersion Model PLUS unstable algorithms (*CTDMPLUS*). AERMOD has a built-in screening tool (AERSCREEN), a surface characteristic pre-processor (AERSURFACE), meteorological data pre-processor (AERMET) and terrain data pre-processor (AERMAP), all of which are available for free download from the U.S. EPA website (http://www.epa.gov/scram001).

Limitations

AERMOD is a large program with many features and input requirements. It is possible to limit the required data input requirements (e.g. by using *AERSCREEN*), but there are still many pre-processors and post-processors that require user input. Additionally, practitioners who wish to become highly proficient at using *AERMOD* may be forced to spend a significant amount of time just familiarizing themselves with the program and its various requirements. As mentioned previously, AERMOD contains a significant amount of modeling capability that is specific only to stationary source modeling, which may be cumbersome for practitioners who only wish to perform analyses for mobile source emissions.

As of November of 2005, *AERMOD* does incorporate the effects of building downwash, which is the common name for the effect buildings have on plume movement and subsequent ground-level pollutant concentrations. However, it is currently necessary to use *ISC-Prime* for all applications where building downwash is expected to have a significant effect on plume dispersion and resultant receptor concentrations.

Applications

AERMOD is recommended for use in nearly all pollutant short-range, short-term dispersion scenarios. It is most commonly used for analysis of stationary point or area sources (such as industrial "smoke stack" type sources). Regardless, AERMOD is capable of modeling all source types, under nearly all atmospheric and terrain conditions (except for building downwash).

Data Requirements

AERMOD requires data input for emissions rates, meteorological conditions (surface-level and vertical profile), receptor locations, source type, terrain characteristics, and site geometry. Unlike models developed specifically for mobile source applications (such as *CALINE4* and *HYROAD*), *AERMOD* processes emission rate factors that can vary by month, season, hour-of-day or optional periods [27].

CAL3QHCR

Description

CAL3QHCR is intended to be a more refined version of *CAL3QHC*. This model uses meteorological data for a one year (on-site) or five year (local airport) period rather than using worst-case meteorological assumptions. *CAL3QHCR* was the solution to a New York lawsuit concerning the tendency of the original version to over predict carbon monoxide concentrations. Concentration estimates produced by *CAL3QHCR* are lower because calm periods, which tend to have the highest concentrations, are not included in multi-hour averages (effectively tossing out the peak concentrations). Some EPA staff have voiced concern over *CAL3QHCR*, but acknowledge that the model is unlikely to be updated since it was created to satisfy a legal settlement.

Strengths

CAL3QHCR allows for the use of one to five years of meteorological data to provide higher resolution results than can be obtained using *CAL3QHC*. In addition to improved meteorological resolution, *CAL3QHCR* also includes the *ISCST* (short term) mixing height algorithm.

Limitations

CAL3QHCR may provide inaccurate results for analyses where the wind speed is close to zero [28]. Also, since its line-source dispersion algorithms are based on those from *CALINE3*, it has the same limitations that *CALINE3* faces (e.g., it is not applicable for modeling links at a height greater than 30 feet above grade).

Applications

CAL3QHCR is intended for analysis of inert pollutants (such as CO and certain types of PM) at or near roadway intersections. The model can include in the analysis up to 1,000 feet of roadway leading to the intersection.

Data Requirements

CAL3QHCR requires the input of roadway geometries, receptor locations, vehicular emission factors (from EMFAC), signal timing, intersection configuration and five years of airport or one year of on-site meteorological data.

CALINE3

Description

CALINE3 can be used to estimate the concentrations of non-reactive pollutants from highway traffic. This steady-state Gaussian model can be applied to determine air pollution concentrations at receptor locations downwind of "at-grade," "fill," "bridge," and "cut section" highways located in relatively uncomplicated terrain. The model has adjustments for averaging time and surface roughness, and can handle up to 20 links and 20 receptors. It also contains an algorithm for deposition and settling velocity so that particulate concentrations can be predicted. *CALINE3* was designed to predict emissions from vehicles under free flow conditions but does not account for emissions from idling vehicles [21].

Strengths

CALINE3 is applicable for all wind directions, highway orientations, and receptor locations. It has been used for many years to model emissions from roadway sources; its line source algorithm has been well refined and its accuracy has been verified.

Limitations

While *CALINE3* is well known and highly developed, it is not valid for analysis of link heights greater than 30 feet.

Applications

CALINE3 is the EPA recommended model for highways with uninterrupted traffic flow. *CALINE3* is appropriate for the analysis of roadways that can be accurately estimated as line sources and divided into segments to account for road sections with non-uniform emissions.

Data Requirements

CALINE3 requires the input of roadway geometries, receptor locations, meteorological conditions, vehicular emissions rates, link information, and surface roughness.

CALINE4

Description

CALINE4 is a multi-source Gaussian dispersion model developed by Caltrans. *CALINE4* is similar to *CAL3QHC*, but has an advanced method for calculating NO_2 concentrations using the Discrete Parcel Method. *CALINE4* employs a mixing zone concept to characterize pollutant dispersion over roadways, which is another improvement over its predecessor, *CALINE3*. Given source strength, meteorology and site geometry, the model can predict pollutant concentrations for receptors located within 500 meters of the roadway. It also has special options for modeling air quality near intersections, street canyons and parking facilities. The revised *CALINE4* user's guide is relatively straightforward and user friendly [29]. *CALINE4* has an intersection modeling option for carbon monoxide that should not be used. That option uses a modal model based on testing of a handful of mid- to late-1970's vehicles; modern vehicles with computer controlled combustion and 3-way catalysts are not represented by the outdated modal information included in *CALINE4*. For intersections, an average speed approach such as that outlined in the CO Protocol [1] should be used.

Strengths

CALINE4 is appropriate for nearly all projects involved with roadway and near road emissions. *CALINE4* is capable of specifying links at heights above grade (z = 0), links as bridges (allowing air to flow above and below the link) and links as parking lots (which should be defined by the user as having a height of zero). In addition to evaluating CO and PM dispersion, *CALINE4* incorporates the Discrete Parcel Method for estimating

NO_2 concentrations. Also, unlike *CAL3QHCR, CALINE4* is capable of analyzing the dispersion of pollutants in winds with speeds of less than 1 m/s [29]. In addition, Caltrans makes available to users a simplified version of *CALINE4*, known as *CL4*, that includes a user-friendly graphic user interface.

Limitations

A study was conducted in 1992 by Benson to evaluate the performance of *CALINE4* compared with data from multiple independent studies, including data from General Motors. *CALINE4* showed poor performance during low wind speed conditions, particularly when wind speeds are parallel to the roadway [30]. Although *CALINE4* also includes a feature for analyzing the effects of nearby canyons or bluffs on pollutant dispersion, it is only recommended for use in rare circumstances and only by very experienced modelers.

Data Requirements

CALINE4 requires the input of run type/averaging time, roughness length (coefficient), roadway geometries, altitude, number of links, link information, number of receptors, averaging interval, mixing zone width (>10 meters), hourly traffic volume, emissions factor (from EMFAC), wind direction and speed, and receptor location(s).

HYROAD

Description

The Hybrid Roadway Intersection Model (*HYROAD*) is designed to predict the concentrations of carbon monoxide (CO) that occur near intersections. *HYROAD* addresses the "three key aspects controlling the magnitude of CO concentrations: traffic operations at intersections; vehicle emissions; and atmospheric transport and dispersion" [31]. *HYROAD*'s dispersion module uses a Gaussian puff approach, with dispersion induced by traffic flow and wind characteristics, and also uses either MOBILE5 or MOBILE6 emissions factors (as specified by the user). *HYROAD* also provides the option of using the emission factor interface to specify other emission factors (such as those derived from EMFAC).

Strengths

HYROAD was developed to have a very modular structure, with three separate programs that process different pieces of the data. Each module can be used as a stand-alone program and is not dependent upon the functionality of the other two modules. *HYROAD* also has the capability to function both as a screening and as a refined model for analyzing CO dispersion.

Limitations

Since *HYROAD* is a very new model, not much is yet known about its accuracy under varying conditions over time. Because of this, a practitioner may be hesitant to use *HYROAD* for emissions analysis since there is little to reference in terms of previous use and expected results for varying conditions.

Applications

HYROAD is intended for use as a roadway intersection model and was designed to account for all of the various aspects of intersection modeling, including queuing, signal timing and other vehicle movement characteristics. Although it is currently considered to be an “alternative” model and is not yet on the U.S. EPA’s refined model list, the model is intended to be useful for regulatory analysis. The design also allows for easy updating of the model as new research results are made available.

Data Requirements

HYROAD requires the input of traffic flow information including peak hour volume, signal timing, roadway geometry, vehicle movement characteristics, emissions rates, meteorological conditions, wind speed and stability, and receptor locations.

ISC3

<u>*Description*</u>

The third version of the Industrial Source Complex model (*ISC3*) is a multi-source dispersion model for point and area/volume sources. It is possible to use *ISC3* to approximate a line source using elongated area or volume sources in close proximity to one another (see the Appendix for additional supporting information). *ISC3* is a relatively sophisticated regulatory model and incorporates features of previously developed models, including the Fugitive Dust Model (*FDM*).

<u>*Strengths*</u>

ISC3 can be used for analysis of virtually any type of project. It is reportedly the model of choice for air quality modeling practitioners at the Sacramento Metropolitan AQMD for both stationary and mobile source emission estimates [25]. *ISC3* was the U.S. EPA-preferred model for a number of regulatory applications until December of 2005, when *AERMOD* officially replaced it as the U.S. EPA-preferred dispersion model for most applications. If high concentrations in a localized area are likely, mobile sources should be modeled as a line source, which must be approximated as either an elongated area source or several volume sources side-by-side [4, 22].

Three versions of the *ISC3* model have been developed: one for Short Term modeling (*ISC3ST*), one for Long Term modeling (*ISC3LT*), and one to incorporate the effect of buildings on the ground-level concentration of pollutants (*ISC-Prime*). The *ISC3ST* model treats source groups independently since source contribution information can be crucial to short term analyses [22]. *ISC-Prime* was developed because *ISC3* and other regulatory models have not historically accounted for the interaction effects that buildings could have (known as "building downwash") on ground-level pollutant concentrations. Building downwash could be an important consideration for many projects, especially those taking place in an urban environment. *ISC-Prime* must be downloaded separately from *ISC3*, but is still available free from the U.S. EPA website (http://www.epa.gov/scram001/dispersion_alt.htm).

Limitations

Despite its versatility, *ISC3* was not developed with the traffic analysis practitioner in mind, which may make it less user-friendly for Caltrans projects than tools like *CALINE3*, *CALINE4* and *HYROAD*. One consideration that should be made is that near-field predictions using *ISC3* are very sensitive to the treatment of source type/ approximation. Also, ISC3 is now considered to be an "alternative" model by the U.S. EPA, and so it may only be approved for use for specific applications on a case-by-case basis.

Applications

Although *ISC3* is most commonly used to model pollution produced at stationary sites as point, area or volume sources, it can be used (like *AERMOD*) to estimate mobile source emissions (the Appendix includes supporting information about how to approximate line sources using *ISC3*).

Data Requirements

ISC3 requires the input of receptor locations, meteorological data, data period (for *ISC3ST*), wind direction, wind speed category, average temperature (for *ISC3LT*), mixing height, and surface roughness/ terrain.

Point, Area, Line (PAL)

Description

PAL is a multi-source model used to estimate dispersion from point, area and line (*PAL*) sources. *PAL* uses steady-state, Gaussian plume dispersion assumptions. *PAL* uses the same line source algorithms used in *CALINE3,* but has added area source algorithms for treating edge effects and inclined line sources. *PAL* is a relatively little used model, but has some application for modeling parking lots. It uses a different solution for the differential equation for transport and dispersion; and allows receptors to be placed adjacent to the parking lot/area source. Most Gaussian models require that the receptor not be closer to the edge of the source than a characteristic dimension of the area source. For example, with most models, a parking lot would have to be represented by many smaller sources such that a receptor can be placed near the parking lot edge; *PAL* avoids that complexity.

Strengths

PAL is capable of predicting the dispersion from a number of different sources and types of sources simultaneously (up to 99 receptor sites and 99 sources in each category).

Limitations

PAL would probably not be used for most Caltrans projects, since it does not improve upon the already existing line-source estimates available in *CALINE3* and is not as accurate at modeling point or area sources as *ISC3* or *AERMODE*. *ISC3* and *AERMOD* have improved utility over *PAL*, allowing for the use of both Cartesian and Polar grid receptor locations and also including the option for volume sources. For this reason, any project that may warrant the use of *PAL* would probably be better served by using one of the *CALINE* models, *ISC3* or *AERMOD*.

Applications

PAL was designed for short time intervals, short-range plume analysis and non-reactive pollutants. *PAL* can be used in urban areas but it is not capable of simulating complex terrain or building downwash. *PAL* is generally used for stationary source analyses, but it is capable of modeling mobile source emissions as well.

Data Requirements

PAL requires the input of receptor locations, source type, wind direction, wind speed, temperature, mixing height and meteorological data.

3.3 Summary

As noted previously, each of the models described above is appropriate for modeling the micro-scale dispersion of inert pollutants such as CO and some types of PM. Some of the models have been developed for specific applications (such as vehicle emissions from intersections), while others may be used in a wide range of applications. All of the models discussed are based on Gaussian modeling principles. Gaussian models treat pollutant emissions as dispersing from a source as a plume, traveling downwind, and spreading horizontally and vertically. With a Gaussian distribution, pollutants are more concentrated near the centerline and less toward the edges; this is also referred to as a "normal" distribution. **Table 3-1** summarizes the tools discussed, and notes their typical use.

Table 3-1. A general comparison of the models discussed in this report.

Model	*Class*	*Source Approx.*	*Sophistication*	*Typical Use*
AERMOD	Gaussian	Point, Area, Volume	Refined	Industrial facilities
CAL3QHC	Gaussian	Line	Screening	49 state roadway CO model
CAL3QHCR	Gaussian	Line	Refined	49 state roadway CO model
CALINE3	Gaussian	Line	Refined	49 state roadway CO model
CALINE4	Gaussian	Line	Refined	Roadway CO in California
HYROAD	Gaussian	Line	Refined	Recently released, developed for roadway CO
ISC3	Gaussian	Point, Area, Volume	Refined	Industrial facilities
PAL	Gaussian	Point, Area, Line	Refined	Uncommon to see but some history with parking lots
SCREEN3	Gaussian	Point, Area, Line	Screening	Industrial facilities

4 U.S. EPA Model Designations

As mentioned in the introduction of this report, the U.S. EPA has developed the Support Center for Regulatory Atmospheric Modeling (SCRAM), which includes a listing of both the preferred and recommended pollutant dispersion models (http://www.epa.gov/scram001/dispersion _prefrec.htm) and alternative models (http://www.epa.gov/scram001/ dispersion_alt.htm). Alternative models are recommended for use only when that use can be justified over the use of a preferred model; alternative model selection occurs on a case-by-case basis and with the proper approval of enforcing agencies.

Of the dispersion models that were reviewed for this report, only five are found on the U.S. EPA's lists of preferred and alternative models: *AERMOD*, *CALINE3* and *CAL3QHC/R* (preferred); and, *HYROAD* and *ISC3* (alternative). Does this mean that these are the only five models that should be considered for all project-level analyses? Not necessarily. What it does mean is that these models have been used and tested by other practitioners and experts in the field and that they are believed to provide accurate estimates of emission concentrations under varying circumstances and for many possible project scenarios. There are some models, such as *CALINE4*, that have been excluded from the list and yet are considered by many to be relatively accurate models. In the case of *CALINE4*, the U.S. EPA has stated that it can be used in areas where it has been used historically for estimating CO emissions, but must be specifically approved for all new regions. In California, *CALINE4* has been widely accepted for many years as the standard modeling tool to evaluate project-level CO impacts.

A listing of preferred models cannot possibly include every model that will be best suited for all possible projects or analyses. For this reason, multiple guides have been produced by the EPA and other agencies to help practitioners compare and evaluate both preferred and non-preferred dispersion models [32-35]. If a practitioner believes that the best model for a particular project is not the EPA-preferred model, it is helpful to speak with

EPA Regional Office staff members, State and local regulatory agencies and the Federal Land Manager as soon as possible [4].

A list of alternative tools can be found in Appendix B of The Guideline [4] and on the EPA SCRAM website (http://www.epa.gov/scram001/dispersion_alt.htm). The web version is the replacement for the Appendix B version of the list, and therefore should be considered the most recent description of which models qualify for EPA “alternative model” designation. Section 3.2 of The Guideline (“Use of Alternative Models”) should be reviewed for guidance on selecting and justifying use of an alternative model [4]. It is necessary to confirm that an alternative model is not biased toward underestimating pollutant concentrations. It is generally easiest to select an EPA-preferred model whenever possible, but when an alternative model is more appropriate for a specific project, the practitioner should use statistical methods as outlined in “Protocol for Determining the Best Performing Model.” [35] or a similar statistical method, to determine whether or not an alternative model can provide statistically significant and accurate results.

5 User Interfacing

While all dispersion models are developed to provide accurate pollutant concentration estimates under specified conditions, it rare to find a regulatory model that incorporates a helpful and intuitive user interface or a visual representation of pollutant sources and plume dispersion. For this reason, it has become common for independent companies and other organizations to build graphic user interfaces (GUIs) to provide ease of use for model practitioners and, in some cases, add utility to existing models.

Serious computer users and programmers often see little need for GUIs, since they are generally associated with limited flexibility with respect to user input and adjustment. While this is often the case with many software GUIs, there are some GUIs that have been developed for use with regulatory dispersion models that actually provide a great deal of user flexibility, data pre-processing assistance, and additional time-saving features. In addition to the previously mentioned GUI for CALINE4 available from Caltrans (*CL4*), other GUIs include:

1. *CALRoads View*: Available from Lakes Environmental Software (http://shop.store.yahoo.com/lakes-environmental/calroadsview1.html), this system includes *CALINE4*, *CAL3QHC* and *CAL3QHCR*. The system is fully integrated with GIS software (ESRI), AutoCAD, added receptor capabilities and graphical input/output. This program is sold by Lakes Environmental Software for $995.

2. *ISC-AERMOD View*: Available from the Scientific Software Group (http://www.scisoftware.com/environmental_software/product_info.php?name=ISC-AERMOD%20View&products_id=28&language=en), this system includes *ISC3*, *AERMOD* and *ISC-Prime* (which incorporates building downwash algorithms). The system includes data pre-processors for *AERMOD* and *ISC3*, graphical input/output, 3D visualization of sources, and a post-processor for overlaying maps. This program is sold by the Scientific Software Group for $1,500 (with a 50% discount for universities).

3. *BEEST Suite*: Available from BEE-Line Software (http://beeline-software.com/beest.htm), this system also includes *ISCST3*, *AERMOD* and *ISC-Prime*. The system includes data pre-processors for *AERMOD* and *ISC3*, graphical input/output, 3D visualization of sources, and a post-processor for overlaying maps. This program is sold by BEE-Line Software for $1,225.

The examples listed above are for reference only and do not constitute an endorsement of these tools by Caltrans or U.C. Davis. Additional resources are commercially available. The retail prices quoted are approximate and are made available to help the reader gain a rough sense of software costs. Software prices vary considerably over time and by commercial outlet; readers should perform a more up-to-date review of cost information before making any purchase decisions.

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Appendix: Supporting Information

A. Modeling Point, Line, and Area/Volume Sources

A source that emits pollutants from a small, discrete location (such as a smoke stack) might be appropriately modeled as a point source. Emissions from a road can often be modeled as a line source, while a field or parking structure could be simulated using an area or volume source approximation. It is important to select a model that most accurately simulates the existing or future emissions source(s), even though it is often difficult to replicate project site characteristics exactly. Some models are capable of using multiple estimation methods (e.g., *ISC3* can model point, area or volume sources), while others are designed for specific applications and use only one approximation method (e.g., *CALINE3*, which uses only a line source approximation).

For obvious reasons, roadways are most commonly approximated as line sources, which can be partitioned into varying segment lengths. The line source algorithm developed for *CALINE3* has been thoroughly verified and applied in multiple other dispersion models, including *CALINE4*, *CAL3QHC*, *CAL3QHCR* and *PAL*. While the *CALINE3* line source algorithm does serve the function of modeling line sources very well, it is not a very good tool for modeling sources that cannot be approximated as lines, such as parking lots or construction sites. In cases where a project-level analysis requires the analysis of sources that cannot be approximated as lines, it is generally necessary for a practitioner to use some model that provides this capability (e.g. *AERMOD*, *ISC3* or *PAL*).

PAL allows the practitioner to model point, area or line sources, which may be convenient in the event that analysis of multiple source types is necessary. *AERMOD* and *ISC3* incorporate more sophistication than *PAL*, but were not designed to model line sources directly. However, it is possible to approximate a line source using either an elongated area source or multiple volume sources joined together. These are common practices implemented by air quality modeling practitioners, and although it has been argued that elongated area sources provide more accurate estimates [36], this is not well supported in the literature. In many cases, it may be left up to the discretion of the practitioner to choose the approximation method that best suits their application needs.

When using elongated area sources to approximate a line, it is important not to extend the aspect ratio of the area beyond about 10:1, and irregular areas must be divided into multiple rectangular areas [22]. This elongated area approach to line source approximation has been adopted by some air quality management districts (AQMDs) and is also implemented by the Federal Aviation Administration (FAA), which uses *AERMOD* as part of their Emissions and Dispersion Modeling System (EDMS) for air quality analysis of aviation sources [36].

To approximate a line using volume sources, it is necessary to specify the volume dimensions and number of discrete volumes. For approximating a line source using volume sources in *ISC3*, it is recommended that each volume has a lateral length that is slightly less than half the longitudinal length, i.e. $L_Y = L_X / 2.15$ [22]. Additionally, the vertical height of the volume should be determined as slightly less than half the source height, i.e. $L_Z = H_o / 2.15$ [22]. For line sources that are quite long, it may be desirable to place volumes at regularly spaced intervals rather than side by side. If this is the case, the *ISC3* guide recommends not spacing the volume sources farther apart than twice the volume width (which is often the lane or road width).

B. Use of Latest Modeling Tools and Assumptions

It cannot be overstated that, in general, the estimation of ***emissions rates*** from a given source is much more important and, for the most part, more difficult to quantify than the estimation of ***emissions dispersion***. The two models most commonly used for calculating emissions rates from mobile sources are MOBILE and EMFAC. In California, EMFAC is the recommended model for estimating emissions rates. These models require a range of input variables, including analysis year, temperature, vehicle fleet distribution, vehicle speeds, cold/hot start percentage and vehicle inspection and maintenance (I/M) program information. Federal guidance states that practitioners must use the most currently available version of MOBILE or EMFAC for deriving emission factors. All assumptions made when estimating emissions rates should be clearly stated and be based on the most current information available for a given region.

C. Gaussian Models Compared to Other Tools

Models can be categorized by the emissions modeling procedure they implement. The three generic modeling classes are *Gaussian*, *numerical* and *empirical*. By far, Gaussian models are the most widely used by practitioners, but for some applications it may be appropriate to use a model that applies numerical or empirical modeling procedures. For a regional project where it is necessary to analyze the formation and dispersion of ozone (O_3), for example, the use of a numerical model may be necessary in order to accurately model the pollutant's highly reactive nature. The major drawback to such models is their requirement of extensive user input and resources, which is one reason why their use is generally reserved for large-scale air quality analysis at the regional level.

Gaussian models are characterized by their use of the Gaussian dispersion method for modeling emissions transport (see footnote in Section 3, page 11, regarding Gaussian principles). Some distinguishing characteristics of different Gaussian models are the level of detail required for their input data, their methods for estimating emission sources and their methods for dealing with the effects of wind, weather and local terrain. Nearly all micro-scale models for estimating the dispersion of non-reactive pollutants such as carbon monoxide (CO) and particulate matter (PM) use some form of a Gaussian dispersion model, making it the most common model class used for project-level air quality analyses. In fact, the only significant difference between most models within the same class, such as Gaussian models, is the degree of detail provided in the input data [4]. Such input data may include wind and weather characteristics, roadway geometry, distribution of receptor sites, characterization of the emissions source, and so on.

D. Screening Tools Compared to Refined Models

Although there is a wide spectrum of sophistication along which different air quality models fall, only two levels of sophistication are distinguished for the purposes of project-level CO and PM analysis. The first set of models, known as *screening models,* are usually more general, relatively simple and do not require as much time or data from the user. Screening models can be useful for identifying emissions sources that clearly will or will not cause or contribute to ambient concentrations in excess of the National Ambient Air Quality Standards (NAAQS) [23]. Although computer operating memory and run-time is no longer the limiting factor that it once was just a few years ago, the use of a screening tool may still save the model practitioner some time by avoiding in-depth modeling of sources that are unlikely to contribute significantly to poor air quality. Since many screening tools use "worst case" scenarios to model pollutant concentrations, they are generally a safe and conservative first estimate of project-level emissions. However, if a screening model produces results indicating that a source may in fact exceed the NAAQS, a model of greater sophistication must be used to provide results with greater resolution.

Models of greater sophistication are sometimes referred to as *refined models*. These models require greater data input but in return provide more refined estimates of emission source impacts. For most analyses, it is recommended that a *screening model* be used first, followed by a more *refined model* when necessary [23].