Technical Report

Going One Step Beyond: A Neighborhood Scale Air Toxics Assessment in North Denver (The Good Neighbor Project)

City and County of Denver
Department of Environmental Health

Final Report
March 9, 2007

Gregg Thomas, Environmental Assessment and Policy Supervisor
Debra Bain, Environmental Scientist
Sabrina Williams, Environmental Scientist

Prepared for:

The Colorado Department of Transportation
Division of Transportation Development
4201 East Arkansas Avenue
Denver, CO 80222

The U.S. Department of Transportation
FHWA – Colorado Division
12300 West Dakota Avenue
Suite 180
Lakewood, CO 80228

DISCLAIMER

This document is disseminated under the sponsorship of the U.S. Department of Transportation in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof.

The contents of this report reflect the views of the contractor, who is responsible for the accuracy of the data presented herein. The contents do not necessarily reflect the official policy of the Department of Transportation.

This report does not constitute a standard, specification, or regulation. The United States Government does not endorse products or manufacturers. Trade or manufacturers' names appear herein only because they are considered essential to the object of this document.

GLOSSARY OF ACRONYMS

AADT	Annual average daily traffic
AERMOD	EPA approved steady-state air dispersion plume model
AIRS	Aerometric Information Retrieval System
ATV	All terrain vehicle
CALPUFF	EPA approved non steady-state air dispersion puff model
CAMP	Consolidate Area Monitoring Program air sampling station
CDOT	Colorado Department of Transportation
CDPHE	Colorado Department of Public Health and Environment
CFD	Computational Fluid Dynamics
CO	Carbon Monoxide
DEH	Denver Department of Environmental Health
DIA	Denver International Airport
DRCOG	Denver Regional Council of Governments
EC	Elemental Carbon
EIS	Environmental Impact Statement
EPA	United States Environmental Protection Agency
FHWA	United States Federal Highway Administration
GIS	Geographic Information System
HDDV	Heavy Duty Diesel Vehicle
HUTF	Highway User Tax Fund
IARC	International Agency for Research on Cancer
ISC3	EPA approved Industrial Source Complex Short-Term Plume Model
Micron	One one-millionth of a meter
MOBILE6.2	EPA approved onroad mobile source emissions model
MSAT	Mobile Source Air Toxics
NATA	EPA National Air Toxics Assessment
NCDC	National Climatic Data Center
NEPA	National Environmental Policy Act
NEI	National Emissions Inventory (replaced NTI in 2002)
NFRAQS	Northern Front Range Air Quality Study
NMIM	National Mobile Inventory Model
NTI	National Toxics Inventory
NWS	National Weather Service
OC	Organic carbon
OZIPR	Ozone Isopleth Plotting Package
PM	Particulate matter, generally associated with diesel PM in this report
$PM_{2.5}$	Particulate matter less than 2.5 microns in diameter
PM_{10}	Particulate matter less than 10 microns in diameter
PPBV	Parts per billion volume
SCIM	Sampled Chronological Input Model, an option in ISC3
SIA	Stapleton International Airport
TDM	Travel Demand Model
TOG	Total organic gases
VMT	Vehicle miles traveled
VOC	Volatile organic compound
WRAP	Western Regional Air Partnership

EXECUTIVE SUMMARY

Background

In 2004, the Denver Department of Environmental Health (DEH) completed a cumulative air toxics assessment for Denver County. This was a baseline assessment using 1996 emissions data from the U.S. EPA National Toxics Inventory (NTI), the U.S. EPA MOBILE6.2 emissions model, and the Colorado Department of Public Health and Environment (CDPHE) stationary source emissions database.

The cumulative assessment included mobile, area, and point source emissions for the six county Metropolitan Denver region (now seven counties). The Industrial Source Complex Short Term (ISC3ST, hereafter referred to as ISC3) air dispersion model was used to predict concentrations of approximately 70 air toxics. Much of the modeling was completed prior to the US EPA promulgating AERMOD as the official model for this type of assessment (before December 2006).

The 1996 baseline assessment apportioned area and mobile source emissions to census block group polygons. In Denver County, the mean block group area is 0.6 km^2 and the median area is 0.3 km^2. This is one of only a few regional air quality assessments with spatial resolution less than 1 km^2.

Model-to-monitor ratios ranged from 0.4 to 1.0. The U.S. EPA generally applies a factor of two criterion for model-to-monitor comparison (0.5 to 2.0) when comparing modeled ambient concentrations with data from air monitoring stations (EPA 2001). Model-to-monitor comparisons for air toxics are performed using annual averages. Paired in time daily average concentrations could be compared, and may demonstrate better comparisons on days with steady-state meteorological conditions, and poorer comparisons on days with highly variable conditions. However, the paired-in-time analysis was outside the scope of this project.

The baseline assessment showed that ISC3 model tended to under predict measured concentrations (annual averages), especially in the urban core. The under prediction bias by ISC3 in Denver could be the result of 1) inaccurate emission inventories, 2) the fact that ISC3 does not carry over emissions from previous hours, and/or 3) allocating emissions across an entire census polygon may result in emissions "smoothing" in polygons where emissions are high (i.e. those with major roadways).

For certain pollutants, such as benzene, it is expected that good model-to-monitor agreement would be observed. There are several reasons why we would expect good agreement between model prediction and monitor results for benzene:

- It is a widely distributed pollutant which is emitted from point, area, and mobile sources. Thus, if the model is biased in the way it handles any one of these source categories, the bias will likely be dampened by one of the other sources;
- There is an estimated background concentration for benzene;

- Monitoring technology for benzene has a long history, suggesting that the monitoring data is reflective of actual ambient concentrations, and
- Benzene emissions have been tracked for many years, so there is some confidence in emission estimates.

The Good Neighbor Project

To test the hypothesis of emissions smoothing across census polygons, a proposal was submitted to the U.S. Federal Highway Administration (FHWA) in 2003 to evaluate these effects. More specifically, this study attempted to explore air concentration gradients near major roadways and how much local sources impact near-highway receptors. As Interstate 70 through Denver is undergoing an Environmental Impact Statement (EIS) for planned capacity building, these issues have been raised by the community.

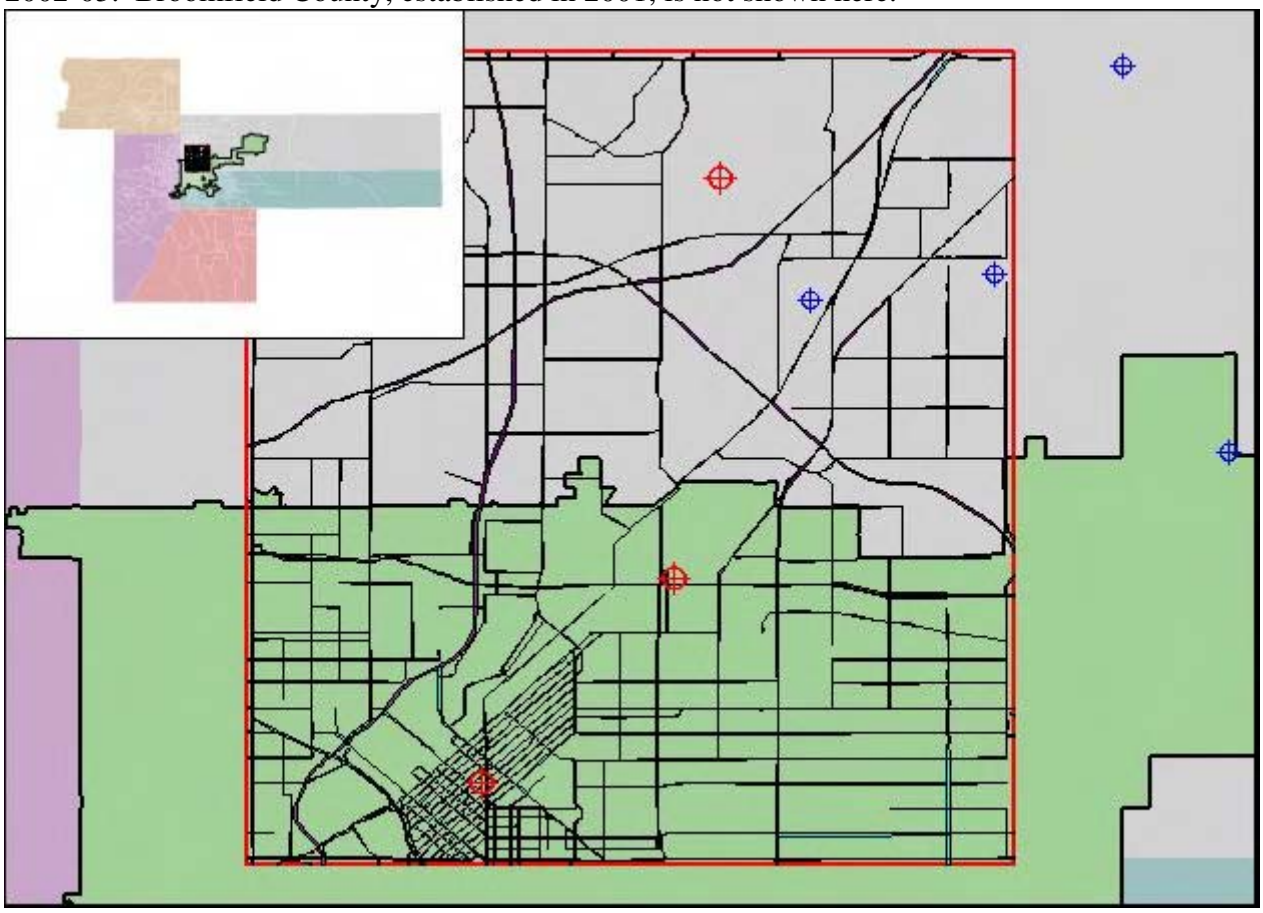
The National Environmental Policy Act (NEPA) requires federal agencies to examine the environmental impacts of their proposed actions and as a part of that, an air quality assessment is usually conducted. Project assessments typically involve some combination of the following: (1) estimating expected emissions associated with the project; (2) estimating ambient pollutant concentrations in the vicinity of the project; and (3) comparing resulting numbers to a baseline (e.g., the emissions from the current year, future emissions without the project, or a threshold value).

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

FHWA issued interim guidance in 2006 on how mobile source air toxics (MSATs) should be addressed in NEPA documents for highway projects (FHWA, 2006). However, even for projects with high potential MSAT effects, only emissions level analyses are recommended as FHWA believes that the state of the science for air dispersion models is not currently adequate for calculating project level air toxics concentrations.

Going One Step Beyond: A Neighborhood Scale Air Toxics Assessment in North Denver (Good Neighbor) was designed as a neighborhood scale "hotspot" assessment for air toxics. A smaller geographic area was selected in north Denver and Commerce City, Colorado, as shown in Figure ES-1. It should be noted that the intent within the focus area was to explicitly assign onroad MSAT emissions to the actual road links. All other emission sources, including MSATs outside the focus area, were modeled using the same methodology employed in the baseline assessment.

Figure ES-1. Modeling domains included in this assessment. Highway, arterial, and collector roads are shown. Crosshairs show locations where air toxics monitoring data was collected in 2002-03. Broomfield County, established in 2001, is not shown here.



Methodology

Emissions

Emissions were updated to 2002 using a combination of the U.S. EPA and CDPHE databases, as well as the MOBILE6.2 emissions model incorporating local data. The focus of this work was the six priority MSATs: 1,3-butadiene, benzene, diesel particulate matter, acrolein, acetaldehyde, and formaldehyde.

The main difference in the current modeling methodology from the 1996 baseline assessment is that on-road mobile source emissions are allocated to the actual roadway polygons, not spread evenly across the entire census block group polygon. This is expected to eliminate the polygon smoothing effect from the baseline assessment and lead to higher predicted concentrations on and near the actual roadways.

Onroad mobile source emissions were zeroed for all block groups in the focus area, except for the emissions generated on local roads. Local road mobile source emissions, which were too numerous to model individually, were modeled as in the baseline assessment, i.e. allocated to the census block group polygons. Area source and nonroad mobile source emissions were also modeled using the baseline methodology.

MOBILE6.2 was used to generate onroad MSAT emission factors for the Good Neighbor Project focus area. MOBILE6.2 is best suited for regional modeling applications. The emission rates produced are intended to be reflective of the overall fleet and road network. However, for certain road types, vehicle emissions characteristics may be drastically different. Therefore, for the Good Neighbor project, adjustments were made to MOBILE6.2 emission factors to account for differences between road types for cold-start, hot stabilized, and evaporative emissions.

For example, highways/freeways see very few vehicles operating in the cold-start mode, therefore cold-start emissions should be heavily weighted to other road types. Similarly, except for running loss emissions, there are few diurnal or resting loss evaporative emissions that occur on freeways. These adjustments lower the MOBILE6.2 benzene emission factor on the freeways by 20 percent and increase it on the local and collector road types as compared to using the fleet average emission factor based on vehicle miles traveled (VMT) across all road types. The effects of applying this methodology to the regional benzene emission inventory is shown in Figure ES-2. Notice that benzene emissions by road type are proportionally higher than VMT on local and collector roads but lower on arterials and highways.

Although the Good Neighbor Project focus area comprises only 1.2 percent of the total area of the seven county metropolitan Denver region, 13 percent of the regional VMT is generated here. For onroad MSATs, the ratios of the emissions within the focus area to the regional emissions range from 10-16 percent. The Good Neighbor MSAT emissions inventory and the ratios to the regional totals are shown in Table ES-1.

Figure ES-2. 2002 regional benzene emissions along with VMT fractions for each road type.

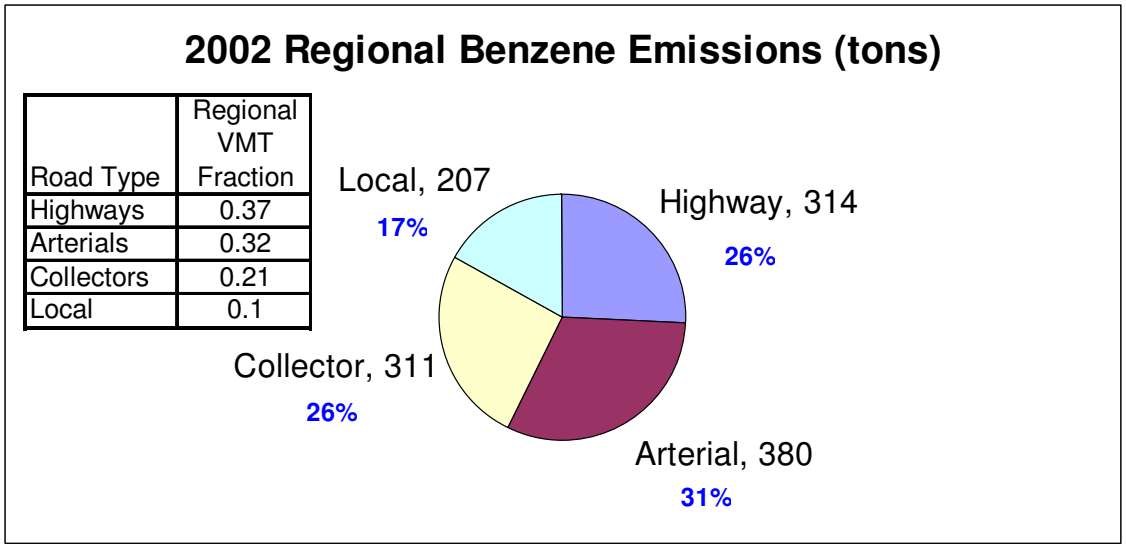


Table ES-1. Good Neighbor focus area MSAT emission inventory and how that compares to regional emission totals. Ratios shown are per emission category for the region.

	Benzene (tons/yr)	FHWA/ Metro Ratio	1,3 Butadiene (tons/yr)	FHWA/ Metro Ratio	Formal-dehyde (tons/yr)	FHWA/ Metro Ratio	Acetal-dehyde (tons/yr)	FHWA/ Metro Ratio	Acrolein (tons/yr)	FHWA/ Metro Ratio	Diesel Exhaust PM NEI vs DEH MOBILE6.2 (tons/yr)	FHWA/ Metro Ratio
FHWA FOCUS AREA												
Onroad Mobile - gasoline	142.2	0.11	18.7	0.11	52.6	0.11	27.3	0.11	2.2	0.11	0	-
Onroad Mobile - diesel	1.7	0.10	1.0	0.11	12.8	0.11	4.6	0.11	0.6	0.11	110.3	0.16
Offroad Mobile - gasoline	28.5	0.07	4.5	0.07	53.5	0.19	26.1	0.22	4	0.36	0	0.07
Offroad Mobile - diesel											75.8	
Area Sources	2.9	0.02	2	0.06	5.6	0.03	10.5	0.27	1	0.02	nd	-
Point Sources	29.6	0.21	0.8	1.00	12.7	0.16	0.4	0.04	0	-	nd	-

Air Dispersion Modeling

For transportation projects, the impacts of emission sources are usually predicted using computer aided modeling. These models vary widely in their intended applications, methodologies, sophistication and required user input. For transportation project analyses, air dispersion models should be applicable for short range (<100 m) and short term analyses (< 24 hours). It may so happen that several models have both application for transportation projects as well as regional scale analyses.

For an excellent overview of the strengths and weaknesses of each model, the reader is referred to Neimeier et al. (2006). However, the primary limiting factor for the Good Neighbor assessment was the ability of the chosen model to predict air toxics concentrations.

Until December 2006, the preferred plume dispersion model for estimating urban-wide concentrations of toxic air pollutants was the Industrial Source Complex Short Term model (ISC3ST) model. The ISC3 and AERMOD models are steady-state Gaussian plume models that can be used to assess pollutant impacts from a wide variety of sources. Gaussian plume modeling is a widely used technique for estimating the impacts of non-reactive pollutants because of its good performance against field measurements, and because it is computationally efficient relative to other types of models, such as grid and puff models. The version of ISC3ST (02035) used in this assessment included enhancements for air toxics applications. Current traffic analysis models have not been updated to address mobile source air toxics (MSATs).

The version of ISC3 (02035) utilized in this assessment incorporated modeling options for air toxics applications. The most important feature of the air toxics enhancements in ISC3 relates to the use of the Sampled Chronological Input Model (SCIM) to significantly reduce model run times. The SCIM option allows the user to specify how frequently meteorological data is sampled. For this assessment, meteorological data was sampled once every 25 hours. Using a five-year meteorological data set (43,824 hours), each hour of the day is sampled 73 times. Therefore, diurnal variations in weather patterns are reflected in the annual average model concentrations. An annual averaging period was utilized in ISC3 because it is primarily long-term exposure to low level concentrations that is of interest for air toxics.

Seasonal, day of week, and hour of day emission factors were applied to account for varying traffic patterns. Within the focus area, onroad mobile source emissions were apportioned to 978 different road links and concentrations were predicted at roughly 2300 receptors. Emissions outside the focus area were modeled to the census block group polygons, as in the 1996 baseline assessment. The ISC3 model typically shows only a minimal influence from sources beyond a few hundred meters from a polygon source.

In addition, a limited comparison study to ISC3 was conducted using the CALPUFF modeling system. CALPUFF is a non-steady-state meteorological and air quality modeling system. CALPUFF can be used in site-specific assessments, though that is not the typical application for this model. CALPUFF is extremely resource intensive compared to the other models.

Results

The air dispersion model was run for the six priority MSATs. For each pollutant, the following model runs were performed:

1) *Inside the focus area*: Denver County highways, Denver County arterials and collectors, Adams County highways, Adams County arterials and collectors;
2) *All block groups*: onroad mobile sources (local road contribution only), nonroad mobile source, area sources, and point sources.

The concentrations from each model run were summed to calculate the predicted primary concentrations. Background and/or secondary concentrations were also added where applicable to calculate the total predicted ambient concentrations. Ambient concentrations of formaldehyde, acetaldehyde, and acrolein all have significant contributions from secondary formation (EPA, 1999b; Ligocki et al., 1992).

Table ES-2 shows predicted maximum and mean concentrations for the six priority MSATs. Not surprisingly, there is a large spread between the mean and maximum concentrations due to the revised methodology. Benzene and 1,3-butadiene have > 60 percent of the mean concentration attributable to onroad mobile sources. Diesel PM is evenly split between onroad and nonroad mobile sources. There is less of a spread for formaldehyde and acetaldehyde; however, these compounds are in large part estimated to be formed via secondary photochemical reactions.

Note the large differences between the maximum and mean concentrations. This stems from the wide range of emission intensities on different road links. While many receptors are on light to moderately traveled collectors and arterials, a smaller subset of receptors shows that concentrations near heavily traveled links are not well represented by the mean value.

Table ES-2. Mean and maximum predicted concentrations for the six priority MSATs and concentrations for each source category. Concentrations are in micrograms per cubic meter.

			Mean Concentration by Source Type (micrograms per cubic meter)						
Pollutant	Max Annual Avg. Conc. ($\mu g/m^3$)	Mean Annual Avg. Conc. ($\mu g/m^3$)	Denver Highways	Denver Arterial & Collector	Adams Highways	Adams Arterial & Collector	All Other Area and Mobile (Regional)	Point Sources	Background
Benzene	7.35	1.87	0.27	0.37	0.22	0.17	0.50	0.08	0.25
1,3 Butadiene	0.97	0.18	0.03	0.05	0.02	0.02	0.06	6.80E-04	0
Formaldehyde	7.16	4.51	0.13	0.16	0.08	0.05	0.23	0.02	3.85 [1]
Acetaldehyde	3.91	2.55	0.05	0.08	0.04	0.03	0.16	4.20E-04	2.19 [2]
Acrolein	0.35	0.23	0.004	0.007	0.003	0.002	0.014	1.00E-05	0.2 [3]
Diesel PM	8.67	1.44	0.24	0.14	0.26	0.06	0.74	N/A	N/A

[1] Estimated background formaldehyde = 0.2 ug/m3 and secondary concentration = 3.65 ug/m3

[2] Estimated background acetaldehyde = 0.16 ug/m3 and secondary concentration = 2.03 ug/m3

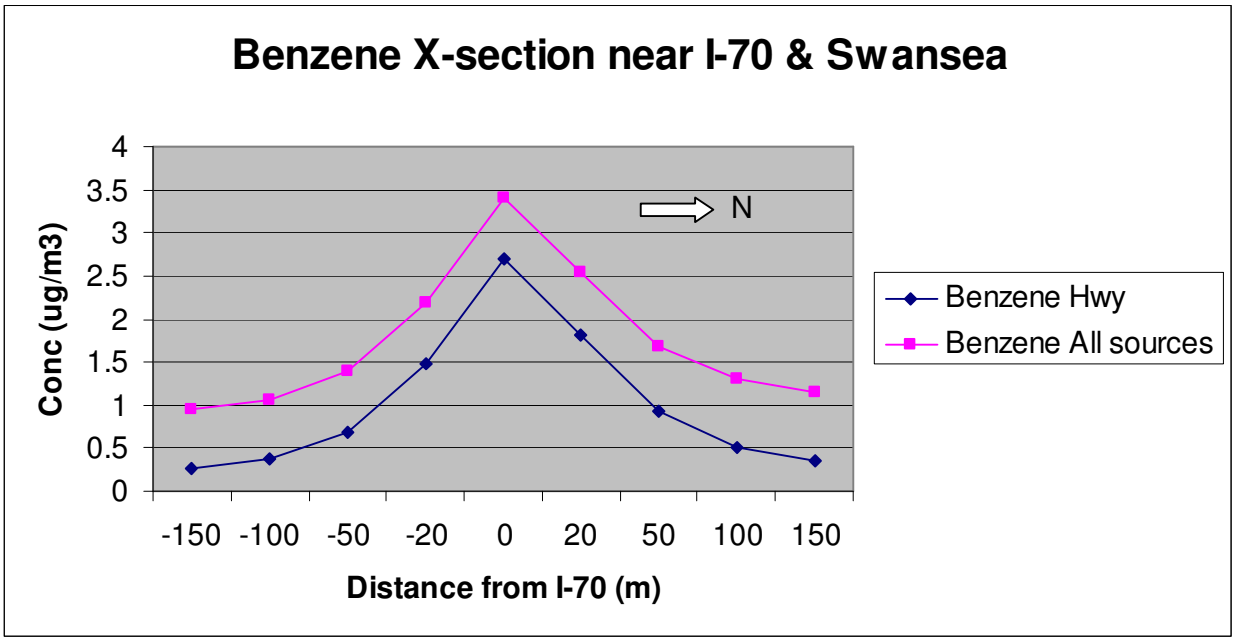
[3] Estimated background acrolein = 0.02 ug/m3 and secondary concentration = 0.18 ug/m3

Utilizing the revised methodology for apportioning onroad MSAT emissions to the major roadway polygons, the predicted maximum annual average concentrations from ISC3 increased by a factor of 2-3 in the immediate vicinity of the roadways, but dropped off sharply within 50 m of the roadways. This corresponds with recent research on highway gradient criteria pollutant monitoring (Zhu et al., 2002).

Figure ES-3 shows a benzene cross section north and south of I-70 as predicted by ISC3. For this analysis, receptors were spaced at intervals of 0, 20, 50, 100, and 150 m north and south of the highway. For highway influences only, predicted concentrations drop off sharply within 50 m of the highway, decreasing to 33 percent of the roadside concentration. At 100 m, highway attributed benzene concentrations are only 20 percent of the roadside concentrations. The gradients are slightly sharper on the south side of I-70, which tends to be in the upwind direction more often.

Zhu et al. (2002) measured ultrafine particle number concentrations (< 0.1 micron), black carbon, and carbon monoxide near the 710 freeway in Los Angeles, CA. Measurements were taken as close as 17 m and out to 300 m downwind of a highway. Carbon monoxide (CO) is expected to behave much like benzene near highways; Zhu et al. found CO concentrations decreased by over 50 percent between the 17 m and 30 m monitors when both monitors were downwind. Results for all time periods, regardless of wind direction, showed a more gradual gradient out to 30 m (26 percent decrease), but concentrations at 90 m were only 22 percent of the average at 17 m. Beyond 100 m from the freeway, concentrations decreased much more gradually. Zhu et al. results agree well with ISC3 predictions in Figure ES-3.

Figure ES-3. Cross section of benzene concentrations north and south of I-70 (east-west highway). The highway receptor is depicted by the zero distance. The prevailing wind direction is from the south in this area.



The ISC3 model under predicted ambient concentrations. This is not surprising based on ISC3 limitations for handling pollutant carry over from hour to hour and its lack of ability to adequately treat complex terrain (e.g. valley drainage flows common in Denver). Model-to-monitor comparisons improved slightly over the baseline methodology and were within a factor of three at all monitors and within a factor of two at the monitors closest to high traffic sources. Using estimated secondary and background concentrations for formaldehyde and acetaldehyde, model-to-monitor ratios were all within a factor of two.

CALPUFF is a non-steady state Gaussian puff model. CALPUFF takes into account plume meandering due to hourly variations in meteorology, and may also be used for long-range transport. CALPUFF is also recommended in applications with complex terrain. CALPUFF was utilized in the Portland Air Toxics Assessment.

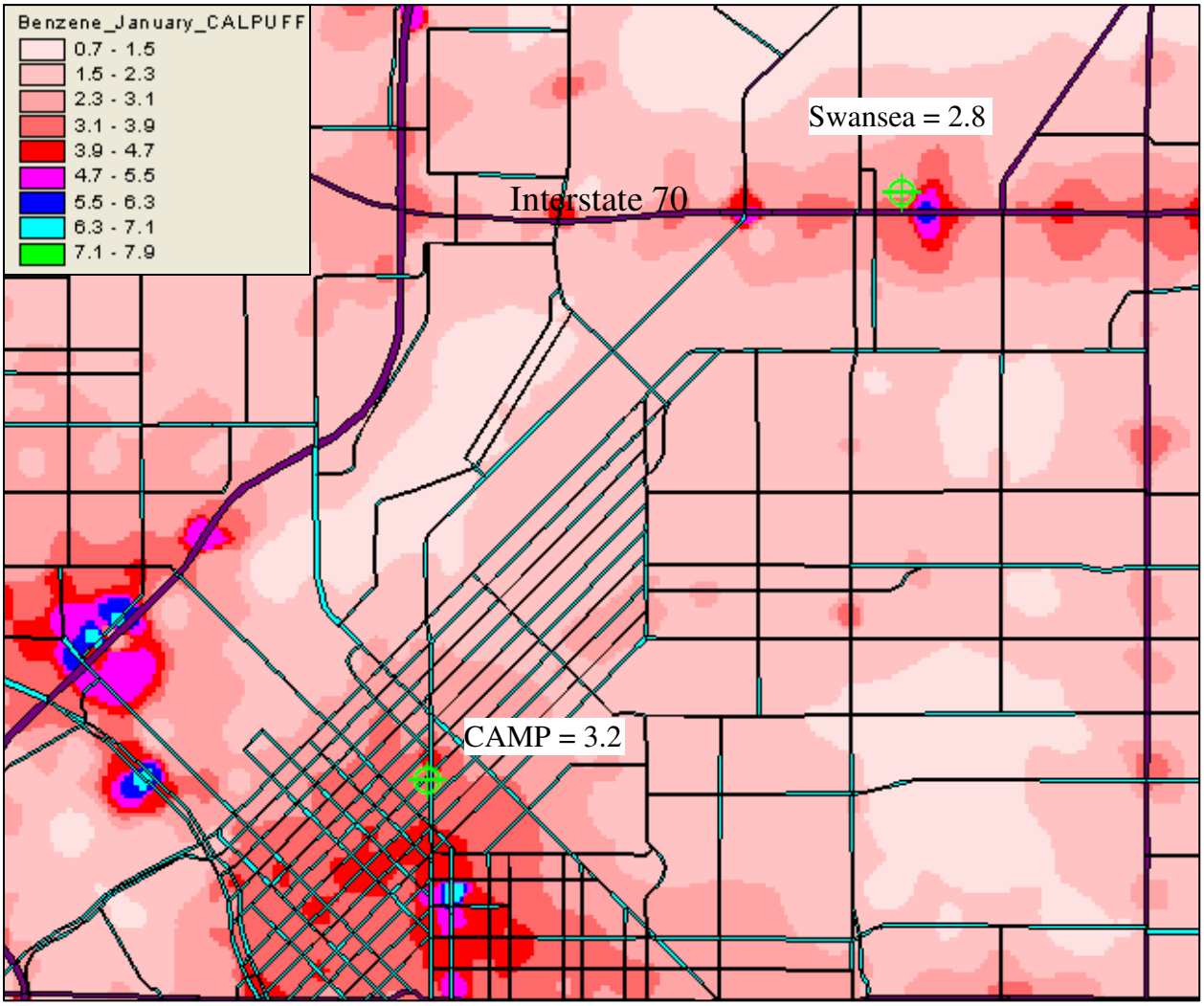
However, CALPUFF is much more resource intensive. A significant amount of work was required to convert the ISC3 model files to CALPUFF files. For example, CALPUFF cannot accept polygon area sources. ISC3 allows up to 20 vertices to describe a curved roadway. CALPUFF currently only allows four vertices to describe area sources. ISC3 polygon area sources were simplified and/or sub-divided to fit the CALPUFF criteria. For the comparison, both models used the same roadway geometry inputs. Emissions for each model were assumed to be constant over 24 hours (a limitation of CALPUFF). Not accounting for temporal emission factors likely biases high the predicted concentrations from both models. In previous work in ISC3, DEH found that the use of temporal emission factors decreased predicted annual average concentrations by approximately 25 percent (Thomas, 2004).

Benzene was used as the pollutant to compare ISC3 and CALPUFF because it is relatively inert and there is sufficient monitoring data with which to compare the predicted concentrations. For this comparison, DEH modeled ISC3 and CALPUFF using only the January 1990 meteorological data. This is because in CALPUFF, 90 hours of computer run time and 5 gigabytes (GB) of hard drive space were required for each month modeled. It should be noted that from ISC3 monthly runs for the entire year, the monthly average concentration for January was close to the annual average concentration (0.36 versus 0.35, respectively). Therefore, January concentrations are not expected to be biased high or low.

Figures ES-4 and ES-5 show detailed views of central Denver with predicted benzene concentrations for January using CALPUFF and ISC3, respectively. Only Denver roadway sources were modeled in CALPUFF; all other source contributions, including regional background, were added to the CALPUFF results based on the ISC3 model results for other sources throughout the project area.

Although we are comparing one-month predictions with annual average measurements, the January average concentration approximated the annual average concentration generated by ISC3. Assuming the same holds true in CALPUFF, CALPUFF model-to-monitor comparisons are much better at Swansea and CAMP, with both ratios equal to 1.1. For the same period, ISC3 ratios at Swansea and CAMP are 0.61 and 0.75, respectively. Either model produces good results, as both are within a factor of two of measured concentrations.

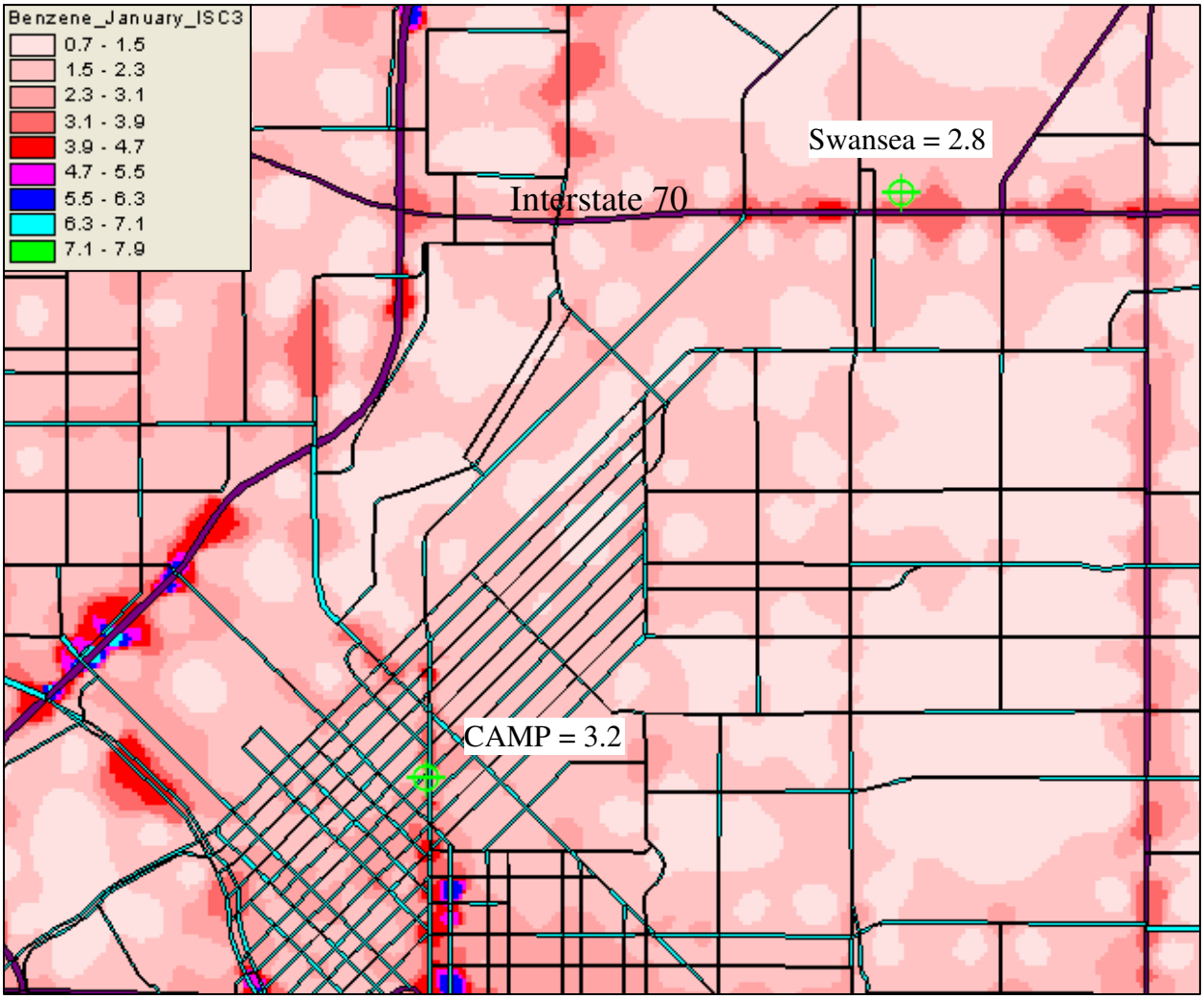
Figure ES-4. CALPUFF predicted monthly average concentrations using January 1990 meteorological data. Monitored concentrations for Swansea and CAMP stations are shown.



The spatial concentration gradient near the roadways is less pronounced in CALPUFF than in ISC3. This can be seen by the "donut-hole" effect from ISC3 as evidenced in Figure ES-5. ISC3 predicts highway impacts drop off by 50-66 percent within 50 m of the roadways, whereas CALPUFF predicts only about a 10-25 percent reduction over that distance.

While recent research generally aligns more with the ISC3 predicted gradients, the body of research is very small and experiments have until now been conducted over very short time frames. Targeted monitoring campaigns within short distances both upwind and downwind of specific roadways would provide valuable information regarding the use of dispersion models for similar types of assessments. Such assessments are planned as a result of US-95 settlement between the Sierra Club and FHWA in 2005. It is unclear whether dispersion models will be utilized in any of those assessments to compare with gradient monitoring results.

Figure ES-5. ISC3 predicted monthly average concentrations using January 1990 meteorological data. Monitored concentrations for Swansea and CAMP stations are shown.



Conclusions and Recommendations

Modeling capabilities have improved sufficiently to enable researchers to better understand the MSAT concentration gradients near roadways, although a combination of modeling and actual monitored data will always be preferable to modeling results alone. EPA and FHWA are in the process of developing a methodology to address MSATs for transportation projects.

The ISC3 air dispersion model was utilized for this assessment as it was still the EPA recommended model for urban air toxics assessments in 2005. ISC3 was run employing both the original DEH methodology, updated with 2002 emissions, along with the revised methodology outlined in this report.

Overall, ISC3 model-to-monitor ratios for benzene improved slightly with the revised methodology at the existing monitor locations (0.32-0.69 versus 0.30-0.62). However, ISC3 maximum predicted concentrations increased by a factor of 2-3 on the roadways, with very sharp concentration gradients within 50 m of the roadways.

CALPUFF model-to-monitor comparisons are much better at Swansea and CAMP, with both ratios equal to 1.1, i.e. a 10% over prediction. For the same period, ISC3 ratios at Swansea and CAMP are 0.61 and 0.75, respectively (a 25-40% under prediction). Either model produces good results, as both are within a factor of two (EPA, 2001) of measured concentrations. However, CALPUFF shows a more gradual concentration gradient out to several hundred meters from the highway.

While model-to-monitor ratios are of paramount interest in evaluating both emissions and dispersion model performance, one should not lose sight of the ability of the models to accurately reproduce spatial variations in pollutant concentrations. Both the 1996 baseline assessment and the Good Neighbor assessment demonstrate that the combination of emissions models, the spatial and temporal allocation methodology, and the dispersion models approximate well the relative differences between sites in Denver where there is measured data. Though not a focus of the Good Neighbor Project, similar results have been demonstrated for carbon monoxide, where there are additional monitoring sites in Denver to compare with predicted concentrations.

The results presented in this report indicate that highly detailed neighborhood scale air toxics modeling assessments are cost-effective and can generate realistic data that match our conceptual model. The project budget for the Good Neighbor project was approximately $40K. Earlier investments by Denver to develop the modeling platform totaled approximately $100K. However, much of that work is geographic information system (GIS) work that represents a one-time investment. Future emissions and dispersion modeling work can be performed quickly at a much cheaper cost.

Historically, ambient air toxics monitors have not been sited close to major roadways. Only one Denver monitor falls within a 50 m distance from a major roadway, with approximately 25,000 vehicles per day passing the site. Targeted monitoring campaigns within short distances both upwind and downwind of specific roadways are needed, preferably coinciding with dispersion model assessments. The results from the combined assessments could provide the public and policy makers with increased confidence in modeled results, which tend to be the predominant tool used to identify mobile source “hotspots”.

TABLE OF CONTENTS

TABLE OF FIGURES

TABLE OF TABLES

1. INTRODUCTION

1.1 Background

In 2004, the Denver Department of Environmental Health (DEH) completed a cumulative air toxics assessment for Denver County. This was a baseline assessment using 1996 emissions data from the U.S. EPA National Toxics Inventory (NTI), the U.S. EPA MOBILE6.2 emissions model, and the Colorado Department of Public Health and Environment (CDPHE) stationary source emissions database.

The assessment included mobile, area, and point source emissions for the then six county Metropolitan Denver region. In 2001, Broomfield County was created but most of Broomfield was still within the original six county boundary. Though similar in concept to the U.S. EPA National Air Toxics Assessment (NATA), this assessment incorporated a wealth of local data not available to the EPA for use in the NATA. In addition, it also incorporated a finer spatial resolution than the NATA. The Industrial Source Complex Short Term (ISC3ST, hereafter referred to as ISC3) air dispersion model was used to predict concentrations of approximately 70 air toxics (Thomas, 2004).

The 1996 baseline assessment evenly allocated area and mobile source emissions across the entire census block group polygon. This had the unintended effect of decreasing concentrations near roadways while increasing them at the census block group boundaries. If the census polygons are small enough, this is less of a concern but still produces the unintended results. In Denver County, the mean area of the census block groups was 0.6 km^2 and the median area was 0.3 km^2. This is one of only a few regional air quality assessments with spatial resolution less than 1 km^2.

Model-to-monitor ratios ranged from 0.4 to 1.0. The U.S. EPA generally applies a factor of two criterion for model-to-monitor comparison (0.5 to 2.0) when comparing modeled ambient concentrations with data from air monitoring stations (EPA 2001). Model-to-monitor comparisons for air toxics are performed using annual averages. Paired in time daily average concentrations could be compared, and may demonstrate better comparisons on days with steady-state meteorological conditions, and poorer comparisons on days with highly variable conditions. However, the paired-in-time analysis is outside the scope of this project.

For certain pollutants, such as benzene, it is expected that good model-to-monitor agreement would be observed. There are several reasons why we would expect good agreement between model prediction and monitor results for benzene:

- It is a widely distributed pollutant which is emitted from point, area, and mobile sources. Thus, if the model is biased in the way it handles any one of these source categories, the bias will likely be dampened by one of the other sources;
- There is an estimated background concentration for benzene;
- Monitoring technology for benzene has a long history, suggesting that the monitoring data is reflective of actual ambient concentrations, and

- Benzene emissions have been tracked for many years, so there is some confidence in emission estimates.

The baseline assessment showed that ISC3 model tended to under predict measured concentrations, especially in the urban core. The under prediction bias by ISC3 in Denver could be the result of 1) inaccurate emission inventories, 2) the fact that ISC3 does not carry over emissions from previous hours, or 3) allocating emissions across an entire census polygon may result in emissions "smoothing" in polygons where emissions are high (i.e. those with major roadways).

1.2 The Good Neighbor Project

The National Environmental Policy Act (NEPA) requires federal agencies to examine the environmental impacts of their proposed actions and as a part of that, an air quality assessment is usually conducted. Project assessments typically involve some combination of the following: (1) estimating expected emissions associated with the project; (2) estimating ambient pollutant concentrations in the vicinity of the project; and (3) comparing resulting numbers to a baseline (e.g., the emissions from the current year, future emissions without the project, or a threshold value).

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

FHWA issued interim guidance in 2006 on how mobile source air toxics (MSATs) should be addressed in NEPA documents for highway projects (FHWA, 2006). However, even for projects with high potential MSAT effects, only emissions level analyses are recommended as FHWA believes that the state of the science for air dispersion models is not currently adequate for calculating project level air toxics concentrations.

To test the hypothesis of emissions smoothing across census polygons, an updated air toxics assessment was proposed by DEH to the U.S. Federal Highway Administration (FHWA) in which emissions would be updated to 2002 and compared with the monitored concentrations collected by CDPHE. This assessment, titled *Going One Step Beyond: A Neighborhood Scale Air Toxics Assessment in North Denver (Good Neighbor)*, would focus on a smaller geographic area in North Denver and Commerce City, Colorado. Significant additional detail would be included in the Good Neighbor assessment, most notably apportioning on-road mobile source emissions to actual roadway polygons within the focus area. Good Neighbor focused on the six priority mobile source air toxics (MSATs): benzene, 1,3-butadiene, acrolein, acetaldehyde, formaldehyde, and diesel particulate matter.

1.3 Content of Report

Chapter 2 of this report describes the emissions inventory. Chapter 3 of this report describes the ISC3 modeling methodology along with the results using both the old (census block group) and new (roadway polygons) assessment methods for the six priority MSATs. Chapter 3 also includes a comparison between the ISC3 and CALPUFF dispersion models for benzene. Finally, Chapter 4 presents conclusions and recommendations.

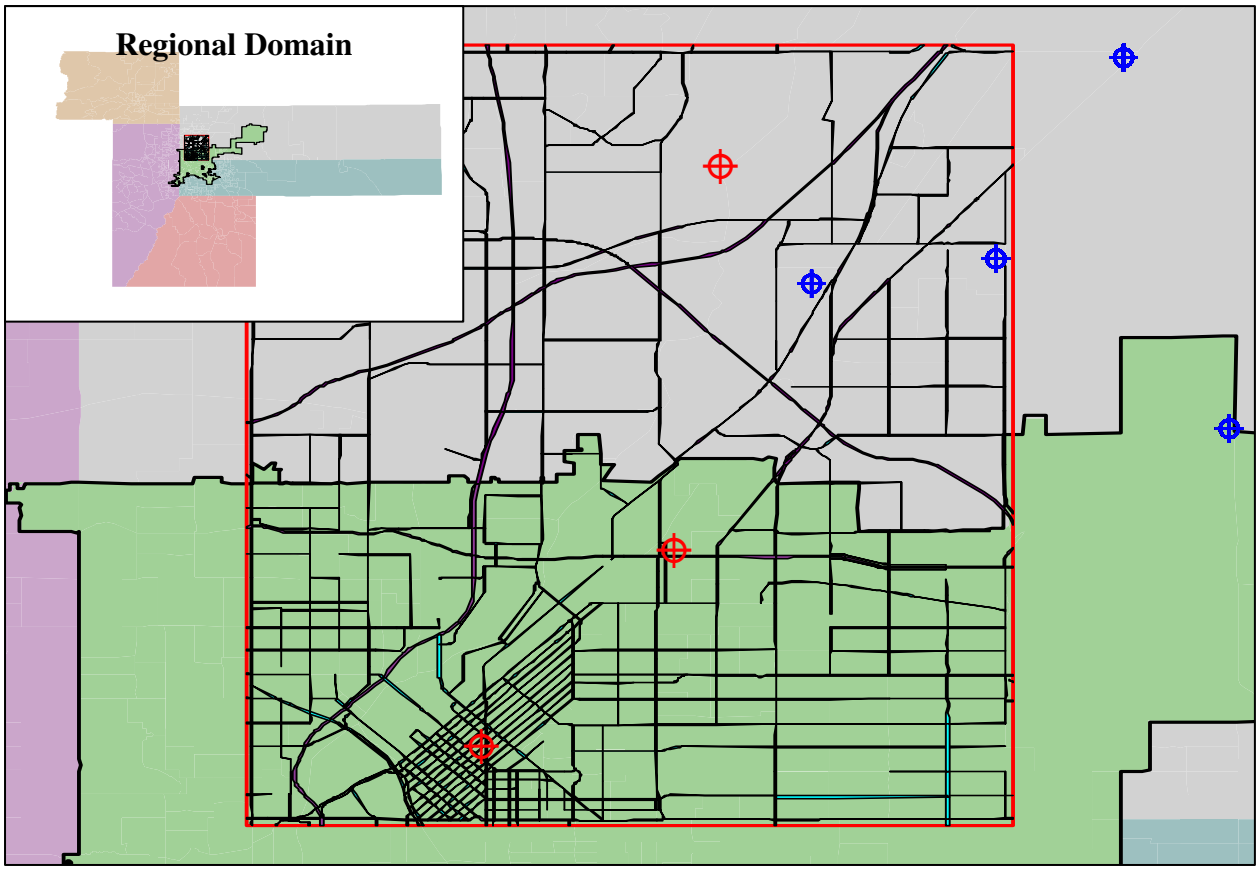
2. EMISSIONS INVENTORY

2.1 Modeling Domains

Figure 2-1 shows the modeling domains used for this assessment. The regional modeling domain is shown in the inset frame while the Good Neighbor focus area is shown in the main frame. The roadways shown in the focus area include highways, arterials, and collector roadways. Emissions (point, area, and mobile) in areas outside of the focus area were spatially and temporally allocated to the census block groups using surrogates such as VMT and population (Thomas, 2004). This was done to account for pollution impacts from outside the focus area and may slightly under or over predict concentrations at the boundaries if a major roadway borders the focus area. The dispersion model (ISC3) used in this assessment generally predicts that concentrations drop off rapidly away from a roadway source, so those effects as presented in this report would be minimal.

The focus area is bounded by Colfax Avenue on the south, Quebec Street to the east, 84th Avenue to the north, and Pecos Blvd to the west. The focus area is 139 km^2, roughly 1.2 percent of the total area of the of the original six county Denver region (11,725 km^2).

Figure 2-1. Modeling domains included in this assessment. Highway, arterial, and collector roads are shown. Crosshairs show locations where air toxics monitoring data was collected in 2002-03. Broomfield County, created in 2001, is not shown here.



2.2 Stationary/Point Source Emissions

The point source (or stationary source) database obtained from CDPHE was an AIRS format database in Microsoft Access. Information such as facility name, location, types and amounts of air toxics emitted, stack parameters, and operating data were provided. DEH also maintains a compliance inspection database for stationary sources that tracks product consumption, from which emissions can be estimated. The DEH database and inspection records were consulted when discrepancies regarding emissions or locations of facilities were in question. Overall, very few changes were made to the original CDPHE emissions database.

It should be noted that the stationary sources included in the CDPHE database cover both major and minor point sources. Major point sources as defined in Section 112 of the Clean Air Act are sources that emit more than 10 tons per year of any individual air toxic or more than 25 tons per year of a combination of air toxics. Depending on the toxicity of a particular pollutant, sources that emit as few as 50 pounds per year of a single air toxic (benzene) may be included in both the CDPHE and DEH point source database.

The point source contribution to the seven county emission inventory for the six priority MSATs is shown in Table A-1 of Appendix A.

2.3 Area Source Emissions

Area sources encompass a broad range of categories including consumer products usage, architectural surface coatings, fossil fuel heating including wood burning, and wildfires. Emission totals for each category and pollutant are provided at the county level. The county level emissions are typically allocated to smaller geographic areas within each county using surrogates such as population or population density (residential activities), inverse population density (agricultural activities), or vehicle miles traveled (traffic marking paints).

One problem that arises with the area source portion of the National Emissions Inventory (NEI) is that sources included in the CDPHE point source inventory may also be included in the area source inventory. This occurs because EPA defines area sources to include most non-major point sources such as gas stations, dry cleaners, and auto body repair shops. These sources can be numerous in urban areas and may not have locational data in the NEI database; therefore emissions are summed at the county level. If the modeler were to use both databases without taking this into account, there could be double counting of emissions for the pollutants emitted by those sources. In the 2002 NEI, this effect in Colorado was minimized due to CDPHE input and review of the NEI area source database. For the six priority MSATs, this potential effect is negligible.

In the final analysis of the area source inventory, only pollutants with greater than one ton per year of emissions at the county level were included in this assessment. The one-ton total when spatially allocated produces negligible predicted concentrations across the county. Particulate air toxics were modeled at less than one-ton emission levels due to their lower toxicity values.

The area source contribution to the seven county emissions inventory for the six priority MSATs is shown in Table A-1 of Appendix A.

2.4 Nonroad Mobile Source Emissions

Nonroad mobile sources include construction and agricultural vehicles, planes, trains and landscaping equipment. Large nonroad engines tend to be diesel powered whereas small engines (boats, ATVs, lawnmowers, leaf blowers) tend to be gasoline powered. While onroad mobile sources have seen successive generations of advanced emission control technology, nonroad vehicle engines are far less advanced and as a result, generally emit more pollution. Therefore, while onroad vehicle use may greatly exceed nonroad vehicle activity, nonroad vehicles are significant contributors to regional air quality for certain pollutants.

DEH used the 2002 NEI nonroad emissions inventory in this assessment. Subtotals for each pollutant by vehicle class were calculated so as to correctly allocate emissions spatially. For example, aircraft emissions were assigned only to airport boundaries. Similarly, railroad emissions were allocated only to census block groups with railroad tracks. Other surrogates such as population (landscaping equipment) and inverse population density (agricultural equipment) were used as well.

The nonroad mobile source contribution to the seven county emissions inventory for the six priority MSATs is shown in Table A-1 of Appendix A.

2.5 Onroad Mobile Source Emissions

Onroad mobile sources include light and heavy duty gasoline and diesel vehicles, including motorcycles. For the six priority MSATs, onroad mobile sources are a major contributor to the emission inventories in urban areas. The main focus of this assessment centered on apportioning on-road mobile source emissions to the actual roadway polygons, for which link-based data were available from the Colorado Department of Transportation (CDOT, 2004).

The 2002 NEI provided onroad mobile source emissions at the county level. However, the methodology used to develop those emission totals looks at fleet-wide average emission rates. This is commonly referred to as a top-down approach, where county emissions are allocated to smaller geographic areas using surrogates such as VMT or population. The 1996 baseline assessment conducted by DEH primarily followed a top-down approach, using VMT data from the Denver Regional Council of Governments (DRCOG) travel demand model (TDM), as well as link-based data provided by CDOT to develop and apportion mobile source air toxics across the region.

This assessment focused on a sub-county area and because link-based data were available for the main thoroughfares, MOBILE6.2 was used by DEH to build more of a bottom-up inventory. This methodology attempts to account for emissions differences between roadway types (highways, arterials, collectors, local roads), such as speed, hot-running versus cold-start emissions, light versus heavy duty VMT fractions, and evaporative emissions.

2.5.1 Roadway Datasets and Traffic Attributes

CDOT (2004) makes available GIS based datasets of highways/freeways and major roads (arterials and collectors) by county. The highway/freeway dataset contains attributes such as link ID, annual average daily traffic (AADT) as well as truck traffic during peak and off-peak hours, and through lane quantity and width. The traffic counts for the highways are generally updated each year, either through actual counts or by projections from counts in recent years. For clarification, the term highways is used throughout this report include interstates, freeways, tollways, and state highways. Major roads, otherwise referred to as arterials and collectors, is an additional classification. Mixing of the terms is not intended.

The major roads data does not contain as many attributes as the highway data, most notably truck VMT fractions. AADT is included with the year that the information was last updated. Some of the AADT are 20 years old. For AADT developed prior to 2002, the existing count was multiplied by a 2.25 percent annual VMT growth factor. This may underestimate VMT in numerous locations as the Denver Regional Council of Governments (DRCOG) reported regional VMT grew at a 4.7 percent annual rate from 1990-2000.

The 2.25 percent growth rate used in this assessment satisfied several manual QA/QC checks for neighboring roads inside the focus area. In several instances, a 4.7 percent growth rate for a known lower traffic road with an older AADT date generated higher 2002 AADT than a more traveled neighboring road with a more recent AADT date. This is likely the result of uncertainties in establishing AADT.

Certain areas in Metropolitan Denver underwent explosive development in the 1990s where VMT growth rates were in the double digits. In already built out areas such as central Denver, growth rates grew as well due to additional commutes to and from work, but slower than the 4.7 percent regional growth rate. Table 2-1 shows traffic counts for certain road types from CDOT for the years 1997-2001 (CDOT, 2004).

From Table 2-1, note that the annual growth rate for Douglas County was nearly 10 percent whereas Boulder County shows a negative VMT growth rate for the selected road types. There appear to be inconsistencies between years for reporting of certain road types. The data are generated by mileage certification data received annually from cities and counties for Highway User Tax Fund (HUTF) reporting purposes.

Table 2-1. CDOT traffic counts and county growth rates for select road types in 1997 and 2001.

	Daily Vehicle Miles Traveled										Annual
	Interstate Urban		Freeway Urban		Other Principal Aterial		Minor Arterial Urban		Total VMT		Percent
County	1997	2001	1997	2001	1997	2001	1997	2001	1997	2001	Change
Adams	2,702,068	2,965,840	953,488	722,042	1,079,038	1,304,213	147,974	194,197	4,882,568	5,186,292	1.6
Arapahoe	1,517,122	1,590,168	757,810	953,660	1,789,145	1,977,343	78,642	99,102	4,142,719	4,620,273	2.9
Boulder	0	0	923,270	743,483	895,506	904,746	94,725	102,268	1,913,501	1,750,497	-2.1
Denver	4,402,044	4,621,391	608,005	665,565	1,764,898	1,878,358	94,037	36,294	6,868,984	7,201,608	1.2
Douglas	446,516	496,002	789,013	1,003,915	30,988	264,663	46,097	61,407	1,312,614	1,825,987	9.8
Jefferson	1,139,206	1,155,590	2,365,210	2,676,947	1,860,752	1,968,509	84,231	99,414	5,449,399	5,900,460	2.1
										Regional Average	**2.6**

VMT for the seven county Denver region, as derived from 2002 Highway Performance Monitoring System (HPMS) was approximately 57,000,000 miles per day in 2002 or 20.8 billion miles per year (Western Regional Air Partnership (WRAP), 2005). The HPMS regional VMT value correlates well with the DRCOG VMT estimates of 56.8 – 61.3 million miles per day. For the highways, arterials, and collectors in the focus area, an estimated 2.68 billion miles were traveled. Although the focus area comprises only 1.2 percent of the total area of metropolitan Denver, 13 percent of the regional VMT is generated here.

The CDOT GIS-based roadway datasets in the focus area were processed by DEH to convert the road line themes to polygon themes. The process for performing said conversion is as follows:

1) clip the county line themes using the focus area boundary;
2) merge all adjacent line segments having the same attributes (AADT) to reduce the number of segments;
3) calculate the length of the new line segments (miles);
4) multiply AADT by segment length to generate VMT;
5) add a field to calculate the width of the roadway by multiplying number of lanes by lane width and adding median and shoulder width (if available), then divide by two;
6) generate square buffers around line segments using value calculated in step 5 but keeping buffer length constrained to the segment length;
7) manually QA/QC road buffer widths using aerial photography adjusting attribute table widths if necessary;
8) convert final buffers to a polygon theme and calculate the area of each polygon;
9) extract vertices that define the polygon boundaries;
10) reduce the number of vertices if possible to adequately define road boundaries and assign x,y coordinates, and
11) export modified attributes to spreadsheet for emissions calculations.

2.5.2 MOBILE6.2 Emissions Model – Regional Emissions

MOBILE6.2 was first run to calculate the 2002 county level emissions in Metropolitan Denver for the six priority MSATs. The purpose in doing so was to generate onroad mobile source emissions outside of the focus area. VMT surrogates were used to spatially allocate regional onroad mobile source emissions to the census block group. VMT surrogates were developed using the 2000-01 DRCOG TDM model output by clipping the TDM and calculating VMT in each census block group.

MOBILE6.2 was not used to generate diesel particulate matter (diesel PM) emissions for the regional domain. The 2002 NEI PM_{10} exhaust totals for diesel engines were used for this purpose and were derived from the EPA National Mobile Inventory Model (NMIM), which utilizes MOBILE6.2 emission factors. This includes all exhaust particulate, including sulfate. The diesel exhaust particulate considered to be an air toxic is primarily composed of elemental and organic carbon (EC/OC). In MOBILE6.2, EC/OC makes up approximately 95% of the PM_{10} exhaust. MOBILE6.2 mean emission factors for onroad diesel engines appear to be biased low in Denver when compared with local HDDV dynamometer testing (Graboski et al, 1998; McCormick et. al, 1999). In the focus area, onroad diesel PM emissions were derived from MOBILE6.2 mean emission rates. The mean HDDV PM_{10} exhaust emission rate from

MOBILE6.2 was 0.45 grams per mile, compared with a 1994 and later model year emission rate of 0.62 grams per mile used by the Western Regional Air Partnership (Pollack et al., 2004).

Table A-1 in Appendix A shows both the 2002 NEI diesel PM_{10} exhaust emissions and the DEH derived MOBILE6.2 diesel PM_{10} exhaust emissions. The main difference between these data sets appears to be the fraction of VMT attributed to HDDV. EPA default HDDV VMT fractions are 8.3 percent of all VMT versus 4.7 percent as derived from CDOT traffic count data (2004).

The focus area onroad emissions for the highways employed heavy duty truck VMT fractions as derived from CDOT GIS data attributes. For the arterial and collector roads, DEH assumed a 6.5 percent HDDV VMT fraction (average of EPA default and CDOT HDDV VMT fractions). The HDDV VMT fraction is expected to be higher in the focus area as compared to the regional HDDV VMT fraction because of the many fleets based in north Denver and Commerce City.

Onroad mobile source emissions were then zeroed for all block groups in the focus area, except for the emissions generated on local roads. Local roads are too numerous to model as polygons and also lack traffic count data, so their emissions were allocated to the census block groups, along with area source and nonroad mobile source emissions. Approximately 17 percent of the benzene onroad inventory was estimated to be generated on local roads (to be discussed in the next section).

2.5.3 MOBILE6.2 Emissions Model – Focus Area Emissions

MOBILE6.2 was run to incorporate as much local data as possible, including fleet VMT fractions, vehicle registration distributions (gasoline and diesel), fuel parameters, and meteorological characteristics. Exhibits B-1 and B-2 in Appendix B contain two MOBILE6.2 input files: Exhibit B-1 contains the regional MOBILE6.2 input file and Exhibit B-2 contains one of the average speed files used in the Good Neighbor focus area.

Local data that was incorporated in the MOBILE6.2 regional and focus area files included:

- 2001 Colorado Department of Revenue vehicle registrations, as analyzed by a CDPHE contractor. Metropolitan Denver registrations for both gasoline and diesel vehicle classes were used;
- VMT by facility and hour and speed VMT files were from CDPHE MOBILE6.2 files used to develop the 2001 carbon monoxide emissions budget;
- Inspection and maintenance (I/M) program data from the 2002 Early Action Compact ozone modeling exercise;
- Seasonal gasoline and diesel fuel parameters were taken from CDPHE supplied data used to develop the 2002 NEI. In large part, this data also matched that used by the WRAP to estimate Colorado onroad mobile source emissions;
- Seasonal hourly temperature distributions were taken from the EPA National Mobile Inventory Model (NMIM) database used to develop the 2002 NEI for Colorado;
- The average speed command was utilized for the focus area input files to determine emission rates for different road types at varying speeds; and
- VMT fractions for sixteen vehicle classes were taken from the 2002 ozone Early Action Compact modeling exercise.

MOBILE6.2 is best suited for regional modeling applications. The emission rates produced are intended to be reflective of the overall fleet and road network. However, for certain road types the emissions characteristics may be drastically different. For example, consider a highway and a local neighborhood street. By the time most vehicles enter a highway, the engine and emission control systems are fully warmed up. The opposite may be true on a local road, especially in the morning. Fully warmed emission control systems result in better pollutant removal efficiency across the catalytic converter, whereas pollutant rates can be much higher during the first few minutes of operation after a cold-start.

Vehicle emissions are also affected by driving patterns. A vehicle operating in congested stop and go traffic emits more than a vehicle in cruising mode. Average speed effects were modeled in MOBILE6.2 to account for road type differences. However, PM_{10} emission factors in MOBILE6.2 are not affected by speed. For this study, only diesel PM_{10} was modeled and it is unclear how the lack of speed sensitivity may affect emissions. During periods of congestion, diesel PM emissions may be underestimated. During periods of free flow traffic, the opposite may be true. Not only is this a time of day issue, but it is also location specific (i.e. downtown versus highway).

Finally, evaporative emissions from vehicle fuel systems vary depending on the operating mode of the vehicle. Evaporative emissions are generated when hot vehicles are shut down (hot soak losses), when vehicles not in use are affected by the daily variations in temperature (diurnal losses), and when the fuel system gets hot and fuel is moving through the system (running losses or "liquid leakers").

2.5.3.1 Start versus Running Emissions by Road Type

MOBILE6.2 can generate composite emission factors as well as start (cold-start) and running (hot stabilized) emission rates for carbon monoxide, nitrogen oxides, and volatile organic compounds (VOCs). During the winter, cold start emissions can exceed hot stabilized emissions on a grams per mile basis.

If the composite emission factor is applied equally to all road types, this would likely lead to an over prediction of emissions on roads with very few cold start emissions (i.e. highways) and an under prediction on roads with frequent cold start emissions (local or collector roads). DEH attempted to account for these differences by applying emission rate scaling factors to the different road types. Since no research was found that used MOBILE6.2 for this type of focused assessment, the scaling factors were developed by consensus.

Table 2-2 shows the scaling factors developed by DEH. For cold-start emissions, local roads and collectors receive 80 percent of the cold start emissions. Conversely, highways and arterials receive 68 percent of the hot-stabilized emissions. For evaporative emissions, local and collector roads receive 90 percent of the diurnal emissions (because of their proximity to residences) and highways and arterials receive 77 percent of the running loss emissions.

Table 2-2. MOBILE6.2 scaling factors for different road types as applied to the six priority MSAT emission rates.

	Highways	Arterials	Collectors	Local	**Sum**
Exhaust Cold -	0.1	0.7	1.2	2	**4**
Exhaust Hot -	1.5	1.2	0.9	0.4	**4**
Evap Hot Soak	0.1	1.1	1.3	1.5	**4**
Evap Diurnal	0	0.3	1.2	2.5	**4**
Evap Running	1.8	1.3	0.8	0.1	**4**
Evap Resting	0	1.1	1.3	1.6	**4**
Evap Refueling	0	0	0	0	**0**

Refueling Emissions are in included in the point source database

To calculate adjusted emission factors and totals for each roadway type and vehicle class, the following methodology was employed:

1. The MOBILE6.2 MSAT exhaust emission factors were multiplied by the fractions of cold-start and running emissions as determined in the criteria pollutant output file for total organic gases – TOG;
2. Those values were then multiplied by the corresponding scaling factors in Table 2-2;
3. Steps 1 and 2 were repeated for evaporative emissions;
4. The exhaust and evaporative emission factors were summed for each vehicle class and pollutant;
5. The weighted emission factors for highways were transferred to the highway dataset and multiplied by the VMT on each link to determine the link-based emissions. The emission rate was then divided by the area of the roadway polygon (units of grams per second per square meter), and
6. Step 5 was repeated for arterial and collector roadways using the average of the emission factors for arterials and collectors.

Figure 2-2 shows the results of this analysis (exhaust emissions only; red bars). The emission factors and totals derived as discussed in this section were used in the air dispersion modeling portion of the assessment.

2.5.3.2 MOBILE6.2 Emission Factors using the Average Speed Command

MOBILE6.2 was also run using the AVERAGE SPEED command. This command overrides the default speed distribution curves and manually fits the distribution to two speed bins around the declared average speed. This is appropriate if the average speed along a particular road is well known. Average speed by road type is an output from the DRCOG travel demand model and CDPHE employs a similar methodology for their MOBILE6.2 model runs. Past DRCOG travel model output speeds have been evaluated and post-processed using speed delay studies.

Figure 2-2 shows adjusted and unadjusted benzene exhaust emission factors from MOBILE6.2. The unadjusted exhaust emission factors are directly from MOBILE6.2 and include both cold-start and hot stabilized running emissions. As previously stated, there are few cold-start emissions on major arterials and highways. When accounting for these factors as well as

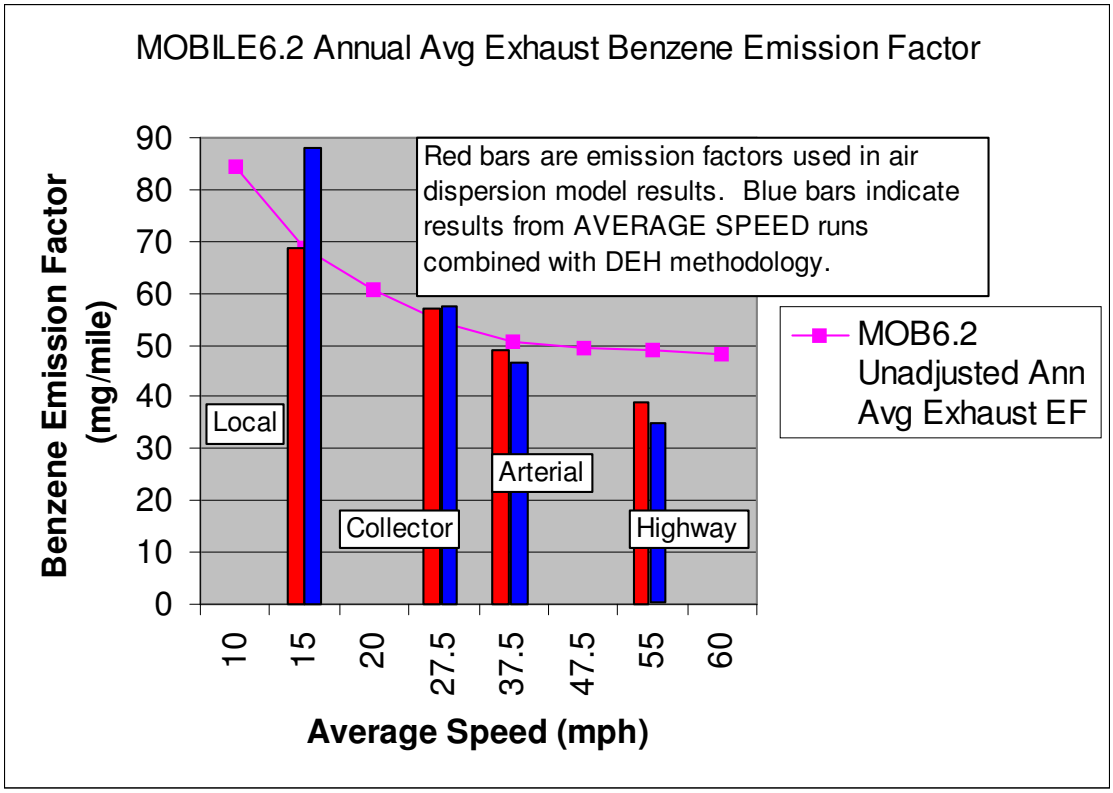
evaporative emission differences, the adjusted benzene emission factors for highways and arterials are lower than the unadjusted MOBILE6.2 emission factors. Highway emission factors are 20 percent lower whereas arterial emission factors, assuming an average speed of 37.5 mph, are only 2 percent lower than unadjusted MOBILE6.2 emission factors.

Of particular interest in these comparisons, the DEH methodology outlined in the previous section produced nearly identical emission factors to those generated using the MOBILE6.2 AVERAGE SPEED command for local, collector, and arterial roads. Applying the DEH methodology to either the single regional MOBILE6.2 run (Exhibit B-1) or the multiple AVERAGE SPEED runs produced differences of less than 10 percent.

However, the methods did differ by about 25 percent for local roads. The DEH adjusted emission factor was used in the air dispersion model because, though VOC emissions are high during the cold-start phase, benzene exhaust emissions on a mass percent basis are higher after the catalytic converter has reached the optimum temperature. Benzene in raw gasoline is about 1 percent by weight, whereas benzene in the exhaust is 3-5 percent by weight (Bruehlmann et al, 2005; Geiger et al., 2003; Schuetzle et al., 1994). Since cold-start emissions tend to inflate benzene on local roads, this is an important consideration.

Although Figure 2-2 depicts only the benzene emission rate, the behavior for the other MSATs (excluding diesel PM) is the same. DEH did not apply its methodology in the calculation of diesel PM, which was only adjusted by changing the HDDV VMT fraction.

Figure 2-2. Adjusted and unadjusted MOBILE6.2 benzene emission rates for various road types.



Of course, cold-start, running, and evaporative emission factor differences between road types are just a few of the factors that affect real-world emission rates. Road congestion and aggressive acceleration were not specifically considered here, though MOBILE6.2 does attempt to account for these factors in the speed distribution by hour and off-cycle effects files.

Using the methodology described in section 2.4.4.1, Figure 2-3 shows the regional benzene emissions by road type generated using MOBILE6.2. Also shown are the estimated VMT fractions for each road type. Although highways generate the greatest VMT, the emissions from highways are approximately the same as collector roads. Conversely, although VMT from local roads is approximately 10 percent of the regional VMT, local roads contribute a higher percentage of the regional MSAT emissions.

Table 2-3 lists the MSAT emissions in the Good Neighbor focus area and depicts the contribution to the regional emissions total. Table A-1 in Appendix A contains the complete MSAT emissions inventory. As was mentioned previously, the focus area makes up only 1.2 percent of the regional area but 13 percent of the regional VMT is generated here. This corresponds with the 11-16 percent contribution of MSATs in the focus area to the regional total.

Offroad mobile sources are significant contributors to formaldehyde, acetaldehyde, acrolein and diesel PM emissions in the focus area. Point source emissions of benzene in the focus area are a disproportionately high fraction of the regional point source benzene emissions, but are only 17 percent of the total benzene inventory. Onroad mobile sources contribute nearly 70 percent of the benzene in the focus area.

Figure 2-3. 2002 regional benzene emissions along with VMT fractions for each road type.

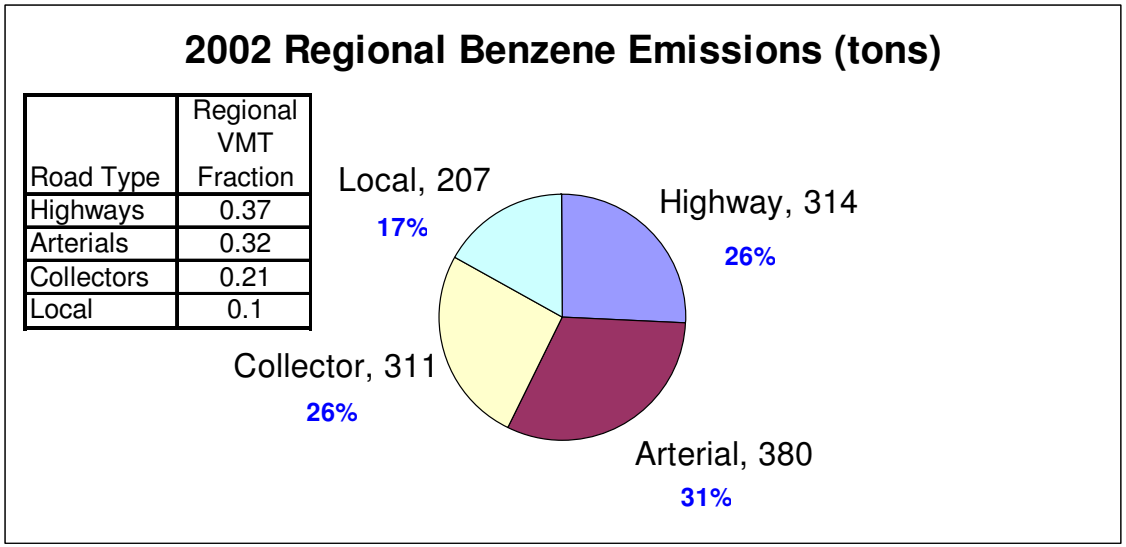


Table 2-3. Good Neighbor focus area MSAT emission inventory and how that compares to regional emission totals. Ratios shown are per emission category for the region. Appendix A contains the complete (regional) emissions inventory.

	Benzene (tons/yr)	FHWA/ Metro Ratio	1,3 Butadiene (tons/yr)	FHWA/ Metro Ratio	Formal-dehyde (tons/yr)	FHWA/ Metro Ratio	Acetal-dehyde (tons/yr)	FHWA/ Metro Ratio	Acrolein (tons/yr)	FHWA/ Metro Ratio	Diesel Exhaust PM NEI vs DEH MOBILE6.2 (tons/yr)	FHWA/ Metro Ratio
FHWA FOCUS AREA												
Onroad Mobile - gasoline	142.2	0.11	18.7	0.11	52.6	0.11	27.3	0.11	2.2	0.11	0	-
Onroad Mobile - diesel	1.7	0.10	1.0	0.11	12.8	0.11	4.6	0.11	0.6	0.11	110.3	0.16
Offroad Mobile - gasoline	28.5	0.07	4.5	0.07	53.5	0.19	26.1	0.22	4	0.36	0	0.07
Offroad Mobile - diesel											75.8	
Area Sources	2.9	0.02	2	0.06	5.6	0.03	10.5	0.27	1	0.02	nd	-
Point Sources	29.6	0.21	0.8	1.00	12.7	0.16	0.4	0.04	0	-	nd	-

3. AIR DISPERSION MODELING

3.1 Air Dispersion Model Selection

For transportation projects, the impacts of emission sources are usually predicted using computer aided modeling. These models vary widely in their intended applications, methodologies, sophistication and required user input.

For transportation project analyses, air dispersion models should be applicable for short range (<100 m) and short term analyses (< 24 hours). It may so happen that several models have both application for transportation projects as well as regional scale analyses. Models that can be employed for transportation projects are listed as follows (Neimeier et al., 2006):

- *AERMOD* is the U.S. EPA-approved dispersion model (as of 2006) for nearly all applications where its use is reasonable (e.g. industrial source emissions modeling), and can be used for mobile source modeling in some cases;
- *CALINE3* and *CALINE4* are two line-source models developed by Caltrans and are used mostly in California for modeling roadway emissions;
- *CAL3QHC* and *CAL3QHCR* are both based on the *CALINE3* dispersion algorithm, but also include additional calculations for approximating emissions near roadway intersections;
- *HYROAD* is a relatively new emissions model that was also developed specifically to monitor pollutant dispersion near roadway intersections;
- The Industrial Source Complex (*ISC3*) is capable of modeling the dispersion of both stationary and mobile source emissions. *ISC3* has a screening version called *SCREEN3* that uses a "worst case" scenario approach for modeling emissions, and
- The Point Area Line (*PAL*) model is capable of analyzing those three source types and was developed for modeling many different source locations simultaneously.

For an excellent overview of the strengths and weaknesses of each model, the reader is referred to Neimeier et al. (2006). However, the primary limiting factor for the Good Neighbor assessment was the ability of the chosen model to predict air toxics concentrations.

Until December 2006, the preferred plume dispersion model for estimating urban-wide concentrations of toxic air pollutants was the Industrial Source Complex Short Term model (ISC3ST) model. The ISC3 and AERMOD models are steady-state Gaussian plume models that can be used to assess pollutant impacts from a wide variety of sources. Gaussian plume modeling is a widely used technique for estimating the impacts of non-reactive pollutants because of its good performance against field measurements, and because it is computationally efficient relative to other types of models, such as grid and puff models. The version of ISC3ST (02035) used in this assessment included enhancements for air toxics applications. Current traffic analysis models have not been updated to address mobile source air toxics (MSATs).

Despite its versatility, ISC3 was not developed with the traffic modeler in mind, which may make it less user-friendly for transportation projects than tools like CALINE3, CALINE4 and HYROAD. One consideration that should be made is that near-field predictions using ISC3 and

AERMOD are very sensitive to the treatment of source type/approximation. Also, ISC3 is now considered to be an "alternative" model by the U.S. EPA, and so it may only be approved for use for specific applications on a case-by-case basis. DEH had already developed an urban air toxics assessment using ISC3, and Good Neighbor built on the work that had already been conducted while ISC3 was still the recommended model for urban air toxics applications.

AERMOD, the next generation successor to ISC3, was not run as part of this assessment. However, it was run for the 1996 DEH baseline air toxics assessment (Thomas, 2004). Using many of the same inputs, AERMOD predicted a median county wide concentration for benzene that was 7 percent lower than ISC3. AERMOD also predicted sharper concentration gradients. Future work will focus on the use of AERMOD, as AERMOD became the EPA preferred model in 2006.

Steady state Gaussian models do not account for the meandering of a plume caused by changing wind direction. Rather, they assume a Gaussian (i.e. normal) distribution of the diffusion of the plume in the lateral directions of the plume travel. In the direction of the wind, the plume is diluted inversely proportional to the wind speed. Thus, these models generally are not suitable for winds speeds that approach zero. In addition, it is assumed that downwind plume travel is instantaneous and infinite. Generally, these models assume all pollutants are non-reactive. Another problem with ISC3 and AERMOD is that they have no memory, meaning each hour the previous hour(s) pollutants are removed from the system.

One exception to these generalizations is the CALPUFF model, which is a non-steady state Gaussian puff model. CALPUFF takes into account plume meandering due to hourly variations in meteorology, and may also be used for long-range transport. CALPUFF is also recommended in applications with complex terrain. CALPUFF was recently utilized in the Portland Air Toxics Assessment (Cohen et al., 2005).

In the late stages of this assessment, DEH successfully set up CALPUFF to model only roadway emissions in the Denver County portion of the focus area and compared CALPUFF to ISC3 predicted concentrations. Those results are presented in section 3.4.

3.2 ISC3 Dispersion Model Inputs

The version of ISC3 (02035) utilized in this assessment incorporated new modeling options for air toxics applications. The most important feature of the air toxics enhancements in ISC3 relates to the use of the Sampled Chronological Input Model (SCIM) to significantly reduce model run times. The SCIM option allows the user to specify which hour(s) of meteorological data will be sampled.

For this assessment, meteorological data was sampled once every 25 hours. Using a five-year meteorological data set (43,824 hours), each hour of the day is sampled 73 times. Therefore, diurnal variations in weather patterns are reflected in the annual average model results. Without the SCIM option, model runs for each gaseous air toxic emitted in the region would have taken several days. The SCIM option can only be used when predicting annual average concentrations and should be utilized only when using five years of meteorological data. Studies have shown

that the uncertainty in modeled results introduced using the SCIM option is generally lower for area sources than for point sources and most of DEH's modeling involves area sources.

An annual averaging period was utilized in ISC3 because the SCIM option requires it and because when dealing with air toxics, it is primarily long-term exposure to low level concentrations that is of interest in the regulatory arena.

Physical and chemical data were also utilized, where available, to account for reactive decay and wet and dry deposition in ISC3. For example, benzene has a half-life of 6 days whereas 1,3-butadiene and formaldehyde are estimated to have atmospheric half-lives of only 2 hours.

The specific model options used in DEH's air toxics assessment are listed in Table C-1 of Appendix C. For more detail, see Thomas (2004).

3.2.1 Meteorological Data

The ISC3ST model requires hourly surface observations of wind speed, wind direction, ambient temperature, atmospheric stability, and atmospheric mixing heights derived from twice-daily upper air soundings as meteorological inputs. The mixing height data, processed by the National Climatic Data Center (NCDC), and the processed hourly surface data for many National Weather Service (NWS) stations are currently available for most cities for years up through 1992 from EPA's SCRAM web site.

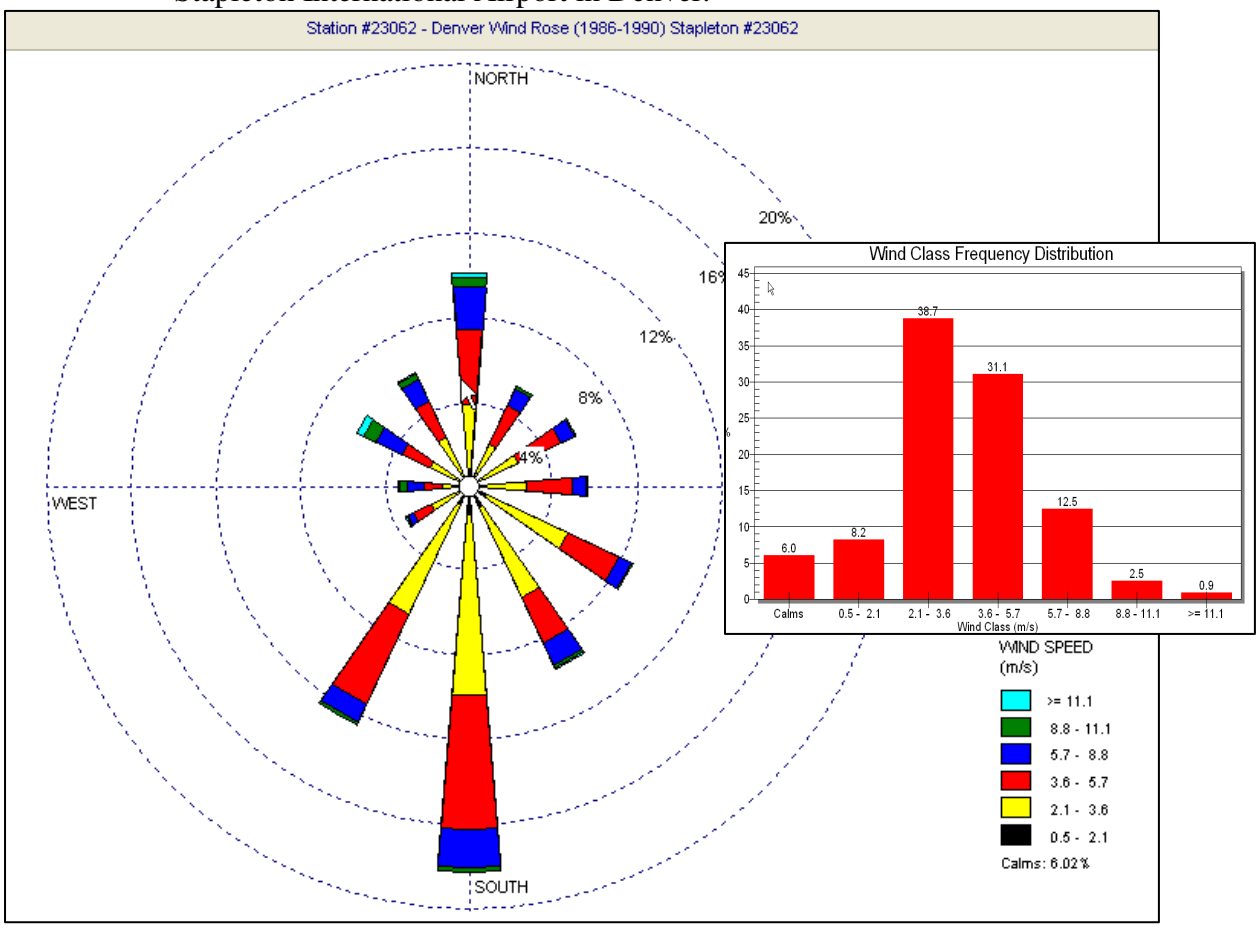
Meteorological data from 1986-1990 were used for this assessment, and were provided by the Colorado Department of Public Health and Environment's (CDPHE) Air Pollution Control Division. The data provided by CDPHE included the precipitation data required for modeling wet deposition.

Both the surface and upper air meteorological data were collected at Stapleton International Airport in Denver County. Although this assessment utilized meteorological data for the years 1986-1990, it is expected that the meteorological conditions for any other five-year period would be much the same. Figure 3-1 shows a wind rose for Denver for the years 1986-1990. Wind roses indicate the frequency of wind directions and wind speeds that occurred over the period. Notice that the predominant wind direction is from the south, with average hourly winds from between SSW and SSE for nearly 40 percent of all hours recorded.

In 1995, the Denver International Airport (DIA) opened for business. Starting in 1996, surface meteorological data collection moved from Stapleton International Airport (SIA) to DIA. However, to this day, upper air soundings continue to be collected at SIA.

Though these sites are only separated by 12 miles, there are slight differences in prevailing wind patterns. Winds are more southwesterly at DIA and mean wind speeds are 4.4 m/s, versus 3.6 m/s at SIA. Figures C-1 and C-2 in Appendix C show the wind roses and frequency distributions for SIA from 1986-1990 and at DIA for the years 1996, 1999, and 2002. The 1986-1990 meteorological data was used in this assessment as it better represents the Good Neighbor focus area. Little difference is expected for annual average concentrations using either data set.

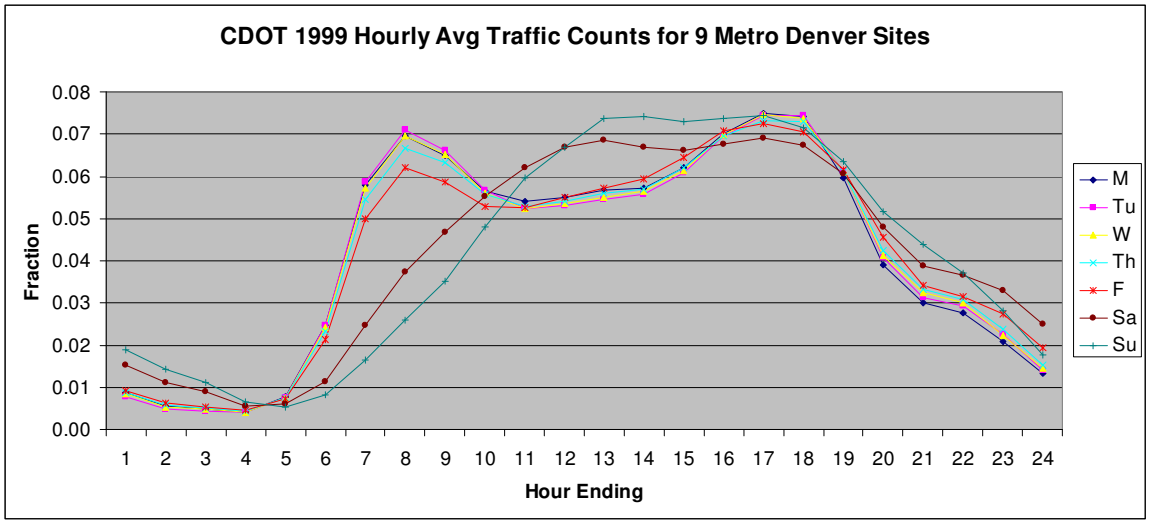
Figure 3-1. Wind rose and frequency distribution for 1986-1990 conditions recorded at Stapleton International Airport in Denver.



3.2.2 Emission Rate Inputs to ISC3

Roadway attributes and emission flux information as calculated in section 2.4.4.1 were transferred to ISC3. In addition, temporal emission factors were input to ISC3 to account for differences in emissions by season, day of week, and hour of day. Figure 3-2 shows 1999 hourly average traffic count distributions at nine sites throughout the Denver region (CDOT, 2004). The ISC3 emission factors were derived from the distribution in Figure 3-2.

Figure 3-2. 1999 hourly average traffic count distribution at 9 sites throughout metropolitan Denver.



3.2.3 Model Receptors

Figure 3-3 shows the receptor file used in ISC3. Concentrations of the priority MSATs were predicted at each receptor. There were a total of 2273 receptors, most of which lie within the roadway polygon boundaries. This was done to capture the expected maximum concentrations on the roadways. Receptors were spaced at approximately 250 m intervals on each road link. Receptors were also placed in areas off of the roadways to determine the predicted concentration gradients. Concentration gradients will be discussed in more detail later in this chapter.

3.2.4 Roadways as Polygon Area Sources

Dispersion models typically allow the user to model sources as point, area, line, or volume sources. Area, volume, and line sources are limited to four vertices. However, many roadways cannot be easily depicted using four vertices, unless they are split into numerous segments. For the Good Neighbor focus area, there were already 978 road links, splitting them to fit the area or volume source criteria would have been extremely time intensive. ISC3 and AERMOD do allow polygon area sources with up to 20 vertices. In nearly every case, 20 vertices were sufficient to describe the actual dimensions of each road link. Figure 3-4 shows a detailed portion of the project area with the road links and their associated vertices.

Figure 3-3. ISC3 model receptors.

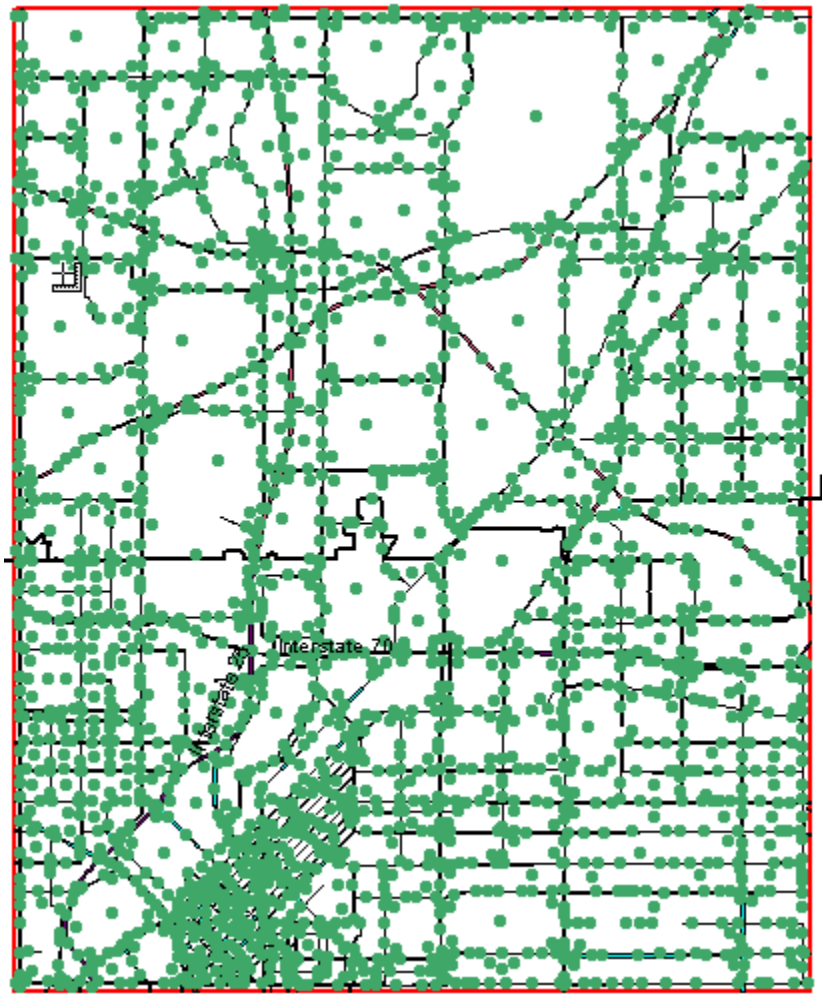
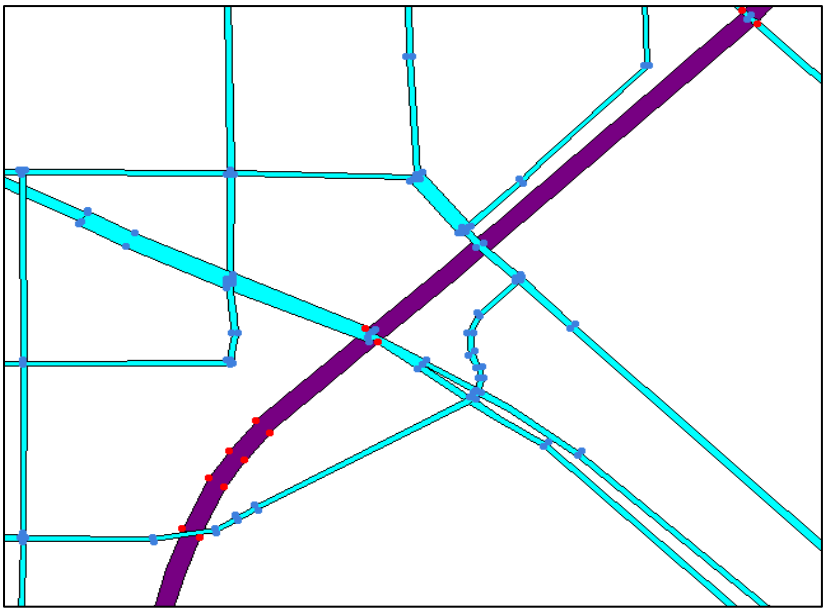


Figure 3-4. Focus area road links and their associated vertices.



3.3 ISC3 Air Dispersion Model Results

The air dispersion model was run for the six priority MSATs. For each pollutant, the following model runs were performed:

3) *Inside the focus area*: Denver County highways, Denver County arterials and collectors, Adams County highways, Adams County arterials and collectors;
4) *All block groups*: onroad mobile sources (local road contribution only), nonroad mobile source, area sources, and
5) Point sources.

The concentrations from each model run were summed to calculate the predicted primary concentrations. Background and/or secondary concentrations were also added where applicable to calculate the total predicted ambient concentrations. Ambient concentrations of formaldehyde, acetaldehyde, and acrolein all have significant contributions from secondary formation (EPA, 1999b; Ligocki et al., 1992).

Table 3-1 lists the predicted mean concentrations and the mean concentration from each source type. Benzene and 1,3-butadiene have > 50 percent of the mean concentration attributable to onroad mobile sources. Diesel PM is evenly split between onroad and nonroad mobile sources. Total mean concentrations of formaldehyde, acetaldehyde, and acrolein are driven largely by secondary photochemical production. As there is uncertainty in how secondary production of carbonyl compounds is estimated, DEH will discuss the results for carbonyls toward the end of this chapter.

Note the large differences between the maximum and mean concentrations. This results from the wide range of emission intensities on different road links. While many receptors are on light to moderately traveled collectors and arterials, a smaller subset of receptors on the heavily traveled links is not well represented by the mean value.

Table 3-1. Mean and maximum predicted concentrations for the six priority MSATs and concentrations for each source category. Concentrations are in micrograms per cubic meter.

			Mean Concentration by Source Type (micrograms per cubic meter)						
Pollutant	Max Annual Avg. Conc. ($\mu g/m^3$)	Mean Annual Avg. Conc. ($\mu g/m^3$)	Denver Highways	Denver Arterial & Collector	Adams Highways	Adams Arterial & Collector	All Other Area and Mobile (Regional)	Point Sources	Background
Benzene	7.35	1.87	0.27	0.37	0.22	0.17	0.50	0.08	0.25
1,3 Butadiene	0.97	0.18	0.03	0.05	0.02	0.02	0.06	6.80E-04	0
Formaldehyde	7.16	4.51	0.13	0.16	0.08	0.05	0.23	0.02	3.85 [1]
Acetaldehyde	3.91	2.55	0.05	0.08	0.04	0.03	0.16	4.20E-04	2.19 [2]
Acrolein	0.35	0.23	0.004	0.007	0.003	0.002	0.014	1.00E-05	0.2 [3]
Diesel PM	8.67	1.44	0.24	0.14	0.26	0.06	0.74	N/A	N/A
[1] Estimated background formaldehyde = 0.2 ug/m3 and secondary concentration = 3.65 ug/m3									
[2] Estimated background acetaldehyde = 0.16 ug/m3 and secondary concentration = 2.03 ug/m3									
[3] Estimated background acrolein = 0.02 ug/m3 and secondary concentration = 0.18 ug/m3									

3.3.1 Benzene

Benzene is a known human carcinogen. This has been confirmed by various human and animal epidemiological studies. Benzene is emitted from a variety of sources, but the majority of benzene emitted in metropolitan Denver is attributed to the combustion and evaporation of gasoline used in mobile sources.

Benzene is a well-studied air toxic in terms of emissions, especially from onroad mobile sources. It is also a relatively inert pollutant, with an atmospheric half-life of approximately 6 days. Little to no secondary formation of benzene occurs in the ambient air. For these reasons, benzene serves as a good tracer to validate air dispersion modeling results.

Benzene was modeled using the original DEH 1996 baseline methodology as well as the methodology presented in this paper. Figure 3-5 shows the predicted 2002 benzene concentrations using the original DEH baseline methodology (i.e. census block group spatial allocation). The scale is set to match that in Figure 3-6 to improve visual comparisons. Notice how there appears to be very little spatial variation in Adams County (top half of Figure 3-5). In fact, there is spatial variation in Adams County, but the scale prevents this from being shown.

From Figure 3-5, the model-to-monitor ratios range from 0.3 at Welby (model is under predicting by a factor of three) to 0.62 at Swansea (model under predicting by 40 percent). Model-to-monitor ratios of 0.1 are generally acceptable, although ratios between 0.5 and 2.0 (i.e. within a factor of two) are generally indicative of good model performance.

Figure 3-6 shows the predicted 2002 benzene concentrations generated using the methodology described in this report. As expected, the predicted concentrations are much higher on and near the roadways. Figure 3-6 appears to depict a more realistic picture of ambient air quality, although ISC3 predicts sharp concentration gradients near the roadways. This issue will be explored later.

From Figure 3-6, the model-to-monitor ratios remained the same at Welby (ratio = 0.32), decreased slightly at Swansea (ratio = 0.55), and improved at CAMP (ratio = 0.69). The model also did a slightly better job at the two Rocky Mountain Arsenal receptors (blue diamonds). Figure 3-7 provides a closer look at central and north Denver.

ISC3 was expected to under predict concentrations due to inherent limitations in the model. For example, the fact that ISC3 has no memory, meaning it does not keep track of previous hours' emissions, is expected to result in a low model bias.

It is unclear as to how previous hours emissions affect benzene concentrations in Denver. While work toward that end was done as part of the 1996 Northern Front Range Air Quality Study (NFRAQS; Lawson et al., 1998), that work was geared mostly toward understanding sources of particulate matter. A significant component of ambient particulate matter is formed through chemical reactions in the atmosphere. This is not the case for benzene. The CALPUFF model takes previous hours' emissions into account. CALPUFF results are discussed in section 3.4.

Figure 3-5. Predicted benzene concentrations (micrograms per cubic meter) using DEH baseline (i.e. regional) modeling methodology. Benzene monitoring locations and data for 2002 are shown.

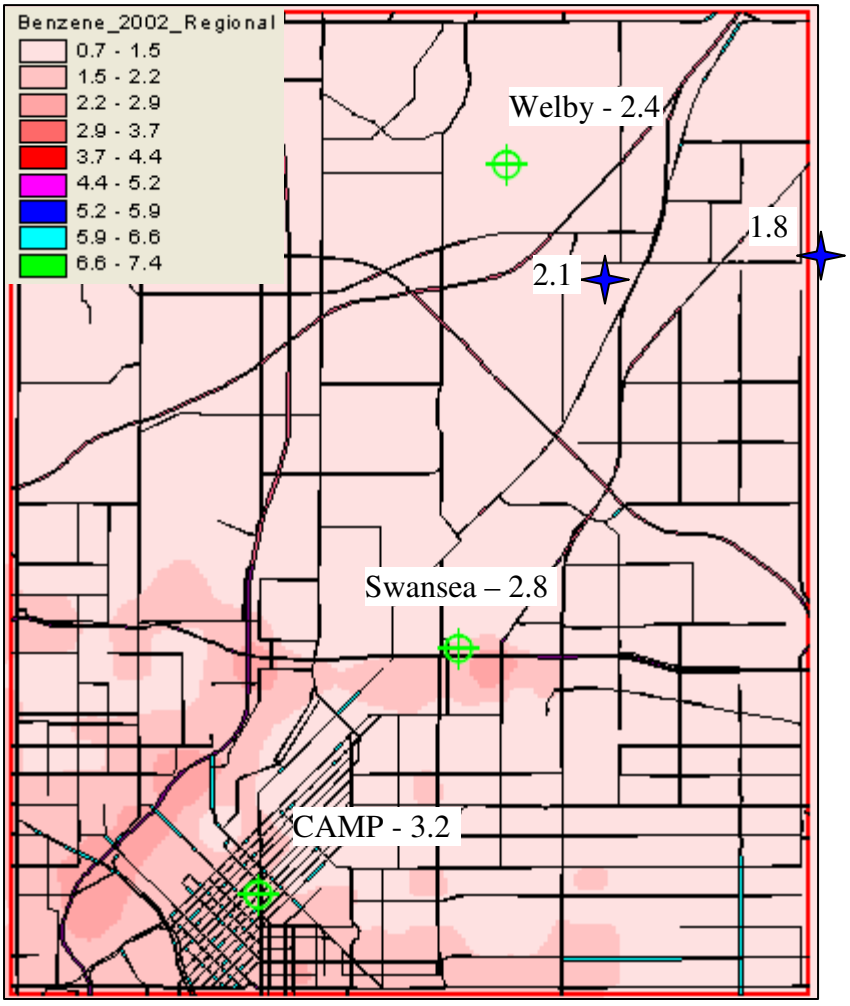


Figure 3-6. Predicted benzene concentrations (micrograms per cubic meter) using the roadway based methodology for onroad mobile source emissions. Benzene monitoring locations and data for 2002 are shown.

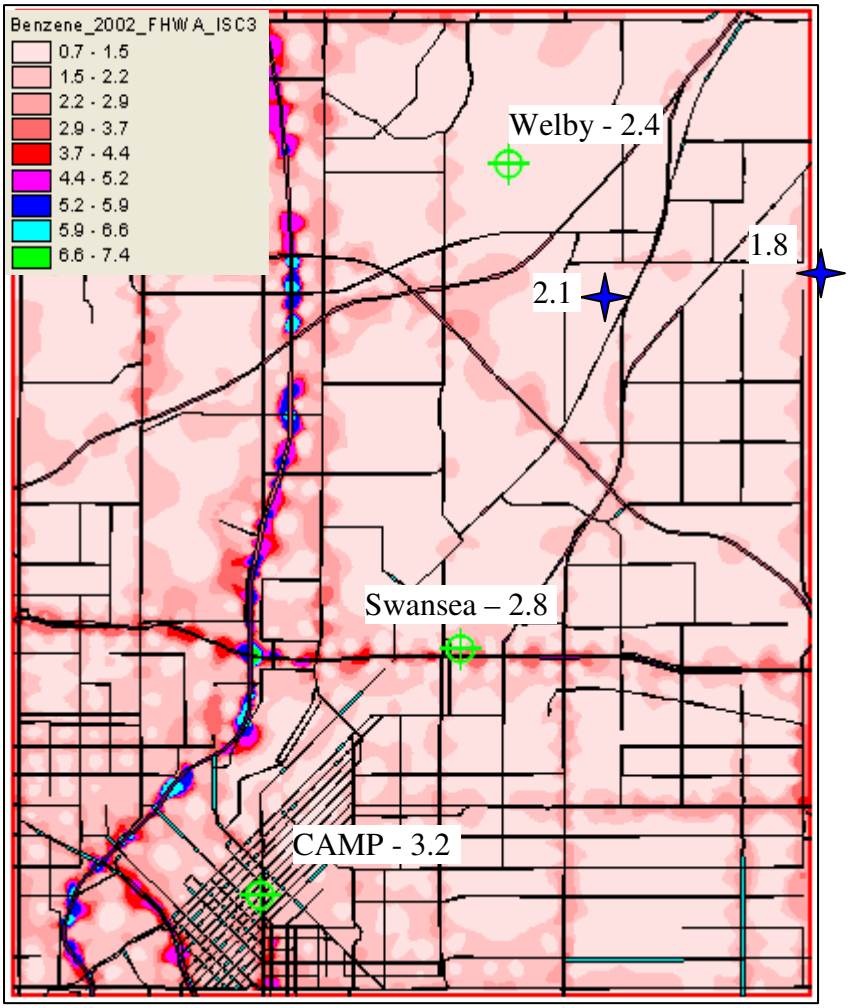
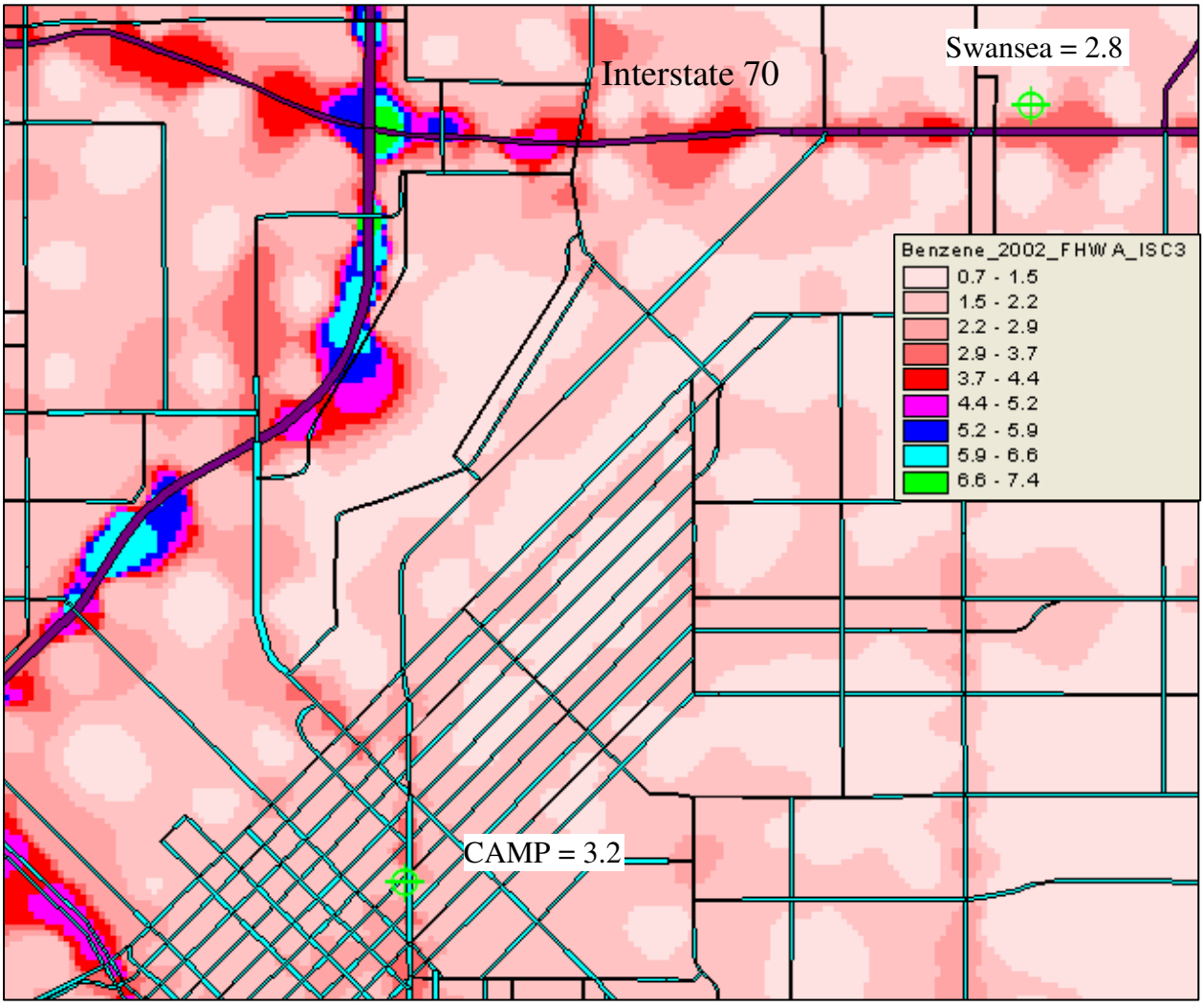


Figure 3-7. Predicted benzene concentrations (micrograms per cubic meter) using the roadway based methodology for onroad mobile source emissions. Benzene monitoring locations and data for 2002 are shown.



ISC3 predicts sharp concentration gradients near the roadways. DEH explored this issue further by setting up a small receptor grid in north Denver along Interstate 70 and I-25. Receptors were spaced at the following distances from the roadway: 0, 20, 50, 100, and 150 m. Receptors were aligned in the north-south or east-west direction depending on the orientation of the roadway.

Figure 3-8 shows the receptors used to conduct the ISC3 concentration gradient tests and the resulting concentrations. Benzene emissions from all sources were included in the gradient model runs. Maximum predicted concentrations were only slightly higher using the gradient receptors; the primary difference was at the junction of I-25 and I-70 where a higher maximum concentration of 10.5 µg/m^3 was predicted.

Figure 3-8. Gradient receptors (a), and predicted benzene concentrations (b)(micrograms per cubic meter).

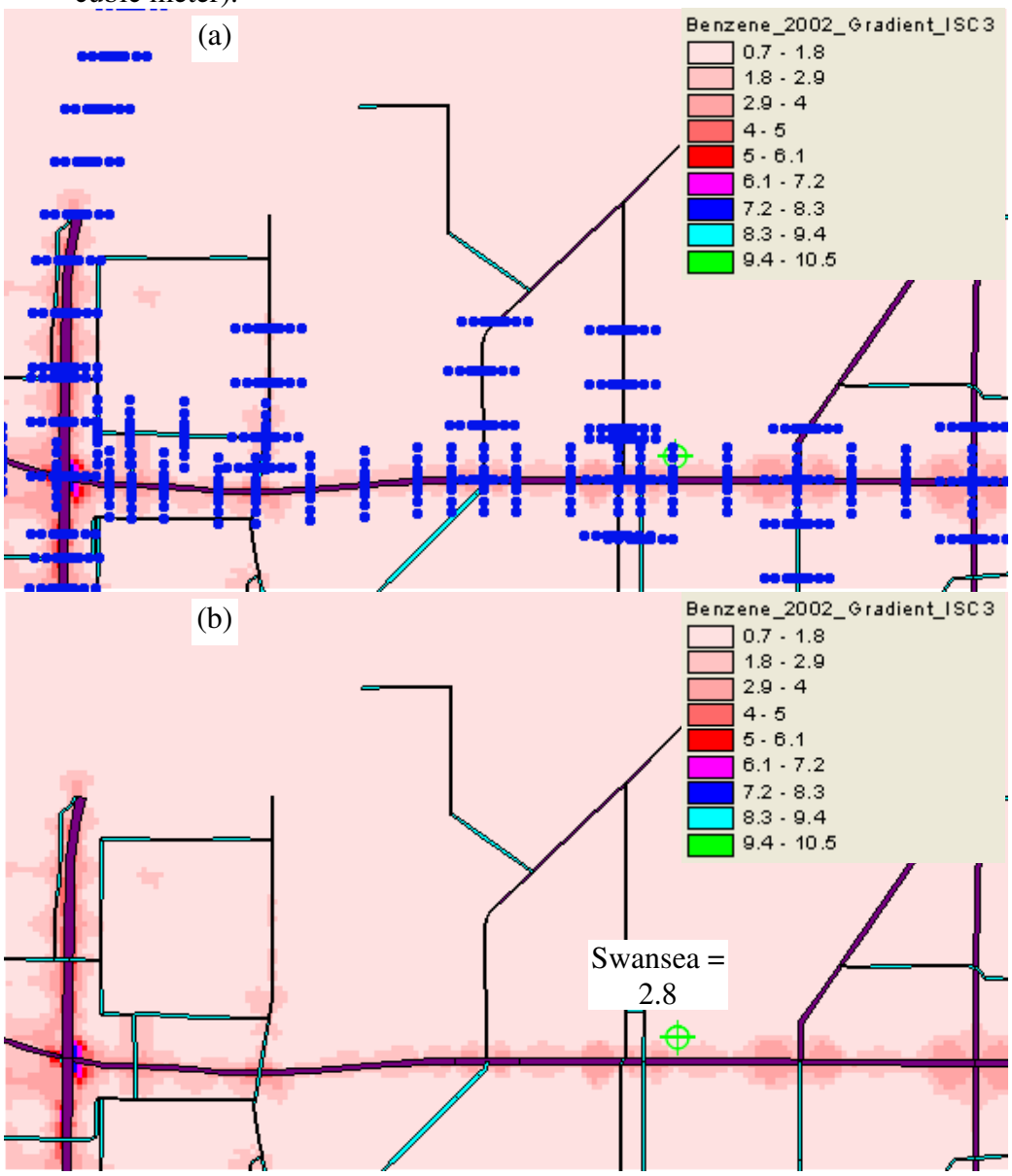
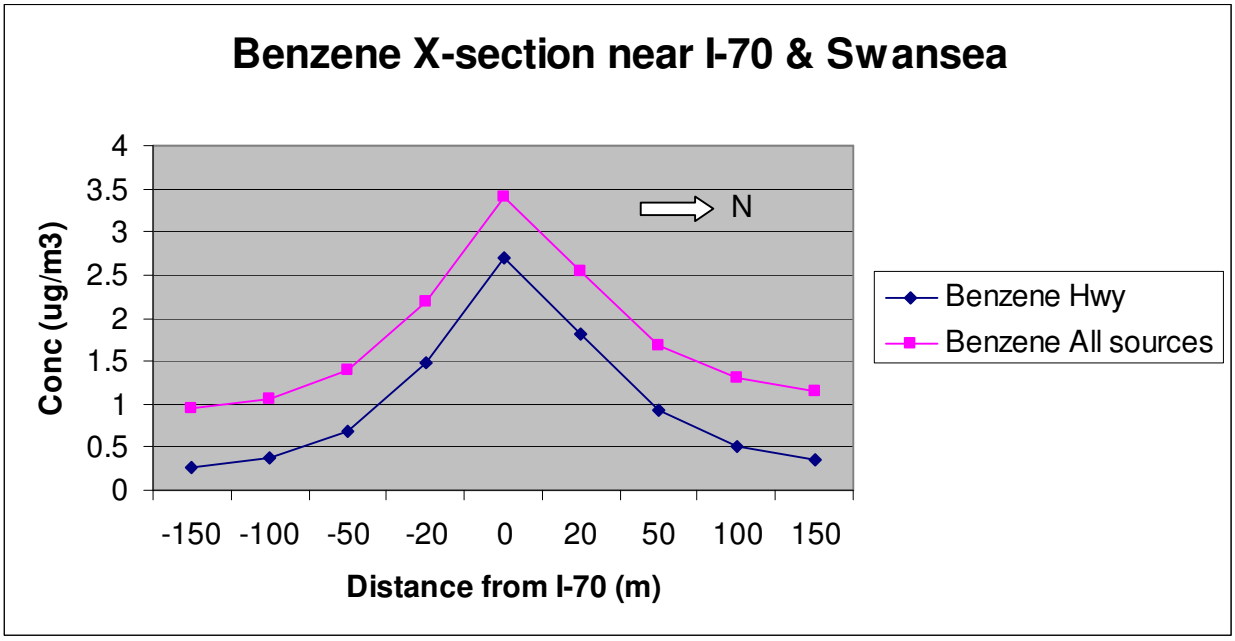


Figure 3-9 shows a cross section north and south of I-70 at the highway receptor closest to the Swansea monitor. For highway influences only, concentrations drop off sharply within 50 m of the highway, decreasing to 33 percent of the roadside concentration. At 100 m, highway based benzene concentrations are only 20 percent of the roadside concentrations. The gradients are slightly sharper on the south side of I-70, which tends to be in the upwind direction more often.

Figure 3-9. Cross section of benzene concentrations north and south of I-70 (east-west highway). The highway receptor is depicted by the zero distance. The prevailing wind direction is from the south in this area.



Recent research has started to focus on concentrations near highways. Most of the research conducted in the U.S. has been geared toward particulate matter. International studies have also studied criteria and air toxics pollutant concentrations to better understand source apportionment.

Zhu et al. (2002) measured ultrafine particle number concentrations (< 0.1 micron), black carbon, and carbon monoxide near the 710 freeway in Los Angeles, CA. Measurements were taken as close as 17 m and out to 300 m downwind of a highway. Carbon monoxide (CO) is expected to behave much like benzene near highways; Zhu et al. found CO concentrations decreased by over 50 percent between the 17 m and 30 m monitors when both monitors were downwind. Results for all time periods, regardless of wind direction, showed a more gradual gradient out to 30 m (26 percent decrease), but concentrations at 90 m were only 22 percent of the average at 17 m. Beyond 100 m from the freeway, concentrations decreased much more gradually. Zhu et al. results agree well with ISC3 predictions in Figure 3-9.

Roorda-Knape et al. (1998) found weekly average benzene concentrations in the Netherlands to be statistically significantly different at 15 m and 115 m at one urban site (27 percent lower),

with no significant difference at the other urban site between 32 m and 82m. Weekly average concentrations would be of greater use if wind directions were constant over time.

Pirjola et al. (2006) conducted a similar study of particles and trace gases at various distances from a city highway in Helsinki, Finland with a mobile laboratory. For carbon monoxide, the concentration ratio for the roadside versus the 65m distance from the roadside was 4.1 in winter and 2.2 in summer, though large variability was reported.

Finally, Huang et al. (2006) performed urban modeling of an elevated highway that crosses through a highly urban area using a computational fluid dynamics (CFD) model. Predicted gradients matched field observations quite well. Predicted gradients were sharp, nearly a 90 percent reduction within 100 m of the roadway.

The referenced studies are in good agreement with the predicted ISC3 concentration gradients.

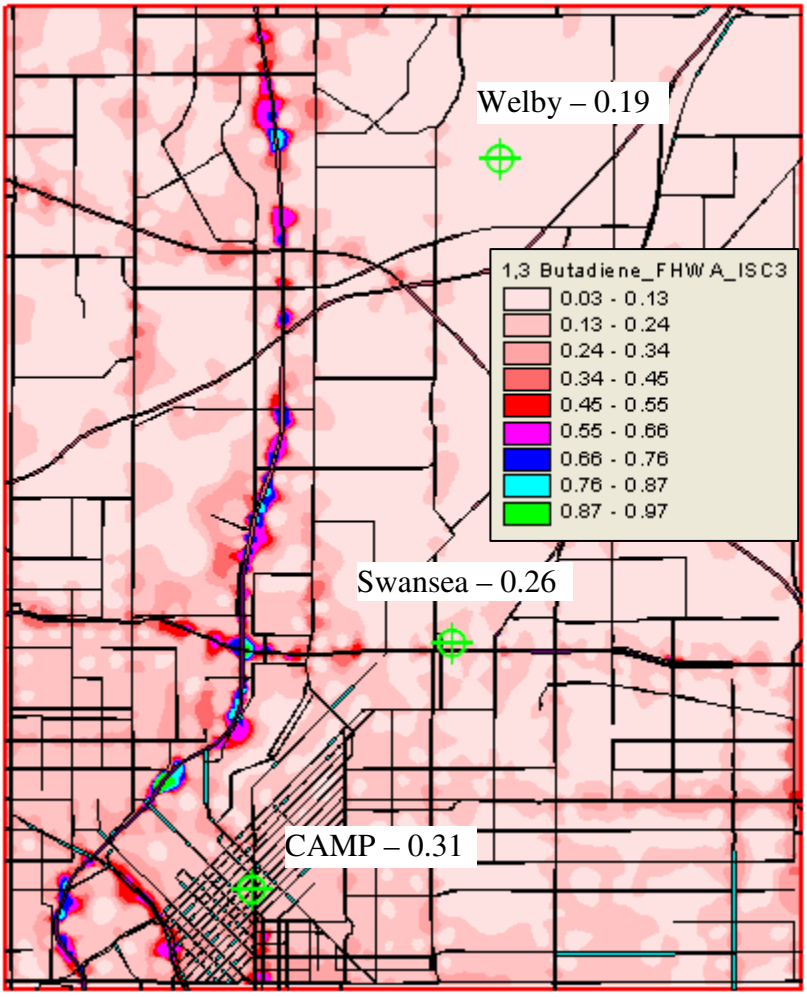
3.3.2 1,3-Butadiene

1,3-butadiene is found in ambient air from motor vehicle exhaust as well as manufacturing and processing facilities, gasoline distribution, production of synthetic plastics and rubber, wastewater processing, forest and wildfires, or other combustion. From Table A-1 in Appendix A, 70 percent of the Denver region 1,3-butadiene emissions emanate from onroad mobile sources.

Figure 3-10 shows predicted 1,3-butadiene concentrations. Not surprisingly, the spatial pattern looks very similar to benzene, as onroad mobile source emissions contribute roughly the same percentages to the overall inventory for each pollutant. 1,3-butadiene is usually seen in minute quantities in the ambient air. Monitored concentrations were above detection limits 60 percent of the time at Welby, 70 percent at Swansea, and 80 percent at CAMP. For data below the detection limits, ½ the MDL was assumed in calculating the average concentrations.

From Figure 3-10, the model-to-monitor ratios range from 0.3 at Welby (model is under predicting by a factor of three) to 0.4 at Swansea (model under predicting by a factor of 2.5), and 0.75 at CAMP (model under predicting by 25 percent).

Figure 3-10. Predicted 1,3-butadiene concentrations (micrograms per cubic meter) using the roadway based methodology for onroad mobile source emissions. 1,3-butadiene monitoring locations and data for 2002 are shown.



3.3.3 Diesel Particulate Matter

Diesel exhaust is a complex mixture of gases and fine particles formed by the combustion of diesel fuel. Many known and potential cancer-causing substances such as arsenic, formaldehyde, nickel, and polycyclic aromatic hydrocarbons (PAHs) are present in the exhaust gases, some of which are bound to the surfaces of the diesel-exhaust particles. Diesel exhaust particles are small enough (less than 10 microns in diameter, about one-seventh of the width of a human hair) to be inhaled deep into the lungs, where they can affect lung performance and cause damage over time. Agencies such as the International Agency for Research on Cancer (IARC), California EPA, U.S. EPA, and the National Toxicology Program have stated that diesel particulate matter (DPM or diesel PM) is a probable or likely human carcinogen.

Due to the complex nature of diesel exhaust gases and particulates, there is no direct way to measure diesel concentrations. Elemental carbon (EC) is a major component of diesel exhaust, constituting approximately 50-85 percent of diesel particulate mass depending on factors such as engine technology, fuel type and state of engine maintenance (Graboski et al., 1998). Because of the large portion of EC in DPM, and the fact that diesel exhaust is one of the major contributors to EC in many ambient environments, ambient DPM concentrations can be estimated using EC measurements. Studies such as the NFRAQS have led to the development of equations used to estimate the lower bound and upper bound DPM concentrations based on EC measurements. Equations 3.1 and 3.2 represent the lower and upper bound estimates, respectively, and Equation 3.3 represents the average of the ranges (EPA, 2002).

DPM = EC*0.62	(lower bound)	(3.1)
DPM = EC*1.31	(upper bound)	(3.2)
DPM = EC*0.89	(average of ranges)	(3.3)

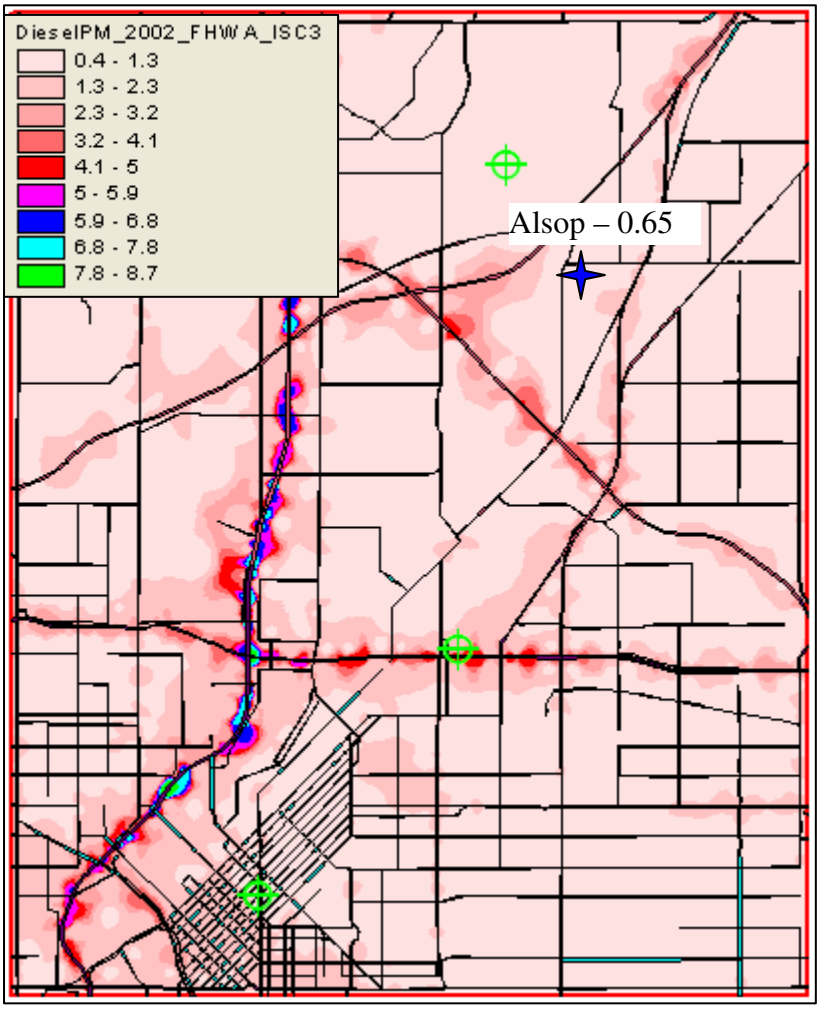
But as diesel technologies improve and the diesel fleet becomes cleaner, it becomes more difficult to use elemental carbon alone as the marker for diesel particulate matter. Since other sources of elemental carbon will become more significant as emissions from the diesel fleet decrease, this increases the uncertainty associated with the diesel particulate matter estimates based on elemental carbon. Other combustion sources such as fireplaces, forest fires, gasoline engines, agricultural burning, and power plants also emit elemental carbon.

Diaz et al. (2005) found that diesel fueled sources contributed an average of 69.5 percent of the ambient elemental carbon concentrations in the southeastern United States through use of the Models3-CMAQ model. Similarly, a speciated elemental carbon emission inventory for Phoeniz, AZ in 1999 showed that about 69 percent came from diesel fueled sources. These studies indicate that equation 3.1 is more appropriate to estimate diesel particulate matter concentrations.

Elemental carbon is only speciated at one site in the Denver region, at 7101 Birch St in Commerce City. An average EC concentration of 1.02 micrograms per cubic meter was measured in 2002. Applying equation 3.1 above to the EC concentration results in an estimated 0.65 $\mu g/m^3$ from diesel sources. This compares well with a 0.64 $\mu g/m^3$ concentration predicted by ISC3 in this assessment. Figure 3-11 shows predicted diesel PM concentrations from ISC3.

The predicted concentration pattern is slightly different than that of benzene and 1,3-butadiene. This is because a higher percentage of heavy duty diesel traffic occurs on the major thoroughfares with less on minor arterial and collector roads.

Figure 3-11. Predicted diesel PM concentrations (micrograms per cubic meter) using the roadway based methodology for onroad mobile source emissions. The lone elemental carbon monitoring location (Alsop Elementary) and data for 2002 is shown.



3.3.4 Formaldehyde

The EPA considers formaldehyde to be a probable human carcinogen. Formaldehyde is unique in that the majority of the concentrations observed in the atmosphere are assumed to result from secondary formation. It is estimated that roughly 80 percent of ambient formaldehyde in summer and 30 percent in winter results from secondary formation (Ligocki et al., 1992). Formaldehyde is also destroyed in the atmosphere, especially in the presence of sunlight, and the estimated half-life in summer is approximately two hours (EPA, 1999a). The processes by which formaldehyde is formed in the atmosphere are complex, and atmospheric reactions of virtually all VOCs will eventually produce some formaldehyde (SAI, 1999). For a general description of how secondary pollutants are formed, refer to EPA (1999b).

ISC3 only predicts primary formaldehyde emissions, including a decay factor. Formaldehyde was assumed to have a year-round half-life of two hours, though this likely overestimates decay during the winter months and also during the nighttime hours (due to reduced photolysis). Sensitivity analyses show that predicted primary concentrations are 25 percent higher if zero decay is assumed. Because primary formaldehyde concentrations make up only a part of the total formaldehyde, secondary concentrations need to be estimated and added to the predicted primary concentrations.

The estimated secondary concentrations were obtained from the USEPA research oriented version of the Ozone Isopleth Plotting Package (OZIPR). EPA ran the OZIPR model for urban and rural counties in and near Denver using 1996 emission estimates.

The EPA OZIPR model predicted an annual average primary formaldehyde concentration of 0.8 $\mu g/m^3$ and a secondary formaldehyde concentration of 5.2 $\mu g/m^3$ in Denver County for a total concentration of 6.0 $\mu g/m^3$ (4.9 ppbv; EPA 1999b). That equates to 87 percent of total annual formaldehyde being formed secondarily.

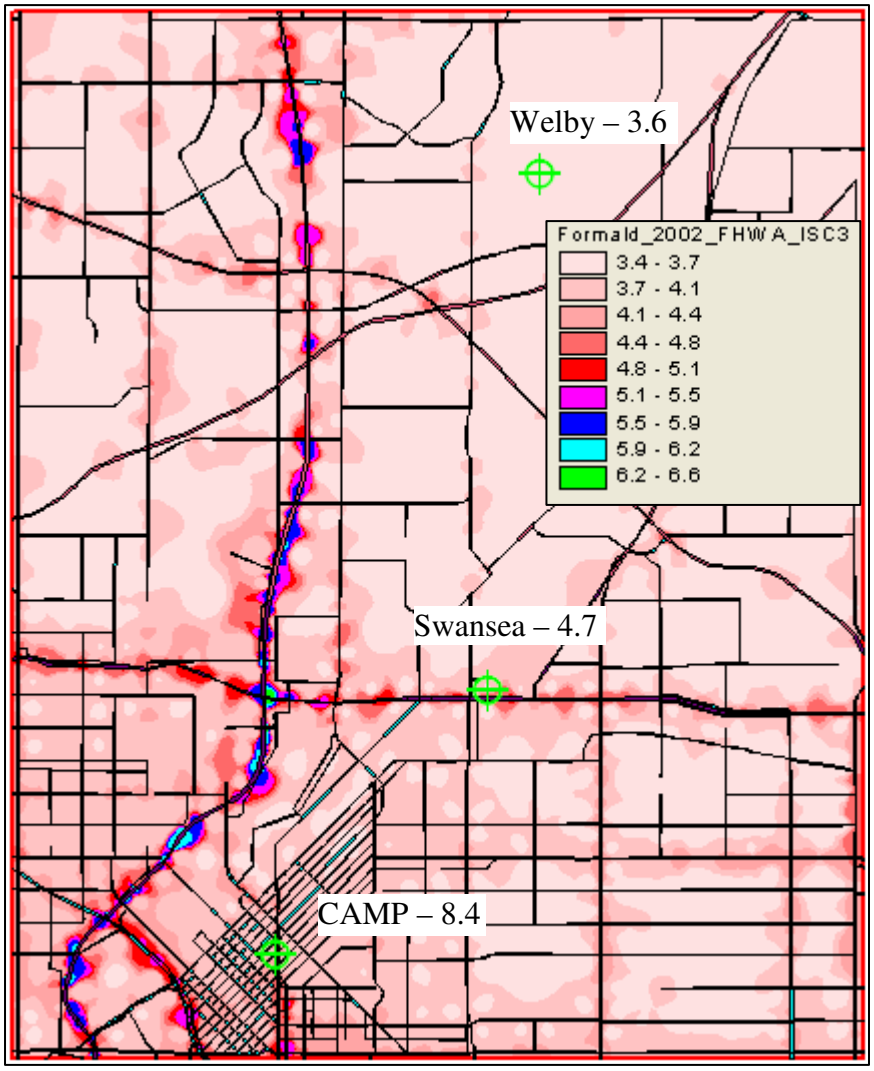
For this assessment, the estimated secondary formaldehyde concentration for the region is **3.06** $\mu g/m^3$. This value was obtained by dividing the ISC3 predicted primary 33^{rd} percentile concentration of 0.4 $\mu g/m^3$ by 0.13 (the primary fraction). The 33^{rd} percentile was chosen because the majority of the receptors are roadway receptors. Choosing the median value may bias the background value high. The 33^{rd} percentile value is more in line with the median value for the regional model runs (non-roadway modeling). Background formaldehyde concentrations of 0.2 $\mu g/m^3$ (see Table 4-1) are taken from McCarthy et al. (2006).

Figure 3-12 shows the total predicted formaldehyde concentrations, including secondary and background concentrations. Model-to-monitor ratios range from 0.93 at Welby, to 0.77 at Swansea, and 0.48 at CAMP.

There is some uncertainty as to how secondary concentrations should be applied. A single secondary concentration value was applied equally across the entire modeling domain. It is unknown whether secondary concentration gradients vary much over a distance of several miles. From the 2002-2003 CDPHE air toxics data, it appears as if there is a noticeable change over the span of a few miles, or else there is a much bigger primary contribution than the emission

inventory indicates. The limited available formaldehyde emission testing data are in line with MOBILE6.2 emission factors, so it seems unlikely that primary emissions explain the large variation between monitors.

Figure 3-12. Predicted formaldehyde concentrations (micrograms per cubic meter) using the roadway based methodology for onroad mobile source emissions. The formaldehyde monitoring locations and data for 2002 are shown.



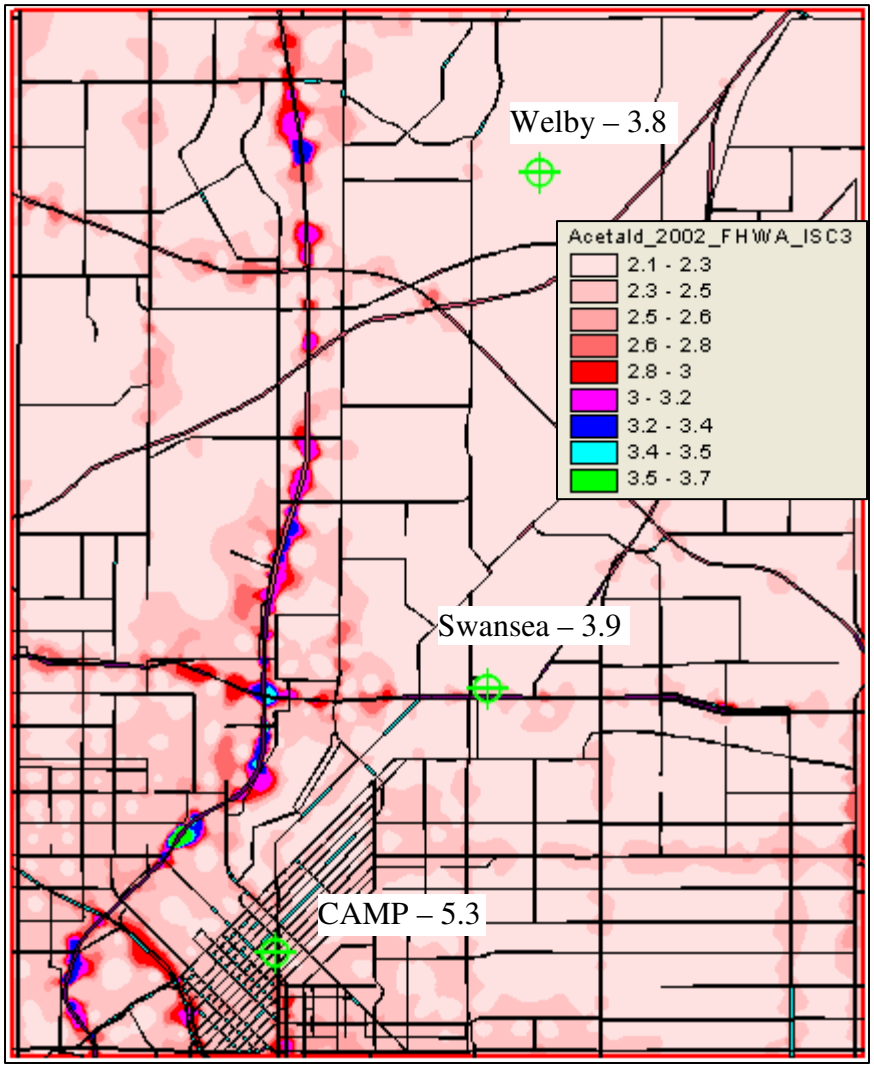
3.3.5 Acetaldehyde

The EPA considers acetaldehyde a probable human carcinogen. As with formaldehyde, acetaldehyde concentrations in the ambient air are estimated to have large contributions from secondary formation. It is estimated that roughly 90 percent of ambient acetaldehyde in summer and 40 percent in winter results from secondary production (Ligocki et al., 1992). A wide variety of VOCs produce secondary acetaldehyde as a result of photochemical reactions.

The secondary concentration of acetaldehyde was determined according to the procedure described for formaldehyde in the previous section. The estimated secondary acetaldehyde concentration in this assessment is 1.85 $\mu g/m^3$ (1.0 ppbv). This value was obtained by dividing the ISC3 predicted 33rd percentile concentration of 0.24 $\mu g/m^3$ (0.13 ppbv) by 0.13 (the primary fraction). Background acetaldehyde concentrations of 0.16 $\mu g/m^3$ (see Table 4-1) are taken from McCarthy et al. (2006).

Figure 3-13 shows the total predicted formaldehyde concentrations, including secondary and background concentrations. Model-to-monitor ratios range from 0.55 at Welby, to 0.58 at Swansea, and 0.46 at CAMP.

Figure 3-13. Predicted acetaldehyde concentrations (micrograms per cubic meter) using the roadway based methodology for onroad mobile source emissions. The acetaldehyde monitoring locations and data for 2002 are shown.



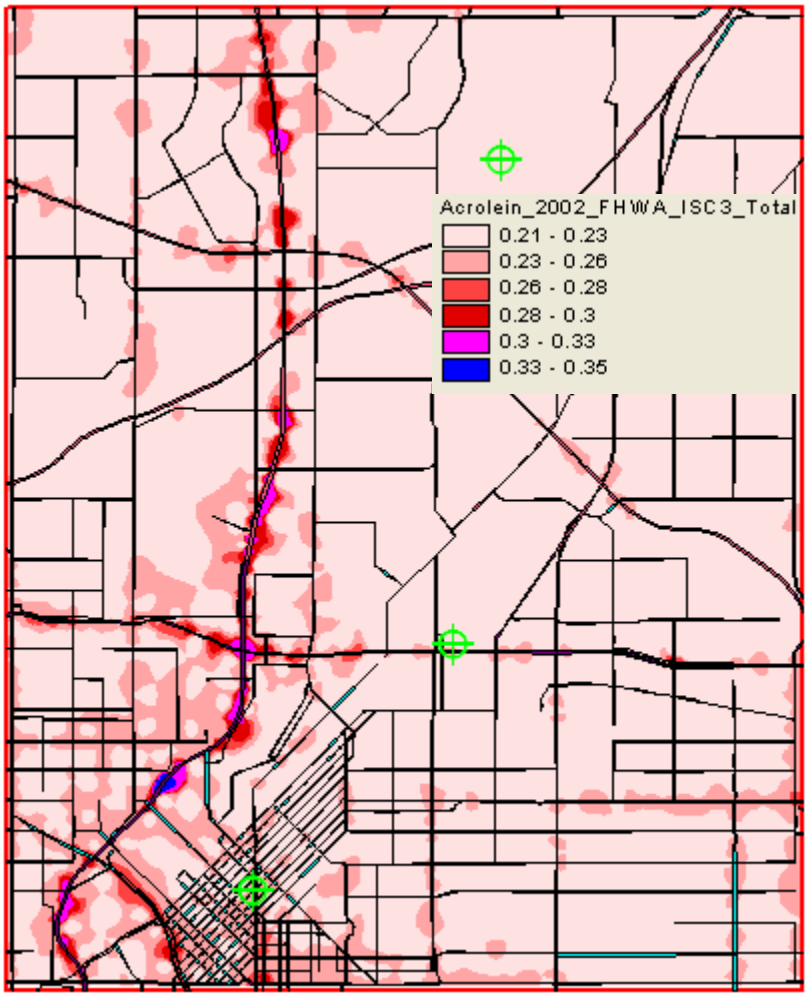
3.3.6 Acrolein

The major effects from chronic (long-term) inhalation exposure to acrolein in humans consist of general respiratory congestion and eye, nose, and throat irritation. As with formaldehyde and acetaldehyde, acrolein concentrations in the ambient air are estimated to have large contributions from secondary formation. Acrolein is primarily used as an intermediate in the manufacture of acrylic acid. It can be formed from the breakdown of certain pollutants in outdoor air or from forest and wildfires, as well as vehicle exhaust.

The secondary concentration of acrolein was determined according to the procedure described for formaldehyde and acetaldehyde in the previous sections. The estimated secondary acrolein concentration in this assessment is 0.16 $\mu g/m^3$ (0.07 ppbv). This value was obtained by dividing the ISC3 predicted 33rd percentile concentration of 0.02 $\mu g/m^3$ by 0.13 (the primary fraction in ambient air).

Figure 3-14 shows the total predicted acrolein concentrations, including secondary concentrations. Acrolein has historically been a difficult pollutant to monitor. It is reactive in the atmosphere with a half life of 12-24 hours, and is unstable in sample media. Historic data in Denver did not contain acrolein data, therefore no model-to-monitor comparisons were made.

Figure 3-14. Predicted acrolein concentrations (micrograms per cubic meter) using the roadway based methodology for onroad mobile source emissions. No acrolein monitoring data is available in Denver.



3.4 ISC3 versus CALPUFF

Steady state Gaussian models such as ISC3 do not account for the meandering of a plume caused by changing wind direction. Rather, they assume a Gaussian distribution of the diffusion of the plume in the lateral directions of the plume travel. In the direction of the wind, the plume is diluted inversely proportional to the wind speed. Thus, these models generally are not suitable for winds speeds that approach zero. In addition, it is assumed that downwind plume travel is instantaneous and infinite. Generally, these models assume all pollutants are non-reactive. Another problem with ISC3 and AERMOD is that they have no memory, meaning each hour, the previous hour(s) pollutants are removed from the system. In the Denver area, high pollution events are caused in part by "sloshing" of aged air masses up and down the South Platte River valley.

One exception to these generalizations is the CALPUFF model, which is a non-steady state Gaussian puff model. CALPUFF takes into account plume meandering due to hourly variations in meteorology, and may also be used for long-range transport. CALPUFF is also recommended in applications with complex terrain. CALPUFF was recently utilized in the Portland Air Toxics Assessment.

3.4.1 CALPUFF Model Inputs

CALPUFF is much more resource intensive. A significant amount of work was required to convert the ISC3 model runs to CALPUFF runs. For example, CALPUFF cannot accept polygon area sources. ISC3 allows up to 20 vertices to describe a curved roadway. CALPUFF currently only allows four vertices to describe area sources. ISC3 polygon area sources were simplified and/or sub-divided to fit the CALPUFF criteria. Emissions of sub-divided polygons were apportioned based on the ratio of the area of the new polygons to the original polygon.

In addition, CALPUFF only allows up to 200 area sources to be modeled in a single run. In Denver County alone, there were 774 polygon links just for arterial and collector roads. For highway sources, there were 151 links. All total, five CALPUFF runs were required to model Denver County roadways as area sources. The Portland Air Toxics Assessment modeled roadway emissions as point sources, using the centroid of each link.

CALMET, the meteorological processor in CALPUFF, accepts the same files as ISC3 and can also accept Mesoscale Model (MM5) data. MM5 data is more highly resolved in both the horizontal and vertical directions. For ease of comparison, the ISC3 meteorological data files were used in CALPUFF.

Benzene was used as the pollutant to compare ISC3 and CALPUFF because it is relatively inert and there is sufficient monitoring data with which to compare the predicted concentrations. For this comparison, DEH modeled ISC3 and CALPUFF using only the January 1990 meteorological data. This is because in CALPUFF, 90 hours of computer run time and 5 gigabytes (GB) of hard drive space were required for each month modeled. It should be noted that from ISC3 monthly runs for the entire year, the monthly average concentration for January

was close to the annual average concentration (0.36 versus 0.35, respectively). Therefore, January concentrations are not expected to be biased high or low.

The same on-road area sources were modeled in ISC3 and CALPUFF using the same number of receptors (2273). For all other emission sources, the predicted concentrations from the ISC3 model runs were added to the CALPUFF model runs. Beyond a few hundred meters from the source, both models generally predicted similar concentrations.

Finally, no temporal emission factors were used in either CALPUFF or ISC3 for this comparison. Data entry into CALPUFF for temporal emission factors is tedious and has to be entered individually for each source. Not accounting for temporal emission factors likely biases high the predicted concentrations from both models. In previous work in ISC3, DEH found that the use of temporal emission factors decreases predicted annual average concentrations by approximately 25 percent (Thomas, 2004).

3.4.2 CALPUFF Results

Figure 3-15 shows a detailed view of central Denver with predicted CALPUFF benzene concentrations for January. Figure 3-16 shows the same for ISC3. Only Denver roadway sources were modeled in CALPUFF; all other source contributions, including regional background, were added using the ISC3 model files for the entire project area.

Although we are comparing one-month predictions with annual average measurements, the January average concentration approximated the annual average concentration generated by ISC3. Assuming the same holds true in CALPUFF, CALPUFF model-to-monitor comparisons are much better at Swansea and CAMP, with both ratios equal to 1.1. For the same period, ISC3 ratios at Swansea and CAMP are 0.61 and 0.75, respectively. Either model produces good results, as both are within a factor of two of measured concentrations.

The spatial concentration gradient near the roadways is less pronounced in CALPUFF than in ISC3. This can be seen by the "donut-hole" effect from ISC3 as evidenced in Figure 3-16. ISC3 predicts highway impacts drop off by 50-66 percent within 50 m of the roadways, whereas CALPUFF predicts only about a 10-25 percent reduction over that distance.

While recent research generally aligns more with the ISC3 predicted gradients, the body of knowledge is very small and experiments have until now been conducted over very short time frames. Targeted monitoring campaigns within short distances both upwind and downwind of specific roadways would provide valuable information regarding the use of dispersion models for similar types of assessments.

Figure 3-15. CALPUFF predicted monthly average concentrations using January 1990 meteorological data. Monitored concentrations for Swansea and CAMP stations are shown.

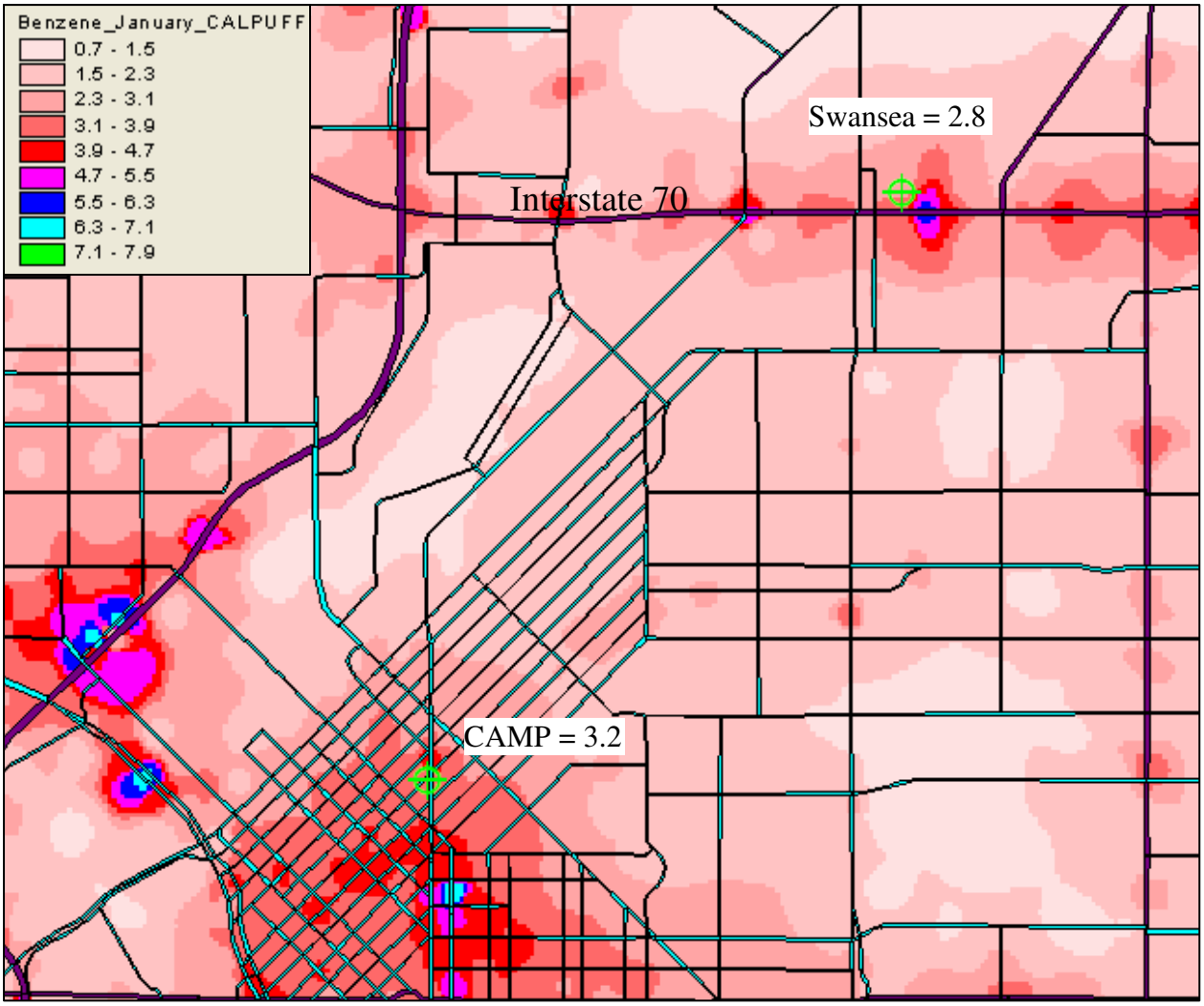
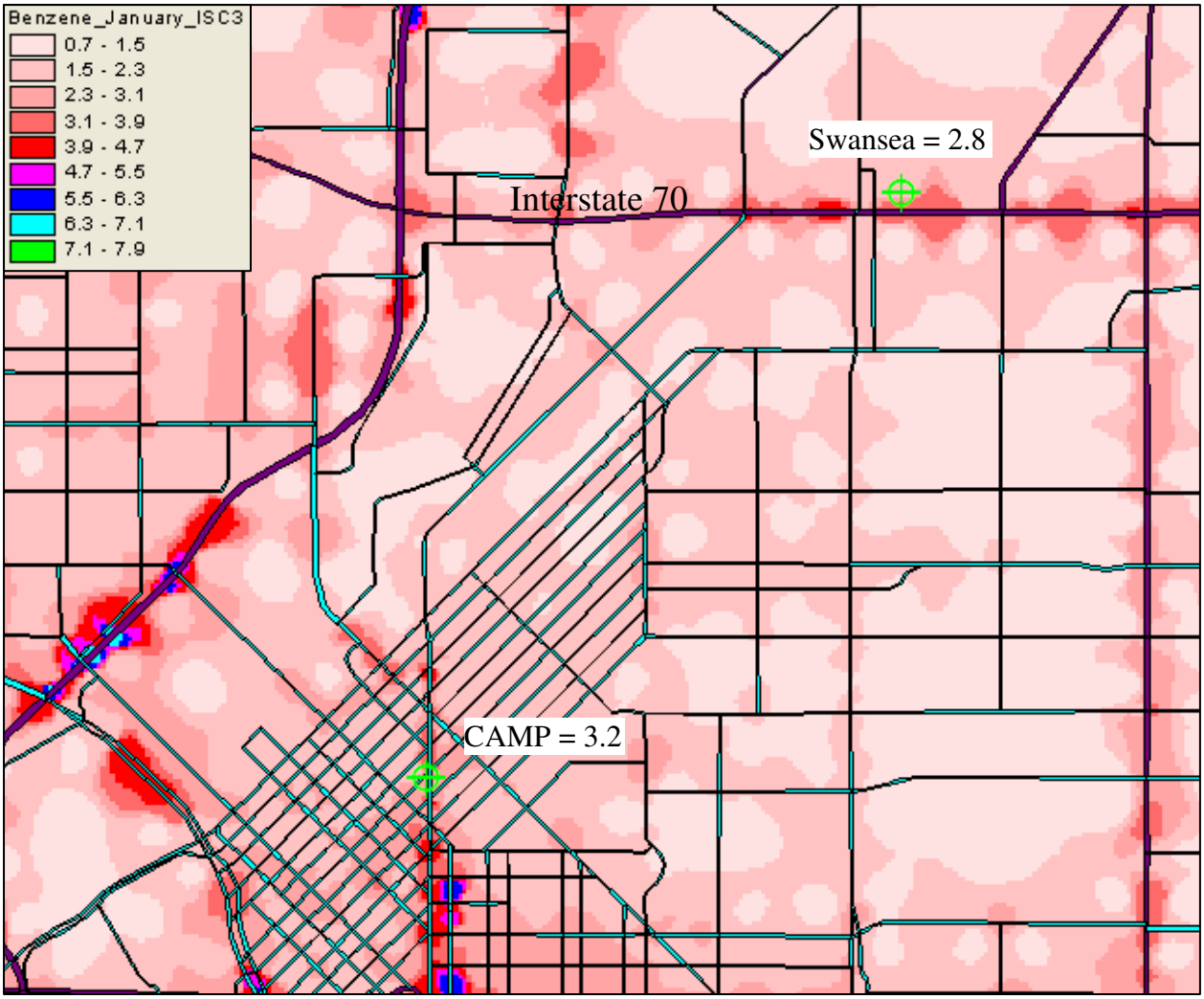


Figure 3-16. ISC3 predicted monthly average concentrations using January 1990 meteorological data. Monitored concentrations for Swansea and CAMP stations are shown.



4. CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

The Good Neighbor project attempts to evaluate the influence of major roadways on ambient air toxics concentrations. More specifically, it assigns link-based onroad mobile source emissions to the respective roadway polygons, instead of distributing those emissions evenly across a predefined a grid (i.e. census block groups). The Good Neighbor project builds on an earlier cumulative baseline assessment conducted by the Denver Department of Environmental Health (DEH). The baseline assessment used 1996 emissions, whereas the Good Neighbor project updated emissions to 2002. Both assessments modeled all known and documented air toxics emissions in Denver, Adams, Arapahoe, Boulder, Douglas, and Jefferson Counties. This includes nonroad mobile source, area source, and point source emissions.

Whereas the baseline assessment used county level emissions from onroad mobile sources and apportioned various fractions to census block groups using surrogate data, the Good Neighbor project generated a link-based emissions inventory using Colorado Department of Transportation (CDOT) GIS-based data including annual average daily traffic (AADT), which was converted to vehicle miles traveled (VMT). Onroad emissions were apportioned to the actual roadway polygons as developed in the GIS.

The U.S. EPA MOBILE6.2 emissions model was used to generate the onroad mobile source inventory. DEH used available local data from CDOT, the Denver Regional Council of Governments (DRCOG), and the Colorado Department of Public Health and Environment (CDPHE) to generate a more complete inventory for Denver. Additional MOBILE6.2 adjustment factors were developed to account for differences in cold-start, running, and evaporative emissions on different facility types. For example, cold-start emissions were weighted significantly to local and collector roads, whereas running loss evaporative emissions were allocated mainly to arterials and highways.

Link-based emission rates were developed for highway, arterial, collector, and local facility types. This was done using the aforementioned adjustment factors developed by DEH and also using the average speed command in MOBILE6.2. Figure 2-2 shows the results for both methods. For local, collector, and arterial roads, the DEH methodology closely approximates the unadjusted MOBILE6.2 emission rates using the average speed command. For highway emissions, the average speed command produces an emission rate that appears to be too high based mainly on what we know about the lack of cold-start emissions on highways. The DEH adjusted emission rate for benzene on highways is approximately 20 percent lower than the MOBILE6.2 unadjusted emission factor. For this reason, benzene constitutes 26 percent of the highway inventory despite highways accounting for 37 percent of the regional VMT.

Table 2-3 contains the emissions totals for the six priority MSATs in the focus area and how those emissions relate to the regional totals for each source category. Table A-1 in Appendix A contains the complete inventory. In the focus area, benzene from onroad gasoline vehicles is 11 percent of the regional inventory, despite the fact that the project area comprises only 1.2 percent

of the regional area. However, the 11 percent benzene contribution is less than the estimated project-to-regional VMT fraction of 13 percent.

Offroad mobile source emissions of acetaldehyde, formaldehyde, acrolein, and diesel PM are significant. For onroad diesel PM, emissions were derived differently than for the other five MSATs. Unadjusted MOBILE6.2 emission rates were taken as the sum of exhaust particulate. Based on previous HDDV emission testing done in Denver, as well as the WRAP modeled emission rates, the MOBILE6.2 emission rates used by DEH are the lowest of the three data sets.

The ISC3 air dispersion model was utilized for this assessment. ISC3 had been used by DEH in the 1996 baseline assessment and was still the EPA recommended model for urban air toxics assessments in 2005. A comparison was conducted using the CALPUFF model, though CALPUFF onroad mobile source estimates were limited to the Denver County portion of the project area.

ISC3 was run employing both the original DEH methodology, updated with 2002 emissions, along with the methodology outlined in this report. Overall, model-to-monitor ratios for benzene improved slightly with the revised methodology at the existing monitor locations (0.32-0.69 versus 0.30-0.62). However, ISC3 maximum predicted concentrations increased by a factor of 2-3 on the roadways, with very sharp concentration gradients within 50 m of the roadways. Historically, ambient air toxics monitors have not been sited close to major roadways. Only the CAMP monitor falls within a 50 m distance from a major roadway, with approximately 25,000 vehicles per day passing the site.

Model-to-monitor ratios for 1,3-butadiene are similar to benzene, ranging from 0.3 at Welby, 0.4 at Swansea, and 0.75 at CAMP. However, concentrations measured above detections limits ranged from 80 percent at CAMP to 60 percent at Welby.

Diesel particulate matter is not directly measured in ambient air. Using speciated elemental carbon concentrations at one site in Commerce City (Alsop Elementary School) and applying equation 3.1, an estimated ambient diesel PM concentration of 0.65 $\mu g/m^3$ compares well with the predicted concentration of 0.64 $\mu g/m^3$.

Ambient formaldehyde, acetaldehyde, and acrolein are all estimated to have significant secondary contributions. Secondary formation is primarily driven by photochemical processes. For this assessment, it was estimated that 87 percent of each compound was formed secondarily. Accounting for secondary and regional background concentrations, model-to-monitor comparisons for formaldehyde ranged from 0.48 at CAMP to 0.93 at Welby. For acetaldehyde the ratios range from 0.46 at CAMP to 0.58 at Swansea. Acrolein has historically been difficult to monitor due to its reactive nature, therefore no model validation was performed for acrolein.

Finally, CALPUFF was run to compare with ISC3. CALPUFF is a non-steady state model that tracks emissions with time and changes in wind direction. The comparison was performed for benzene due to its inert properties. Due to model run time and data storage needs, only Denver roadways within the project area were modeled. In addition, each model was run only using

January 1990 meteorological data. ISC3 annual modeling files showed that the monthly average concentrations for January were approximately equal to the annual mean concentrations.

CALPUFF model-to-monitor comparisons are much better at Swansea and CAMP, with both ratios equal to 1.1. For the same period, ISC3 ratios at Swansea and CAMP are 0.61 and 0.75, respectively. Either model produces good results, as both are within a factor of two of measured concentrations. However, CALPUFF shows a more gradual concentration gradient out to several hundred meters from the highway.

The results presented in this report indicate that small-scale, but highly detailed air toxics assessments are cost-effective and can generate realistic data that match our conceptual model.

4.2 Recommendations

Air toxics analysis is a continuing area of research. While much work has been done to assess the overall health impacts of air toxics, many questions remain unanswered. In particular, the tools and techniques for assessing project-specific health impacts from MSATs are limited. These limitations impede FHWA's ability to evaluate how MSAT impacts should factor into project-level decision-making under the National Environmental Policy Act (NEPA). In addition, EPA has not established regulatory concentration targets for the six relevant MSATs appropriate for use in the project development process.

Nonetheless, air toxics are being raised more frequently on transportation projects during the NEPA process. As the science emerges, the public and other agencies are expecting FHWA to address MSAT impacts in their environmental documents. Research projects like Good Neighbor may help define impacts from MSAT emissions associated with transportation projects. However, while this and other research is ongoing, FHWA issued interim guidance in 2006 on how MSATs should be addressed in NEPA documents for highway projects (FHWA, 2006). Improved modeling capabilities of MSATs may eventually lead to the possibility that a risk assessment methodology may be developed in the future.

Recently, some projects have looked at MSAT inventories and projections for future years to evaluate the potential MSAT impacts of these highway improvements. Modeling capabilities have improved enough to enable researchers to better understand the MSAT concentration gradients near roadways, although a combination of modeling and actual monitored data will always be preferable to modeling results alone.

State and local agencies have begun studying this issue. DEH developed a regional air toxics modeling methodology that has been refined and expanded for the Good Neighbor project. The results are encouraging but in order to adequately validate such modeling, more specifically the predicted concentration gradients near highways, highway specific monitoring at several points within a couple hundred meters of a highway is required.

National and international studies have started to look at this issue, but specific research on air toxics has been limited due to measurement capabilities and costs. Based on modeling results presented in this report, as well as published research, DEH proposes an outline for such a study:

1. Obtain and evaluate meteorological data in the study area. Department of Transportation (DOT) data from roadway networks is ideal. The most important factors to evaluate are prevailing wind direction(s).
2. Identify candidate highways keeping in mind upwind and downwind monitoring locations. Highways in along-wind directions (i.e. parallel to prevailing winds) are poor candidates for gradient monitoring studies. Highways somewhat isolated from other busy roadways are ideal candidates to minimize the influence from other sources. Highways with continuous traffic count sensors and/or continuous long-term data are desirable.
3. Select at least four monitoring sites. In the prevailing wind direction, one site should be on or near roadside, one within 50 m of the road, and another at 100 m. On the upwind side, place one monitor either 50 m or 100 m from the road. A fifth site would be preferable at a distance of 200 m from the road.
4. The closest prevailing downwind site should be equipped with the following continuous analyzers: an aethalometer (to measure soot), $PM_{2.5}$, carbon monoxide, nitrogen oxides. These analyzers could be fixed or housed in a mobile unit to allow for occasional migration to all sites.
5. All sites should be equipped with VOC and carbonyl samplers. To capture the diurnal effects of traffic and meteorology, four 6-hour average samples could be collected (4 am – 10 am, etc…). Samples could be collected every six days for one month in each of four seasons (~18 sample days per year).
6. Labor costs for sample prep, setup, pickup, and delivery as well as data processing and analysis.

The costs to perform a highway specific air toxics assessment are significant, but not significantly different than current ambient air monitoring studies. For the steps listed above, the potential costs are estimated as shown in Table 4-1 assuming existing equipment is not available.

Table 4-1. Highway specific air toxics monitoring costs.

Equipment/Supplies/Tasks	Unit Cost	# of Units	# of Samples	Cost
Met Data Analysis				$1,000
Site Preparation	$5,000	5		$25,000
Continuous Analyzers				
Aethalometer	$16,000	1	Continuous	$16,000
$PM_{2.5}$	$17,000	1	Continuous	$17,000
CO	$10,000	1	Continuous	$10,000
NOx	$10,000	1	Continuous	$10,000
Data Acquisition	$15,000	1	Continuous	$15,000
Met Tower	$2,000	1	Continuous	$2,000
Shelter/Trailer	$12,000	1	--	$12,000
VOC Auto-Samplers	$6,000	4	--	$24,000
Carbonyl Auto-Samplers	$4,600	4	--	$18,400
Summa Canisters	$550	50	--	$27,500
Carbonyl Tubes	$25	350	--	$8,750
TO-15 Lab Analyses	$350		350	$122,500

Carbonyl TO-11A Lab Analyses	$200		350	$70,000
Sample Setup and Handling	$50,000	1	--	$50,000
Data Processing & Analysis	$75,000	1	--	$75,000
			Total Project Costs	**~$500,000**

5. REFERENCES

Bruehlmann, S.; Forss, A.M.; Steffen, D.; Heeb, N., 2004. Benzene: A Secondary Pollutant Formed in the Three-Way Catalyst, *Environ. Sci. Technol.* 2005, 39, 331-338.

Cohen, J.; Cook, R.; Bailey, C.R.; Carr, E., 2005. Relationship between motor vehicle emissions of hazardous pollutants, roadway proximity, and ambient concentrations in Portland, Oregon. *Environmental Modelling & Software* 20(1): 7-12.

Diaz, L.A.; Reed, G.D.; Fu, L.S., 2005. Source Apportionment of Diesel Particulate Matter in the Southeastern United States Using Models3/CMAQ. U.S. EPA 14th International Emission Inventory Conference "*Transforming Emission Inventories - Meeting Future Challenges Today*" Paper available at: http://www.epa.gov/ttn/chief/conference/ei14/session5/diaz.pdf

EPA, 1999a. *Air Dispersion Modeling of Toxic Pollutants in Urban Areas – Guidance, Methodology and Example Applications*. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards (EPA-454/R-99-021).

EPA, 1999b – *A Simplified Approach for Estimating Secondary Production of Hazardous Air Pollutants (HAPs) Using the OZIPR Model* (EPA-454/R-99-054). Replaces Section 2.4 in *Air Dispersion Modeling of Toxic Pollutants in Urban Areas*, EPA-454/R-99-021. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards.

EPA, 2001. *National-Scale Air Toxics Assessment for 1996 EPA Science Advisory Board Review*. Washington, DC:U.S. Environmental Protection Agency. Available: http://www.epa.gov/ttn/atw/sab/sabrev.html#A1

EPA, 2002 – *Health Assessment Document for Diesel Exhaust* (EPA-600/8-90/057F). U.S. Environmental Protection Agency, National Center for Environmental Assessment, Office of Research and Development.

Federal Highway Adminsitration, 2006. Memorandum on Interim Guidance on Air Toxic Analysis in NEPA Documents. Available at http://www.fhwa.dot.gov/environment/airtoxic/020306guidmem.htm

Geiger, H.; Becker, K.H.; Wiesen, P., 2003. Effect of Gasoline Formulation on the Formation of Photosmog: A Box Model Study, *J. Air & Waste Manage. Assoc.* 53:425–433.

Graboski, M.S.; McCormick, R.L.; Yanowitz, J.; Ryan, L., (1998). *Heavy Duty Diesel Vehicle Testing for the Northern Front Range Air Quality Study*. Colorado Institute for Fuels and Engine Research, Colorado School of Mines, Golden, CO. Report available at: http://www.nfraqs.colostate.edu/nfraqs/index2.html.

Huang, H.; Ooka, R.; Kato, S.; Jiang, T.; Takehashi, T.; Watanabe, T., 2006. Validation and Application of CFD Modeling for Predicting Traffic Induced Air Pollution in a Complex Urban Area. 86th American Meteorological Society Annual Meeting, Sixth Symposium on the Urban

Environment, 14th Joint Conference on the Applications on Air Pollution Meteorology with the Air and Waste Management Association, paper J5.4.

Lawson, D.R.; Smith, R.E., 1998. *Northern Front Range Air Quality Study – A Report to the Governor and General Assembly*. Report available at http://www.nfraqs.colostate.edu/nfraqs/index2.html.

Ligocki, M. P., R. R. Schulhof, R. E. Jackson, M. M. Jimenez, G. Z. Whitten, G. M. Wilson, T. C. Myers, and J. L. Fieber. 1992. *Modeling the Effects of Reformulated Gasoline on Ozone and Toxics Concentrations in the Baltimore and Houston Areas*. Systems Applications International, San Rafael, California (SYSAPP-92/127).

McCarthy, M.C.; Hafner, H.R.; Montzka, S.A., 2006. Background Concentrations of 18 Air Toxics in North America, *J. Air & Waste Manage. Assoc.* 56:3-11.

McCormick, R.L; Graboski, M.S.; Alleman, T.L.; Alvarez, J.R.; Kado, N.Y.; Kuzmicky, P.A.; Kobayashi, R.; Duleep, K.G., 2001. *Quantifying the Emissions Benefit of Opacity Testing and Repair of Heavy-Duty Diesel Vehicles*. Final Report to the Colorado Department of Public Health and Environment.

Neimeier, D.; Eisinger, D.; Kear, T.; Jungers, B.D., 2006. *A Survey of Air Dispersion Models for Project Level Conformity Analysis*. UC Davis-Caltrans Air Quality Project Task Order No. 44, prepared for the California Dept. of Transportation. Report available at: http://AQP.engr.ucdavis.edu/

Pirjola, L.; Paasonen, P.; Pfeiffer, D.; Hussein, T.; Hameri, K.; Koskantalo, T.; Virtanen, A.; Ronkko, T.; Keskinen, J.; Paakanen, T.A.; Hillamo, R.E., 2006. Dispersion of particles and trace gases nearby a city highway: Mobile laboratory measurements in Finland, *Atmospheric Environment* 40 (2006) 867-879.

Pollack, A.K; Chi, R.; Lindhjem, C.; Tran, C.; Chandraker, P.; Heirigs, P.; Williams, L.; Delaney, S.S.; Mullen, M.A.; Thesing, K.B., 2004. *Development of WRAP Mobile Source Emission Inventories – Final Report.* Report available at: http://www.wrapair.org/forums/ef/inventories/mobile/040209Final_MSEI.pdf

Roorda-Knape, M.C.; Janssen, N.A.H; De Hartog, J.J.; Van Vliet, P.H.N.; Harssema, H.; Brunekreef, B., 1998. Air Pollution from Traffic in City Districts near Major Motorways, *Atmospheric Environment* 32 (1998) 1921-1930.

Schuetzle, D.; Siegl, W.O.; Jensen, T.E.; Dearth, M.A.; Kaiser, E.W.; Gorse, R.; Kreucher, W.; Kulik, E., 1994. The Relationship between Gasoline Composition and Vehicle Hydrocarbon Emissions: A Review of Current Studies and Future Research Needs**,** *Environmental Health Perspectives,* 102(Suppl 4):3-12.

Systems Application International (SAI), 1999. *Modeling Cumulative Outdoor Concentrations of Hazardous Air Pollutants*. Systems Application International Inc., a division of ICF Kaiser Consulting Group.

Thomas, G.W., 2004. *The Denver Urban Air Toxics Assessment: Methodology, Results, Risks.* Available upon request.

Western Regional Air Partnership, 2005. *Colorado MOBILE6.2 Inputs by County in Support of the 2002 Base Year Emissions Inventory.* http://www.wrapair.org/forums/ef/UMSI/index.html

Zhu, Y.; Hinds, W.C.; Kim, S.; Shen, S.; Sioutas, C., 2002. Study of Ultrafine Particles near a Major Highway with Heavy-Duty Diesel Traffic, *Atmospheric Environment* 36 (2002) 4323–4335.

APPENDIX A – EMISSION INVENTORIES

Table A-1. MSAT emissions for FHWA focus area and seven county metropolitan Denver region. FHWA focus area fall within Adams and Denver Counties.

	Benzene (tons/yr)	1,3 Butadiene (tons/yr)	Formal-dehyde (tons/yr)	Acetal-dehyde (tons/yr)	Acrolein (tons/yr)	Diesel Exhaust PM NEI vs DEH MOBILE6.2 (tons/yr)
FHWA FOCUS AREA						
Onroad Mobile - gasoline	142.2	18.7	52.6	27.3	2.2	0
Onroad Mobile - diesel	1.7	1.0	12.8	4.6	0.6	110.3
Offroad Mobile - gasoline	28.5	4.5	53.5	26.1	4	0
Offroad Mobile - diesel						75.8
Area Sources	2.9	2	5.6	10.5	1	nd
Point Sources	29.6	0.8	12.7	0.4	0	nd
ADAMS COUNTY						
Onroad Mobile - gasoline	202.2	27.0	73.8	38.9	3.1	0
Onroad Mobile - diesel	2.5	1.4	17.8	6.6	0.8	105.2 / 74.4
Offroad Mobile - gasoline	37.1	5.6	8.8	3.7	0.5	0
Offroad Mobile - diesel	5	0.6	30.3	13.6	0.9	221.2
Area Sources	16.5	4.2	29	5.1	6.1	8.9
Point Sources	74	0.8	60	1.7	0	nd
ARAPAHOE COUNTY						
Onroad Mobile - gasoline	279.1	37.2	101.8	53.7	4.2	0
Onroad Mobile - diesel	3.4	2.0	24.6	9.0	1.1	119.3 / 103
Offroad Mobile - gasoline	92.8	14.6	24.4	9.7	1.5	0
Offroad Mobile - diesel	5.9	0.6	34.5	15.5	0.9	228.7
Area Sources	18.2	4.2	29.8	5.4	6.7	12
Point Sources	17.7	0	9	0.7	0	nd
BOULDER COUNTY						
Onroad Mobile - gasoline	92.4	12.3	33.7	17.8	1.4	0
Onroad Mobile - diesel	1.1	0.7	8.1	3.0	0.4	78 / 34
Offroad Mobile - gasoline	49.6	7.3	10.8	3.8	0.7	0
Offroad Mobile - diesel	3.4	0.4	20.2	9.1	0.5	138.2
Area Sources	34	9.5	62.1	10.5	11.1	24.3
Point Sources	8.7	0	1.9	0	0	nd
BROOMFIELD COUNTY						
Onroad Mobile - gasoline	17.7	2.4	6.4	3.4	0.3	0
Onroad Mobile - diesel	0.2	0.1	1.6	0.6	0.1	16.5 / 6.5
Offroad Mobile - gasoline	5.4	0.8	1.2	0.5	0.08	0
Offroad Mobile - diesel	0.5	0.05	2.9	1.3	0.07	18.5
Area Sources	1.1	n/a	1.4	n/a	n/a	1.8
Point Sources	nd	nd	nd	nd	nd	nd

Table A-1 (cont.). MSAT emissions for FHWA focus area and seven county metropolitan Denver region.

	Benzene (tons/yr)	1,3 Butadiene (tons/yr)	Formal-dehyde (tons/yr)	Acetal-dehyde (tons/yr)	Acrolein (tons/yr)	Diesel Exhaust PM NEI vs DEH MOBILE6.2 (tons/yr)
DENVER COUNTY						
Onroad Mobile - gasoline	297.0	39.6	108.4	57.1	4.5	0
Onroad Mobile - diesel	3.7	2.1	26.2	9.6	1.2	145 / 109.2
Offroad Mobile - gasoline	84.7	16.1	21.9	8.9	1.4	0
Offroad Mobile - diesel	6.9	0.7	59.3	19	1.6	261.2
Area Sources	8.3	0.4	6.2	1.7	2.9	13
Point Sources	14.6	0	5.6	1	0	nd
DOUGLAS COUNTY						
Onroad Mobile - gasoline	130.7	17.4	47.7	25.1	2.0	0
Onroad Mobile - diesel	1.6	0.9	11.5	4.2	0.5	77 / 48.1
Offroad Mobile - gasoline	44.2	6.8	10.7	4.4	0.7	0
Offroad Mobile - diesel	3.5	0.4	20.9	9.4	0.6	141.6
Area Sources	15.9	4.4	27.1	4.7	5.2	5
Point Sources	6.1	0	0.1	0	0	nd
JEFFERSON COUNTY						
Onroad Mobile - gasoline	308.6	41.1	112.6	59.4	4.7	0
Onroad Mobile - diesel	3.8	2.2	27.2	10.0	1.2	148.7 / 113
Offroad Mobile - gasoline	77.3	11.8	18.9	7.6	1.2	0
Offroad Mobile - diesel	4	0.4	23.2	10.4	0.6	152
Area Sources	37.6	10.4	64.2	11.2	12.2	11.7
Point Sources	19.4	0	4.1	6.3	0	nd

APPENDIX B – MOBILE 6.2 EMISSIONS MODEL INPUT FILES

Exhibit B-1. MOBILE6.2 input file used in this assessment. Emissions from this output file were adjusted and used in the air dispersion model.

```
MOBILE6 INPUT FILE : Estimated Emissions for 2002; incl. some modified files
* This input file calculates Regional emissions
****************************** HEADER SECTION *********************************

POLLUTANTS         : HC CO NOx

PARTICULATES       :

AIR TOXICS         :

SPREADSHEET        : DEN02DEH

****************************** RUN DATA SECTION *******************************

RUN DATA

EXPRESS HC AS TOG  :

EXPAND EXHAUST     :
* TOG output given as start emissions and running/stabilized emissions

EXPAND EVAPORATIVE :

STARTS PER DAY     : stperday.d
* EPA Default

START DIST         : sdist.d
* EPA Default

NO REFUELING       :

REG DIST           : REG_MET.D
* The registration distribution above and below is altered based on CDPHE
* 2001 Dept of Revenue data analysis of Colorado specific registrations

DIESEL FRACTIONS   :
0.0010 0.0010 0.0019 0.0012 0.0015 0.0011 0.0016 0.0006 0.0003 0.0003
0.0005 0.0007 0.0004 0.0003 0.0002 0.0022 0.0023 0.0103 0.0138 0.0297
0.0417 0.0437 0.0236 0.0150 0.0039
0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0002 0.0002 0.0003 0.0015
0.0029 0.0050 0.0000 0.0000 0.0000
0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0015 0.0018 0.0026 0.0077
0.0131 0.0089 0.0000 0.0000 0.0001
0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
0.0000 0.0000 0.0000 0.0000 0.0015 0.0017 0.0045 0.0063 0.0093 0.0193
0.0330 0.0008 0.0000 0.0002 0.0001
0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
0.0000 0.0000 0.0000 0.0000 0.1518 0.1304 0.3134 0.3516 0.5339 0.5956
0.7188 0.0052 0.0000 0.0017 0.0010
0.3773 0.4341 0.3071 0.3335 0.1707 0.3644 0.3231 0.3004 0.2508 0.2529
0.1983 0.1180 0.0958 0.0600 0.0773 0.0801 0.1011 0.0879 0.1200 0.1094
0.0834 0.0059 0.0013 0.0000 0.0012
0.6884 0.5574 0.4422 0.5647 0.5423 0.4717 0.3662 0.2996 0.2310 0.3102
0.2804 0.1166 0.2037 0.0816 0.0408 0.0071 0.0606 0.0158 0.0098 0.0215
```

```
0.0373 0.0047 0.0000 0.0051 0.0030
0.1333 0.6429 0.1889 0.2465 0.2667 0.3414 0.4111 0.4861 0.1992 0.1762
0.1436 0.0615 0.0364 0.0463 0.0178 0.0156 0.0273 0.0154 0.0000 0.0000
0.0000 0.0027 0.0000 0.0000 0.0000
1.0000 1.0000 0.6429 0.2813 0.3250 0.1145 0.1120 0.0952 0.1897 0.5652
0.3548 0.0952 0.3333 0.1875 0.2692 0.2143 0.4000 0.4118 0.3333 0.2500
0.3077 0.1250 0.2500 0.1212 0.0168
1.0000 0.9630 0.5627 0.6414 0.9591 0.8261 0.8483 0.6988 0.7273 0.6250
0.3952 0.4608 0.4400 0.6076 0.2893 0.2929 0.3608 0.4017 0.4571 0.3333
0.2881 0.3088 0.1642 0.1348 0.0227
1.0000 1.0000 1.0000 0.9883 1.0000 0.9847 0.9924 0.9463 0.9342 0.8875
0.9231 0.8235 0.9020 0.9118 0.8814 0.9155 0.8681 0.8101 0.7471 0.9375
0.7826 0.6087 0.6667 0.3714 0.4306
1.0000 1.0000 0.9889 0.9938 0.9962 1.0000 0.9925 1.0000 0.9935 1.0000
1.0000 1.0000 1.0000 0.9955 0.9947 0.9841 0.9884 0.9879 0.9765 1.0000
0.9775 1.0000 0.9659 0.9798 0.9515
1.0000 1.0000 0.9915 0.9940 0.9824 0.9944 0.9873 0.9957 0.9918 0.9948
0.9938 1.0000 0.9847 1.0000 0.9897 1.0000 0.9880 0.9895 0.9831 1.0000
1.0000 1.0000 1.0000 0.9535 0.9273
0.8986 0.5748 0.7405 0.7478 0.6667 0.8283 0.7241 0.5579 0.7327 0.6056
0.7597 0.8370 0.8033 0.8354 0.8289 0.7627 0.8547 0.6897 0.5075 0.0526
0.6122 0.7706 0.6250 0.6102 0.0658

VMT BY FACILITY    : fvmt_u.def
* The facility by VMT shows CDPHE/DRCOG TDM estimates for urban classes

VMT BY HOUR        : hvmt_u.def
* CDPHE/DRCOG derived file

SPEED VMT          : svmt_u.def
* CDPHE/DRCOG derived file

WE DA TRI LEN DI   : WEDATRIP.D
* EPA Default

* -------------------------------- I/M Program Data --------------------------
* Evaluation year 2002 only
* Program data from inspection year 2000
* Basic and Enhanced I/M Programs
* Pass/fail Idle only for all HDGV vehicles >1981
* Colorado 2002 I/M240 cutpoints for cars and trucks

I/M PROGRAM        : 1 1982 2050 1 T/O IDLE
I/M MODEL YEARS    : 1 1952 1980
I/M VEHICLES       : 1 22222 22222222 2
I/M STRINGENCY     : 1 21.0
I/M COMPLIANCE     : 1 95.0
I/M WAIVER RATES   : 1 .09 .00 (Post 1980 waiver rate not applicable)
I/M GRACE PERIOD   : 1 5

I/M PROGRAM        : 2 1982 2050 1 T/O 2500/IDLE
I/M MODEL YEARS    : 2 1981 1981
I/M VEHICLES       : 2 22222 22222222 2
I/M STRINGENCY     : 2 21.0 (Pre 1981 stringency rate not applicable)
I/M COMPLIANCE     : 2 95.0
I/M WAIVER RATES   : 2 .00 .37 (Pre 1981 waiver rate not applicable)
I/M GRACE PERIOD   : 2 5

I/M PROGRAM        : 3 1982 2050 2 T/O IDLE
I/M MODEL YEARS    : 3 1982 2050
```

```
I/M VEHICLES       : 3 11111 22222222 2
I/M STRINGENCY     : 3 21.0 (Pre 1981 stringency rate not applicable)
I/M COMPLIANCE     : 3 95.0
I/M WAIVER RATES   : 3 .00 .57 (Pre 1981 waiver rate not applicable)
I/M GRACE PERIOD   : 3 5

I/M PROGRAM        : 4 1982 2050 2 T/O IM240
I/M MODEL YEARS    : 4 1982 2050
I/M CUTPOINTS      : 4 02CUTPC.D
I/M VEHICLES       : 4 21111 11111111 1
* different cutpoints for light duty passenger cars and trucks
I/M STRINGENCY     : 4 21.0 (Pre 1981 stringency rate not applicable)
I/M COMPLIANCE     : 4 95.0
I/M WAIVER RATES   : 4 .00 .82 (Pre 1981 waiver rate not applicable)
I/M GRACE PERIOD   : 4 5

I/M PROGRAM        : 5 1982 2050 2 T/O IM240
I/M MODEL YEARS    : 5 1982 2050
I/M CUTPOINTS      : 5 02CUTPT.D
I/M VEHICLES       : 5 12222 11111111 1
* cutpoints above are for light duty trucks 1,2,3,4
* Mobile6 does not use heavy duty truck cutpoints
I/M STRINGENCY     : 5 21.0 (Pre 1981 stringency rate not applicable)
I/M COMPLIANCE     : 5 95.0
I/M WAIVER RATES   : 5 .00 1.12 (Pre 1981 waiver rate not applicable)
I/M GRACE PERIOD   : 5 5

ANTI-TAMP PROG      : 82 75 98 22222 22222222 2 12 095. 22111112

*FUEL PROGRAM       : 4
* Post 1999 Fuel Sulfur Phase in program for Conventional Gasoline West


****************************** SCENARIO SECTION ******************************

*-------------------------------------------------------------------------------
SCENARIO REC       : Denver HC Output as TOG - Winter
*-------------------------------------------------------------------------------

FUEL PROGRAM       : 4
262.2  262.2  262.2  262.2  230.0  200.0   60.0   33.0
 33.0   30.0   30.0   30.0   30.0   30.0   30.0   30.0
600.0  600.0  600.0  600.0  303.0  303.0   90.0   90.0
 80.0   80.0   80.0   80.0   80.0   80.0   80.0   80.0
* 2002 NEI - CDPHE supplied data
* Different from gasoline sulfur levels from Alliance of Automobile
* Manufacturers samples for Denver as used by the WRAP for their 2002 inputs to
* MOBILE6.2 - AAM values were lower ~ 150 ppm

VMT FRACTIONS      :
0.4843 0.0766 0.2554 0.0776 0.0373 0.0201 0.0020 0.0015
0.0012 0.0044 0.0053 0.0057 0.0205 0.0035 0.0016 0.0030
* taken from CDPHE 2002 summer input file for urban classes

ALTITUDE           : 2
* 1 = low altitude, 2 = high altitude

PARTICULATE EF     : PMGZML.CSV PMGDR1.CSV PMGDR2.CSV PMDZML.CSV PMDDR1.CSV
PMDDR2.CSV
```

```
PARTICLE SIZE      : 10.0

DIESEL SULFUR      : 360.00
* 2002 NEI - CDPHE supplied fuel parameters

GAS AROMATIC%      : 18.7
GAS OLEFIN%        : 8.9
GAS BENZENE%       : 1.3
E200               : 61.1
E300               : 88.5
* Data from 2002 NEI CDPHE supplied parameters
OXYGENATE          : MTBE 0.0  0.00
                   : ETBE 0.0  0.00
                   : ETOH 8.1  1.00
                   : TAME 0.0  0.00

ADDITIONAL HAPS    : otherhap.csv

HOURLY TEMPERATURES: 16.5 16.4 19.2 26.8 33.9 39.4 43.4 45.4 45.9 45.3 42.9 37.2
32.0 28.8 26.5 24.8 23.2 21.9 20.6 19.6 18.8 18.1 17.4 16.9
* Hourly temps are from 2002 NEI data files for EPA NMIM inputs
* Differ widely from median temps by hour & season calculated from 1986-1990
* meteorological data file
* 6-7 am is the first hour !!

CALENDAR YEAR      : 2002

EVALUATION MONTH   : 1

FUEL RVP           : 12.8
* Data from 2002 NEI CDPHE supplied parameters
* Alliance of Automobile Manufacturers samples for Denver as used by the
* WRAP for their 2002 inputs to MOBILE6.2 was 14.2

ABSOLUTE HUMIDITY  : 65.0
* default is 75 grains/lb

SUNRISE/SUNSET     : 7 5
* default is 6 am and 9 pm

*-------------------------------------------------------------------------------
SCENARIO REC       : Denver HC Output as TOG - Spring
*-------------------------------------------------------------------------------

FUEL PROGRAM       : 4
285.7  285.7  285.7  285.7  235.0  200.0   60.0   33.0
 33.0   30.0   30.0   30.0   30.0   30.0   30.0   30.0
600.0  600.0  600.0  600.0  303.0  303.0   90.0   90.0
 80.0   80.0   80.0   80.0   80.0   80.0   80.0   80.0
* 2002 NEI - CDPHE supplied data
* Different from gasoline sulfur levels from Alliance of Automobile
* Manufacturers samples for Denver as used by the WRAP for their 2002 inputs to
* MOBILE6.2 - AAM values were lower ~ 160 ppm

VMT FRACTIONS      :
0.4843 0.0766 0.2554 0.0776 0.0373 0.0201 0.0020 0.0015
0.0012 0.0044 0.0053 0.0057 0.0205 0.0035 0.0016 0.0030
* taken from CDPHE 2002 summer input file for urban classes

ALTITUDE           : 2
```

```
* 1 = low altitude, 2 = high altitude

PARTICULATE EF     : PMGZML.CSV PMGDR1.CSV PMGDR2.CSV PMDZML.CSV PMDDR1.CSV
PMDDR2.CSV

PARTICLE SIZE      : 10.0

DIESEL SULFUR      : 380.00
* 2002 NEI - CDPHE supplied fuel parameters

GAS AROMATIC%      : 22.8
GAS OLEFIN%        : 9.2
GAS BENZENE%       : 1.4
E200               : 55.5
E300               : 86.5
* Data from 2002 NEI CDPHE supplied parameters
OXYGENATE          : MTBE 0.0  0.00
                   : ETBE 0.0  0.00
                   : ETOH 5.1  1.00
                   : TAME 0.0  0.00

ADDITIONAL HAPS    : otherhap.csv

HOURLY TEMPERATURES: 33.7 37.8 43.5 48.7 53.3 56.9 59.6 61.1 61.8 61.8 60.9 59.3
55.8 51.2 47.7 45.3 43.1 41.0 38.8 37.3 36.0 34.8 33.6 32.9
* Hourly temps are from 2002 NEI data files for EPA NMIM inputs
* Differ widely from median temps by hour & season calculated from 1986-1990
* meteorological data file
* 6-7 am is the first hour !!

CALENDAR YEAR      : 2002

EVALUATION MONTH   : 7
* can select July or January - difference will be slightly newer fleet in July

FUEL RVP           : 10.4
* Data from 2002 NEI CDPHE supplied parameters
* Alliance of Automobile Manufacturers samples for Denver as used by the
* WRAP for their 2002 inputs to MOBILE6.2 was 9.0

ABSOLUTE HUMIDITY  : 65.0
* default is 75 grains/lb

SUNRISE/SUNSET     : 6 8
* default is 6 am and 9 pm

*-------------------------------------------------------------------------------
SCENARIO REC       : Denver HC Output as TOG - Summer
*-------------------------------------------------------------------------------

FUEL PROGRAM       : 4
298.7  298.7  298.7  298.7  298.7  200.0   60.0   33.0
 33.0   30.0   30.0   30.0   30.0   30.0   30.0   30.0
600.0  600.0  600.0  600.0  303.0  303.0   90.0   90.0
 80.0   80.0   80.0   80.0   80.0   80.0   80.0   80.0
* 2002 NEI - CDPHE supplied data
* Different from gasoline sulfur levels from Alliance of Automobile
* Manufacturers samples for Denver as used by the WRAP for their 2002 inputs to
* MOBILE6.2 - AAM values were lower ~ 170 ppm
```

```
VMT FRACTIONS      :
0.4843 0.0766 0.2554 0.0776 0.0373 0.0201 0.0020 0.0015
0.0012 0.0044 0.0053 0.0057 0.0205 0.0035 0.0016 0.0030
* taken from CDPHE 2002 summer input file for urban classes

ALTITUDE           : 2
* 1 = low altitude, 2 = high altitude

PARTICULATE EF     : PMGZML.CSV PMGDR1.CSV PMGDR2.CSV PMDZML.CSV PMDDR1.CSV
PMDDR2.CSV

PARTICLE SIZE      : 10.0

DIESEL SULFUR      : 400.00
* 2002 NEI - CDPHE supplied fuel parameters

GAS AROMATIC%      : 25.0
GAS OLEFIN%        : 9.4
GAS BENZENE%       : 1.4
E200               : 51.9
E300               : 85.4
* Data from 2002 NEI CDPHE supplied parameters
OXYGENATE          : MTBE 0.0  0.00
                   : ETBE 0.0  0.00
                   : ETOH 3.4  1.00
                   : TAME 0.0  0.00
* Volume % Ethanol from AAM for Denver = 4.2
* 2002 RAQC Ozone workgroup discussions stated 25% total oxygenated market share

ADDITIONAL HAPS    : otherhap.csv

HOURLY TEMPERATURES: 56.0 61.6 66.8 71.9 76.5 80.2 83.0 84.3 85.0 84.2 82.7 80.7
77.8 73.7 69.4 66.5 64.3 62.3 60.2 58.6 57.0 55.6 54.3 53.2
* Hourly temps are from 2002 NEI data files for EPA NMIM inputs
* Differ widely from median temps by hour & season calculated from 1986-1990
* meteorological data file
* 6-7 am is the first hour !!

CALENDAR YEAR      : 2002

EVALUATION MONTH   : 7
* can select July or January - difference will be slightly newer fleet in July

FUEL RVP           : 9.1
* Data from 2002 NEI CDPHE supplied parameters
* Alliance of Automobile Manufacturers samples for Denver as used by the
* WRAP for their 2002 inputs to MOBILE6.2 was 9.0
* Summer 2002 RVP = 8.4 - Source: Kim Livo - ozone modeling

ABSOLUTE HUMIDITY  : 65.0
* default is 75 grains/lb

SUNRISE/SUNSET     : 6 9
* default is 6 am and 9 pm

*-------------------------------------------------------------------------------
SCENARIO REC       : Denver HC Output as TOG - Fall
*-------------------------------------------------------------------------------

FUEL PROGRAM       : 4
```

```
289.6  289.6  289.6  289.6  289.6  200.0   60.0   33.0
 33.0   30.0   30.0   30.0   30.0   30.0   30.0   30.0
600.0  600.0  600.0  600.0  303.0  303.0   90.0   90.0
 80.0   80.0   80.0   80.0   80.0   80.0   80.0   80.0
* 2002 NEI - CDPHE supplied data
* Different from gasoline sulfur levels from Alliance of Automobile
* Manufacturers samples for Denver as used by the WRAP for their 2002 inputs to
* MOBILE6.2 - AAM values were lower ~ 160 ppm

VMT FRACTIONS      :
0.4843 0.0766 0.2554 0.0776 0.0373 0.0201 0.0020 0.0015
0.0012 0.0044 0.0053 0.0057 0.0205 0.0035 0.0016 0.0030
* taken from CDPHE 2002 summer input file for urban classes

ALTITUDE           : 2
* 1 = low altitude, 2 = high altitude

PARTICULATE EF     : PMGZML.CSV PMGDR1.CSV PMGDR2.CSV PMDZML.CSV PMDDR1.CSV
PMDDR2.CSV

PARTICLE SIZE      : 10.0

DIESEL SULFUR      : 380.00
* 2002 NEI - CDPHE supplied fuel parameters

GAS AROMATIC%      : 23.4
GAS OLEFIN%        : 9.2
GAS BENZENE%       : 1.4
E200               : 54.4
E300               : 86.1
* Data from 2002 NEI CDPHE supplied parameters
OXYGENATE          : MTBE 0.0  0.00
                   : ETBE 0.0  0.00
                   : ETOH 3.4  1.00
                   : TAME 0.0  0.00

ADDITIONAL HAPS    : otherhap.csv

HOURLY TEMPERATURES: 34.0 36.3 42.6 49.3 55.1 59.5 62.9 64.8 65.3 65.0 63.2 59.0
53.5 49.5 46.8 44.4 42.3 40.6 39.6 38.2 37.2 36.2 35.3 34.6
* Hourly temps are from 2002 NEI data files for EPA NMIM inputs
* Differ widely from median temps by hour & season calculated from 1986-1990
* meteorological data file
* 6-7 am is the first hour !!

CALENDAR YEAR      : 2002
EVALUATION MONTH   : 7
* can select July or January - difference will be slightly newer fleet in July
FUEL RVP           : 10.0
* Data from 2002 NEI CDPHE supplied parameters
* Alliance of Automobile Manufacturers samples for Denver as used by the
* WRAP for their 2002 inputs to MOBILE6.2 was 9.9
ABSOLUTE HUMIDITY  : 65.0
* default is 75 grains/lb

SUNRISE/SUNSET     : 6 7
* default is 6 am and 9 pm

END OF RUN
```

Exhibit B-2. Example MOBILE6.2 input file to calculate emission factors using the AVERAGE SPEED command. A series of these were run to compare with DEH adjusted emission factors.

```
MOBILE6 INPUT FILE : Estimated Emissions for 2002; incl. some modified files
****************************** HEADER SECTION *********************************

POLLUTANTS         : HC CO NOx

PARTICULATES       :

AIR TOXICS         :

SPREADSHEET        : DEN02DEH

****************************** RUN DATA SECTION *******************************

RUN DATA

EXPRESS HC AS TOG  :

EXPAND EXHAUST     :
* TOG output given as start emissions and running/stabilized emissions

EXPAND EVAPORATIVE :

STARTS PER DAY     : stperday.d
* EPA Default

START DIST         : sdist.d
* EPA Default

NO REFUELING       :

REG DIST           : REG_MET.D
* The registration distribution above and below is altered based on CDPHE
* 2001 Dept of Revenue data analysis of Colorado specific registrations

DIESEL FRACTIONS   :
0.0010 0.0010 0.0019 0.0012 0.0015 0.0011 0.0016 0.0006 0.0003 0.0003
0.0005 0.0007 0.0004 0.0003 0.0002 0.0022 0.0023 0.0103 0.0138 0.0297
0.0417 0.0437 0.0236 0.0150 0.0039
0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0002 0.0002 0.0003 0.0015
0.0029 0.0050 0.0000 0.0000 0.0000
0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0015 0.0018 0.0026 0.0077
0.0131 0.0089 0.0000 0.0000 0.0001
0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
0.0000 0.0000 0.0000 0.0000 0.0015 0.0017 0.0045 0.0063 0.0093 0.0193
0.0330 0.0008 0.0000 0.0002 0.0001
0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
0.0000 0.0000 0.0000 0.0000 0.1518 0.1304 0.3134 0.3516 0.5339 0.5956
0.7188 0.0052 0.0000 0.0017 0.0010
0.3773 0.4341 0.3071 0.3335 0.1707 0.3644 0.3231 0.3004 0.2508 0.2529
0.1983 0.1180 0.0958 0.0600 0.0773 0.0801 0.1011 0.0879 0.1200 0.1094
0.0834 0.0059 0.0013 0.0000 0.0012
0.6884 0.5574 0.4422 0.5647 0.5423 0.4717 0.3662 0.2996 0.2310 0.3102
0.2804 0.1166 0.2037 0.0816 0.0408 0.0071 0.0606 0.0158 0.0098 0.0215
0.0373 0.0047 0.0000 0.0051 0.0030
```

```
0.1333 0.6429 0.1889 0.2465 0.2667 0.3414 0.4111 0.4861 0.1992 0.1762
0.1436 0.0615 0.0364 0.0463 0.0178 0.0156 0.0273 0.0154 0.0000 0.0000
0.0000 0.0027 0.0000 0.0000 0.0000
1.0000 1.0000 0.6429 0.2813 0.3250 0.1145 0.1120 0.0952 0.1897 0.5652
0.3548 0.0952 0.3333 0.1875 0.2692 0.2143 0.4000 0.4118 0.3333 0.2500
0.3077 0.1250 0.2500 0.1212 0.0168
1.0000 0.9630 0.5627 0.6414 0.9591 0.8261 0.8483 0.6988 0.7273 0.6250
0.3952 0.4608 0.4400 0.6076 0.2893 0.2929 0.3608 0.4017 0.4571 0.3333
0.2881 0.3088 0.1642 0.1348 0.0227
1.0000 1.0000 1.0000 0.9883 1.0000 0.9847 0.9924 0.9463 0.9342 0.8875
0.9231 0.8235 0.9020 0.9118 0.8814 0.9155 0.8681 0.8101 0.7471 0.9375
0.7826 0.6087 0.6667 0.3714 0.4306
1.0000 1.0000 0.9889 0.9938 0.9962 1.0000 0.9925 1.0000 0.9935 1.0000
1.0000 1.0000 1.0000 0.9955 0.9947 0.9841 0.9884 0.9879 0.9765 1.0000
0.9775 1.0000 0.9659 0.9798 0.9515
1.0000 1.0000 0.9915 0.9940 0.9824 0.9944 0.9873 0.9957 0.9918 0.9948
0.9938 1.0000 0.9847 1.0000 0.9897 1.0000 0.9880 0.9895 0.9831 1.0000
1.0000 1.0000 1.0000 0.9535 0.9273
0.8986 0.5748 0.7405 0.7478 0.6667 0.8283 0.7241 0.5579 0.7327 0.6056
0.7597 0.8370 0.8033 0.8354 0.8289 0.7627 0.8547 0.6897 0.5075 0.0526
0.6122 0.7706 0.6250 0.6102 0.0658

*VMT BY FACILITY    : fvmt_u.def
* The facility by VMT shows CDPHE/DRCOG TDM estimates for urban classes

VMT BY HOUR        : hvmt_u.def
* CDPHE/DRCOG derived file

*SPEED VMT          : svmt_u.def
* CDPHE/DRCOG derived file

WE DA TRI LEN DI   : WEDATRIP.D
* EPA Default

* ------------------------------- I/M Program Data --------------------------
* Evaluation year 2002 only
* Program data from inspection year 2000
* Basic and Enhanced I/M Programs
* Pass/fail Idle only for all HDGV vehicles >1981
* Colorado 2002 I/M240 cutpoints for cars and trucks

I/M PROGRAM        : 1 1982 2050 1 T/O IDLE
I/M MODEL YEARS    : 1 1952 1980
I/M VEHICLES       : 1 22222 22222222 2
I/M STRINGENCY     : 1 21.0
I/M COMPLIANCE     : 1 95.0
I/M WAIVER RATES   : 1 .09 .00 (Post 1980 waiver rate not applicable)
I/M GRACE PERIOD   : 1 5

I/M PROGRAM        : 2 1982 2050 1 T/O 2500/IDLE
I/M MODEL YEARS    : 2 1981 1981
I/M VEHICLES       : 2 22222 22222222 2
I/M STRINGENCY     : 2 21.0 (Pre 1981 stringency rate not applicable)
I/M COMPLIANCE     : 2 95.0
I/M WAIVER RATES   : 2 .00 .37 (Pre 1981 waiver rate not applicable)
I/M GRACE PERIOD   : 2 5

I/M PROGRAM        : 3 1982 2050 2 T/O IDLE
I/M MODEL YEARS    : 3 1982 2050
I/M VEHICLES       : 3 11111 22222222 2
```

```
I/M STRINGENCY     : 3 21.0 (Pre 1981 stringency rate not applicable)
I/M COMPLIANCE     : 3 95.0
I/M WAIVER RATES   : 3 .00 .57 (Pre 1981 waiver rate not applicable)
I/M GRACE PERIOD   : 3 5

I/M PROGRAM        : 4 1982 2050 2 T/O IM240
I/M MODEL YEARS    : 4 1982 2050
I/M CUTPOINTS      : 4 02CUTPC.D
I/M VEHICLES       : 4 21111 11111111 1
* different cutpoints for light duty passenger cars and trucks
I/M STRINGENCY     : 4 21.0 (Pre 1981 stringency rate not applicable)
I/M COMPLIANCE     : 4 95.0
I/M WAIVER RATES   : 4 .00 .82 (Pre 1981 waiver rate not applicable)
I/M GRACE PERIOD   : 4 5

I/M PROGRAM        : 5 1982 2050 2 T/O IM240
I/M MODEL YEARS    : 5 1982 2050
I/M CUTPOINTS      : 5 02CUTPT.D
I/M VEHICLES       : 5 12222 11111111 1
* cutpoints above are for light duty trucks 1,2,3,4
* Mobile6 does not use heavy duty truck cutpoints
I/M STRINGENCY     : 5 21.0 (Pre 1981 stringency rate not applicable)
I/M COMPLIANCE     : 5 95.0
I/M WAIVER RATES   : 5 .00 1.12 (Pre 1981 waiver rate not applicable)
I/M GRACE PERIOD   : 5 5

ANTI-TAMP PROG      : 82 75 98 22222 22222222 2 12 095. 22111112

*FUEL PROGRAM       : 3
* Post 1999 Fuel Sulfur Phase in program for Conventional Gasoline West
* This gets overridden by Fuel Program commands in the Scenario section


****************************** SCENARIO SECTION ******************************

*-------------------------------------------------------------------------------
SCENARIO REC       : Denver HC Output as TOG - Winter
*-------------------------------------------------------------------------------

FUEL PROGRAM       : 4
262.2  262.2  262.2  262.2  230.0  200.0   60.0   33.0
 33.0   30.0   30.0   30.0   30.0   30.0   30.0   30.0
600.0  600.0  600.0  600.0  303.0  303.0   90.0   90.0
 80.0   80.0   80.0   80.0   80.0   80.0   80.0   80.0
* 2002 NEI - CDPHE supplied data
* Different from gasoline sulfur levels from Alliance of Automobile
* Manufacturers samples for Denver as used by the WRAP for their 2002 inputs to
* MOBILE6.2 - AAM values were lower ~ 150 ppm

AVERAGE SPEED      : 10.0 Arterial

VMT FRACTIONS      :
0.4843 0.0766 0.2554 0.0776 0.0373 0.0201 0.0020 0.0015
0.0012 0.0044 0.0053 0.0057 0.0205 0.0035 0.0016 0.0030
* taken from CDPHE 2002 summer input file for urban classes

ALTITUDE           : 2
* 1 = low altitude, 2 = high altitude
```

```
PARTICULATE EF     : PMGZML.CSV PMGDR1.CSV PMGDR2.CSV PMDZML.CSV PMDDR1.CSV
PMDDR2.CSV

PARTICLE SIZE      : 10.0

DIESEL SULFUR      : 360.00
* 2002 NEI - CDPHE supplied fuel parameters

GAS AROMATIC%      : 18.7
GAS OLEFIN%        : 8.9
GAS BENZENE%       : 1.3
E200               : 61.1
E300               : 88.5
* Data from 2002 NEI CDPHE supplied parameters
OXYGENATE          : MTBE 0.0  0.00
                   : ETBE 0.0  0.00
                   : ETOH 8.1  1.00
                   : TAME 0.0  0.00

ADDITIONAL HAPS    : otherhap.csv

HOURLY TEMPERATURES: 16.5 16.4 19.2 26.8 33.9 39.4 43.4 45.4 45.9 45.3 42.9 37.2
32.0 28.8 26.5 24.8 23.2 21.9 20.6 19.6 18.8 18.1 17.4 16.9
* Hourly temps are from 2002 NEI data files for EPA NMIM inputs
* Differ widely from median temps by hour & season calculated from 1986-1990
* meteorological data file
* 6-7 am is the first hour !!

CALENDAR YEAR      : 2002

EVALUATION MONTH   : 1

FUEL RVP           : 12.8
* Data from 2002 NEI CDPHE supplied parameters
* Alliance of Automobile Manufacturers samples for Denver as used by the
* WRAP for their 2002 inputs to MOBILE6.2 was 14.2

ABSOLUTE HUMIDITY  : 65.0
* default is 75 grains/lb

SUNRISE/SUNSET     : 7 5
* default is 6 am and 9 pm

*-------------------------------------------------------------------------------
SCENARIO REC       : Denver HC Output as TOG - Spring
*-------------------------------------------------------------------------------

FUEL PROGRAM       : 4
285.7  285.7  285.7  285.7  235.0  200.0   60.0   33.0
 33.0   30.0   30.0   30.0   30.0   30.0   30.0   30.0
600.0  600.0  600.0  600.0  303.0  303.0   90.0   90.0
 80.0   80.0   80.0   80.0   80.0   80.0   80.0   80.0
* 2002 NEI - CDPHE supplied data
* Different from gasoline sulfur levels from Alliance of Automobile
* Manufacturers samples for Denver as used by the WRAP for their 2002 inputs to
* MOBILE6.2 - AAM values were lower ~ 160 ppm

AVERAGE SPEED      : 10.0 Arterial

VMT FRACTIONS      :
```

```
0.4843 0.0766 0.2554 0.0776 0.0373 0.0201 0.0020 0.0015
0.0012 0.0044 0.0053 0.0057 0.0205 0.0035 0.0016 0.0030
* taken from CDPHE 2002 summer input file for urban classes

ALTITUDE           : 2
* 1 = low altitude, 2 = high altitude

PARTICULATE EF     : PMGZML.CSV PMGDR1.CSV PMGDR2.CSV PMDZML.CSV PMDDR1.CSV
PMDDR2.CSV

PARTICLE SIZE      : 10.0

DIESEL SULFUR      : 380.00
* 2002 NEI - CDPHE supplied fuel parameters

GAS AROMATIC%      : 22.8
GAS OLEFIN%        : 9.2
GAS BENZENE%       : 1.4
E200               : 55.5
E300               : 86.5
* Data from 2002 NEI CDPHE supplied parameters
OXYGENATE          : MTBE 0.0  0.00
                   : ETBE 0.0  0.00
                   : ETOH 5.1  1.00
                   : TAME 0.0  0.00

ADDITIONAL HAPS    : otherhap.csv

HOURLY TEMPERATURES: 33.7 37.8 43.5 48.7 53.3 56.9 59.6 61.1 61.8 61.8 60.9 59.3
55.8 51.2 47.7 45.3 43.1 41.0 38.8 37.3 36.0 34.8 33.6 32.9
* Hourly temps are from 2002 NEI data files for EPA NMIM inputs
* Differ widely from median temps by hour & season calculated from 1986-1990
* meteorological data file
* 6-7 am is the first hour !!

CALENDAR YEAR      : 2002

EVALUATION MONTH   : 7
* can select July or January - difference will be slightly newer fleet in July

FUEL RVP           : 10.4
* Data from 2002 NEI CDPHE supplied parameters
* Alliance of Automobile Manufacturers samples for Denver as used by the
* WRAP for their 2002 inputs to MOBILE6.2 was 9.0

ABSOLUTE HUMIDITY  : 65.0
* default is 75 grains/lb

SUNRISE/SUNSET     : 6 8
* default is 6 am and 9 pm

*-------------------------------------------------------------------------------
SCENARIO REC       : Denver HC Output as TOG - Summer
*-------------------------------------------------------------------------------

FUEL PROGRAM       : 4
298.7  298.7  298.7  298.7  298.7  200.0   60.0   33.0
 33.0   30.0   30.0   30.0   30.0   30.0   30.0   30.0
600.0  600.0  600.0  600.0  303.0  303.0   90.0   90.0
 80.0   80.0   80.0   80.0   80.0   80.0   80.0   80.0
```

```
* 2002 NEI - CDPHE supplied data
* Different from gasoline sulfur levels from Alliance of Automobile
* Manufacturers samples for Denver as used by the WRAP for their 2002 inputs to
* MOBILE6.2 - AAM values were lower ~ 170 ppm

AVERAGE SPEED      : 10.0 Arterial

VMT FRACTIONS      :
0.4843 0.0766 0.2554 0.0776 0.0373 0.0201 0.0020 0.0015
0.0012 0.0044 0.0053 0.0057 0.0205 0.0035 0.0016 0.0030
* taken from CDPHE 2002 summer input file for urban classes

ALTITUDE           : 2
* 1 = low altitude, 2 = high altitude

PARTICULATE EF     : PMGZML.CSV PMGDR1.CSV PMGDR2.CSV PMDZML.CSV PMDDR1.CSV
PMDDR2.CSV

PARTICLE SIZE      : 10.0

DIESEL SULFUR      : 400.00
* 2002 NEI - CDPHE supplied fuel parameters

GAS AROMATIC%      : 25.0
GAS OLEFIN%        : 9.4
GAS BENZENE%       : 1.4
E200               : 51.9
E300               : 85.4
* Data from 2002 NEI CDPHE supplied parameters
OXYGENATE          : MTBE 0.0  0.00
                   : ETBE 0.0  0.00
                   : ETOH 3.4  1.00
                   : TAME 0.0  0.00
* Volume % Ethanol from AAM for Denver = 4.2
* 2002 RAQC Ozone workgroup discussions stated 25% total oxygenated market share

ADDITIONAL HAPS    : otherhap.csv

HOURLY TEMPERATURES: 56.0 61.6 66.8 71.9 76.5 80.2 83.0 84.3 85.0 84.2 82.7 80.7
77.8 73.7 69.4 66.5 64.3 62.3 60.2 58.6 57.0 55.6 54.3 53.2
* Hourly temps are from 2002 NEI data files for EPA NMIM inputs
* Differ widely from median temps by hour & season calculated from 1986-1990
* meteorological data file
* 6-7 am is the first hour !!

CALENDAR YEAR      : 2002

EVALUATION MONTH   : 7
* can select July or January - difference will be slightly newer fleet in July

FUEL RVP           : 9.1
* Data from 2002 NEI CDPHE supplied parameters
* Alliance of Automobile Manufacturers samples for Denver as used by the
* WRAP for their 2002 inputs to MOBILE6.2 was 9.0
* Summer 2002 RVP = 8.4 - Source: Kim Livo - ozone modeling

ABSOLUTE HUMIDITY  : 65.0
* default is 75 grains/lb

SUNRISE/SUNSET     : 6 9
```

```
* default is 6 am and 9 pm

*-------------------------------------------------------------------------------
SCENARIO REC       : Denver HC Output as TOG - Fall
*-------------------------------------------------------------------------------

FUEL PROGRAM       : 4
289.6  289.6  289.6  289.6  289.6  200.0   60.0   33.0
 33.0   30.0   30.0   30.0   30.0   30.0   30.0   30.0
600.0  600.0  600.0  600.0  303.0  303.0   90.0   90.0
 80.0   80.0   80.0   80.0   80.0   80.0   80.0   80.0
* 2002 NEI - CDPHE supplied data
* Different from gasoline sulfur levels from Alliance of Automobile
* Manufacturers samples for Denver as used by the WRAP for their 2002 inputs to
* MOBILE6.2 - AAM values were lower ~ 160 ppm

AVERAGE SPEED      : 10.0 Arterial

VMT FRACTIONS      :
0.4843 0.0766 0.2554 0.0776 0.0373 0.0201 0.0020 0.0015
0.0012 0.0044 0.0053 0.0057 0.0205 0.0035 0.0016 0.0030
* taken from CDPHE 2002 summer input file for urban classes

ALTITUDE           : 2
* 1 = low altitude, 2 = high altitude

PARTICULATE EF     : PMGZML.CSV PMGDR1.CSV PMGDR2.CSV PMDZML.CSV PMDDR1.CSV
PMDDR2.CSV

PARTICLE SIZE      : 10.0

DIESEL SULFUR      : 380.00
* 2002 NEI - CDPHE supplied fuel parameters

GAS AROMATIC%      : 23.4
GAS OLEFIN%        : 9.2
GAS BENZENE%       : 1.4
E200               : 54.4
E300               : 86.1
* Data from 2002 NEI CDPHE supplied parameters
OXYGENATE          : MTBE 0.0  0.00
                   : ETBE 0.0  0.00
                   : ETOH 3.4  1.00
                   : TAME 0.0  0.00

ADDITIONAL HAPS    : otherhap.csv

HOURLY TEMPERATURES: 34.0 36.3 42.6 49.3 55.1 59.5 62.9 64.8 65.3 65.0 63.2 59.0
53.5 49.5 46.8 44.4 42.3 40.6 39.6 38.2 37.2 36.2 35.3 34.6
* Hourly temps are from 2002 NEI data files for EPA NMIM inputs
* Differ widely from median temps by hour & season calculated from 1986-1990
* meteorological data file
* 6-7 am is the first hour !!

CALENDAR YEAR      : 2002

EVALUATION MONTH   : 7
* can select July or January - difference will be slightly newer fleet in July

FUEL RVP           : 10.0
```

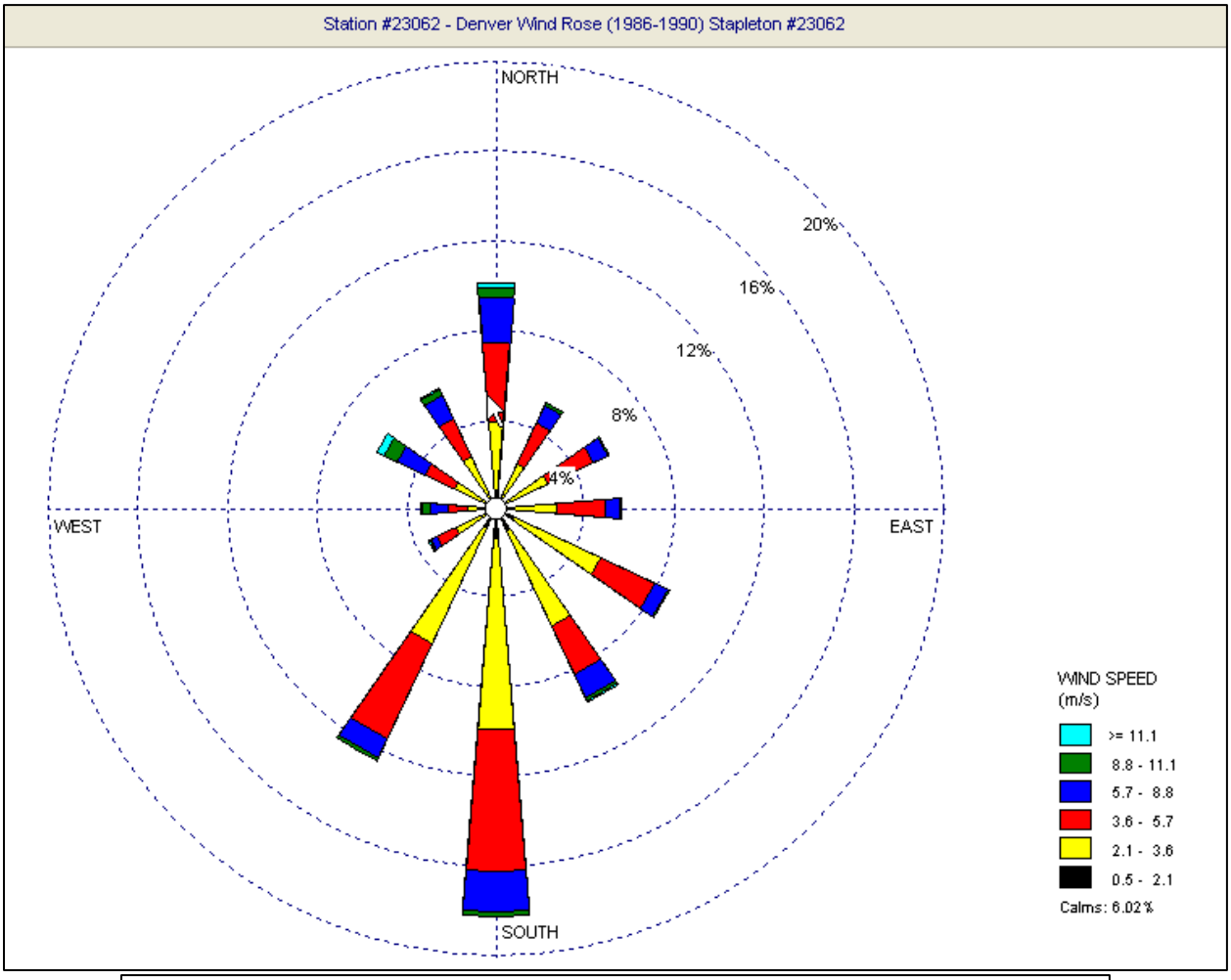
```
* Data from 2002 NEI CDPHE supplied parameters
* Alliance of Automobile Manufacturers samples for Denver as used by the
* WRAP for their 2002 inputs to MOBILE6.2 was 9.9

ABSOLUTE HUMIDITY  : 65.0
* default is 75 grains/lb

SUNRISE/SUNSET     : 6 7
* default is 6 am and 9 pm

END OF RUN
```

APPENDIX C – AIR DISPERSION MODEL OPTIONS AND METEOROLOGICAL DATA

Table C-1. ISC3ST model options utilized in the Good Neighbor project.

ISC3ST Model Options Utilized	Description
Toxics Options (non-regulatory)	Allows the use of air toxics enhancements
Sampled Chronological Input Model (SCIM)	Reduces model run time; met data sampled every 25 hours
Averaging Period	Annual average must be selected to use SCIM option
Effective Area Source Depletion Factor	Optimized area source dry depletion algorithm for use with non-point sources
Include Calm Meteorological Hours	Bypasses calm wind processing routine that sets concentrations to zero during calm wind hours
Terrain Options	Both simple and complex terrain algorithms selected
Plume Depletion	Both dry and wet selected for point sources; dry depletion not needed when using effective depletion factor for area sources
Dry and Wet Deposition	Both selected to produce least conservative estimates of concentrations
Land Use	Urban selected for entire modeling domain; sensitivity analysis also performed using rural dispersion
Halflife/Decay	Halflife was used; varies by pollutant
Flagpole Receptors	1.5 meters above each receptor elevation used to simulate breathing zone
Dry Deposition Parameters	Model default parameters were utilized
State of Vegetation	Active and Unstressed; affects rate of deposition to vegetative surfaces
Liquid and Frozen Precipitation Gas Scavenging	Is a function of particle/molecule size
Gas Dry Deposition Variables	Vary by pollutant

Figure C-1. Wind rose and frequency distribution for 1986-1990 meteorological data recorded at Stapleton International Airport in Denver.



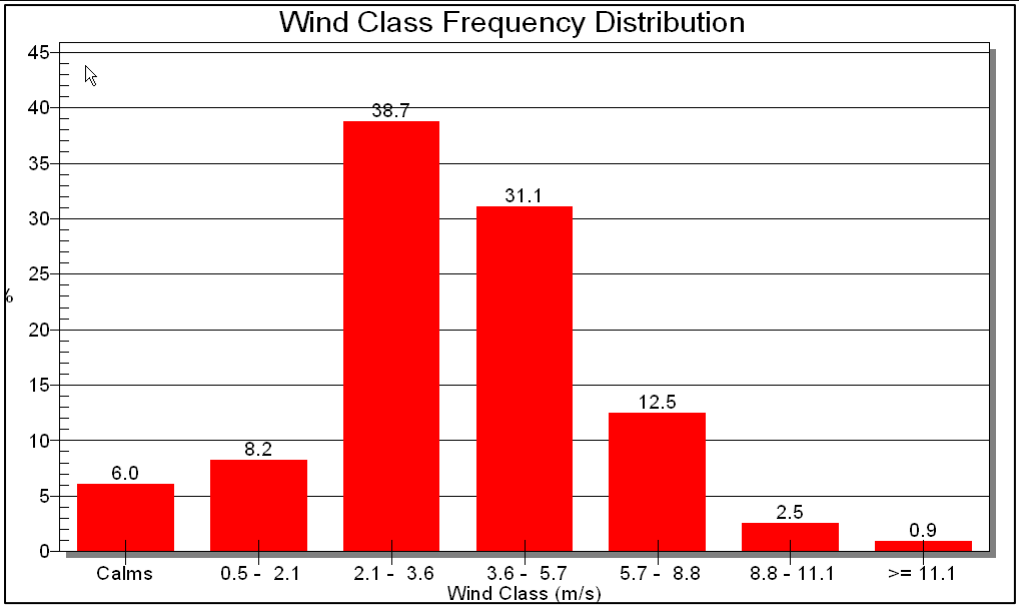


Figure C-2. Wind rose and frequency distribution for 1996, 1999, and 2002 meteorological data recorded at Denver International Airport in Denver.