Application of a Microscale Emission Factor Model for Particulate Matter (MicroFacPM) in Conjunction with CALINE4 Model

Proceedings of the 95th Annual Conference of the A&WMA, Baltimore, MD, June 2002
Paper # 42816

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ABSTRACT

The United States Environmental Protection Agency's (EPA) National Exposure Research Laboratory is developing improved methods for modeling the pollutant sources through the air pathway to human exposure in significant microenvironments of exposure. As a part of this project, we developed MicroFacPM, a microscale emission factor model for predicting real-world real-time motor vehicle particulate matter (PM_{10} and $PM_{2.5}$) emissions. MicroFacPM uses available information on the vehicle fleet composition. The main input variables required are the characterization of on-road vehicle fleet, time and day of the year, ambient temperature, relative humidity and percentage of smoking vehicles. Using the fleet information, MicroFacPM estimates a Composite Emission Factor (milligrams per mile). This paper presents the use of MicroFacPM to calculate the contribution of $PM_{2.5}$ from motor vehicle sources along an example roadway as input to a roadway air dispersion model. The contribution of $PM_{2.5}$ is presented per vehicle class (light, heavy duty), vehicle age, fuel type (gasoline, diesel), brake wear and tire wear sources.

INTRODUCTION

The United States Environmental Protection Agency's (EPA) National Exposure Research Laboratory has an ongoing project to improve the methodology for modeling human exposures to motor vehicle emissions. The overall project goal is to develop improved methods for modeling from the source through the air pathway to human exposure, within significant microenvironments of exposure. Roadway dispersion models use the source strength of particles or gases in terms of concentration per unit distance (e.g. milligrams per mile; mg/mi) as an input to predict particle or gas concentrations in space or time. Detailed and correct knowledge of emission characteristics is therefore an essential prerequisite to developing a reliable human exposure model.

In response to the request from Congress, the National Research Council established the Committee to Review The Environmental Protection Agency's Mobile Source Emission Factor (MOBILE)[1] Model in October 1998. The Committee's findings are published recently.[2] The report followed the earlier published NRC recommendations, which identified outdoor concentrations versus actual human exposure, characterization of emission sources, air-quality-model development and testing as among the top 10 research areas of highest priority.[3] The mobile source emission models, such as MOBILE (used in the United States except California) and EMFAC[4] (used in California only), are suitable for supporting regional scale modeling and emission inventory. These emission models have not been designed to estimate real-time emission needed to support human exposure studies near roadways. In the absence of microscale emission models, these models are being used for microenvironmental modeling applications. Site-specific real-time modeling is necessary for assessing human exposures in different roadway microenvironments, such as in-vehicles and near roadways; and to understand complex relationships between roadway fixed-site ambient monitoring data and actual human exposure.

In view of the above need, a microscale emission factor model for predicting real-world real-time motor vehicle particulate matter (MicroFacPM) emissions for TSP (total suspended particulate matter), PM_{10} (particulate matter less than 10 μm aerodynamic diameter) and $PM_{2.5}$ (particulate matter less than 2.5 μm aerodynamic diameter) has been developed.[5,6] The sensitivity analysis and evaluation of MicroFacPM has shown very encouraging results.[7]

This paper presents the application of MicroFacPM in conjunction with CALINE4 to calculate roadside concentrations of $PM_{2.5}$.

MicroFacPM MODEL

The MicroFacPM model provides a composite emissions factor (mg/mi) for a specified site-specific real-time vehicle fleet. The schematic diagram of MicroFacPM is shown in Figure 1. The vehicle classification and symbols used in MicroFacPM is listed in Table 1. The algorithm used to calculate emission factors in MicroFacPM is disaggregated based on the on-road vehicle fleet, and calculates emission rates from a site-specific fleet over any selected averaging time. The model requires only a few input variables that are necessary to characterize the real-time fleet. The main input variables required are the characterization of on-road vehicle fleet, time and day of the year, ambient temperature, relative humidity and percentage of smoking vehicles. The speed correction factor is calculated for speeds other than 19.6 mi/h for heavy-duty diesel vehicles. The fuel additive correction factor is accounted for if oxygenated fuel is used. The cold engine correction factor is calculated for the vehicles running with cold engines based on their trip length and ambient temperature. The air conditioning correction factor for light-duty gasoline vehicles is applied for the apparent temperatures (heat index) greater than 65°F.

The primary emission rates are calculated per vehicle type and model year based on their emission categories (normal and non-normal high emitters). MicroFacPM first calculates the fraction of vehicles in each category for a 25-year vehicle age distribution and then groups these into either the normal or non-normal emitting categories. Then the vehicle miles accumulated for each vehicle are calculated based on the model year. The vehicle miles accumulated without age are used to calculate primary normal emission rates in mg/mi for heavy-duty diesel vehicles (>8500 lbs) and buses. MicroFacPM then calculates correction factors based on the vehicle type, model year and emission rates. Finally, corrected emission rates for individual vehicles are calculated, and multiplied by the fraction of vehicles of each model year and vehicle class. The sum of these yields a composite emission factor for the on-road vehicle fleet.

$$CEF = \sum_{i,j} (ER_{i,j} \times VEH_{i,j})$$

Where,
CEF = Composite emission factor; mg/mi
$ER_{i,j}$ = Composite emission rate for vehicle type i and model year j,; mg/mi
$VEH_{i,j}$ = Fraction of vehicles for vehicle type i and model year j.

Figure 1. The schematic diagram of the MicroFacPM general model structure

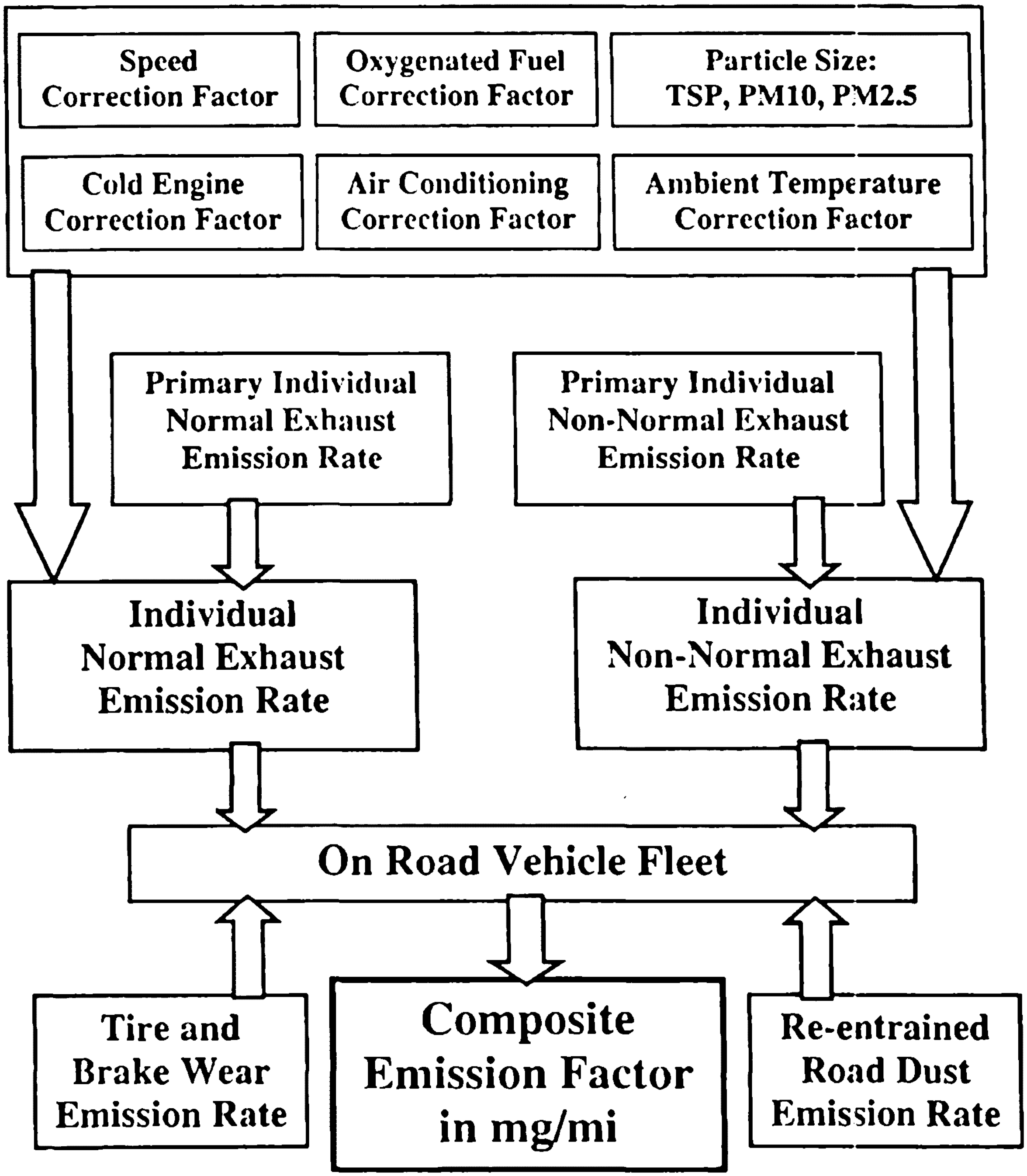


Table 1. Vehicle classification used in MicroFacPM

SN	DESCRIPTION	Gross Vehicle Weight (lbs)	Symbol
Light-duty vehicles (LD)			
Gasoline vehicles			
1	Light-duty gasoline vehicles (cars)	0-6000	LDGV
2	Light-duty gasoline trucks 1	0-3750	LDGT1
3	Light-duty gasoline trucks 2	3750-6000	LDGT2
4	Light-duty gasoline trucks 3	6001-7250	LDGT3
5	Light-duty gasoline trucks 4	7251-8500	LDGT4
6	Motor cycles	All	MC
Diesel vehicles			
7	Light-duty diesel vehicles (cars)	0-6000	LDDV
8	Light-duty diesel trucks 1	0-3750	LDDT1
9	Light-duty diesel trucks 2	3750-6000	LDDT2
10	Light-duty diesel trucks 3	6001-7250	LDDT3
11	Light-duty diesel trucks 4	7251-8500	LDDT4
Heavy-duty vehicles (HD)			
Gasoline vehicles			
12	Heavy-duty gasoline vehicles class 2B	8501-10000	HDGV2B
13	Heavy-duty gasoline vehicles class 3	10001-14000	HDGV3
14	Heavy-duty gasoline vehicles class 4	14001-16000	HDGV4
15	Heavy-duty gasoline vehicles class 5	16001-19500	HDGV5
16	Heavy-duty gasoline vehicles class 6	19501-26000	HDGV6
17	Heavy-duty gasoline vehicles class 7	26001-33000	HDGV7
18	Heavy-duty gasoline vehicles class 8A	33001-60000	HDGV8A
19	Heavy-duty gasoline vehicles class 8B	>60000	HDGV8B
20	Heavy-duty gasoline school bus	All	HDGSB
21	Heavy-duty gasoline transit bus	All	HDGTB
Diesel vehicles			
22	Heavy-duty diesel vehicles class 2B	8501-10000	HDDV2B
23	Heavy-duty diesel vehicles class 3	10001-14000	HDDV3
24	Heavy-duty diesel vehicles class 4	14001-16000	HDDV4
25	Heavy-duty diesel vehicles class 5	16001-19500	HDDV5
26	Heavy-duty diesel vehicles class 6	19501-26000	HDDV6
27	Heavy-duty diesel vehicles class 7	26001-33000	HDDV7
28	Heavy-duty diesel vehicles class 8A	33001-60000	HDDV8A
29	Heavy-duty diesel vehicles class 8B	>60000	HDDV8B
30	Heavy-duty diesel school bus	All	HDDSB
31	Heavy-duty diesel transit bus	All	HDDTB

APPLICATION OF MicroFacPM

ROADWAY DISPERSION MODEL

Roadway dispersion models require emission factors, traffic flow information, meteorological data and site geometry to predict the air pollutant concentration at a receptor location for certain time averages. Most of the flat terrain roadway air pollution assessment models in use today are of the Gaussian plume variety, because Gaussian models are easy to formulate and code, inexpensive computationally, moderately flexible in terms of including a wide variety of phenomena, have simple meteorological input requirements and perform as well or better than more sophisticated numerical approaches.[8] A literature review by Yamartino, Strimaitis and Messier[8] of the existing flat terrain dispersion models, such as EPA-HIWAY[9] and HIWAY-2[10], PAL[11], CALINE 3[12], and ALSM[13], and the model inter-comparison study by Martinez et al.[14] revealed CALINE3 as the best model. CALINE4[15,16], which uses the Gaussian diffusion equation and mixing zone concept for pollutant dispersion near roads, is the most recent in the series and is an updated and expanded version of CALINE3. It can predict pollutant concentrations (CO, NO_2 and suspended particles) for receptors located within 500 meters of the roadway. In complex terrain, the use of CALINE4 should be restricted to receptors immediately adjacent to the primary source of emission.[17]

We applied MicroFacPM in conjunction with CALINE4 for a typical urban setting to predict hourly average roadside concentration of PM_{2}. The trial was run on Capital Boulevard in Raleigh, NC for 24 hrs staring at 8:00 AM on July 10, 2001.

EMISSION FACTORS

The following input values are required to run MicroFacPM:

- Date
- Time
- Vehicle fleet characteristics
- Ambient temperature
- Atmospheric relative humidity
- Average speed
- Cold mileage option (Yes or No)
- Fuel type (Oxygenated or Non oxygenated)
- Smoking vehicles percentage

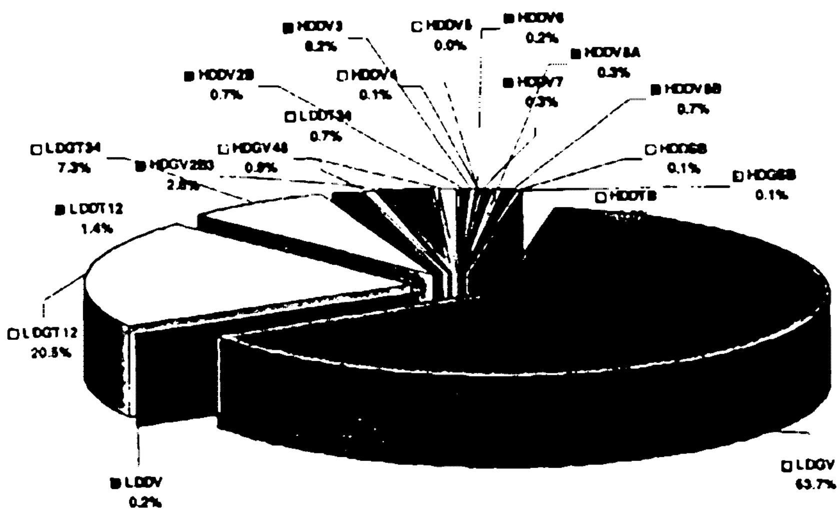
MicroFacPM was run with the cold mileage option, oxygenated fuel and assuming no smoking vehicles in the fleet. The hourly vehicle volume, volume/capacity ratio, assumed vehicle speed, ambient temperature and relative humidity used as input to the MicroFacPM predicted composite emission factor for the fleet in grams per mile per hour (g/mi/h) are shown in Table 2. The meteorological data were obtained from a nearby meteorological site. Another input "mixing ght" was modeled for the local area. The values given in Table 2 are modeled values for the cal 1995 vehicle fleet. North Carolina Department of Transportation has maps on their website with traffic count information (http://www.dot.state.nc.us/planning/statewide/trafficsurvey/).[18] Unfortunately, at the time of this study the information was temporarily unavailable. The posted speed limit on Capital Boulevard is 45 mi/h. Vehicles speeds were assumed based on a Volume to Capacity ratio on the road.

Table 2. The hourly vehicle volume, volume/capacity ratio, assumed vehicle speed, ambient temperature, relative humidity and emission factor for the fleet in grams per mile per hour (g/mi/h) on Capital Boulevard Raleigh, NC

Date	Time Ending (1hour)	Vehicles/ hour	Volume/ Capacity Ratio	Assumed Speed mi/h	Ambient Temperature °F	Relative Humidity	Composite Emission Factor g/mi/h
7/10/01	9:00	2971	0.578	30	60.0	56	81.9
7/10/01	10:00	1574	0.306	40	64.5	48	42.4
7/10/01	11:00	1326	0.258	40	67.6	49	34.6
7/10/01	12:00	1814	0.353	40	69.5	36	48.7
7/10/01	13:00	2915	0.567	30	71.5	28	79.9
7/10/01	14:00	2223	0.432	40	72.4	28	59.8
7/10/01	15:00	2075	0.404	40	71.6	28	55.8
7/10/01	16:00	2609	0.507	30	71.2	28	71.4
7/10/01	17:00	2766	0.538	30	67.0	38	75.8
7/10/01	18:00	3904	0.760	20	59.5	64	120.7
7/10/01	19:00	2919	0.568	30	54.8	80	80.9
7/10/01	20:00	2144	0.417	40	52.3	86	58.5
7/10/01	21:00	1138	0.221	50	53.1	80	30.7
7/10/01	22:00	970	0.189	50	54.1	74	25.9
7/10/01	23:00	465	0.091	50	52.2	80	12.5
7/10/01	24:00	367	0.071	50	53.8	76	9.8
7/11/01	1:00	81	0.016	50	47.7	82	2.2
7/11/01	2:00	66	0.013	50	48.5	78	1.8
7/11/01	3:00	41	0.008	50	48.6	75	1.1
7/11/01	4:00	12	0.002	50	47.7	77	0.3
7/11/01	5:00	45	0.009	50	47.3	77	1.2
7/11/01	6:00	292	0.057	50	42.7	91	7.9
7/11/01	7:00	1534	0.298	40	48.6	77	42.0
7/11/01	8:00	4314	0.839	20	55.5	67	133.8

The vehicle fleet composition used to run the model is shown in Figure 2. The vehicle fleet composition and vehicle age distribution for a light-duty fleet (<8500 lbs) was assumed to be that in Wake and Durham Counties, while for a heavy-duty vehicle fleet (>8500 lbs) the average default US vehicle fleet were used because local information was not available.

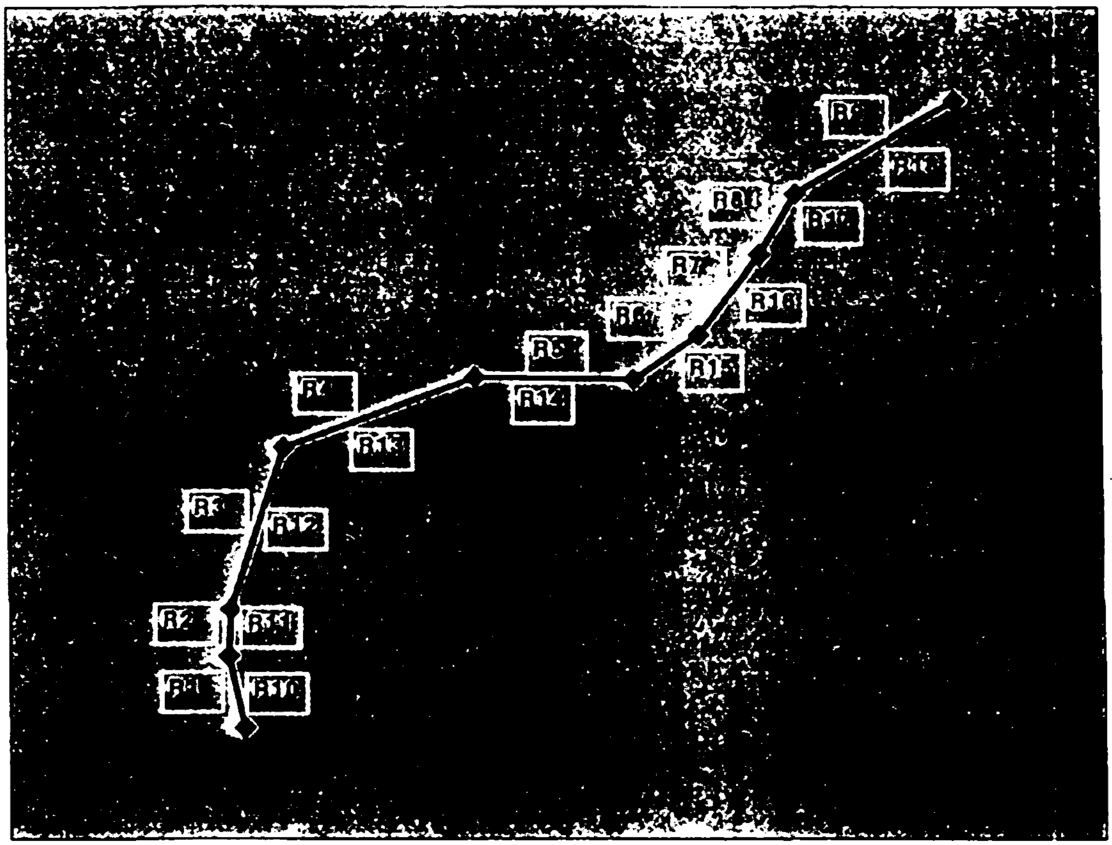
Figure 2: The vehicle fleet composition for Capital Boulevard, Raleigh, NC



LINK COORDINATES AND RECEPTOR POSITIONS

The coordinates of the Capital Boulevard were obtained by using GIS software (vertical axis in Figure 3 is in South to North direction). Capital Boulevard is not a straight road and can be divided into 9 major links (Figure 3). The road width on Capital Boulevard was assumed to be constant approximately 30 meters, [i.e. CALINE4 estimated mixing zone width of 36 m]. Ambient $PM_{2.5}$ concentrations were calculated for the receptors, assumed to be located near the middle of the each roadlink and about 8 meters away from the edge of the road, i.e. 5 meters away from the mixing zone width on both sides of the road (height 1.8 m). When traveling Northward on Capital Boulevard receptors R1 to R9 are located on the left side of the road and R10 to R18 are on the right side of the road.

Figure 3. Receptor positions for the Capital Boulevard, Raleigh



ROADSIDE CONCENTRATIONS

The roadside concentrations were generated at 5 meters outside of the mixing zone of each road segment using CALINE4 for 24 one-hour time-periods starting at 8:00 AM on July 10, 2001. $PM_{2.5}$ roadside ambient concentrations modeled here shows a very large variation in roadside concentrations (Figure 4). The estimated roadside concentrations are very low late at night after the traffic volumes become low. Within the daytime period of high emissions there is significant variation of the estimated concentrations due to wind speed and especially orientation of the wind direction relative to the roadway segment. Roadside concentrations on the downwind side are naturally high relative to the upwind side.

This example has demonstrated the usefulness of real-time modeling of MicroFacPM. Some other applications are also discussed in other presentation.[19] The scope of this modeling approach can be enhanced to include the network of roads including intersections. This modeling framework is a very useful tool to generate the emission factors and identify hot spots as we are planning.

Figure 4a. Roadside PM2.5 ambient concentartions on leftside of the Capital Boulevard when moving towards North-East

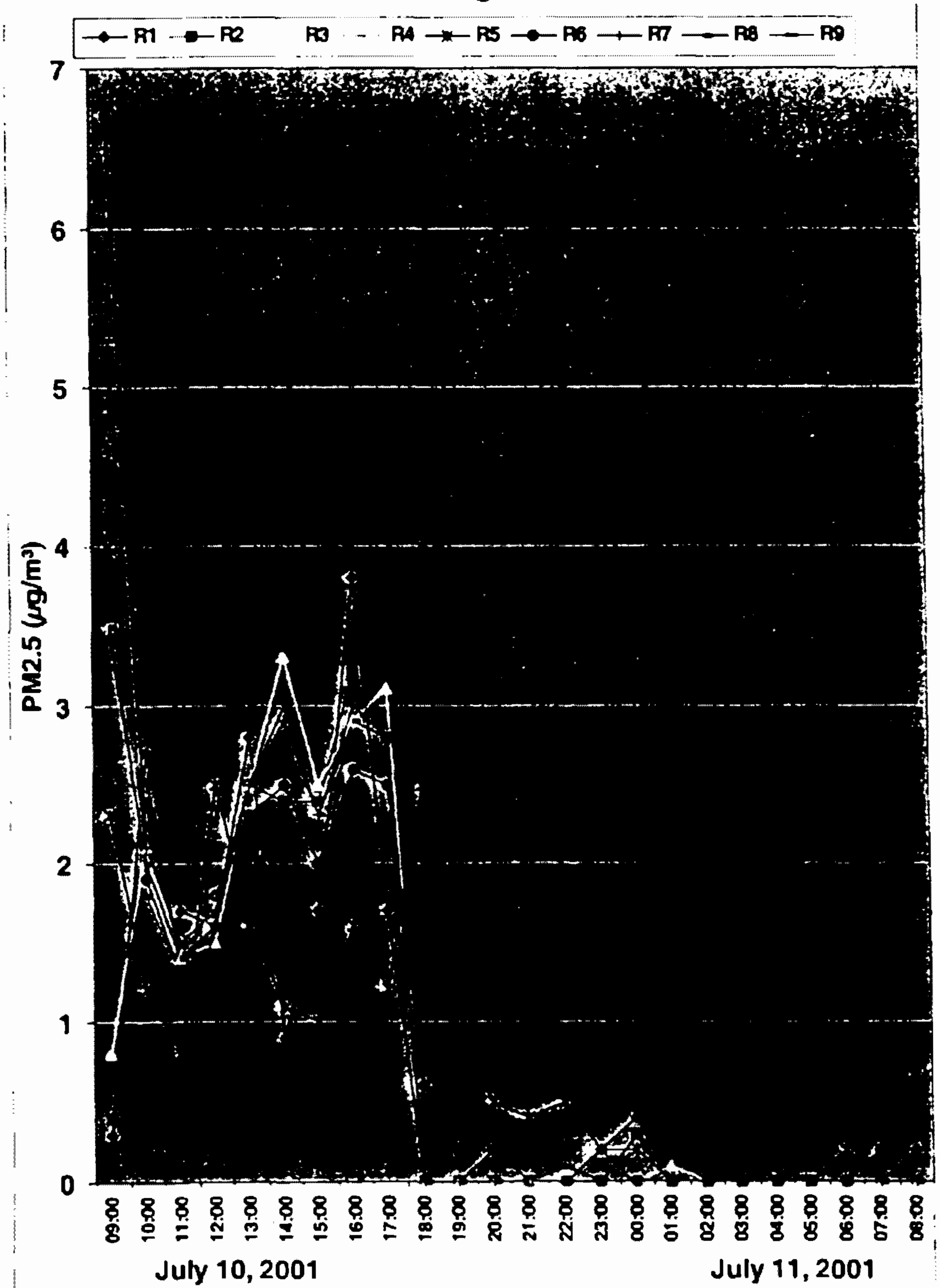
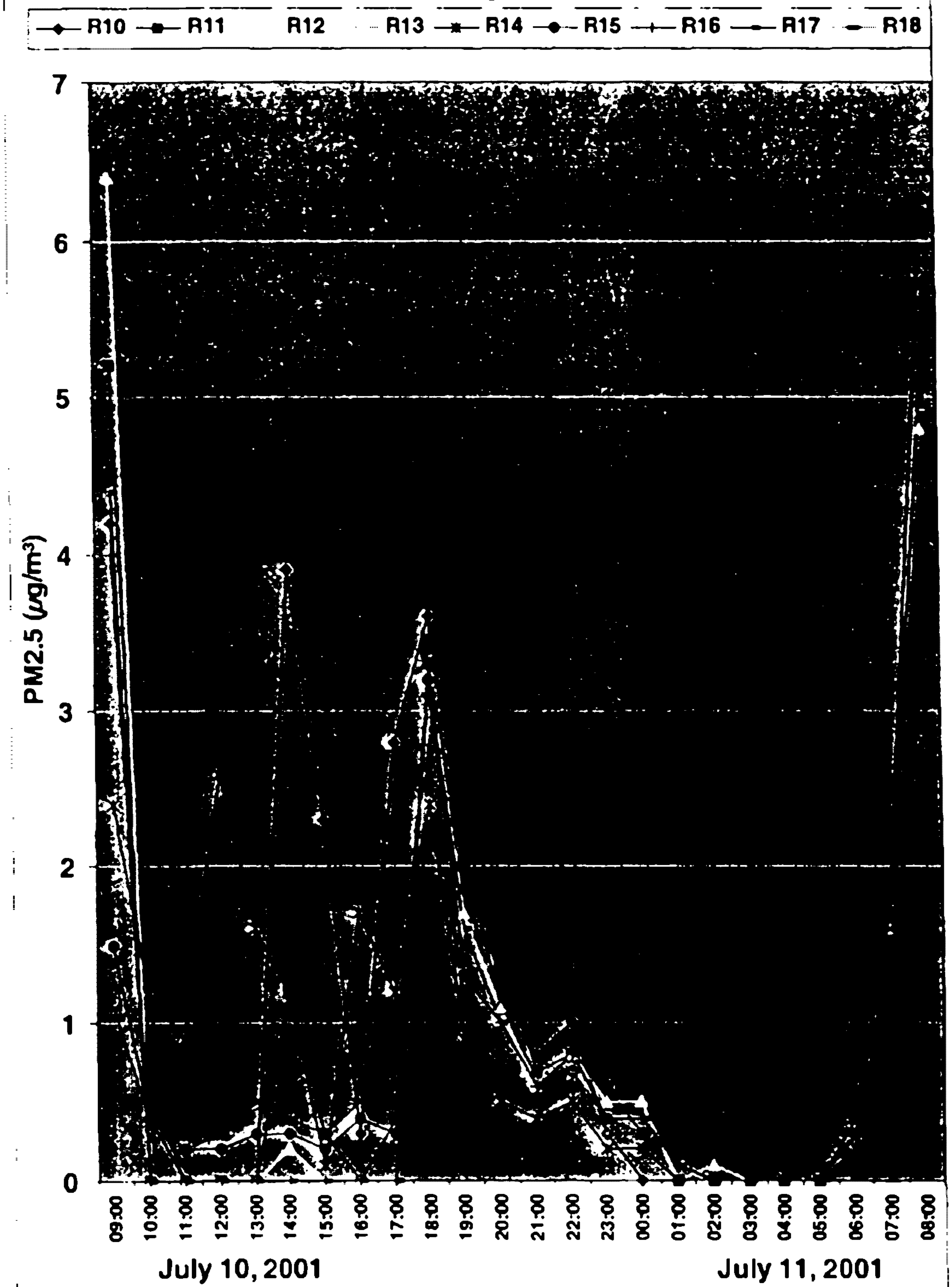


Figure 4b. Roadside PM2.5 ambient concentartions on rightside of the Capital Boulevard when moving towards North-East



CONCLUSION

A microscale emission factor model for predicting real-world real-time motor vehicle particulate matter (MicroFacPM) emission has been developed. MicroFacPM requires a few input variables, which are necessary to characterize the local real-time fleet. MicroFacPM calculates the contribution of PM emissions from different vehicle categories. MicroFacPM emission estimations are suitable for modeling air quality in real-time at a microscale level and useful for improving human exposure estimates for microenvironments near roadways. MicroFacPM should be applied where local site specific information is available or good estimates can be assumed to support the model application.

ACKNOWLEDGEMENT

The authors gratefully acknowledge Robert Gilliam (State Climate Office of North Carolina, Marine Earth and Atmospheric Sciences Department, North Carolina State University, Raleigh, NC 27695) for providing coordinates for the Capital Boulevard and modeling mixing height needed to run CALINE4. Thanks are also due to Chuck Mann and Sue Kimbrough (United States Environmental Protection Agency, National Risk Management Research Laboratory) for providing traffic fleet information for Wake-Durham County and traffic volume information for Capital Boulevard, Raleigh, NC.

DISCLAIMER

The U.S. Environmental Protection Agency through its Office of Research and Development funded the research described here. It has been subjected to Agency review and approved for Publication. Mention of trade names or commercial products does not constitute an endorsement or recommendation for use.

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TECHNICAL REPORT DATA

1. REPORT NO	2.	3.
4. TITLE AND SUBTITLE Application of a Microscale Emission Factor Model for Particulate Matter (MicroFacPM) in Conjunction with CALINE4-Model	5. REPORT DATE 6. PERFORMING ORGANIZATION CODE	
7. AUTHOR(S) [1]Rakesh B. Singh, [2]Alan H. Huber	8. PERFORMING ORGANIZATION REPORT NO	
9. PERFORMING ORGANIZATION NAME AND ADDRESS [1]National Research Council Research Associate USEPA/NERL RTP, NC 27711 [2]Same as block 12	10. PROGRAM ELEMENT NO 11. CONTRACT/GRANT NO	
12. SPONSORING AGENCY NAME AND ADDRESS National Exposure Research Laboratory Office of Research and Development U.S. Environmental Protection Agency Research Triangle Park, NC 27711	13. TYPE OF REPORT AND PERIOD COVERED 14. SPONSORING AGENCY CODE EPA/600/9	
15. SUPPLEMENTARY NOTES		

16. ABSTRACT

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17. KEY WORDS AND DOCUMENT ANALYSIS

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

18. DISTRIBUTION STATEMENT RELEASE TO PUBLIC	19. SECURITY CLASS *(This Report)* UNCLASSIFIED	21. NO. OF PAGES
	20. SECURITY CLASS *(This Page)* UNCLASSIFIED	22. PRICE

EPA-2220