Near-road Dispersion Modeling Of Mobile Source Air Toxics (msats) In Florida

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NEAR-ROAD DISPERSION MODELING OF MOBILE SOURCE AIR TOXICS (MSATs) IN FLORIDA

by

KURT KARL IVAN WESTERLUND, E.I., E.P.I.
B.S.Env.E., University of Central Florida, 2009
M.S.Env.E., University of Central Florida, 2010

A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Environmental Engineering in the Department of Civil, Environmental, & Construction Engineering in the College of Engineering and Computer Science at the University of Central Florida Orlando, Florida

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Major Professor: C. David Cooper
ABSTRACT

There is a growing public concern that emissions of mobile source air toxics (MSATs) from motor vehicles may pose a threat to human health. At present, no state or federal agencies require dispersion modeling of these compounds, but many agencies are concerned about potential future requirements. Current air pollution professionals are familiar with Federal Highway Administration (FHWA) and U.S. Environmental Protection Agency (EPA) requirements for dispersion modeling to produce predicted concentrations for comparison with appropriate standards. This research examined a method in which the potential near-road concentrations of MSATs were calculated. It was believed that by assessing MSATs in much the same way that are used for other pollutants, the model and methods developed in this research could become a standard for those quantifying MSAT concentrations near-roadways.

This dissertation reports on the results from short-term (1-hour) and long-term (annual average) MSATs dispersion modeling that has been conducted on seven intersections and seven freeway segments in the state of Florida. To accomplish the modeling, the CAL3QHC model was modified to handle individual MSAT emissions input data and to predict the concentrations of several MSATs around these roadway facilities. Additionally, since the CAL3MSAT model is DOS based and not user-friendly, time was invested to develop a Windows® graphical user interface (GUI). Real-world data (traffic volumes and site geometry) were gathered, worst-case meteorology was selected, mobile source emission factors (EFs) were obtained from MOVES2010a, and worst-case modeling was conducted. Based on a literature search, maximum acceptable concentrations (MACs) were proposed for comparison with the modeled results, for both a short-term (1-hour) averaging time and a long-term (1-year) averaging time.
Results from this CAL3MSAT modeling study indicate that for all of the intersections and freeway segments, the worst-case 1-hour modeled concentrations of the MSATs were several orders of magnitude below the proposed short-term MACs. The worst-case 1-year modeled concentrations were of the same order of magnitude as the proposed long-term MACs.

The 1-year concentrations were first developed by applying a persistence factor to the worst-case 1-hour concentrations. In the interest of comparing the predicted concentrations from the CAL3MSAT persistence factor approach to other dispersion models, two EPA regulatory models (CAL3QHCR and AERMOD) with the ability to account for yearly meteorology, traffic, and signal timing were used. Both hourly and annual MSAT concentrations were predicted at one large urban intersection and compared for the three different dispersion models. The short-term 1-hour results from CAL3MSAT were higher than those predicted by the two other models due to the worst-case assumptions. Similarly, results indicate that the CAL3MSAT persistence factor approach predicted a worst-case annual average concentration on the same order of magnitude as the two other more refined models. This indicated that the CAL3MSAT model might be useful as a worst-case screening approach.
Every honest researcher I know admits he's just a professional amateur. He's doing whatever he's doing for the first time. That makes him an amateur. He has sense enough to know that he's going to have a lot of trouble, so that makes him a professional.

-Charles Franklin Kettering
ACKNOWLEDGMENTS

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LIST OF ACRONYMS/ABBREVIATIONS

µg/m$^3$ microgram per cubic meter
ADT average daily traffic
AEGL-1 Acute Exposure Guidelines Level 1
AEGL-2 Acute Exposure Guidelines Level 2
AERMOD AMS/EPA Regulatory Model
AMS American Meteorological Society
ATSDR Agency for Toxic Substances and Disease Registry
Caltrans California Department of Transportation
CNG compressed natural gas
CO carbon monoxide
CR cancer risk
DEOG diesel exhaust organic gases
DOT Department of Transportation
DPM diesel particulate matter
EF emission factor
EPA United States Environmental Protection Agency
EPRI Electric Power Research Institute
FDEP Florida Department of Environmental Protection
FDOT Florida Department of Transportation
FHWA Federal Highway Administration
FL Florida
FLLS finite length line source
GUI graphical user interface
HAP hazardous air pollutant
HEI Health Effects Institute
HQ hazard quotient
I/M inspection and maintenance
IRIS Integrated Risk Information System
ISC Industrial Source Complex
ISCST2 Industrial Source Complex Short Term Model
MAC maximum acceptable concentration
MOVES Motor Vehicle Emission Simulator
MOWT molecular weight
MPF meteorological persistence factor
mph miles per hour
MSAT mobile source air toxic
NAAQS National Ambient Air Quality Standards
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>NATA</td>
<td>National Scale Air Toxics Assessment</td>
</tr>
<tr>
<td>NDOT</td>
<td>Nevada Department of Transportation</td>
</tr>
<tr>
<td>NWS</td>
<td>National Weather Service</td>
</tr>
<tr>
<td>OAQPS</td>
<td>Office of Air Quality, Planning, and Standards</td>
</tr>
<tr>
<td>OEHHA</td>
<td>Office of Environmental Health Hazard Assessment</td>
</tr>
<tr>
<td>PBL</td>
<td>planetary boundary layer</td>
</tr>
<tr>
<td>PM</td>
<td>particulate matter</td>
</tr>
<tr>
<td>POM</td>
<td>polycyclic organic matter</td>
</tr>
<tr>
<td>ppb, ppbv</td>
<td>parts per billion, parts per billion by volume</td>
</tr>
<tr>
<td>ppm, ppmv</td>
<td>parts per million, parts per million by volume</td>
</tr>
<tr>
<td>PRIME</td>
<td>Plume Rise Model Enhancements</td>
</tr>
<tr>
<td>Rfc</td>
<td>reference concentration</td>
</tr>
<tr>
<td>RVP</td>
<td>Reid vapor pressure</td>
</tr>
<tr>
<td>SCRAM</td>
<td>EPA's Support Center for Regulatory Atmospheric Modeling</td>
</tr>
<tr>
<td>SIP</td>
<td>state implementation plan</td>
</tr>
<tr>
<td>TPF</td>
<td>total persistence factor</td>
</tr>
<tr>
<td>TRB</td>
<td>Transportation Research Board</td>
</tr>
<tr>
<td>UCF</td>
<td>University of Central Florida</td>
</tr>
<tr>
<td>URE</td>
<td>unit risk estimate</td>
</tr>
<tr>
<td>U.S.</td>
<td>United States</td>
</tr>
<tr>
<td>V/C</td>
<td>volume-to-capacity ratio</td>
</tr>
<tr>
<td>VMT</td>
<td>vehicle miles traveled</td>
</tr>
<tr>
<td>VOC</td>
<td>volatile organic compounds</td>
</tr>
<tr>
<td>VPF</td>
<td>vehicle persistence factor</td>
</tr>
<tr>
<td>vph</td>
<td>vehicles per hour</td>
</tr>
<tr>
<td>vphpl</td>
<td>vehicles per hour per lane</td>
</tr>
<tr>
<td>VSP</td>
<td>vehicle specific power</td>
</tr>
</tbody>
</table>
CHAPTER 1: INTRODUCTION

1.1 Problem Statement

Hazardous air pollutants (HAPs), or air toxics, are chemicals that cause or may cause cancer and other serious health effects. The Clean Air Act Amendments of 1990 designated 188 air toxic pollutants as HAPs and required the United States Environmental Protection Agency (EPA) to undertake regulatory activities to reduce HAP emissions (Carr et al., 2007). Most air toxics originate from human-made sources such as industries (point sources) and vehicles (mobile sources). Those associated closely with mobile sources are known as mobile source air toxics (MSATs). There are many MSATs (see EPA, 2006), but the EPA identified eight “priority” MSATs of concern in its 2001 and 2007 Mobile Source Air Toxics Rules (EPA, 2001; EPA, 2007). They include acetaldehyde, acrolein, benzene, 1,3-butadiene, diesel particulate matter plus diesel exhaust organic gases (DPM+DEOG), formaldehyde, naphthalene, and polycyclic organic matter (POM). A significant amount of air toxics emissions in urban areas have been attributed to motor vehicles (Tam and Neumann, 2004; EPA, 2012a), and data published in 2009 and 2011 from the EPA’s 2002 and 2005 National Scale Air Toxics Assessments (NATA) showed that some background concentrations of HAPs exceed acceptable health risk levels (EPA, 2009; EPA, 2012a). As such, there is more awareness of the presence of these HAPs (and MSATs) in the urban environment (EPA, 2012a). It can be seen in Table 1 that for the selected HAPs, a significant portion of total emissions in the U.S. can usually be attributed to the on-road mobile sources. NATA includes all sources (point, area, and mobile), but this work is focused only on on-road mobile sources.
Table 1: Selected HAP Emission Contributions from Various Sources*

<table>
<thead>
<tr>
<th>Selected HAP</th>
<th>Emission Contribution by Source (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Area Fires</td>
</tr>
<tr>
<td>Acetaldehyde</td>
<td>25</td>
</tr>
<tr>
<td>Acrolein</td>
<td>71</td>
</tr>
<tr>
<td>Benzene</td>
<td>20</td>
</tr>
<tr>
<td>1,3-Butadiene</td>
<td>39</td>
</tr>
<tr>
<td>Formaldehyde</td>
<td>48</td>
</tr>
</tbody>
</table>

*From EPA, 2012a

An indirect source is a facility, building, or installation which attracts mobile sources. Examples include highways, roads, and parking facilities. Traditionally, indirect source modeling has been applied to carbon monoxide (CO) and is of interest mostly in urban areas. Indirect sources attract large number of vehicles to a particular location and thus indirectly contribute to potentially high localized concentrations of certain pollutants (Cooper, 1987). MSAT concentrations are higher near large intersections and freeways than at other locations in a city but no worst-case “hot-spot” modeling analyses were found in the literature that quantify the MSATs coming from one particular roadway facility. Similarly, it was recognized that long-term exposures and chronic (perhaps carcinogenic) health effects are a major concern associated with MSATs. It was also found that there were no studies conducted that showed how the prediction of long-term MSAT concentrations from roadways could potentially be addressed.

There are no vehicle emissions standards nor ambient air quality standards specifically for MSATs [but some MSATs are a subset of volatile organic compounds (VOCs) or particulate matter (PM)], and the U.S. Department of Transportation, Federal Highway Administration (FHWA) presently does not require dispersion modeling of these compounds for a project-level analysis. However, a court settlement agreement among the FHWA, the Nevada Department of
Transportation (NDOT), and the Sierra Club has caused concern among many state DOTs that future highway projects may be subject to MSAT monitoring requirements and/or modeling studies (FHWA, 2011). Until recently, there has not been a good method for quantifying estimates of these emissions, and there still is no approved dispersion model for estimating concentrations of MSATs near roadways and intersections.

1.2 Objectives

Most recent work by different states and the EPA to assess the potential impact of MSATs are risk-based assessments. These assessments have typically been made with set risk parameters established by the EPA; as opposed to using regulated “threshold” concentrations. The first step in this research was to identify from literature maximum acceptable concentrations (MACs) for certain modeled MSATs in units of μg/m³ and ppbv. Since effects of both short-term (1-hour) and long-term (annual) concentrations are important, two sets of MACs were developed.

The next step involved the prediction of maximum MSAT concentrations around large “representative” urban roadway facilities in Florida. The FHWA and the EPA does not currently require dispersion modeling of MSATs like they do for carbon monoxide (CO) or particulate matter (PM). Therefore, a dispersion model capable of handling the input and output of MSATs was investigated. Ultimately, a model was developed for certain MSATs and both worst-case short-term and long-term modeling studies were conducted. The new model was based closely on the widely-accepted EPA model CAL3QHC. With the worst-case (highest) MSAT concentrations predicted, these values were then compared to the proposed MACs and an
assessment on possible impacts to individuals in the state of Florida was made. In addition, conclusions were drawn and recommendations were made on the MSATs modeling process.

1.3 Importance

The contribution from this research is significant in that it will be the first known attempt at determining the concentration of MSATs near roadways though “hot-spot” modeling. The concern over the threat of potential adverse human health effects due to the exposure to MSATs became more apparent once the EPA designated the eight “priority” MSATs of concern in 2001 and 2007. With the approaches proposed by this researcher, air pollution professionals and engineers will have a tool available to them in order to predict the potential concentrations of such pollutants at and around roadways. Also, this type of procedure where one would be able to model a specific roadway traffic scenario is appealing due to the following reasons.

States may want to conduct their own modeling to assess the potential concentrations of MSATs that may exist near major facilities in order to prepare for possible future requirements from federal organizations. Other reasons to model include that it is impossible to measure future impacts, the costs of field measurements can be prohibitive, and it is possible to compare roadway alternatives if different scenarios are being evaluated for road construction or expansion projects.

1.4 Overview of the Modeling Study

The atmospheric dispersion characteristics of MSATs likely are similar to those of pollutants for which dispersion models exist. Turbulent dispersion of low concentrations of gases is different from molecular diffusion, and does not depend on molecular weight. Near-road dispersion is a relatively fast phenomenon, and the dispersion of the somewhat reactive MSATs
should be similar to that of CO at least over short times and distances. As part of a study for the Florida Department of Transportation (FDOT, 2011a), this researcher modified the widely-accepted roadway and intersection model, CAL3QHC, to allow for the dispersion modeling of various MSATs at large intersections and freeways. CAL3QHC and the science behind it have been widely used and accepted for many years for near-road dispersion modeling of CO and PM. The routines for the input of (and subsequent calculations involving) compounds other than CO were modified, as were the output routines and formats; the basic dispersion algorithms were not modified. The modified model (dubbed CAL3MSAT) was given to FDOT, and the modified Fortran code can be seen in APPENDIX A: CAL3MSAT FORTRAN CODE.

The EPA’s mobile-source emissions model, MOVES2010a (MOVES), was used to generate MSAT emission factors (EFs) (which are some of the required inputs into the dispersion model), and CAL3MSAT was used to conduct the dispersion modeling. MSAT modeling was conducted at seven large intersections and seven large freeway segments in Florida. A Florida-specific default worst-case approach (FDEP, 2004) was used (peak-hour traffic volumes, winter-time temperatures, 1.0 m/s wind speed, neutral stability, and wind angle search) to predict the worst-case 1-hour MSAT concentrations near each facility. The seven cities from which geometric and traffic data were gathered included Jacksonville, Miami-Ft. Lauderdale, Orlando, Pensacola, Naples-Sarasota, Tallahassee, and St. Petersburg-Tampa. The year 2010 was used with peak-hour traffic speeds in MOVES to generate emission factors. MSAT EFs are projected to decrease over the next 20 years at a rate faster than traffic volumes are projected to grow (Carr et al., 2007). This implies that all future years should have lower concentrations than those modeled for 2010.
There are no regulatory ambient air quality standards for MSATs. Based on a literature review, maximum acceptable concentrations (MACs) were proposed for both a short-term (1-hour) averaging time and a long-term (annual) averaging time for some of these compounds. Since the overarching goal of this study was the demonstration of project-level MSAT analysis, only five of the identified “priority” MSATs were examined (examination of all the MSATs was not needed for this proposed hot-spot screening approach). They are acrolein, acetaldehyde, benzene, 1,3-butadiene, and formaldehyde. The modeled worst-case (maximum) concentrations obtained from the CAL3MSAT dispersion model were compared to the proposed MACs for both short and long-term averaging times. The long-term (annual) concentrations were modeled through the use of a persistence factor (Cooper et al., 1989; Cooper et al., 1992).

In the interest of comparing the predicted MSAT concentrations from the CAL3MSAT approach, two other dispersion models (CAL3QHCR and AERMOD) with the ability to account for yearly meteorology and varying traffic volumes were used. Benzene concentrations (both 1-hour and annual) were predicted at one large intersection, and a comparison of the different modeling approaches was completed. Conclusions and recommendations for MSAT short and long-term modeling were also made.

1.5 Dissertation Organization

This dissertation is organized into six chapters. Chapter 1 provides introductory material including problem statements and objectives of this modeling study. Chapter 2 provides a review of current literature related to this research. Chapter 3 discusses the worst-case (short-term) MSAT modeling work that was conducted. Chapter 4 discusses the long-term modeling efforts
of this research. Chapter 5 covers the results and discussion from the modeling study. Chapter 6 provides conclusions and recommendations for those conducting MSAT dispersion modeling.
CHAPTER 2: LITERATURE REVIEW

2.1 Mobile Source Air Toxics

Air toxics are pollutants known for, or suspected of, causing cancer or other serious health problems, such as asthma or birth defects. The EPA estimates that approximately one in every 20,000 people have an increased likelihood of contracting cancer as a result of breathing air toxics from outdoor sources if they were exposed to 2005 emission levels over the course of their lifetime (EPA, 2011). However, much progress has been made in reducing air toxics emissions in the U.S. between 1990 and 2005. Total air toxics emissions declined by roughly 42 percent from all sources and the EPA continues to implement the Clean Air Act to achieve further reductions in these HAPs (Strum et al., 2006; EPA, 2011). It has been seen that urban areas tend to have higher concentrations of air toxics than rural areas due to an increased number of mobile and industrial sources. Due to the concern about human health risks from inhalation of these pollutants in more recent years, the EPA has completed and reported the results from a number of studies assessing the risk posed by the emissions of air toxics in 1996, 1999, 2002, and 2005.

On March 11, 2011, the EPA released the fourth version of the National Air Toxics Assessment (NATA), an analytical tool that helps federal, state, and local governments and other users better understand the potential health risks from breathing air toxics (EPA, 2011). The NATA tool itself is a prioritization tool used to identify geographic areas, pollutants, and emission sources that should be further evaluated to gain a better understanding of the health risk posed by air toxics. Emission information from the year 2005 was the most recent data available when the EPA developed the newest version of the NATA. The NATA was developed since
there is not a large, nationwide monitoring network in place for the 188 pollutants identified as air toxics (EPA, 2011). It was concluded that the pollutants that contribute most to the overall cancer risks are formaldehyde and benzene. Acrolein contributed most to the non-cancer risk nationwide. Figure 1 is a map of the United States, and the cancer risk due to the inhalation of air toxics is summarized. It should be noted that the increased cancer risk due to all air toxics emissions in the state of Florida is estimated to vary from 25 to 75 in a million. However, an important implication of the 2005 NATA is the following. NATA provides broad estimates of health risks over geographic areas of the country, not definitive risks to specific individuals. This is because NATA uses the emission estimates to calculate risks rather than a more formal process involving dispersion and exposure modeling. It is not designed to determine concentrations at specific locations nor health risks for individual people (EPA, 2011). Also, NATA is designed to prioritize pollutants and areas for further study, not to compare one area of the country’s risk to another.
Figure 1: Cancer Risk in the United States due to Air Toxics (EPA, 2011)

What the 2005 NATA evaluated is the increased risk due to all emissions including large factories, airports, etc. Certain HAPs can also have a large contribution from mobile sources (see Table 1). Mobile sources include both on-road and non-road sources; however, in larger urban settings on-road vehicles contribute greatly to the total emissions of MSATs. In further detail, the EPA identified eight priority MSATs of concern in its 2001 and 2007 Mobile Source Air Toxics Rules due to their high relation between emissions and risk and because state agencies have indicated that these pollutants are major mobile source pollutants of concern (EPA, 2001; EPA, 2007; Carr, 2007). They include acetaldehyde, acrolein, benzene, 1,3-butadiene, diesel particulate matter plus diesel exhaust organic gases (DPM+DEOG), formaldehyde, naphthalene,
and polycyclic organic matter (POM). It is noted that most work completed now by different states and the EPA to assess the potential impact of MSATs is risk based. This means that these assessments have typically been made with set risk parameters established by the EPA; and are not based on regulated maximum acceptable concentrations (MACs).

### 2.2 Mobile Source Emission Factor Models

To predict the concentration of pollutants along roadways with dispersion modeling, one must know the fleet-averaged emission factor (EF), which is the average (over all vehicles in the fleet) mass of a pollutant emitted per unit activity rate (vehicle distance traveled or idling time). For example, for moving vehicles EFs are reported as grams per vehicle mile, and for idling vehicles EFs are in units of grams per vehicle hour. The way these values for a vehicle fleet have been determined historically has been through the use of an emissions modeling program developed by the EPA. The emissions models have evolved over time, but the fundamental concept has remained the same. The modeler selects user-defined or national default input data in order to produce EFs. These emission factors are a function of many variables including the type, size, and age of the vehicle, condition of the engine, fuel, the nature and condition of any emission control equipment, and the way in which the vehicle is operated (Joumard, 1995). Also, the road grade, ambient temperature, humidity, and local control programs can all have an influence on the EFs. These EFs can then be used in an emission inventory model or in a dispersion model; seen graphically in Figure 2. For this research specifically, an emissions model output was used as input into a dispersion model that predicted near-road MSAT concentrations.
Figure 2: Possible Ways in Which to Use the Results of an Emissions Model
### 2.2.1 MOVES

The latest computer program designed by the EPA to estimate air pollution emissions from mobile sources is MOVES (MOtor Vehicle Emissions Simulator). In 2012, MOVES officially replaced the EPA’s previous emissions model for on-road mobile sources, MOBILE6.2 (EPA, 2010c). MOVES can be used to estimate exhaust and evaporative emissions as well as brake and tire wear emissions from all types of on-road vehicles. It can be used to estimate national, state, and county level inventories of criteria air pollutants, greenhouse gas emissions, and some mobile source air toxics from highway vehicles. Gaseous MSAT exhaust EFs are often calculated using air toxic-to-VOC ratios (EPA, 2012d), thus factors that affect VOC emissions also affect MSAT emissions. Key parameters in MOVES for predicting EFs include the following:

- The source (vehicle) types (cars, trucks, etc.)
- The source type fractions (fractions of each type of vehicle)
- The age distribution of the vehicles (newer vehicles emit less than older ones)
- Inspection/Maintenance (I/M) programs
- The operating mode distribution (speed, idling, acceleration, load)
- The “link” parameters (road type, length, volume, average speed, average grade)
- The fuel supply & formulation (gasoline, diesel, Reid vapor pressure (RVP), oxygen content, sulfur content)
- Meteorological conditions (temperature, humidity)

MOVES was designed with the Java programming language, and the model is integrated with the MySQL relational database management system. The national-default and user-defined input files are stored in a MySQL input database, and after the model runs, the results are stored
in a similar MySQL database. The results from MOVES can then be accessed using the MySQL Query Browser program. In this program, query statements can be created to manipulate the data and the final results can then be exported into another format. The exported values and resultant emission factors can be used in a dispersion model to predict concentrations of pollutants near a roadway.

2.2.1.1 Characterization of Vehicle Operation

There are three ways in which vehicle operation (e.g., the speed, acceleration, and power) can be characterized in MOVES. Depending on the information available for a roadway, a user may enter an average speed, a drive schedule, or an operating mode distribution. The easiest method (and the one closest to MOVES predecessor MOBILE6.2) is the average speed approach, where just the average speed of the vehicle fleet and roadway grade is given. For the drive schedule approach, a user must enter the speed of the vehicle fleet and roadway grade on a second-by-second basis. Finally, in order to use the operating mode distribution approach, a user must report the modes (e.g., acceleration, deceleration, cruise, and idle) of vehicle activity distinguished as vehicle specific power (VSP). VSP represents the power demand placed on a vehicle as a function of its speed and weight (EPA, 2009).

2.3 Mobile Source Dispersion Models

Roadway dispersion models have been used for decades to model near-road pollutant concentrations, especially CO. Typically, emissions are treated as being from either idling or cruising vehicles. The emissions are carried by the mean wind and disperse both horizontally and vertically, resulting in concentrations that follow Gaussian distributions (Chen et al. 2008). Equation (1) depicts the Gaussian approach to a line source where an incremental addition to the
centration of a pollutant at point \(x,y,z\) (\(dC\)) is the result of a small amount of emissions coming from a small section of the roadway (Cooper and Alley, 2011):

\[
dC = \frac{q \cdot dy}{2 \cdot \pi \cdot u \cdot \sigma_y \cdot \sigma_z} \cdot \exp\left(\frac{-1 \cdot y^2}{2 \cdot \sigma_y^2}\right) \cdot \left\{\exp\left[\frac{-1 \cdot (z - H)^2}{2 \cdot \sigma_z^2}\right] + \exp\left[\frac{-1 \cdot (z + H)^2}{2 \cdot \sigma_z^2}\right]\right\}
\]

where \(dC\) is the differential amount of the total concentration contributed by the small section of roadway (\(\mu g/m^3\)), \(q\) is the line source emissions rate (\(\mu g/m\cdot s\)), \(dy\) is the differential line-source length (m), \(\sigma_y\) and \(\sigma_z\) are the horizontal and vertical dispersion coefficients (m), \(u\) is the average wind speed (m/s), \(y\) is the horizontal distance from the \(x\)-axis (m), \(z\) is the vertical distance from ground level (m), and \(H\) is the effective release height above the ground, which is typically zero for mobile source modeling (m).

A number of mobile source dispersion models have been created, however the California Department of Transportation (Caltrans) developed one of the most well-known roadway dispersion models, CALINE3 (Benson, 1979). This model was important since it divided individual roadway links into a series of elements from which incremental pollutant concentrations are computed and then summed to form a total concentration estimate for a particular receptor location near the roadway. In this way, each element is modeled as a finite length line source (FLLS) positioned normal to the wind direction and centered at the element midpoint. The emissions from the vehicles are then assumed to disperse in a Gaussian manner downwind from the element. These concepts are displayed graphically in Figure 3. With advancements to the field brought on by CALINE3, the EPA further refined this dispersion model and created the program known as CAL3QHC (EPA, 1992a).
2.3.1 CAL3QHC

CAL3QHC is a dispersion model written in the Fortran computer programming language, that is used to predict carbon monoxide and particulate matter concentrations from motor vehicles at roadways and intersections. This model is also the recommended freeway and intersection CO and PM screening model, and has been in use since the early 1990’s. Since CAL3QHC includes the CALINE3 dispersion mode, many of the input variables are the same. However, CAL3QHC is more refined than CALINE3 since a traffic algorithm for estimating
vehicular queue lengths at signalized intersections is included in the program code (EPA, 1992a). Therefore, CAL3QHC enhances CALINE3 by incorporating methods to estimate the contribution of a particular pollutant due to the emissions from idling vehicles, using FLLSs as represented through Equation (1). To model vehicle and buoyancy-induced turbulence, a uniform mixing zone is created over the roadway with a width that includes the roadway plus 3 meters (10 feet) on each side of the roadway for the wake created by moving vehicles. This total width represents the initial horizontal dispersion (Kim, 2004). In contrast, the initial vertical dispersion height is determined through an empirical equation as a function of the estimated residence time within the mixing zone (Kim, 2004).

In the program a user must define different “links.” A link is defined as a straight segment of roadway having a constant width, height, traffic volume, and vehicle emission factor (Benson, 1979). Therefore, for a given roadway or intersection, if any one of these constants change on the traveled way, a new link must be defined. Depending on the scenario, the number of links can be quite large. CAL3QHC estimates an air pollutant concentration at user-defined receptor locations given the on-road vehicular fleet-average emission factors, the roadway geometry, signal and traffic conditions, and the site meteorology. Emission factors are estimated from the EPA approved emission factors model; currently MOVES. Emissions are evenly distributed along the length of each link. The roadway geometry, signal, and traffic data are obtained from various sources such as traffic engineers. Meteorological variables are also important inputs and will be discussed in further detail.

With CAL3QHC, the user must make certain assumptions concerning the meteorological variables. Typically, worst-case values as specified by the EPA or suggested by air quality modeling guidance from the state where the roadway facility is located are assumed. The
meteorological variables of atmospheric stability, wind speed, and wind direction are taken as constants for the modeled averaging time which is typically 1-hour. CAL3QHC can search all wind directions to find the highest concentration at each receptor.

CAL3QHC has been used in modeling numerous times and is well documented. Much has been written on comparing actual pollutant monitored values to the model’s predicted values. For example, before release of the model, the EPA performed an evaluation of the model with data gathered from a portion of Route 9A in New York City. The results of this evaluation indicated that CAL3QHC was one of the best performing models (EPA, 1992a). Extensive work was completed during the testing of this model by the EPA, but also case studies indicate that even after many years, the model is still adequate to predict CO concentrations near roadways. In one particular case study (Abdul-Wahab, 2004), CO concentrations at an existing intersection in the country of Oman were measured and then CAL3QHC was used to predict the concentration of CO at receptors around the intersection. The results from this study show that CO concentrations predicted from the model compared favorably with the measured concentrations (Abdul-Wahab, 2004). Studies such as this show that even though the model might seem “dated,” it still performs well in predicting how pollutants disperse around roadways. The model and the science behind it are well-tested and proven to be valid for air pollution modeling.

CAL3QHC has been used many times to predict the concentration of CO and PM around roadways. A similar dispersion model could be used to predict the near-road concentration of MSATs; however, nowhere in a review of the literature did the author find any instances of the use of a model like CAL3QHC. A large reason is that the current Fortran programming language source code does not allow for this. The model also has rounding routines put in place that round some of the calculations to the nearest tenth of a ppm. This is because when the model was
developed, the emission factors from vehicles were much larger then vehicles today and the emission rate of CO is orders of magnitude higher than any of the MSATs.

2.3.2 CAL3QHCR

CAL3QHCR is an enhanced, but separate, version of CAL3QHC and includes the same basic algorithms as in CAL3QHC. CAL3QHC was designed to process one hour of traffic volume, signal timing, and meteorology data. CAL3QHCR has been programmed to process up to a year of hourly meteorological, vehicular emissions, traffic volume, and signal timing data in one run using the basic algorithms from CAL3QHC (EPA, 1995a). By using CAL3QHCR, modelers are given more assurance that they will find the highest reasonable pollutant concentrations without having to assume inputs. Users are given more flexibility with CAL3QHCR with the incorporation of “tiered” approaches.

With the first approach (referred to as Tier I), a full year of hourly meteorology data are entered into CAL3QHCR in place of the one hour of worst-case data that are entered into CAL3QHC (but still only one hour of traffic volume, emissions, and signal timing data are used). In the second approach (referred to as Tier II), the same hourly meteorology data from a Tier I approach are entered into the model. Then, 24-hour traffic volume, emissions, and signal timing are entered for a 7-day week (composed of weekdays and weekends). The weekly data are synchronized to the day of the week of the meteorological data year and the weekly traffic conditions are assumed to be the same for each week throughout the modeled year (EPA, 1995a).

With CAL3QHC, predicted pollutant concentrations are typically reported for a 1-hour averaging time. One benefit of yearly data in CAL3QHCR is the ability to predict more realistic concentrations, especially for longer averaging times.
2.3.3 AERMOD

The American Meteorological Society (AMS)/EPA Regulatory Model (AERMOD) is a steady-state Gaussian plume model used to determine atmospheric concentrations from emissions sources (EPA, 2004a). AERMOD is a recommended EPA model (typically for point sources like power plants) and considered to be a new generation plume model. AERMOD is the successor to the EPA’s older Industrial Source Complex (ISC) dispersion model (EPA, 2005). The AERMOD modeling system is composed of three modules: (1) the dispersion algorithms (AERMOD), (2) AERMET, the meteorological preprocessor, and (3) AERMAP, the terrain preprocessor (Kim, 2004).

AERMOD improves upon ISC in large part through better characterization of the planetary boundary layer (PBL); the lowest part of the atmosphere where behavior is directly influenced by its contact with the planetary surface. AERMOD also includes the abilities to model stack-tip and building downwash through the incorporation of the Electric Power Research Institute’s (EPRI’s) Plume Rise Model Enhancements (PRIME) algorithms (Kim, 2004). Similarly to ISC (many of ISC’s algorithms are incorporated into AERMOD), AERMOD allows the modeling of point, volume, and area sources. Although generally associated with modeling stationary point sources, the AERMOD user’s guide says roadways can be possibly modeled by characterizing vehicle emissions as either area or volume sources (EPA, 2004a).

Since AERMOD is not a roadway specific dispersion model, traffic volumes and signal timing must be processed differently and one must choose how the emission sources should be characterized. As with CAL3QHCR, a full year of meteorology data and emissions can be input into the model. Again, the main benefit of allowing the input of yearly data in AERMOD is the ability to predict concentrations for various averaging times. Certain aspects of the AERMOD
modeling system may replicate atmospheric conditions better than CAL3QHC or CAL3QHCR; however, AERMOD also increases the complexity of the model runs and parameter specifications due to relatively intensive data needs (Chen et al., 2008).

2.4 MSAT Dispersion Modeling

No MSAT “hot-spot” modeling papers for roadway facilities were found in the literature; however, one article was found reporting on MSAT roadway dispersion modeling. This modeling study compared monitored data for pollutants including benzene and 1,3-butadiene from a highway in Raleigh, North Carolina, with predicted concentrations with AERMOD (Venkatram et al., 2009). Those authors concluded that the performance of AERMOD in explaining near-road concentrations supports its use in estimating local-scale (generally less than 100 m) impacts of traffic emissions in the absence of concentration measurements. In addition, as of June 2005, the FHWA entered into an agreement to study the emissions of several pollutants including priority MSATs identified in 2001 and 2007 by EPA from a site in Las Vegas, Nevada (Black et al., 2009). Data collection from this study, along with one in Detroit, Michigan, was completed February 2010 and June 2011, respectively (FHWA, 2011; Kimbrough et al., 2012).

2.5 Air Toxics Maximum Acceptable Concentrations (MACs)

There are National Ambient Air Quality Standards (NAAQS) for CO such as 35 parts per million by volume (ppmv) and 9 ppmv for the CO 1-hour and 8-hour standards, respectively. But, there are no federal, state, or local regulations that govern any type of threshold or “acceptable” concentrations for any air toxic. Therefore, a review of current literature was necessary in order
to identify (or find ways in which to determine) short-term (1-hour) and long-term (annual) MACs for the modeled MSATs.

2.5.1 Short-term (1-hour) MACs

Sources reviewed for potential short-term MACs, include the EPA’s Integrated Risk Information System (IRIS) and the Office of Air Quality, Planning, and Standards (OAQPS), the Agency for Toxic Substances and Disease Registry (ATSDR), the Health Effects Institute (HEI), and other EPA and FHWA publications (OEHHA) (EPA, 2010a; EPA, 2010b; HHS, 2010; HEI, 2007; EPA, 2012b; FHWA, 2010).

The only values identified for an averaging period of 1-hour were the National Research Council’s Acute Exposure Guideline Levels (AEGLs) (EPA, 2012b). Acute Exposure Level 1 and 2 Guidelines (AEGL-1 and AEGL-2) in units of μg/m³ and ppmv are presented in Table 2. The Level-1 values represent the airborne concentration of a substance above which it is predicted that the general population, including susceptible individuals, could experience notable discomfort, irritation, or certain asymptomatic nonsensory effects. However, the effects are not disabling and are transient and reversible upon cessation of exposure (HEI, 2007). The Level-2 values represent the airborne concentration of a substance above which it is predicted that the general population, including susceptible individuals, could experience irreversible or other serious, long-lasting adverse health effects or an impaired ability to escape (HEI, 2007). All values were originally reported in terms of mass concentrations, but calculations were completed by the author [that included using Equation (4), with noted assumptions], to report values also in units of ppmv (please see the next section for the derivation of this formula).
Table 2: Short-term AEGL Concentrations for the Modeled MSATs*

<table>
<thead>
<tr>
<th>Modeled MSAT</th>
<th>1-hour AEGL-1 (μg/m³)</th>
<th>(ppm)</th>
<th>1-hour AEGL-2 (μg/m³)</th>
<th>(ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetaldehyde</td>
<td>8.10x10⁴</td>
<td>45.0</td>
<td>4.80x10³</td>
<td>266</td>
</tr>
<tr>
<td>Acrolein</td>
<td>7.00x10¹</td>
<td>0.03</td>
<td>2.30x10²</td>
<td>0.10</td>
</tr>
<tr>
<td>Benzene</td>
<td>1.66x10⁵</td>
<td>52.0</td>
<td>2.55x10⁶</td>
<td>798</td>
</tr>
<tr>
<td>1,3-Butadiene</td>
<td>1.48x10⁵</td>
<td>669</td>
<td>1.17x10⁷</td>
<td>5,290</td>
</tr>
<tr>
<td>Formaldehyde</td>
<td>1.11x10³</td>
<td>0.90</td>
<td>1.72x10⁴</td>
<td>14.0</td>
</tr>
</tbody>
</table>

*From EPA, 2012b

2.5.2 Long-term (Annual Average) MACs

Sources reviewed for potential long-term MACs, include the EPA’s Integrated Risk Information System and the Office of Air Quality, Planning, and Standards, the Agency for Toxic Substances and Disease Registry, the Health Effects Institute, FHWA publications, and the State of California’s Office of Environmental Health Hazard Assessment (OEHHA) (EPA, 2010a; EPA, 2010b; HHS, 2010; HEI, 2007; FHWA, 2010; OEHHA, 2010).

No annual average maximum acceptable concentrations were found in the literature. Therefore, ways were investigated in which long-term MACs for the modeled MSATs could be derived. With information from various literature sources, cancer inhalation unit risk estimates (UREs) and non-cancer inhalation reference concentrations (RfCs) were determined. These cancer and non-cancer values were used in deriving potential MACs for the MSATs of interest.

2.5.2.1 Cancer Values

A cancer inhalation unit risk estimate was determined for each modeled MSAT. The URE for a chemical species is defined as the upper-bound excess lifetime (70-year) cancer risk estimated to result from continuous exposure to an agent at a concentration of 1 μg/m³ in air (EPA, 2007). The inhalation unit risk is derived using mathematical models that assume a non-
threshold approach where some risk of cancer would occur at any level of exposure. The methods used to derive these inhalation unit risk values result in an “upper bound” estimate, that is, the true risk is unlikely to exceed this value and may be much lower (McCarthy et al., 2006). UREs were found for four of the modeled MSATs (Table 3). Acrolein has no EPA-published URE, and the EPA states that data for acrolein are “inadequate for an assessment of human carcinogenic potential” (EPA, 2003).

**Table 3: URE Values for the Modeled MSATs**

<table>
<thead>
<tr>
<th>Modeled MSAT</th>
<th>Molecular Formula</th>
<th>Molecular Weight (g/mol)</th>
<th>Carcinogenic Class (EPA)</th>
<th>URE (µg/m$^3$)$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetaldehyde</td>
<td>CH$_3$CHO</td>
<td>44.05</td>
<td>B2-Probable</td>
<td>2.20x10$^{-6}$</td>
</tr>
<tr>
<td>Acrolein</td>
<td>C$_3$H$_4$O</td>
<td>56.06</td>
<td>Inl-Inadequate Information</td>
<td>Cannot be quantified</td>
</tr>
<tr>
<td>Benzene</td>
<td>C$_6$H$_6$</td>
<td>78.11</td>
<td>A-Known</td>
<td>7.80x10$^{-6}$</td>
</tr>
<tr>
<td>1,3-Butadiene</td>
<td>C$_4$H$_6$</td>
<td>54.09</td>
<td>A-Known</td>
<td>3.00x10$^{-5}$</td>
</tr>
<tr>
<td>Formaldehyde</td>
<td>CH$_2$O</td>
<td>30.03</td>
<td>B1-Probable</td>
<td>5.50x10$^{-9}$</td>
</tr>
</tbody>
</table>

*From EPA, 2010a; HHS, 2010

To measure risks of developing cancer, many assessments use the metric Cancer Risk (CR) (Carr et al., 2007). This parameter represents the probability that an individual will develop cancer in their lifetime as a result of a lifetime exposure to a pollutant at a certain concentration. EPA generally considers a CR benchmark of less than 10$^{-6}$ (one-in-a-million) to be acceptable, and acts to reduce cancer risks greater than 10$^{-4}$ (100-in-a-million) (Carr et al., 2007; EPA, 2007). It is noted that for some chemicals, risks (for the same exposure) are significantly greater for young people (EPA, 2011).

Following Tam and Neumann (2004), CR for any MSAT could be calculated using its URE, in units of (µg/m$^3$)$^{-1}$. 
\[ CR = C_{\text{mass}} \cdot URE \] (2)

To determine a long-term MAC \((C_{\text{mass}})\) in units of \(\mu g/m^3\) for an MSAT, the CR can be set to the EPA benchmark of \(10^{-6}\) and Equation (3) can be derived (assuming exposure to this concentration for a lifetime).

\[ C_{\text{mass}} = \frac{CR}{URE} \] (3)

A long-term MAC can be converted to a volume-based concentration \((C_{\text{vol}})\) [see Equation (4)] at standard temperature and pressure in units of parts-per-billion (ppbv) by knowing its molecular weight (MOWT) (Cooper and Alley, 2011). Molecular weights for the modeled MSATs can be seen in Table 3.

\[ C_{\text{vol}} = C_{\text{mass}} \cdot \left( \frac{24.45}{MOWT} \right) \] (4)

2.5.2.2 Non-cancer Values

A Reference Concentrations (Rfc) was determined for each modeled MSAT, and could potentially be used to calculate a long-term annual average MAC. The Rfc is an estimate, with uncertainty spanning perhaps an order of magnitude, of a continuous inhalation exposure to the human population (including sensitive subgroups which include children, asthmatics and the elderly) that is likely to be without an appreciable risk of deleterious effects during a lifetime (EPA, 2012c). It can be derived from various types of human or animal data, with uncertainty
factors generally applied to reflect limitations of the data used. The RfCs for the modeled MSATs can be seen in Table 4.

Table 4: RfC Values for the Modeled MSATs*

<table>
<thead>
<tr>
<th>Modeled MSAT</th>
<th>RfC (μg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetaldehyde</td>
<td>9.00</td>
</tr>
<tr>
<td>Acrolein</td>
<td>0.02</td>
</tr>
<tr>
<td>Benzene</td>
<td>30.0</td>
</tr>
<tr>
<td>1,3-Butadiene</td>
<td>2.00</td>
</tr>
<tr>
<td>Formaldehyde</td>
<td>9.80</td>
</tr>
</tbody>
</table>

*From EPA, 2010a; EPA, 2010b

To measure non-cancer risk, it is common to use the metric known as hazard quotient (HQ) (Carr et al., 2007). The HQ is a ratio of the potential exposure to a substance and the level at which no adverse effects are expected (EPA, 2009). If the HQ is calculated to be less than 1.0, then no adverse health effects are expected as a result of exposure. On the other hand, if the HQ is greater than 1.0, then adverse health effects are possible (EPA, 2009). The HQ cannot be translated to a probability that adverse health effects will occur, and is unlikely to be proportional to risk. It is especially important to note that an HQ exceeding 1.0 does not necessarily mean that adverse effects will occur (EPA, 2009). The calculation of the HQ in Equation (5) is dependent on the RfC, in units of μg/m³:

\[ HQ = \frac{C_{mass}}{RfC} \]  

(5)

To determine a long-term MAC in units of μg/m³ for an MSAT, the HQ can be set to the EPA benchmark of 1 and Equation (6) can be derived (assuming exposure to this concentration
for a lifetime). Similarly, a long-term MAC can be converted to a volume-based concentration \( (C_{vol}) \) at standard temperature and pressure in units of parts-per-billion (ppbv) [see Equation (4)].

\[
C_{mass} = HQ \cdot Rfc
\]  

(6)
CHAPTER 3: WORST-CASE (SHORT-TERM) MODELING

3.1 Overview

There has been more focus in the literature on determining the risk that is associated with the inhalation of MSATs, as opposed to the application of a dispersion model to predict concentrations. There have been very few case studies where an actual dispersion modeling program was used to predict various mobile source air toxics concentrations at roadways. A worst-case (screening), project-level dispersion modeling approach was investigated. First, MSAT emission factors were obtained from MOVES; next, these EFs were used as inputs in the newly developed dispersion model CAL3MSAT; and finally the predicted concentrations were compared with proposed short-term MACs. After considering the usability of the DOS based CAL3MSAT, a graphical user interface was developed in concert with Dr. Michael Claggett of the FHWA for the model and used during this study. A general overview of the interface functions and features are provided in this Chapter

3.2 MOVES Emission Factor Modeling

On-road vehicular fleet-average emission factors for the modeled gaseous MSATs were obtained for the seven urban areas in Florida for urban unrestricted access (arterial) and urban restricted access (freeway) road types in the year 2010. For the intersections, EFs were obtained from MOVES2010a (MOVES) for both the specific A.M. and P.M. peak hours due to the difference in traffic volumes and signal timing. For the freeways (since roadway geometry was the same for both directions of travel), only the peak-hour (e.g., whichever hour – A.M. or P.M. – had the maximum number of vehicles) EFs were determined. EFs for multiple MSATs were obtained every time MOVES was “run.” Therefore, MOVES (and subsequently MySQL Query
Browser) were run a total of 21 times. The general emission factors calculation procedure involving MOVES for the worst-case modeling can be seen in Figure 4, and the following sections discuss the specific inputs required for this study.

**Figure 4: MOVES Emission Factors Calculation Procedure**

3.2.1 Operating Mode Characterization

As discussed in Section 2.2.1 MOVES, there are three different ways in which operating vehicles can be characterized with MOVES. For this modeling study, the “average speed” characterization was chosen. By selecting this, MOVES produced fleet-average emission factors in units of grams per vehicle mile (g/veh-mi) based on all vehicles in the fleet cruising at a given speed. Average speed EFs for all 21 “runs” were obtained in 5 mph increments from 5 to 50 mph. However, for intersections idling queue vehicles were also modeled, so EFs in units of grams per vehicle hour (g/veh-hr) were obtained for the 14 intersection “runs” by using an average speed of 0 mph. Average cruise speeds for the modeled vehicles were estimated using the following method.
3.2.1.1 Adjustment of Vehicle Speeds

For dispersion modeling with CAL3MSAT, emission factors that are a function of speed on each roadway link are needed. Since specific vehicle speed data were not available from the FDOT, the posted speed limits for the modeled roadways were first obtained, and then the speeds were adjusted downwards (as explained below) to account for congestion associated with peak-hour traffic conditions. Assumed vehicle saturation flow rates were obtained from the Transportation Research Board’s (TRB) Highway Capacity Manual, and then graphs expressing the decline in vehicle operating speed as a function of volume-to-capacity-ratio (V/C) were first used to determine speed reduction as a function of traffic per lane (TRB, 2000). Next, actual hourly traffic counts from the turning movements obtained from the various FDOT districts were developed for the peak hours. Finally, the number of lanes for a given roadway were used to determine the traffic per lane, and then resultant “congested” cruise speeds were established. An example of how these concepts were used for urban arterial roadways in the modeling study can be seen in Table 5. In this table, vehicle speed reduction as a function of traffic volume is expressed. Not surprisingly, as the traffic volume increases [expressed as vehicles per hour (vph)] (and thus the V/C), the predicted vehicle speed reduction increases.

<table>
<thead>
<tr>
<th>V/C</th>
<th>Traffic Volume (vph)</th>
<th>Speed Reduction (mph)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;.50</td>
<td>&lt; 799</td>
<td>0</td>
</tr>
<tr>
<td>0.50</td>
<td>800-959</td>
<td>2</td>
</tr>
<tr>
<td>0.60</td>
<td>960-1119</td>
<td>5</td>
</tr>
<tr>
<td>0.70</td>
<td>1120-1279</td>
<td>8</td>
</tr>
<tr>
<td>0.80</td>
<td>1280-1349</td>
<td>10</td>
</tr>
<tr>
<td>0.85</td>
<td>1350-1439</td>
<td>12</td>
</tr>
<tr>
<td>0.90</td>
<td>1440-1519</td>
<td>15</td>
</tr>
<tr>
<td>0.95</td>
<td>1520-1599</td>
<td>19</td>
</tr>
<tr>
<td>1.00</td>
<td>&gt;1600</td>
<td>25</td>
</tr>
</tbody>
</table>
3.2.2 Input Parameters

3.2.2.1 Source (Vehicle) Types

MOVES has the ability to predict the emissions from 13 different types of sources (vehicles). A list of these sources with descriptions can be seen in Table 6. For this study, all 13 source types were used. One of the inputs into the model is the source type fractions. These fractional values represent the volume of traffic driven by each source during the hour modeled on the given roadway type. MOVES county-specific source type fractions were used since such data were not available from previous FDOT studies. Example fractions for Duval County, Florida, for the morning peak-hour for both an urban unrestricted access (arterial) and urban restricted access (freeway) roadway can be seen in Table 7. Similar fractions for each road type were reported from the model for the six remaining counties. It was noted (and intuition agrees), that there are a higher fraction of long-haul trucks on the freeway compared to the arterial roadway.
Table 6: MOVES Source Types with Descriptions (adapted from EPA, 2012e)

<table>
<thead>
<tr>
<th>Source Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motorcycle</td>
<td>Vehicles with less than four wheels</td>
</tr>
<tr>
<td>Passenger Car</td>
<td>Four wheel, two axle vehicles whose primary function is passenger transport</td>
</tr>
<tr>
<td>Passenger Truck</td>
<td>Four wheel, two axle trucks whose primary functional design is for cargo, but are used primarily for passenger transport</td>
</tr>
<tr>
<td>Light Commercial Truck</td>
<td>Four wheel, two axle trucks used primarily for cargo transport</td>
</tr>
<tr>
<td>Intercity Bus</td>
<td>Passenger vehicles with a capacity of 15 or more persons primarily used for transport between cities</td>
</tr>
<tr>
<td>Transit Bus</td>
<td>Passenger vehicles with a capacity of 15 or more persons primarily used for transport within cities</td>
</tr>
<tr>
<td>School Bus</td>
<td>Passenger vehicles with a capacity of 15 or more persons used primarily for transport of students for school</td>
</tr>
<tr>
<td>Refuse Truck</td>
<td>Trucks primarily used to haul refuse to a central location</td>
</tr>
<tr>
<td>Single Unit Short-haul Truck</td>
<td>Single unit trucks with more than four tires with a range of operation of up to 200 miles</td>
</tr>
<tr>
<td>Single Unit Long-haul Truck</td>
<td>Single unit trucks with more than four tires with a range of operation of over 200 miles</td>
</tr>
<tr>
<td>Motor Home</td>
<td>Trucks whose primary functional design is to provide sleeping quarters</td>
</tr>
<tr>
<td>Combination Short-haul Truck</td>
<td>Combination tractor/trailer trucks with more than four tires with a range of operation of up to 200 miles</td>
</tr>
<tr>
<td>Combination Long-haul Truck</td>
<td>Combination tractor/trailer trucks with more than four tires with a range of operation of over 200 miles</td>
</tr>
</tbody>
</table>

Table 7: MOVES Default Source Type Fractions – Duval County, FL

<table>
<thead>
<tr>
<th>Source Type</th>
<th>Roadway Type</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Urban Unrestricted Access (Arterial)</td>
</tr>
<tr>
<td>Motorcycle</td>
<td>0.48</td>
</tr>
<tr>
<td>Passenger Car</td>
<td>56.84</td>
</tr>
<tr>
<td>Passenger Truck</td>
<td>28.83</td>
</tr>
<tr>
<td>Light Commercial Truck</td>
<td>9.63</td>
</tr>
<tr>
<td>Intercity Bus</td>
<td>0.06</td>
</tr>
<tr>
<td>Transit Bus</td>
<td>0.02</td>
</tr>
<tr>
<td>School Bus</td>
<td>0.06</td>
</tr>
<tr>
<td>Refuse Truck</td>
<td>0.03</td>
</tr>
<tr>
<td>Single Unit Short-haul Truck</td>
<td>1.81</td>
</tr>
<tr>
<td>Single Unit Long-haul Truck</td>
<td>0.25</td>
</tr>
<tr>
<td>Motor Home</td>
<td>0.10</td>
</tr>
<tr>
<td>Combination Short-haul Truck</td>
<td>0.79</td>
</tr>
<tr>
<td>Combination Long-haul Truck</td>
<td>1.11</td>
</tr>
</tbody>
</table>
3.2.2.2 Vehicle Ages

Another MOVES input that effects the predicted emissions is the age distribution of the vehicles. Again, due to a lack of specific data being available, a national default distribution of source ages provided by the EPA were used. For each source, MOVES has 30 age ID values that represent the fraction of vehicles in a specific age group (i.e., an ID of 1 represents a vehicle that is 1-year old in reference to the selected year for modeling). These national default age distributions for the 13 source types can be seen in Table 8. For convenience, fractional values for every five years were added together and reported as a percent. If the age group percentages are added across the table for a given source, the value is 100%.

<table>
<thead>
<tr>
<th>Source Type</th>
<th>% Distribution of Vehicle Ages (groups are in years)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>new - 5</td>
</tr>
<tr>
<td>Motorcycle</td>
<td>87.55</td>
</tr>
<tr>
<td>Passenger Car</td>
<td>36.74</td>
</tr>
<tr>
<td>Passenger Truck</td>
<td>36.65</td>
</tr>
<tr>
<td>Light Commercial Truck</td>
<td>36.65</td>
</tr>
<tr>
<td>Intercity Bus</td>
<td>36.75</td>
</tr>
<tr>
<td>School Bus</td>
<td>35.67</td>
</tr>
<tr>
<td>Refuse Truck</td>
<td>28.86</td>
</tr>
<tr>
<td>Single Unit Short-haul Truck</td>
<td>34.04</td>
</tr>
<tr>
<td>Single Unit Long-haul Truck</td>
<td>43.88</td>
</tr>
<tr>
<td>Motor Home</td>
<td>35.37</td>
</tr>
<tr>
<td>Combination Short-haul Truck</td>
<td>32.47</td>
</tr>
<tr>
<td>Combination Long-haul Truck</td>
<td>39.59</td>
</tr>
</tbody>
</table>
3.2.2.3 Fuel Types

MOVES has the ability to model a number of different vehicle/fuel combinations [including the source types listed in Table 6 and fuels including gasoline, diesel, compressed natural gas (CNG), and alternatives]. For this study, all sensible source types and gasoline or diesel fuel combinations were modeled (for example a diesel motorcycle was not included). In addition to the fuel supply, specific details regarding fuel formulation are required. Parameters include the Reid vapor pressure (RVP), sulfur level, ethanol volume, and aromatic content. MOVES county-specific values for Florida were used.

3.2.2.4 Meteorology

Average temperature and humidity data for the hour being modeled were required inputs to MOVES. Since the county-specific data included in MOVES are based on 30-year average temperature and humidity data for each county, month, and hour (EPA, 2012c), these default values were used.

3.2.2.5 Additional Parameters

A few additional parameters including average road grade and if there are any inspection and maintenance (I/M) programs are accounted for in MOVES. Currently, there are no IM programs in Florida, and due to the geography of Florida, the grades of all modeled roadways were assumed to be equal to zero.
3.3 Development and Description of CAL3MSAT

3.3.1 Modification of CAL3QHC Fortran Source Code

CAL3QHC was chosen because it is recognized as one of the best roadway dispersion models. The original CAL3QHC Fortran source code was reviewed and examined extensively. Many lines were removed or altered, and new code was added that accounts for the input and output of the modeled MSATs of concern and a few other pollutants including DPM, naphthalene, other gases, and other particulates. The “new” compiled program is referred to as CAL3MSAT. One example of modification that was made by the author can be seen in Figure 5 (before) and Figure 6 (after) where MSAT molecular weights were added to the original CAL3QHC code in order to report predicted concentrations in both units of µg/m³ and ppb. Another important change is that the CAL3QHC model had rounding routines that were put in place to report the concentration of pollutants to the nearest tenth decimal; however, since MSATs are typically emitted at a much lower rate than CO, this routine was removed and all results were reported in scientific notation. The complete CAL3MSAT code can be seen in APPENDIX A: CAL3MSAT FORTRAN CODE. The executable version of CAL3MSAT was created through the use of a Lahey Fortran compiler.

| REAL | BRGV(361), MOWT, NE, LIM, K2, LB, LBRG(120), INC, MIXH, K1, IDLFAC(120), PSCALE | V2EC |
|      |                                                                                   | V2ECF |

Figure 5: Example of Fortran Code from CAL3QHC (before Modification)
3.3.2 CAL3MSAT Input Data

In order to properly create the necessary input files for the newly developed CAL3MSAT, various FDOT districts were contacted in order to obtain traffic and roadway data for intersections and freeways in seven urban areas: Jacksonville, Miami-Ft. Lauderdale, Orlando, Pensacola, Naples-Sarasota, Tallahassee, and St. Petersburg-Tampa. The most current data that were collected for the specific intersection and freeway segments in Table 9 includes traffic counts (as traffic turning movements), signal timing (as signal phase diagrams), posted speed limits (if possible), and roadway geometry (as intersection or freeway schematics).
### Table 9: Intersections and Freeway Segments for Which Data were Gathered

<table>
<thead>
<tr>
<th>FDOT District</th>
<th>Urban Area</th>
<th>City</th>
<th>Intersection</th>
<th>Freeway Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Naples-Sarasota</td>
<td>Sarasota</td>
<td>SR-72 &amp; Beneva Rd.</td>
<td>I-75</td>
</tr>
<tr>
<td>2</td>
<td>Jacksonville</td>
<td>Jacksonville</td>
<td>SR-115 &amp; SR-152</td>
<td>I-95</td>
</tr>
<tr>
<td>3</td>
<td>Pensacola</td>
<td>Pensacola</td>
<td>SR-290 &amp; SR-291</td>
<td>I-10</td>
</tr>
<tr>
<td>3</td>
<td>Tallahassee</td>
<td>Tallahassee</td>
<td>SR-261 &amp; SR-20</td>
<td>I-10</td>
</tr>
<tr>
<td>5</td>
<td>Orlando</td>
<td>Orlando</td>
<td>SR-50 &amp; SR-434</td>
<td>I-4</td>
</tr>
<tr>
<td>6</td>
<td>Miami-Ft. Lauderdale</td>
<td>Miami</td>
<td>SW 8th St. &amp; SW 137th St.</td>
<td>I-95</td>
</tr>
<tr>
<td>7</td>
<td>St. Petersburg-Tampa</td>
<td>Tampa</td>
<td>SR-600 &amp; W Columbus Dr.</td>
<td>I-4</td>
</tr>
</tbody>
</table>

Traffic counts obtained for earlier years were adjusted to the year 2010 (assuming traffic volume growth of 2.5%/year), so that the results from the seven cities in Florida could be compared for the same year. For intersections, both the A.M. and P.M. peak hours were modeled due to the differences in traffic conditions for each scenario. For the freeway segments, only the peak hour where the greatest traffic volume occurred was modeled. For each intersection and peak hour, five MSATs were modeled. Therefore, 70 intersection input files (seven intersections, two peak hours, and five MSATs), and 35 freeway segment input files (seven freeway segments and five MSATs) were created. CAL3MSAT was run using a total of 105 different input files.

#### 3.3.2.1 Model Variables

In a CAL3MSAT input file (like CAL3QHC), a user must define different “links.” A link is defined as a straight segment of roadway having a constant width, height, traffic volume, and fleet EF (Benson 1979). For a given roadway or intersection, if any one of these constants change, a new link must be defined; the number of links can be quite large. All modeled intersections and freeway segments were carefully drawn using AutoCAD®, but to make the screening results more generically applicable, the geometries of the roadways were adjusted.
slightly to ensure that all links were straight and perfectly aligned north-south and east-west (see an example of the Tampa intersection in Figure 7).

Figure 7: Example Intersection Roadway Geometry and Receptor Placement – Tampa, FL
3.3.2.1.1 Worst-Case Meteorology and Receptors

With CAL3MSAT, the user must make assumptions concerning the meteorological variables. The meteorological variables of atmospheric stability, wind speed, and wind direction were taken as constants for the modeled averaging time – 1-hour. The worst-case wind direction was determined by CAL3MSAT through a wind angle search. These variables are the main determinants of the diluting effect of the atmosphere as the pollutant is carried along and dispersed by the wind (Abdul-Wahab 2004). In Florida, a worst-case analysis uses a wind speed of 1.0 m/s, a stability class of D for urban or suburban land uses (E for rural), and all wind angles around the compass are tested (using 10-degree increments) (FDEP, 2004). Surface roughness is assumed to be uniform throughout the roadway area and nearby surroundings (Benson 1979). In Florida, 175 cm, 108 cm, and 10 cm are the default surface roughness values for urban, suburban, and rural areas, respectively. Worst-case receptors were located at EPA-recommended distances of 3 m (10 ft) from the roadway edges (EPA, 1992a). For the modeled intersections, a total of 44 receptors were considered (11 in each quadrant) with spacing of 25 m (82 ft) between many of them, as seen in Figure 7. For the freeway segments, five receptors were located on each side of the roadway (a total of ten receptors) near the midpoint of the link and at perpendicular distances away from the roadway edge at 6.1, 20.2, 18.3, 24.4, and 30.5 meters (from 20 to 100 feet).

3.3.2.1.2 Background Concentrations

The total pollutant concentration near a roadway is the sum of the contributions from vehicles on the facility being modeled and from all other sources (the background). In urban areas, air toxics are emitted from industrial operations (e.g., refineries and chemical plants), from
area sources (e.g., fueling stations, print shops, and fires), and from vehicles on more distant roadways than the one being modeled, but each case is site specific. No measured background concentrations were available, and it would be inappropriate to just assume a background concentration. Therefore no background concentrations were added to the modeling results. This enabled the researcher to assess more clearly the contribution of just the modeled facility. It is understood that the total MSAT concentration near any particular roadway facility likely is higher than that coming from the facility itself. Furthermore, the total concentrations are important when assessing exposure and human health effects, so the results should not be viewed as total concentrations.

3.3.1.1.3 Usability

As far as usability of the CAL3MSAT program, it is DOS based and the input files are tedious to create and populate (usually done in Notepad or WordPad) since the files are similar to the CALINE3 input files developed in the 1980’s. An example of a simple input text file can be seen in Figure 8. For more detailed modeling, the input text is many times this length. For ease of program use, and since other modelers might use the program, developing a Windows® graphical user interface (GUI) to model the concentration of MSATs in Florida and elsewhere was considered desirable.
As stated, the CAL3MSAT model is based on CAL3QHC and thus was developed as a DOS version written in the Fortran programming language. Due to a number of reasons, including that users might be “uncomfortable” using a DOS based program, a GUI that runs in Windows® was developed by the FHWA working in conjunction with this author. In addition, options were made available for modelers to select Florida default values to help reduce time in the modeling process if they are in the state of Florida. The Windows® GUI is user-friendly and allows for easier data input and manipulation than creating a text file to run in the DOS based version. Also, a graphical image of the actual roadway being modeled is displayed to the user, thus allowing the user to make sure that the traffic scenario they created are what was intended.

The Windows® GUI is written in Visual Basic, and was created mostly by Dr. Michael Claggett of the FHWA. The program has been titled CAL3i interface (due to its ability to run the CALINE3, CAL3QHC, and CAL3MSAT models), and the GUI will run the DOS based

### Figure 8: Example of Simple CAL3MSAT Input File

```plaintext
'ORLANDO FREEWAY', 60, 108, 0, 0, 0, 0.3048, 1, 1
'Receptor 1', 98, 0, 6
'Receptor 2', 118, 0, 6
'Receptor 3', 138, 0, 6
'Receptor 4', 158, 0, 6
'Receptor 5', 178, 0, 6
'Receptor 6', -98, 0, 6
'Receptor 7', -118, 0, 6
'Receptor 8', -138, 0, 6
'Receptor 9', -158, 0, 6
'Receptor 10', -178, 0, 6
'I-4 PEAK HOUR', 2, 1, 0, 'A
1
'I-4 EB','AG', 44,-5000, 44, 5000, 6454, .00432, 0, 68
1
'I-4 WB','AG',-44,-5000,-44, 5000, 6969, .00432, 0, 68
1,0,4,1000,0,'Y',5,0,72
```
CAL3MSAT program very easily. This author (Kurt Westerlund) had significant input into the design of a number of the interface features, and completed most of the testing and debugging. Figure 9, shows an example of a screen that users see with the CAL3i interface. From there the user can select the model to use, the screening level (which includes Florida defaults), and the input/output options. In addition, with this interface, the user is able to create a general intersection or roadway in order to simplify the input file creation process.

![Figure 9: Example of CAL3i Interface Screen](image)

Although a significant amount of time was spent using this program to conduct the modeling, the input variables used for the modeling have already been described. The next section provides an overview of the functionality and features of the GUI. A more detailed description of the GUI can be seen in the FDOT’s User’s Guide to CAL3i and CAL3MSAT,
which was authored by this researcher (FDOT, 2011b). Therefore, only an overview of the GUI is provided to give the reader a basic understanding of the GUI’s capabilities.

3.3.3.1 General Interface Functions and Features

By using the GUI one is able to run the CAL3MSAT model much quicker, while graphically being able to see the layout of the roadway being modeled. In addition, variable error checking was built into the interface and the results can be exported directly into Microsoft Excel®, instead of having to read the results from a text file.

A view of the opening screen of CAL3i can be seen in Figure 10. From here, a user is able to navigate between the interface’s control operations (see Figure 11) and CAL3MSAT input forms (see Figure 12).

Figure 10: Opening Screen of CAL3i
The interface extends the functionality of the CAL3MSAT model by offering three screening options:

1. The analyst may choose to enter all data required for a model run, or;

2. The analyst may have the interface enter some applicable EPA-recommended default data values for receptor and meteorology variables, or;

3. The analyst may have the interface enter all applicable FL-recommended default data values (refer to APPENDIX B: CAL3MSAT AND CAL3i DEFAULT VALUES for details).

Also, a utility has been incorporated into CAL3i, the use of which is optional, to generate a simplified receptor/highway layout for screening applications. A simplified layout is created and displayed on the interface by adding northbound/southbound travel lanes and/or eastbound/westbound travel lanes and specifying the total number of lanes in each direction. Default receptor points and receptor numbers are shown, along with free-flow highway links shaded green and queue highway links shaded red. Queue links include an arrowhead pointing in
the direction of the traffic signal as an aid in confirming that the link end point coordinates have been entered properly.

The default configuration of the simplified layout generated is assumed to be representative of freeway travel, either a single freeway segment or a freeway crossover. A traffic signal may be added at the junction of two roadways, whereby the default configuration is changed from a freeway crossover to one representative of a signalized arterial intersection as illustrated in Figure 13. The assumed traffic and signal timing defaults invoked with this screening option can be seen in APPENDIX B: CAL3MSAT AND CAL3i DEFAULT VALUES.

![Figure 13: CAL3i Roadway Screening Utility](image)

Finally, after CAL3MSAT is run, a summary table of results is displayed for the predicted MSAT concentrations (see Figure 14). On the right side of the results table the
receptors where the highest predicted MSAT concentrations occurred are placed in order from highest to lowest, for 20 receptors. A user can also view a bar chart (Figure 15) of the results or the actual printout from the CAL3MSAT model.

Figure 14: CAL3MSAT Results Table in CAL3i
Figure 15: CAL3MSAT Bar Chart Results in CAL3i
CHAPTER 4: LONG-TERM MODELING

4.1 Overview

With MSATs, exposures to concentrations over longer averaging times (perhaps annual or greater) are important. One goal of this research was to compare the predicted 1-hour MSAT concentrations with short-term MACs; however, further modeling was completed to demonstrate how one could address the issue of predicting long-term concentrations to compare with long-term MACs. The first approach to long-term modeling investigated was the simplest: converting the modeled 1-hour maximum concentrations from CAL3MSAT to annual concentrations using a persistence factor. The annual average concentrations were then compared to proposed long-term MACs.

Another goal of this research was the comparison of the CAL3MSAT persistence factor approach to additional approaches involving other dispersion models. Two dispersion models with the ability to account for long-term annual average concentrations were utilized: CAL3QHCR and AERMOD. Concentrations of benzene from the large urban Tampa intersection were predicted using these three models, and the results were compared not only to the proposed long-term benzene MAC, but model-to-model.

4.2 MOVES Emission Factors

The same emission factors obtained from MOVES for short-term modeling were also used in the long-term modeling. After using MOVES2010a, results were obtained and exported with the aid of MySQL Query Browser and the “running” EFs were calculated in terms of grams/vehicle-mile while idling vehicle EFs were calculated as grams/vehicle-hour. For example, benzene exhaust EFs as a function of vehicle speed for an urban unrestricted access
roadway in Hillsborough County, Florida (which contains the city of Tampa and the modeled intersection used for part of the long-term study) can be seen in Figure 16.

The numerical values output from MOVES were used directly in CAL3QHCR. The MOVES MSAT EFs were also used in AERMOD, but had to be adjusted accordingly in order to satisfy proper model input file syntax (see the text in Section 4.4.3 AERMOD). For more details on how EFs were produced from MOVES, please refer back to Section 3.2 MOVES Emission Factor Modeling.

![Figure 16: Urban Unrestricted Access Roadway Exhaust Benzene EFs as a Function of Speed for Hillsborough County, FL](image)

4.3 Persistence Factor

The modeled annual concentration of a pollutant near a roadway will be much lower than the modeled worst-case (peak) 1-hour concentration because: (1) the average rate of emissions from vehicles during the whole year is much lower than during the peak hour, and (2) the
adverse meteorological conditions (low wind speed, wind angle search, January average temperatures, and neutral stability class) assumed in modeling a worst-case 1-hour concentration do not persist over the whole year. A persistence factor is a number less than 1.0 that is used to adjust a short-term worst-case (maximum) concentration to a “longer-term” concentration. It reflects the fact that the worst-case conditions do not “persist” over longer averaging times. The persistence factor method has been used for years in CO modeling to convert 1-hour concentrations to 8-hour concentrations (Thullier, 1978; Cohn and McVoy, 1982; Cooper et al., 1989; and Cooper et al., 1992).

A total persistence factor (TPF) is the product of a meteorological persistence factor (MPF) times a vehicle persistence factor (VPF), with values for the MPF and VPF determined from literature. The VPF accounts for the fact that during non-peak-hours, the average hourly traffic volumes (and emissions) are much lower over longer averaging times than the peak-hour values. The MPF accounts for the fact that the wind speed and direction, and stability class do not remain constant over longer averaging times. The TPF method applies to non-reactive pollutants. The possible atmospheric reactions of some of the air toxics were not taken into account. If such phenomena were considered, the modeled long-term concentrations would be lower for many MSATs. However, some MSATs (e.g., formaldehyde) may be produced from the reactions that destroy others, and thus some concentrations might actually increase (EPA, 2012a).

The persistence factor approach to screening has also been used for point sources (EPA, 1992b). Persistence factors were developed for low emission height point sources for estimating maximum concentrations for averaging times as long as one year with a strong degree of conservatism (to provide reasonable assurance that maximum concentrations for annual values
will not be underestimated). Therefore, a TPF was identified to calculate an annual average concentration from the predicted CAL3MSAT 1-hour concentrations. This concept is seen in Equation (7).

\[
MSAT_{1-year} = MSAT_{1-hour} \cdot MPF \cdot VPF
= MSAT_{1-hour} \cdot TPF
\]  

(Equation 7)

EPA suggested an average persistence factor of 0.10 (0.08 ± 0.02) to estimate the annual concentration starting from a 1-hour worst-case concentration (EPA, 1992b). This estimated annual concentration is expected to be the highest 1-year concentration seen over a period of years. Thus, this estimated value would be a worst-case annual average concentration. In the EPA document, hourly source emission rates were held constant at the maximum rate (EPA, 1992b). This means that the persistence factor of 0.10 was due solely to variability in meteorology, and thus was really only a MPF. With traffic, the emissions clearly do not remain constant at peak hour values over all 24 hours of the day. Typically, about 8-9% of the average daily traffic (ADT) occurs during the peak hour. The other 91-92% occurs in the other 23 hours, yielding an average hourly traffic flow of about 4% of the ADT. Therefore, a 1-hour to 24-hour VPF of 0.50 (4% of ADT/8% of ADT) can be derived (Cooper, 1987). An annual VPF would be even lower for other reasons, including that traffic flow patterns on weekends are usually lower than during weekdays. Therefore, an MPF of 0.10 and a VPF of 0.50 could be selected, and a TPF of 0.05 could potentially be used to estimate a worst-case annual concentration from a modeled worst-case 1-hour concentration. Even though using a TPF may be problematic for long averaging times (such as one year) this method has the advantage of taking less time and resources to obtain worst-case long-term concentrations.
4.4 Dispersion Model Comparison

4.4.1 Investigated Approaches

In the interest of showing how long-term MSAT concentrations can be predicted and how they vary depending on the model selected, benzene concentrations were modeled at the intersection of North Dale Mabry Highway and West Columbus Drive in Tampa, Florida. Three different models with various approaches were used to predict annual average benzene concentrations including: (1) a CAL3MSAT worst-case 1-hour, adjusted by a TPF approach, (2) a CAL3QHCR Tier II approach, (3) an AERMOD volume source characterization approach, and (4) an AERMOD area source characterization approach. Additionally, with CAL3QHCR and AERMOD, the maximum 1-hour concentrations were obtained, and were compared with the worst-case concentration from CAL3MSAT. As many variables as possible were kept constant among the three models. Potential MSAT reactivity was not accounted for in any of the modeling approaches. After obtaining results from the different long-term modeling approaches, conclusions were drawn.

4.4.2 CAL3QHCR

CAL3QHCR was the first long-term dispersion model investigated due to its similarity to CAL3QHC. Therefore, emission sources are modeled as line sources [see Equation (1)]. CAL3QHCR is a roadway specific EPA model and a Tier II approach was utilized where an annual average concentration was calculated by inputting a whole year’s worth of hourly traffic and meteorological data (EPA, 1995a). The general inputs are identical to CAL3QHC (and hence CAL3MSAT), except a modeler must make sure to correctly account for increased traffic volume, signal timing, EF, and meteorology input data requirements. A general input file for
CAL3QHCR can be seen in APPENDIX C: LONG-TERM MODELING MATERIAL. Many of the variables, including roadway and link geometry, and receptor locations remained the same as from the CAL3MSAT short-term worst-case modeling.

4.4.2.1 Traffic and Signal Timing

Traffic counts for the modeled intersection were obtained from the FDOT in the form of a turning movement. The number of vehicles per hour (vph) as a function of the time of the day can be seen in Figure 17 and Figure 18 for North Dale Mabry Highway and West Columbus Drive, respectively. In the resultant diurnal traffic patterns it is noticed that the south and westbound directions have larger volumes in the A.M. peak-hours, whereas the north and eastbound directions have higher volumes due to individuals leaving the metropolitan area during the P.M. peak-hours.

![Figure 17: Weekday Traffic Pattern for North Dale Mabry Highway](image_url)
The turning movement data were for a weekday only, so volume factors (which can be used to approximate weekend traffic volumes) applicable for the intersection were also obtained from the FDOT. With an average volume factor for weekends, a second 24-hour traffic pattern was developed. The Tier II approach was able to account for not only variable traffic volume, but also variable signal timing. This variable signal timing as a function of the hour of the day is reflected in Table 10, and was taken into consideration when modeling the intersection with CAL3QHCR.
Table 10: Signal Timing vs. the Hour of the Day for the Intersection of N Dale Mabry Hwy and W Columbus Dr

<table>
<thead>
<tr>
<th>Hour of the Day (hr)</th>
<th>Total Cycle Time (sec)</th>
<th>Red Time (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>NBL</td>
</tr>
<tr>
<td>0</td>
<td>120</td>
<td>96</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>200</td>
<td>173</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>160</td>
<td>126</td>
</tr>
<tr>
<td>8</td>
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</tr>
<tr>
<td>9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>180</td>
<td>148</td>
</tr>
<tr>
<td>11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td></td>
<td></td>
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<tr>
<td>13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>200</td>
<td>174</td>
</tr>
<tr>
<td>16</td>
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<td></td>
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<td>17</td>
<td></td>
<td></td>
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<tr>
<td>18</td>
<td></td>
<td></td>
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<tr>
<td>19</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>180</td>
<td>145</td>
</tr>
<tr>
<td>21</td>
<td></td>
<td></td>
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<tr>
<td>22</td>
<td></td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>120</td>
<td>96</td>
</tr>
</tbody>
</table>

Note: NBL=northbound left turn, SBT=southbound through, EBL=eastbound left turn, WBT=westbound through, etc.
4.4.2.2 Meteorology

Yearly National Weather Service (NWS) meteorology data for CAL3QHCR had to be preprocessed with the EPA program PCRAMMET (EPA, 1999). Five years of continuous data from 1987-1991 were acquired for the Tampa International Airport. These data included mixing height and surface meteorological files, and they were obtained from the EPA’s Support Center for Regulatory Atmospheric Modeling (SCRAM). Once processed, output data from PCRAMMET used as inputs for CAL3QHCR included hourly calculations for atmospheric stability and mixing heights.

In CAL3MSAT, worst-case meteorology is assumed in order to predict worst-case (maximum) pollutant concentrations. CAL3QHCR incorporates more refined meteorology algorithms from the EPA’s Industrial Source Complex Short Term Model (IS CST2). CAL3QHCR is also capable of modeling both rural and urban locations. For a modeled urban location (like the Tampa intersection), CAL3QHCR reads urban mixing height values from the meteorology input file and assumes that stability classes E and F values cannot exist close to the ground (EPA, 1995a).

4.4.3 AERMOD

Similar data from CAL3QHCR can be used in the refined EPA model known as AERMOD, but not directly since AERMOD was originally developed more to predict the concentrations from the emissions of point sources; however, recently its use as a roadway model has been encouraged for hot-spot pollutants (EPA, 2010d). The same traffic and signal timing data from CAL3QHCR were also used in AERMOD to predict concentrations from the...
urban Tampa intersection. A general input file for AERMOD can be seen in APPENDIX C: LONG-TERM MODELING MATERIAL.

4.4.3.1 Meteorology

As with CAL3QHCR, five years (1987-1991) of actual upper and surface air data for the intersection were obtained for the nearby Tampa International Airport. These data were then preprocessed with the EPA program AERMET before being used in AERMOD (EPA, 2004b). The AERMET output data written for AERMOD included a file of hourly boundary layer parameter estimates and a file of multiple-level observations of wind speed and direction, temperature, and standard deviation of the fluctuating components of the wind (EPA, 2004b).

AERMOD is considered a “state-of-the-art” dispersion model since it incorporates the most recent knowledge on the characterization of the planetary boundary layer (PBL). According to the EPA, better modeling of the PBL allows for a fundamental improvement in the representation of atmospheric turbulence (EPA, 2004a), and hence predicted pollutant concentrations should be more accurate.

4.4.3.2 Emission Source Characterization

With CAL3MSAT and CAL3QHCR, the emissions are treated as continuous line sources [see Equation (1)]. With AERMOD, the EPA has suggested that line sources can be modeled as a string of volume sources or as elongated area sources (EPA, 2004a). Therefore, both source characterization approaches were investigated in the long-term modeling analysis.

AERMOD uses a virtual point algorithm to model the effects of volume sources, which means that an imaginary point is located at a certain distance upwind of the volume source to account for the initial size of the volume source plume (EPA, 1995b). Therefore, the traditional
steady-state Gaussian plume equation for an elevated source is used to calculate concentrations produced by volume source emissions. Area source concentrations are also calculated using the traditional steady-state Gaussian plume equation; however, numerical integration is performed over the area in the upwind and crosswind directions (EPA, 1995b). By using these two different characterization approaches, AERMOD input parameters varied and are discussed in the following sections.

4.4.3.2.1 Source Parameters

For an area source characterization, vehicles traveling on the roadway were represented as elongated rectangles. The width of the rectangle was determined from the width of the roadway. Different rectangles were drawn for vehicles in different operating modes and for vehicles going in different directions. For example, the vehicles cruising through an intersection were represented as a different rectangle from the idling vehicles, while the vehicles turning left or right (as opposed to through) were represented as another. Parameters needed by AERMOD to model an area source includes the emission rate (discussed in the next section), the pollutant release height (typically 0 meters), the length of the east-west direction of the rectangle, the length of the north-south direction of the rectangle, the orientation angle of the rectangle (in degrees from North), and the initial vertical dimension of the source.

Instead of rectangles, vehicle emissions could also be represented as circular volume sources. Similar to the area sources, vehicles in the same operating mode and in the same direction of travel were able to be represented as lines of circles. Parameters needed by AERMOD to model a volume source includes the emission rate (discussed in the next section), the release height (typically 0 m), and the initial lateral and vertical dimensions.
Instead of defining start and end points for a line of vehicles (as is done in CAL3MSAT and CAL3QHCR), each source must have a defined location and set of parameters. AERMOD was also developed in Fortran so text input files were developed to model the Tampa intersection. The data entry process was much more labor intensive, reflected in the fact that 777 volume sources had to be defined to model the intersection (as opposed to 37 FLLSs in CAL3MSAT).

4.4.3.3 Emission Rate Calculations

Unlike CAL3MSAT and CAL3QHCR, emissions factors generated from MOVES cannot be used directly in AERMOD. Since AERMOD was not developed as a roadway specific model, adjustments must be made to the MOVES EFs depending on the way in which the vehicle emissions are characterized. This is important since traffic volume and signal timing must be incorporated directly into the source emission rates and are not specified as separate variables. EFs obtained from MOVES were converted into units of grams/sec/m\(^2\) for area sources and into grams/sec for volume sources. Since EFs from MOVES are reported in grams/vehicle/mi (or hr), appropriate conversions were made using the number of vehicles and unit conversion factors. Signal timing for each source were taken into account with the AERMOD emission rates by considering the ratio of total cycle time to the portion of the time the modeled vehicles were in a given operating mode. In AERMOD, concentrations are predicted every hour, so the total cycle time in an hour was calculated. The time the vehicles spent cruising or idling was determined based on the green and red times.

Due to the data requirements, much of the input text files were prepared with the aid of Microsoft Excel®. Another parameter that had to be specified for each source was how their
emission rate varied throughout the modeled year. The “SHRDOW” keyword was used in order to vary emission rates by season, hour-of-day, and day-of-week (Monday-Friday, Saturday, and Sunday). This meant that for each source, 288 emission rates had to be specified.
CHAPTER 5: RESULTS AND DISCUSSION

5.1 MOVES Emission Factors

To obtain overall average vehicle fleet emission factors (necessary inputs for the dispersion models) the EPA’s state-of-the-art mobile source emissions model, MOVES 2010a, was used. In order to run MOVES, parameters for a specific project-level scenario were used to create a Run Specification that included input default and user-defined database files. In the modeling process, vehicle types, time periods, geographical areas, pollutants, vehicle operating characteristics, and road types to be modeled were specified. The model performed a series of calculations, which have been carefully developed to accurately reflect vehicle operating processes (EPA, 2012e). It is important to reiterate that the “average speed” approach was used to define vehicle specific power in MOVES, and when necessary, national-default data were used.

On-road vehicular fleet-average emission factors for the modeled gaseous MSATs were obtained for the seven urban areas in Florida for urban unrestricted access (arterial) and urban restricted access (freeway) road types for the year 2010. For the intersections, EFs were obtained from MOVES for both the specific A.M. and P.M. peak hours due to the difference in traffic volumes and signal timing. For the freeways (since roadway geometry was the same for both directions of travel), only the peak-hour (e.g., whichever hour – A.M. or P.M. – had the maximum number of vehicles) EFs were determined. Individual input files were created for each MSAT and for each peak hour modeled. Table 11 and Table 12 present MSAT emission factors generated by MOVES as a function of average speed, for the A.M. peak-hour in Duval County, Florida, for both urban unrestricted access and restricted access road types, respectively.
Table 11: MOVES MSAT Emission Factors as a Function of Average Speed for an Urban Unrestricted Access (Arterial) Road Type – Duval County, FL

<table>
<thead>
<tr>
<th>Speed (mph)</th>
<th>Emission Factor (idle, g/veh-hr; cruise, g/veh-mi)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Acetaldehyde</td>
</tr>
<tr>
<td>Idle</td>
<td>0.0530</td>
</tr>
<tr>
<td>10</td>
<td>0.0085</td>
</tr>
<tr>
<td>20</td>
<td>0.0053</td>
</tr>
<tr>
<td>30</td>
<td>0.0039</td>
</tr>
<tr>
<td>40</td>
<td>0.0032</td>
</tr>
</tbody>
</table>

Table 12: MOVES MSAT Emission Factors as a Function of Average Speed for an Urban Restricted Access (Freeway) Road Type – Duval County, FL

<table>
<thead>
<tr>
<th>Speed (mph)</th>
<th>Emission Factor (cruise, g/veh-mi)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Acetaldehyde</td>
</tr>
<tr>
<td>20</td>
<td>0.0057</td>
</tr>
<tr>
<td>30</td>
<td>0.0043</td>
</tr>
<tr>
<td>40</td>
<td>0.0036</td>
</tr>
<tr>
<td>50</td>
<td>0.0032</td>
</tr>
</tbody>
</table>

Similar results were obtained for the other urban areas, peak hours, and road types, but values are not reported because of the similarity in predicted EFs. The average difference between the minimum and maximum predicted acrolein, acetaldehyde, benzene, 1,3-butadiene, and formaldehyde EFs (considering all urban areas, both road types, and peak-hours) is 0.46, 2.27, 2.42, 5.32, and 1.9 %, respectively. These small differences in predicted EFs are due to using MOVES national and county-specific default data (specifically the vehicle ages and source type distributions), which did not vary greatly amongst the different Florida urban areas.
5.2 MSAT Maximum Acceptable Concentrations (MACs)

5.2.1 1-Hour Averaging Time

The National Research Council, National Advisory Committee Acute Exposure Guidelines Level 1 (AEGL-1) values ultimately were selected as the proposed short-term 1-hour MACs (EPA, 2012b). These values were chosen partly because they are supported by the EPA’s OAQPS for use in screening-level risk assessments for HAPs (EPA, 2012c). The proposed 1-hour values, reported in units of ppmv, (see Table 13) represent concentrations where the general population (including susceptible individuals) could experience notable discomfort or irritation as opposed to more permanent effects (EPA, 2012b). These “discomfort” concentrations are always lower than those that cause more serious short-term effects, and were chosen for conservatism.

Table 13: Proposed 1-hour MACs for the Modeled MSATs

<table>
<thead>
<tr>
<th>Modeled MSAT</th>
<th>Proposed 1-hour MAC (ppmv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetaldehyde</td>
<td>45</td>
</tr>
<tr>
<td>Acrolein</td>
<td>0.03</td>
</tr>
<tr>
<td>Benzene</td>
<td>52</td>
</tr>
<tr>
<td>1,3-Butadiene</td>
<td>669</td>
</tr>
<tr>
<td>Formaldehyde</td>
<td>0.90</td>
</tr>
</tbody>
</table>

5.2.2 Annual Averaging Time

Table 14 lists the proposed long-term annual average MACs for the modeled MSATs in units of μg/m³ and ppbv. These values were derived by using Equations (3) and (4) and setting the value of CR equal to $10^{-6}$ (one-in-a-million). The long-term MACs were developed by
considering both the cancer and non-cancer parameters discussed in the literature, but for conservatism, the cancer values were selected since the derived long-term MACs are lower concentrations. Acrolein has no published URE and the EPA does not support any URE values for this pollutant. This has been expressed by the EPA as the following: “Data are inadequate for an assessment of human carcinogenic potential by either the inhalation or oral routes of exposure” (EPA, 2003). Therefore, no annual average MAC for acrolein was proposed. It is noted that if the CR was set at $10^{-4}$, values for those proposed annual average MACs would be 100 times greater than the ones presented.

### Table 14: Proposed Annual Average MACs for the Modeled MSATs

<table>
<thead>
<tr>
<th>Modeled MSAT</th>
<th>Proposed Annual Average MAC</th>
<th>(µg/m$^3$)</th>
<th>(ppbv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetaldehyde</td>
<td>0.4545</td>
<td>0.252</td>
<td></td>
</tr>
<tr>
<td>Acrolein</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Benzene</td>
<td>0.1282</td>
<td>0.0401</td>
<td></td>
</tr>
<tr>
<td>1,3-Butadiene</td>
<td>0.0333</td>
<td>0.0151</td>
<td></td>
</tr>
<tr>
<td>Formaldehyde</td>
<td>0.0769</td>
<td>0.0626</td>
<td></td>
</tr>
</tbody>
</table>

### 5.3 Short-term (Worst-case) Modeling

#### 5.3.1 Intersections

The modeled worst-case, peak-hour concentrations for the MSATs at each intersection are presented both in Table 15 and in Figure 19 (respective MACs are shown in the caption). These results indicate that the modeled worst-case, peak-hour concentrations are multiple orders of magnitude lower than the proposed 1-hour MACs. Therefore, (from an individual facilities contribution) there is essentially little to no reason for concern about short-term (1-hour) exposures to MSATs at urban intersections around Florida.
Table 15: Worst-case A.M. and P.M. Intersection Peak-hour Maximum Concentrations Compared to Proposed MACs

<table>
<thead>
<tr>
<th>Modeled MSAT</th>
<th>Predicted Worst-Case Peak-Hour Concentration (ppbv)</th>
<th>Proposed 1-hr MAC (ppbv)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Jacksonville</td>
<td>Miami</td>
</tr>
<tr>
<td>Acetaldehyde</td>
<td>A.M.</td>
<td>P.M.</td>
</tr>
<tr>
<td>Acrolein</td>
<td>0.080</td>
<td>0.104</td>
</tr>
<tr>
<td>Benzene</td>
<td>1.51</td>
<td>1.98</td>
</tr>
<tr>
<td>1,3-Butadiene</td>
<td>0.423</td>
<td>0.556</td>
</tr>
<tr>
<td>Formaldehyde</td>
<td>2.95</td>
<td>3.86</td>
</tr>
</tbody>
</table>
Figure 19: Worst-case A.M. and P.M. Peak-hour MSAT Concentrations for Various Urban Florida Intersections

(Proposed MACs in ppbv: Acetaldehyde = 45,000; Acrolein = 30; Benzene = 52,000; 1,3-Butadiene = 670,000; Formaldehyde = 900)
5.3.2 Freeways

A segment of a large freeway from each urban area was chosen for modeling. Each freeway segment was at least 10,000 feet long and four lanes wide. The modeled worst-case, peak-hour MSAT concentrations near each urban freeway segment are presented in Table 16 and in Figure 20 (respective MACs are shown in the caption). As with the intersections, the modeled worst-case, peak-hour concentrations are much lower than the proposed MACs. This again led to the conclusion that there is probably little concern associated with short-term (1-hour) exposure to MSATs at urban freeways around Florida.
Table 16: Worst-case Freeway Peak-hour Maximum Concentrations Compared to Proposed MACs

<table>
<thead>
<tr>
<th>Modeled MSAT</th>
<th>Jacksonville</th>
<th>Miami</th>
<th>Orlando</th>
<th>Pensacola</th>
<th>Sarasota</th>
<th>Tallahassee</th>
<th>Tampa</th>
<th>Proposed 1-hr MAC (ppbv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetaldehyde</td>
<td>1.08</td>
<td>1.62</td>
<td>1.04</td>
<td>0.262</td>
<td>0.584</td>
<td>0.364</td>
<td>0.661</td>
<td>45,000</td>
</tr>
<tr>
<td>Acrolein</td>
<td>0.0736</td>
<td>0.108</td>
<td>0.0700</td>
<td>0.0174</td>
<td>0.0391</td>
<td>0.0245</td>
<td>0.0435</td>
<td>30</td>
</tr>
<tr>
<td>Benzene</td>
<td>1.12</td>
<td>1.62</td>
<td>0.902</td>
<td>0.268</td>
<td>0.600</td>
<td>0.372</td>
<td>0.652</td>
<td>52,000</td>
</tr>
<tr>
<td>1,3-Butadiene</td>
<td>0.333</td>
<td>0.515</td>
<td>0.322</td>
<td>0.0803</td>
<td>0.179</td>
<td>0.112</td>
<td>0.208</td>
<td>669,000</td>
</tr>
<tr>
<td>Formaldehyde</td>
<td>2.76</td>
<td>4.12</td>
<td>2.65</td>
<td>0.672</td>
<td>1.49</td>
<td>0.938</td>
<td>1.68</td>
<td>900</td>
</tr>
</tbody>
</table>
Figure 20: Worst-case Peak-hour MSAT Concentrations for Various Urban Florida Freeway Segments (proposed MACs in ppbv: Acetaldehyde = 45,000; Acrolein = 30; Benzene = 52,000; 1,3-Butadiene = 670,000; Formaldehyde = 900)
5.4 Long-term Modeling

5.4.1 Persistence Factor Approach

5.4.1.1 Intersections

The modeled worst-case, annual average concentrations (predicted through the use of the CAL3MSAT, TPF approach) for the MSATs at each intersection are presented in Table 17 and Figure 21. The respective MACs appear as horizontal lines in Figure 21.

These results indicate that for benzene, 1,3-butadiene, and formaldehyde, the modeled worst-case, annual concentrations exceeded the proposed 1-year MACs (developed by using a CR of $10^{-6}$). Such exceedances indicate that there might be valid concerns associated with long-term exposures to MSATs around Florida urban intersections. If however, a CR of $10^{-4}$ was used, then the proposed 1-year MACs would be 100 times larger, which would result in no exceedances, and hence potentially no concern about localized MSATs.
Table 17: Worst-case Annual Average A.M. and P.M. Intersection Concentrations Compared to Proposed MACs

<table>
<thead>
<tr>
<th>Modeled MSAT</th>
<th>Predicted Annual Average Concentration (ppbv)</th>
<th>Proposed Annual Average MAC (ppbv)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Jacksonville</td>
<td>Miami</td>
</tr>
<tr>
<td>Acetaldehyde</td>
<td>A.M.</td>
<td>P.M.</td>
</tr>
<tr>
<td></td>
<td>0.064</td>
<td>0.084</td>
</tr>
<tr>
<td>Acrolein</td>
<td>A.M.</td>
<td>P.M.</td>
</tr>
<tr>
<td></td>
<td>0.004</td>
<td>0.005</td>
</tr>
<tr>
<td>Benzene</td>
<td>A.M.</td>
<td>P.M.</td>
</tr>
<tr>
<td></td>
<td>0.076</td>
<td>0.099</td>
</tr>
<tr>
<td>1,3-Butadiene</td>
<td>A.M.</td>
<td>P.M.</td>
</tr>
<tr>
<td></td>
<td>0.021</td>
<td>0.028</td>
</tr>
<tr>
<td>Formaldehyde</td>
<td>A.M.</td>
<td>P.M.</td>
</tr>
<tr>
<td></td>
<td>0.148</td>
<td>0.193</td>
</tr>
</tbody>
</table>
Figure 21: Worst-case Annual Average A.M. and P.M. MSAT Concentrations for Various Urban Florida Intersections (proposed MACs in ppbv for the modeled MSATs appear as horizontal lines)
5.4.1.2 Freeways

The modeled worst-case, annual average concentrations for the MSATs at each freeway segment are presented in Table 18 and Figure 22. The proposed 1-year MACs appear as horizontal lines in Figure 22.

These results indicate that for benzene, 1,3-butadiene, and formaldehyde, the modeled worst-case, annual concentrations sometimes exceeded the proposed 1-year MACs (developed by using a CR of $10^{-6}$). Such exceedances indicate that there might be valid concerns associated with long-term exposures to MSATs around Florida urban freeway segments. If however, a CR of $10^{-4}$ was used, then the proposed 1-year MACs would be 100 times larger, which would result in no exceedances, and hence potentially no concern about localized MSATs. It is also noted that when the annual average freeway segment results are compared to the intersection results, there are less facilities where the predicted concentrations exceeded the proposed long-term MACs. A discussion on why this is observed can be seen in the following section.
Table 18: Worst-case Peak-hour Annual Average Freeway Concentrations Compared to Proposed MACs

<table>
<thead>
<tr>
<th>Modeled MSAT</th>
<th>Acetaldehyde</th>
<th>Acrolein</th>
<th>Benzene</th>
<th>1,3-Butadiene</th>
<th>Formaldehyde</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Predicted Annual Average Concentration (ppbv)</td>
<td>Proposed Annual Average MAC (ppbv)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Jacksonville</td>
<td>Miami</td>
<td>Orlando</td>
<td>Pensacola</td>
<td>Sarasota</td>
</tr>
<tr>
<td>Acetaldehyde</td>
<td>0.0540</td>
<td>0.0810</td>
<td>0.0520</td>
<td>0.0131</td>
<td>0.0292</td>
</tr>
<tr>
<td>Acrolein</td>
<td>0.0037</td>
<td>0.0054</td>
<td>0.0035</td>
<td>0.0009</td>
<td>0.0020</td>
</tr>
<tr>
<td>Benzene</td>
<td>0.0560</td>
<td>0.0810</td>
<td>0.0451</td>
<td>0.0134</td>
<td>0.0300</td>
</tr>
<tr>
<td>1,3-Butadiene</td>
<td>0.0167</td>
<td>0.0258</td>
<td>0.0161</td>
<td>0.0040</td>
<td>0.0090</td>
</tr>
<tr>
<td>Formaldehyde</td>
<td>0.138</td>
<td>0.206</td>
<td>0.133</td>
<td>0.0336</td>
<td>0.0745</td>
</tr>
</tbody>
</table>
Figure 22: Worst-case Peak-hour Annual Average MSAT Concentrations for Various Urban Florida Freeway Segments (proposed MACs in ppbv for the modeled MSATs appear as horizontal lines)
5.5 CAL3MSAT Modeling Observations

After viewing these results, it can be seen that the predicted worst-case, peak-hour maximum concentrations are multiple orders of magnitude different than proposed MACs. However, for benzene, 1,3-butadiene, and formaldehyde, the predicted worst-case, maximum annual average concentrations exceed the proposed MACs. Several comments about these modeled exceedances are in order. First, the proposed MACs are extremely conservative values. Second, worst-case receptor placement was used (this concept is further explained below). Third, the TPF used to adjust the 1-hour averaging time to an annual averaging time is also a very conservative value. Fourth, maximum values for peak-hour traffic volumes were used. Fifth, and perhaps most importantly, these high concentrations are found only at receptors very near the roadways, where lifetime exposure may not be meaningful. It is extremely unlikely that someone might stay located ten feet away from a large intersection or freeway segment for their lifetime.

To show how predicted concentrations decrease rapidly away from the edge of any given intersection, several modeling runs were completed using the Orlando data. The results are shown in Table 19 and Table 20, and in Figure 23. At many reasonable residential or commercial receptors, the concentrations likely would be below the proposed MACs even if the 10-foot (3-m) concentration would be above the proposed MAC. So ultimately, this means that (based on this modeling), it is likely that human health is not impacted by exposure to the modeled MSATs near intersections or freeways.
Table 19: Modeled Worst-case 1-hour MSAT Concentrations at Various Distances from the Roadway Edge*

<table>
<thead>
<tr>
<th>Modeled MSAT</th>
<th>Worst-Case Peak-Hour Concentration (ppbv)</th>
<th>Proposed 1-hr MAC (ppbv)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Receptor Distance from Roadway</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3 m</td>
<td>50 m</td>
</tr>
<tr>
<td>Acetaldehyde</td>
<td>1.35</td>
<td>0.625</td>
</tr>
<tr>
<td>Acrolein</td>
<td>0.0845</td>
<td>0.0390</td>
</tr>
<tr>
<td>Benzene</td>
<td>1.60</td>
<td>0.740</td>
</tr>
<tr>
<td>1,3-Butadiene</td>
<td>0.451</td>
<td>0.208</td>
</tr>
<tr>
<td>Formaldehyde</td>
<td>3.14</td>
<td>1.45</td>
</tr>
</tbody>
</table>

*Results are from using the Orlando intersection during the A.M. peak-hour

Table 20: Modeled Worst-case Annual Average MSAT Concentrations at Various Distances from the Roadway Edge*

<table>
<thead>
<tr>
<th>Modeled MSAT</th>
<th>Predicted Annual Average Concentration (ppbv)</th>
<th>Proposed Annual Average MAC (ppbv)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Receptor Distance from Roadway</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3 m</td>
<td>50 m</td>
</tr>
<tr>
<td>Acetaldehyde</td>
<td>0.0675</td>
<td>0.0313</td>
</tr>
<tr>
<td>Acrolein</td>
<td>0.0042</td>
<td>0.0020</td>
</tr>
<tr>
<td>Benzene</td>
<td>0.0800</td>
<td>0.0370</td>
</tr>
<tr>
<td>1,3-Butadiene</td>
<td>0.0226</td>
<td>0.0104</td>
</tr>
<tr>
<td>Formaldehyde</td>
<td>0.157</td>
<td>0.0725</td>
</tr>
</tbody>
</table>

*Results are from using the Orlando intersection during the A.M. peak-hour
Regarding the geographic variability of the results, generally, the predicted worst-case concentrations were higher in the larger urban areas (i.e., Jacksonville, Miami, Orlando, and Tampa) than the smaller urban areas. An obvious conclusion is that with a greater volume of vehicles, the total emissions of MSATs are larger, and thus resulting concentrations are higher. Secondly, higher concentrations of MSATs were generally predicted for intersections than the freeways, even though the freeways carried higher peak-hour volumes of traffic. The emissions from queuing vehicles at intersections contribute significantly to the predicted concentrations.
5.6 Dispersion Model Comparison

5.6.1 Tampa Intersection

Three different models with various approaches were used to predict benzene concentrations at an urban Tampa intersection including: (1) a CAL3MSAT worst-case 1-hour, adjusted by a TPF approach, (2) a CAL3QHCR Tier II approach, (3) an AERMOD volume source characterization approach, and (4) an AERMOD area source characterization approach. The results of this effort, seen in Table 21, show several interesting results. First, the highest 1-hour concentrations from CAL3QHCR and AERMOD (both approaches) were significantly less than the worst-case 1-hour concentration from CAL3MSAT, indicating the validity of the worst-case assumptions. Second, applying a TPF of 0.05 to the CAL3MSAT 1-hour worst-case concentration produced a modeled annual average concentration that was comparable to the more refined modeling approaches. It was in fact higher than the 5-year maximum annual average from the CAL3QHCR Tier II approach, and significantly higher than the AERMOD area source approach, but lower than the AERMOD volume source approach. The CAL3CHR Tier II and AERMOD area source characterization approaches resulted in consistently lower predicted annual average benzene concentrations (over each of the five years modeled). By changing just the source characterization type from area to volume in AERMOD (identical emissions from MOVES were used), the predicted 1-hour and annual maximum values are roughly 100% and 560% higher, respectively.
Table 21: Model Comparison of Predicted Benzene Concentrations

<table>
<thead>
<tr>
<th>Dispersion Model</th>
<th>Emission Source Characterization</th>
<th>Meteorology Data</th>
<th>Maximum Predicted Benzene Concentration (ppbv)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>1-Hour</td>
</tr>
<tr>
<td>CAL3MSAT</td>
<td>Line</td>
<td>1-hr worst-case</td>
<td>2.47</td>
</tr>
<tr>
<td>CAL3QHCR</td>
<td>Line</td>
<td>5-years&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.42&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>AERMOD</td>
<td>Area</td>
<td>5-years&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.42&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>AERMOD</td>
<td>Volume</td>
<td>5-years&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.82&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Annual Average</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.124</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.104&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.025&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.165&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a</sup> Hourly meteorology data from 1987-1991 for Tampa International Airport.

<sup>b</sup> Max. 1-hour is the highest hourly value from all the hours in five year period; annual average is the highest value of the five years.

5.6.2 Observations

CAL3MSAT predicted the highest 1-hour benzene concentration, which was expected since a worst-case (screening) approach was taken. By including real meteorology and varying traffic and signal timing data in the CAL3QHCR Tier II approach, the predicted maximum 1-hour concentration was lower than the worst-case value and presumably more “realistic.” But much more effort and time was required to use CAL3QHCR and AERMOD. AERMOD is a more refined model than CAL3QHCR, but since the model was designed more for point source applications, there is still much uncertainty about its use as a highway model. The results of this study show much variability in the predicted AERMOD concentrations, depending on whether one uses an area source or volume source approach.

The difference in AERMOD results due to how the emission sources are characterized has been mentioned in literature. Schewe and Smith (2009) conducted an analysis on a hypothetical haul road and showed that by using an AERMOD volume source characterization, maximum annual average concentrations of particulate matter were up to 2.58 times that of those predicted with an area source characterization. They further explain that this difference is to be
expected due to the way AERMOD treats each source type. A volume source uses the
dimensions of the source to establish an initial lateral dimension of a virtual-point source plume
at the point of release at the source. This value is a fraction of the actual dimension of the source.
The area source treatment in AERMOD uses integration across the whole extent of the source
thus, giving the source a much broader plume at the initial outset of dispersion and transport
(Schewe and Smith, 2009). Wayson (2012) also notes that due to the AERMOD source
algorithms, plume overlap (which is not a real phenomenon) can potentially occur and predicted
concentrations will be greater where this occurs. Further refinement of AERMOD for use as a
highway model is still needed and could potentially be addressed by the inclusion of some type
of line source characterization (as seen in CAL3MSAT and CAL3QHCR).

5.6.3 Implications

A main goal of this part of the modeling study was not only the numerical comparison of
the predicted concentrations from the CAL3MSAT approach with CAL3QHCR and AERMOD,
but with answering the question of whether or not an agency such as the EPA or a municipality
could potentially use CAL3MSAT as a screening method. The advantages of being able to
reliably use CAL3MSAT as a screening approach for predicting MSAT concentrations includes
the time, resources, and funds that would be saved from not having to use more refined models
such as CAL3QHCR and AERMOD. From the numerical results presented in Table 21, it can be
seen that for the 1-hour and (most likely) for the annual concentrations, the CAL3MSAT worst-
case approach predicted higher concentrations. For a modeler, these results are expected because
of the use of worst-case assumptions; however, the benefits and implications for a different
audience are discussed below.
Table 22 is presented to highlight the difference in data input between the four dispersion model/emission source characterization approaches. It can easily be seen that the CAL3MSAT screening approach required much less input data to model the Tampa intersection when compared to CAL3QHCR and AERMOD. The amount of effort needed to input receptor data was roughly the same for any model selected. One large difference is that 1-year of meteorology data had to be obtained and then preprocessed for CAL3QHCR and AERMOD; whereas for CAL3MSAT, this was not the case. The largest difference with the input requirements was with the emission source data. With CAL3MSAT and CAL3QHCR (since they are roadway specific models), sources are either classified as idling or cruising vehicles. Therefore, the resultant number of values required for each classification varies. With CAL3QHCR and AERMOD (for both source characterization approaches), the number of input values required was much greater due to the yearly variation in source emission rates. This was especially true for the AERMOD volume source characterization approach due to the extremely large number of sources that had to be defined (see Table 22). It should again be noted that significant emission rate preprocessing had to be completed for AERMOD in order to incorporate the signal timing and the EFs from MOVES.
<table>
<thead>
<tr>
<th>Model</th>
<th>Emission Source Characterization</th>
<th>Meteorology Preprocessor</th>
<th>Meteorology Data</th>
<th>Emission Source Data</th>
<th>Receptor Data</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Number of Sources</td>
<td>Number of Receptors</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td># of Values per Source</td>
<td># of Values per Receptor</td>
</tr>
<tr>
<td>CAL3MSAT</td>
<td>Line</td>
<td>None</td>
<td>1-hour</td>
<td>29/8&lt;sup&gt;a&lt;/sup&gt;</td>
<td>44</td>
</tr>
<tr>
<td>CAL3QHCR</td>
<td>Line</td>
<td>PCRAMMET</td>
<td>1-year</td>
<td>29/8&lt;sup&gt;a&lt;/sup&gt;</td>
<td>44</td>
</tr>
<tr>
<td>AERMOD</td>
<td>Area</td>
<td>AERMET</td>
<td>1-year</td>
<td>37</td>
<td>44</td>
</tr>
<tr>
<td>AERMOD</td>
<td>Volume</td>
<td>AERMET</td>
<td>1-year</td>
<td>777</td>
<td>44</td>
</tr>
</tbody>
</table>

<sup>a</sup> the first value indicates the number of cruise links/the second number indicates the number of queue links

<sup>b</sup> the first value indicates the number of values input for cruise links/the second number indicates the number of values input for queue links
Benefits of the CAL3MSAT screening model approach are presented in Table 23. This table is a modeling comparison matrix that evaluates the four modeling approaches against five categories. These categories, and how matrix selections were made, are described below.

- **Purchase cost** – This category relates to the cost that one (such as a municipality) would have to pay in order to obtain the model. All models are rated equally since they are distributed freely by the FDOT (CAL3MSAT) and the EPA (CAL3QHCR and AERMOD).

- **Program usability** – CAL3MSAT was given the advantage over CAL3QHCR and AERMOD since CAL3MSAT is run by CAL3i, the Windows® GUI. Data input through the DOS based CAL3QHCR and AERMOD are much more tedious, and mistakes are more easily made in the text input file without built-in error checking like that provided in CAL3i.

- **User skills** – These skills refer to those a modeler needs in order to use the given dispersion model correctly. Again, since CAL3MSAT is run by the CAL3i interface, a user only needs basic skills since all input variables are organized (and described) logically in different input forms. Also, since CAL3MSAT is a screening approach with worst-case assumptions, the amount of different variables and terminology a user must be familiar with are less than that for AERMOD. CAL3QHCR and AERMOD requires the use of meteorology preprocessing and the incorporation of yearly (as opposed to hourly) emission, traffic, and signal timing data; the use of which requires a more advanced user.

- **Data requirements** – As seen from Table 22, the data requirements in terms of values that must be input by the modeler, are significantly lower for CAL3MSAT (one of the main advantages of a screening approach – hourly as opposed to yearly data). CAL3QHCR
(like CAL3MSAT) is a roadway specific model, and the input variables reflect this (i.e., specific input of traffic volumes, signal cycle times, etc.); however, AERMOD is not, and thus the modeling process is more complicated since the input variables are not always easily adapted for roadway modeling. The point can also be made that models with fewer variables, such as CAL3MSAT, allow for more reproducible results (from user-to-user) due to less variability introduced by modeler assumptions.

- Maintenance requirements – This category refers to a number of different factors including: the runtime of a model; the training time required for a modeler to understand how to use a modeling approach and how to interpret the results; and the amount of time or funds related to acquiring and processing input data. Additionally, with the EPA models (specifically AERMOD) updates are released and the most current version of the model must be used for studies (often this can require spending additional time learning how the model changed). CAL3MSAT has a lower maintenance cost than the other models since it is a worst-case screening model (which is not continually updated) and is run through the user friendly CAL3i interface, where modelers with a nominal amount of guidance can run the model and predict MSAT concentrations.
<table>
<thead>
<tr>
<th>Modeling Approach</th>
<th>Purchase Cost</th>
<th>Program Usability</th>
<th>User Skills</th>
<th>Data Requirements</th>
<th>Maintenance Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Basic</td>
<td>Advanced</td>
<td>Low</td>
</tr>
<tr>
<td>CAL3MSAT</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td></td>
<td>✔</td>
</tr>
<tr>
<td>CAL3QHCR</td>
<td>✔</td>
<td></td>
<td>✔</td>
<td></td>
<td>✔</td>
</tr>
<tr>
<td>AERMOD (area)</td>
<td>✔</td>
<td></td>
<td>✔</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AERMOD (volume)</td>
<td>✔</td>
<td></td>
<td>✔</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
CHAPTER 6: CONCLUSION

6.1 Conclusions

There are concerns amongst the public and some agencies that the concentrations of air toxics (a significant percentage of which are emitted directly from motor vehicles) pose a threat to human health in urban areas. For a project-level hot-spot analysis it is important to assess the concentrations near a single large intersection or freeway. The results of the CAL3MSAT short-term modeling analysis indicate that, in the state of Florida, the worst-case 1-hour modeled MSAT concentrations near intersections and freeways are orders of magnitude lower than the proposed short-term MACs, so concerns about short-term exposures may not be warranted. Modeled annual average concentrations with the CAL3MSAT TPF approach were, in some cases, higher than the proposed 1-year MACs. If the proposed MACs are correct, there may be a valid concern over long-term MSAT exposure to people living near large roadway facilities.

Different dispersion models and emission source characterizations were examined to show how the prediction of long-term concentrations of MSATs from a roadway facility could potentially be addressed. Predicted annual average benzene concentrations using the worst-case TPF (screening) approach were larger than those predicted from both a CAL3QHCR Tier II and AERMOD area source characterization approach. The AERMOD volume source characterization approach produced a higher annual average concentration than the other three approaches. None of the approaches included MSAT reactivity (either the destruction or formation through atmospheric reactions), background concentrations (which are not easily determined), or the effects of nearby MSAT emission sources. There is still a need for continued investigation in the way to properly apply AERMOD to highway projects. Finally, the highest
concentrations were found at receptors very near the roadways (3 to 6 meters from roadway edges) where long-term exposure may not be meaningful.

This researcher does not mean to diminish the public health concerns about exposure to MSATs. The project-level analysis showed that the concentrations of the modeled MSATs owing to any one particular intersection or freeway are very low. In some urban areas, concentrations of certain HAPs are high enough to warrant considerable efforts to reduce city-wide emissions, and it is recognized that motor vehicles contribute significantly to the overall emissions of some of these compounds. In the aggregate, as vehicles become cleaner in the future, it is expected that overall MSAT emissions will continue to decline and MSAT concentrations in urban areas will most likely follow this trend. However, it is possible that, as alternative fuels (e.g., alcohols) become a greater percentage of the fuel mix, concentrations of some MSATs may increase.

6.2 Recommendations

During the course of this modeling study, several recommendations and areas for future research were identified. The following will help further refine MSAT dispersion modeling conducted with CAL3MSAT, and would help for better acceptability by the modeling community:

- After comparing the MSAT modeling approaches, it was seen that CAL3MSAT can likely be used as a conservative screening tool, saving much time compared with CAL3QHCR and AERMOD. But, since this method utilizes a number of worst-case assumptions, the resulting modeled maximum 1-hour and 1-year concentrations may be inordinately high. It is recommended that a validation study be conducted for
CAL3MSAT by obtaining real-world MSAT concentration (and other) data. This process would be a long and intensive effort due to the types and volume of data required including: the use of EPA preferred methods to collect MSAT air samples; a repetitive sampling schedule; the proper analysis of these samples at a certified laboratory; and the accurate collection of additional CAL3MSAT input parameters such as vehicle volumes and speeds, signal timing, and meteorology data (through the use of deployable meteorology stations). MSAT background concentrations should also be measured through proper upwind sampling. This would allow for the determination of how much of a given MSAT’s concentration can be attributed to the roadway facility, as opposed to surrounding sources. Collected data could then be used to create an input file that CAL3MSAT would use to predict MSAT concentrations. The predicted values from CAL3MSAT (including background) could then be compared to the measured air sample values, and conclusions on the validity of CAL3MSAT could be drawn.

- Destruction (or formation) of MSATs due to their reactivity was not accounted for in CAL3MSAT. This could potentially have large implications on the results of this modeling study if such reactivity is characterized accurately. It is recommended that appropriate reactivity algorithms be incorporated into CAL3MSAT in order for the model predictions to be more accurate.

- Investigation into additional short-term MACs and continued refinement of the method to calculate the long-term proposed MACs are recommended. Potential changes to the proposed MACs could alter the conclusions reached during this modeling study.

- Investigation into the possible inclusion of modal (i.e., acceleration and deceleration) emission factors for more “refined” modeling are also recommended. Before the release
of MOVES, this ability was not an option for analysts using EPA emission models, but now it is. Again, incorporation of this could lead to potentially more accurate model predictions.

- EPA seems to have implied through recent roadway pollutant guidance documents that they see AERMOD as the future of near-road dispersion modeling. For future MSAT modeling research, it is recommended that the inclusion of a line source algorithm (as seen in CAL3MSAT and CAL3QHCR) into AERMOD’s state-of-the-art modeling framework to allow for the more accurate prediction of MSAT concentrations, be investigated.
APPENDIX A: CAL3MSAT FORTRAN CODE
Modification to the original CAL3QHC source code by this author can be seen by the initials V2KW in the right-hand column.

PROGRAM: CAL3MSAT

This program is a modified version of the CAL3QHC dispersion model code used in the FHWA’s CAL3Interface, but allows for the additional modeling of the original 6 priority mobile source air toxics (MSATs) and a few others (including any particulate or gaseous pollutant). The program is still a modeling methodology for predicting pollutant concentrations near roadway intersections.

CAL3MSAT (2011) was recompiled using Lahey ED4W. For this, the subroutine "GETFIL" previously commented out, was added back into the program code. Also, the Microsoft date and time call commands were commented out, and the original Lahey commands were reintroduced. In addition, the CAL3Interface code provided by Dr. Michael Claggett included an increased maximum number of links from 120 to 1200 and the maximum number of receptors from 60 to 100.

DEVELOPED BY: KURT K. WESTERLUND, M.S., E.I, E.P.I. &

C. DAVID COOPER, PhD., P.E., Q.E.P.

UNIVERSITY OF CENTRAL FLORIDA

FUNDED BY: FLORIDA DEPARTMENT OF TRANSPORTATION

DATE: MARCH 2011

CAL3QHC (DATED 04244)

*** SEE CAL3QHC MCB#6 ***

ON THE SUPPORT CENTER FOR REGULATORY AIR MODELS WEBSITE

http://www.epa.gov/scram001

PROGRAM: CAL3QHC - A modeling methodology for predicting pollutant concentrations near roadway

92
intersections.

CAL3QHC is a consolidation of the CALINE-3 dispersion model and a queuing algorithm that internally estimates the length of the queues formed by idling vehicles at a signalized intersections. It calculates the contribution of the emissions from these idling vehicles, and internally converts these sources into CALINE-3 link format.

MODIFIED BY: TEREZA STRATOU
------------ PARSONS BRINCKERHOFF QUADE & DOUGLAS, INC.
DATE: AUGUST 1990
-----

CAL3QHC - (dated 93157)

The difference between the original CAL3QHC model and this revised version (dated 93157) pertains to the calculation of intersection capacity, delay, and queue lengths. This version includes three new optional traffic parameters that could be specified by the user: Saturation Flow Rate, Signal Type, and Arrival Type. This revised version also replaces the stopped delay (used in the queue calculation) with the approach delay.

MODIFIED BY: STEVEN WARSHAW
------------ PARSONS BRINCKERHOFF QUADE & DOUGLAS, INC.
DATE: OCTOBER 1991
-----

CAL3QHC - (dated 93157) EXPANDED CAPACITY

The capacity of the program has been increased from 55 links to 1200 links and from 20 receptors to 100 receptors. The output has the option to be printed in either Metric or English units. The idle emission factor must be input in grams per hour (instead of the original grams per minute). All input queue parameters are printed in the output.

MODIFIED BY: INGRID ENG
------------ PARSONS BRINCKERHOFF QUADE & DOUGLAS, INC.
DATE: JANUARY 1992
-----

******************************************************************************
INPUT FORMAT

Note: Input is in free format. Single quotes need to be placed around 'character string input'. All data that could be entered optionally under the old fixed input format, needs to be entered.

93
'Title (up to 40 Char.)' ATIM, ZO, VS, VD, NR, SCAL, IOPT, IDEBUG.
Receptor name, X- and Y-coordinate, elevation.
(The last line is repeated for each receptor)
'Run name' number of links, lines of MET data, PRINT2 flag, mode.
One entry for each link:
Link flow type (IQ, 1 free flow, 2 queue).
For IQ = 1:
'Link name', 'type', beginning X, Y-coords, ending X, Y-Coords,
link volume, emission rate, source height, mixing zone width.
For IQ = 2:
'Link name', 'type', beginning X, Y-coords, ending X, Y-coords,
source height, mixing zone width, number of lanes.
Traffic light cycle time, average red, yellow factor, approach
volume, idle emiss. factor, saturation flow rate, signal type, arrival
rate.
wind speed, actual wind direction, stability class, mixing height,
ambient background concentration, 'wind direction variation flag',
direction variation increment,
lower boundary of the wind dir. range variation increment multiplier,
upper boundary of the wind dir. range variation increment multiplier.

***************************************************************************
PROGRAM CAL3MSAT_LAHEY
***************************************************************************

<table>
<thead>
<tr>
<th>VARIABLE DECLARATION STATEMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>-------------------------------</td>
</tr>
</tbody>
</table>

CHARACTER  X1(100)*15, VAR*1, REC(100)*5, RUN*40, JOB*40, STB(6)*1,
+ LNK(1200)*20, MODE*1, RCP(100)*20, TYP(1200)*2
CHARACTER  IDATE*8, ITIME*5, FILE5*40, FILE6*40
CHARACTER  COMPOUND*50
REAL       BRGV(361), MOWT, NE, LIM, KZ, LB, LBRG(1200),
+ INC, MIXH, K1, IDLFAC(1200), PScale,
+ MOWT_A, MOWT_R, MOWT_B, MOWT_U, MOWT_F,
+ MOWT_N, MOWT_I, MOWT_G,
+ CONVERT_A, CONVERT_R, CONVERT_B, CONVERT_U,
+ CONVERT_F, CONVERT_N, CONVERT_I, CONVERT_G

**FOR ANSWER IN PPB**

<table>
<thead>
<tr>
<th>ADDED IN NEW MOLECULAR WEIGHTS FOR SIX PRIMARY MSATs</th>
</tr>
</thead>
</table>

1) MOWT_A=Acetaldehyde
2) MOWT_R=Acrolein
3) MOWT_B=Benzene
4) MOWT_U=1,3-Butadiene
5) MOWT_F=Formaldehyde
6) MOWT_D=DPM+DEOG (UNKNOWN AT THIS TIME)

<table>
<thead>
<tr>
<th>ADDED IN NEW MOLECULAR WEIGHTS FOR ADDITIONAL POLLUTANTS</th>
</tr>
</thead>
</table>

7) MOWT_N=Naphthalene
8) MOWT_I=Nitrogen Dioxide
9) MOWT_G=Other Gases
10) MOWT_O = Other Particulates (UNKNOWN AT THIS TIME)  

INTEGER DEGR, ANGMAX(100), VA(361), VA(2), PRINT2,  
+ PGCT, PCLAS, CLAS, COD(1200), KQ, CAVG(1200), RAVG(120)  

INTEGER SFR(1200), ST(1200), AT(1200), IDC, IORDER(100)  

DOUBLE PRECISION HYP, SIDE, FAC2, PD, A, B, L, D, LL(120), INTG(6), LL1,  
+ XPRI, YPRI, APR, BPRI, DPRI, XD, YD, D1, D2, ABSQD,  
+ XW1, YW1, XW2, YW2, LLW, HLW, WLW, XWR, YWR, ZWR  

DIMENSION CRMAX(100), COMAX(1200, 100), C(1200, 100),  
+ COMAX(1200, 100), XRL(1200), YRL(1200), ZR(1200), XRL1(1200),  
+ XL2(1200), YL2(1200), VLPHL(1200), EFL(1200),  
+ HLL(1200), WLL(1200), AZ(6), AY1(6), AY2(6), Y(6), WT(5),  
+ QA(1200), GAVG(1200), VL(1200), DJ(1200), V(1200),  
+ IMU(1200), YFA(1200), IQ(1200), IV(1200), RC(1200), X(1200),  
+ ZFA(1200), DC(1200), YQD(1200), YOD(1200), NLANES(1200),  
+ TER(1200), THETA(1200)  

DIMENSION DDJ(1200)  

REAL PAF(5, 3, 3)  

DATA AZ/1112., 566., 353., 219., 124., 56./  
DATA AY1/0.46, 0.29, 0.18, 0.11, 0.087, 0.057/  
DATA AY2/1831., 1155., 717., 438., 346., 227./  
DATA WT/0.25, 0.75, 1., 0.75, 0.25/  

DATA STB/'A', 'B', 'C', 'D', 'E', 'F'/  
DATA REC/ 'REC1', 'REC2', 'REC3', 'REC4', 'REC5', 'REC6',  
+ 'REC7', 'REC8', 'REC9', 'REC10', 'REC11', 'REC12',  
+ 'REC13', 'REC14', 'REC15', 'REC16', 'REC17', 'REC18',  
+ 'REC19', 'REC20', 'REC21', 'REC22', 'REC23', 'REC24',  
+ 'REC25', 'REC26', 'REC27', 'REC28', 'REC29', 'REC30',  
+ 'REC31', 'REC32', 'REC33', 'REC34', 'REC35', 'REC36',  
+ 'REC37', 'REC38', 'REC39', 'REC40', 'REC41', 'REC42',  
+ 'REC43', 'REC44', 'REC45', 'REC46', 'REC47', 'REC48',  
+ 'REC49', 'REC50', 'REC51', 'REC52', 'REC53', 'REC54',  
+ 'REC55', 'REC56', 'REC57', 'REC58', 'REC59', 'REC60',  
+ 'REC61', 'REC62', 'REC63', 'REC64', 'REC65', 'REC66',  
+ 'REC67', 'REC68', 'REC69', 'REC70', 'REC71', 'REC72',  
+ 'REC73', 'REC74', 'REC75', 'REC76', 'REC77', 'REC78',  
+ 'REC79', 'REC80', 'REC81', 'REC82', 'REC83', 'REC84',  
+ 'REC85', 'REC86', 'REC87', 'REC88', 'REC89', 'REC90',  
+ 'REC91', 'REC92', 'REC93', 'REC94', 'REC95', 'REC96',  
+ 'REC97', 'REC98', 'REC99', 'REC100'/  
DATA X1/100*------------------------'/  

<table>
<thead>
<tr>
<th>DIMENSION ARRAYS</th>
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<thead>
<tr>
<th>LOOKUP TABLE ARRAY DECLARATION</th>
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</thead>
</table>

REAL PAF(5, 3, 3)  

DATA STB/'A', 'B', 'C', 'D', 'E', 'F'/  
DATA REC/ 'REC1', 'REC2', 'REC3', 'REC4', 'REC5', 'REC6',  
+ 'REC7', 'REC8', 'REC9', 'REC10', 'REC11', 'REC12',  
+ 'REC13', 'REC14', 'REC15', 'REC16', 'REC17', 'REC18',  
+ 'REC19', 'REC20', 'REC21', 'REC22', 'REC23', 'REC24',  
+ 'REC25', 'REC26', 'REC27', 'REC28', 'REC29', 'REC30',  
+ 'REC31', 'REC32', 'REC33', 'REC34', 'REC35', 'REC36',  
+ 'REC37', 'REC38', 'REC39', 'REC40', 'REC41', 'REC42',  
+ 'REC43', 'REC44', 'REC45', 'REC46', 'REC47', 'REC48',  
+ 'REC49', 'REC50', 'REC51', 'REC52', 'REC53', 'REC54',  
+ 'REC55', 'REC56', 'REC57', 'REC58', 'REC59', 'REC60',  
+ 'REC61', 'REC62', 'REC63', 'REC64', 'REC65', 'REC66',  
+ 'REC67', 'REC68', 'REC69', 'REC70', 'REC71', 'REC72',  
+ 'REC73', 'REC74', 'REC75', 'REC76', 'REC77', 'REC78',  
+ 'REC79', 'REC80', 'REC81', 'REC82', 'REC83', 'REC84',  
+ 'REC85', 'REC86', 'REC87', 'REC88', 'REC89', 'REC90',  
+ 'REC91', 'REC92', 'REC93', 'REC94', 'REC95', 'REC96',  
+ 'REC97', 'REC98', 'REC99', 'REC100'/  
DATA X1/100*------------------------'/  

<table>
<thead>
<tr>
<th>DATA INPUT</th>
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</thead>
</table>

DATA AZ/1112., 566., 353., 219., 124., 56./  
DATA AY1/0.46, 0.29, 0.18, 0.11, 0.087, 0.057/  
DATA AY2/1831., 1155., 717., 438., 346., 227./  
DATA WT/0.25, 0.75, 1., 0.75, 0.25/  

ERROR
! LOOKUP TABLE DEFINITION

===============

DATA PAF /1.85, 1.35, 1.00, 0.72, 0.53,
+ 1.50, 1.22, 1.00, 0.82, 0.67,
+ 1.40, 1.18, 1.00, 0.90, 0.82,
+ 1.54, 1.08, 0.85, 0.62, 0.40,
+ 1.25, 0.98, 0.85, 0.71, 0.50,
+ 1.16, 0.94, 0.85, 0.78, 0.61,
+ 1.85, 1.35, 1.00, 0.72, 0.42,
+ 1.50, 1.22, 1.00, 0.82, 0.53,
+ 1.40, 1.18, 1.00, 0.90, 0.65/

===============================================

| MAXIMUM NUMBER OF RECEPTORS AND LINKS ALLOWED BY PROGRAM |

MAXR=100
MAXL=1200
IN = 7
IOUT = 6
IPO = 8

CALL GETDAT (IYR, IMON, IDAY) ! LINES USED FOR
CALL GETTIM (IIHR, IMIN, ISEC, IX) ! MICROSOFT COMPILER
CALL TIME(ITIME)
CALL DATE(IDATE)

CALL GETFIL(FILE5,FILE6)
OPEN (IN,FILE=FILE5,STATUS='OLD')
OPEN (IPO,FILE=FILE6,STATUS='UNKNOWN')

===============================================

INITIALIZATION OF CONSTANTS AND COUNTERS

DO 3 I=1,1200
COD(I)=I
3 CONTINUE

PGCT=0
PI=3.1415926
RAD=PI/180.
DEG=180./PI
PSCALE=1/0.3048

--- MOLECULAR WEIGHT OF CO AND PRIMARY MSATS---
MOWT=28.01
MOWT_A=44.05 ! **FOR ANSWER IN PPM**
MOWT_R=56.06 ! -----------------------------------------------
MOWT_B=78.11 ! | ADDED THESE 5 MOLECULAR WEIGHTS FOR |
MOWT_U=54.09 ! | THE NEW MSATS |
MOWT_F=30.03 ! ---------------------------------------------

--- MOLECULAR WEIGHT OF ADDITIONAL POLLUTANTS---
MOWT_N=128.17 ! **FOR ANSWER IN PPM**
MOWT_I=46.01

DREF=ALOG(10000.)
10 READ (IN,*) JOB, ATIM, Z0, VS, VD, NR, SCAL, IOPT, IDEBUG
   IF (JOB(1:1) .NE. CHAR(39)) GOTO 4

5 WRITE(IOUT,6)
6 FORMAT('                      NOTICE'/
      +5x,'CAL3QHC has been made user-friendlier by using a ','/5x,
      +'free format. However, the program has detected the',
      + 'possible use ','/5x,
      +'of the old format. If this is so, please review the Input ',
      + 'Format section','/5x,
      +'of the CAL3QHC source code AND Readme file. The program will',
      + 'continue','/5x,
      +'until another error is detected./')
PAUSE '            Please press any key to continue'
4 CONTINUE
   IF(IDEBUG.EQ.1)WRITE(IOUT,120)JOB, ATIM, Z0, VS, VD, NR, SCAL

            ATIM = AVERAGING TIME (MINUTES)
            Z0 = ROUGHNESS (CM)
            VS = SETTLING VELOCITY (CM/SEC)
            VD = DEPOSITION VELOCITY (CM/SEC)
            NR = NUMBER OF RECEPTORS

VS1=VS  
VD1=VD

---------------------
| CONVERT M/S TO M/S |
---------------------
VS=VS/100.
VD=VD/100.
V1=VD-VS/2.

---------------------
| RECEPTOR LOCATIONS |
---------------------

DO 1000 I=1,NR
   READ (IN,*) RCP(I), XR(I), YR(I), ZR(I)
   IF(IDEBUG.EQ.1) WRITE(IOUT,130) RCP(I), XR(I), YR(I), ZR(I)
   XR(I)=SCAL*XR(I)
   YR(I)=SCAL*YR(I)
   ZR(I)=SCAL*ZR(I)
1000 CONTINUE
--- LINK & MET CONDITIONS ---

NL = NUMBER OF LINKS
NM = NUMBER OF MET CONDITIONS

READ (IN,*) RUN,NL,NM,PRINT2,MODE
IF(IDEBUG.EQ.1)WRITE(IOUT,150) RUN,NL,NM,PRINT2,MODE

MODE = 12

IF (MODE .EQ. 'c') MODET = 0
IF (MODE .EQ. 'C') MODET = 0
IF (MODE .EQ. 'p') MODET = 1 ! ADDED THESE MODES FOR THE SIX PRIMARY MSATS
IF (MODE .EQ. 'A') MODET = 2 ! ADDED THESE MODES FOR THE SIX PRIMARY MSATS
IF (MODE .EQ. 'r') MODET = 3 ! 2) 'a','A'=Acetaldehyde
IF (MODE .EQ. 'R') MODET = 3 ! 3) 'r','R'=Acrolein
IF (MODE .EQ. 'b') MODET = 4 ! 4) 'b','B'=Benzene
IF (MODE .EQ. 'B') MODET = 4 ! 5) 'u','U'=1,3-Butadiene
IF (MODE .EQ. 'u') MODET = 5 ! 6) 'f','F'=Formaldehyde
IF (MODE .EQ. 'U') MODET = 5 ! 7) 'd','D'=DPM+DEOG
IF (MODE .EQ. 'f') MODET = 6
IF (MODE .EQ. 'F') MODET = 6
IF (MODE .EQ. 'd') MODET = 7
IF (MODE .EQ. 'D') MODET = 7

IF (MODE .EQ. 'n') MODET = 8 ! 8) 'n','N'=Naphthalene
IF (MODE .EQ. 'N') MODET = 8 ! 9) 'i','I'=Nitrogen Dioxide
IF (MODE .EQ. 'i') MODET = 9 ! 10)'g','G'=Other Gases
IF (MODE .EQ. 'g') MODET = 10
IF (MODE .EQ. 'o') MODET = 11
IF (MODE .EQ. 'O') MODET = 11

IF (MODET .EQ. 12) THEN
WRITE(IOUT,*) ''
WRITE(IOUT,*) 'THE MODE VARIABLE ',MODE,'
+ WAS INCORRECTLY ENTERED.'
WRITE(IOUT,*) ''
WRITE(IOUT,20)
20 FORMAT ('PLEASE USE ONE OF THE FOLLOWING AS THE MODE:',/,' ',V2KW
+ 99('=',)
+ ',2X,'(1) C - CARBON MONOXIDE',7X,'(7) F - FORMAL',
+ 'DEHYDE',
+ ',2X,'(2) P - PARTICULATE MATTER',4X,'(8) D - DPM',
+ '+DEOG',
+ ',2X,'(3) A - ACETALDEHYDE',10X,'(9) N - NAPHTHAL',
+ 'EN',
+ ',2X,'(4) R - ACROLEIN',14X,'(10) I - NITROGEN DIO',
+ 'XIDE',
+ ',2X,'(5) B - BENZENE',15X,'(11) G - OTHER GASES',
+ ',2X,'(6) U - 1,3-BUTADIENE',9X,'(12) O - OTHER PA',
+ 'RTICULATES'/)
PAUSE
STOP
END IF

--- NEW COMMANDS FOR NAMING AND MW INPUT INTO THE PROGRAM ---
IF (MODET .EQ. 10) THEN
  WRITE (*,*) ''
  WRITE (*,53)
  WRITE (*,54)
  WRITE (*,53)
  WRITE (*,*) ''
  53  FORMAT (2X,60('='))
  54  FORMAT (' | PLEASE ENTER THE NAME OF THE COMPOUND (NO ' + 'SPACES ALLOWED): | ')
  READ (*,*) COMPOUND
  WRITE (*,*) ''
WRITE (*,51)
  51  FORMAT (2X,53('='))
  52  FORMAT (' | PLEASE ENTER THE MOLECULAR WEIGHT OF THIS ' + 'COMPOUND: | ')
  READ (*,*) MOWT_G
  WRITE (*,*) ' '
END IF

IF (MODET .EQ. 11) THEN
  WRITE (*,*) ' '
  WRITE (*,*) ' ======================================== '
  WRITE (*,*) '| PLEASE ENTER THE NAME OF THE COMPOUND: | '
  WRITE (*,*) ' '  ' --------------------------------------- '
  WRITE (*,*) ' '
  READ (*,*) COMPOUND
  WRITE (*,*) ' '
END IF

IF (MODET .EQ. 0) THEN
  FPPM=0.0245/MOWT  !    **FO
  ELSE IF (MODET .EQ. 2) THEN  !
    CONVERT_A=24.5/MOWT_A  ! | ADJUSTED FFPM FACTOR FOR |
    ELSE IF (MODET .EQ. 3) THEN  ! | EACH DIFFERENT MSAT BY |
      FPPM=1  ! | DIVIDING BY APPROPRIATE |
      CONVERT_R=24.5/MOWT_R  ! | MOLECULAR WEIGHT |
    ELSE IF (MODET .EQ. 4) THEN
      FPPM=1
      CONVERT_B=24.5/MOWT_B
    ELSE IF (MODET .EQ. 5) THEN
      FPPM=1
      CONVERT_U=24.5/MOWT_U
    ELSE IF (MODET .EQ. 6) THEN
      FPPM=1
      CONVERT_F=24.5/MOWT_F
    ELSE IF (MODET .EQ. 7) THEN
      FPPM=1
    ELSE IF (MODET .EQ. 8) THEN
      FPPM=1
      CONVERT_N=24.5/MOWT_N
    ELSE IF (MODET .EQ. 9) THEN
      FPPM=1
      CONVERT_I=24.5/MOWT_I
    ELSE IF (MODET .EQ. 10) THEN
      FPPM=1
      CONVERT_G=24.5/MOWT_G
    ELSE IF (MODET .EQ. 11) THEN
      FPPM=1
  ELSE IF (MODET .EQ. 10) THEN
    WRITE (*,*) ''
    WRITE (*,53) 
    WRITE (*,54) 
    WRITE (*,53) 
    WRITE (*,*) '' 
  53  FORMAT (2X,60('=')) 
  54  FORMAT (' | PLEASE ENTER THE NAME OF THE COMPOUND (NO ' + 'SPACES ALLOWED): | ') 
  READ (*,*) COMPOUND 
  WRITE (*,*) '' 
  51  FORMAT (2X,53('=')) 
  52  FORMAT (' | PLEASE ENTER THE MOLECULAR WEIGHT OF THIS ' + 'COMPOUND: | ') 
  READ (*,*) MOWT_G 
  WRITE (*,*) '' 
END IF
ELSE
    FPPM = 1
END IF

! CHECK NUMBER OF LINKS INPUT DOES NOT EXCEED MAXIMUM ALLOWED.
!
IF(NL.GT.MAXL)THEN
  WRITE(IOUT,168)NL,MAXL
  STOP
END IF
!
DO 1051 I=1,NL
  READ(IN,*) IQ(I)
  IF(IDEBUG.EQ.1)WRITE(IOUT,14) IQ(I)
!
! -----------------------------------------------------
!       IF IQ=1 FREE FLOW LINK. IF IQ=2 QUEUE LINK.
! -----------------------------------------------------
!       IF IQ(I) = 1 PROGRAM SKIPS QUEUE LINK READ STATEMENTS
! -----------------------------------------------------
!
IF(IQ(I).EQ.1) GOTO 2
!
-----------------------------------------------------------------
!       XL1, YL1 = COORDINATES FOR START OF QUEUE.
!       XL2, YL2 = COORDINATES FOR THE END OF AN ASSUMED QUEUE.
!
! The length defined by these coordinates can be anything except
! zero. It is used by the program to orient the calculated queue.
!
WL(I) = WIDTH OF LINK.
NLANES(I) = NUMBER OF LANES IN LINK.
IUFAC(I) = FREE FLOW SPEED ON LINK.
CAVG(I) = AVERAGE SIGNAL CYCLE LENGTH.
RAVG(I) = AVERAGE RED TIME.
IWIDTH(I) = DISTANCE ACROSS INTERSECTION TO CLEAR VEHICLE.
IV(I) = APPROACH VOLUME ON LINK.
IDLFAC(I) = IDLE EMISSION FACTOR. (INPUT IN gm/hr UNITS.  
            INTERNAL CONVERSION WILL BE MADE TO gm/min UNITS.
            SFR(I) = SATURATION FLOW RATE (DEFAULT = 1600)
            ST(I) = SIGNAL TYPE (DEFAULT = 1)
            1: PRETIMED
            2: ACTUATED
            3: SEMIACTUATED
            AT(I) = ARRIVAL RATE (DEFAULT = 3)
            1: WORST PROGRESSION
            2: BELOW AVERAGE
            3: AVERAGE
            4: ABOVE AVERAGE
            5: BEST PROGRESSION
            TYP = HIGHWAY TYPE
            AG: AT-GRADE
            DP: DEPRESSED (CUT)
            FL: FILL
            BR: BRIDGE
            VPVH = TRAFFIC VOLUME (VEHICLES/HR)
            HL = SOURCE HEIGHT (M)
            WL = MIXING ZONE WIDTH (M)

100
! READ(IN,*) LNK(I),TYP(I),XL1(I),YL1(I),XL2(I),YL2(I), V2EC
+   HL(I),WL(I),NLANES(I) V2EC
+ IF(IDEBUG.EQ.1) WRITE(IOUT,15) LNK(I),TYP(I),XL1(I), V2EC
+   YL1(I),XL2(I),YL2(I),HL(I),WL(I),NLANES(I) V2EC
READ(IN,*) CAVG(I),RAVG(I),YFAC(I),IV(I),IDLFAC(I) V2
+   SFR(I),ST(I),AT(I) V2
+ IF(IDEBUG.EQ.1) WRITE(IOUT,1) CAVG(I),RAVG(I),YFAC(I),IV(I) V2EC
+   IDLFAC(I),SFR(I),ST(I),AT(I) V2EC
!------------------
!       | ENFORCE DEFAULTS |                                            V2
!------------------
! IF (SFR(I) .EQ. 0) SFR(I) = 1600 V2
! IF (ST(I)  .EQ. 0) ST(I)  = 1 V2
! IF (AT(I)  .EQ. 0) AT(I)  = 3 V2
! GOTO 5555
2   READ(IN,*) LNK(I),TYP(I),XL1(I),YL1(I),XL2(I),YL2(I), V2EC
+   VPHL(I),EFL(I),HL(I),WL(I) V2EC
+ IF(IDEBUG.EQ.1) WRITE(IOUT,160) LNK(I), TYP(I), XL1(I), V2EC
+   YL1(I),XL2(I),YL2(I),VPHL(I),EFL(I),HL(I),WL(I) V2EC
!-------------------
!       | SCALE ADJUSTEMENT |
!-------------------
5555   XL1(I)=SCAL*XL1(I) V2
XL2(I)=SCAL*XL2(I) V2
YL1(I)=SCAL*YL1(I) V2
YL2(I)=SCAL*YL2(I) V2
HL(I) =SCAL*HL(I) V2
WL(I) =SCAL*WL(I) V2
!-------------------
!       | LINK LENGTH |
!-------------------
LL(I) =SQRT((XL1(I)-XL2(I))**2+(YL1(I)-YL2(I))**2) V2KW
IF (LL(I).GE.WL(I)) GOTO 1025 V2KW
WRITE (IOUT,170) V2KW
PAUSE V2KW
STOP
1025   IF (ABS(HL(I)).LE.10.) GOTO 1050 V2KW
WRITE (IOUT,180) V2KW
PAUSE V2KW
STOP
!----------------------------------------------------------
!      | CALCULATION OF THETA(I), THE ANGLE FORMED BY THE ASSUMED |
!      | QUEUE A AND THE CHOSEN COORDINATE SYSTEM.              |
!----------------------------------------------------------
![1050 XQD(I)=XL2(I)-XL1(I) V2EC
YQD(I)=YL2(I)-YL1(I) V2EC
ABSQD=ABS(XQD(I)/LL(I)) V2EC
IF(ABSQD.GT.1.0) ABSQD=1.0 V2EC
THETA(I)=DEG*DACOS(ABSQD) V2EC
IF (XQD(I).GT.0. .AND. YQD(I).GE.0.) THETA(I)=90.-THETA(I) V2EC
+ IF (XQD(I).GE.0. .AND. YQD(I).LT.0.) THETA(I)=90.+THETA(I) V2EC
+ IF (XQD(I).LT.0. .AND. YQD(I).LE.0.) THETA(I)=270.-THETA(I) V2EC
+ IF (XQD(I).LE.0. .AND. YQD(I).GT.0.) THETA(I)
+ YQD(I).GT.0.) THETA(I)=270.+THETA(I)

SKIPS QUEUE CALCULATION IF FREE FLOW LINK.
IF(IQ(I).EQ.1) GOTO 1051

QUEUE CALCULATION
V(I)=IV(I)/NLANES(I)

To start the queue calculations, assume time lost getting queue in motion is maximum (K1= 2.0 seconds).

RC(I) = RED TO CYCLE RATIO.
K1=2.0
GAVG(I)=FLOAT(CAVG(I)-RAVG(I))
RC(I)=FLOAT(RAVG(I))/FLOAT(CAVG(I))

CALCULATE INTERSECTION CAPACITY, X(I).
CONVERT MPH TO FEET PER SECOND.
SFR(I) IS IN VEHICLES PER HOUR  V2
CMAX IS SECONDS  
((3600 IS SECONDS PER HOUR))  V2
((2.0 IS SECONDS OF HEADWAY PER VEHICLE.))  V2
------------------------------------------------
X(I)=SFR(I)/FLOAT(CAVG(I))  V2
----------------------------------------------------
ZFAC(I)=TIME (sec) AVAILABLE MINUS START DELAY MINUS TIME FOR VEHICLE TO CLEAR INTERSECTION (YFAC).
--------------------------------
110 ZFAC(I)=GAVG(I)-K1-YFAC(I)
--------------------------------
IMU(I)=INTERSECTIONAL CAPACITY (VEH/HOUR)/SEC*SEC
IMU(I)=X(I)*ZFAC(I)

CALCULATION OF DEMAND-CAPACITY RATIO.
DC(I)=V(I)/FLOAT(IMU(I))

CALCULATE THE PAF LOOKUP LINE BASED ON THE V/C RATIO.
IF (DC(I) .LE. 0.6) THEN
IDC = 1
ELSE IF (DC(I) .LE. 0.8) THEN
IDC = 2
ELSE
IDC = 3
END IF
DELAY CALCULATIONS FOR QAVG4 ACCORDING TO 1985 HIGHWAY CAPACITY MANUAL FORMULA.

111

A1 = 0.38 * CAVG(I)
A2 = QAVG(I) / FLOAT(CAVG(I))
A3 = (1 - A2)**2
PECK1 = AMIN1(DC(I), 1.0)
A4 = 1 - A2 * PECK1
A6 = (PECK1 - 1) + SQRT((PECK1 - 1)**2 + 16 * (PECK1 / IMU(I)))
DJ(I) = (A5 + (173 * PECK1**2) * A6) * PAF(AT(I), IDC, ST(I))

APPROACH DELAY: DDJ(I) = STOPPED DELAY DJ(I) * 1.3

DDJ(I) = DJ(I) * 1.3

CONVERT APPROACH VOLUME TO VEHICLES PER SECOND.
VJ(I) = V(I) / 3600.

COMPUTE TOTAL LOST TIME.
QAVG4(I) = MAX((VJ(I)*RAVG(I)/2) + (VJ(I)*DDJ(I)), VJ(I)*RAVG(I))

**************
UNDER-CAPACITY
**************

COMPUTE NEW LINE LENGTH ASSUMING 6 METERS PER VEHICLE.
LL(I) = QAVG4(I) * 6

IF (DC(I) .LE. 1.0) GOTO 1111

OVER-CAPACITY
**************
LL1 = 3 * (V(I) - IMU(I))
LL(I) = LL1 + LL(I)
QAVG4(I) = LL1 / 6.0 + QAVG4(I)

COMPUTE NEW XL2 AND YL2 COORDINATES TO TELL PROGRAM END OF QUEUE.

1111

IF(THETA(I) .GT. 90. AND. THETA(I) .LE. 180)
+ XL2(I) = XL1(I) + LL(I) * SIN(RAD*(180. - THETA(I)))
+ YL2(I) = YL1(I) - LL(I) * COS(RAD*(180. - THETA(I)))

IF(THETA(I) .GT. 180. AND. THETA(I) .LE. 270)
+ XL2(I) = XL1(I) - LL(I) * COS(RAD*(270. - THETA(I)))
+ YL2(I) = YL1(I) - LL(I) * SIN(RAD*(270. - THETA(I))))
IF(THETA(I).GT.180.AND.THETA(I).LE.270) + YL2(I)=YL1(I)-LL(I)*SIN(RAD*(270.-THETA(I)))
IF(THETA(I).GT.270.AND.THETA(I).LE.360) + XL2(I)=XL1(I)-LL(I)*SIN(RAD*(360.-THETA(I)))
IF(THETA(I).GT.0.AND.THETA(I).LE.90) + YL2(I)=YL1(I)+LL(I)*COS(RAD*THETA(I))
IF(THETA(I).GT.0.AND.THETA(I).LE.90) + XL2(I)=XL1(I)+LL(I)*SIN(RAD*THETA(I))

--------------------------------------
| COMPUTE TOTAL EMISSION RATE FOR LINK.|
--------------------------------------
TER(I)=IDLFAC(I)*1000000./3600./6.*NLANES(I)*RC(I)  V2EF

SET ASSUMED EMISSION FACTOR.
-----------------------------
IF(MODET .LE. 1)THEN  V2KW
EFL(I)=100.  V2KW
ELSE  V2KW
EFL(I)=.055  V2KW
END IF  V2KW

-----------------------------------------------
COMPUTE NUMBER OF VEHICLES THAT MULTIPLIED BY THE E.F. OF 100.
WILL GIVE THE REQUIRED EMISSION RATE.
CALINE 3 USES Q=0.1726*VPHL*E.F., THEREFORE-
---------------------------------------------------------------
VPHL(I)=TER(I)/(.1726*EFL(I))  V2KW

CONTINUE

=================================
| METEOROLOGICAL DATA LOOP |
=================================
U = WIND SPEED (M/S)
BRG = WIND DIRECTION (DIRECTION WIND IS BLOWING FROM - IN DEGREES)
CLAS = STABILITY CLASS (A-F)
MIXH = MIXING HEIGHT (M)
AMB = AMBIENT CONCENTRATION (PPM or ug/m^3)
-----------------------------------
DO 9000 IM=1,NM
IF(IM.NE.1) THEN
NEW=0
NEW=1
END IF

READ(IN,*) U, BRG, CLAS, MIXH, AMB, VAR, DEGR, (VAI(I),I=1,2)  V2EC
IF(IDEBUG.EQ.1)WRITE(IOUT,190) U,BRG,CLAS,MIXH,AMB,VAR,DEGR,  V2EC
+ (VAI(I), I=1,2)

IF(IM.EQ.1) GOTO 9061
IF(PU.NE.U) THEN
  NEW=1
  GOTO 9061
END IF
IF(PCLAS.NE.CLAS) THEN
  NEW=1
  GOTO 9061
END IF
IF(PMIXH.NE.MIXH) THEN
  NEW=1
  GOTO 9061
END IF
IF(PAMB.NE.AMB) THEN
  NEW=1
END IF

9061 IF(VAR.EQ.'N') GOTO 9066

-----------------------------------
Determine the consecutive wind angle multipliers
-----------------------------------
DO 9059 J=1,361
  IF(J.EQ.1) THEN
    VA(J)=VAI(1)
    GOTO 9059
  END IF
  VA(J)=VA(J-1)+1
  IF(VA(J).EQ.VAI(2)) THEN
    NANGLE=J
    GOTO 9065
  END IF
9059 CONTINUE

-----------------------------------
Set default wind directions if not given by the user
-----------------------------------
9065 IF(DEGR.EQ.0) THEN
  DEGR=3
  NANGLE=9
  VA(1)=-4
  DO 9064 K3=2,NANGLE
  VA(K3)=VA(K3-1)+1
  VA(K3)=VA(K3-1)+1
  NANGLE=9
  END IF
9066 IF(VAR.EQ.'N') NANGLE=1

OPEN temporary file.
OPEN(16,STATUS='UNKNOWN',FILE='CAL3QHC.U16')

*********************
Wind direction loop
*********************
BRG2=BRG
DO 8999 K4=1,NANGLE
  BRG=BRG2+(DEGR*VA(K4))
  IF (BRG .GT. 360) BRG = BRG - 360.
WRITE(IOUT,112) RUN,BRG
112 FORMAT(1X,A40,' - ANGLE: ',F4.0,'(degrees)')

BRGV(K4)=BRG
8020 BRG1=BRG

---------------------
WIND ANGLE FOR OUTPUT
---------------------
BRG=BRG+180.
IF (BRG.GE.360.) BRG=BRG-360.

--------------------------------
VIRTUAL DISPLACEMENT VECTORS
--------------------------------
XVEC=COS(RAD*(450.-BRG))
YVEC=SIN(RAD*(450.-BRG))

CORRECTIONS FOR AVERAGING TIME AND SURFACE ROUGHNESS
-----------------------------------------------------
AFAC=(ATIM/3.0)**.2

*** ALOG(SIGMA Y) AT 1 M AND 10 M
SY1=ALOG(AY1(CLAS)*((Z0/3.)**.2)*AFAC)
SY10=ALOG(AY2(CLAS)*((Z0/3.)**.07)*AFAC)

PY1=EXP(SY1)
PY2=(SY10-SY1)/DREF
SZ10=ALOG(AZ(CLAS)*((Z0/10.)**.07)*AFAC)

-------------------------
ZERO CONCENTRATION MATRIX
-------------------------
DO 720 I=1,NL
   DO 720 J=1, NR
      C(I,J)=0.
720 CONTINUE

----------
LINK ROUTINE
----------
DO 8000 IL=1,NL
   VPH=VPHL(IL)
   EF=EFL(IL)
   IF (TYP(IL).EQ.'DP'.OR.TYP(IL).EQ.'FL') GOTO 870
   H=HL(IL)
   GOTO 880
870 H=0.
880 W=WL(IL)

 LINK ROUTINE
 -----------
 W2=W/2.

*** LINEAL SOURCE STRENGTH PARALLEL TO HIGHWAY
   IN MICRO-GRAMS/(METER*SEC)
Q1=0.1726*VPH*EF
XD = XL2(IL) - XL1(IL)
YD = YL2(IL) - YL1(IL)
ABSXD = DABS(XD)
ABSQD = ABSXD / LL(IL)
IF (ABSQD .GT. 1.0) ABSQD = 1.0

*** LINK BEARING
LB = DEG * DACOS(ABSQD)

*** LINK BEARING MATRIX FOR OUTPUT
IF (XD .GT. 0. .AND. YD .GE. 0.) LB = 90. - LB
IF (XD .GE. 0. .AND. YD .LT. 0.) LB = 90. + LB
IF (XD .LT. 0. .AND. YD .LE. 0.) LB = 270. - LB
IF (XD .LE. 0. .AND. YD .GT. 0.) LB = 270. + LB
LBRG(IL) = LB

*** WIND ANGLE WITH RESPECT TO LINK
PHI = ABS(BRG - LB)

*** SET ELEMENT GROWTH BASE
IF (PHI .LE. 90.) GOTO 7600
IF (PHI .GE. 270.) GOTO 5000
PHI = ABS(PHI - 180.)
GOTO 7600
5000 PHI = ABS(PHI - 360.)
7600 IF (PHI .LT. 20.) GOTO 7630
IF (PHI .LT. 50.) GOTO 7620
IF (PHI .LT. 70.) GOTO 7610
BASE = 4.
GOTO 7650
7610 BASE = 2.
GOTO 7650
7620 BASE = 1.5
GOTO 7650
7630 BASE = 1.1

*** CONVERSION OF PHI FROM DEGREES TO RADIANS
7650 PHI = RAD * (PHI)

IF (PHI .GT. 1.5706) PHI = 1.5706
IF (PHI .LT. 0.00017) PHI = 0.00017

-----------------
DEPRESSED SECTION
-----------------
IF (HL(IL) .LT. -1.5) GOTO 7700
DSTR = 1.
HDS = 1.
GOTO 7800
7700 HDS = HL(IL)
DSTR = 0.72 * ABS(HDS) ** 0.83

*** RESIDENCE TIME
7800 TR = DSTR * W2 / U

*** SIGMA Z POWER CURVE
SGZ1 = ALOG((1.8 + 0.11 * TR) * (ATIM / 30.) ** 0.2)

*** ALOG(SIGMA Z) AT W2
PZ2 = (SZ10 - SGZ1) / (DREF - ALOG(W2))
PZ1 = EXP((SZ10 + SGZ1 - PZ2 * (DREF + ALOG(W2))) / 2.)
DO 6000 IR=1,NR

*** OFFSET LENGTH
A=(XR(IR)-XL1(IL))**2+(YR(IR)-YL1(IL))**2
B=(XR(IR)-XL2(IL))**2+(YR(IR)-YL2(IL))**2
L=(B-A-LL(IL))**2/(2.*LL(IL))

*** RECEPTOR DISTANCE
IF (A.GT.L**2) D=DSQRT(A-L**2)
IF (A.LE.L**2) D=0.

*** UPWIND AND DOWNWIND LENGTH
UWL=LL(IL)+L
DWL=L

IF(D.EQ.0.D0) DVIR=1.D0
IF(D.NE.0.D0) DVIR=D
XPR=XR(IR)+DVIR*XVEC
YPRI=YR(IR)+DVIR*YVEC
APRI=(XPR-XL1(IL))**2+(YPRI-YL1(IL))**2
BPRI=(XPR-XL2(IL))**2+(YPRI-YL2(IL))**2
LPRI=(BPRI-APRI-LL(IL)**2)/(2.*LL(IL))
IF (APRI.GT.LPRI**2) DPRI=DSQRT(APRI-LPRI**2)
IF (APRI.LE.LPRI**2) DPRI=0.
IF (DPRI.LT.D) GOTO 5725,5735,5735
IF (LPRI-L) 5725,5735,5735

5725 TEMP=UWL
UWL=-DWL
DWL=-TEMP
5735 IF (TYP(IL).EQ.'AG' .OR.TYP(IL).EQ.'BR') GOTO 5750

D1=W2+2.*ABS(HL(IL))
D2=W2

*** SINGLE PRECISION TO DOUBLE PRECISION FOR LOGICAL 'IF'
IF (DABS(D).GE.D1) GOTO 5750

*** 2:1 SLOPE ASSUMED
IF (DABS(D).LE.D2) Z=ZR(IR)-HL(IL)
IF (DABS(D).GT.D2)
  Z=ZR(IR)-HL(IL)*(1.-((DABS(D)-W2)/(2.*ABS(HL(IL)))))
GOTO 3050
5750 Z=ZR(IR)

-----------------------
CALINE3 ROUTINE
-----------------------
DETERMINES DIRECTION ALONG LINK
+1 --> UPWIND ELEMENTS; -1 --> DOWNWIND ELEMENTS
-----------------------
3050 SGN=1.

*** ELEMENT NUMBER, STEP FACTOR AND LOOP END INITIALIZATION
3060 NE=0.
STP=1.
FINI=1.

IF (SGN.EQ.1. .AND.
  UWL.LE.0. .AND.
+       DWL.LT.0.) SGN=-1.
3080   IF (SGN.EQ.-1. .AND.
+       UWL.GT.0. .AND.
+       DWL.GE.0.) GOTO 6000
|
|       ------------
|       ELEMENT LOOP
|       ------------
|
|       *** INITIALIZATION OF ELEMENT LIMITS
ED1=0.
ED2=SGN*W
|
| 3110   IF (SGN.EQ.-1.) GOTO 3160
IF (ED1.LE.DWL .AND. ED2.LE.DWL) GOTO 3770
IF (ED1.GT.DWL .AND. ED2.LT.UWL) GOTO 3250
IF (ED1.LE.DWL) ED1=DWL
IF (ED2.LT.UWL) GOTO 3250
ED2=UWL
SGN=-1.
NE=-1.
GOTO 3250
|
| 3160   IF (ED1.GE.UWL .AND. ED2.GE.UWL) GOTO 3770
IF (ED1.LT.UWL .AND. ED2.GT.DWL) GOTO 3250
IF (ED1.GE.UWL) ED1=UWL
IF (ED2.GT.DWL) GOTO 3250
ED2=DWL
FINI=0.
|
|       *** ELEMENT HALF-DISTANCE
EL2=ABS(ED2-ED1)/2.
|
|       *** ELEMENT CENTERLINE DISTANCE
ECLD=(ED1+ED2)/2.
|
|       *** EQUIVALENT LINE HALF-LENGTH
ELL2=W2/COS(PHI)+(EL2-W2*TAN(PHI))*SIN(PHI)
|
|       *** CENTRAL SUB-ELEMENT HALF-LENGTH
IF (PHI.GE.ATAN(W2/EL2)) CSL2=W2/SIN(PHI)
IF (PHI.LT.ATAN(W2/EL2)) CSL2=EL2/COS(PHI)
|
|       *** CENTRAL SUB-ELEMENT HALF-WIDTH
EM2=ABS((EL2-W2/TAN(PHI))*SIN(PHI))
|
|       *** PERIPHERAL SUB-ELEMENT WIDTH
EN2=(ELL2-EM2)/2.
|
|       ----------------------
|       RECEPTOR DISTANCE LOOP
|       ----------------------
|
|       *** CENTRAL SUB-ELEMENT LINEAL SOURCE STRENGTH
QE=Q1*CSL2/W2
|
|       *** ELEMENT FETCH
FET=(ECLD+D*TAN(PHI))*COS(PHI)
|
|       *** Y DISTANCE FROM ELEMENT CENTER TO RECEPTOR
HYP=ECLD**2+D**2
SIDE=FET**2
IF (SIDE.GT.HYP) YE=0.
IF (SIDE.LE.HYP) YE=D SQRT(HYP-SIDE)
IF (FET.LE.-CSL2) GOTO 3830

*** ELEMENT DOES NOT CONTRIBUTE
IF (FET.GE.CSL2) GOTO 3320

*** RECEPTOR WITHIN ELEMENT
DETERMINE SIGMA Y AND SIGMA Z
QE=QE*(FET+CSL2)/(2.*CSL2)
FET=(CSL2+FET)/2.
3320   SGZ=PZ1*FET**PZ2
KZ=SGZ**2*U/(2.*FET)

*** VERTICAL DIFFUSIVITY ESTIMATE
SGY=PY1*FET**PY2

*** SOURCE STRENGTH - WIND SPEED FACTOR
FAC1=0.399/(SGZ*U)

----------------------------------
ADJUSTMENT FOR ELEMENT END EFFECT
(POLYNOMIAL APPROXIMATION)
----------------------------------
Y(1)=YE+ELL2
Y(2)=Y(1)-EN2
Y(3)=Y(2)-EN2
Y(4)=Y(3)-2*EM2
Y(5)=Y(4)-EN2
Y(6)=Y(5)-EN2

----------------------------------
SUB ELEMENT SOURCE STRENGTH LOOP
----------------------------------
DO 3480 I=1,6
   LIM=ABS(Y(I)/SGY)
   T=1./((1.+0.23164*LIM)
   ARG=LIM**2/(-2.)
   IF (LIM.GT.5.) INTG(I)=0.
   IF (LIM.LE.5.) INTG(I)=0.3989*EXP(ARG)*(0.3194*T**3-1.7815*T**4+1.3303*T**5)
3480   CONTINUE

FAC2=0.
DO 3530 I=1,5
   IF (((SIGN(1.,Y(I))).EQ.(SIGN(1.,Y(I+1))))
      +PD=DABS(INTG(I+1)-INTG(I))
   IF (((SIGN(1.,Y(I))).NE.(SIGN(1.,Y(I+1))))
      +PD=1.-INTG(I)-INTG(I+1)
3530   CONTINUE

** NORMAL PROBABILITY DENSITY FUNCTION
   FAC2=FAC2+PD*QE*WT(I)
3530   CONTINUE

FACT=FAC1*FAC2

------------------
DEPRESSED SECTION
------------------
IF (HDS.LT.-1.5 .AND.DABS(D).LT.(W2-3.*HDS)) GOTO 3560
GOTO 3580
3560   IF (DABS(D).LE.W2) FACT=FACT*DSTR
IF (DABS(D).GT.W2) FACT=FACT*(DSTR-(DSTR-1.)*(DABS(D)-W2)/(-3.*HDS))

*** ADJUST FOR DEPRESSED SECTION WIND SPEED

*** DEPOSITION CORRECTION

3580 FAC3=0.
IF (V1.EQ.0.) GOTO 3670
ARG=V1*SGZ/(KZ*SQRT(2.))+(Z+H)/(SGZ*SQRT(2.))
IF (ARG.GT.5.) GOTO 3770
T=1./(1.+0.47047*ARG)
EFRC=(.3480242*T-.0958798*T**2+.7478556*T**3)*
+EXP(-1.*ARG**2)
FAC3=(SQRT(2.*PI)*V1*SGZ*EXP(V1*(Z+H)/KZ+.5*(V1*SGZ/KZ)**2)
+*EFRC)/KZ
IF (FAC3.GT.2.) FAC3=2.

*** SETTLING CORRECTION

3670 IF (VS.EQ.0.) GOTO 3710
FAC4=EXP(-VS*(Z-H)/(2.*KZ)-(VS*SGZ/KZ)**2/8.)
FACT=FACT*FAC4

*** INCREMENTAL CONCENTRATION

3710 FAC5=0.
CNT=0.
3720 EXLS=0.
3730 ARG1=-0.5*((Z+H+2.*CNT*MIXH)/SGZ)**2
IF (ARG1.LT.-44.) EXP1=0.
IF (ARG1.GE.-44.) EXP1=EXP(ARG1)
ARG2=-0.5*((Z-H+2.*CNT*MIXH)/SGZ)**2
IF (ARG2.LT.-44.) EXP2=0.
IF (ARG2.GE.-44.) EXP2=EXP(ARG2)
FAC5=FAC5+EXP1+EXP2

-----

BYPASS MIXING HEIGHT CALCULATION

-----

IF (MIXH.GE.1000.) GOTO 3760

IF ((EXP1+EXP2+EXLS).EQ.0. .AND. CNT.LE.0.) GOTO 3760
3740 IF (CNT.GT.0.) GOTO 3750
CNT=ABS(CNT)+1.
GOTO 3720
3750 CNT=-1.*CNT
EXLS=EXP1+EXP2
GOTO 3730

*** INCREMENTAL CONCENTRATION FROM ELEMENT

3760 INC=FACT*(FAC5-FAC3)

*** SUMMATION OF CONCENTRATIONS
C(IL,IR)=C(IL,IR)+INC

3770 IF (FINI.EQ.0.) GOTO 6000
NE=NE+1.

*** STEP FACTOR
STP=BASE**NE

*** INCREMENT TO NEXT ELEMENT
IF (NE.EQ.0.) GOTO 3080
ED1=ED2
ED2 = ED2 + SGN * STP * W

! GOTO 3110
3830 IF (SGN.EQ.1.) GOTO 3770

6000 CONTINUE
8000 CONTINUE

---------------------------------------------
CONVERT CONC. OF POLLUTANTS FROM MICROGRAMS/M**3 TO PPM
---------------------------------------------

DO 1020 I=1,NL
   DO 1010 J=1,NR
      C(I,J) = C(I,J) * FPPM
   1010 CONTINUE
1020 CONTINUE

|=| OUTPUT |
|=|

IF(K4.GT.1) GOTO 1249

*PRINT SITE & METEOROLOGICAL VARIABLES*

IF(IM.NE.1) THEN
   IF(NEW.EQ.1) THEN
      PGCT = PGCT + 1
      ICOUNT = 7
      WRITE(IPO,202) CHAR(12), PGCT
      WRITE(IPO,210) JOB, RUN
      WRITE(IPO,221)
      IF (VAR.EQ.'Y') GOTO 1005
      IF (MODET.EQ.0) THEN
         WRITE(IPO,240) U, CLAS, STB(CLAS), ATIM, MIXH, AMB, BRG1
      ELSE IF (MODET.GT.1) THEN
         WRITE(IPO,242) U, CLAS, STB(CLAS), ATIM, MIXH, AMB
      ELSE
         WRITE(IPO,241) U, CLAS, STB(CLAS), ATIM, MIXH, AMB
      END IF
   GOTO 1249
   ELSE IF (MODET.GT.1) THEN
      WRITE(IPO,242) U, CLAS, STB(CLAS), ATIM, MIXH, AMB
   ELSE
      WRITE(IPO,241) U, CLAS, STB(CLAS), ATIM, MIXH, AMB
   END IF
   GOTO 1249
1005 IF (MODET.EQ.0) THEN
      WRITE(IPO,231) U, CLAS, STB(CLAS), ATIM, MIXH, AMB
   ELSE IF (MODET.GT.1) THEN
      WRITE(IPO,233) U, CLAS, STB(CLAS), ATIM, MIXH, AMB
   ELSE
      WRITE(IPO,232) U, CLAS, STB(CLAS), ATIM, MIXH, AMB
   END IF
   GOTO 1249
END IF
! IF(IM.NE.1) GOTO 1249
PGCT = PGCT + 1
IF (MODET.LE.1) THEN

112
WRITE (IPO,200) CHAR(12), PGCT V2KW
ELSE V2KW
WRITE (IPO,201) CHAR(12), PGCT V2KW
END IF V2KW
WRITE (IPO,210) JOB, RUN V2KW
C WRITE (IPO, 462) IMON, IDAY, IYR V2KW
C WRITE (IPO, 463) IIHR, IMIN, ISEC V2KW
WRITE (IPO,'(6X,A6,A8,2X,A7,A5/)) V2EC/V2KW
+ DATE: ', IDATE, ' TIME: ', ITIME V2EC/V2KW
IF (MODET .EQ. 0) THEN
WRITE(IPO,23) MODE(1:1) V2KW
END IF
IF (MODET .EQ. 1) THEN
WRITE(IPO,24) MODE(1:1) V2KW
END IF
!                                          ! | NEW STATMENTS ADDED FOR | V2KW
! | SIX NEW DIFFERENT MSAT MODES | V2KW
!                                          ! -------------------------
IF (MODET .EQ. 2) THEN
WRITE(IPO,25) MODE(1:1) V2KW
END IF
IF (MODET .EQ. 3) THEN
WRITE(IPO,26) MODE(1:1) V2KW
END IF
IF (MODET .EQ. 4) THEN
WRITE(IPO,27) MODE(1:1) V2KW
END IF
IF (MODET .EQ. 5) THEN
WRITE(IPO,28) MODE(1:1) V2KW
END IF
IF (MODET .EQ. 6) THEN
WRITE(IPO,29) MODE(1:1) V2KW
END IF
IF (MODET .EQ. 7) THEN
WRITE(IPO,30) MODE(1:1) V2KW
END IF
IF (MODET .EQ. 8) THEN
WRITE(IPO,31) MODE(1:1) V2KW
END IF
IF (MODET .EQ. 9) THEN
WRITE(IPO,32) MODE(1:1) V2KW
END IF
IF (MODET .EQ. 10) THEN
WRITE(IPO,33) MODE(1:1), TRIM(COMPOUND) V2KW
END IF
IF (MODET .EQ. 11) THEN
WRITE(IPO,34) MODE(1:1), TRIM(COMPOUND) V2KW
END IF
WRITE(IPO,220) V2KW
WRITE(IPO,230) VS1, VD1, Z0 V2KW
IF (VAR.EQ.'Y') GOTO 1205 V2KW
1211 IF ( MODET .EQ. 0) THEN
WRITE(IPO,240) U, CLAS, STB(CLAS), ATIM, MIXH, AMB, BRG1 V2KW
! ELSE IF (MODET .GT. 1) THEN
WRITE(IPO,242) U, CLAS, STB(CLAS), ATIM, MIXH, AMB, BRG1 V2KW
! ELSE
WRITE(IPO,241) U, CLAS, STB(CLAS), ATIM, MIXH, AMB, BRG1 V2KW
END IF
GOTO 1206 V2KW
1205 IF ( MODET .EQ. 0) THEN
V2KW
WRITE(IPO,231) U, CLAS, STB(CLAS), ATIM, MIXH, AMB
!
ELSE IF (MODET .GT. 1) THEN
WRITE(IPO,233) U, CLAS, STB(CLAS), ATIM, MIXH, AMB
!
ELSE
WRITE(IPO,232) U, CLAS, STB(CLAS), ATIM, MIXH, AMB
END IF
!
************************
* PRINT LINK VARIABLES *
************************

1206 ICOUNT=ICOUNT+12
KQ=1
DO 1250 I=1,NL
IF(KQ.EQ.1) THEN
WRITE(IPO,250)
IF(MODET .LE. 1) THEN
IF(IOPT.EQ.1) THEN
WRITE(IPO,265) V2EF
WRITE(IPO,275) V2EF
ELSE
WRITE(IPO,260)
WRITE(IPO,270) V2EF
END IF
ELSE
WRITE(IPO,261)
WRITE(IPO,271) V2EF
END IF
IF (MODET .LE. 1) THEN
WRITE(IPO,280) V2EF/V2KW
ELSE
WRITE(IPO,281) V2KW
END IF
ICOUNT=ICOUNT+4
KQ=0
END IF!
IF(ICOUNT.GE.60) THEN
PGCT=PGCT+1
WRITE(IPO,202) CHAR(12), PGCT
WRITE (IPO,210) JOB, RUN
C WRITE (IPO, 462) IMON, IDAY, IYR V2KW
C WRITE (IPO, 463) HHHR, MIN, ISEC V2KW
' DATE: ',IDATE,' TIME: ',ITIME V2EF/V2KW
+ WRITE(IPO,250)
IF(MODET .LE. 1) THEN
IF(IOPT.EQ.1) THEN
WRITE(IPO,265) V2EF/V2KW
WRITE(IPO,275) V2KW
ELSE
WRITE(IPO,260)
WRITE(IPO,270) V2EF/V2KW
END IF
ELSE
WRITE(IPO,261)
WRITE(IPO,271) V2KW
END IF
IF(IOPT.EQ.1) THEN
  WRITE(IPO,266)
  WRITE(IPO,276)
ELSE
  WRITE(IPO,261)
  WRITE(IPO,271)
END IF
! IF(MODET .LE. 1) THEN
  WRITE(IPO,280)
ELSE
  WRITE(IPO,281)
END IF
! ICOUNT=9
END IF
!
IF(IOPT.NE.1) THEN
  
  IF(MODET .LE. 1) THEN
    IF(IQ(I).EQ.2) THEN
      WRITE(IPO,290) COD(I),LNK(I),XL1(I),YL1(I),XL2(I),
                   YL2(I),LL(I),LBRG(I),TYP(I),VPHL(I),
                   EFL(I),HL(I),WL(I),DC(I),QAVG4(I)
    ELSE
      WRITE(IPO,290) COD(I),LNK(I),XL1(I),YL1(I),XL2(I),
                   YL2(I),LL(I),LBRG(I),TYP(I),VPHL(I),
                   EFL(I),HL(I),WL(I)
    END IF
  ELSE
    IF(IQ(I).EQ.2) THEN
      WRITE(IPO,291) COD(I),LNK(I),XL1(I),YL1(I),XL2(I),
                   YL2(I),LL(I),LBRG(I),TYP(I),VPHL(I),
                   EFL(I),HL(I),WL(I),DC(I),QAVG4(I)
    ELSE
      WRITE(IPO,291) COD(I),LNK(I),XL1(I),YL1(I),XL2(I),
                   YL2(I),LL(I),LBRG(I),TYP(I),VPHL(I),
                   EFL(I),HL(I),WL(I)
    END IF
  END IF
ELSE
  XW1=XL1(I)*PSCALE
  XW2=XL2(I)*PSCALE
  YW1=YL1(I)*PSCALE
  YW2=YL2(I)*PSCALE
  LLW=LL(I)*PSCALE
  HLW=HL(I)*PSCALE
  WLW=WL(I)*PSCALE
  IF(MODET .LE. 1) THEN
    IF(IQ(I).EQ.2) THEN
      WRITE(IPO,290) COD(I),LNK(I),XW1,YW1,XW2,
                   YW2,LLW,LBRG(I),TYP(I),VPHL(I),
                   EFL(I),HLW,WLW,DC(I),QAVG4(I)
    ELSE
      WRITE(IPO,290) COD(I),LNK(I),XW1,YW1,XW2,
                   YW2,LLW,LBRG(I),TYP(I),VPHL(I),
                   EFL(I),HLW,WLW
    END IF
  ELSE
    WRITE(IPO,290) COD(I),LNK(I),XW1,YW1,XW2,
                   YW2,LLW,LBRG(I),TYP(I),VPHL(I),
                   EFL(I),HLW,WLW
  END IF
ELSE
  V2EF

V2EF/V2KW
V2KW/V2KW
V2KW
V2KW/V2KW
V2KW
V2KW
V2KW/V2KW
V2KW
V2KW
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V2KW
V2KW
V2KW
IF(IQ(I).EQ.2)THEN                                                     V2KW
    WRITE(IPO,291) COD(I),LNK(I),XW1,YW1,XW2,                           V2KW
    +       YW2,LLW,LIBR(I),TYP(I),VPHL(I),                           V2KW
    +       EFL(I),HLW,WLW,DC(I),QAVG4(I)                            V2KW
! ELSE                                                                   V2KW
    WRITE(IPO,291) COD(I),LNK(I),XW1,YW1,XW2,                         V2KW
    +       YW2,LLW,LIBR(I),TYP(I),VPHL(I),                           V2KW
    +       EFL(I),HLW,WLW                                            V2KW
END IF                                                                  V2KW
END IF                                                                  V2EF
ICOUNT=ICOUNT+1                                                         V2EF
1250 CONTINUE                                                            V2EF

***************************************************************************** V2EF
* PRINT ADDITIONAL QUEUE LINK PARAMETERS *                               V2EF
***************************************************************************** V2EF
ICOUNT=61                                                                V2EF
DO 1154 I=1,NL                                                           V2EF
IF(ICOUNT.GE.60) THEN                                                    V2EF
    PGCT=PGCT+1                                                           V2EF
    WRITE(IPO,202) CHAR(12), PGCT                                       V2EF
    WRITE (IPO,210) JOB, RUN                                             V2EF
    C WRITE (IPO, 462) IMON, IDAY, IYR                                  V2EF/V2KW
    C WRITE (IPO, 463) IIHR, IMIN, ISEC                                 V2EF/V2KW
    +         \"DATE: \',IDATE,\' TIME: \',ITIME\"                         V2EF/V2KW
    ICOUNT = 4                                                             V2EF
    IF (MODET .GE. 0) THEN                                               V2EF
        WRITE(IPO,401)                                                  V2EF
        WRITE(IPO,402)                                                  V2EF
        WRITE(IPO,403)                                                  V2EF
        WRITE(IPO,404)                                                  V2EF
        WRITE(IPO,405)                                                  V2EF
        ICOUNT = ICOUNT + 6                                             V2EF
    END IF                                                                V2EF
END IF                                                                  V2EF
IF(IQ(I).EQ.2)THEN                                                        V2EF
    IF(MODET .LE. 1)THEN                                                 V2EF
        WRITE(IPO,406)COD(I),LNK(I),CAVG(I),RAVG(I),YFAC(I),            V2EF/V2KW
        +         IV(I),SFR(I),IDLFA(I),ST(I),AT(I)                      V2EF/V2KW
        ICOUNT=ICOUNT+1                                                  V2EF/V2KW
    ELSE                                                                 V3KW
        WRITE(IPO,407)COD(I),LNK(I),CAVG(I),RAVG(I),YFAC(I),            V2KW
        +         IV(I),SFR(I),IDLFA(I),ST(I),AT(I)                      V2KW
        ICOUNT=ICOUNT+1                                                  V2KW
    END IF                                                                V2KW
END IF                                                                  V2KW
1154 CONTINUE                                                            V2EF

***************************************************************************** V2EF
* SUMMARY OUTPUT FOR RECEPTOR LOCATIONS *                                 V2EF
***************************************************************************** V2EF
ICOUNT=ICOUNT+1                                                          V2EF
KQ=1
DO 1151 I=1,NR
    IF(KQ.EQ.1)THEN
        WRITE(IPO,300)
    IF(IOPT.EQ.1)THEN
        WRITE(IPO,310)
    ELSE
        WRITE(IPO,309)
    END IF
    WRITE(IPO,321)
    WRITE(IPO,331)
    ICOUNT=ICOUNT+4
    KQ=0
ENDIF
!
IF(ICOUNT.GE.60) THEN
    PGCT=PGCT+1
    WRITE(IPO,202) CHAR(12), PGCT
    WRITE (IPO,210)JOB,RUN
    WRITE (IPO,462) IMON, IDAY, IYR
    WRITE (IPO,463) IIHR, IMIN, ISEC
    WRITE(IPO,'(6X,A6,A8,2X,A7,A5/)') 'DATE: ',IDATE,' TIME: ',ITIME
    WRITE(IPO,300)
    IF(IOPT.EQ.1)THEN
        WRITE(IPO,310)
    ELSE
        WRITE(IPO,309)
    ENDIF
    WRITE(IPO,321)
    WRITE(IPO,331)
    ICOUNT=10
ENDIF
!
IF(IOPT.EQ.1)THEN
    XWR=XR(I)*PSCALE
    YWR=YR(I)*PSCALE
    ZWR=ZR(I)*PSCALE
    WRITE (IPO,441) I,RCP(I),XWR,YWR,ZWR
ELSE
    WRITE (IPO,441) I,RCP(I),XR(I),YR(I),ZR(I)
ENDIF
ICOUNT=ICOUNT+1
!
1151 CONTINUE
*
** ***************
* MODEL RESULTS *
** ***************
*
** -------------------------------------------
** CALCULATION OF THE TOTAL POLLUTANT CONC. AT EACH RECEPTOR
** PRODUCED BY ALL THE LINKS, FOR EACH WIND ANGLE.
** -------------------------------------------
!
1249 DO 1152 I=1,NR
    CSUM=0.0
    DO 1252 J=1,NL
        C(J,I)=10.*C(J,I)+.5
        K=C(J,I)
        C(J,I)=K/10.
        CSUM=CSUM+C(J,I)
C!
CONTINUE
!
DO 1252 J=1,NL
C(J,I)=C(J,I)
CSUM=CSUM+C(J,I)
!
1252 CONTINUE
!
CSUM=CSUM+AMB
CON(I)=CSUM
!
*** Keep in memory only the concentrations (for each receptor per link) for the wind angle that produces the maximum sums.
!
IF (K4.EQ.1) THEN
CRMAX(I)=CSUM
DO 1153 J=1,NL
COMAX(J,I)=C(J,I)
1153 CONTINUE
ANGMAX(I)=BRGV(K4)
IF (CSUM .GT. CMAX) THEN
CMAx = CSUM
IRMAX = I
END IF
ELSE
IF(CSUM.GT.CRMAX(I)) THEN
DO 1254 J=1,NL
COMAX(J,I)=C(J,I)
1254 CONTINUE
ANGMAX(I)=BRGV(K4)
CRMAX(I) =CSUM
END IF
IF (CSUM .GT. CMAX) THEN
CMAx = CSUM
IRMAX = I
END IF
END IF
!
1152 CONTINUE
!
IF(K4.GT.1) THEN
IF(ICOUNT.GE.60) THEN
PGCT=PGCT+1
WRITE(IPO,202) CHAR(12), PGCT
WRITE(IPO,210) JOB, RUN
WRITE(IPO,8500)
IF (MODET .EQ. 0) THEN
WRITE(IPO,8510)
ELSE IF (MODET .GT. 1) THEN
WRITE(IPO,8515)
ELSE
WRITE(IPO,8520)
END IF
!
ELSE IF (MODET .GT. 1) THEN
WRITE(IPO,8513) (REC(J),J=1,NR)
WRITE(IPO,8514) (X1(J),J=1,NR)
ELSE
WRITE(IPO,8511) (REC(J),J=1,NR)
WRITE(IPO,8512) (X1(J),J=1,NR)
END IF
END IF
ICOUNT=8
END IF
GOTO 1189
END IF

LIN=ICOUNT+13+NANGLE+4
IF(LIN.GE.60) THEN
PGCT=PGCT+1
WRITE(IPO,202) CHAR(12), PGCT
WRITE(IPO,210) JOB, RUN
ICOUNT=3
END IF

WRITE(IPO,8399)
WRITE(IPO,8400)
ICOUNT=ICOUNT+9

1189 IF(K4.GT.1) GOTO 8998
IF(VAR.EQ.'N') GOTO 1190

TRANGE=BRGV(1)
BRANGE=BRG2+(DEGR*VA(NANGLE))
WRITE(IPO,8499) TRANGE, BRANGE
ICOUNT=ICOUNT+2

C 1190 WRITE(IPO,8500)
C IF (MODET .EQ. 0) THEN
C WRITE(IPO,8510)
C !
C ELSE IF (MODET .GT. 1) THEN
C WRITE(IPO,8515)
C !
C ELSE
C WRITE(IPO,8520)
C END IF
C IF(NR.LE.20)THEN
C IF(MODET .LE. 1) THEN
C WRITE(IPO,8511) (REC(J),J=1,NR)
C WRITE(IPO,8512) (X1(J),J=1,NR)
C ELSE
C WRITE(IPO,8513) (REC(J),J=1,NR)
C WRITE(IPO,8514) (X1(J),J=1,NR)
C END IF
C ELSE
C IF(MODET .LE. 1) THEN
C WRITE(IPO,8511) (REC(J),J=1,20)
C WRITE(IPO,8512) (X1(J),J=1,20)
C ELSE
C WRITE(IPO,8513) (REC(J),J=1,20)
C WRITE(IPO,8514) (X1(J),J=1,20)
C END IF
C END IF
C ICOUNT=ICOUNT+4
C
1190 WRITE(IPO,8500)
IF (MODET .LE. 1) THEN
IF (FPPM .NE. 1) THEN
WRITE(IPO,8510)
ELSE
WRITE(IPO,8520)
END IF
IF(NR.LE.20)THEN
WRITE(IPO,8511) (REC(J),J=1,NR)
WRITE(IPO,8512) (X1(J),J=1,NR)
ELSE
WRITE(IPO,8511) (REC(J),J=1,20)
WRITE(IPO,8512) (X1(J),J=1,20)
ENDIF
ELSE
WRITE(IPO,8515)
IF(NR.LE.13)THEN
WRITE(IPO,8513) (REC(J),J=1,NR)
WRITE(IPO,8514) (X1(J),J=1,NR)
ELSE
WRITE(IPO,8513) (REC(J),J=1,13)
WRITE(IPO,8514) (X1(J),J=1,13)
ENDIF
ENDIF
ICOUNT=ICOUNT+4
!
8998 IF (NR.LE.20)THEN
   IF (MODET .EQ. 0) THEN
      WRITE(IPO,8530) BRG1,(CON(J),J=1,NR)
   ELSE IF (MODET .GT. 1) THEN
      WRITE(IPO,8532) BRG1,(CON(J),J=1,NR)
   ELSE
      WRITE(IPO,8531) BRG1,(CON(J),J=1,20)
   END IF
   WRITE(16,165) BRG1,(CON(J),J=21,NR)
   END IF
ELSE
IF (FPPM .NE. 1) THEN
   WRITE(IPO,8530) BRG1,(CON(J),J=1,NR)
ELSE
   WRITE(IPO,8531) BRG1,(CON(J),J=1,20)
ENDIF
ENDIF
ELSE
IF (NR .LE. 13)THEN
WRITE(IPO,8532) BRG1,(CON(J),J=1,13)
ELSE
WRITE(IPO,8532) BRG1,(CON(J),J=1,13)
ENDIF
WRITE(16,165) BRG1,(CON(J),J=21,NR)  
END IF  
ICOUNT=ICOUNT+1  
!
8999 CONTINUE  

**************************************************************************
CHECK AND PRINT MAXIMUM OF 20 OR 13 RECEPTORS PER PAGE.  
**************************************************************************
!
IF(MODET .LE. 1) THEN  
MAXRPT=20  
IRP=1  
ELSE  
MAXRPT=13  
IRP=1  
END IF  
!
!  
!     CHECK IF RECEPTORS EQUALS 20 OR LESS OR 13 OR LESS FOR MSATS  
!  
!     IF (NR.LE.MAXRPT) THEN  
NRP=NR  
ELSE  
NRP=MAXRPT  
END IF  
!
9019 IF(VAR .EQ. 'Y') THEN  
!     IF(MODET .LE. 1) THEN  
WRITE(IPO,8512) (X1(J),J=IRP,NRP)  
ELSE  
WRITE(IPO,8514) (X1(J),J=IRP,NRP)  
END IF  
!
!     IF(MODET .EQ. 0) THEN  
WRITE(IPO,9040) (CRMAX(I) ,I=IRP,NRP)  
ELSE IF (MODET .GT. 1) THEN  
WRITE(IPO,9045) (CRMAX(I) ,I=IRP,NRP)  
ELSE  
WRITE(IPO,9050) (CRMAX(I) ,I=IRP,NRP)  
END IF  
!
!     IF(MODET .LE. 1) THEN  
WRITE(IPO,9042) (ANGMAX(I),I=IRP,NRP)  
WRITE(IPO,'(1X)')  
ELSE  
WRITE(IPO,9044) (ANGMAX(I),I=IRP,NRP)  
WRITE(IPO,'(1X)')  
END IF  
!
END IF  
!
IF(NR.LE.MAXRPT)GO TO 9023  
IF (MODET .LE. 1) THEN  
MAXRPT=MAXRPT+20  
IRP=IRP+20  
ELSE  
MAXRPT=MAXRPT+13  
IRP=IRP+13  
END IF  
IF(NR.LE.MAXRPT)THEN
! NRP=NR
ELSE
NRP=MAXRPT
END IF
REWIND 16
!
ICOUNT=61
DO 9021 K4=1,NANGLE
READ(16,165) BRG1,(CON(J),J=21,NRP)
IF(ICOUNT.GE.60)THEN
PGCT=PGCT+1
WRITE(IPO,202) CHAR(12), PGCT
WRITE(IPO,210)JOB,RUN
ICOUNT=3
! IF(K4.EQ.1) THEN
WRITE(IPO,8399)
WRITE(IPO,8400)
ICOUNT=ICOUNT+9
END IF
! IF(VAR.EQ.'N') GOTO 1191
! TRANGE=BRGV(1)
BRANGE=BRG2+(DEGR*VA(NANGLE))
WRITE(IPO,8499) TRANGE,BRANGE
ICOUNT=ICOUNT+2
1191 WRITE(IPO,8500)
IF(MODET .EQ. 0) THEN
WRITE(IPO,8510)
ELSE IF(MODET .GT. 1) THEN
ELSE
END IF
! IF(MODET .LE. 1) THEN
WRITE(IPO,8511) (REC(J),J=IRP,NRP)
WRITE(IPO,8512) (X1(J),J=IRP,NRP)
ELSE
WRITE(IPO,8513) (REC(J),J=IRP,NRP)
WRITE(IPO,8514) (X1(J),J=IRP,NRP)
END IF
ICOUNT=ICOUNT+4
END IF
! IF(MODET .EQ. 0) THEN
WRITE(IPO,8530) BRG1,(CON(J),J=IRP,NRP)
ELSE IF(MODET .GT. 1) THEN
ELSE
WRITE(IPO,8531) BRG1,(CON(J),J=IRP,NRP)
END IF
ICOUNT=ICOUNT+1
9021 CONTINUE
GO TO 9019
! 9023 CLOSE(16,STATUS='DELETE')
! PRINT OUT TOP THREE VALUES OF MAXIMUM CONCENTRATION WITH
! CORRESPONDING WIND ANGLE AND RECEPTOR NUMBERS.
! DO 9026 I=1,NR
  IORDER(I)=I
 CONTINUE
!
! IF(VAR .EQ. 'N') THEN
  IF(MODET .LE. 1) THEN
    WRITE(IPO,8512) (X1(J),J=IRP,NRP)
  ELSE
    WRITE(IPO,8514) (X1(J),J=IRP,NRP)
  END IF
END IF
!
IF(MODET .EQ. 0) THEN
  WRITE(IPO,9043) CMAX,REC(IRMAX)
ELSE IF(MODET .EQ. 2) THEN
  WRITE(IPO,9049) CMAX,REC(IRMAX)
  WRITE(IPO,9047) CMAX*CONVERT_A,REC(IRMAX)
ELSE IF(MODET .EQ. 3) THEN
  WRITE(IPO,9049) CMAX,REC(IRMAX)
  WRITE(IPO,9047) CMAX*CONVERT_R,REC(IRMAX)
ELSE IF(MODET .EQ. 4) THEN
  WRITE(IPO,9049) CMAX,REC(IRMAX)
  WRITE(IPO,9047) CMAX*CONVERT_B,REC(IRMAX)
ELSE IF(MODET .EQ. 5) THEN
  WRITE(IPO,9049) CMAX,REC(IRMAX)
  WRITE(IPO,9047) CMAX*CONVERT_U,REC(IRMAX)
ELSE IF(MODET .EQ. 6) THEN
  WRITE(IPO,9049) CMAX,REC(IRMAX)
  WRITE(IPO,9047) CMAX*CONVERT_G,REC(IRMAX)
ELSE IF(MODET .EQ. 7) THEN
  WRITE(IPO,9049) CMAX,REC(IRMAX)
  WRITE(IPO,9047) CMAX*CONVERT_F,REC(IRMAX)
ELSE IF(MODET .EQ. 8) THEN
  WRITE(IPO,9049) CMAX,REC(IRMAX)
  WRITE(IPO,9047) CMAX*CONVERT_N,REC(IRMAX)
ELSE IF(MODET .EQ. 9) THEN
  WRITE(IPO,9049) CMAX,REC(IRMAX)
  WRITE(IPO,9047) CMAX*CONVERT_I,REC(IRMAX)
ELSE IF(MODET .EQ. 10) THEN
  WRITE(IPO,9049) CMAX,REC(IRMAX)
  WRITE(IPO,9047) CMAX*CONVERT_G,REC(IRMAX)
ELSE IF(MODET .EQ. 11) THEN
  WRITE(IPO,9049) CMAX,REC(IRMAX)
  WRITE(IPO,9047) CMAX*CONVERT_H,REC(IRMAX)
ELSE
  WRITE(IPO,9046) CMAX,REC(IRMAX)
END IF
CMAX = 0.0
!
IF(PRINT2.NE.1) GOTO 9000

! IRP=INITIAL RECEPTOR NUMBER TO PRINT ON PAGE.
! NRP=LAST RECEPTOR NUMBER TO PRINT ON PAGE.

IF(MODET .LE. 1) THEN
  IRP=1
  MAXRPT=20
ELSE
  IRP=1
END IF
MAXRPT=13
END IF

9025 IF (NR.LE.MAXRPT) THEN
    NRP=NR
ELSE
    NRP=MAXRPT
END IF

PGCT=PGCT+1
WRITE(IPO,202) CHAR(12), PGCT
WRITE(IPO,210) JOB, RUN

C WRITE (IPO, 462) IMON, IDAY, IYR
C WRITE (IPO, 463) IIHR, IMIN, ISEC
WRITE (IPO,'(6X,A6,A8,2X,A7,A5/)')
+            'DATE: ',IDATE,' TIME: ',ITIME
WRITE(IPO,9032)

9032 FORMAT (/,6X,'RECEPTOR - LINK MATRIX FOR THE ANGLE PRODUCING',
+           /,6X,'THE MAXIMUM CONCENTRATION FOR EACH RECEPTOR')

! IF(MODET .EQ. 0) THEN
    WRITE(IPO,9031) (REC(LLL),LLL=IRP,NRP)
ELSE IF(MODET .EQ. 2) THEN
    WRITE(IPO,9010) (REC(LLL),LLL=IRP,NRP)
ELSE IF(MODET .EQ. 3) THEN
    WRITE(IPO,9011) (REC(LLL),LLL=IRP,NRP)
ELSE IF(MODET .EQ. 4) THEN
    WRITE(IPO,9012) (REC(LLL),LLL=IRP,NRP)
ELSE IF(MODET .EQ. 5) THEN
    WRITE(IPO,9013) (REC(LLL),LLL=IRP,NRP)
ELSE IF(MODET .EQ. 6) THEN
    WRITE(IPO,9014) (REC(LLL),LLL=IRP,NRP)
ELSE IF(MODET .EQ. 7) THEN
    WRITE(IPO,9015) (REC(LLL),LLL=IRP,NRP)
ELSE IF(MODET .EQ. 8) THEN
    WRITE(IPO,9016) (REC(LLL),LLL=IRP,NRP)
ELSE IF(MODET .EQ. 9) THEN
    WRITE(IPO,9017) (REC(LLL),LLL=IRP,NRP)
ELSE IF(MODET .EQ. 10) THEN
    WRITE(IPO,9018) TRIM(COMPOUND),(REC(LLL),LLL=IRP,NRP)
ELSE IF(MODET .EQ. 11) THEN
    WRITE(IPO,9018) TRIM(COMPOUND),(REC(LLL),LLL=IRP,NRP)
ELSE
    WRITE(IPO,9035) (REC(LLL),LLL=IRP,NRP)
END IF

9010 FORMAT(/,10X,'*',4X,'ACETALDEHYDE/LINK(ug/m**3)',/,
+          10X,'*',4X,'ANGLE (DEGREES)',/,
+          10X,'*',13(A6,3X))
9011 FORMAT(/,10X,'*',4X,'ACROLEIN/LINK(ug/m**3)',/,
+          10X,'*',4X,'ANGLE (DEGREES)',/,
+          10X,'*',13(A6,3X))
9012 FORMAT(/,10X,'*',4X,'BENZENE/LINK(ug/m**3)',/,
+          10X,'*',4X,'ANGLE (DEGREES)',/,
+          10X,'*',13(A6,3X))
9013 FORMAT(/,10X,'*',4X,'BUTADIENE/LINK(ug/m**3)',/,
+          10X,'*',4X,'ANGLE (DEGREES)',/,
+          10X,'*',13(A6,3X))
9014 FORMAT(/,10X,'*',4X,'FORMALDEHYDE/LINK(ug/m**3)',/,
+          10X,'*',4X,'ANGLE (DEGREES)',/,
+          10X,'*',13(A6,3X))
9015 FORMAT(/,10X,'*',4X,'DPM+DEOG/LINK(ug/m**3)',/, V2KW
+ 10X,'*',4X,'ANGLE (DEGREES)',/, V2KW
+ 10X,'*',13(A6,3X)) V2KW
!
9016 FORMAT(/,10X,'*',4X,'NAPHTHALENE/LINK(ug/m**3)',/, V2KW
+ 10X,'*',4X,'ANGLE (DEGREES)',/, V2KW
+ 10X,'*',13(A6,3X)) V2KW
9017 FORMAT(/,10X,'*',4X,'NITROGEN DIOXIDE/LINK(ug/m**3)',/, V2KW
+ 10X,'*',4X,'ANGLE (DEGREES)',/, V2KW
+ 10X,'*',13(A6,3X)) V2KW
9018 FORMAT(/,10X,'*',4X,A,'/LINK(ug/m**3)',/, V2KW
+ 10X,'*',4X,'ANGLE (DEGREES)',/, V2KW
+ 10X,'*',13(A6,3X)) V2KW
!
9031 FORMAT(/,10X,'*',4X,'CO/LINK  (PPM) ',/, V2KW
+ 10X,'*',4X,'ANGLE (DEGREES)',/, V2KW
+ 10X,'*',20(1X,A5)) V2KW
9035 FORMAT(/,10X,'*',4X,'PM/LINK(ug/m**3)',/, V2KW
+ 10X,'*',4X,'ANGLE (DEGREES)',/, V2KW
+ 10X,'*',20(1X,A5)) V2KW
!
IF(MODET .LE. 1) THEN V2KW
  WRITE(IPO,9034) (ANGMAX(LLL),LLL=IRP,NRP) V2KW
ELSE V2KW
  WRITE(IPO,9210) (ANGMAX(LLL),LLL=IRP,NRP) V2KW
END IF V2KW
!
9034 FORMAT (3X,'LINK # ','*',20(3X,I3)) V2KW
9210 FORMAT (3X,'LINK # ','*',13(I5,4X)) V2KW
!
IF(MODET .LE. 1) THEN V2KW
  WRITE(IPO,9033) (X1(L1),L1=IRP,NRP) V2KW
ELSE IF(MODET .EQ. 2) THEN V2KW
  WRITE(IPO,9010) (REC(LLL),LLL=IRP,NRP) V2KW
ELSE IF(MODET .EQ. 3) THEN V2KW
  WRITE(IPO,9011) (REC(LLL),LLL=IRP,NRP) V2KW
ELSE IF(MODET .EQ. 4) THEN V2KW
  WRITE(IPO,9012) (REC(LLL),LLL=IRP,NRP) V2KW
ELSE IF(MODET .EQ. 5) THEN V2KW
  WRITE(IPO,9013) (REC(LLL),LLL=IRP,NRP) V2KW
ELSE IF(MODET .EQ. 6) THEN V2KW
  WRITE(IPO,9014) (REC(LLL),LLL=IRP,NRP) V2KW
ELSE IF(MODET .EQ. 7) THEN V2KW
  WRITE(IPO,9015) (REC(LLL),LLL=IRP,NRP) V2KW
ELSE IF(MODET .EQ. 8) THEN V2KW
!
ICOUNT=15 V2EC
DO 9051 I=1,NL
  IF(ICOUNT.GE.60) THEN V2KW
    PGCT=PGCT+1
    WRITE(IPO,202) CHAR(12), PGCT
    WRITE(IPO,210) JOB,RUN
  !
  IF (MODET .EQ. 0) THEN V2KW
    WRITE(IPO,9031) (REC(LLL),LLL=IRP,NRP) V2KW
  !
  ELSE IF(MODET .EQ. 2) THEN V2KW
    WRITE(IPO,9010) (REC(LLL),LLL=IRP,NRP) V2KW
  ELSE IF(MODET .EQ. 3) THEN V2KW
    WRITE(IPO,9011) (REC(LLL),LLL=IRP,NRP) V2KW
  ELSE IF(MODET .EQ. 4) THEN V2KW
    WRITE(IPO,9012) (REC(LLL),LLL=IRP,NRP) V2KW
  ELSE IF(MODET .EQ. 5) THEN V2KW
    WRITE(IPO,9013) (REC(LLL),LLL=IRP,NRP) V2KW
  ELSE IF(MODET .EQ. 6) THEN V2KW
    WRITE(IPO,9014) (REC(LLL),LLL=IRP,NRP) V2KW
  ELSE IF(MODET .EQ. 7) THEN V2KW
    WRITE(IPO,9015) (REC(LLL),LLL=IRP,NRP) V2KW
  !
  ELSE IF(MODET .EQ. 8) THEN V2KW
WRITE(IPO,9016) (REC(LLL),LLL=IRP,NRP)
ELSE IF(MODET .EQ. 9) THEN
  WRITE(IPO,9017) (REC(LLL),LLL=IRP,NRP)
ELSE IF(MODET .EQ. 10) THEN
  WRITE(IPO,9018) (REC(LLL),LLL=IRP,NRP)
ELSE IF(MODET .EQ. 11) THEN
  WRITE(IPO,9018)
ELSE
  WRITE(IPO,9035) (REC(LLL),LLL=IRP,NRP)
END IF
!
ELSE IF(MODET .LE. 1) THEN
  WRITE(IPO,9034) (ANGMAX(LLL),LLL=IRP,NRP)
ELSE
  WRITE(IPO,9210) (ANGMAX(LLL),LLL=IRP,NRP)
END IF
!
ELSE IF(MODET .LE. 1) THEN
  WRITE(IPO,9033) (X1(L1),L1=IRP,NRP)
ELSE
  WRITE(IPO,9211) (X1(L1),L1=IRP,NRP)
END IF
!
ICOUNT=7
END IF
!
ELSE IF(MODET .LE. 1) THEN
  WRITE(IPO,9041) I,(COMAX(I,J),J=IRP,NRP)
ELSE
  WRITE(IPO,9212) I,(COMAX(I,J),J=IRP,NRP)
END IF
9041    FORMAT (5X,I3,'  *',20(1X,F5.1))
9212    FORMAT (5X,I3,'  *',13(1X,ES8.2E1))
ICOUNT=ICOUNT+1
9051    CONTINUE
!
IF (MODET .LE. 1) THEN
  IF(NR.LE.MAXRPT) GO TO 9000
  IRP=MAXRPT+1
  MAXRPT=MAXRPT+20
  GO TO 9025
ELSE
  IF(NR.LE.MAXRPT) GO TO 9000
  IRP=MAXRPT+1
  MAXRPT=MAXRPT+13
  GO TO 9025
END IF
!
9000    CONTINUE
GOTO 10
!

-----------------
!       FORMAT STATEMENTS
-----------------
!

*** INPUT FORMATS
1  FORMAT(5X,2(I5,5X),F5.1,I5,F7.2,1X,I4,1X,I1,1X,I1)  V2
11  FORMAT(2F4.0,2F5.0,I2,F10.4)
12  FORMAT(3F10.0)
14  FORMAT(I3)
15  FORMAT(1X,A20,A2,4F7.0,F8.0,F4.0,I4)
The MODE flag has been set to 'CO' for calculating CO averages.
The MODE flag has been set to 'PM' for calculating PM averages.
The MODE flag has been set to 'Acetaldheyde' for calculating Acetaldheyde averages.
The MODE flag has been set to 'Acrolein' for calculating Acrolein averages.
The MODE flag has been set to 'Benzene' for calculating Benzene averages.
The MODE flag has been set to '1,3-Butadiene' for calculating 1,3-Butadiene averages.
The MODE flag has been set to 'Formaldehyde' for calculating Formaldehyde averages.
The MODE flag has been set to 'DPM+DEOG' for calculating DPM+DEOG averages.
The MODE flag has been set to 'Naphthalene' for calculating Naphthalene averages.
The MODE flag has been set to 'Nitrogen Dioxide' for calculating Nitrogen Dioxide averages.
FORMAT (6X, 'SITE & METEOROLOGICAL VARIABLES ', '(', 7X, '------------------------------')

FORMAT (7X, 'VS = ', F5.1, ' CM/S, 7X, 'VD = ', F5.1, ' CM/S, 
  7X, 'HZ0 = ', F4.0, ' CM')

FORMAT (8X, 'HU = ', F4.1, ' M/S, 9X, 'CLAS = ', I1, ' (', A1, ')', 
  5X, 'ATIM = ', F4.0, ' MINUTES, 5X, 'MIXH = ', F6.0, ' H M, 
  3X, 'AMB = ', F4.1, ' PPM')

FORMAT (6X, 24(1H - ), 1H*, 80(1H - ))

FORMAT (5X, 'RECEPTOR LOCATIONS', '(', 7X, '------------------------------')

FORMAT (30X, 'COORDINATES (M) *'), 5X, 'COORDINATES (FT) *')

FORMAT (9X, 'RECEPTOR', 13X, 'COORDINATES (M) *')

FORMAT (5X, 'ADDITIONAL QUEUE LINK PARAMETERS', '(', 7X, '-------------------------------')

FORMAT (30X, 4H*, 6HLENGTH, 4X, 4HTIME, 9HFLOW RATE, 4X, 7HARRIVAL)
! FORMAT (5X,I2,2H. ,A20,1X,1H*,4X,F8.1,3X,F8.1,3X,F8.1, V2EF
+ 3X,1H*)
461 FORMAT (30X,27H* COORDINATES (M),11X,1H*)
462 FORMAT(/6X,'DATE : ',I2,'/',I2,'/',I2)
463 FORMAT(6X,'TIME : ','I2,':','I2,':', 'I2/)

8399 FORMAT(/,7X,'MODEL RESULTS',/,,
+ 7X,'------------------')
8400 FORMAT(/,7X,'REMARKS : In search of the angle corresponding to',
+ /,'17x, the maximum concentration, only the first',/,,
+ /,'17x, angle, of the angles with same maximum',/,,
+ /,'17x, concentrations, is indicated as maximum.')
8499 FORMAT(/,1X,'WIND ANGLE RANGE: ',F4.0,'
361','-',F4.0)
8500 FORMAT(/,1X,'WIND ',1H*,1X,'CONCENTRATION ')
8510 FORMAT(  1X,'ANGLE ',1H*,6X, '(PPM)')
8511 FORMAT(  1X, '(DEGR)',1H*,20(1X,A5))
8512 FORMAT(  1X,'------',1H*,20A6)
8520 FORMAT(  1X,'ANGLE ',1H*,6x, '(ug/m**3)')
8530 FORMAT(  1X,F4.0,2X,1H*,20(1X,F5.1))
8531 FORMAT(  1X,F4.0,2X,1H*,20(1X,F5.0))
9040 FORMAT(  ' MAX  ',1H*,20(1X,F5.1))
9050 FORMAT(  ' MAX  ',1H*,20(1X,F5.0))
9042 FORMAT(  ' DEGR. ',1H*,20(1X,I4,1X))
9043 FORMAT(  ' THE HIGHEST CONCENTRATION OF ',F6.2,' PPM',
+ ' OCCURRED AT RECEPTOR ',A5,'.')
9045 FORMAT(  ' THE HIGHEST CONCENTRATION OF ',F6.0,' ug/m**3',
+ ' OCCURRED AT RECEPTOR ',A5,'.')

-----------------------------------------------------------------------
! ***NEW MSAT FORMAT STATEMENTS***
!
! LINK VARIABLES
261 FORMAT (9X,16HLINK DESCRIPTION,5X, V2KW
+ 42H* LINK COORDINATES (M) *,4X,6HLINK DESCRIPTION,5X,
+ 2X,3HBRG,1X,4HTYPE,3X,3HVPH,5X,2HEF,8X,1IH,
+ 3X,1HW,3X,3HV/C,2X,5HQU)
266 FORMAT (9X,16HLINK DESCRIPTION,5X, V2KW
+ 42H* LINK COORDINATES (FT) *,4X,6HLINK DESCRIPTION,5X,
+ 2X,3HBRG,1X,4HTYPE,3X,3HVPH,5X,2HEF,8X,1IH,
+ 3X,1HW,3X,3HV/C,2X,5HQU)
271 FORMAT(30X,42H* X1 Y1 X2 Y2 *,5X,3H(MV2KW
+),3X,5H(VEH)),276 FORMAT(30X,42H* X1 Y1 X2 Y2 *,5X,3H(MV2KW
+),3X,5H(VEH))
281 FORMAT (6X,24(1H-),1H*,40(1H-),1H*,60(1H-))
291 FORMAT (5X,13,2H. ,A20,1H*,4(1X,F8.1,1X),1H*,4x,F5.0,
+ 3X,F4.0,1X,A2,1X,F7.0,2X,ES7.2E1,1X,F5.1,1X,F4.1,1X,F4.2,1X,
+ F5.1) V2KW
!
! ADDITIONAL QUEUE LINK PARAMETERS
407 FORMAT (5X,13,2H. ,A20,1H*,2(3X,I5,1X),4X,F5.1,
+ 5X,I5,7X,I4,4X,ES7.2E1,5X,II,8X,II)
!
! SITE & METEOROLOGICAL VARIABLES
233 FORMAT (8X,4HU =$F4.1,4H M/S,9X,9HCLASS = ,I1,3H (.A1,1H), V2KW
+ 5X,7HATIM = ,F4.0,8H MINUTES,5X,7HMIH = ,F6.0,2H M,
+ 3X,6HAMB = ,ES7.2E1, '"ug/m**3'/)
242 FORMAT (8X,4HU = $F4.1,4H M/S,9X,9HCLASS = ,I1,3H (.A1,1H), V2KW
+ 5X,7HATIM = ,F4.0,8H MINUTES,5X,7HMIH = ,F6.0,2H M,
+ 3X,6HAMB = ,ES7.2E1, '"ug/m**3' ,2X,6HBRG = ,F4.0,8H DEGREES/) V2KW

129
MODEL RESULTS

8515 FORMAT( 1X,'ANGLE ',1H*,6X,'(ug/m**3)') V2KW
11/12/2009

8513 FORMAT( 1X,'(DEGR)',1H*,13(2X,A6,1X)) V2KW
11/12/2009

8514 FORMAT( 1X,'------',1H*,13A9) V2KW
11/18/2010

8532 FORMAT( 1X,F4.0,2X,1H*,13(1X,ES8.2E1)) V2KW
9045 FORMAT( ' MAX ',1H*,13(1X,ES8.2E1)) V2KW
11/18/2010

9044 FORMAT( ' DEGR. ',1H*,13(1X,I6,2X)) V2KW
11/12/2009

9047 FORMAT(' THE HIGHEST CONCENTRATION OF ',ES7.2E1,' PPB', V2KW
11/18/2010
+ ' OCCURRED AT RECEPTOR ',A5,'.') V2KW

9049 FORMAT(' THE HIGHEST CONCENTRATION OF ',ES7.2E1,' ug/m**3', V2KW
11/18/2010
+ ' OCCURRED AT RECEPTOR ',A5,'.')

******************************************************************************

9999 STOP
END

***********************************************************************
*THIS SUBROUTINE WAS ADDED FOR A LAHEY COMPILER*
***********************************************************************

SUBROUTINE GETFIL(FILEIN, FILEOUT)
C
C This subroutine puts the name of the input file in FILEIN and the name
C of the output file in FILEOUT. First it looks at the command line
C for arguments specifying these file names. If they are not found
C there it prompts the user for these file names.
C
C This subroutine was designed to work with Lahey FORTRAN.
C
CHARACTER*80 CM
CHARACTER*40 FILEIN, FILEOUT
INTEGER*2 BEGI,ENDI,BEGO,ENDO,POS,LEN
DATA (CM(i:i),i=1,80) /80*' '/

FILEIN='                                        '
FILEOUT='                                        '
C get the command line
CALL GETCL(CM)
BEGI=0
ENDI=0
BEGO=0
ENDO=0
C calculate command line length into 'LEN'
LEN=NBLANK(CM)
C
IF (LEN .EQ. 0) GOTO 49
POS = 0
C find the next non-space character
C (the beginning of the input file name)
I
POS = POS + 1
IF(POS.GT.LEN) THEN
BEGI=LEN
GOTO 49
END IF
IF (CM(POS:POS) .EQ. ' ') GOTO 1
BEGI = POS

******************************************************************************
C find the next space character (the end of the input file name)
11    POS = POS + 1
     IF(POS.GT.LEN) THEN
        ENDI=LEN
        GOTO 49
     END IF
     IF (CM(POS:POS) .NE. ' ') GOTO 11
     ENDI = POS-1
C find the next non-space character
C (the beginning of the output file name)
21    POS = POS + 1
     IF(POS.GT.LEN) THEN
        BEGO=LEN
        GOTO 49
     END IF
     IF (CM(POS:POS) .EQ. ' ') GOTO 21
     BEGO = POS
C find the next space character (the end of the output file name)
31    POS = POS + 1
     IF(POS.GT.LEN) THEN
        ENDO=LEN
        GOTO 49
     END IF
     IF (CM(POS:POS) .NE. ' ') GOTO 31
     ENDO = POS-1
C
49    IF ((BEGI.GT.0) .AND.(ENDI.GT.0)) THEN
     FILEIN=CM(BEGI:ENDI)
     ELSE
     WRITE(*,41) V2KW
     READ(*,*) FILEIN
     END IF
     IF ((BEGO.GT.0) .AND.(ENDO.GT.0)) THEN
     FILEOUT=CM(BEGO:ENDO)
     ELSE
     WRITE(*,42) V2KW
     READ(*,*) FILEOUT
     WRITE(*,*) V2KW
     END IF
RETURN
END
APPENDIX B: CAL3MSAT AND CAL3i DEFAULT VALUES
Presented in this section are the inputs supplied by CAL3i (and subsequently used for CAL3MSAT) when the user selects the “Florida Default Data Values” screening option. The specific control, receptor, link, and meteorological data are listed.

<table>
<thead>
<tr>
<th>Data Form</th>
<th>Parameter</th>
<th>Recommended Default Values</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Control</strong></td>
<td>Length Units of Input Data</td>
<td>Feet</td>
</tr>
<tr>
<td></td>
<td>IOPT - Length Units in Printout</td>
<td>Feet</td>
</tr>
<tr>
<td></td>
<td>PRINT2 - Model Printout Format</td>
<td>Summary</td>
</tr>
<tr>
<td><strong>Receptors</strong></td>
<td>ZR - Receptor Height</td>
<td>1.8 m (5.9 ft)</td>
</tr>
<tr>
<td><strong>Links</strong></td>
<td>Link TYP - Link Type</td>
<td>AG - At-Grade</td>
</tr>
<tr>
<td></td>
<td>HL - Source Height</td>
<td>0.0 m (0.0 ft)</td>
</tr>
<tr>
<td></td>
<td>YFAC - Clearance Lost Time</td>
<td>2.0 s</td>
</tr>
<tr>
<td></td>
<td>SFR - Saturation Flow Rate</td>
<td>1600 vphpl</td>
</tr>
<tr>
<td></td>
<td>ST - Signal Type</td>
<td>1 - Pre-Timed</td>
</tr>
<tr>
<td></td>
<td>AT - Arrival Rate</td>
<td>3 - Average</td>
</tr>
<tr>
<td><strong>Meteorology</strong></td>
<td>ATIM - Averaging Time</td>
<td>60 min</td>
</tr>
<tr>
<td></td>
<td>1-hr to 24-hr Persistence Factor</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td>1-hr to Annual Persistence Factor</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td>U - Wind Speed</td>
<td>1.0 m³/s</td>
</tr>
<tr>
<td></td>
<td>BRG - Wind Direction</td>
<td>0.0 °</td>
</tr>
<tr>
<td></td>
<td>CLAS - Atmospheric Stability</td>
<td>Class 4 (D)</td>
</tr>
<tr>
<td></td>
<td>MIXH - Mixing Height</td>
<td>1000 m³</td>
</tr>
<tr>
<td></td>
<td>VAR - Vary the Wind Direction?</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>DEGR - Direction Increment Angle</td>
<td>10.0 °</td>
</tr>
<tr>
<td></td>
<td>VIA(1) - First Increment Multiplier</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>VIA(2) - Last Increment Multiplier</td>
<td>35</td>
</tr>
</tbody>
</table>
Default Receptor/Highway Layout Parameters and Traffic Signal Data

This section presents the highway configuration assumptions built into the utility for generating a simplified receptor/highway layout for screening and adding a traffic signal. These data are fully editable by the analyst by invoking the Refine the Receptor / Highway Layout control and the Change the Traffic Signal Data control.

Traffic volumes (vph) are set to reflect at-capacity operating conditions, which are assumed to be 2,200 vehicles per hour per lane (vphpl) for each freeway link and 1,600 vphpl (the EPA-recommended saturation flow rate) for each arterial link times the number of lanes. The traffic volumes should be changed to reflect locale-specific capacities and maximum levels of congestion. Traffic volumes approaching the midpoint of the highway segment and traffic volumes departing the midpoint of the highway segment are specified. The default lane width is 12 ft; the default approach segment length is 1,200 ft; the default median width is 0 ft; and the approach segment offset angle is 0° (i.e., no skew).

An average total signal cycle length of 120 s and an average red cycle length of 62 sec are used based on information provided in NCHRP Report 387 (TRB, 1997). The average red cycle length was based on the suggested weighted effective green time of 0.45 (TRB, 1997), a clearance lost time of 2 sec (EPA, 1992c), and a start-up delay of 2 sec (EPA, 1992c). Traffic volumes for intersection configurations are set to reflect over-capacity operating conditions characterized by a level of service (LOS) of E and a volume-to-capacity ratio (V/C) of 1.44 (TRB, 1997). The capacity of each arterial link is assumed to be 1,600 vphpl per hour of green (the EPA-recommended saturation flow rate). The signal timing and traffic volumes should be changed to reflect local maximum levels of congestion.
APPENDIX C: LONG-TERM MODELING MATERIAL
CAL3QHCR Input File Data

The following text [adapted from (EPA, 1995a)] shows the input file format used in order to complete the long-term modeling with CAL3QHCR. A description of the variables can be seen in the next section.

First line: JOB, ATIM, ZO, VS, VD, NR, SCAL, IOPT
Second line: START, END
Third line: METSF, METSYR, METUA, METUYR
Fourth line: FLINK, FAMB, RU
Fifth line: RCP, XR, YR, ZR
  **(The fifth line is repeated; once for each receptor.)
Sixth line: JTIER, MODE
Seventh line: IPATRY
Eight line: RUN, NUMLNK
Ninth line: COD, IQ
  (if IQ = 1)
Tenth line: LNK, TYP, X1, Y1, X2, Y2, SH, WL
  (if IQ = 2)
Tenth line: LNK, TYP, X1, Y1, X2, Y2, SH, WL, NLANE
  **(The ninth and tenth lines are repeated; once for each link)
Eleventh line: HE, AMB
  (if IQ = 1)
Twelfth line: COD, VPHL, EFL
  (if IQ = 2)
Twelfth line: COD, CAVG, RAVG, YFAC, IV, IDLFAC, SFR, ST, AT
  **(The twelfth line is repeated for each link depending on IQ)

*** End of Tier I input ***

For Tier II input, the eleventh and twelfth lines are repeated 24 times for each 24 hour traffic pattern. A pattern needs to be entered for each day of a week that has an unique diurnal traffic flow.

*** End of Tier II input ***
**CAL3QHCR Variable Description**

A description of each variable was adapted from the CAL3QHCR User’s Guide (EPA, 1995a).

<table>
<thead>
<tr>
<th>Variable Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>JOB</td>
<td>Run title or description (Up to 40 characters are allowed)</td>
</tr>
<tr>
<td>ATIM</td>
<td>Run averaging time (minutes)</td>
</tr>
<tr>
<td>ZO</td>
<td>Roughness length (cm)</td>
</tr>
<tr>
<td>VS</td>
<td>Settling velocity (cm/s)</td>
</tr>
<tr>
<td>VD</td>
<td>Deposition velocity (cm/s)</td>
</tr>
<tr>
<td>NR</td>
<td>Number of receptors. Maximum 60</td>
</tr>
<tr>
<td>SCAL</td>
<td>Units to meters conversion factor</td>
</tr>
<tr>
<td>IOPT</td>
<td>Output units expressed in feet (1) or meters (0)</td>
</tr>
<tr>
<td>START</td>
<td>Gregorian start processing date in month, day, year format (Year must equal END year)</td>
</tr>
<tr>
<td>END</td>
<td>Gregorian end processing date in month, day, year (Year must equal START year)</td>
</tr>
<tr>
<td>METSF</td>
<td>Meteorological data surface station number.</td>
</tr>
<tr>
<td>METSYR</td>
<td>Meteorological surface data year</td>
</tr>
<tr>
<td>METUA</td>
<td>Meteorological data upper air station number.</td>
</tr>
<tr>
<td>METUYR</td>
<td>Meteorological upper air data year</td>
</tr>
<tr>
<td>FLINK</td>
<td>Print link contribution flag (Yes = 1, NO = 0).</td>
</tr>
<tr>
<td>FAMB</td>
<td>Print table of concentrations with average hourly ambient background concentrations included in the average calculations (Yes = 1, No = 0)</td>
</tr>
<tr>
<td>RU</td>
<td>Rural(R)/Urban(U) switch</td>
</tr>
<tr>
<td>RCP</td>
<td>Receptor name (Up to 20 characters allowed)</td>
</tr>
<tr>
<td>XR</td>
<td>Receptor X-coordinate (user units)</td>
</tr>
<tr>
<td>YR</td>
<td>Receptor Y-coordinate (user units)</td>
</tr>
<tr>
<td>ZR</td>
<td>Receptor Z-coordinate (user units)</td>
</tr>
<tr>
<td>JTIER</td>
<td>Specifies whether the program will perform a Tier I (1) or II (2) approach</td>
</tr>
<tr>
<td>MODE</td>
<td>Specifies whether the data has been prepared for CO ('C') or PM ('P') calculations</td>
</tr>
<tr>
<td>IPATRY</td>
<td>A pattern contains 24 hourly sets of emission, traffic, and signal values</td>
</tr>
<tr>
<td>RUN</td>
<td>Title or description of the intersection (Up to 40 characters are allowed)</td>
</tr>
<tr>
<td>NUMLNK</td>
<td>Number of Links to be processed</td>
</tr>
<tr>
<td>COD</td>
<td>Link number</td>
</tr>
<tr>
<td>IQ</td>
<td>Free flow link (1) or Queue link (2)</td>
</tr>
<tr>
<td>LNK</td>
<td>Link name (Up to 20 characters are allowed)</td>
</tr>
<tr>
<td>TYP</td>
<td>Link highway type (Two character input)</td>
</tr>
<tr>
<td>X1</td>
<td>Link X - coordinate start point (User's units)</td>
</tr>
<tr>
<td>X2</td>
<td>Link X - coordinate end point (User's units)</td>
</tr>
<tr>
<td>Y1</td>
<td>Link Y - coordinate start point (User's units)</td>
</tr>
<tr>
<td>Variable Name</td>
<td>Description</td>
</tr>
<tr>
<td>---------------</td>
<td>-------------</td>
</tr>
<tr>
<td>Y2</td>
<td>Link Y - coordinate end point (User's units)</td>
</tr>
<tr>
<td>SH</td>
<td>Source height (User's units)</td>
</tr>
<tr>
<td>WL</td>
<td>Mixing zone width (User's units)</td>
</tr>
<tr>
<td>NLANE</td>
<td>Number of queuing lanes</td>
</tr>
<tr>
<td>HE</td>
<td>Hour ending</td>
</tr>
<tr>
<td>AMB</td>
<td>Hourly ambient background concentration (PPM for CO, μg/m3 for PM)</td>
</tr>
<tr>
<td>VPHL</td>
<td>Hourly average free flow traffic volume (veh/hr).</td>
</tr>
<tr>
<td>EFL</td>
<td>Free flow emission factor (g/veh-mi)</td>
</tr>
<tr>
<td>CAVG</td>
<td>Traffic light cycle time (seconds)</td>
</tr>
<tr>
<td>RAVG</td>
<td>Red light duration time (seconds)</td>
</tr>
<tr>
<td>YFAC</td>
<td>Portion of yellow time not used for vehicle movement (seconds)</td>
</tr>
<tr>
<td>IV</td>
<td>Queue traffic volume (veh/hr)</td>
</tr>
<tr>
<td>IDLFAC</td>
<td>Idle time emission factor (g/veh-hr)</td>
</tr>
<tr>
<td>SFR</td>
<td>Saturation flow volume (veh/hr/lane)</td>
</tr>
<tr>
<td>ST</td>
<td>Signal type (Enter 1 for pretimed, 2 for actuated, 3 for semiactuated)</td>
</tr>
<tr>
<td>AT</td>
<td>Arrival rate (Enter 1 for worst progression, 2 for below average progression, 3 for average, progression, 4 for above average progression, and 5 for best progression)</td>
</tr>
</tbody>
</table>
**AERMOD Input File Data**

The following text shows the input file format used in order to complete the long-term modeling with AERMOD. A description of the variables can be seen in the next section.

```
CO STARTING
CO TITLEONE Title1
CO MODELOPT FLAT CONC
CO POLLUTID Pollut
CO AVERTIME TimeN
CO URBANOPT Urbpop
CO FLAGPOLE Flagdf
CO RUNORNOT RUN
CO FINISHED

SO STARTING
SO ELEVUNIT METERS
SO LOCATION Srcid Srctyp Xs Ys Zs
   (This last line is repeated; once for each source)
SO SRCPARAM Srcid Aremis Relhgt Xinit Yinit Angle Szinit
   **For AREA sources: (This last line is repeated; once for each source)
SO SRCPARAM Srcid Vlemis Relhgt Syinit Szinit
   **For VOLUME sources: (This last line is repeated; once for each source)
SO URBAN SRC Srcid’s
   **(This last line is repeated; once for each source)
SO EMISFACT EMISFACT Srcid Qflag Qfact(1,n)
   **(This last line is repeated; once for each source)
SO SRCGROUP Grpid Srcid’s
SO FINISHED

RE STARTING
RE ELEVUNIT METERS
RE DISCCART Xcoord Ycoord
   **(This last line is repeated; once for each receptor)
RE FINISHED

ME STARTING
ME SURFFILE Sfcfil
ME PROFFILE Profil
ME SURFDATA Stanum Year
ME UAIRDATA Stanum Year
ME PROFBASE BaseElev Units
ME FINISHED

OU STARTING
OU MAXTABLE Aveper Maxnum
   **(This last line is repeated; once for each averaging time)
OU FINISHED
```
AERMOD Variable Description

The variables are listed in order of appearance from the previous AERMOD input file. A description of each variable was adapted from the AERMOD User’s Guide (EPA, 2004a).

<table>
<thead>
<tr>
<th>Variable Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO</td>
<td>Control pathway</td>
</tr>
<tr>
<td>STARTING</td>
<td>Identifies the start of inputs for a particular pathway</td>
</tr>
<tr>
<td>TITLEONE</td>
<td>First line of title for output</td>
</tr>
<tr>
<td>Title1</td>
<td>First line of title for output, character string of up to 68 characters</td>
</tr>
<tr>
<td>MODELOPT</td>
<td>Job control and dispersion options</td>
</tr>
<tr>
<td>FLAT</td>
<td>Option to assume flat terrain</td>
</tr>
<tr>
<td>CONC</td>
<td>Specifies calculation of concentration values</td>
</tr>
<tr>
<td>POLLUTID</td>
<td>Identifies type of pollutant being modeled</td>
</tr>
<tr>
<td>Pollut</td>
<td>Identifies type of pollutant being modeled</td>
</tr>
<tr>
<td>AVERTIME</td>
<td>Averaging time(s) to process</td>
</tr>
<tr>
<td>TimeN</td>
<td>Nth optional averaging time</td>
</tr>
<tr>
<td>URBANOPT</td>
<td>Specifies parameters for urban dispersion option</td>
</tr>
<tr>
<td>Urbpop</td>
<td>Specifies the population of the urban area</td>
</tr>
<tr>
<td>FLAGPOLE</td>
<td>Specifies whether to accept receptor heights above local terrain (m) for use with flagpole receptors, and allows for a default flagpole height to be specified</td>
</tr>
<tr>
<td>Flagdf</td>
<td>Default value for height of (flagpole) receptors above local ground level</td>
</tr>
<tr>
<td>RUNORNOT</td>
<td>Identifies whether to run model or process setup information only</td>
</tr>
<tr>
<td>RUN</td>
<td>Indicates to run full model calculations</td>
</tr>
<tr>
<td>FINISHED</td>
<td>Identifies the end of inputs for a particular pathway</td>
</tr>
<tr>
<td>SO</td>
<td>Source pathway</td>
</tr>
<tr>
<td>ELEVUNIT</td>
<td>Defines input units for source elevations</td>
</tr>
<tr>
<td>METERS</td>
<td>Specifies input units for source elevations of meters</td>
</tr>
<tr>
<td>LOCATION</td>
<td>Identifies coordinates for particular source</td>
</tr>
<tr>
<td>Srcid</td>
<td>Source identification code</td>
</tr>
<tr>
<td>Srtyp</td>
<td>Source type (AERA or VOLUME)</td>
</tr>
<tr>
<td>Xs</td>
<td>x-coord of source location, SW corner for AREA</td>
</tr>
<tr>
<td>Ys</td>
<td>y-coord of source location, SW corner for AREA</td>
</tr>
<tr>
<td>Zs</td>
<td>Optional z-coord of source location</td>
</tr>
<tr>
<td>SRCPARAM</td>
<td>Identifies source parameters for a particular source</td>
</tr>
<tr>
<td>Aremis</td>
<td>Area source emission rate in g/s/m²</td>
</tr>
<tr>
<td>Relhgt</td>
<td>Source physical release height above ground</td>
</tr>
<tr>
<td>Xinit</td>
<td>Length of side of AREA source in X-direction</td>
</tr>
<tr>
<td>Yinit</td>
<td>Length of side of AREA source in Y-direction</td>
</tr>
<tr>
<td>Variable Name</td>
<td>Description</td>
</tr>
<tr>
<td>---------------</td>
<td>-------------</td>
</tr>
<tr>
<td>Angle</td>
<td>Orientation angle of AREA source relative to North (degrees), measured positive clockwise, rotated around the source location</td>
</tr>
<tr>
<td>Szinit</td>
<td>Initial vertical dimension of VOLUME or AREA source</td>
</tr>
<tr>
<td>Vlemis</td>
<td>Volume source emission rate in g/s</td>
</tr>
<tr>
<td>Syinit</td>
<td>Initial lateral dimension of VOLUME source</td>
</tr>
<tr>
<td>URBANSRC</td>
<td>Identifies which sources to model with urban effects</td>
</tr>
<tr>
<td>EMISFACT</td>
<td>Optional input for variable emission rate factors</td>
</tr>
<tr>
<td>Qflag</td>
<td>Variable emission rate flag (SHRDOW)</td>
</tr>
<tr>
<td>Qfact(1,n)</td>
<td>Array of scalar emission rate factors (SHRDOW, n=288)</td>
</tr>
<tr>
<td>SRCCGROUP</td>
<td>Identification of source groups</td>
</tr>
<tr>
<td>Grpid</td>
<td>Group ID</td>
</tr>
<tr>
<td>RE</td>
<td>Receptor pathway</td>
</tr>
<tr>
<td>DISCART</td>
<td>Defines the discretely placed receptor locations referenced to a Cartesian system</td>
</tr>
<tr>
<td>Xcoord</td>
<td>x-coordinate for discrete receptor location</td>
</tr>
<tr>
<td>Ycoord</td>
<td>y-coordinate for discrete receptor location</td>
</tr>
<tr>
<td>ME</td>
<td>Meteorology pathway</td>
</tr>
<tr>
<td>SURFFILE</td>
<td>Describes input meteorological surface data file</td>
</tr>
<tr>
<td>Srcfil</td>
<td>Specify filename for surface meteorological input file</td>
</tr>
<tr>
<td>PROFFILE</td>
<td>Describes input meteorological profile data file</td>
</tr>
<tr>
<td>Profil</td>
<td>Specify filename for profile meteorological input file</td>
</tr>
<tr>
<td>SURFDATA</td>
<td>Describes surface meteorological station</td>
</tr>
<tr>
<td>Stanum</td>
<td>Station number</td>
</tr>
<tr>
<td>Year</td>
<td>Year of data being processed</td>
</tr>
<tr>
<td>UAIRDATA</td>
<td>Describes upper air meteorological station</td>
</tr>
<tr>
<td>PROFBASE</td>
<td>Specifies the base elevation for the potential temperature profile</td>
</tr>
<tr>
<td>BaseElev</td>
<td>Base elevation (above MSL) for the potential temperature profile</td>
</tr>
<tr>
<td>Units</td>
<td>Units of BaseElev</td>
</tr>
<tr>
<td>OU</td>
<td>Output pathway</td>
</tr>
<tr>
<td>MAXTABLE</td>
<td>Option to summarize the overall maximum values</td>
</tr>
<tr>
<td>Aveper</td>
<td>Averaging period to summarize with maximum values</td>
</tr>
<tr>
<td>Maxnum</td>
<td>Specifies number of overall maximum values to summarize</td>
</tr>
</tbody>
</table>
LIST OF REFERENCES


Florida Department of Transportation (FDOT). (2011a). Modeling of concentrations of MSATs (mobile source air toxics) along highways and near intersections in Florida, Tallahassee, FL.

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