Abridged User's Guide for CALINE-3

The document contained in this file is an abridged version of the CALINE-3 User's Guide. This document has been placed on the SCRAM website to facilitate the immediate use of the CALINE-3 model without having to wait for delivery of the complete user's guide. Although some portions of the User's Guide have been omitted to keep the file size to a reasonable size, nothing was omitted that is needed by the user to run the model. Nevertheless, the user is strongly encouraged to obtain the complete user's guide from NTIS. The NTIS document number and ordering information can be found on the SCRAM website on the User’s Guide page under NTIS Availability.

CALINE3 - A Versatile Dispersion Model
for Predicting Air Pollutant Levels
Near Highways and Arterial Streets

by

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Abridged Version by Computer Sciences Corporation

Abridgement of:
Report No. FHWA/CA/TL-79/23
Interim Report
Nov. 1979

NOTICE

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Neither the State of California nor the United States Government endorse products or manufacturers. Trade or manufacturers' names appear herein only because they are considered essential to the object of this document.

ACKNOWLEDGMENTS

The author wishes to express his appreciation to Messrs. Edward Wong and Michael Van De Pol for their assistance on this project. Mr. Wong carried out the model sensitivity analysis and, with the assistance of Mr. Ray Baishiki (Office of Computer Systems), was responsible for the FORTRAN conversion of CALINE3 and much of the user instructions. Mr. Van De Pol conducted the complex verification analysis including comparisons between CALINE2 and CALINE3. The guidance received from Drs. Leonard Myrup and Daniel Chang of the University of California at Davis was also especially helpful, as was the report review by Messrs. Earl Shirley and Roy Bushey. Mrs. Marion Ivester is responsible for the excellent graphics contained in the report, and Ms. Darla Bailey for turning the numerous, illegible rough drafts into a readable, typewritten report.

PREFACE TO ABRIDGED VERSION

This abridged version of the most recent CALINE3 User's Guide has been created for users of the Support Center for Regulatory Air Models Bulletin Board System (SCRAM BBS). It is stored in Word Perfect format on the SCRAM BBS in the Regulatory Models Section under Documentation. The availability of this and other model user's guides on the SCRAM BBS will facilitate the immediate use of models which have been downloaded from the SCRAM BBS, without having to wait for delivery of the complete user's guide.

Although some portions of the User's Guide have been omitted to save space, nothing was omitted that is needed by the user to run the model. Nevertheless, the user is strongly encouraged to obtain the complete user's guide from NTIS. NTIS Document Numbers for model user's guides can be found on the SCRAM BBS in the Models/Documents Section under News.

Note that the actual page numbers in your copy of the document may differ from those indicated in the Table of Contents, depending on the kind of printer (as well as the available type font) that is used to print your copy of this document.

The abridged version of the CALINE3 User's Guide was composed by Computer Sciences Corporation, RTP, NC, for the SCRAM BBS.

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CONVERSION FACTORS

English to Metric System (SI) of Measurement

Quantity	English unit	Multiply by	To get metric equivalent
Length	inches (in) or (")	25.40	millimeters (mm)
		.02540	meters (m)
	feet (ft) or (')	.3048	meters (m)
	miles (mi)	1.609	kilometers (km)
Area	square inches (in^2)	6.432×10^{-4}	square meters (m^2)
	square feet (ft^2)	.09290	square meters (m^2)
	acres	.4047	hectares (ha)
Volume	gallons (gal)	3.785	liters (1)
	cubic feet (ft^3)	.02832	cubic meters (m^3)
	cubic yards (yd^3)	.7646	cubic meters (m^3)
Volume/Time			
(Flow)	cubic feet per second (ft^3/s)	28.317	liters per second (l/s)
	gallons per minute (gal/min)	.06309	liters per second (l/s)
Mass	pounds (lb)	.4536	kilograms (kg)
Velocity	miles per hour (mph)	.4470	meters per second (m/s)
	feet per second (fps)	.3048	meters per second (m/s)
Accelera- tion	feet per second squared (ft/s^2)	.3048	meters per second squared (m/s^2)
	acceleration due to force of gravity (G)	9.807	meters per second squared (m/s^2)
Weight Density	pound per cubic (lb/ft^3)	16.02	kilograms per cubic meter (kg/m^3)
Force	pounds (lbs)	4.448	newtons (N)
	kips (1000 lbs)	4.448	newtons (N)

Thermal Energy	British thermal unit (BTU)	1055	joules (J)
Mechanical Energy	foot-pounds(ft-lb) foot-kips (ft-k)	1.356 1.356	joules (J) joules (J)
Bending Moment or Torque	inch-pounds(in-lbs) foot-pounds(ft-lbs)	.1130 1.356	newton-meters (Nm) newton-meters (Nm)
Pressure	pounds per square inch (psi)	6895	pascals (Pa)
	pounds per quare foot (psf)	47.88	pascals (Pa)
Stress (metre)$^{1/2}$ Intensity	kips per square inch square root inch (ksi (in)$^{1/2}$)	1.0988	mega pascals (MPa (m)$^{1/2}$)
(meter)$^{1/2}$	pounds per square inch square root inch (psi (in)$^{1/2}$)	1.0988	kilo pascals (KPa (m)$^{1/2}$)
Plane Angle	degrees (E)	0.0175	radians (rad)
Temperature	degrees fahrenheit (F)	$\frac{tF - 32}{1.8} = tC$	degrees celsius (EC)

1. INTRODUCTION

CALINE3 is a third generation line source air quality model developed by the California Department of Transportation. It is based on the Gaussian diffusion equation and employs a mixing zone concept to characterize pollutant dispersion over the roadway.

The purpose of the model is to assess air quality impacts near transportation facilities in what is known as the microscale region. Given source strength, meteorology, site geometry, and site characteristics, the model can reliably predict pollutant concentrations for receptors located within 150 meters of the roadway. At present, the model can handle only inert pollutants such as carbon monoxide, or particulates. It is anticipated that nitrogen dioxide predictive capabilities will be added to the model within the next year.

Historically, the CALINE series of models required relatively minimal input from the user. Spatial and temporal arrays of wind direction, wind speed and diffusivity were not used by the models. While CALINE3 has several added inputs over its predecessor, CALINE2, it must still be considered an extremely easy model to implement. More complex models are unnecessary for most applications because of the uncertainties in estimating emission factors and traffic volumes for future years. As a predictive tool, CALINE3 is well balanced in terms of the accuracy of state-of-the-art emissions and traffic models, and represents a significant improvement over CALINE2 in this respect. The new model also possesses much greater flexibility than CALINE2 at little cost to the user in terms of input complexity.

This report should help the potential user of CALINE3 to understand and apply the model. Users should become thoroughly familiar with the workings of the model and, particularly, its limitations. This knowledge will aid them in deciding when and how to use CALINE3. Also, users should become familiar with the response of the model to changes in various input parameters. This information is contained in the sensitivity analysis portion of this report.

The results of a verification study using three separate data bases are also contained in this report. Dramatic improvements over CALINE2 are shown, particularly for parallel winds and stable atmospheric conditions. User instructions have been added along with several examples of CALINE3 applications which illustrate the variety of situations for which the model can be used.

2. BACKGROUND

In response to the National Environmental Policy Act of 1969, Caltrans published its first line source dispersion model for inert gaseous pollutants in 1972(1). Model verification using the rudimentary field observations then available was inconclusive.

In 1975, the original model was replaced by a second generation model, CALINE2(2). The new model was able to compute concentrations for depressed sections and for winds parallel to the highway alignment. The two models were compared using 1973 CO bag sampling data from Los Angeles with CALINE2 proving superior.

Sometime after the dissemination of CALINE2, users began to report suspiciously high predictions by the model for stable, parallel wind conditions. As a result, a more complete verification of the model was undertaken by Caltrans using the 1974-75 Caltrans Los Angeles Data Base(3), and the 1975 GM Sulfate Experiment Data Base(4). Comparison of predicted and measured results showed that the predicted CO concentrations near the roadway were two to five times greater than measured values for stable, parallel wind conditions. An independent study by Noll in 1977(5) concluded that CALINE2 overpredicted for parallel winds by an average of 66% for all stabilities.

Overpredictions by CALINE2 for the stable, parallel wind case were particularly significant. This configuration was usually selected as the worst case condition for predicting highway impact on air quality in the microscale region. Thus, beneficial highway projects might have been delayed or cancelled on the basis of inaccurate results from CALINE2.

Inadequacies in the model also needed rectification. The inability to specify line source length and ground roughness severely limited the number of situations in which the model could be properly applied. Also, predicting impacts from multiple sources required a series of runs with varying receptor distances. Such an unwieldy procedure could lead to erroneous results.

In view of the inaccuracies and inadequacies of CALINE2, the model assumptions and computational methods were reviewed with the idea of revising the model. Since, in some cases, the mathematical approach in CALINE2 emphasized convenience and computational efficiency rather than a rigorous treatment, it became apparent that revisions would not suffice and a completely new model was needed. The new model would retain the Gaussian formulation so that input requirements could be kept at a minimum. However, the highway would be modeled as a series of finite line sources positioned perpendicular to the wind direction, as opposed to the series of virtual point sources used by CALINE2. Also, it was felt that new vertical dispersion curves were needed. The curves used by CALINE2 were modified versions of Turner's curves(6). These curves were derived for averaging times of 10 minutes or less and extremely smooth terrain. Both of these factors contributed to the overpredictions for one-hour urban CO concentrations. Recent research by Caltrans(7) concluded that the amount of vertical mixing near the roadway increased as wind speed decreased. These findings were combined with more recently developed dispersion curves published by Pasquill in 1974(8). Adjustments for averaging time and surface roughness also were included in the dispersion curve algorithms.

3. CONCLUSIONS AND RECOMMENDATIONS

The comparisons of CALINE2 and CALINE3 made in the Verification Analysis portion of this report clearly demonstrate the improved performance of the new model. It is concluded that the new algorithms contained in CALINE3 represent the dispersion process near highways in a more realistic way than did CALINE2. In addition, the greater flexibility of the new model makes it adaptable to many modeling applications not appropriate for CALINE2. Finally, CALINE3 does not require additional computational time over CALINE2 for equivalent applications. For these reasons, it is recommended that CALINE3 replace CALINE2 as the official line source air quality model used by Caltrans.

There are some aspects of CALINE3 on which further research is recommended:

1. The residence time hypothesis needs to be studied for vehicle speeds under 30 miles/hour.

2. Verification of the model for intersection analysis must be carried out.

3. Validation of the deposition and settling velocity components of the model is needed.

4. Study of worst case meteorology as a function of land use and geography is needed for more accurate evaluation of multi-hour averages.

5. NO_2 predictive capabilities must be added to the model and verified.

4. IMPLEMENTATION

This section was intentionally omitted in this abridged version to save space. Nothing in the section is needed by the user to run the model. The complete document is available from NTIS.

5. MODEL DESCRIPTION

5.1 Gaussian Element Formulation

CALINE3 divides individual highway links into a series of elements from which incremental concentrations are computed and then summed to form a total concentration estimate for a particular receptor location. The receptor distance is measured along a perpendicular from the receptor to the highway centerline. The first element is formed at this point as a square with sides equal to the highway width. The lengths of subsequent elements are described by the following formula:

$$EL = W*BASE^{(NE-1)}$$

Where, EL = Element Length
W = Highway Width
NE = Element Number
BASE = Element Growth Factor

PHI<20E, BASE=1.1
20E#PHI<50E, BASE=1.5
50E#PHI<70E, BASE=2.0
70E#PHI , BASE=4.0

Where, PHI = the angle between the wind direction and the direction of the roadway.

(Note: Capitalized variables shown in text are identical to those used in the computer coding.)

Thus, as element resolution becomes less important with distance from the receptor, elements become larger to permit efficiency in computation. The choice of the element growth factor as a function of roadway-wind angle (PHI) range represents a good compromise between accuracy and computational efficiency. Finer initial element resolution is unwarranted because the vertical dispersion curves used by CALINE3 have been calibrated for the link half-width (W2) distance from the element centerpoint.

Each element is modeled as an "equivalent" finite line source (EFLS) positioned normal to the wind direction and centered at the element midpoint. A local x-y coordinate system aligned with the wind direction and originating at the element midpoint is defined for each element. The emissions occurring within an element are assumed to be released along the EFLS representing the element. The emissions are then assumed to disperse in a Gaussian manner downwind from the element. The length and orientation of the EFLS are functions of the element size and the angle (PHI,φ) between the average wind direction and highway alignment. Values of PHI=0 or PHI=90 degrees are altered within the program an insignificant amount to avoid division by zero during the EFLS trigonometric computations.

In order to distribute emissions in an equitable manner, each element is divided into five discrete sub-elements represented by corresponding segments of the EFLS. The use of five sub-elements yields reasonable continuity to the discrete element approximation used by the model while not excessively increasing the computational time. The source strength for the segmented EFLS is modeled as a step function whose value depends on the sub-element emissions. The emission rate/unit area is assumed to be uniform throughout the element for the purposes of computing this step function. The size and location of the sub-elements are a function of element size and wind angle.

Downwind concentrations from the element are modeled using the crosswind finite line source (FLS) Gaussian formulation.

5.2 Mixing Zone Model

CALINE3 treats the region directly over the highway as a zone of uniform emissions and turbulence. This is designated as the mixing zone, and is defined as the region over the traveled way (traffic lanes - not including shoulders) plus three meters on either side. The additional width accounts for the initial horizontal dispersion imparted to pollutants by the vehicle wake effect.

Within the mixing zone, the mechanical turbulence created by moving vehicles and the thermal turbulence created by hot vehicle exhaust is assumed to predominate near the ground. Evidence indicates that this is a valid assumption for all but the most unstable atmospheric conditions(7). Since traffic emissions are released near the ground level and model accuracy is most important for neutral and stable atmospheric conditions, it is reasonable to model initial vertical dispersion (SGZ1) as a function of the turbulence within the mixing zone.

Analyses by Caltrans of the Stanford Research Institute(10) and General Motors(4) data bases indicate that SGZ1 is insensitive to changes in traffic volume and speed within the ranges of 4,000 to 8,000 vehicles/hr and 30 to 60 mph(7).

This may be due in part to the offsetting effects of traffic speed and volume. Higher volumes increase thermal turbulence but reduce traffic speed, thus reducing mechanical turbulence. For the range of traffic conditions cited, mixing zone turbulence may be considered a constant. However, pollutant residence time within the mixing zone, as dictated by the wind speed, significantly affects the amount of vertical mixing that takes place within the zone. A distinct linear relationship between SGZ1 and residence time was exhibited by the two data bases studied.

CALINE3 arbitrarily defines mixing zone residence time as:

$$TR = W2/U$$

Where, W2 = Highway half-width

U = wind speed

This definition is independent of wind angle and element size. It essentially provides a way of making the EFLS model compatible with the actual two-dimensional emissions release within an element. For oblique winds and larger elements, the plume is assumed to be sufficiently dispersed after traveling a distance of W2 such that the mixing zone turbulence no longer predominates.

The equation used by CALINE3 to relate SGZ1 to TR is:

$$\underset{(m)}{SGZ1} = 1.8 + 0.11 * \underset{(secs.)}{TR}$$

This was derived from the General Motors Data Base. It is adjusted in the model for averaging times other than 30 minutes by the following power law(11):

$$SGZ1_{ATIM}\ SGZ1_{30} * (ATIM/30)^{0.2}$$

Where, ATIM = Averaging time (minutes)

The value of SGZ1 is considered by CALINE3 to be independent of surface roughness and atmospheric stability class. The user should note that SGZ1 accounts for all the enhanced dispersion over and immediately downwind of the roadway. Thus, the stability class used to run the model should be representative of the upwind or ambient stability without any additional modifications for traffic turbulence.

5.3 Vertical Dispersion Curves

The vertical dispersion curves used by CALINE3 are formed by using the value of SGZ1 from the mixing zone model, and the value of σ_z at 10 kilometers (SZ10) as defined by Pasquill(8). In effect, the power curve approximation suggested by Pasquill is elevated near the highway by the intense mixing zone turbulence. The significance of this added turbulence to plume growth lessens with increased distance from the source, though, in theory, it will never disappear. Extrapolated σ_z curves measured out to distances of 150 meters from the highway centerline under stable conditions for both the GM and SRI data bases intersect the Pasquill curves at roughly 10 kilometers. Beyond this point the power curve approximation to the true Pasquill curve, which is actually concave to the Rnx axis, becomes increasingly inaccurate. Thus, the model should not be used for distances greater than 10 kilometers. As will be seen in the sensitivity analysis, contributions from elements greater than 10 kilometers from the receptor are insignificant even under the most stable atmospheric conditions.

For a given set of meteorological conditions, surface roughness (Z0) and averaging time (ATIM), CALINE3 uses the same vertical dispersion curve for each element within a highway link. This is possible since SGZ1 is always defined as occurring at a distance W2 downwind from the element centerpoint. SZ10 is adjusted for Z0 and ATIM by the following power law factors(11):

$$SZ10_{ATIM,Z0} = SZ10*(ATIM/3)^{0.2}*(Z0/10)^{0.07}$$

Where, ATIM = Averaging time (minutes)
Z0 = Surface roughness (cm)

Table 1 contains recommended values of Z0 for representative land use types(12).

The vertical dispersion of CO predicted by the model can be confined to a shallow mixed layer by means of the conventional Gaussian multiple reflection formulation(6). This capability was included in the model to allow for analysis of low traffic flow situations occurring during extended nocturnal low level inversions. Surprisingly high 8 hour CO averages have been measured under such conditions (13).

It is recommended for these cases that reliable, site specific field measurements be made. The following mixing height model proposed by Benkley and Schulman (14) can then be used:

$$MIXH = (0.185*U*k)/(\ln(Z/Z0)*f)$$

Where, U = Wind speed (m/s)
Z = Height U measured at (m)
Z0 = Surface roughness (m)
k = von Karman constant (0.35)
f = Coriolis parameter
= $1.45 \times 10^{-4} \cos \theta$ (radians/sec)
θ = 90° - site latitude

TABLE 1

Surface Roughness for Various Land Uses

Type of Surface	Z0 (cm)
Smooth mud flats	0.001
Tarmac (pavement)	0.002
Dry lake bed	0.003
Smooth desert	0.03
Grass (5-6 cm)	0.75
(4 cm)	0.14
Alfalfa (15.2 cm)	2.72
Grass (60-70 cm)	11.4
Wheat (60 cm)	22.
Corn (220 cm)	74.
Citrus orchard	198.
Fir forest	283.
City land-use	
Single family residential	108.
Apartment residential	370.
Office	175.
Central Business District	321.
Park	127.

For nocturnal conditions with low mixing heights, wind speeds are likely to be less than 1 M/S. Extremely sensitive wind speed and direction instrumentation would be required for reliable results at such low wind speeds. In order to use CALINE3 for these conditions, measurements of the horizontal wind angle standard deviation will be needed. The model can then be modified to calculate horizontal dispersion parameters based on the methodology developed by Pasquill (15) or Draxler (16) The user is cautioned that the model has not been verified for wind speeds below 1 M/S, and that assumptions of negligible along-wind dispersion and steady state conditions are open to question at such low wind speeds.

Mixing height computations must be made for each element receptor combination, and thus add appreciably to program run time. As will be seen in the sensitivity analysis, the mixing height must be extremely low to generate any significant response from the model. Therefore, it is recommended that the user bypass the mixing height computations for all but special nocturnal simulations. This is done by assigning a value of 1000 meters or greater to MIXH.

5.4 Horizontal Dispersion Curves

The horizontal dispersion curves used by CALINE3 are identical to those used by Turner(6) except for averaging time and surface roughness power law adjustments similar to those made for the vertical dispersion curves. The model makes no corrections to the initial horizontal dispersion near the roadway. The only roadway related alterations to the horizontal dispersion curves occur indirectly by defining the highway width as the width of the traveled way plus 3 meters on each side, and assuming uniform emissions throughout the element.

If field measurements of the horizontal wind angle standard deviation are available, site specific horizontal dispersion curves can be generated using the methodology developed by Pasquill (15) or Draxler (16). CALINE3 can then be easily reprogrammed to incorporate the modified curves. This approach is recommended whenever manpower and funding are available for site monitoring.

5.5 Site Geometry

CALINE3 permits the specification of up to 20 links and 20 receptors within an X-Y plane (not to be confused with the local x-y coordinate system associated with each element). A link is defined as a straight segment of roadway having a constant width, height, traffic volume, and vehicle emission factor. The location of the link is specified by its end point coordinates. The location of a receptor is specified in terms of X, Y, Z coordinates. Thus, CALINE3 can be used to model multiple sources and receptors, curved alignments, or roadway segments with varying emission factors. The wind angle (BRG) is given in terms of an azimuth bearing (0 to 360E). If the Y-axis is aligned with due north then wind angle inputs to the model will follow accepted meteorological convention (i.e., 90E equivalent to a wind directly from the east).

The program automatically sums the contributions from each link to each receptor. After this has been completed for all receptors, an ambient or background value (AMB) assigned by the user is added. Surface roughness is assumed to be reasonably uniform throughout the study area. The meteorological variables of atmospheric stability, wind speed, and wind direction are also taken as constant over the study area. The user should keep this assumption of horizontal homogeneity in mind when assigning link lengths. Assigning a 10 kilometer link over a region with a terrain induced wind shift after the first 2 kilometers should be avoided. A 2 kilometer link would be more appropriate.

The elements for each link are constructed as a function of receptor location as described in Section 5.1. This scheme assures that the finest element resolution within a link will occur at the point closest to the receptor. An imaginary displacement of the receptor in the direction of the wind is used by CALINE3 to determine whether the receptor is upwind or downwind from the link.

For each highway link specified, CALINE3 requires an input for highway width (W) and height (H). The width is defined as the width of the traveled way (traffic lanes only) plus 3 meters on each side. This 3 meter allowance accounts for the wake-induced horizontal plume dispersion behind a moving vehicle. The height is defined as the vertical distance above or below the local ground level or datum. CALINE3 should not be used in areas where the terrain in the vicinity of the highway is uneven enough to cause major spatial variability in the meteorology. Also, the model should not be used for links with values of H greater than 10 meters or less than -10 meters.

Elevated highway sections may be of either the fill or bridge type. For a bridge, air flows above and below the source in a relatively undisturbed manner. This sort of uniform flow with respect to height is an assumption of the Gaussian formulation. For bridge sections, H is specified as the height of the roadway above the surrounding terrain. For fill sections, however, the model automatically sets H to zero. This assumes that the air flow streamlines follow the terrain in an undisturbed manner. Given a 2:1 fill slope (effectively made more gradual as the air flow strikes the highway at shallower horizontal wind angles) and stable atmospheric conditions (suppressing turbulence induced by surface irregularities), this is a reasonable assumption to make (17).

For depressed sections greater than 1.5 meters deep, CALINE3 increases the residence time within the mixing zone by the following empirically derived factor based on Los Angeles data(3):

$$DSTR = 0.72 * ABS(H)^{0.83}$$

This leads to a higher initial vertical dispersion parameter (SGZ1) at the edge of the highway. The increased residence time, characterized in the model as a lower average wind speed, yields extremely high concentrations within the mixing zone. The wind speed is linearly adjusted back to the ambient value at a distance of 3*H downwind from the edge of the mixing zone. By this point the effect of the higher value for SGZ1 dominates, yielding lower concentrations than an equivalent at-grade section.

For depressed sections, the model is patterned after the behavior observed at the Los Angeles depressed section site studied by Caltrans(3). Compared to equivalent at-grade and elevated sites, higher initial vertical dispersion was occurring simultaneously with higher mixing zone concentrations. It was concluded that channeling and eddying effects were effectively decreasing the rate of pollutant transport out of the depressed section mixing zone. Lower concentrations downwind of the highway were attributed to the more extensive vertical mixing occurring within the mixing zone. Consequently, the model yields higher values for concentrations within or close to the mixing zone, and somewhat lower values than would be obtained for an at-grade section for downwind receptors. Except for these adjustments, CALINE3 treats depressed sections computationally by the same as at-grade sections.

It has been suggested that the model could be used for evaluating parking lot impacts. If the user wishes to run the model to simulate dispersion from a parking lot, it is recommended that SGZ1 be kept constant at 1 meter, and that the mixing zone width not be increased by 3 meters on each side as in the normal free flow situation. This is because the slow moving vehicles within a parking lot will impart much less initial dispersion to their exhaust gases.

5.6 Deposition and Settling Velocity

Deposition velocity (VD) is a measure of the rate at which a pollutant can be adsorbed or assimilated by a surface. It involves a molecular, not turbulent, diffusive process through the laminar sublayer covering the surface. Settling velocity (VS) is the rate at which a particle falls with respect to its immediate surroundings. It is an actual physical velocity of the particle in the downward direction. For most situations, a class of particles with an assigned settling velocity will also be assigned the same deposition velocity.

CALINE3 contains a method by which predicted concentrations may be adjusted for pollutant deposition and settling. This procedure, developed by Ermak (18), is fully compatible with the Gaussian formulation of CALINE3. It allows the model to include such factors as the settling rate of lead particulates near roadways (19) or dust transport from unpaved roads. A recent review paper by McMahon and Denison (20) on deposition parameters provides an excellent reference.

Most studies have indicated that CO depositing is negligible. In this case, both deposition and settling velocity adjustments can be easily bypassed in the model by assigning values of 0 to VD and VS.

6. SENSITIVITY ANALYSIS

A sensitivity analysis for CALINE3 has been omitted from this abridged document to save space. It is included in the complete document which is available from NTIS.

7. MODEL VERIFICATION

The Model Verification Chapter has been omitted from this abridged document to save space. It is included in the complete document which is available from NTIS.

8. USER INSTRUCTIONS

8.1 Restrictions and Limitations

8.1.1 Core requirements: approximately 60K.

8.1.2 CALINE3 can process a maximum of 20 links per job. For each link, the following must remain constant: The section type (TYP$), the source height (HL), the mixing zone width (WL), the traffic volume (VPHL), and the emission factor (EFL). If for any reason one of the variables changes, it must be accounted for by a different link or an averaged value. In the case in which two links are parallel and identical, the two links may be considered as one with mixing zone width equal to the sum of the two traveled way widths plus the edge-to-edge median width plus 6 meters. The median width may not exceed 10 meters.

8.1.3 CALINE3 can process a maximum of 20 receptors per job.

8.1.4 For any job, CALINE3 can process an unlimited number of

8.1.5 In setting up link dimensions, the link length should always be greater than the link width.

8.1.6 Input variable limits:

Variable	Suggested and Mandatory Limits	Reason
Wind Speed	U$1 m/s	Gaussian assumption; with U$1 m/s, along-wind diffusion can be considered negligible relative to U.
Wind Direction	OE#BRG#360E	Wind azimuth bearing relative to positive Y-axis.
Averaging Time	3 min<ATIM<120 min	Reasonable limits of power law approximation.
Surface Roughness	3 cm#ZO#400 cm	Reasonable limits of power law approximation.
Mixing Zone	W$10 m	Minimum of 1 lane plus 3 meters per side of link.
Link Length	W#LL#10 km	Link length, as defined by link endpoint coordinates (X1,Y1,X2,Y2), must be greater than or equal to link width for correct element resolution, and less than or equal to 10 km since vertical dispersion curve approximations are only valid for downwind distances of 10 km or less.
Stability Class	CLAS=1,2,3,4,5,6	Pasquill stability class scheme.
Source Height	-10 m#H#10 m	Not verified outside of given range.
Receptor Height	Z$O	Gaussian plume reflected at air-surface interface; model assumes plume transport over horizontal plane.

NOTE: For depressed sections Z$H (where H is negative) is permitted for receptors within the section.

8.1.7 The model should not be used in areas where the terrain in the vicinity of the highway is sufficiently rugged to cause significant spatial variability in the local meteorology.

8.1.8 The model should not be used for streets within a central business district where the so-called street canyon effect is significant.

8.2 Grid Orientation

CALINE3 uses a combination of the X-Y Cartesian coordinate system and the standard compass system to establish coordinate locations and link geometry. The standard, 360E compass is overlaid onto the X-Y coordinate plane such that north corresponds to the +Y direction and east corresponds to the +X direction. Wind angles (BRG) are measured as the azimuth bearing of the direction from which the wind is coming (i.e., BRG = 270E for a wind from the west). Coordinates, link height and link width may be assigned in any consistent length units. The user must input a scale factor (SCAL) to convert the chosen units to meters (SCAL=1. if coordinates and link height and width are input in meters).

The X-Y grid and compass systems are combined into a single system and may be used with north representing true or magnetic north or an assumed north. In either case, once north has been chosen, all angles and X-Y pairs must be consistently assigned. Negative coordinates are permitted.

8.3 Input

Card Sequence Number	Variable Name	Card Columns	Variable Description[*]
1	JOB	1-40	Current job title[**]
	ATIM	41-44	Averaging time, in minutes[***]
	ZO	45-48	Surface roughness, in cm
	VS	49-53	Settling velocity, in cm/s
	VD	54-58	Deposition velocity, in cm/s; if the settling velocity is greater than 0 cm/s, the deposition velocity should be set equal to the settling velocity.
	NR	59-60	Number of receptors; NR_{max}=20 (Integer)
	SCAL	61-70	Scale factor to convert receptor and link coordinates, and link height and width to meters.
2	RCP	1-20	Receptor name
	XR	21-30	X-coordinate of receptor
	YR	31-40	Y-coordinate of receptor
	ZR	41-50	Z-coordinate of receptor
		NOTE: Card sequence "2" must appear NR times.	
3	RUN	1-40	Current run title
	NL	41-43	Number of links; NL_{max}=20 (Integer)

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[*] Real variables, except titles, must contain a decimal point and integer variables are right justified.

[**] Data type real unless specified otherwise.

[***] See restrictions and limitations for additional information on variable limits.

	NM	44-46	Number of meteorological conditions; no maximum (Integer)
4	LNK	1-20	Link title
	TYP	21-22	Section type AJ=At-Grade FL=Fill BR=Bridge DP=Depressed
	XL1, YL1	23-29, 30-36	Coordinates of link endpoint 1
	XL2, YL2	37-43, 44-50	Coordinates of link endpoint 2
	VPHL	51-58	Traffic volume in vehicles per hour
	EFL	59-62	Emission factor, in grams/mile
	HL	63-66	Source height
	WL	67-70	Mixing zone width

NOTE: Card sequence number "4" must appear NL times.

5	U	1-3	Wind speed, in m/s
	BRG	4-7	Wind angle with respect to positive Y-axis in degrees; may range between 0E-360E, inclusive.
	CLAS	8	Atmospheric stability class, in numeric format (1-6=A-F) (Integer)
	MIXH	9-14	Mixing height, in meters
	AMB	15-18	Ambient concentration of pollutant, in ppm

NOTE: Card sequence number "5" must appear NM times.

8.4 Output

Output for CALINE3 consists of printed listings containing a summary of all input variables and model results. The input variables are separated into site, link and receptor variables. Model results of CO concentration are given in parts per million (ppm) for each receptor-link combination, and are totaled (including ambient) for each receptor. A separate page of output is generated for each meteorological condition (three-page output format is used when NL exceeds 10).

Other inert gaseous pollutants (such as SF_6 tracer) may be run by changing the molecular weight variable (MOWT) within the program to the appropriate value, and modifying the output headings. Similarly, to run the model for particulates, set FPPM=1 and again modify the headings. Results will be in units of Fg/m^3. For both cases, the fixed point format for the output should be modified to handle the range of results expected.

Jobs may be run consecutively, with a new series of pages being started for each job. A brief data edit is executed for each job run. If an error is found, a diagnostic is printed and program execution ends.

8.5 Examples

Four examples have been prepared to assist the user in understanding the model's capabilities. Each example demonstrates several important characteristics of the model. The user should note that the emission factors quoted in these examples are not rigorously derived values.

Input data for all four examples are included in the file named CALINE3.EXP. The resulting output is contained in CALINE3.LST. Below is an abbreviated description of the four examples. A more complete description can be found in the complete document which is available from MTIS.

8.5.1 Example One - Single Link

Example One is a simple illustration of a single link with one receptor located near the downwind edge of the highway. The purpose of this example is to show how the model handles links which are identical in every way except for their section type and source height.

The link runs in a north-south direction and is 10,000 meters long. The vehicle volume (VPH) is 7500 vehicles/hour, the emission factor (EF) is 30 grams/mile and the mixing zone width (W) is 30 meters. The site variables used are an averaging time (ATIM) of 60 minutes, an atmospheric stability (CLAS) of 6(F), deposition and settling velocities (VD,VS, respectively) of 0 cm/second, an ambient CO concentration (AMB) of 3.0 ppm, and a surface roughness (ZO) of 10 cm. The value for the surface roughness of 10 cm was chosen because the link is assumed to be located in a flat, rural area composed mainly of open fields. The meteorological conditions of wind speed (U) and wind angle (BRG) are 1 m/s and 270 degrees, respectively. The 270 degree wind angle puts the direction of the wind perpendicular to the link (crosswind) and from the west. The receptor is located 30 meters east of the highway centerline at a "nose height" of 1.8 meters.

For case one, the link is defined as an at-grade type (TYP=AG, H=0). For this configuration, the model calculates a CO concentration of 7.6 ppm. This includes the 3.0 ppm ambient value shown under site variables.

Cases two and four involve elevated links. Each link is assigned a height of 5 meters above the datum, but for case two the link is defined as a bridge section (TYP=BR), while in case four it is considered a fill section (TYP=FL). The resulting CO concentrations are 6.2 ppm for the "bridge" link and 7.6 ppm for the "fill" link. The difference in concentration is due to the method in which contributions from the "bridge" and "fill" links are calculated. For the "bridge" link in case two, it is assumed that the wind is not only blowing over the link, but also underneath it. Thus, the model can use the Gaussian adjustment for source height which assumes a uniform vertical wind distribution both above and below the elevated source. For the "fill" link, the model assumes that the wind streamlines pass over the fill parallel to the ground. Thus, the model treats case four just as if it were an at-grade section.

For case three, the link is designated a depressed section (TYP=DP). All conditions are identical to the previous cases except the source height. CALINE3 increases the pollutant residence time within the mixing zone of a depressed section, thus enhancing initial vertical dispersion. This accounts for the low CO concentration of 5.8 ppm predicted for case three.

8.5.2 Example Two - Rural Curved Alignment

Example two depicts the application of CALINE3 to a rural, curved alignment. Ten connecting links are used to model the highway. The ten links represent three straight sections, a 45E curve, and a 90E curve. The 90E curve is made up of five links, while the 45E curve is made up of only two links. The finer resolution for the 90E curve is needed to obtain an adequate approximation of the highway alignment for the nearby receptors. For the given wind angle, the 45E curve will not contribute significantly to any of the receptors, and thus is only divided up into two links.

The link conditions placed on this example are a constant vehicle volume of 8500 vehicles per hour and a constant emission factor of 30 grams/mile. Also constant for all ten links are the at-grade source height, and mixing zone width of 28 meters.

The two important site variables to note are the ambient concentration (3.0 ppm) and the surface roughness (50 cm). The surface roughness of 50 cm corresponds to assumed rolling, lightly wooded terrain. The model results, which include the ambient concentration, appear to be consistent with what would be expected under the wind angle of 45E.

8.5.3 Example Three - Urban Intersection

Example three represents a conventional urban intersection. The user should note that CALINE3 is not a street canyon model, and therefore should not be used to model central business district intersections (i.e., surrounded by buildings of 4 stories or more).

Each street is divided into three links. The intersection links are assigned a much higher emission factor (100 grams/mile) than the approaching links because of the vehicle idling and acceleration that occurs at the intersection. In practice, a modal emissions model would be used to predict a composite emission factor for the driving cycle characteristic of the intersection being modeled. Since the short intersection links are separate from the longer approaching links, the width of the short links can be made wider to include turn lanes. Thus, the multiple link capability of CALINE3 allows the model to take into account differences that exist along an arterial roadway.

The example is set in an urban location so that a surface roughness of 100 cm is used. As in the preceding examples, a worst case 1 hour stability class of F is assumed.

The model results include a 5.0 ppm ambient CO concentration.

8.5.4 Example Four - Urban Freeway

The final example is designed to show CALINE3's versatility. The example consists of two primary links running east-west, 16 kilometers long. Set in an urban location, the primary links carry traffic volumes of approximately 10,000 vehicles/ hour, with an emission factor of 30 grams/mile. An on-ramp link is also included in the example. Because of the constant acceleration occurring at the on-ramp, an emission factor of 150 grams/mile is used. As in Example three, this figure would be based on a modal emissions model. Crossing the primary links are two bridge links with traffic volumes of 4000 and 5000 vehicles/hour.

Twelve receptors are scattered all throughout the study area. By running the model at wind angle increments around the compass, the user can then identify the most critically affected receptors. For this example, 90E increments will be used. In practice, 10E increments are recommended.

With six links, twelve receptors, and four meteorological conditions, CALINE3 is able to handle all situations in a single run.

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