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USER'S GUIDE TO CAL3QHC VERSION 2.0: A MODELING METHODOLOGY FOR PREDICTING POLLUTANT CONCENTRATIONS NEAR ROADWAY INTERSECTIONS (REVISED)

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(Revised)

User's Guide to CAL3QHC Version 2.0: A Modeling Methodology for Predicting Pollutant Concentrations Near Roadway Intersections

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DISCLAIMER

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PREFACE

The CAL3QHC Version 2.0 model has been slightly revised. The revisions to the model are reflected in this version of the user's guide. The CAL3QHC Version 2.0 input structure has been converted from a "fixed format" to a "free format". Also, the CAL3QHC source code has been enhanced to permit the calculating of Particulate Matter (PM) concentrations. These revisions to CAL3QHC Version 2.0 will not change previous model results.

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ACKNOWLEDGEMENTS

Peter Eckhoff of EPA has revised the CAL3QHC Version 2.0 model and user's guide to allow input data in "free format" and to allow for the analysis of Particulate Matter (PM) impacts.

The original CAL3QHC Version 2.0 User's Guide was prepared for the United States Environmental Protection Agency (EPA), Office of Air Quality Planning and Standards (OAQPS) under contract No. 68-D90067. The authors, Guido Schattanek and June Kahng, would like to express special acknowledgements to the EPA technical director, Thomas N. Braverman, for his guidance and assistance in resolving technical issues, and to Donald C. DiCristofaro of Sigma Research Corporation, Concord, Massachusetts, for his contribution to the update of Chapters 4, 5, and 6, and the overall compilation of the report.

The initial User's Guide to CAL3QHC was prepared in 1990 for the EPA/OAQPS under Contract No. 68-02-4394 by the authors at Parsons Brinckerhoff Quade & Douglas, Inc. in New York, New York. Special acknowledgements for their contribution to the initial report are given to Thomas Wholley who provided the first concept of CAL3Q and offered technical guidance; George Schewe (Environmental Quality Management) for his assistance and direction in this effort; John Sun (Bechtel/Parsons Brinckerhoff) whose initial recommendations led to the use of Highway Capacity Manual procedures; James Brown and Joel Soden (Parsons Brinckerhoff) for their guidance and review of this document; and Tereza Stratou, Steven Warshaw, and Ingrid Eng for their Fortran programming efforts.

SECTION 1
INTRODUCTION

CAL3QHC is a microcomputer based model to predict carbon monoxide (CO) or other inert pollutant concentrations from motor vehicles at roadway intersections. The model includes the CALINE-3 line source dispersion model[1] and a traffic algorithm for estimating vehicular queue lengths at signalized intersections.

CALINE-3 is designed to predict air pollutant concentrations near highways and arterial streets due to emissions from motor vehicles operating under free flow conditions. However, it does not permit the direct estimation of the contribution of emissions from idling vehicles. CAL3QHC enhances CALINE-3 by incorporating methods for estimating queue lengths and the contribution of emissions from idling vehicles. The model permits the estimation of total air pollution concentrations from both moving and idling vehicles. It is a reliable tool[2] for predicting concentrations of inert air pollutants near signalized intersections. Because idle emissions account for a substantial portion of the total emissions at an intersection, the model is relatively insensitive to traffic speed, a parameter difficult to predict with a high degree of accuracy on congested urban roadways without a substantial data collection effort.

CAL3QHC requires all the inputs required for CALINE-3 including: roadway geometries, receptor locations, meteorological conditions and vehicular emission rates. In addition, several other parameters are necessary, including signal timing data and information describing the configuration of the intersection being modeled.

The principal difference between the original CAL3QHC model and CAL3QHC Version 2.0 pertains to the calculation of intersection capacity, vehicle delay, and queue length. Version 2.0 includes three new traffic parameters: Saturation Flow Rate, Signal Type, and Arrival Type. These parameters permit more precise specification of the operational characteristics of an intersection than in the original CAL3QHC model. Version 2.0 also replaces "stopped" delay (used in the queue calculation) with "approach" delay. These modifications are based on recommendations from the 1985 Highway Capacity Manual (HCM)[3]. CAL3QHC Version 2.0 can accommodate up to 120 roadway links, 60 receptor locations, and 360 wind angles, an increase from the original version which could accommodate 55 links and 20 receptors. This allows the modeling of adjacent intersections that interact with each other within a short distance.

The revised CAL3QHC Version 2.0 converts the input structure from "fixed format" to "free format." In addition, the revised CAL3QHC Version 2.0 model allows for the analysis of Particulate Matter (PM) impacts in micrograms per cubic meter.

This User's Guide is intended to provide the information necessary to run CAL3QHC Version 2.0. Development of the model is discussed in Section 2. Section 3 contains a technical description of how the different components and algorithms operate within the program. In addition, future research areas are discussed in Section 3. Model inputs and outputs, instructions for executing the model on a personal computer, and example applications are contained in Section 4. Section 5 presents a sensitivity analysis evaluating the effect of changes in model inputs on resultant pollutant concentration estimates. Section 6 summarizes the results of model verification tests completed by the United States Environmental Protection Agency [2].

While this document includes information on CALINE-3 necessary for using the CAL3QHC model, it does not describe the theory underlying CALINE-3. It is recommended that the user consult the CALINE-3 User's Guide[1] for information on the theoretical aspects of CALINE-3.

SECTION 2
BACKGROUND

When originally published in 1978, Volume 9 of the EPA Guidelines for Air Quality Maintenance Planning and Analysis[4] was considered to be the most appropriate methodology for calculating CO concentrations near congested intersections. The workbook procedure described in Volume 9 is composed of three components: traffic, emissions, and dispersion. Although no one model has been developed to replace all of the procedures in Volume 9, various procedures have been devised that have improved each component.

The manual workbook procedures included in Volume 9 are cumbersome and time consuming to use in situations where there are numerous roadway intersections or multiple traffic alternatives. In addition, Volume 9 utilizes an outdated modal emissions model, and its procedures are limited to situations where the estimated volume of traffic (V) approaching an intersection is less than the theoretical capacity (C) of the intersection ($V/C<1$). Consequently, during the period 1985 to 1987, Thomas Wholley and Thomas Hansen from the U.S. EPA Regional Offices I and IV developed CAL3Q, a computer-based procedure for estimating CO concentrations near roadway intersections. CAL3Q used the running and idling emission rates from the U.S. EPA mobile source emission factor model to estimate emissions, a queuing algorithm developed by the Connecticut Department of Transportation (CONDOT) to estimate queue lengths, and the CALINE-3 line source dispersion model to estimate dispersion.

While CAL3Q provided a means for considering the effect of queuing vehicles on pollutant concentrations, testing of the model indicated that it failed to accurately estimate queue lengths under near-saturated and over-saturated traffic conditions (i.e., when the approach volume reaches or surpasses the capacity of the roadway). Since these conditions are common occurrences in many congested urban areas and are of particular concern in determining the worst (maximum) air quality impacts of a proposed action, an extensive re—evaluation of the traffic assumptions used in determining delays and queue lengths at congested intersections was undertaken.

One of the principal recommendations of the re-evaluation was to replace the delay formulas included in CAL3Q with a hybrid methodology based on the signalized intersection analysis technique presented in the 1985 Highway Capacity Manual (HCM)[3] and the Deterministic Queuing Theory[5,6]. In the hybrid methodology, a simplified 1985 HCM procedure is used to estimate the average vehicle delay for the under-saturated condition. The additional delay associated with over-saturation conditions is estimated based on the Deterministic Queuing Theory procedure. Using the average vehicle delay estimated through the hybrid methodology, queue length is subsequently estimated based on a queuing formula developed by Webster[7,8] and the Deterministic Queuing Theory. The revised version of CAL3Q was named CAL3QHC, and was applied extensively to model conditions near locations where traffic conditions were near or over the capacity of the intersection, and at complex intersections where roadways interacted with ramps and elevated highways.

During 1989-1990 the U.S. EPA commissioned a performance evaluation of eight intersection models. The results of this study indicated that of the models tested, CAL3QHC performed well in predicting CO concentrations in the vicinity of a congested intersection. Based on the results of that evaluation, the original CAL3QHC User's Guide was prepared for EPA OAQPS and released in September 1990. On February 13, 1991, EPA issued a notice of proposed rulemaking identifying CAL3QHC as the recommended model for estimating carbon monoxide concentrations in the vicinity of intersections.

During 1991, comments were received in response to the proposed rulemaking and as part of the Fifth Conference on Air Quality Modeling. Most of the commentors pointed out that, given the great degree of variability in the operational characteristics of a signalized intersection, more consideration should be given to the calculation of delay and intersection capacity.

In order to address these comments, the model has been revised to: (1) give the user more options in determining the capacity of an intersection, and (2) consider the effects of different types of signals and arrival rates. All the changes were based on recommendations from the 1985 HCM.

During 1991, EPA sponsored another evaluation[2] of the performance of eight different modeling methodologies (including CAL3QHC Version 2.0) in estimating CO concentrations using both the MOBILE4 and MOBILE4.1 emission factor models. The data used for this evaluation were collected during 1989-1990 as part of a major air quality study performed in response to the proposed reconstruction of a portion of Route 9A in New York City, and included traffic, meteorological, and CO data collected at six intersections during a three-month period. The results of this evaluation indicated that CAL3QHC was one of the best performing models.

SECTION 3
MODEL DESCRIPTION

3.1 OVERVIEW

CAL3QHC is a consolidation of the CALINE-3 line source dispersion model[1] and an algorithm that estimates the length of the queues formed by idling vehicles at signalized intersections. The contribution of the emissions from idling vehicles is estimated and converted into line sources using the CALINE-3 link format. CAL3QHC requires all input parameters necessary to run CALINE-3 plus the following additional inputs: idling emission rates, the number of "moving" lanes in each approach link and the signal timing of the intersection. Version 2.0 of CAL3QHC also includes three additional traffic parameters that must be provided by the user: Saturation Flow Rate, Signal Type, and Arrival Type. Figure 1 depicts the major routines of the CAL3QHC program and how they interact. A description of these routines and how each input parameter is used in the model is provided below.

3.2 SITE GEOMETRY

CAL3QHC permits the specification of up to 120 roadway links and 60 receptor locations within an XYZ plane. The Y-axis is aligned due north, with wind angle inputs to the model following accepted meteorological convention -- e.g. 270° represents a wind from the west. The positive X-axis is aligned due east. A link can be specified as either a free flow or a queue link. The program automatically sums the contributions from each link to each receptor. Surface roughness and meteorological variables (such as atmospheric stability, wind speed and wind direction) are assumed to be spatially constant over the entire study area.

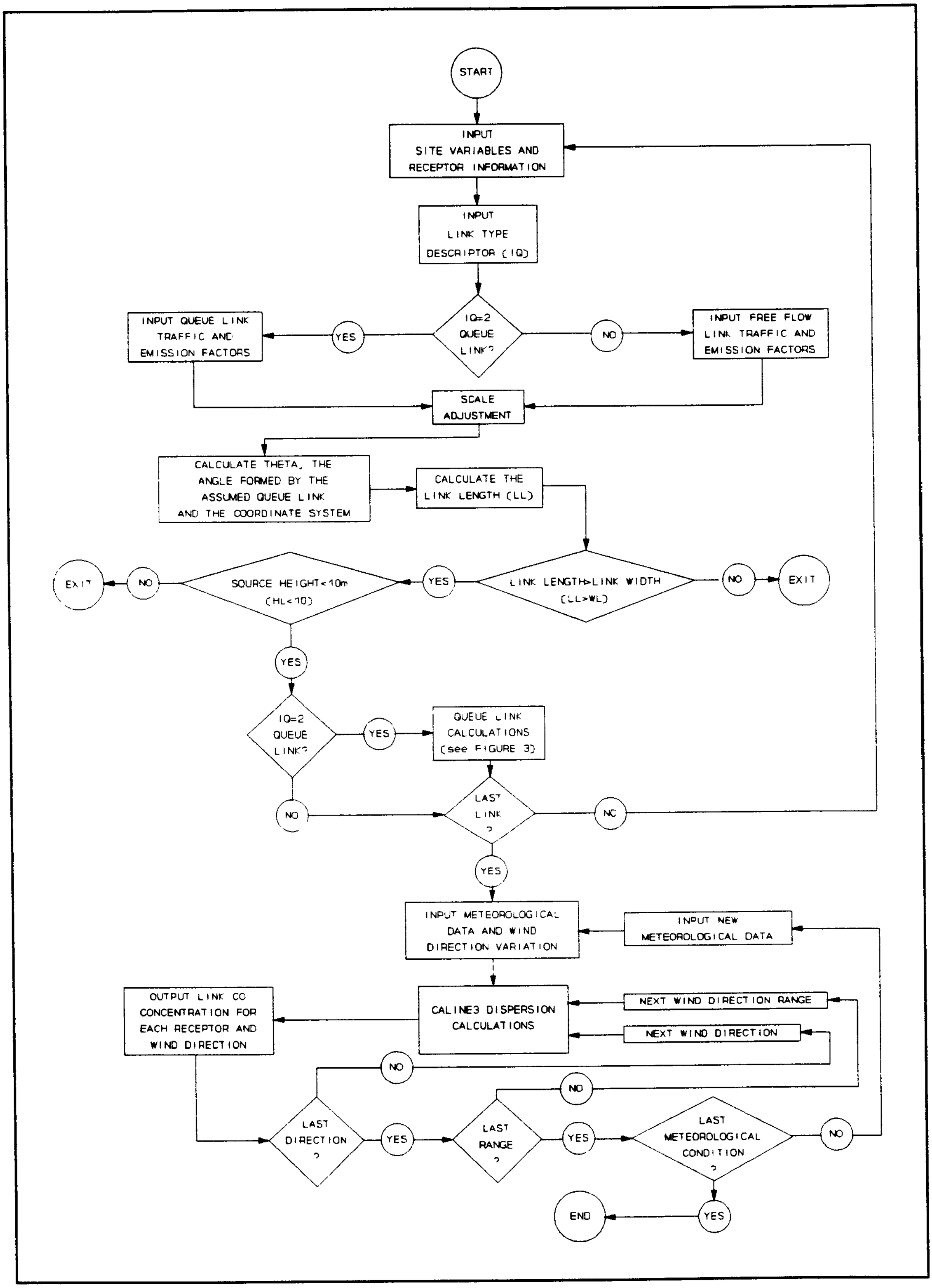


Figure 1. Flowchart for CAL3QHC routines.

3.2.1 Free Flow Links

A free flow link is defined as a straight segment of roadway having a constant width, height, traffic volume, travel speed, and vehicle emission factor. The location of the link is specified by its end point coordinates, X1, Y1, and X2, Y2 (see Figure 2). It is not necessary to specify which way traffic is moving on a free flow link, but the link length must be greater than link width for proper element resolution. A new link must be coded when there is a change in width, traffic volume, travel speed or vehicle emission factor.

Link width is defined as the width of the travelled roadway (lanes of moving traffic only) plus 3 meters (10 feet) on each side to account for the dispersion of the plume generated by the wake of moving vehicles. Link height cannot be greater than 10 meters (elevated section) or less than -10 meters (depressed section), since CALINE-3 has not been validated outside of this range. In most cases (at grade section), a link height of 0 meters should be used.

3.2.2 Queue Links

A queue link is defined as a straight segment of roadway with a constant width and emission source strength, on which vehicles are idling for a specified period of time. The location of a link is determined by its beginning point (i.e., X1, Y1 coordinates of the locations at which vehicles start queuing at an intersection "stopping line") and an arbitrary end point (i.e., X2, Y2 coordinates of any point along the line where the queue is forming.) (See Figure 2). The purpose of specifying a queue link end point is to specify the direction of the queue. The actual length of the queue is estimated by the program based on the traffic volume and the capacity of the approach. (Section 3.4 describes how queue length is estimated.)

Link width is determined by the width of the travelled roadway only (width of the lanes on which vehicles are idling). Three meters are not added on each side since vehicles are not moving and no wake is generated. Lane widths typically vary between 10 feet (3 m) and 12 feet (4 m) per lane depending on site characteristics.

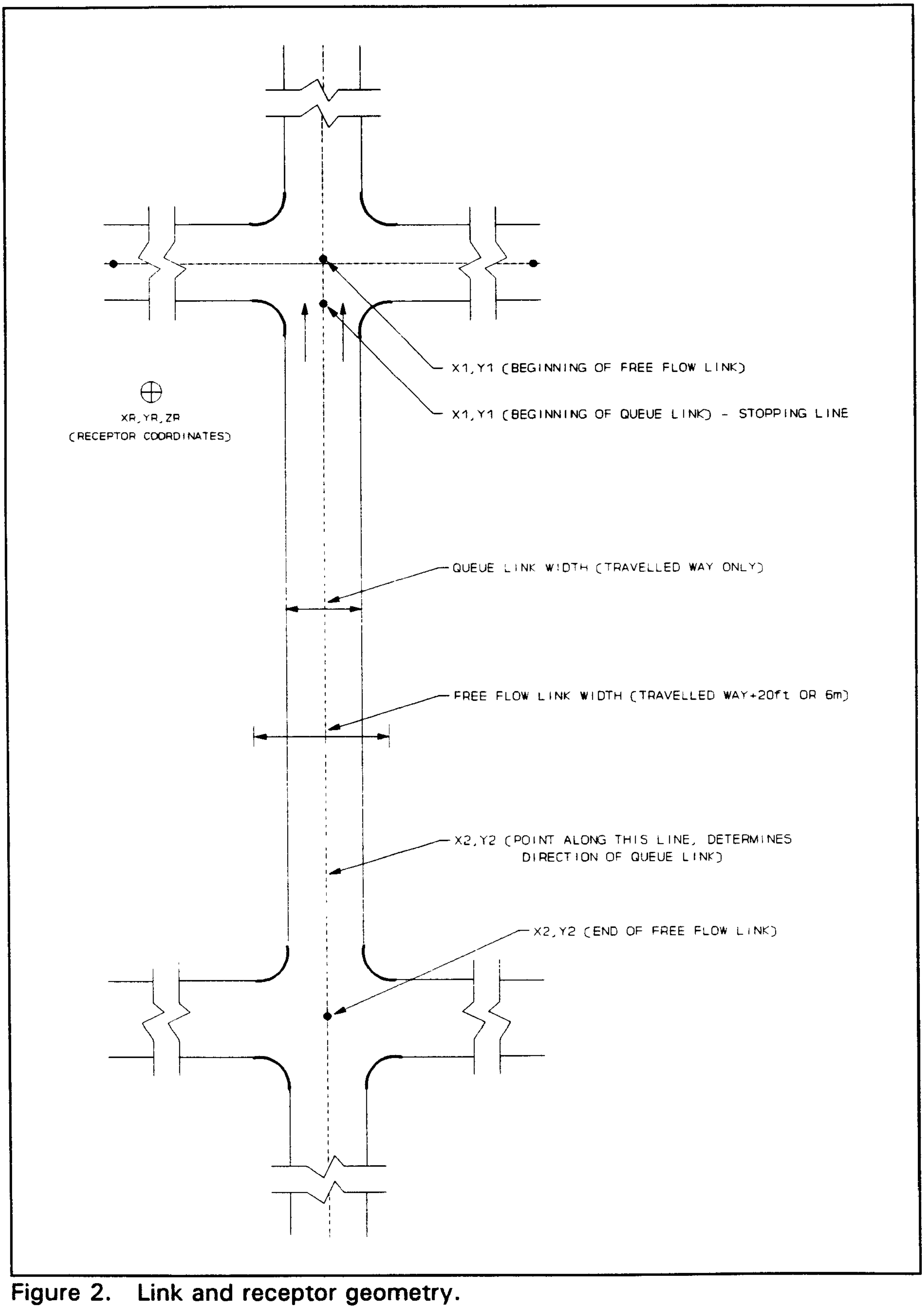


Figure 2. Link and receptor geometry.

3.2.3 Receptor Locations

Receptor locations are specified in terms of X, Y, and Z coordinates. A receptor should be located outside the "mixing zone" of the free flow links (i.e., total width of travel lanes plus 3 meters (10 feet) on each of the outside travel lanes) (See Figure 2). The mixing zone is considered to be the area of uniform emissions and turbulence. The 10 meter (32 foot) link-height restriction does not apply to receptor-height; receptors can be specified at elevations greater than 10 meters (32 feet) if so desired. In most applications, receptors are entered at an assumed breathing height of 1.8 meters.

3.3 EMISSION SOURCES

Separate emissions estimates must be provided as input data for each free flow and queue link. Emissions from vehicles travelling from point "A" to point "B" are calculated using the composite emission rate for the length of the link. (This composite emission rate is the resultant of the average speed of a driving cycle that includes different levels of acceleration and deceleration.) When vehicles are idling at an intersection (i.e., not moving), emissions are calculated using the idle emission rate for the duration of the idling time. While a sub-population of approach traffic experience idling (i.e., are queued), the number of the queued vehicles varies significantly as discussed in section 3.4.

Although CAL3QHC can be used with any mobile source emission factor model, it is recommended that carbon monoxide emission source strength be estimated using the most recent version of the U.S. EPA mobile source emission factor model (MOBILE5[9] is currently the most recent version of this program), or in California, where different automobile emission standards apply, the most current version of EMFAC[10] (Emission Factor program for California). For Particulate Matter (PM) emission factors, the latest version of the PART5 emission factor model is recommended.[11]

Pollutant concentration estimates are directly proportional to the emission factors used as input data to the program. Consequently, the accuracy of the results of a microscale air quality analysis is dependent on the accuracy of the emission factors used. The most critical variables affecting the emission factors are: average link speed, vehicle operating conditions (percent cold/hot starts), and ambient temperature.

3.3.1 Free flow links

Vehicles are assumed to be travelling without delay along free flow links. The link speed for a free flow link represents the speed of a vehicle travelling along the link in the absence of the delay caused by traffic signals.

It is recommended that this free flow speed be obtained either from actual field measurements or from a traffic engineer with adequate local knowledge of the intersections under consideration. In the absence of these information sources, the use of the free flow speeds presented on the following page may be considered within the context of the locally posted speed limits. However, considerable caution should be exercised in using these speeds since they represent the traffic operating environment with minimal to moderate pedestrian/parking frictions. In urban areas with significant pedestrian/vehicle conflicts and/or parking activities (e.g., Central Business Districts, Fringe Business Districts), the use of substantially lower free flow speeds (e.g., 15 mph to 20 mph) may be warranted.

Free Flow Speeds for Arterials

(Source: 1985 Highway Capacity Manual[3], Chapter 11)

Arterial Class	**I**	**II**	**III**
Range of free flow speeds (mph)	35 to 45	30 to 35	25 to 30
Typical free flow speeds (mph)	40	33	27

The criteria for the classification of arterials for use in conjunction with the free flow speeds mentioned above, are presented as follows:

Arterial Class According to Function and Design Category

(Source: 1985 Highway Capacity Manual[3], Chapter 11)

	Functional Category	
Design Category	**Principal Arterial**	**Minor Arterial**
Suburban	I	II
Intermediate (Suburban/Urban)	II	III
Urban	III	III

The composite running emission rate in "grams/vehicle mile" should be obtained for the average link speed, operating conditions of the engine, and vehicle mix for each free flow link using the current version of the U.S. EPA MOBILE emissions factor model, EMFAC, or other appropriate emission estimation programs. (Appropriate inspection/maintenance program, anti-tampering program, vehicle age distribution, and analysis year must be specified to accurately develop emission rates.)

3.3.2 Queue Links

Vehicles are assumed to be in an idling mode of operation during a specified period of time along a queue link. CAL3QHC assumes that vehicles will be in an idling mode of operation only during the red phase of the signal cycle. Based on a user-specified idling emission rate, the number of lanes of vehicles idling at the stopping line, and the percentage of red time, CAL3QHC calculates the emission source strength and converts it to a line source value, so that the CALINE-3 model can process it as a nominal free flow link. The strength per unit length of a line source is not dependent on the approach traffic volume or capacity. These parameters are only used to determine the length of the line source for the queue link.

An idle emission factor in "grams per vehicle-hour" must be converted to "micrograms per meter-second" to calculate linear source strength. "Grams per vehicle-hour" is converted to "micrograms per vehicle-hour" by multiplying by a million. "Micrograms per vehicle-hour" is converted to "micrograms per vehicle-second" by dividing by 3600. Based on the assumption that there is a distance of 6 meters (20 feet) per vehicle in a queue, "micrograms per vehicle-second" is converted to "micrograms per meter- second" by dividing by 6. Thus, by converting the units of the idling emission factor, the Linear Source Strength (Q_1) for "one traffic lane for one meter over one second" can be determined as follows:

$$Q_1 = \frac{\text{Idle Emission factor (g/veh-hr)} \times 10^6}{3600 \times 6} \quad [\mu g/m\text{-}s]$$

To determine the total Linear Source Strength (Q_t) for a queuing link, the total number of lanes in the queue link and the percent of time that vehicles are estimated to be idling in the queue link must be considered. This is done by multiplying the Linear Source Strength for one lane (Q_1) by the number of traffic lanes in the link and the percent of red time during the signal cycle. The total Linear Source Strength (Q_t) for the queuing link in "micrograms per meter- second" is calculated as follows:

$$Q_t = Q_1 \times \text{number of lanes} \times \text{percent red time} \quad [\mu g/m\text{-}s]$$

It is assumed that the vehicles will be in the idling mode of operation only during the Red Time phase of the signal cycle.

CALINE-3 estimates total Linear Source Strength (Q_t) as follows:

$$Q_t = 0.1726 \times VPH \times EF \quad [\mu g/m\text{-}s]$$

where: VPH = Vehicles per hour

EF = Emissions factor (g/mi)

To convert the Linear Source Strength into the CALINE-3 format, CAL3QHC fixes one of the two variables by assigning an arbitrary value of 100 to EF (as seen in the output line for the queue link). VPH can then be calculated as follows:

$$VPH = \frac{Q_t}{0.1726 \times 100}$$

As seen in the output line for the queue link, this VPH will give the appropriate total Linear Source Strength for the queue link when multiplied by EF=100.

Since the current MOBILE emissions model estimates idle emission rates in "grams per vehicle hour", CAL3QHC Version 2.0 also requires that the idle emission rate be input in "grams per vehicle hour." (It should be noted that the original CAL3QHC required idle emission rate input in "grams per vehicle minute").

3.4 QUEUING ALGORITHM

3.4.1 Overview

Figure 3 depicts the queue length estimation procedure employed in CAL3QHC. The input parameters required to determine the queue length are: traffic volume of the link, signal cycle length, red time length, and clearance interval lost time. The following additional parameters need to be specified:

- SFR - saturation flow rate [vehicles per hour of effective green time, vphg]
- ST - traffic signal type [pretimed (=1), actuated (=2), or semiactuated (=3)]
- AT - "arrival type" of vehicle platoon [worst (=1) through most favorable (=5)]

The capacity of an intersection approach lane is determined by applying the effective green time to its saturation flow rate (SFR). Saturation flow rate represents the maximum number of vehicles that can pass through a given intersection approach lane assuming that the approach lane had 100 percent of real time as effective green time[3]. CAL3QHC Version 2.0 allows the input of 1600 vphg as a default saturation flow rate to represent an urban intersection. Saturation flow rate may vary substantially from this default value depending on site specific traffic conditions and site geometry.

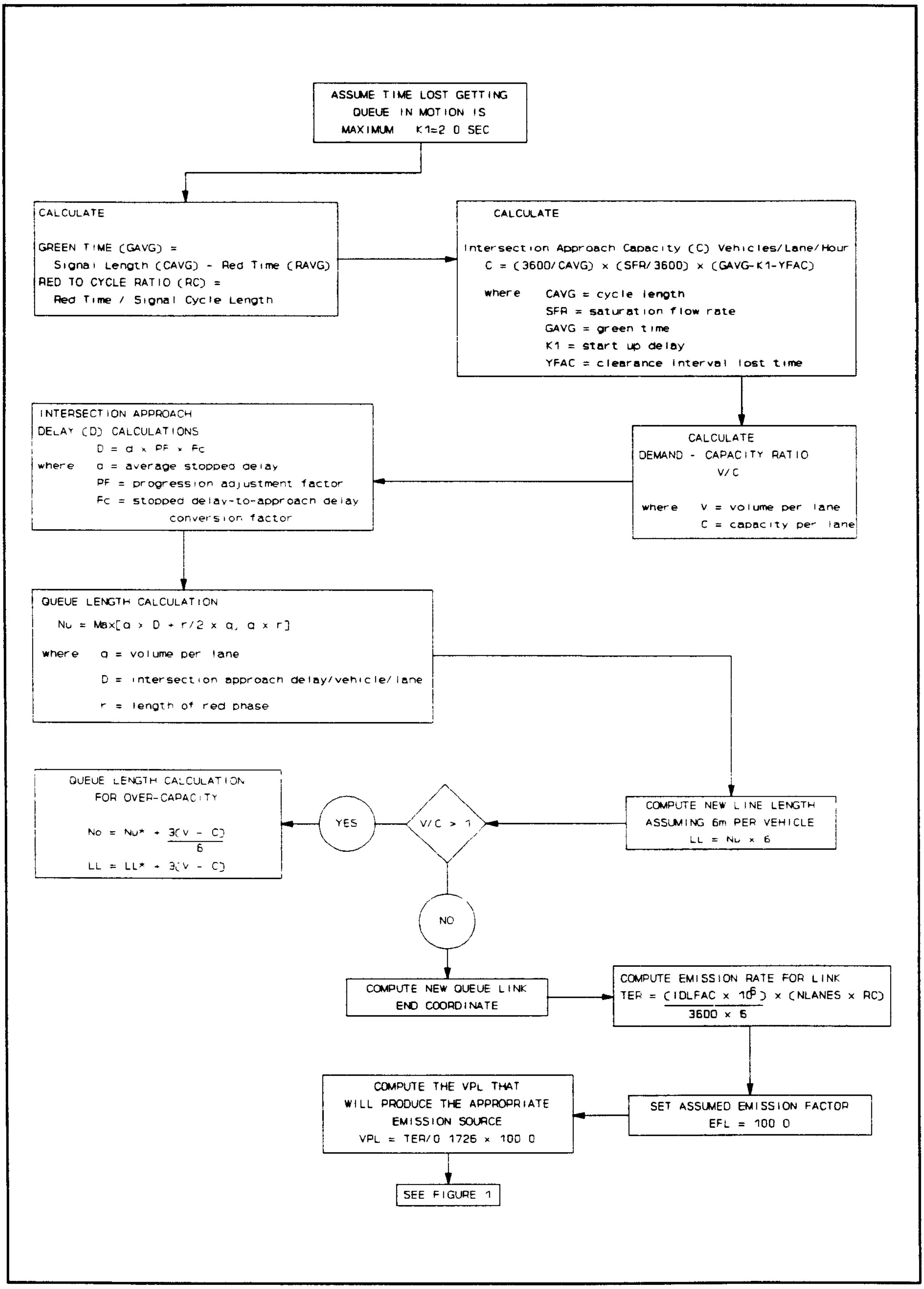


Figure 3. Flowchart for queue link calculations.

Effective green time is calculated by subtracting the amount of red time, start up delay (2.0 seconds) and the time lost during the clearance interval[12] from total signal cycle length. The clearance interval lost time represents the portion of the yellow phase (i.e. the period between the green and red phases) that is not used by the motorists. It's value is a function of signal timing and driver characteristics. While a clearance interval lost time of 2 seconds is recommended as a default value to reflect "normal/average" driver behavior[13], the model permits the user to specify clearance lost time to reflect site-specific traffic conditions (e.g., 0 to 1 seconds for "aggressive" drivers and 3 to 4 seconds for "conservative" drivers)[13].

Thus, the capacity of the intersection approach per lane is calculated as:

$$C = (SFR) \times \frac{(CAVG - RAVG - K1 - YFAC)}{CAVG}$$

where: C = hourly capacity per lane [veh/hr/lane]

SFR = saturation flow rate [veh/lane/hr of green time]

CAVG = cycle length [s]

RAVG = length of red phase [s]

K1 = start-up delay [s] = 2 s

YFAC = clearance interval lost time [s]

Vehicles arriving at a signalized intersection during the red phase queue-up behind the stopping line of the approach. After the signal turns to green, the first vehicle on the queue proceeds forward after a start-up delay of approximately 2 seconds, followed by the remaining vehicles in the queue. This results in the propagation of a "shock-wave" traveling backwards toward the last vehicle in the queue. Vehicles arriving during the green phase prior to the dissipation of the queue are stopped and join the end of the queue. Figure 4 illustrates this process, assuming a uniform vehicle arrival rate, q [vehicles/lane/second], and a uniform departure rate, s [vehicles/lane/second] for a near-saturated cycle (i.e., volume-to-capacity ratio, V/C, is close to 1). In Figure 4, the vertical distance (Δy) between the cumulative arrival curve, A(t), and the cumulative departure curve, D(t), represents the queue on each approach lane (i.e., the number of vehicles idling) at time t[5,6]. The horizontal distance (Δx) between the two curves, $t_2 - t_1$, represents the stopped delay experienced by the n^{th} vehicle arriving at the intersection

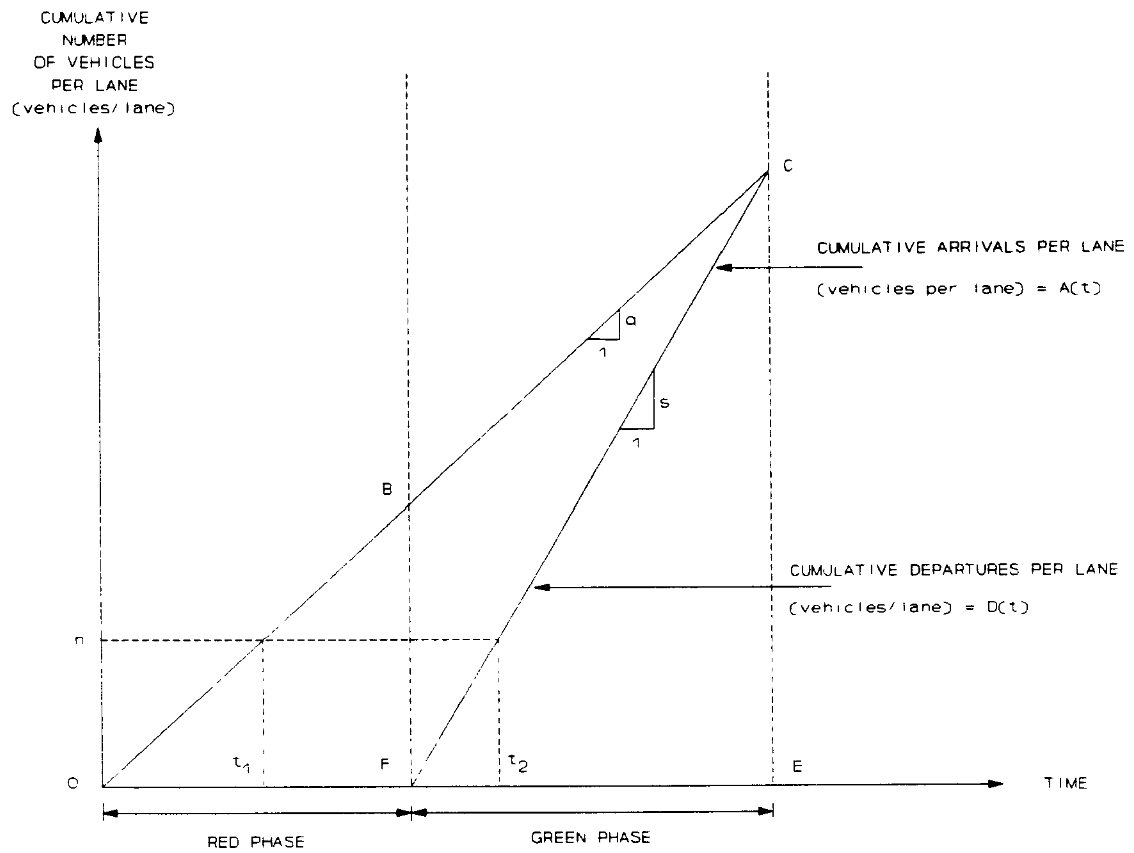


Figure 4. Queue and delay relationships for a near-saturated signalized intersection.

approach lane at time $t = t_1$. The total vehicle delay for each approach lane during the cycle is represented by the area of the triangle OCF. When the approach is at a near-saturation condition and the signal timing has a 50-50 split between red and green time, (i.e., 50 percent of the cycle is red phase), the total vehicle delay per lane, W, may be approximated as follows:

$$\begin{aligned} W &= FB \times OE \times 1/2 \\ &= FB \times OF \end{aligned} \quad (1)$$

where: W = total vehicle delay per lane during a cycle [vehicles x second/lane]

FB = average number of vehicles queued per lane at the beginning of the green phase [veh]

OE = cycle length [s]

OF = the duration of the red phase [s]

Since CAL3QHC assumes that the queued vehicles idle only for the duration of the red phase (i.e., average delay is equivalent to the duration of the red phase, OF), the corresponding queue yielding a correct estimation of total vehicle delay per lane is defined as FB, (i.e., the number of queued vehicles at the beginning of the green phase) using the Equation (1).

3.4.2 Queue Estimation for Under-Saturated Conditions

In the under-saturated condition (i.e., volume to capacity ratio, v/c, is less than 1), the number of vehicles queued at an intersection at the beginning of the green phase is estimated based on the following formula from Webster[7,8]:

$$FB = N_u = MAX\,[q \times D + r/2 \times q,\ q \times r] \quad (2)$$

where: N_u = average queue per lane at the beginning of green phase in under-saturated conditions [veh/lane]

q = vehicle arrival rate per lane [veh/lanes/s]

D = average vehicle approach delay [s/veh]

r = length of the red phase [s]

For light traffic flow conditions, the second term of Equation (2), q x r gives a good approximation of the queue at the beginning of the green phase. However, for heavier traffic flow conditions, Webster found the first term, q x D + r/2 x q, produces a more accurate estimate of the average queue at the beginning of the green phase. The first component of the first term of Equation (2), q x D, represents the average queue length throughout the signal cycle. The second component, r/2 x q, represents the average fluctuation of the queue during the red phase. Since the queue generally reaches its maximum at the end of the red phase (i.e., at the beginning of the green phase) in under-saturated condition, these two components are added together in the first term to estimate the average queue at the beginning of the green phase.

The average approach vehicle delay, D, in Equation (2) is estimated using the following formula for signalized intersection delay given in Chapters 9 and 11 of the 1985 Highway Capacity Manual (HCM)[3]:

$$D = d \times PF \times F_c \tag{3}$$

where:
- d = average stopped delay per vehicle [s/veh]
- PF = progression adjustment factor
- F_c = stopped delay-to-approach delay conversion factor (= 1.3)

The first term in Equation (3), d, the average stopped delay per vehicle for an assumed random arrival pattern for approaching vehicles, is estimated using the following formula from the 1985 HCM:

$$d = (0.38)(CAVG)\frac{\left[1-\frac{GAVG}{CAVG}\right]^2}{\left[1-\left(\frac{GAVG}{CAVG}\right)X\right]} + 173X^2\left[(X-1)+\sqrt{(X-1)^2+\frac{16X}{C}}\right] \tag{4}$$

where:
- GAVG = length of green phase [s]
- CAVG = cycle length [s]
- C = hourly capacity per lane [veh/hr/lane]
- X = volume-to-capacity ratio = V/C
- V = hourly approach volume per lane [veh/hr/lane]

The first term of Equation (4) accounts for uniform delay, (i.e., the delay that occurs if the arrival of vehicles is uniformly distributed over the cycle). The second term of the equation accounts for additional delay due to random arrivals and/or occasional cycle failures.

The second term in Equation (3), the progression adjustment factor (PF), is included to account for the variation of stopped delay with traffic flow progression quality. Progression adjustment factors are determined using the following key variables:

- Arrival Type (AT) - a general categorization of the way the platoon of vehicles arrives at the intersection. Five arrival types are defined in the 1985 HCM:

  1 = worst platoon condition (dense platoon arriving at the beginning of the red phase)

  2 = unfavorable platoon condition (dense or dispersed platoon arriving during the red phase)

  3 = average condition (random arrivals)

  4 = moderately favorable platoon condition (dense or dispersed platoon arriving during the green phase)

  5 = most favorable platoon condition (dense platoon arriving at the beginning of the green phase)

- Signal Type (ST) - user may select one of the following three traffic signal types:

  1 = pretimed

  2 = actuated

  3 = semiactuated

3.4.3 Queue Estimation for Over-Saturated Conditions

In the over-saturation condition (i.e. volume to capacity ratio, V/C, greater than one), the queue consists of the two components, N_1 and N_2, as illustrated in Figure 5. A'(t) in depicts the cumulative arrivals per lane in an over-saturated condition (i.e., V/C greater than 1). A(t) represents the cumulative arrivals per lane during at-capacity condition (i.e., V/C equal to 1). Other symbols are similar to those defined in Figure 4. N_1 is the vertical

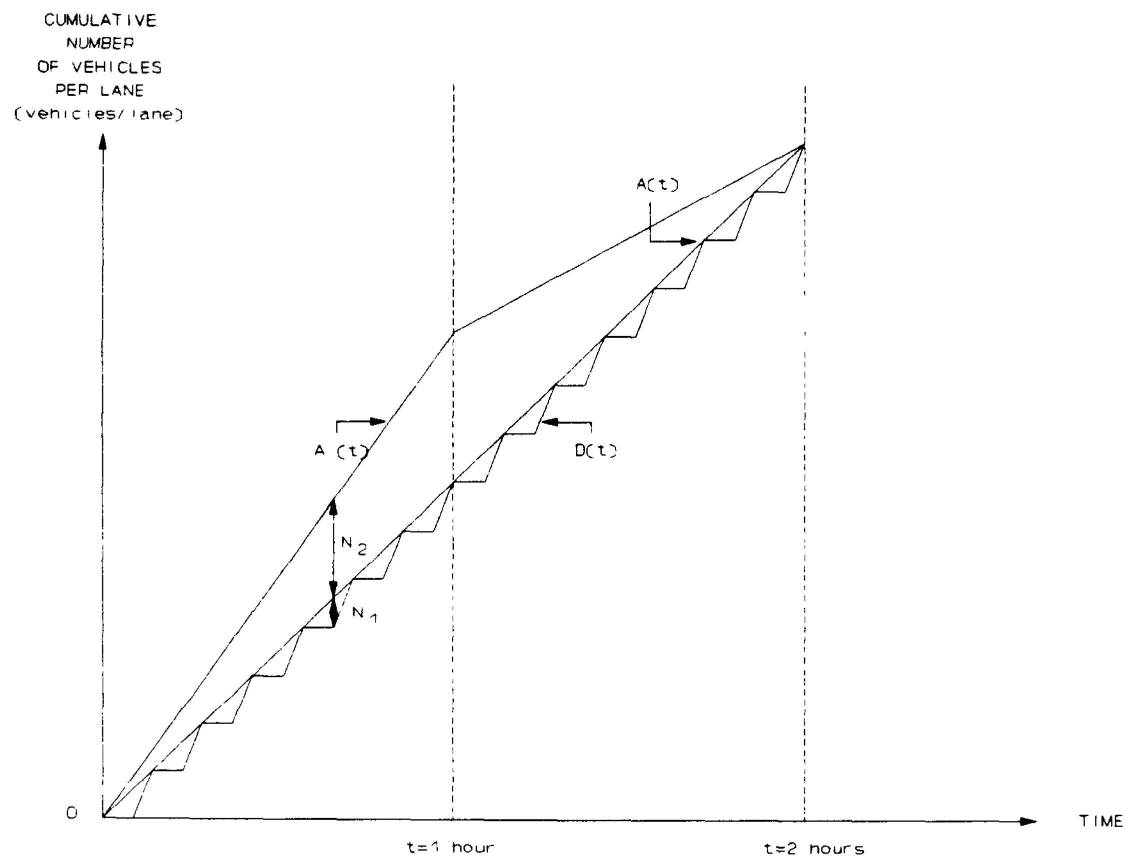


Figure 5. Queue and delay relationships for an over-saturated signalized intersection.

difference between A(t) and D(t) and represents the normal fluctuation of a queue during at-capacity conditions due to change of signal phase (i.e., from green to red, etc.). As shown in Equation (5), the estimate of the average of N_1 at the beginning of the green phase, denoted by N_u*, is identical to that of N_u, which can be estimated based on the procedures provided in section 3.4.2.:

$$N_u^* = MAX\,[q^* \times D^* + r/2 \times q^*, r \times q^*] \quad (5)$$

where: q^* = vehicle arrival rate per lane during at-capacity operating conditions (i.e. V/C = 1.0) [veh/lane/s]

D^* = average vehicle delay during at-capacity operating conditions (i.e. V/C = 1.0) [s/veh]

r = length of the red phase [s]

N_2, which is the vertical difference between A'(t) and A(t), represents the additional queue resulting from over-saturation. In the over-saturated condition, N_2 continues to grow until the slope of A'(t) is lower than that of A(t). Thus, the average of N_2, denoted by N_2*, for the first hour can be estimated as one half of the difference between the A'(t) and A(t) at t = 1 hour as shown in the following equation:

$$N_2^* = 1/2 \times [A'(t)-A(t)], \text{ at } t = 1 \text{ hour}$$
$$= 1/2 \times (V-C) \quad (6)$$

where: N_2* = average additional queue per lane due to over-saturation [veh/lane]

A'(t) = cumulative vehicular arrivals per lane in over-saturated condition [veh/lane]

A(t) = cumulative vehicular arrivals per lane in at-capacity condition [veh/lane]

V = hourly approach volume per lane (i.e., A'(t) at t = 1 hour) [veh/lane/hr]

C = hourly capacity per lane (i.e., A(t) at t = 1 hour) [veh/lane/hr]

Therefore, the average queue at the beginning of the green phase during over-saturated conditions, N_0, may be approximated by the following equation:

$$N_0 = N_u^* + N_2^*$$
$$= MAX [q^* \times D^* + r/2\ q^*, r \times q^*] + 1/2 \times (V\text{-}C) \quad (7)$$

where: N_0 = average queue per lane at the beginning of the green phase in an over-saturated condition [veh],

q^*, D^*, r, V and C are the same as defined in Equations (5) and (6).

For both under- and over-saturated situations, the length of the queue link is calculated by multiplying the number of vehicles in the queue by 6 m (20 ft) per vehicle. If the predicted queue extends into the next intersection, it is recommended to stop the queue at the end of the modeled block by adjusting the specified link endpoints.

3.5 DISPERSION COMPONENT

The dispersion component used in CAL3QHC is CALINE-3, a line source dispersion model developed by the California Department of Transportation. CALINE-3 estimates air pollutant concentrations resulting from moving vehicles on a roadway based on the assumptions that pollutants emitted from motor vehicles travelling along a segment of roadway can be represented as a "line source" of emissions, and that pollutants will disperse in a Gaussian distribution from a defined "mixing zone" over the roadway being modeled. For a complete discussion of the theory and application of CALINE-3 the user is referred to CALINE-3: A Versatile Dispersion Model for Predicting Air Pollutant Levels Near Highways and Arterial Streets[1].

3.6 FUTURE RESEARCH AREAS

While CAL3QHC includes improved procedures for estimating air pollutant levels in the vicinity of intersections, there remain potential areas of further study which could result in higher levels of accuracy in completing air quality studies. These include:

- The derivation of queue length for the under-saturated condition (i.e., V/C less or equal to 1) was simplified by assuming a near-capacity (i.e., V/C approximately equal to 1) operation and an even-split of signal timing (i.e. 50% of the cycle length is green phase). This procedure works the best for near and over-saturated conditions (i.e., conditions of most concern) but it could be refined to produce a more precise estimation of queue length for cases deviating significantly from the assumed condition.

- The average additional queue due to over-saturation was assumed to be idling only during the red phase of the signal cycle. Further investigation is required to fully validate this assumption.

- While the model provides the general concept for estimating emissions at signalized intersections, there remain other traffic controls, such as stop signs or toll plazas, where a similar concept could be extended. Future research and testing is necessary to adapt this program for such situations.

- The model assumes flat topography. Its handling of vehicular queuing could be adapted to urban canyon situations.

SECTION 4
USER INSTRUCTIONS

4.1 DATA REQUIREMENTS

The accuracy of the results of a microscale air quality analysis is directly dependent on the accuracy of the input parameters. Meteorology, traffic, and emission factors can vary widely and in many situations there is a great degree of uncertainty in their estimation. The user should have a high degree of confidence in these data before proceeding to apply the model. It is recommended that the user contact the EPA or appropriate state or local air pollution control agency prior to selecting meteorological parameters and estimating composite running and idling emission factors, since these factors depend on many variables unique to a particular region (e.g., thermal state of engines, ambient air temperatures, local inspection and maintenance program, and anti-tampering credits all vary by region).

The following parameters are required input to the program, (Section 4.2 provides recommendations on how to use these factors and Section 4.3 describes their location in the input file):

Meteorological Variables:

- Averaging Time [min]
- Surface Roughness coefficient [cm]
- Settling Velocity [cm/s]
- Deposition Velocity [cm/s]
- Wind Speed [m/s]
- Stability Class [1 to 6 = A to F]
- Mixing Height [m]

Site Variables:

- Roadway Coordinates [X,Y,Z] [m or ft]
- Roadway Width [m or ft]
- Receptor Coordinates [X,Y,Z] [m or ft]

Traffic Variables:

Traffic Volume [each link] [veh/hr]

Traffic Speed [each link] [mi/hr]

Average Signal Cycle Length [each intersection] [s]

Average Red Time Length [each approach] [s]

Clearance Lost Time [s]

Saturation Flow Rate [veh/hr]

Signal Type [pretimed, actuated, or semiactuated]

Arrival Rate [worst, below average, average, above average, best progression]

Emission Variables:

Composite Running Emission Factor [each free flow link] [g/veh-mi]

Idle Emission Factor [each queue link] [g/veh-hr]

4.2 LIMITATIONS AND RECOMMENDATIONS

- CAL3QHC can process up to 120 links and 60 receptor locations for all 360 degree wind angles. A new link is required when there is a change in link width, traffic volume, travel speed or emission factor.

- In specifying link geometry, link length must always be greater than the link width. Otherwise, correct element resolution cannot be calculated (error message will appear).

- Since emissions from idling vehicles account for a substantial portion of the total emissions from an intersection, it is recommended that roadway segments up to 1000 feet from the intersection of interest be included in the site geometry. Testing of the model indicates that links beyond 1000 feet from the receptor locations will have a minor contribution to the results.

- In overcapacity situations, where V/C > 1, the " model predicted queue length" could be larger than the physical roadway configuration. The user could either revise the traffic assumption for the link, or limit the length of the queue by running the analysis in the following manner: 1) input the queue link as a free flow link; 2) specify X1, Y1, X2, Y2 coordinates that determine the physical limits of the queue (i.e., the physically largest queue length); and 3) input the emission source as the equivalent VPH (from the output run on the queue link) with an emission rate of EF = 100. This will provide the appropriate emission source for the queue link with the manually determined queue length.

- When the site specific clearance lost time (portion of the yellow phase that is not used by motorist) is unknown, a default value of 2 seconds may be used.

- Source height should be within ± 10 m (± 32 ft), (+10 m for an elevated roadway section and -10 m for a depressed section). CALINE-3 has not been validated outside this range (error message will appear). In most applications (at-grade), a source height of 0 m should be used.

- Receptor height should be greater than the roadway height, except for elevated roadway sections, since CALINE-3 assumes plume transport over a horizontal plane. The 10 m height limitation does not apply to receptors; which may be placed at any height above the roadway. For most applications, receptors should be placed at an assumed breathing height of 1.8 m.

- Wind speed should be at least 1 m/s. (CALINE-3 has not been validated for wind speeds below 1 m/s).

- Surface roughness coefficient (z_o) should be within the range of 3 cm to 400 cm. Table 1, which is reprinted from the CALINE-3 manual, provides the recommended surface roughness coefficients for various land uses.

- Averaging time should be within the range of 30 min to 60 min. The most common value is 60 min, since most predictions are performed for a one hour period.

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

TABLE 1

SURFACE ROUGHNESS LENGTHS (Z_o) FOR VARIOUS LAND USES

Type of Surface	Z_o (cm)
Smooth desert	0.03
Grass (5-6 cm)	0.75
Grass (4 cm)	0.14
Alfalfa (15.2 cm)	2.72
Grass (60-70 cm)	11.40
Wheat (60 cm)	22.00
Corn (220 cm)	74.00
Citrus orchard	198.00
Fir forest	283.00
City land-use	
Single family residential	108.00
Apartment residential	370.00
Office	175.00
Central business district	321.00
Park	127.00

- Free flow link width should be equal to the width of the traveled roadway plus 3 m (10 ft) on each side of the roadway (to account for the mixing zone created by the dispersion of the plume generated by the wake of moving vehicles).

- Queue link width should be equal to the width of the traveled roadway only.

- Receptors should always be located outside of the mixing zone (link width) of the free flow and queue links. In the case of urban intersections, where buildings are located closer than 3 m (10 ft) from the roadway and the speed of the traffic is very slow, a reduced mixing zone should be considered to maintain receptor locations outside of the mixing zone.

- It is recommended that the link speed information be obtained from traffic engineers familiar with the area under consideration. The link speed for a free flow link represents the speed experienced by drivers travelling along the link in the absence of the delay caused by traffic signals. In the absence of recommended information from traffic engineers, the use of the free flow speeds presented in Section 3.3.1 may be considered.

- The saturation flow rate or the hourly capacity per lane should be determined by the user depending on the characteristics and operation of the intersection. A default value of 1600 vehicles per hour, which is representative of an urban intersection, may be used in the absence of locally derived values.

- The signal type should be input as:

  1 = Pretimed
  2 = Actuated
  3 = Semiactuated

  In the case of actuated or semiactuated signals, the user must input the estimated red time for each approach.

The arrival type should be input as:

1 = Worst progression (dense platoon at beginning of red)

2 = Below average progression (dense platoon during middle of red)

3 = Average progression (random arrivals)

4 = Above average progression (dense platoon during middle of green)

5 = Best progression (dense platoon at beginning of green)

Note: If CAL3QHC were used to predict CO concentrations near highways or arterial streets where only free flow links interact (i.e., not for a signalized intersection), it would produce the same results as CALINE-3.

4.3 INPUT DESCRIPTION

The revised CAL3QHC Version 2.0 input has been converted to a free format for easier and more error-free input generation. The line by line structure remains the same, while the exact column positional placement of each value is no longer necessary. However, because of its free format nature, single quotes need to be placed around all input character data such as 'titles', 'run names', 'link and receptor names', 'grade type (TYP)' and 'angle variation flags (VAR)'. Also, all data that may have been previously omitted using the old format, needs to be entered. Actual, default, or 0 values need to be entered on the appropriate line for each variable.

An additional variable, MODE, has also been added to Line Number 3 of the input file structure. This variable allows the user to calculate either CO or Particulate Matter (PM) concentrations. CO output concentration averages are in parts per million (ppm) while PM concentration averages are in micrograms per cubic meter. The following is a tabular description of the CAL3QHC Version 2.0 variables.

LINE NUMBER	VARIABLE NAME	VARIABLE TYPE	VARIABLE DESCRIPTION
1	'JOB'	Character	Current job title (Limit of 40 Characters).
	ATIM	Real	Averaging time [min].
	ZO	Real	Surface roughness [cm].
	VS	Real	Settling velocity [cm/s].
	VD	Real	Deposition velocity [cm/s].
	NR	Integer	Number of receptors,max = 60.
	SCAL	Real	Scale conversion factor [if units are in feet enter 0.3048, if they are in meters enter 1.0].
	IOPT	Integer	Metric to english conversion in output option. Enter "1" for output in feet. Otherwise, enter a "0" for output in meters.
	IDEBUG	Integer	Debugging option. Enter "1" for this option which will cause the input data to be echoed onto the screen. The echoing process stops when an error is detected. Enter a "0" if the debugging option is not wanted.
2	'RCP'	Character	Receptor name (Limit of 20 Characters).
	XR	Real	X-coordinate of receptor.

LINE NUMBER	VARIABLE NAME	VARIABLE TYPE	VARIABLE DESCRIPTION
	YR	Real	Y-coordinate of receptor.
	ZR	Real	Z-coordinate of receptor.
	*** Repeat line 2 for NR (number of receptors) times ***		
3	'RUN'	Character	Current run title (Limit of 40 Characters).
	NL	Integer	Number of links, max = 120.
	NM	Integer	Number of meteorological conditions, unlimited number. Each unique wind speed, stability class, mixing height, or wind angle range constitutes a new meteorological condition.
	PRINT2	Integer	Enter "1" for the output that includes the receptor - link matrix tables (Long format), enter "0" for the summary output (Short format).
	'MODE'	Character	Enter 'C' for CO or 'P' for Particulate Matter (PM) calculations.
4	IQ	Integer	Enter "1" for free flow and "2" for queue links
	**** Enter lines 5a and 5b for IQ = 2 (queue link). **** **** Enter line 5c for IQ = 1 (free flow link) ****		
5a	'LNK'	Character	Link description (Limit of 20 Characters).
	'TYP'	Character	Link type. Enter 'AG' for "at grade" or 'FL' for "fill," 'BR' for "bridge" and 'DP' for "depressed".
	XL1	Real	Link X-coordinate for end point 1 at intersection stopping line.

LINE NUMBER	VARIABLE NAME	VARIABLE TYPE	VARIABLE DESCRIPTION
	YL1	Real	Link Y-coordinate for end point 1 at intersection stopping line.
	XL2	Real	Link X-coordinate for end point 2.
	YL2	Real	Link Y-coordinate for end point 2.
	HL	Real	Source height.
	WL	Real	Mixing zone width.
	NLANES	Integer	Number of travel lanes in queue link.
5b	CAVG	Integer	Average total signal cycle length [s].
	RAVG	Integer	Average red total signal cycle length [s].
	YFAC	Real	Clearance lost time (portion of the yellow phase that is not used by motorist) [s].
	IV	Integer	Approach volume on the queue link [veh/hr].
	IDLFAC	Real	Idle emission factor [g/veh-hr].
	SFR	Integer	Saturation flow rate [veh/hr/lane]. Enter 1600 for a default value.
	ST	Integer	Signal type. Enter 1 for pretimed, 2 for actuated, 3 for semiactuated. Enter 1 for a default value.
	AT	Integer	Arrival rate. Enter 1 for worst progression, 2 for below average progression, 3 for average progression, 4 for above average progression, 5 for best progression. Enter 3 for a default value.

LINE NUMBER	VARIABLE NAME	VARIABLE TYPE	VARIABLE DESCRIPTION
5c	'LNK'	Character	Link description (Limit of 20 Characters).
	'TYP'	Character	Link type. Enter 'AG' for "at grade" or 'FL' for "fill," 'BR' for "bridge" and 'DP' for "depressed".
	XL1	Real	Link X-coordinate for end point 1.
	YL1	Real	Link Y-coordinate for end point 1.
	XL2	Real	Link X-coordinate for end point 2.
	YL2	Real	Link Y-coordinate for end point 2.
	VPHL	Real	Traffic volume on link [veh/hr].
	EFL	Real	Emission factor [g/veh-mi].
	HL	Real	Source height.
	WL	Real	Mixing zone width.

*** Repeat lines 4 and 5 for NL (number of links) times ***

LINE NUMBER	VARIABLE NAME	VARIABLE TYPE	VARIABLE DESCRIPTION
6	U	Real	Wind speed [m/s].
	BRG	Real	Wind direction (angle from which the wind is coming). Enter 0 if wind direction variation data follow. Enter actual wind direction, if only one wind direction will be used.
	CLAS	Integer	Stability class.
	MIXH	Real	Mixing height [m].
	AMB	Real	Ambient background concentration [ppm].

LINE NUMBER	VARIABLE NAME	VARIABLE TYPE	VARIABLE DESCRIPTION
	'VAR'	Character	Enter 'Y' if wind direction variation data follow. Enter 'N' if only one wind direction [BRG] will be considered.
	DEGR	Integer	Wind direction increment angle [degrees].
	VAI(1)	Integer	Lower boundary of the variation range (First increment multiplier).
	VAI(2)	Integer	Upper boundary of the variation range (Last increment multiplier).

*** Repeat line 6 for each time that new ***
*** meteorological conditions ***
*** are to be run ***

TABLE 2

DESCRIPTION OF TYPE OF VARIABLES

VARIABLE TYPE	EXPLANATION
CHARACTER	A string of alphanumeric characters that are bracketed by single quotes. (e.g. 'Lanes 1, 2 & 3 Northbound')
INTEGER	A number with no decimal point. (e.g. 12)
REAL	A number with a decimal point separating the whole number part from the fractional number part. (e.g. 234.16)

4.4 RUN PROCEDURE

CAL3QHC is designed to operate on any IBM compatible personal computer. A math co-processor is not required, but its use will speed the overall program run time considerably. The memory requirements are 512 KB. A hard disk is not needed, but if it is available, the program should be copied onto the hard disk.

To execute the program, at the DOS prompt, type:

CAL3QHC <input file name> <output file name>

If a CAL3QHC file produced for the original version is run with Version 2.0, the idle emission factor must be input in grams per hour (instead of the original grams per minute). The rest of the input format is the same with the exception of the addition of traffic parameters.

4.5 OUTPUT DESCRIPTION

The output from CAL3QHC consists of printed listings showing a summary of all input variables and model results.

The first page of the output format is divided into two sections:

- The first section presents the site name, meteorological variables and ambient background concentration.

- The second section shows the link description and a list of the following link specific parameters: X1, Y1, X2, Y2 coordinates (ft or m), the link length (ft or m), BRG-the link direction (degrees), the type of link, the width (ft or m) and height (ft or m) of the link, the link volume (VPH), and the emission factor (EF) in g/veh-mi. In the case of queue links, VPH multiplied by EF = 100 represents the strength of the appropriate emission source, as described in Section 3.3.2 Also, in the case of queue links, the V/C ratio is calculated and shown in the output. The last column shows the estimated number of vehicles in the queue. (This number, multiplied by 6 m/veh, determines the length of the queue as used in the program).

- The second page of the output shows the queue specific input parameters: cycle length, red time, clearance lost time, approach volume, saturation flow rate, idle emission factor, signal type, and arrival rate.

- The second section on the second page lists the receptor locations and the X, Y, Z coordinates (in ft or m) for each receptor.

The third page lists the model results in parts per million (ppm). Two output versions are available. The short version of the output (summary table) lists the total CO concentration (ppm) at each receptor for each wind angle analyzed, together with the maximum total concentration at each receptor with the corresponding angle. The long version of the output prints the same summary table with the total CO concentrations for each receptor as printed in the short version, plus a table showing the contribution from each link to the total CO concentration at each receptor for the angle where the maximum total CO concentration occurs.

In the case where multiple meteorological conditions are run, one printout with all the results will be generated for each meteorological condition. The following section describes three examples showing the different types of output that could be generated.

4.6 EXAMPLES

Three example cases are described in this section: 1) a signalized intersection with an under-capacity situation where V/C ratios are less than 1.0 for all approaches; 2) a two way multiphase intersection with an over-capacity situation, where V/C ratios are above 1.0 for some approaches; and 3) an urban highway where only free flow links interact.

In order to highlight how the model could be used, all these examples were kept as simple as possible, however realistic values for traffic parameters, emission rates, and roadway configuration were used. For all cases, a map showing the geometric configuration of the intersection being modeled is followed by a description of all input parameters and the model input/output formats.

4.6.1 Example 1: Two-way Signalized Intersection (Under-Capacity)

This intersection consists of a two-way main street intersecting a one-way local street. Figure 6 shows the geometric configuration of the site and the X, Y coordinates of each link and receptor location. Table 3 shows all the input parameters with their corresponding units, in the same order as they are used in the input file.

4.6.2 Example 2: Two-way Multiphase Signalized Intersection (Over-Capacity)

This example consists of a two-way main street with exclusive left turning bays intersecting with a two-way local street. The signal cycle of this intersection is considered a three phase signal, where the left turning movements from the main street (Northbound and Southbound left turns) have an exclusive green phase, separate from the main street green phase for the through traffic. Figure 7 shows the geometric configuration of the site and the X, Y coordinates of each link and receptor locations. Table 4 shows all the input parameters with their corresponding units, in the same order as they are used in the input file.

In order to show a variation of the short output format, several wind angle ranges with different wind speeds were run:

1st wind direction range from 150° to 210,° in 5° increments,
wind speed = 1 m/s

2nd wind direction range from 240° to 300° in 3° increments,
wind speed = 1 m/s

3rd wind direction range from 330° to 70° (430°) in 10° increments,
wind speed = 2 m/s

4.6.3 <u>Example 3: Urban Highway</u>

This example consists of a two-way highway with an exit ramp, where only free flow links interact. Figure 8 and Table 5 show the geometric configuration of the site and all the input parameters with their corresponding units in the same order as they are used in the input file.

In this case the long version of the output format is printed. The second page of the output shows the summary table with results for all wind angles, and the third page shows the contribution from each link for the angle producing the maximum concentration at each receptor.

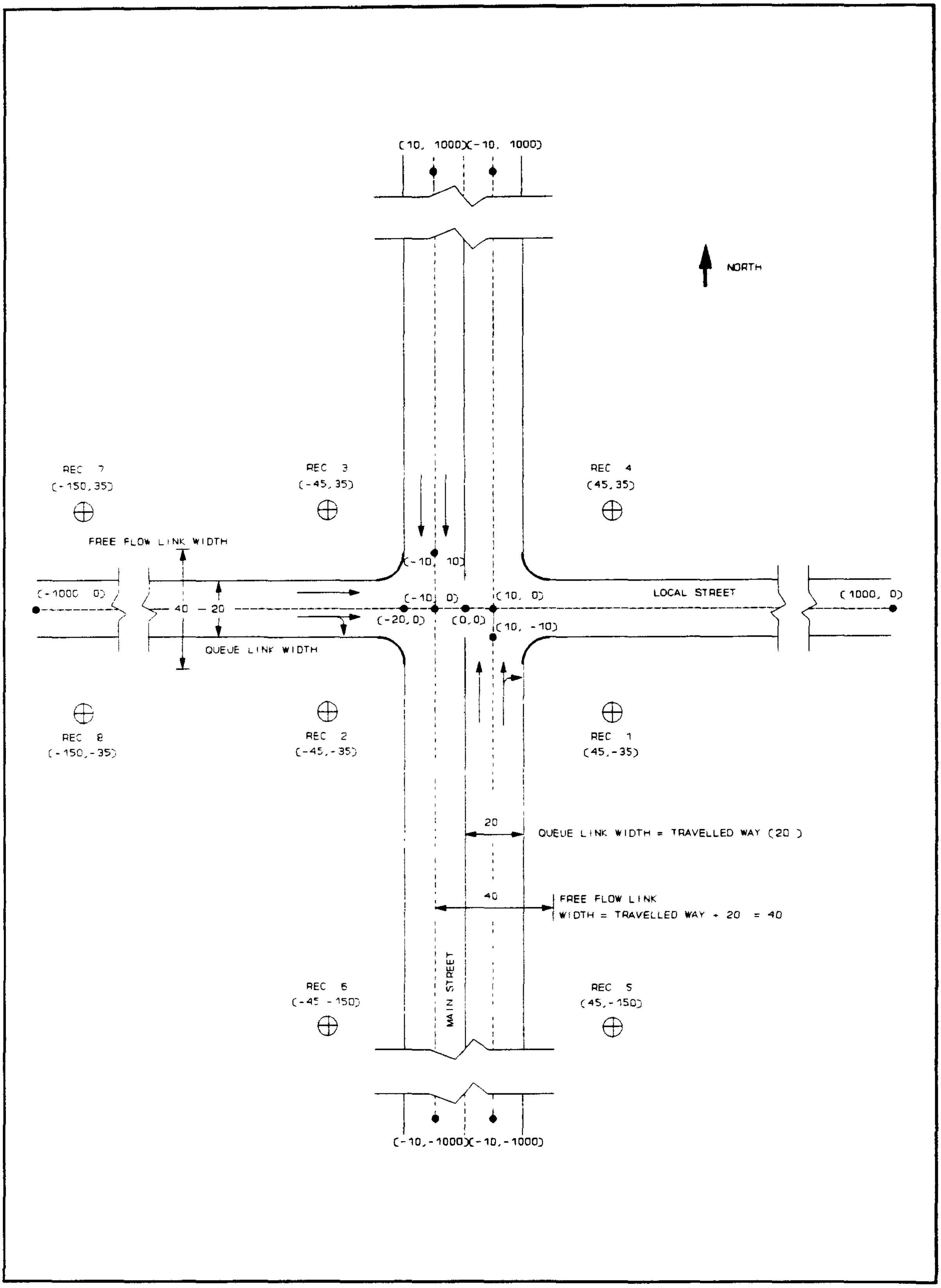


Figure 6. Example 1: Geometric configuration for a two-way intersection (units are in feet).

TABLE 3

EXAMPLE - 1: Two-way Signalized Intersection (Under-Capacity)

Input and output in feet

Description of Parameters:

Site Variables:

Averaging time (ATIM)	=	60 min
Surface roughness length (z_0)	=	175 cm
Settling velocity (V_s)	=	0 cm/s
Deposition velocity (V_d)	=	0 cm/s
Number of receptors	=	8
Scale conversion factor	=	0.3048(units are in ft)
Output in feet	=	1

Main St. NB Approach Link:

X1, Y1 coordinates	=	10, -1000 (ft)
X2, Y2 coordinates	=	10, 0 (ft)
Traffic volume	=	1500 veh/hr
Emission factor	=	41.6 g/veh-mi (*)
Source height	=	0 ft
Mixing zone width	=	40 ft

Main St. NB Queue Link:

X1, Y1 coordinates	=	10, -10 (ft)
X2, Y2 coordinates	=	10, -1000 (ft)
Source height	=	0
Mixing zone width	=	20 ft
Number of travel lanes	=	2
Avg. signal cycle length	=	90 s
Avg. red time length	=	40 s
Clearance lost time	=	3 s
Approach traffic volume	=	1500 veh/hr
Idle emission factor	=	735.0 g/veh-hr (**)
Saturation flow rate	=	1600 veh/hr/lane
Signal type	=	1 (pretimed)
Arrival rate	=	3 (average progression)

TABLE 3 (Continued)

<u>Main St. NB Departure Link:</u>

X1, Y1 coordinates	=	10, 0 (ft)
X2, Y2 coordinates	=	10, 1000 (ft)
Traffic volume	=	1500 veh/hr
Emission factor	=	41.6 g/veh-mi (*)
Source height	=	0 ft
Mixing zone width	=	40 ft

<u>Main St. SB Approach Link:</u>

X1, Y1 coordinates	=	-10, 1000 (ft)
X2, Y2 coordinates	=	-10, 0 (ft)
Traffic volume	=	1200 veh/hr
Emission factor	=	41.6 g/veh-mi (*)
Source height	=	0 ft
Mixing zone width	=	40 ft

<u>Main St. SB Queue Link:</u>

X1, Y1 coordinates	=	-10, 10 (ft)
X2, Y2 coordinates	=	-10, 1000 (ft)
Source height	=	0 ft
Mixing zone width	=	20 ft
Number of travel lanes	=	2
Avg. signal cycle length	=	90 s
Avg. red time length	=	40 s
Clearance lost time	=	3 s
Approach traffic volume	=	1200 veh/hr
Idle emission factor	=	735.0 g/veh-hr (**)
Saturation flow rate	=	1600 veh/hr/lane
Signal type	=	1 (pretimed)
Arrival type	=	3 (average progression)

<u>Main St. SB Departure Link:</u>

X1, Y1 coordinates	=	-10, 0 (ft)
X2, Y2 coordinates	=	-10, -1000 (ft)
Traffic volume	=	1200 veh/hr
Emission factor	=	41.6 g/veh-mi (*)
Source height	=	0 ft
Mixing zone width	=	40 ft

TABLE 3 (Continued)

<u>Local St. Approach Link:</u>		
X1, Y1 coordinates	=	-1000, 0 (ft)
X2, Y2 coordinates	=	0, 0 (ft)
Traffic volume	=	1000 veh/hr
Emission factor	=	41.6 g/veh-mi (*)
Source height	=	0 ft
Mixing zone width	=	40 ft
<u>Local St. Queue Link:</u>		
X1, Y1 coordinates	=	-20, 0 (ft)
X2, Y2 coordinates	=	-1000, 0 (ft)
Source height	=	0 ft
Mixing Zone Width	=	20 ft
Number of travel lanes	=	2
Avg. signal cycle length	=	90 s
Avg. red time length	=	50 s
Clearance lost time	=	3 s
Approach traffic volume	=	1000 veh/hr
Idle emission factor	=	735.0 g/veh-hr (**)
Saturation flow rate	=	1600 veh/hr/lane
Signal type	=	1 (pretimed)
Arrival rate	=	3 (average progression)
<u>Local St. Departure Link:</u>		
X1, Y1 coordinates	=	0, 0 (ft)
X2, Y2 coordinates	=	1000, 0 (ft)
Traffic volume	=	1000 veh/hr
Emission factor	=	41.6 g/veh-mi (*)
Source height	=	0 ft
Mixing zone width	=	40 ft
<u>Site Meteorology</u>		
Wind speed	=	1 m/s
Wind direction	=	0°
Stability class	=	4 (D)
Mixing height	=	1000 m
Background concentrations	=	0.0 ppm

TABLE 3 (Continued)

Site Meteorology (Continued)		
Multiple wind directions	=	Yes
Wind direction increment angle	=	10°
First increment multiplier	=	0°
Last increment multiplier	=	36

(*) Emission factor = 41.6 g/veh-mi, obtained from MOBILE 4.1 emission factor model, assuming: average speed = 20 mph, Year 1990, ambient temperature = 30° F, default for vehicle mix and thermal states, no I/M program, no ATP program, RVP = 11.5 psi, and ASTM = C.

(**) Idle emission factor = 735.0 g/veh-hr obtained from MOBILE 4.1 emission factor model.

INPUT EXAMPLE 1

```
'EXAMPLE - TWO WAY INTERSECTION (EX-1)' 60. 175.  0. 0.  8   0.3048 1 1
'REC 1 (SE CORNER)  '        45.       -35.       6.0
'REC 2 (SW CORNER)  '       -45.       -35.       6.0
'REC 3 (NW CORNER)  '       -45.        35.       6.0
'REC 4 (NE CORNER)  '        45.        35.       6.0
'REC 5 (E MID-MAIN) '        45.      -150.       6.0
'REC 6 (W MID-MAIN) '       -45.      -150.       6.0
'REC 7 (N MID-LOCAL)'      -150.        35.       6.0
'REC 8 (S MID-LOCAL)'      -150.       -35.       6.0
'MAIN ST. AND LOCAL ST. INTERSECTION'       9  1  0  'C'
  1
'Main St.NB Appr.  '  'AG'    10. -1000.    10.      0. 1500.  41.6  0. 40.
  2
'Main St.NB Queue  '  'AG'    10.   -10.    10. -1000.     0.  20.0   2
        90        40       3.0 1500 735.0 1600 1 3
  1
'Main St.NB Dep.   '  'AG'    10.     0.    10.  1000. 1500.  41.6  0. 40.
  1
'Main St.SB Appr.  '  'AG'   -10.  1000.   -10.      0. 1200.  41.6  0. 40.
  2
'Main St.SB Queue  '  'AG'   -10.    10.   -10.  1000.     0.  20.0   2
        90        40       3.0 1200 735.0 1600 1 3
  1
'Main St.SB Dep.   '  'AG'   -10.     0.   -10. -1000. 1200.  41.6  0. 40.
  1
'Local St.Appr.Lnk.'  'AG' -1000.     0.     0.      0. 1000.  41.6  0. 40.
  2
'Local St.Queue Lnk.' 'AG'   -20.     0. -1000.      0.    0.  20.0   2
        90        50       3.0 1000 735.0 1600 1 3
  1
'Local St.Dep.Lnk.'   'AG'     0.     0.  1000.      0. 1000.  41.6  0. 40.
 1.0 00. 4 1000. 0.  'Y' 10  0 36
```

OUTPUT EXAMPLE 1 (Short Version)

CAL3QHC: LINE SOURCE DISPERSION MODEL - VERSION 2.0 Dated 95221 PAGE 1

JOB: EXAMPLE - TWO WAY INTERSECTION (EX-1) RUN: MAIN ST. AND LOCAL ST. INTERSECTION

DATE : 8/19/95
TIME : 16: 5:14

The MODE flag has been set to C for calculating CO averages.

SITE & METEOROLOGICAL VARIABLES

VS = .0 CM/S VD = .0 CM/S Z0 = 175. CM
U = 1.0 M/S CLAS = 4 (D) ATIM = 60. MINUTES MIXH = 1000. M AMB = .0 PPM

LINK VARIABLES

LINK DESCRIPTION	LINK COORDINATES (FT) X1	Y1	X2	Y2	LENGTH (FT)	BRG (DEG)	TYPE	VPH	EF (G/MI)	H (FT)	W (FT)	V/C	QUEUE (VEH)
1. Main St.NB Appr.	10.0	-1000.0	10.0	.0	1000.	360.	AG	1500.	41.6	.0	40.0		
2. Main St.NB Queue	10.0	-10.0	10.0	-238.5	229.	180.	AG	1752.	100.0	.0	20.0	.94	11.6
3. Main St.NB Dep.	10.0	.0	10.0	1000.0	1000.	360.	AG	1500.	41.6	.0	40.0		
4. Main St.SB Appr.	-10.0	1000.0	-10.0	.0	1000.	180.	AG	1200.	41.6	.0	40.0		
5. Main St.SB Queue	-10.0	10.0	-10.0	141.2	131.	360.	AG	1752.	100.0	.0	20.0	.75	6.7
6. Main St.SB Dep.	-10.0	.0	-10.0	-1000.0	1000.	180.	AG	1200.	41.6	.0	40.0		
7. Local St.Appr.Lnk.	-1000.0	.0	.0	.0	1000.	90.	AG	1000.	41.6	.0	40.0		
8. Local St.Queue Lnk.	-20.0	.0	-165.4	.0	145.	270.	AG	2191.	100.0	.0	20.0	.80	7.4
9. Local St.Dep.Lnk.	.0	.0	1000.0	.0	1000.	90.	AG	1000.	41.6	.0	40.0		

OUTPUT EXAMPLE 1 (Continued)

JOB: EXAMPLE - TWO WAY INTERSECTION (EX-1)   RUN: MAIN ST. AND LOCAL ST. INTERSECTION

DATE : 8/19/95
TIME : 16: 5:14

ADDITIONAL QUEUE LINK PARAMETERS

LINK DESCRIPTION	*	CYCLE LENGTH (SEC)	RED TIME (SEC)	CLEARANCE LOST TIME (SEC)	APPROACH VOL (VPH)	SATURATION FLOW RATE (VPH)	IDLE EM FAC (gm/hr)	SIGNAL TYPE	ARRIVAL RATE
2. Main St.NB Queue	*	90	40	3.0	1500	1600	735.00	1	3
5. Main St.SB Queue	*	90	40	3.0	1200	1600	735.00	1	3
8. Local St.Queue Lnk.	*	90	50	3.0	1000	1600	735.00	1	3

RECEPTOR LOCATIONS

RECEPTOR	*	COORDINATES (FT) X	Y	Z	*
1. REC 1 (SE CORNER)	*	45.0	-35.0	6.0	*
2. REC 2 (SW CORNER)	*	-45.0	-35.0	6.0	*
3. REC 3 (NW CORNER)	*	-45.0	35.0	6.0	*
4. REC 4 (NE CORNER)	*	45.0	35.0	6.0	*
5. REC 5 (E MID-MAIN)	*	45.0	-150.0	6.0	*
6. REC 6 (W MID-MAIN)	*	-45.0	-150.0	6.0	*
7. REC 7 (N MID-LOCAL)	*	-150.0	35.0	6.0	*
8. REC 8 (S MID-LOCAL)	*	-150.0	-35.0	6.0	*

OUTPUT EXAMPLE 1 (Continued)

JOB: EXAMPLE - TWO WAY INTERSECTION (EX-1) RUN: MAIN ST. AND LOCAL ST. INTERSECTION

MODEL RESULTS

REMARKS : In search of the angle corresponding to the maximum concentration, only the first angle, of the angles with same maximum concentrations, is indicated as maximum.

WIND ANGLE RANGE: 0.-360.

WIND ANGLE (DEGR)	*	CONCENTRATION (PPM) REC1	REC2	REC3	REC4	REC5	REC6	REC7	REC8
0.	*	4.1	9.3	3.0	2.6	4.7	5.5	.4	5.6
10.	*	2.3	11.3	5.1	1.0	2.0	6.7	1.0	6.6
20.	*	1.4	11.6	6.4	.3	.7	6.9	1.3	7.2
30.	*	1.1	10.1	6.9	.0	.4	6.9	1.5	7.6
40.	*	1.2	8.3	6.9	.0	.5	6.3	1.6	8.3
50.	*	1.3	6.6	6.5	.0	.5	6.1	2.0	8.9
60.	*	1.4	6.0	6.4	.0	.5	6.0	2.3	9.0
70.	*	1.6	6.1	6.3	.1	.5	5.7	2.6	8.1
80.	*	1.6	6.4	6.8	.5	.4	5.7	3.3	6.4
90.	*	1.1	6.2	7.2	1.1	.2	5.4	4.9	4.7
100.	*	.5	5.8	7.7	1.6	.0	5.3	6.6	3.2
110.	*	.1	5.3	7.6	1.6	.0	5.2	8.2	2.6
120.	*	.0	5.5	7.7	1.4	.0	5.5	9.0	2.6
130.	*	.0	5.6	8.2	1.3	.0	5.4	9.0	2.6
140.	*	.0	6.1	9.4	1.2	.0	5.2	8.5	2.2
150.	*	.0	6.3	10.6	1.1	.0	4.9	7.9	1.8
160.	*	.4	6.1	11.4	1.6	.3	4.4	7.4	1.4
170.	*	1.5	5.0	10.8	3.0	1.1	3.6	6.7	1.0
180.	*	4.1	2.9	8.7	5.6	2.9	2.3	5.6	.4
190.	*	6.6	1.1	6.9	8.0	4.8	1.0	4.7	.0
200.	*	7.8	.3	6.0	8.4	6.1	.2	3.8	.0
210.	*	7.7	.0	5.7	7.6	6.7	.0	2.8	.0
220.	*	7.4	.0	6.1	6.9	7.0	.0	2.1	.0
230.	*	6.8	.0	6.3	7.0	6.6	.0	1.7	.0
240.	*	6.4	.0	6.2	8.2	6.4	.0	1.5	.0
250.	*	6.4	.1	5.5	9.4	6.2	.0	1.6	.1
260.	*	7.5	.8	4.0	9.4	6.2	.0	1.5	.5
270.	*	9.2	2.2	2.1	8.2	6.4	.2	1.1	1.1
280.	*	10.7	4.0	.8	6.5	6.6	.4	.5	1.5
290.	*	10.8	5.5	.1	5.4	7.0	.5	.1	1.6
300.	*	9.9	6.2	.0	5.5	7.6	.6	.0	1.5
310.	*	8.6	6.3	.0	5.7	8.4	.9	.0	1.7
320.	*	7.9	6.0	.0	5.8	9.4	1.4	.0	2.1
330.	*	7.4	5.7	.0	5.4	9.8	1.8	.0	2.8
340.	*	7.0	6.0	.3	4.9	9.3	2.4	.0	3.8
350.	*	5.9	7.1	1.2	4.1	7.7	3.4	.0	4.8
360.	*	4.1	9.3	3.0	2.6	4.7	5.5	.4	5.6
MAX	*	10.8	11.6	11.4	9.4	9.8	6.9	9.0	9.0
DEGR.	*	290	20	160	250	330	20	120	60

THE HIGHEST CONCENTRATION OF 11.60 PPM OCCURRED AT RECEPTOR REC2 .

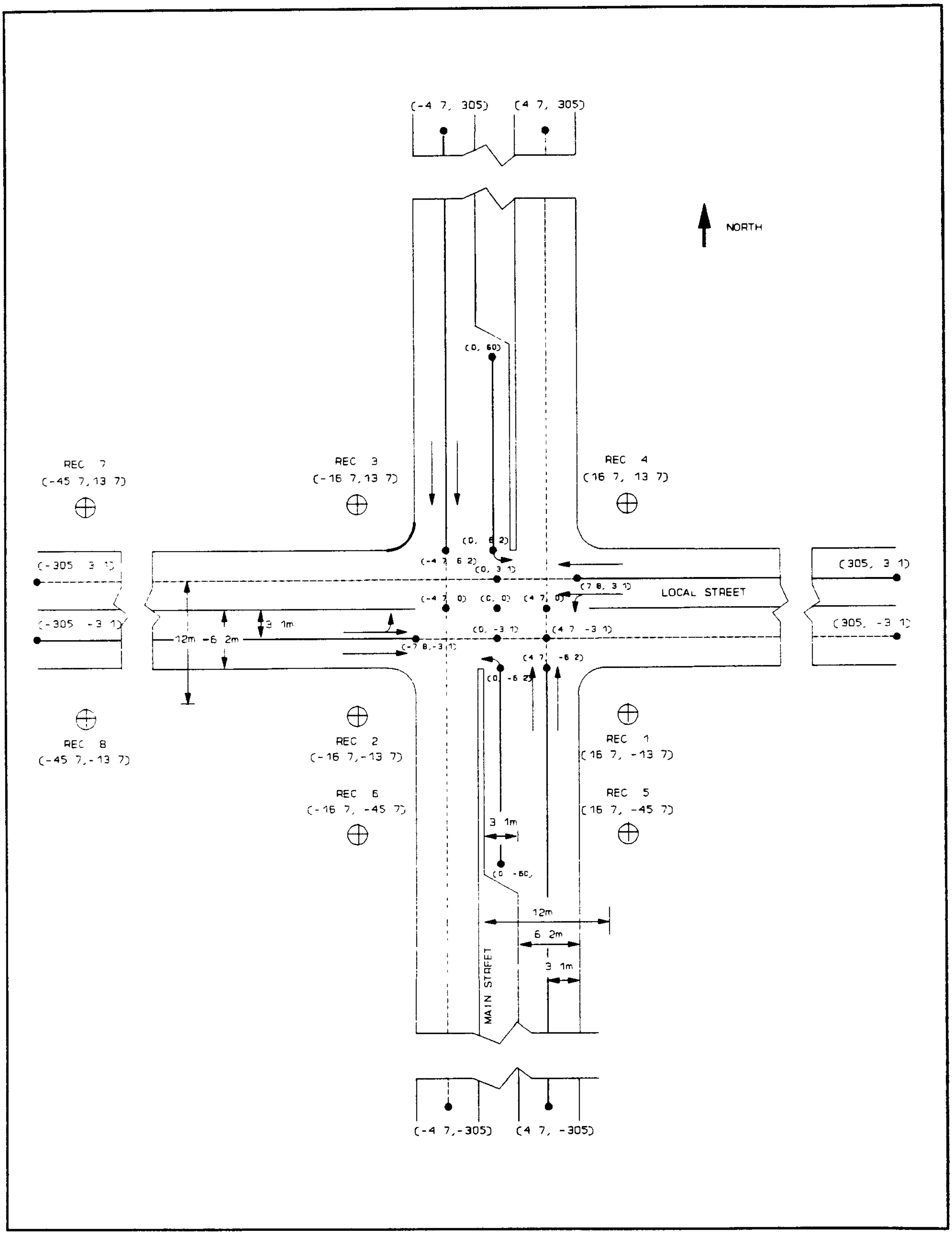


Figure 7. Example 2: Geometric configuration for a two-way multiphase intersection (units in meters).

TABLE 4

EXAMPLE - 2: Two-way Multiphase Signalized Intersection (Over-Capacity)

Input and output in meters

Description of Parameters:

Site Variables:

Averaging time (ATIM)	=	60 min
Surface roughness length (z_o)	=	175 cm
Settling velocity (V_s)	=	0 cm/s
Deposition velocity (V_d)	=	0 cm/s
Number of receptors	=	8
Scale conversion factor	=	1.0 (units are in m)

Main St. NB Approach Link:

X1, Y1 coordinates	=	4.7, -305 (m)
X2, Y2 coordinates	=	4.7, 0 (m)
Traffic volume	=	1730 veh/hr
Emission factor	=	41.6 g/veh-mi (*)
Source height	=	0 m
Mixing zone width	=	12 m

Main St. NB Queue Link:

X1, Y1 coordinates	=	4.7, -6.2 (m)
X2, Y2 coordinates	=	4.7, -305 (m)
Source height	=	0 m
Mixing zone width	=	6.2 m
Number of travel lanes	=	2
Avg. signal cycle length	=	90 s
Avg. red time length	=	45 s
Clearance lost time	=	2 s
Approach traffic volume	=	1500 veh/hr
Idle emission factor	=	720.0 g/veh-hr (**)
Saturation flow rate	=	1700 veh/hr/lane
Signal type	=	2 (actuated)
Arrival rate	=	1 (worst progression)

TABLE 4 (Continued)

Main St. NB Queue Left Turn:

X1, Y1 coordinates	=	0, -6.2 (m)
X2, Y2 coordinates	=	0, -60 (m)
Source height	=	0 m
Mixing zone width	=	3.1 m
Number of travel lanes	=	1
Avg. signal cycle length	=	90 s
Avg. red time length	=	75 s
Clearance lost time	=	2 s
Approach traffic volume	=	230 veh/hr
Idle emission factor	=	720.0 g/veh-hr (**)
Saturation flow rate	=	1400 veh/hr/lane
Signal type	=	2 (actuated)
Arrival rate	=	3 (average progression)

Main St. NB Departure Link:

X1, Y1 coordinates	=	4.7, 0 (m)
X2, Y2 coordinates	=	4.7, 305 (m)
Traffic volume	=	1500 veh/hr
Emission factor	=	41.6 g/veh-mi (*)
Source height	=	0 m
Mixing zone width	=	12 m

Main St. SB Approach Link:

X1, Y1 coordinates	=	-4.7, 305 (m)
X2, Y2 coordinates	=	-4.7, 0 (m)
Traffic volume	=	1950 veh/hr
Emission factor	=	41.6 g/veh-mi (*)
Source height	=	0 m
Mixing zone width	=	12 m

Main St. SB Queue Link:

X1, Y1 coordinates	=	-4.7, 6.2 (m)
X2, Y2 coordinates	=	-4.7, 305 (m)
Source height	=	0 m
Mixing zone width	=	6.2 m
Number of travel lanes	=	2
Avg. signal cycle length	=	90 sec
Avg. red time length	=	45 sec

TABLE 4 (Continued)

Main St. SB Queue Link (Continued):

Clearance lost time	=	2 s
Approach traffic volume	=	1750 veh/hr
Idle emission factor	=	720.0 g/veh-hr (**)
Saturation flow rate	=	1800 veh/hr/lane
Signal type	=	2 (actuated)
Arrival rate	=	1 (worst progression)

Main St. SB Queue Left Turn

X1, Y1 coordinates	=	0, 6.2 (m)
X2, Y2 coordinates	=	0, 60 (m)
Source height	=	0 m
Mixing zone width	=	3.1 (m)
Number of travel lanes	=	1
Avg. signal cycle length	=	90 s
Avg. red time length	=	75 s
Clearance lost time	=	2 s
Approach traffic volume	=	200 veh/hr
Idle emission factor	=	720.0 g/veh-hr (**)
Saturation flow rate	=	1400 veh/hr/lane
Signal type	=	2 (actuated)
Arrival rate	=	3 (average progression)

Main St. SB Departure Link:

X1, Y1 coordinates	=	-4.7, 0 (m)
X2, Y2 coordinates	=	-4.7, -305 (m)
Traffic volume	=	1750 veh/hr
Emission factor	=	41.6 g/veh-mi (*)
Source height	=	0 m
Mixing zone width	=	12 m

Local St. EB Approach Link:

X1, Y1 coordinates	=	-305, -3.1 (m)
X2, Y2 coordinates	=	0, -3.1 (m)
Traffic volume	=	450 veh/hr
Emission factor	=	41.6 g/veh-mi (*)
Source height	=	0 m
Mixing zone width	=	12 m

TABLE 4 (Continued)

Local St. EB Queue Link:

X1, Y1 coordinates	=	-7.8, -3.1 (m)
X2, Y2 coordinates	=	-305, -3.1 (m)
Source height	=	0 m
Mixing zone width	=	6.2 m
Number of travel lanes	=	2
Avg. signal cycle length	=	90 s
Avg. red time length	=	60 s
Clearance lost time	=	2 s
Approach traffic Volume	=	450 veh/hr
Idle emission factor	=	720.0 g/veh-hr (**)
Saturation flow rate	=	1400 veh/hr/lane
Signal type	=	2 (actuated)
Arrival rate	=	3 (average progression)

Local St. EB Departure Link:

X1, Y1 coordinates	=	0, -3.1 (m)
X2, Y2 coordinates	=	305, -3.1 (m)
Traffic volume	=	680 veh/hr
Emission factor	=	41.6 g/veh-mi (*)
Source height	=	0 m
Mixing zone width	=	12 m

Local St. WB Approach Link:

X1, Y1 coordinates	=	305, 3.1 (m)
X2, Y2 coordinates	=	0, 3.1 (m)
Traffic volume	=	510 veh/hr
Emission factor	=	41.6 g/veh-mi (*)
Source height	=	0 m
Mixing zone width	=	12 m

Local St. WB Queue Link:

X1, Y1 coordinates	=	7.8, 3.1 (m)
X2, Y2 coordinates	=	305, 3.1 (m)
Source height	=	0 m
Mixing zone width	=	6.2 m
Number of travel lanes	=	2
Avg. signal cycle length	=	90 s
Avg. red time length	=	60 s

TABLE 4 (Continued)

<u>Local St. WB Queue Link (Continued):</u>

Clearance lost time	=	2 s
Approach traffic volume	=	510 veh/hr
Idle emission factor	=	720.0 g/veh-hr (**)
Saturation flow rate	=	1400 veh/hr/lane
Signal type	=	2 (actuated)
Arrival rate	=	3 (average progression)

<u>Local St. WB Departure Link:</u>

X1, Y1 coordinates	=	0, 3.1 (m)
X2, Y2 coordinates	=	-305, 3.1 (m)
Traffic volume	=	710 veh/hr
Emission factor	=	41.6 g/veh-mi (*)
Source height	=	0 m
Mixing zone width	=	12 m

<u>Site Meteorology for wind angle range (150 to 210° in 5° increments)</u>

Wind speed	=	1 m/s
Wind direction	=	0°
Stability class	=	4 (D)
Mixing height	=	1000 m
Background concentrations	=	0.0 ppm
Multiple wind directions	=	Yes
Wind direction increment angle	=	5°
First increment multiplier	=	30
Last increment multiplier	=	42

<u>Site Meteorology for wind angle range (240 to 300° in 3° increments)</u>

Wind speed	=	1 m/s
Wind direction	=	0°
Stability class	=	4 (D)
Mixing height	=	1000 m
Background concentrations	=	0.0 ppm
Multiple wind directions	=	Yes
Wind direction increment angle	=	3°
First increment multiplier	=	80
Last increment multiplier	=	100

TABLE 4 (Continued)

Site Meteorology for wind angle range (330 to 70° [430°] in 10° increments)

Wind speed	=	2 m/s
Wind direction	=	0°
Stability class	=	4 (D)
Mixing height	=	1000 m
Background concentrations	=	0.0 ppm
Multiple wind directions	=	Yes
Wind direction increment angle	=	10°
First increment multiplier	=	33
Last increment multiplier	=	43

(*) Emission factor = 41.6 g/veh-mi, obtained from MOBILE 4.1 emission factor model, assuming: average speed = 20 mph, Year 1990, ambient temperature = 30°F, default for vehicle mix and thermal states, no I/M program, no ATP program, RVP = 11.5 psi, and ASTM = C.

(**) Idle emission factor = 720.0 g/veh-hr obtained from the MOBILE 4.1 emission factor model.

INPUT EXAMPLE 2

```
'EXAMPLE-TWO WAY MULTIPHASE INT.(EX-2)' 60. 175.  0. 0.  8  1.0 0 0
'REC 1 (SE CORNER)  '      16.7      -13.7       1.8
'REC 2 (SW CORNER)  '     -16.7      -13.7       1.8
'REC 3 (NW CORNER)  '     -16.7       13.7       1.8
'REC 4 (NE CORNER)  '      16.7       13.7       1.8
'REC 5 (E MID-MAIN) '      16.7      -45.7       1.8
'REC 6 (W MID-MAIN) '     -16.7      -45.7       1.8
'REC 7 (N MID-LOCAL)'     -45.7       13.7       1.8
'REC 8 (S MID-LOCAL)'     -45.7      -13.7       1.8
'MAIN ST. AND LOCAL ST. INTERSECTION'      14  3  0  'c'
  1
'Main St.NB Appr. '   'AG'    4.7  -305.    4.7     0. 1730.  41.6  0. 12.
  2
'Main St.NB Queue '   'AG'    4.7    -6.2   4.7  -305.    0.   6.2   2
        90        45        2.0 1500 720.0  1700 2 1
  2
'Main St.NB Q.Left'   'AG'    0.0    -6.2   0.0   -60.    0.   3.1   1
        90        75        2.0  230 720.0  1400 2 3
  1
'Main St.NB Dep.  '   'AG'    4.7     0.    4.7   305. 1500.  41.6  0. 12.
  1
'Main St.SB Appr. '   'AG'   -4.7   305.   -4.7     0. 1950.  41.6  0. 12.
  2
'Main St.SB Queue '   'AG'   -4.7     6.2  -4.7   305.    0.   6.2   2
        90        45        2.0 1750 720.0  1800 2 1
  2
'Main St.SB Q.Left'   'AG'    0.0     6.2   0.0    60.    0.   3.1   1
        90        75        2.0  200 720.0  1400 2 3
  1
'Main St.SB Dep.  '   'AG'   -4.7     0.   -4.7  -305. 1750.  41.6  0. 12.
  1
'Local St.EB Appr.'   'AG'  -305.    -3.1    0.   -3.1  450.  41.6  0. 12.
  2
'Local St.EB Queue'   'AG'   -7.8    -3.1 -305.   -3.1    0.   6.2   2
        90        60        2.0  450 720.0  1400 2 3
  1
'Local St.EB Dep. '   'AG'     0.    -3.1  305.   -3.1  680.  41.6  0. 12.
  1
'Local St.WB Appr.'   'AG'   305.     3.1    0.    3.1  510.  41.6  0. 12.
  2
'Local St.WB Queue'   'AG'    7.8     3.1  305.    3.1    0.   6.2   2
        90        60        2.0  510 720.0  1400 2 3
  1
'Local St.WB Dep. '   'AG'     0.     3.1 -305.    3.1  710.  41.6  0. 12.
 1.0 00. 4 1000. 0.  'Y'  5 30  42
 1.0 00. 4 1000. 0.  'Y'  3 80 100
 2.0 00. 4 1000. 0.  'Y' 10 33  43
```

OUTPUT EXAMPLE 2 (Short Version)

```
            CAL3QHC: LINE SOURCE DISPERSION MODEL - VERSION 2.0 Dated 95221                       PAGE  1

JOB: EXAMPLE-TWO WAY MULTIPHASE INT.(EX-2)              RUN: MAIN ST. AND LOCAL ST. INTERSECTION

DATE :  8/23/95
TIME : 15:34:20

   The MODE flag has been set to c for calculating CO averages.

 SITE & METEOROLOGICAL VARIABLES
 ------------------------------
 VS =    .0 CM/S       VD =    .0 CM/S       Z0 = 175. CM
  U =  1.0 M/S         CLAS =   4  (D)     ATIM =  60. MINUTES     MIXH =  1000. M   AMB =    .0 PPM

 LINK VARIABLES
 --------------
```

LINK DESCRIPTION	X1	Y1	X2	Y2	LENGTH (M)	BRG (DEG)	TYPE	VPH	EF (G/MI)	H (M)	W (M)	V/C	QUEUE (VEH)
1. Main St.NB Appr.	4.7	-305.0	4.7	.0	305.	360.	AG	1730.	41.6	.0	12.0		
2. Main St.NB Queue	4.7	-6.2	4.7	-100.5	94.	180.	AG	1931.	100.0	.0	6.2	.97	15.7
3. Main St.NB Q.Left	.0	-6.2	.0	-232.1	226.	180.	AG	1609.	100.0	.0	3.1	1.35	37.6
4. Main St.NB Dep.	4.7	.0	4.7	305.0	305.	360.	AG	1500.	41.6	.0	12.0		
5. Main St.SB Appr.	-4.7	305.0	-4.7	.0	305.	180.	AG	1950.	41.6	.0	12.0		
6. Main St.SB Queue	-4.7	6.2	-4.7	294.8	289.	360.	AG	1931.	100.0	.0	6.2	1.07	48.1
7. Main St.SB Q.Left	.0	6.2	.0	135.7	129.	360.	AG	1609.	100.0	.0	3.1	1.17	21.6
8. Main St.SB Dep.	-4.7	.0	-4.7	-305.0	305.	180.	AG	1750.	41.6	.0	12.0		
9. Local St.EB Appr.	-305.0	-3.1	.0	-3.1	305.	90.	AG	450.	41.6	.0	12.0		
10. Local St.EB Queue	-7.8	-3.1	-30.3	-3.1	23.	270.	AG	2575.	100.0	.0	6.2	.56	3.8
11. Local St.EB Dep.	.0	-3.1	305.0	-3.1	305.	90.	AG	680.	41.6	.0	12.0		
12. Local St.WB Appr.	305.0	3.1	.0	3.1	305.	270.	AG	510.	41.6	.0	12.0		
13. Local St.WB Queue	7.8	3.1	33.3	3.1	26.	90.	AG	2575.	100.0	.0	6.2	.63	4.3
14. Local St.WB Dep.	.0	3.1	-305.0	3.1	305.	270.	AG	710.	41.6	.0	12.0		

ADDITIONAL QUEUE LINK PARAMETERS

LINK DESCRIPTION	CYCLE LENGTH (SEC)	RED TIME (SEC)	CLEARANCE LOST TIME (SEC)	APPROACH VOL (VPH)	SATURATION FLOW RATE (VPH)	IDLE EM FAC (gm/hr)	SIGNAL TYPE	ARRIVAL RATE
2. Main St.NB Queue	90	45	2.0	1500	1700	720.00	2	1
3. Main St.NB Q.Left	90	75	2.0	230	1400	720.00	2	3
6. Main St.SB Queue	90	45	2.0	1750	1800	720.00	2	1
7. Main St.SB Q.Left	90	75	2.0	200	1400	720.00	2	3
10. Local St.EB Queue	90	60	2.0	450	1400	720.00	2	3
13. Local St.WB Queue	90	60	2.0	510	1400	720.00	2	3

OUTPUT EXAMPLE 2 (Continued)

JOB: EXAMPLE-TWO WAY MULTIPHASE INT.(EX-2)   RUN: MAIN ST. AND LOCAL ST. INTERSECTION

DATE : 8/23/95
TIME : 15:34:20

RECEPTOR LOCATIONS

RECEPTOR	X (M)	Y (M)	Z (M)
1. REC 1 (SE CORNER)	16.7	-13.7	1.8
2. REC 2 (SW CORNER)	-16.7	-13.7	1.8
3. REC 3 (NW CORNER)	-16.7	13.7	1.8
4. REC 4 (NE CORNER)	16.7	13.7	1.8
5. REC 5 (E MID-MAIN)	16.7	-45.7	1.8
6. REC 6 (W MID-MAIN)	-16.7	-45.7	1.8
7. REC 7 (N MID-LOCAL)	-45.7	13.7	1.8
8. REC 8 (S MID-LOCAL)	-45.7	-13.7	1.8

MODEL RESULTS

REMARKS : In search of the angle corresponding to the maximum concentration, only the first angle, of the angles with same maximum concentrations, is indicated as maximum.

WIND ANGLE RANGE: 150.-210.

WIND ANGLE (DEGR)	REC1	REC2	REC3	REC4	REC5	REC6	REC7	REC8
	CONCENTRATION (PPM)							
150.	.0	9.3	11.8	6.5	.0	8.7	6.5	4.0
155.	.1	9.5	12.7	6.8	.1	8.7	6.0	3.8
160.	.4	9.3	13.3	7.2	.4	8.5	5.4	3.4
165.	1.0	9.0	13.6	7.7	.9	7.9	4.6	2.8
170.	2.2	7.8	13.1	9.0	1.9	6.9	3.9	2.1
175.	4.0	6.4	11.9	11.0	3.2	5.5	2.9	1.4
180.	6.1	4.7	10.2	13.0	5.1	4.0	2.1	.8
185.	8.2	3.1	8.6	14.9	7.1	2.7	1.7	.4
190.	9.9	1.6	6.9	16.2	8.6	1.5	1.4	.1
195.	10.9	.7	5.9	16.5	10.0	.7	1.2	.0
200.	11.3	.3	5.3	15.8	10.6	.3	1.2	.0
205.	11.3	.1	4.7	14.8	10.7	.1	1.2	.0
210.	10.9	.0	4.2	13.7	10.6	.0	1.2	.0
MAX	11.3	9.5	13.6	16.5	10.7	8.7	6.5	4.0
DEGR.	200	155	165	195	205	150	150	150

THE HIGHEST CONCENTRATION OF 16.50 PPM OCCURRED AT RECEPTOR REC4 .

JOB: EXAMPLE-TWO WAY MULTIPHASE INT.(EX-2) RUN: MAIN ST. AND LOCAL ST. INTERSECTION

MODEL RESULTS

REMARKS : In search of the angle corresponding to the maximum concentration, only the first angle, of the angles with same maximum concentrations, is indicated as maximum.

WIND ANGLE RANGE: 240.-300.

WIND ANGLE (DEGR)	*	CONCENTRATION (PPM) REC1	REC2	REC3	REC4	REC5	REC6	REC7	REC8
240.	*	9.0	.0	2.0	9.0	9.0	.0	1.5	.0
243.	*	8.9	.0	1.9	8.9	8.9	.0	1.6	.0
246.	*	8.9	.0	1.8	9.0	8.9	.0	1.6	.0
249.	*	9.0	.0	1.7	9.3	8.9	.0	1.6	.0
252.	*	8.9	.1	1.8	9.3	8.7	.0	1.7	.1
255.	*	9.3	.2	1.7	9.3	8.9	.0	1.6	.2
258.	*	9.4	.3	1.6	9.2	8.8	.0	1.6	.3
261.	*	9.6	.4	1.6	9.0	8.8	.0	1.5	.4
264.	*	9.9	.6	1.4	9.0	8.7	.0	1.4	.6
267.	*	10.4	.8	1.3	8.9	8.9	.2	1.2	.8
270.	*	10.7	1.1	1.1	8.6	8.9	.2	1.1	1.0
273.	*	11.1	1.3	.9	8.4	8.9	.2	.8	1.2
276.	*	11.4	1.5	.7	8.2	9.0	.3	.7	1.2
279.	*	11.4	1.7	.5	7.9	9.1	.4	.5	1.4
282.	*	11.5	2.0	.4	7.9	9.2	.5	.4	1.4
285.	*	11.7	2.1	.3	7.7	9.2	.5	.2	1.5
288.	*	11.6	2.4	.1	7.5	9.4	.5	.1	1.5
291.	*	11.0	2.7	.1	7.7	9.4	.5	.1	1.5
294.	*	10.7	3.0	.0	7.6	9.6	.5	.0	1.5
297.	*	10.5	3.3	.0	7.7	9.7	.5	.0	1.5
300.	*	10.1	3.6	.0	7.8	9.8	.5	.0	1.4
MAX	*	11.7	3.6	2.0	9.3	9.8	.5	1.7	1.5
DEGR.	*	285	300	240	249	300	282	252	285

THE HIGHEST CONCENTRATION OF 11.70 PPM OCCURRED AT RECEPTOR REC1 .

OUTPUT EXAMPLE 2 (Continued)

JOB: EXAMPLE-TWO WAY MULTIPHASE INT.(EX-2)   RUN: MAIN ST. AND LOCAL ST. INTERSECTION

METEOROLOGICAL VARIABLES

U = 2.0 M/S   CLAS = 4 (D)   ATIM = 60. MINUTES   MIXH = 1000. M   AMB = .0 PPM

MODEL RESULTS

REMARKS : In search of the angle corresponding to the maximum concentration, only the first angle, of the angles with same maximum concentrations, is indicated as maximum.

WIND ANGLE RANGE: 330.-430.

WIND ANGLE (DEGR)	CONCENTRATION (PPM) REC1	REC2	REC3	REC4	REC5	REC6	REC7	REC8
330.	6.3	3.3	.0	5.0	6.8	.5	.0	.6
340.	7.3	3.7	.3	5.3	7.3	1.0	.0	.6
350.	7.4	5.1	1.5	4.7	6.3	2.5	.1	.7
360.	5.7	7.3	3.7	2.8	4.5	4.3	.7	1.4
10.	3.8	9.1	5.9	1.0	2.3	5.6	1.7	2.5
20.	2.9	8.8	6.3	.2	1.0	5.8	2.5	3.2
30.	2.4	7.4	5.9	.0	.5	5.4	2.7	3.5
40.	2.2	5.9	5.5	.0	.4	5.5	2.7	3.8
50.	1.7	5.3	5.0	.0	.3	5.0	2.4	4.0
60.	1.2	5.1	4.9	.0	.3	4.6	2.3	4.6
70.	1.0	5.0	4.8	.0	.3	4.3	2.3	4.6
MAX	7.4	9.1	6.3	5.3	7.3	5.8	2.7	4.6
DEGR.	350	10	20	340	340	20	30	60

THE HIGHEST CONCENTRATION OF 9.10 PPM OCCURRED AT RECEPTOR REC2 .

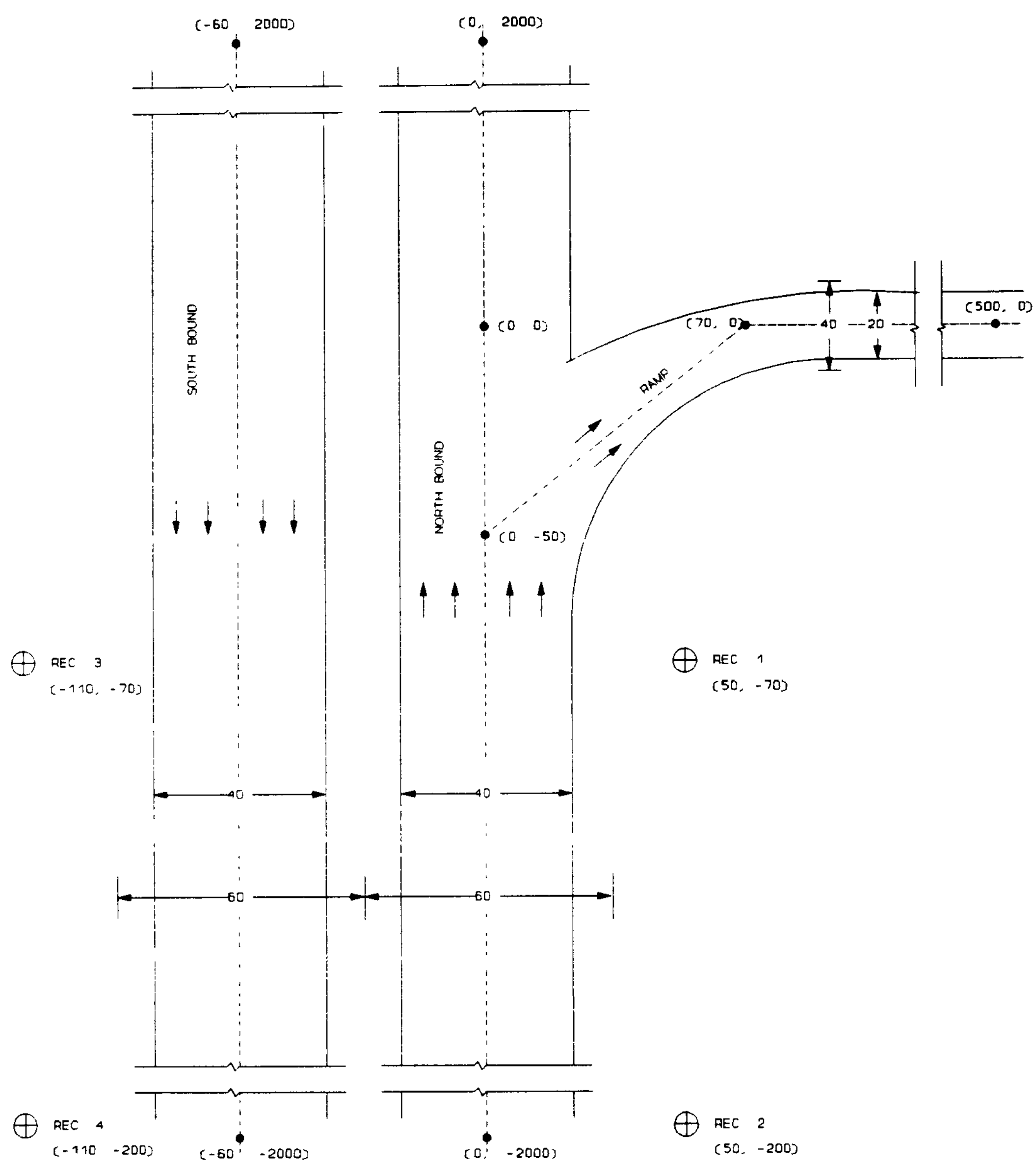


Figure 8. Example 3: Geometric configuration for an urban highway (units are in feet).

TABLE 5

EXAMPLE - 3: Urban Highway

Description of Parameters:
Input and Output in meters

Site Variables:

Averaging Time (ATIM)	=	60 min
Surface roughness length (z_o)	=	175 cm
Settling velocity (V_s)	=	0 cm/s
Deposition velocity (V_d)	=	0 cm/s
Number of receptors	=	4
Scale conversion factor	=	0.3048 (units are in ft)

Northbound Link 1:

X1, Y1 coordinates	=	0, -2000 (ft)
X2, Y2 coordinates	=	0, -50 (ft)
Traffic volume	=	5000 veh/hr
Emission factor	=	29.6 g/veh-mi (*)
Source height	=	0 ft
Mixing zone width	=	60 ft

Northbound Link 2:

X1, Y1 coordinates	=	0, -50 (ft)
X2, Y2 coordinates	=	0, 2000 (ft)
Traffic volume	=	4000 veh/hr
Emission factor	=	29.6 g/veh-mi (*)
Source height	=	0 ft
Mixing zone width	=	60 ft

Exit Ramp Link 3:

X1, Y1 coordinates	=	0, -50 (ft)
X2, Y2 coordinates	=	70, 0 (ft)
Traffic volume	=	1000 veh/hr
Emission factor	=	54.0 g/veh-mi (**)
Source height	=	0 ft
Mixing zone width	=	40 ft

TABLE 5 (Continued)

Exit Ramp Link 4:		
X1, Y1 coordinates	=	70, 0 (ft)
X2, Y2 coordinates	=	500, 0 (ft)
Traffic volume	=	1000 veh/hr
Emission factor	=	54.0 g/veh-mi (**)
Source height	=	0 ft
Mixing zone width	=	40 ft
Southbound Link 5:		
X1, Y1 coordinates	=	-60, 2000 (ft)
X2, Y2 coordinates	=	-60, -2000 (ft)
Traffic volume	=	5000 veh/hr
Emission factor	=	29.6 g/veh-mi (*)
Source height	=	0 ft
Mixing zone width	=	60 ft
Site Meteorology		
Wind speed	=	1 m/s
Wind direction	=	0°
Stability class	=	4 (D)
Mixing height	=	1000 m
Background concentrations	=	0.0 ppm
Multiple wind directions	=	Yes
Wind direction increment angle	=	10°
First increment multiplier	=	0
Last increment multiplier	=	36

(*) Emission factor = 29.6 g/veh-mi, obtained from the MOBILE 4.1 emission factor model, assuming: average speed = 55 mph, Year 1990, ambient temperature = 30°F, default for vehicle mix and thermal states, no I/M program, no ATP program, RVP = 11.5 psi, and ASTM = C.

(**) Emission factor = 54.0 g/veh-mi, obtained from the MOBILE 4.1 emission factor model, assuming: average speed = 15 mph, Year 1990, ambient temperature = 30°F, default for vehicle mix and thermal states, no I/M program, no ATP program, RVP = 11.5 psi, and ASTM = C.

INPUT EXAMPLE 3

```
'EXAMPLE - URBAN HIGHWAY (EX-3)'  60. 175.    0. 0.    4     0.3048 0 0
'REC 1 (SE RAMP)'             50.      -70.      6.0
'REC 2 (SE)'                  50.     -200.      6.0
'REC 3 (SW)'                -110.      -70.      6.0
'REC 4 (SW)'                -110.     -200.      6.0
'URBAN HIGHWAY (FREE FLOW LINKS ONLY)'      5  1  1  'C'
 1
'Northbound Lnk.1'     'AG'      0. -2000.      0.    -50. 5000.   29.6   0. 60.
 1
'Northbound Lnk.2'     'AG'      0.    -50.      0.  2000. 4000.   29.6   0. 60.
 1
'Exit Ramp  Lnk.3'     'AG'      0.    -50.     70.      0. 1000.   54.0   0. 40.
 1
'Exit Ramp  Lnk.4'     'AG'     70.      0.    500.      0. 1000.   54.0   0. 40.
 1
'Southbound Lnk.5'     'AG'    -60.  2000.    -60. -2000. 5000.   29.6   0. 60.
 1.0 00. 4 1000. 0.  'Y' 10  0 36
```

OUTPUT EXAMPLE 3 (Long Version)

CAL3QHC: LINE SOURCE DISPERSION MODEL - VERSION 2.0 Dated 95221 PAGE 1

JOB: EXAMPLE - URBAN HIGHWAY (EX-3) RUN: URBAN HIGHWAY (FREE FLOW LINKS ONLY)

DATE : 8/23/95
TIME : 15:35: 5

The MODE flag has been set to c for calculating CO averages.

SITE & METEOROLOGICAL VARIABLES

VS = .0 CM/S	VD = .0 CM/S	Z0 = 175. CM		
U = 1.0 M/S	CLAS = 4 (D)	ATIM = 60. MINUTES	MIXH = 1000. M	AMB = .0 PPM

LINK VARIABLES

LINK DESCRIPTION	X1	Y1	X2	Y2	LENGTH (M)	BRG (DEG)	TYPE	VPH	EF (G/MI)	H (M)	W (M)	V/C	QUEUE (VEH)
1. Northbound Lnk.1	.0	-609.6	.0	-15.2	594.	360.	AG	5000.	29.6	.0	18.3		
2. Northbound Lnk.2	.0	-15.2	.0	609.6	625.	360.	AG	4000.	29.6	.0	18.3		
3. Exit Ramp Lnk.3	.0	-15.2	21.3	.0	26.	54.	AG	1000.	54.0	.0	12.2		
4. Exit Ramp Lnk.4	21.3	.0	152.4	.0	131.	90.	AG	1000.	54.0	.0	12.2		
5. Southbound Lnk.5	-18.3	609.6	-18.3	-609.6	1219.	180.	AG	5000.	29.6	.0	18.3		

OUTPUT EXAMPLE 3 (Continued)

PAGE 2

JOB: EXAMPLE - URBAN HIGHWAY (EX-3)

RUN: URBAN HIGHWAY (FREE FLOW LINKS ONLY)

DATE : 8/23/95
TIME : 15:35: 5

ADDITIONAL QUEUE LINK PARAMETERS

LINK DESCRIPTION	CYCLE LENGTH (SEC)	RED TIME (SEC)	CLEARANCE LOST TIME (SEC)	APPROACH VOL (VPH)	SATURATION FLOW RATE (VPH)	IDLE EM FAC (gm/hr)	SIGNAL TYPE	ARRIVAL RATE

RECEPTOR LOCATIONS

RECEPTOR	COORDINATES (M) X	Y	Z
1. REC 1 (SE RAMP)	15.2	-21.3	1.8
2. REC 2 (SE)	15.2	-61.0	1.8
3. REC 3 (SW)	-33.5	-21.3	1.8
4. REC 4 (SW)	-33.5	-61.0	1.8

OUTPUT EXAMPLE 3 (Continued)

JOB: EXAMPLE - URBAN HIGHWAY (EX-3) RUN: URBAN HIGHWAY (FREE FLOW LINKS ONLY)

MODEL RESULTS

REMARKS : In search of the angle corresponding to the maximum concentration, only the first angle, of the angles with same maximum concentrations, is indicated as maximum.

WIND ANGLE RANGE: 0.-360.

WIND ANGLE (DEGR)	*	CONCENTRATION (PPM) REC1	REC2	REC3	REC4
0.	*	5.9	5.4	5.1	5.1
10.	*	3.1	2.4	7.3	7.5
20.	*	1.6	.9	7.4	7.6
30.	*	1.1	.5	6.8	7.2
40.	*	1.1	.5	6.1	6.9
50.	*	1.0	.5	5.9	6.7
60.	*	1.1	.4	6.0	6.4
70.	*	1.1	.2	6.3	5.9
80.	*	.8	.1	6.5	5.8
90.	*	.4	.0	6.3	5.7
100.	*	.1	.0	5.8	5.7
110.	*	.0	.0	5.6	5.6
120.	*	.0	.0	5.9	5.8
130.	*	.0	.0	6.1	6.1
140.	*	.0	.0	6.6	6.6
150.	*	.0	.0	7.3	7.3
160.	*	.5	.5	8.0	8.0
170.	*	2.1	2.1	7.8	7.8
180.	*	5.3	5.3	5.3	5.2
190.	*	7.8	7.8	2.1	2.1
200.	*	8.0	8.0	.5	.5
210.	*	7.3	7.3	.0	.0
220.	*	6.6	6.6	.0	.0
230.	*	6.1	6.1	.0	.0
240.	*	5.8	5.8	.0	.0
250.	*	5.6	5.6	.0	.0
260.	*	5.8	5.7	.0	.0
270.	*	5.7	5.7	.0	.0
280.	*	6.0	5.6	.0	.0
290.	*	6.0	5.5	.0	.0
300.	*	6.2	5.8	.0	.0
310.	*	6.5	6.2	.0	.0
320.	*	6.9	6.5	.0	.0
330.	*	7.4	7.1	.0	.0
340.	*	8.0	7.7	.5	.5
350.	*	8.0	7.8	2.0	2.0
360.	*	5.9	5.4	5.1	5.1
MAX	*	8.0	8.0	8.0	8.0
DEGR.	*	200	200	160	160

THE HIGHEST CONCENTRATION OF 8.00 PPM OCCURRED AT RECEPTOR REC3 .

OUTPUT EXAMPLE 3 (Continued)

JOB: EXAMPLE - URBAN HIGHWAY (EX-3)   RUN: URBAN HIGHWAY (FREE FLOW LINKS ONLY)

DATE : 8/23/95
TIME : 15:35: 5

RECEPTOR - LINK MATRIX FOR THE ANGLE PRODUCING
THE MAXIMUM CONCENTRATION FOR EACH RECEPTOR

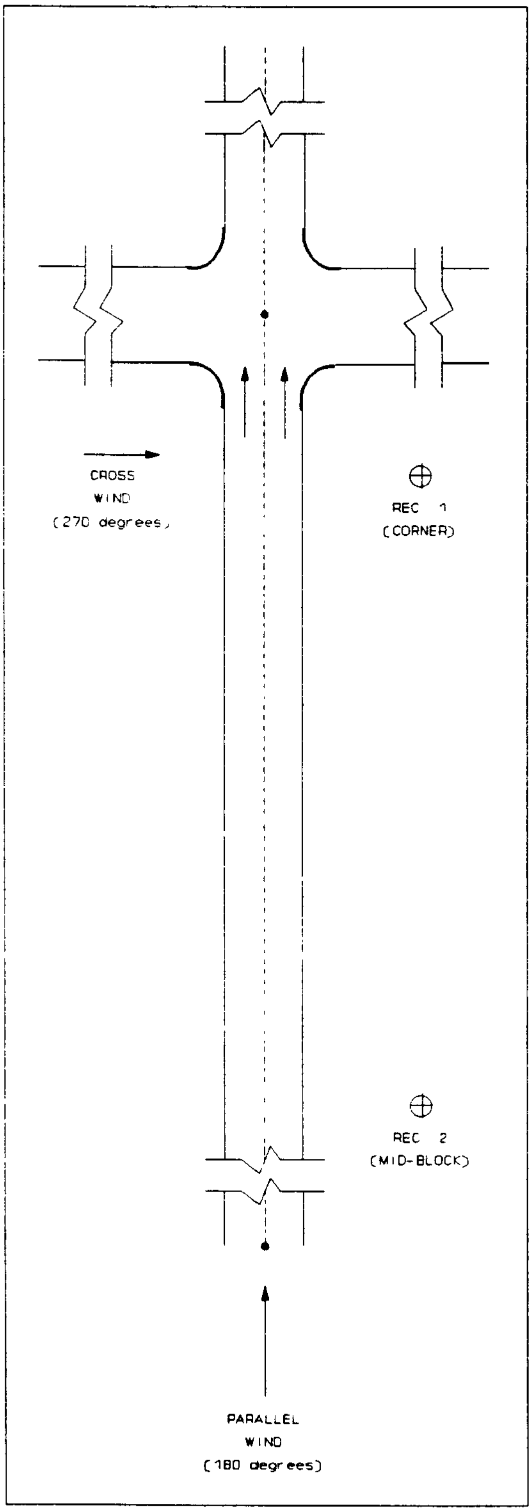
	CO/LINK (PPM) ANGLE (DEGREES)			
	REC1	REC2	REC3	REC4
LINK #	200	200	160	160
1	5.2	5.2	2.8	2.8
2	.0	.0	.0	.0
3	.0	.0	.0	.0
4	.0	.0	.0	.0
5	2.8	2.8	5.2	5.2

SECTION 5
SENSITIVITY ANALYSIS

5.1 OVERVIEW

The CAL3QHC model includes the CALINE-3 line source dispersion model[1] and a traffic algorithm for estimating vehicular queue lengths at signalized intersections. Because CAL3QHC includes CALINE3, the sensitivity analyses presented in the CALINE-3 manual are directly applicable to CAL3QHC. The user should refer to the CALINE-3 manual for discussion of the sensitivity of the model results with respect to: wind speed, atmospheric stability, highway width, highway length, surface roughness, averaging time, deposition velocity, settling velocity, wind angle, source height, mixing height, and median width.

Because its difference with the CALINE-3 model relates primarily to the handling of vehicular queues, the two areas in which CAL3QHC warrants a separate sensitivity discussion are: 1) the emission source strength of the vehicles in the queue, and 2) the link length representing the number of vehicles in a queue. The variability of these two parameters results in a nonlinear relationship between the source strengths and the predicted concentrations -- as opposed to CALINE-3, where predicted concentrations are directly proportional to source strengths. The three variables that directly affect the calculation of vehicular queues are: signal timing, traffic volume on the queue link, and number of traffic lanes in the queue link. To determine the effect of the variability of each of these parameters on resultant pollutant levels, a series of model runs was performed in which each of these three parameters were individually varied. The sensitivity runs were performed for a single roadway segment representing two traffic lanes (each 10 feet wide) with one receptor near the corner and one receptor at mid-block. Figure 9 shows the configuration of the roadway segment and the variables used in the sensitivity run. Plots were then completed depicting CO concentrations versus wind angle (with 180° representing a parallel wind and 270° representing a crosswind).



Site Variables

Averaging Time	= 60 min
Surface Roughness	= 175 cm
Settling Velocity	= 0
Deposition Velocity	= 0
Wind Speed	= 1 m/sec
Wind Direction	= (variable)
Stability Class	= 4 (D)
Background Concentration	= 0
Mixing Height	= 1000 meters

Receptor Locations

REC 1 (CORNER)	35, -35 6 feet
REC 2 (MID-BLOCK)	35, -150 6 feet

Link Variables

Approach link

X1, Y1 coordinates	= 0, -1000 feet
X2, Y2 coordinates	= 0, 0 feet
Source Height	= 0
Mixing Zone Width	= 40 feet
Traffic Volume	= 1500 VPH
Emission Factor	= 40 7 (gr x veh/mile)

Queue Link

X1, Y1 coordinates	= 0, -10 feet
X2, Y2 coordinates	= 0, -1000 feet
Mixing Zone Width	= 20 feet
Number of Travel Lanes	= 2
Average Signal Cycle Length	= 90 sec
Average Red Time Length	= 36 sec
Clearance Lost Time	= 2 sec.
Traffic Volume	= 1500 VPH
Idle Emission Factor	= 735 g/hr

Figure 9. Sensitivity analysis example run.

5.2 SIGNAL TIMING

Signal timing affects the computation in two ways. The emission source for the queue links depends on both the idling emission factor and the fraction of red time (the larger the fraction of red time, the stronger the emission source). In addition, the length of the queue is determined by the volume to capacity ratio (V/C) of the approach link. Since the capacity of the link is affected by the fraction of red time, the longer the red phase, the smaller the available capacity, and the longer the queue length.

Three cases were analyzed: 30 percent red time, 40 percent red time, and 50 percent red time. As seen in Figure 10, the increase in percent red time results in an increase of CO. For the corner receptor the peak concentration, which occurs under a cross wind condition in the case of 30 percent red (low V/C and short queues), shifts toward an almost parallel wind condition for the 50 percent red case (higher V/C and longer queues). For the midblock receptor, the CO increase is substantial when the length of the queue reaches the midblock location.

5.3 TRAFFIC VOLUME ON THE QUEUE LINK

An increase in the traffic volume on an approach link will result in a longer queue length but will not effect the strength of the emission source for the queue link. As explained in Section 3.3.2, the strength of this line source is not dependent on the approach volume. Three approach volumes were evaluated: 1000, 1500, and 2000 vehicles per hour (VPH). As seen in Figure 11, an increase in traffic volume results in increased CO concentrations and a shift in peak CO values from a cross wind situation, in the case of short queues, to a parallel wind condition, as the queues get longer. For the midblock receptor, the CO increase is substantial when the length of the queue reaches the midblock location.

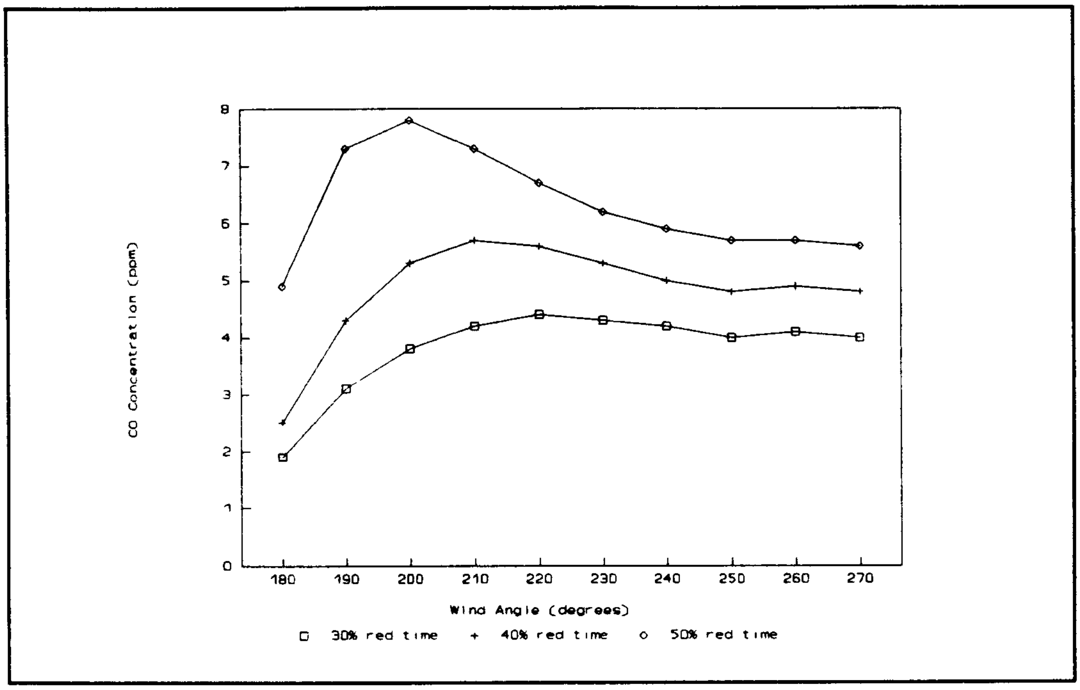


Figure 10a. Variation of CO concentrations (ppm) at receptor 1 (corner) versus wind angle for three different values of signal timing: 30% red time (V/C = 0.75, queue = 5.6 vehicles), 40% red time (V/C = 0.88, queue = 9.0 vehicles), and 50% red time (V/C = 1.08, queue = 42.9 vehicles).

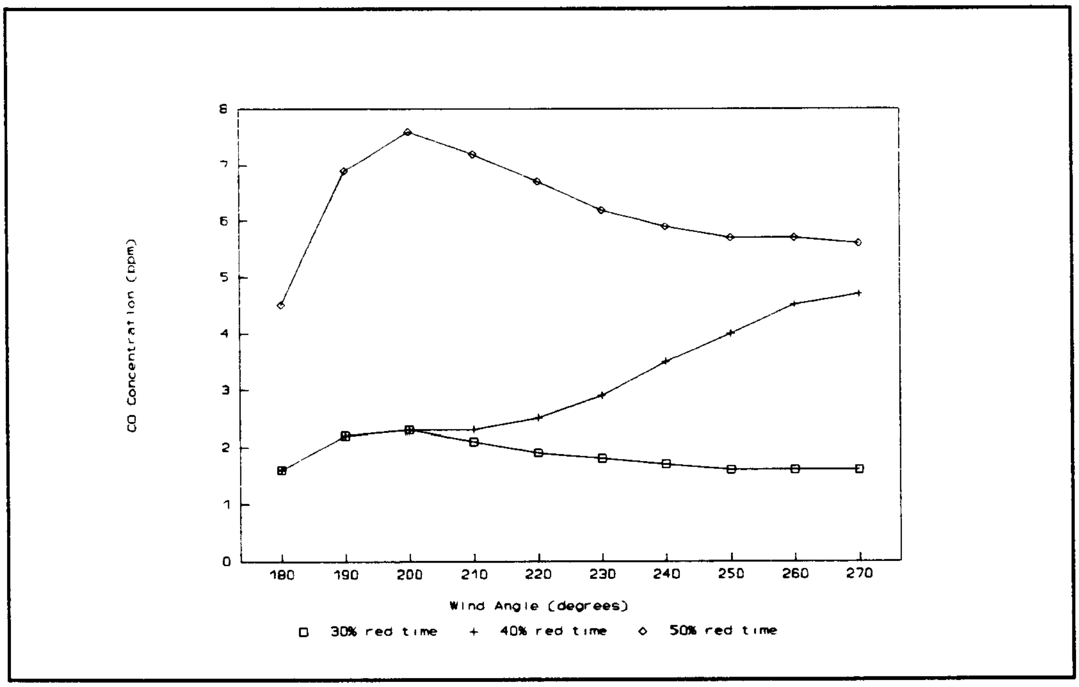


Figure 10b. Same as Figure 10a except at receptor 2 (midblock)

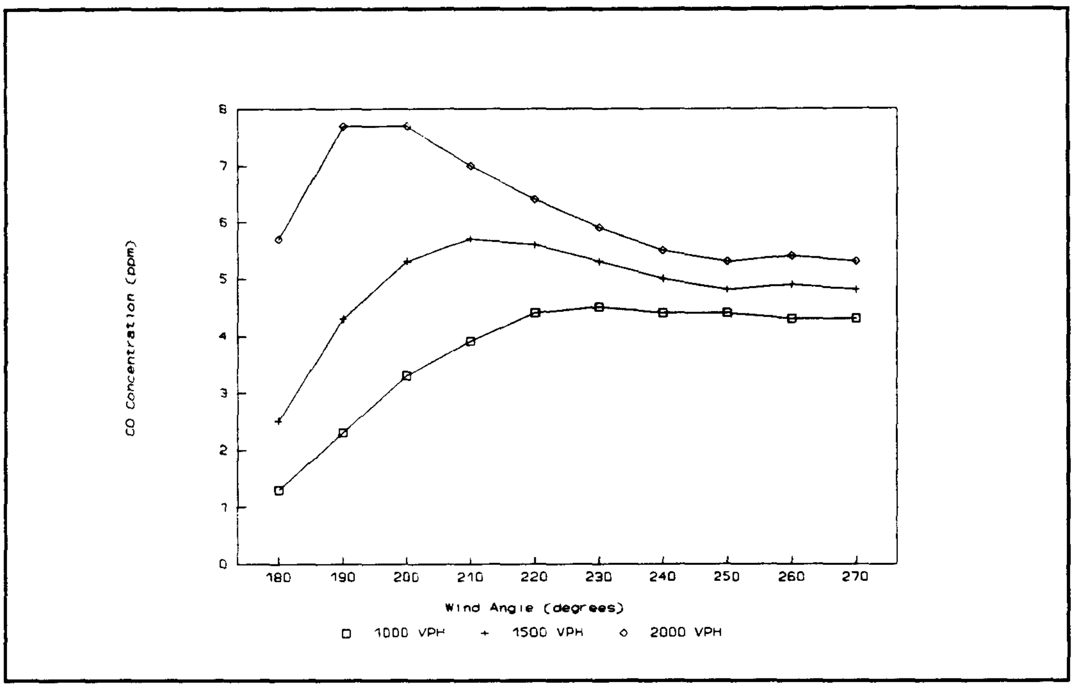


Figure 11a. Variation of CO concentrations (ppm) at receptor 1 (corner) versus wind angle for three different values of approach traffic volume: 1000 vph (V/C = 0.59, queue = 5.0 vehicles), 1500 vph (V/C = 0.88, queue = 9.0 vehicles), and 2000 vph (V/C = 1.18, queue = 93.5 vehicles).

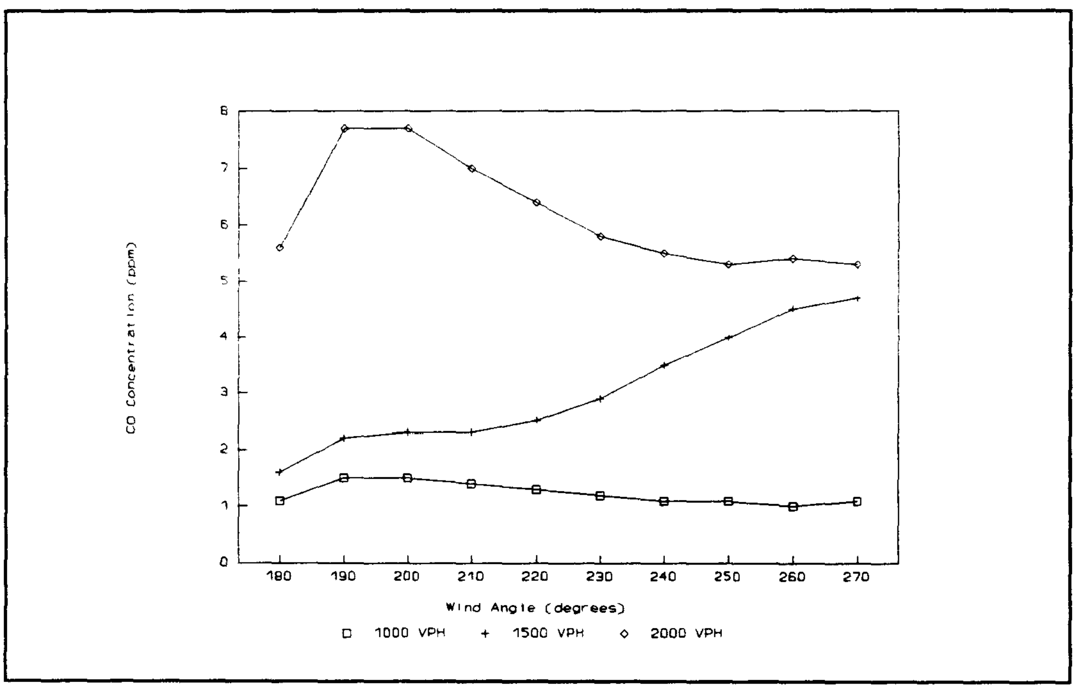


Figure 11b. Same as Figure 11a except at receptor 2 (mid-block).

5.4 TRAFFIC LANES IN THE QUEUE LINK

The number of moving lanes affects the computations in two ways. First, the strength of the emission source for a queue link is directly proportional to the number of moving lanes (e.g. doubling the number of lanes at an intersection will double the source strength). Second, the addition of lanes increases capacity. Thus by adding more available lanes with the roadway traffic volume held constant, the length of the queue is shortened. The net effect of these two components on CO concentrations is dependent on the wind angle and the relative location of the receptor with respect to the intersection. An increase of the number of available traffic lanes will not necessarily result in a reduction of predicted CO concentration, since the strength of the line source will increase (more rows of idling vehicles), but the queue will shorten (less vehicles queuing per lane). If the receptor is very close to the intersection, with a larger number of lanes under cross-wind conditions, higher CO levels may be predicted; but if the receptor is further away from the intersection, a smaller number of lanes (a longer queue) under near parallel winds will result in higher predicted CO levels. Two cases were analyzed for two and three traffic lanes for the approach. As seen in Figure 12, even though the case with three traffic lanes has more capacity and shorter queues compared with that of two traffic lanes, the cross wind condition results in higher CO concentration at the corner receptor in the case of three traffic lanes. For the midblock receptor, which is farther away from the intersection, two traffic lanes (with the longer queues) result in higher CO concentrations.

5.5 TRAFFIC PARAMETERS

The three traffic parameters (Saturation Flow Rate, Signal Type, and Arrival Type) affect the calculation of intersection capacity, delay, and queue length.

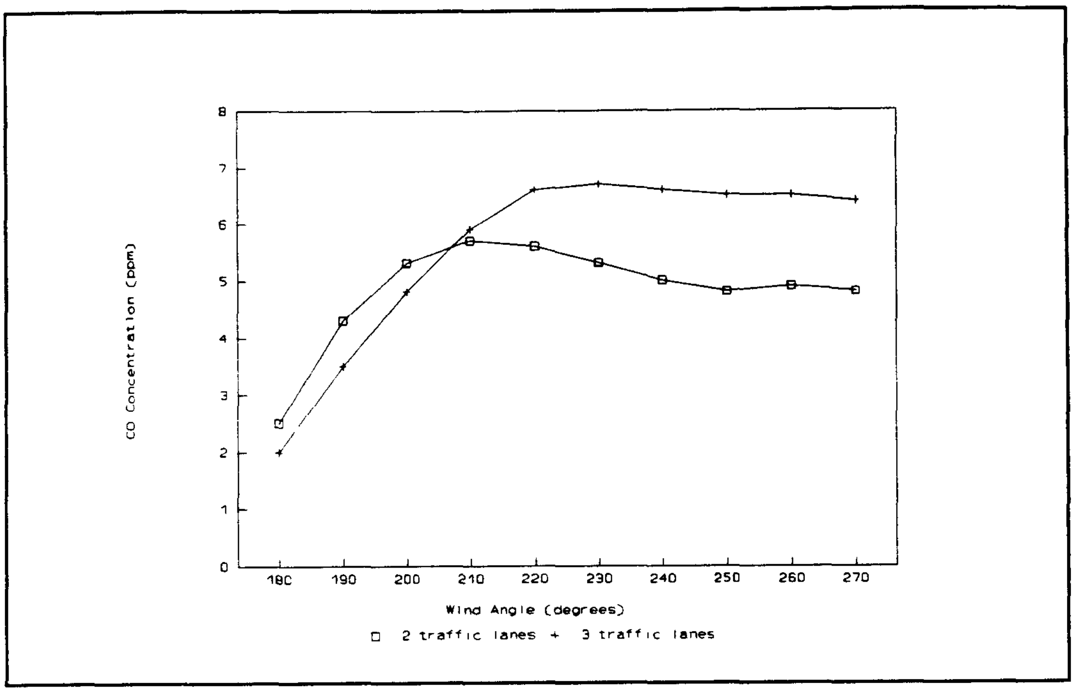


Figure 12a. Variation of CO concentrations (ppm) at receptor 1 (corner) versus wind angle for different number of traffic lanes: two traffic lanes (V/C = 0.88, queue = 9.0 vehicles) and three traffic lanes (V/C = 0.59, queue = 5.0 vehicles).

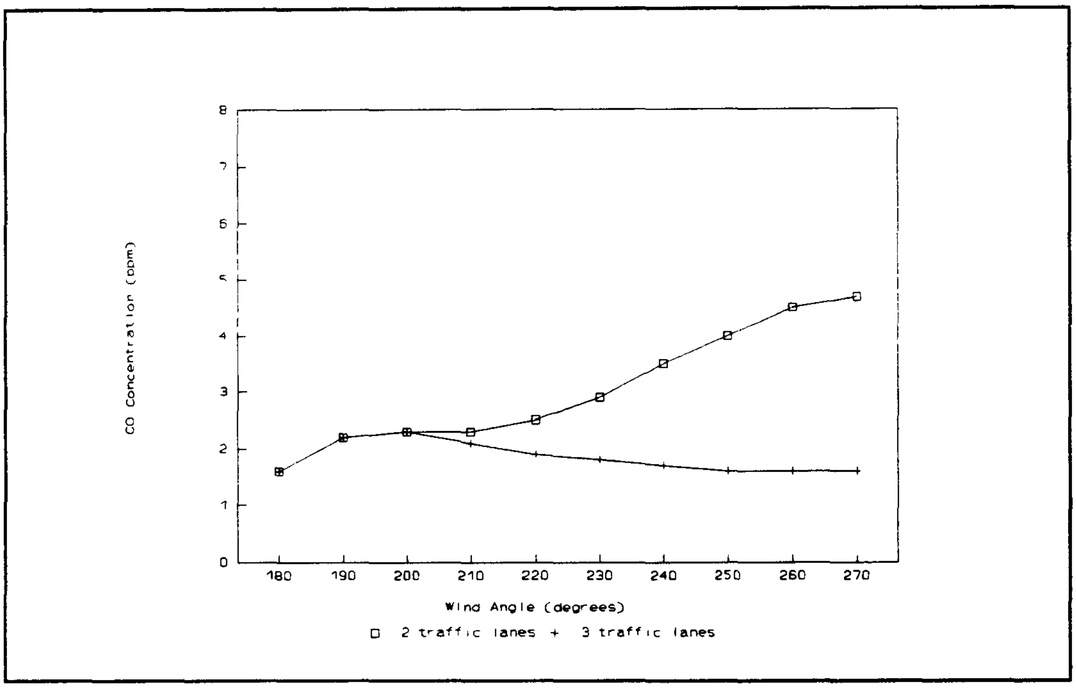


Figure 12b. Same as Figure 12a except at receptor 2 (mid-block).

Saturation flow rate is used in the calculation of intersection capacity and V/C ratio, having a direct effect of the calculation of approach delay; the lower the saturation flow rate, the higher the delay. Signal type and arrival type are used in the calculation of the progression adjustment factor which has an effect on the approach delay but not on the V/C ratio; the worst the progression, the higher the approach delay.

The effect of these parameters on the resulting CO concentrations is only significant when the intersection operates at medium to high V/C ratios (near or over saturation conditions), which are the conditions when higher delay results in longer queues and higher CO levels. In the case of light traffic conditions (low V/C ratios), the change in approach delay has minimum effect on the length of the queue and the resulting CO levels.

SECTION 6
MODEL VALIDATION

6.1 OVERVIEW

The U.S. EPA completed the performance evaluation of eight intersection models in simulating CO concentrations at the six intersections monitored as part of the Route 9A Reconstruction Project in New York City[2]. The eight models evaluated included CAL3QHC Version 2.0, FHWAINT[14], GIM[15], EPAINT[14], CALINE4[16], VOL9MOB4 (Volume 9[4] updated with MOBILE4), TEXIN2[17], and IMM[18]. A complete phase I model evaluation study was conducted using MOBILE4 emissions estimates. The phase I evaluation included all eight intersection models at all six intersections. In late 1991, the MOBILE4.1 emissions model[9], an update to MOBILE4, was released. Thus, a phase II evaluation utilizing MOBILE4.1 was conducted using a subset of the intersection models. Of the three EPA intersection models (EPAINT, VOL9MOB4, and CAL3QHC), CAL3QHC performed best using MOBILE4. Of the two models utilizing the FHWA advocated average speed approach rather than explicit queuing (FHWAINT and GIM), GIM performed best. Therefore, the phase II MOBILE4.1 analysis was performed for the following five models: CAL3QHC, GIM, IMM, TEXIN2, and CALINE4. When collecting and compiling the New York City database, the best quality assurance procedures (e.g., analysis and comparison of collected data) were followed at two of the six intersection sites, Site #1 (West/Chambers) and Site #2 (34th/8th). A uniform wind analysis (e.g., similar wind speed and direction for different monitors at the same intersection) conducted for each site indicated that Sites #5 (34th/12th) and #1 are best in terms of unhindered approach wind flows and wind field uniformity. Thus, the phase II MOBILE4.1 analysis was performed for the intersections at Sites #1, 2, and 5.

6.2 THE NEW YORK CITY DATABASE

A major air quality monitoring study was conducted in 1989-1990 in response to the proposed reconstruction of a portion of Route 9A in New York City. As part of the monitoring project, meteorological and CO air quality data were collected at two background sites (Battery Park and Post Office) and six different intersections (Site #1 West/Chambers; #2 34th/8th; #3 65th/Broadway; #4 57th/7th; #5 34th/12th; #6

Battery Tunnel). These sites are all located in midtown or lower Manhattan. The meteorological data collected at each intersection included wind direction, wind speed, temperature, and the fluctuation of the wind direction (sigma theta). These data were measured at two towers per intersection except at site #2 where they were measured at three towers. The meteorological measurements were taken at a height of 10 m ± 1 m.

In order to obtain detailed information concerning the traffic characteristics, a series of video cameras were used to film the traffic at each site. Three months of continuous traffic data were collected at each site producing approximately 13,000 hours of video recordings. A limited number of videotaped hours from the Route 9A Study were examined in order to obtain detailed information about the local traffic. The collected traffic data were concurrent with the observed CO data. The examined traffic data are comprised of the top 50 hours of CO concentrations observed for each of three months at Sites #1 and 2 and the top 25 hours observed for each of three months at the remaining sites.

All traffic data were obtained from videotapes except for the acceleration/deceleration rates and the cruise speed. The acceleration/deceleration rates and cruise speeds were obtained through the use of a vehicle outfitted with a travel-log machine that recorded instantaneous speed versus time while traveling. Cruise speeds were taken directly from the strip charts created in this way; acceleration/deceleration rates were determined from the slope of the lines on the strip charts.

6.3 MODELING METHODOLOGY

The hourly averaged temperature data from the meteorological towers at each site were averaged to calculate a site specific hourly value. For the remaining meteorological input data, the meteorological tower closest to the CO monitor location was used. Mixing heights of 1000 m were used, since the results are not affected if the mixing height is between 100 and 1000 m high and mixing heights below 100 m in Manhattan do not occur on a frequent basis.

The closest background concentration (Battery Park or the Post Office Station) was subtracted out of the observed concentration at each monitor. All modeling was performed for one hour averages only. After the removal of the background concentrations, a screening threshold of 0.5 ppm was used. When both the observed and predicted concentrations at a monitor are less than 0.5 ppm that data pair was eliminated from the data set.

A surface roughness length of 3.21 m was used for approach flows over numerous city blocks. Lower values of the surface roughness length (0.03 m) were used at Site #5 (34th/12th) when the intersection was exposed to flows over the Hudson River without intervening buildings. For modeling CO concentrations, the settling velocity and deposition velocity were set at zero because CO is a gaseous emission. An averaging time of 60 minutes was used. Finally, a temperature-sensitive conversion of the modeled concentrations from mg/m^3 to parts per million (ppm) was conducted.

6.4 MODEL EVALUATION RESULTS

6.4.1 Regulatory Default Analysis

The ten hours with the highest observed concentrations were used to compare the CAL3QHC predicted concentrations using the regulatory default meteorology to the observed concentrations. The comparisons for each site are presented in Table 6. The regulatory default meteorological conditions are defined as: Wind Speed = 1 m/s; Stability Class = D; Sigma-Theta = 25°; Observed Temperature; and "Worst Case" Wind Direction Angle (determined using ten degree increments).

At Site #1, the highest observed CO concentration of 10.6 ppm is nearly matched (10.4 ppm) by CAL3QHC unpaired in time or space. At Site #2, the maximum predicted concentration by CAL3QHC of 8.0 ppm underpredicts the maximum observed concentration of 11.5 ppm. Finally, at Site #5, the maximum observed concentration of 15.5 ppm is nearly matched by CAL3QHC which predicts 15.1 ppm.

6.4.2 Scoring Scheme Results

A method for aggregating component results of model performance (using the observed meteorology) into a single performance measure[19] was used to compare the overall performance of the five models evaluated at three intersection sites. The bootstrap

TABLE 6

COMPARISON OF TOP TEN OBSERVED CONCENTRATIONS WITH CAL3QHC PREDICTED CONCENTRATIONS

Site #1		Site #2		Site #5	
Observed ppm	Predicted ppm	Observed ppm	Predicted ppm	Observed ppm	Predicted ppm
10.6	7.5	11.5	5.4	15.5	9.2
9.1	9.8	10.5	8.0	14.6	8.4
9.0	9.8	10.4	7.0	10.4	11.5
8.6	7.0	10.2	6.9	9.9	10.3
8.2	10.4	10.2	3.9	9.3	11.4
7.8	8.2	9.1	4.7	8.9	10.5
7.6	10.0	8.8	4.9	8.7	10.7
7.5	9.8	8.5	7.3	8.4	11.6
7.5	8.0	8.4	6.7	7.6	15.1
7.4	9.9	8.3	6.1	7.4	10.8

re-sampling technique[20] was used to determine the significance of differences in composite performance between models.

The statistical analysis uses the robust highest concentration (RHC) for one-hour averages. The RHC is based on a tail exponential fit to the upper end of the distribution and is calculated as follows

$$RHC = x(n) + (\bar{x} - x(n)) \log\frac{(3n - 1)}{2} \tag{5}$$

where $\bar{x}$ = average of the n-1 largest values

x(n) = nth largest value

n = number of values exceeding the threshold value (n=26 or less)

The size of the three intersection data sets requires the value of n to be less than 26. The value of n was nominally set to 11 so that the number of values averaged ($\bar{x}$) was 10. In general, the RHCs are largest using the operational (or entire) dataset for each site. When calculating either the fractional bias (FB) or the absolute fractional bias (AFB),

$$AFB = |FB| = 2\left|\frac{(OB - PR)}{(OB + PR)}\right| \tag{6}$$

where OB and PR refer to the averages of the observed and predicted values, the RHC is used rather than the mean of the highest 10 concentrations. The RHC is preferred in this type of statistical evaluation because of its stability[19]. Also, the bootstrap distribution of the RHCs is not artificially bounded at the maximum predicted or observed concentration, which allows for a continuous range of concentrations.

When comparing these performance measures, one would like to know if differences are significant. Simultaneous confidence intervals for each pair of models were calculated[21] in order to ensure an adequate confidence level and to protect against falsely concluding that two models are different. A composite performance measure (CPM) is calculated for each model as a weighted linear combination of the individual absolute fractional bias components. The operational component is given a weight that is equal to the weight of the combined scientific components. The scientific component refers to the evaluation of peak concentrations during specific meteorological conditions and the operational component refers to the evaluation of peak averages independent of meteorological conditions. The results from the different data bases (intersections) are given equal weight. The CPM is defined as

$$CPM = \frac{1}{2}AVG(AFB(i)) + \frac{1}{2}AFB(1) \tag{7}$$

where AFB(i) = Absolute fractional bias weighted for each scientific category i,

AFB(1) = Absolute fractional bias for the operational one-hour averages.

The wind speed (u) $\leq$ 6 mph and neutral/stable category is weighted more than the other two categories because of the importance of this category for regulatory modeling purposes. Thus, the average of AFB(i) is

$$\begin{aligned} AVG(AFB(i)) = 0.5\ AFB(u \leq 6\ mph,\ Neutral/Stable) + \\ 0.25\ AFB(u \leq 6\ mph,\ Unstable) + \\ 0.25\ AFB(u > 6\ mph,\ All\ stabilities) \end{aligned} \tag{8}$$

A combination of the CPM values across all three sites yields the composite model comparison measure (CM). The CM results, shown in Figure 13, indicates that the best performing models are CAL3QHC, TEXIN2, and CALINE4. Similarly, the AFB from scientific category 1 (u $\leq$ 6 mph, neutral/stable) can also be combined over all three sites into a single model comparison measure (CM). This category is typically most important in terms of regulatory applications. As shown in Figure 14, CAL3QHC has the lowest CM by a factor of two.

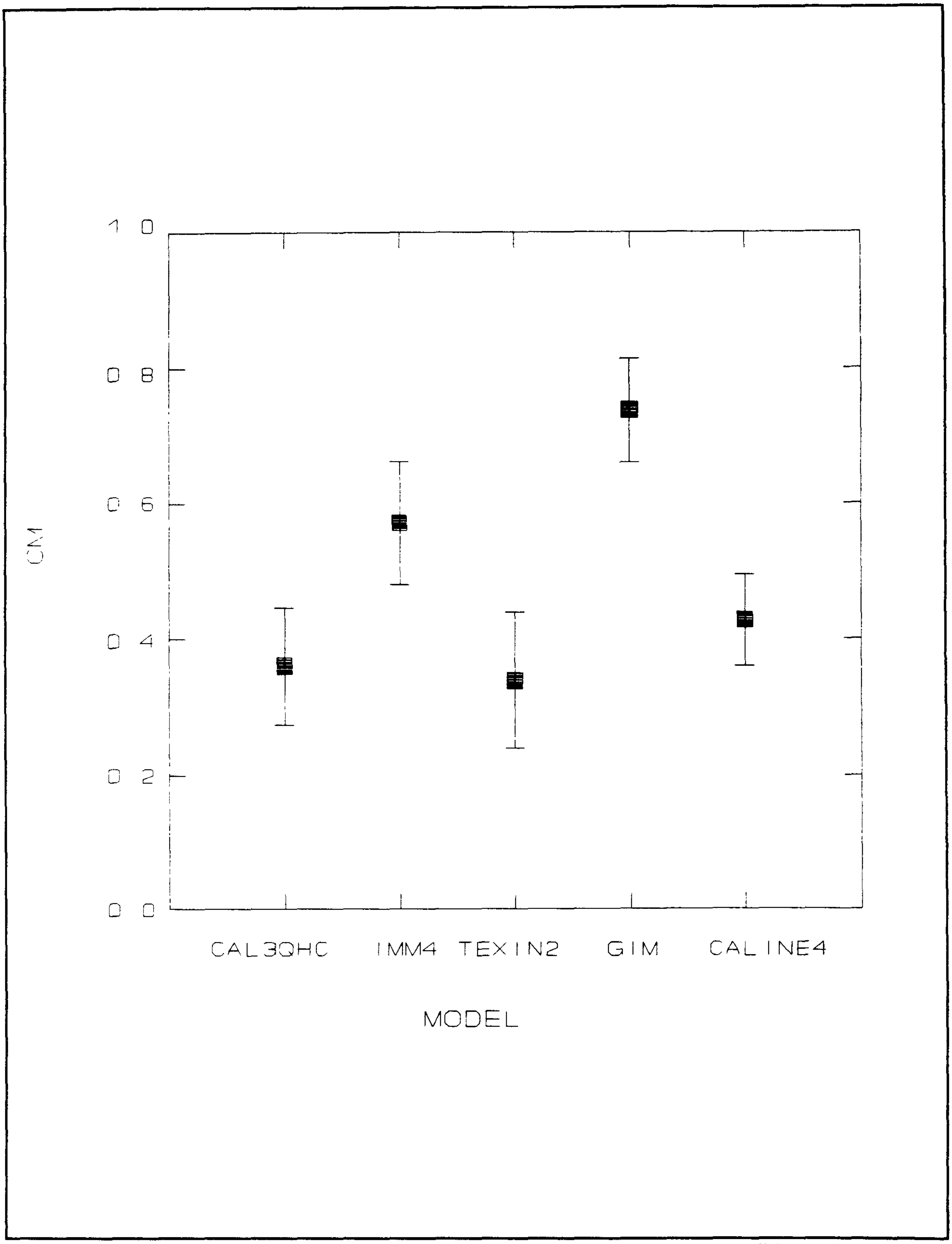


Figure 13. The composite model comparison measure (CM) with 95% confidence limits using CPM statistics.

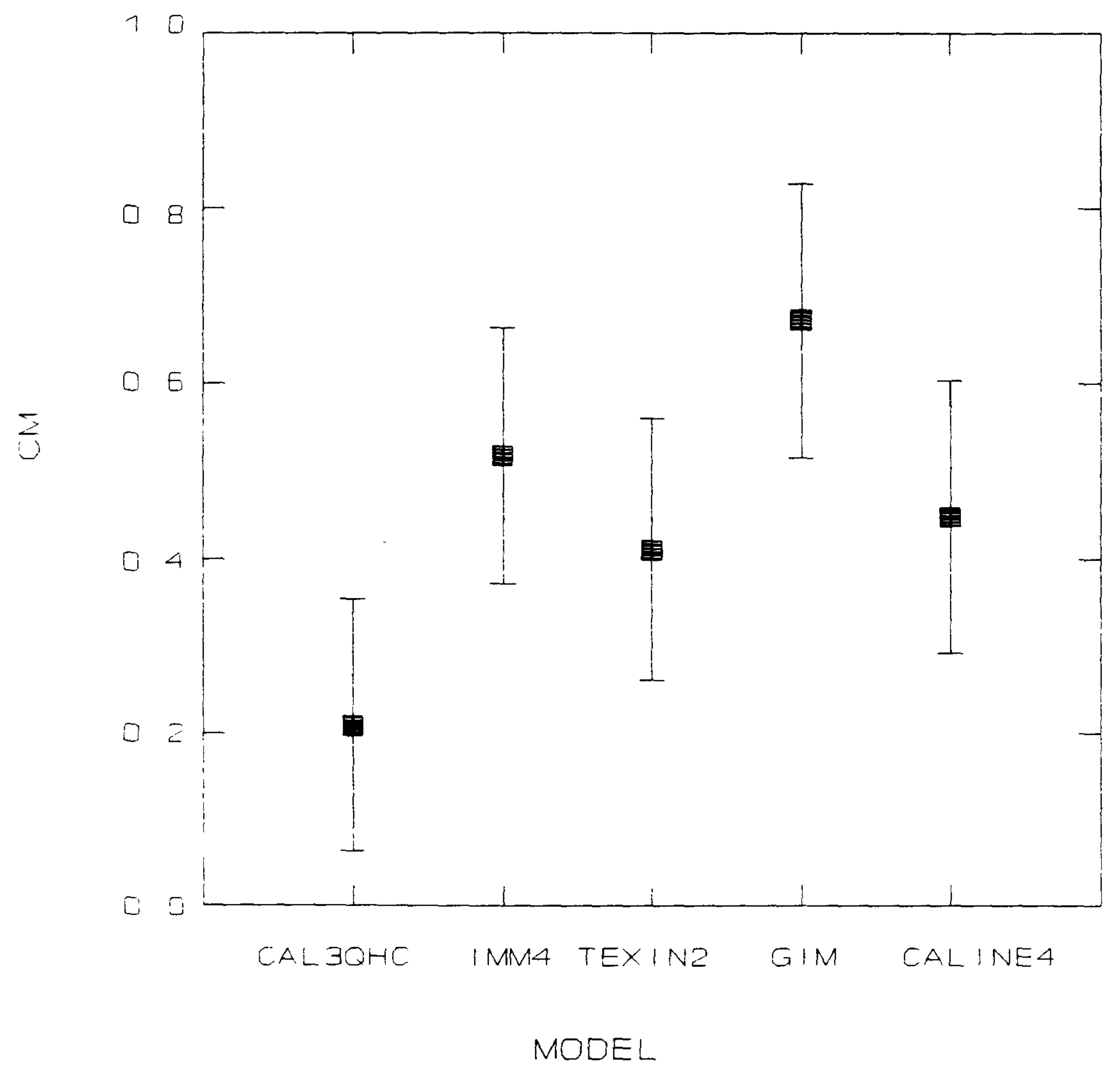


Figure 14. CM with 95% confidence limits using AFB of scientific category 1.

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16. ABSTRACT

CAL3QHC is a microcomputer based model to predict carbon monoxide (CO) or other pollutant concentrations from motor vehicles at roadway intersections. The model includes the CALINE3 dispersion model along with a traffic algorithm to estimate vehicular queue lengths at signalized intersections. CAL3QHC estimates total air pollutant concentrations from both moving and idling vehicles. This document provides a technical description of the model, user instructions, and example applications.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
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