Final Report

Improvement of the PM Emission Inventory for the Lake Tahoe Region

Prepared for:
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Disclaimer

The statements and conclusions in this report are those of the contractor and not necessarily those of the California Air Resources Board. The mention of commercial products, their source or test use in connection with the materials reported herein is not to be construed as either an actual or implied endorsement of such products.

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Statement of Significance

Lake Tahoe is a beautiful lake located in California and Nevada. The lake is well known for its pristine water clarity and color, and is a popular vacation destination. However, since the 1960's, the water clarity of the lake has been steadily declining. It is believed that the degradation in the water clarity is of increases in the input of particles and biologically available phosphorus and nitrogen. A significant fraction of this input is estimated to be through the atmosphere. Possible sources of particles, phosphorus and nitrogen deposition from the atmosphere include smoke from residential wood burning, prescribed files, wildfires, vehicle exhaust, roadway dust, and regional transport. Currently, the quantity and impact from these and other sources are not well understood. This project explores characterizing the emissions contained in wood burning activities and quantifying the amount and type of wood burning in the Tahoe region. In addition, the type and amount of on-road vehicle activity is better characterized. This information will aid in understanding the magnitude and sources of nutrients and particulate matter deposited to Tahoe Lake, to enable the development of a plan for reducing emissions and improving water quality.

Executive Summary

The California Air Resources Board, in conjunction with the Tahoe Regional Planning Agency and the Regional Water Quality Control Board, is conducting a project to understand the sources and quantities of nutrients and particulate matter in the Tahoe region atmosphere. As part of this project, CE-CERT has characterized the particulate matter resulting from wood burning activities in the Tahoe area, including wood burning stoves and fireplaces, and prescribed burns. A wood burning survey was conducted to better understand campfire activity and a residential wood burning use. In addition, the vehicle activity and fleet composition was investigated by collecting video images and driving pattern data. This information was compared with existing data provided by the States to identify areas where improvements in modeling assumptions can be made.

From the results of the limited survey data, it was estimated that the average camper conducts a 2-hour fire every evening, burning an average of 4 logs. The average resident burns 7.4 logs over 6 hours a day during the winter months. The wood burned is a combination of hard and soft wood, and comes from both commercial sales and privately cut reserves.

The fleet and driving patterns of vehicles in the Tahoe Basin were studied to identify potential differences in the current data used in mobile emissions models. It was found that distinct seasonal differences exist in both the fleet makeup, amount of driving, and driving behavior that is not currently accounted for in the modeling. Some areas of discrepancy in fleet makeup, such as percentage of travel from light duty vehicles and heavy duty trucks, and amount of out-of-state vehicles, and driving velocities, are discussed as potential areas where improvements could be made. These differences could have a significant impact on the amount of emissions projected from mobile sources in the Tahoe Basin.

1. Background and Objectives

In the early 1980's, the Tahoe Regional Planning Agency (TRPA), in cooperation with the States of California and Nevada, established a program to maintain significant scenic, recreational, educational, scientific, or natural values of the Region or to maintain public health and safety within the Region. The program has identified nine areas of focus, one of these being water quality. Since then, significant progress has been made toward meeting some of the areas, such as the carbon monoxide and ozone TRPA-adopted Air Quality Thresholds. Although degradation has recently plateaued, lake water clarity has not yet improved.

To improve the water clarity in Lake Tahoe, an understanding of the sources and quantities of nutrient and particulate matter are needed. There is currently very little known about the contribution of wood burning and vehicle activities to the nutrient loading in the Lake. The objective for this project was to conduct research to better understand the sources and quantities of elemental nutrients and PM in the atmosphere from wood burning activities and vehicle emissions in the Tahoe Basin. This research was conducted via three specific tasks:

1. Characterize Particulate Emissions from Prescribed Burns, Fire Places, and Wood Burning Stoves

2. Fuel Use Activity Determination

3. Vehicle Activity Determination

Section 2 of this report describes the approach and process of collections and processing of the data for each of these three tasks. Section 3 presents the results, and section 4 summarizes and presents recommendations for future investigation.

2. Data Collection and Processing

2.1 Methods and Protocols to Characterize Particulate Emissions from Prescribed Burns and Wood Burning Stoves and Fireplaces

Sampling Equipment and Analysis

- **Primary Samplers**

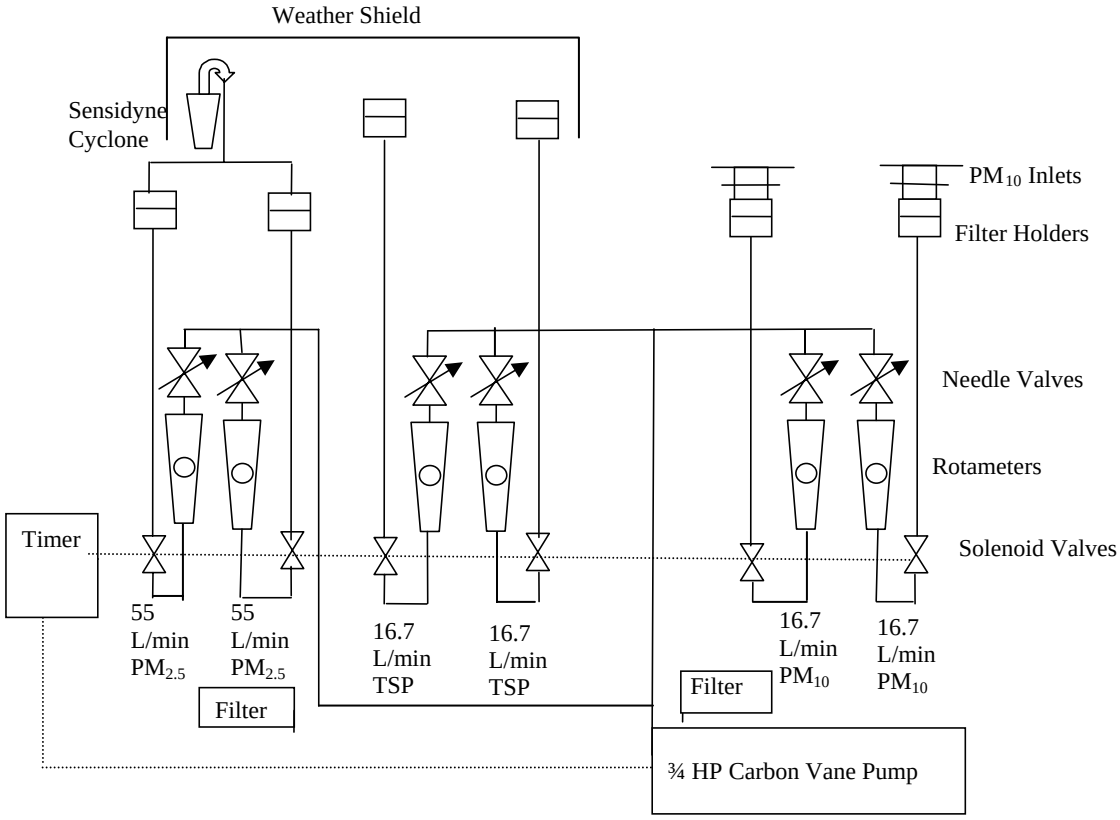
A custom sampler was fabricated to simultaneously collect PM samples on both Teflon membrane (Gelman Teflo) and quartz fiber (Pallflex QAT) filters. Substrates were collected for three size fractions: total suspended particulate (TSP), particulate less than 10 µm aerodynamic diameter (PM_{10}) and 2.5µm aerodynamic diameter ($PM_{2.5}$). The flow rate for the PM10 and TSP sample substrates was 18 L/min while those for the $PM_{2.5}$ were 55 L/min. Figure 2.1.1 shows a schematic diagram of the sampler.

A Sensidyne model 240 cyclone was used for the $PM_{2.5}$ size cut. This cyclone has been used in many specialized air quality studies and has a well-characterized cut-point at 110 L/min (the combined flow of both the Teflo and quartz substrates). Copper tubing (1/2 inch OD) was used to split the sample stream and transport the sample from the cyclone to diffuser tubes (1.75mm

ID, 30cm long) and then to two open-face filter holders, one for Teflo polyolefin-ringed filters and the other for quartz filters. The diffuser tubes were used to obtain an even deposit on the filter. PM_{10} samples were collected on both quartz and Teflo filters using separate Andersen model 245B size-selective inlet that have been EPA-certified as equivalent to the PM_{10} reference method. The inlets were modified to directly accept Savillex 47mm open face filter holders. Separate inlets were used for each type of filter. TSP samples were collected by open-face filters placed under a weather shield.

The Teflo filters were weighed to the nearest microgram before and after sampling at CE-CERT after equilibrating for at least 24 hours at 25ºC and 40%RH. The balance used for filter weighing was calibrated with a 200 mg class M NIST-traceable weight before and after each weighing session. The measurement variability was approximately 2 µg. The filters were then sent to the University of Nevada Desert Research Institute (DRI) laboratory for elemental analysis by x-ray fluorescence (xrf). The quartz samples were sent directly to the DRI laboratory packed in frozen "Blue Ice") for assay of elemental and organic carbon using the thermo optical reflectance method. Concentrations were then calculated based on sampling flow rates and times.
Rotameters were calibrated on-site with a mass flow meter and flows were set at 40 and 130 standard cubic feet per hour (SCFH) to achieve flow rates of 18 and 55 actual liters per minute based on the altitude.

Figure 2.1.1. Schematic of the primary sampler



- **Portable Samplers**

MiniVol samplers (AIRmetrics, Inc.) were used to collect samples on both Teflo and quartz substrates. Both TSP and PM_{10} inlets were used. These are battery-powered and use impactors to make the PM_{10} size-cut.

Sampling Sites

- **Prescribed Burns**

The sampling site was Washoe Meadows State Park near South Lake Tahoe, California. Pile burning was conducted on December 5th and 6th 2002 at two separate locations within the Park. These types of burns, performed by private contractors, are typical of those conducted in the Lake Tahoe area in the fall, prior to the first major snowstorm. Fires are generally ignited in the morning, burn vigorously for one or more hours, and smolder overnight. Sampling locations were set up to be downwind of the fire. Figure 2.1.2 shows the location of the park and where the sampling was conducted. Figure 2.1.7 shows the relationship of this site to the lake. Only the portable samplers were used for these collections.

- *First Burn (Started 12/5/02)*
  Figure 2.1.3 shows the sampling sites and neighboring burn piles used for the burn started on December 5, 2002. All samplers were positioned to be generally downwind of the burn piles. Each burn pile consisted primarily of sugar pine from salvage operations. Figure 2.1.4 is a photograph of a typical pile. Piles #1 and #2 of the first prescribed burn were ignited at 9 am and pile #3 was ignited at 10 am. Figure 2.1.5 is a photograph of the burning operation near a sampler. Note that although the sampler was placed downwind of the burning pile that smoke was not significantly impacting the sampler at the time the photograph was taken. This meandering of the plume is typical under the low wind conditions under which burns are performed and leads to sporadic smoke impact at the sampling point. PM_{10} Teflo and quartz samples at were collected at sites 1-3 until about 16:30 hours when the substrates were changed and allow to collect overnight while the fire smoldered. A single pair of samples was also collected the next day at site 4 while the fire continued to smolder.
- *Second Burn (Started 12/6/02*)
  Figure 2-6 shows the sampling sites and the neighboring burn piles used for the burn started on December 6, 2002. Each of the approximately 50 burn piles also consisted primarily of sugar pine. Pairs of PM_{10} samplers were used to collect PM_{10} Teflo and quartz samples at both sites 5B and 6. A single pair of TSP samples was collected at site 5A. The burn was started at approximately 9am and samples were collected until 3pm. It was necessary to move samplers at 5A and 5B to an alternative location for approximately 30 minutes due to excessive heat. A second set of samples was collected while the fire smoldered.

Figure 2.1.2. Location of Washoe Meadows State Park and the prescribed burn sampling site.

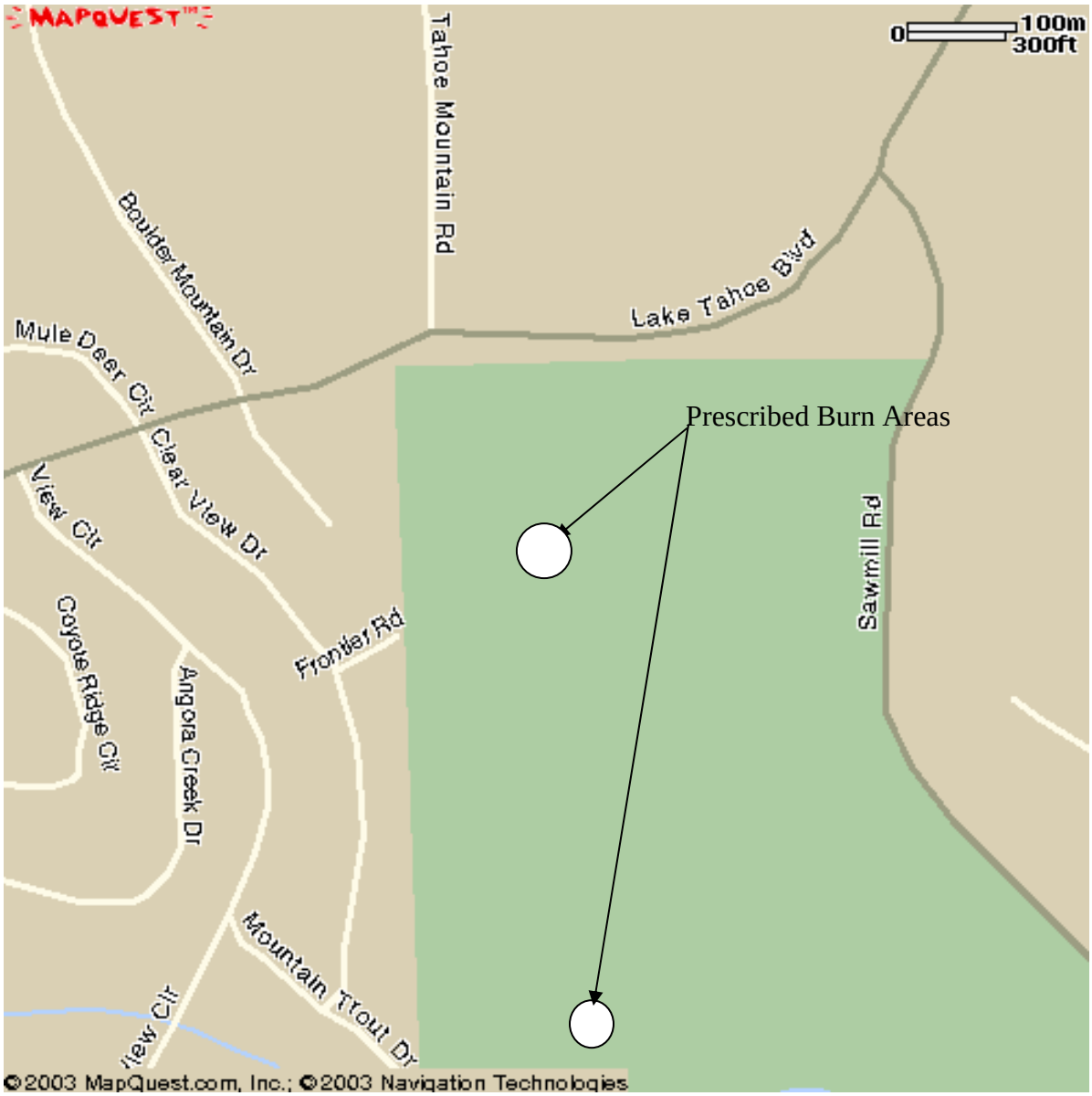


Figure 2.1.3 Layout of prescribed burn and sampling equipment at first burn location.

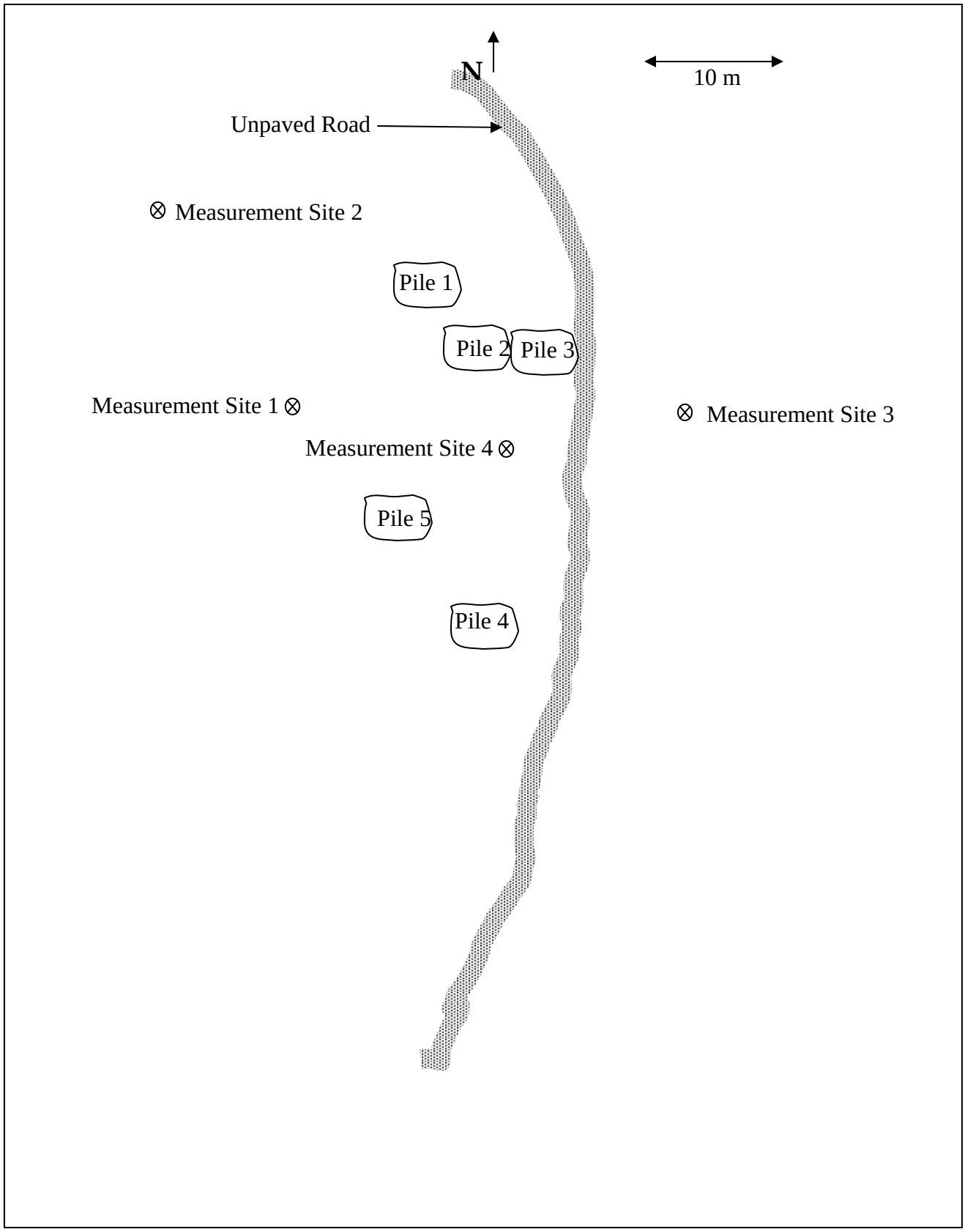
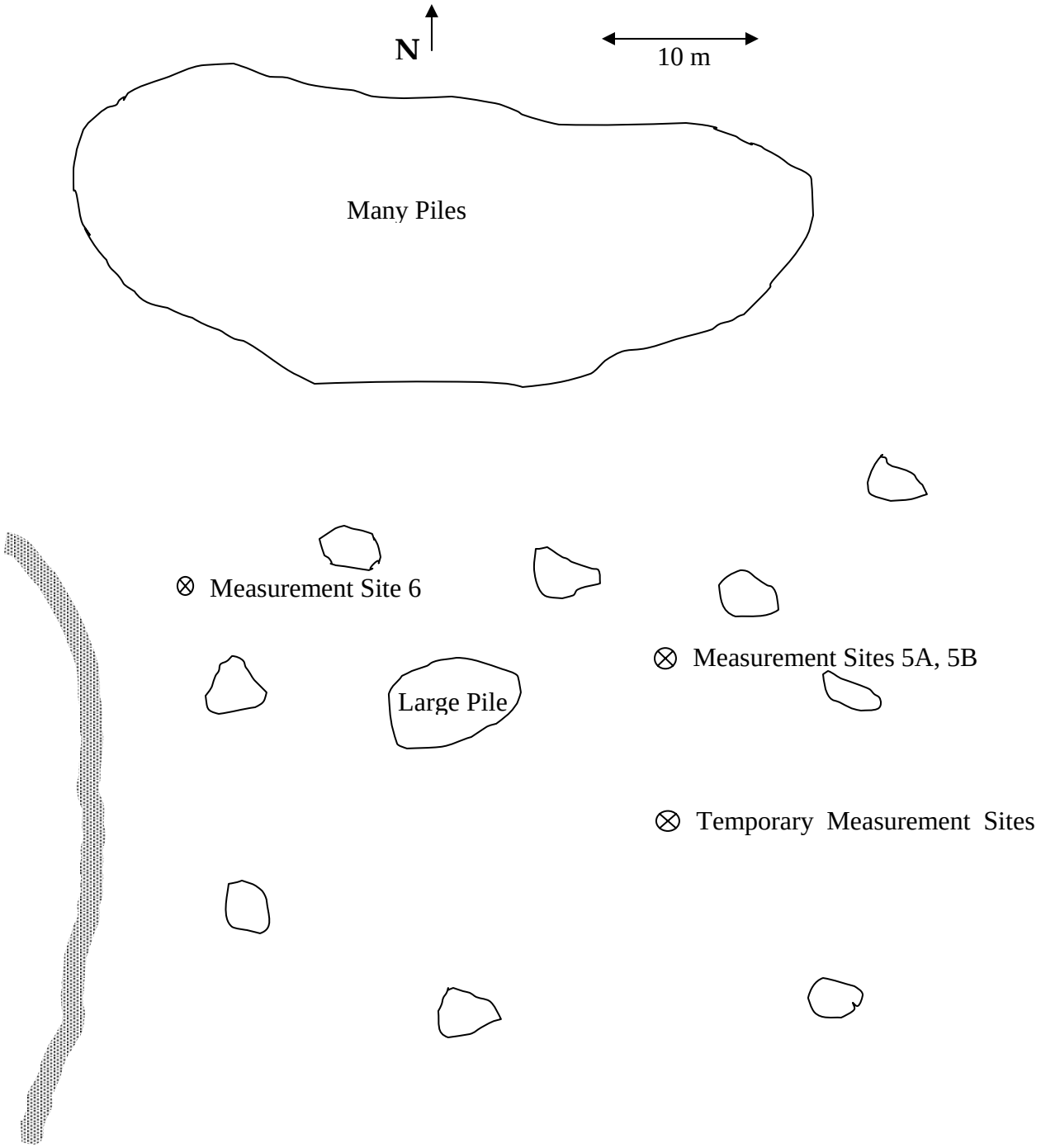


Figure 2.1.4 Photo of a typical pile at the first burn location

Figure 2-5. Photo of the prescribed burn at the first burn location

Figure 2.1.6. Layout of prescribed burn and sampling equipment at the second burn location.



- **Wood Burning Stove and Fireplace Characterization**

Five sites and a backup were selected and secured around the South Lake Tahoe area. Figure 2-7 is a map showing these locations. The site at South Upper Truckee was a back-up site that was not used. All sites were in residential areas typical of the City where wood burning is used for residential heating. Samplers were set up to collect ambient air near these residences where the air quality would be impacted by neighborhood wood burning. Only primary samplers were used and they were programmed to operate between 6pm and 11pm. Sample collection was started at the Clement Street site only on December 29th. Sampling at all sites was started on the 30th, but a severe snowstorm struck that night and it was not possible to retrieve substrates the next day. These substrates therefore collected an additional five hours the next evening. Figure 2-8 is a photograph of one of the sites after the snowstorm. Samples were also collected the evening of January 1st and 2nd. The sampler at Clement was found running at 12:36 pm the 2nd. The timer had evidently failed and started the sampler at 08:00 am, an additional 276 minutes of sample was therefore collected on the substrates that sampled the evening before.

Figure 2.1.7. Location of the sites for characterizing wood-burning fireplaces and stoves

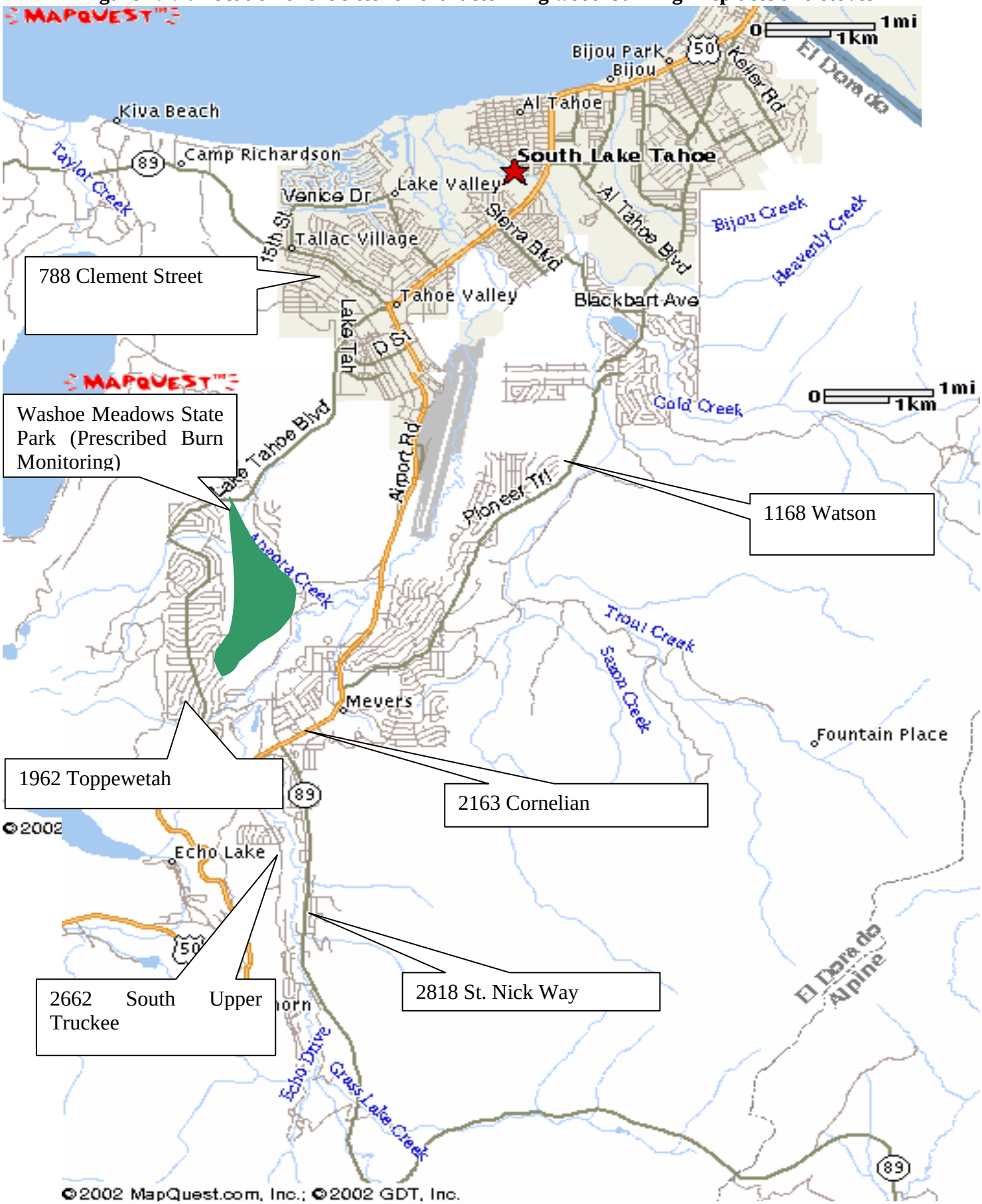


Figure 2.1.8 Sampling equipment on January 1, 2003 after a snowstorm.

2.2 Fuel Use Activity Determination

The original intention of the Fuel Use Survey portion of this project was to gather information on residential and commercial businesses to determine which types of heating are used (eg. propane, natural gas, or wood), how much fuel is used, and when. However, the initial scope of the survey was revised after conversations with the ARB staff and other experts, and after reviewing the existing fuel use data in the Lake Tahoe region. Meetings were held with the ARB, CE-CERT, University of California, Davis, TRPA, and the Desert Research Institute. It was determined that some useful fuel use information for the state of California existed; however, very little data had been collected specifically in the Lake Tahoe area. The consensus was to focus on wood burning (as opposed to an "all fuel") survey. Two important wood burning activities were targeted for this study:

- Residential (wintertime) wood burning
- Campfire (summertime) wood burning

Initially, it was thought that fuel surveys would be conducted via mailings, phone surveys, and face-to-face interviews if necessary. The goal was to obtain 500 surveys for each season sampled. However, both the scope of the survey and information on survey success rates warranted a change in the survey approach. The University of California, Berkley had done extensive fuel use survey and indicated that phone surveys and mailed questionnaires were not successful due to an extremely low rate of return (~1%). They indicated they had the best response conducting door-to-door surveying, however, it was extremely time consuming. Other suggestions for survey collection included visual observation of wood piles at the beginning and end of the season, establishing booths at public areas, such as supermarkets, and asking select groups, such as classrooms or churches, to pass out and collect the surveys. Important considerations in selecting a survey method included time and budget constraints, safety, rate of return, and unbiased and accurate data collection. It was concluded campfire surveys would be conducted on foot at selected campgrounds by TRPA staff. CE-CERT arranged the locations, times and proper permissions for conducting the surveys. Residential surveys were collected in public areas such as shopping centers during the winter of 2002.

With input from the research experts mentioned above and the ARB, both campfire and residential wood burning questionnaires were developed (Appendix A). Important variables in the questionnaires included wood type, amount and time of burning, purpose of burning, and wood burning equipment. A Spanish version of the residential survey was developed for limited English, Spanish speaking Tahoe residents. Part way into the residential survey, it was determined by a staff member at the TRPA that a much greater response rate was achieved by simplifying the survey even further.

Campfire surveys were conducted by TRPA staff in August and September 2002 at several campgrounds along the Lake (Table 2.2.1). In August, a total of 43 campsites in Zephyr Cove were surveyed. Because of scheduling issues, the next surveys were to be conducted in mid September. However, by the second week in September, temperatures at the camps were reaching below freezing and there were only a few campers left. The TRPA staff drove through the Campground at the Lake and determined there were only a couple of campers, and so there were no further campfire surveys conducted.

Table 2.2.1. Dates and Locations of Campfire Surveying

Location	Date	Time	Day of Week	# of Surveys Collected
Zephyr Cove	24-Aug	~4:30 - 6:30 PM	Saturday	36
Zephyr Cove	28-Aug	~4:30 - 6:30 PM	Wednesday	7
Campground by the Lake	14-Sep	~4:30 - 6:30 PM	Saturday	0
Campground by the Lake	18-Sep	~4:30 - 6:30 PM	Wednesday	0

During the winter, one student from CE-CERT and a TRPA staff member distributed residential wood burning surveys to Tahoe residents. Several locations such as supermarkets were identified before the field study and permission received to ask customers to fill out the surveys while waiting in line. However, poor weather conditions at the time of the survey are believed to be a limiting factor in the collection of many surveys. In addition, TRPA staff found that revising the survey to a simpler form provided a greater response rate (Appendix A). A total of 119 usable surveys were collected during the winter testing period (Table 2.2.2). At CE-CERT, the survey responses were entered into an Access database for evaluation. These results are presented in the next section.

Table 2.2.2. Locations of Residential Surveying

Location	# of Surveys Collected
Zypher Cove, NV	7
Incline Village, NV	3
Tahoe City, CA	15
South Lake Tahoe, CA	94

2.3 Vehicle Activity Determination

The accuracy of on-road vehicle emissions models is limited by the available data inputs. Because of the unique situation of Lake Tahoe, cross state traffic and fleet distribution may differ significantly from current emissions inputs. Additionally, the topography and climate of the Lake Tahoe area affects driving patterns and road grade which has not explicitly been accounted for in the current emissions inventory models. The purpose of this task is to compare existing information to new local information collected on the fleet makeup and driving patterns of vehicles in the Tahoe basin. The Vehicle Activity Determination broken up into three specific tasks:

- Analysis of Available Traffic Counts and Speeds
- Fleet Profiling (video data collection to determine fleet mix)
- Driving Pattern Characterization (instrumented vehicle data collection to determine vehicle speed profiles, etc)

Summary of Collected Information

The purpose of the first task was to collect existing traffic and fleet information in the Tahoe Basin. Several conference calls with staff at the ARB, CalTrans, and Nevada DOT were conducted and the appropriate contacts from each agency were identified. Scott Forsythe from CalTrans served as the sole contact for providing vehicular and roadway data for the California side of Lake Tahoe. Dave Manning of NDOT served as the contact for information in Nevada. Ben Hancock and the Mobile Source Control Division of the ARB helped identify existing information on the Tahoe area in terms of vehicle fleet mix, count and speed used in current mobile source emission inventory development.

California

A total of 9 trend stations in California were identified as providing useful information in the Tahoe Basin and a request was sent to Caltrans for hourly counts from these locations during the time of the study. However, count stations 154, 666, 667, and 656 were out of service awaiting signal project (PERMIT 0301-NSN1180) the entire duration of the project. Both identified stateline stations were not being collected by the state of California. California provided data on the remaining three locations for the testing times in December. For reasons unknown, there was no available data for the August testing dates. Information from the beginning of August was made available for analysis as an alternative. The trend stations provide hourly vehicle count on the selected roadways. Not recorded by Caltrans is information on vehicle type or speed.

ARB Mobile Source Division uses registration information (by zip code) and mileage accumulation (from smog check data) to determine the total VMT for the California portion of the Basin. While this approach is a very good estimate of the VMT in these zip codes, it possibly leaves important information gaps. EMFAC does account for some influx of "Mexican" vehicles in Southern California, however, the VMT and vehicle registration distribution does not account for out-of-state and out-of county vehicles. These “visitors” make up a little over 5% of the vehicle fleet in Placer and El Dorado Counties.

EMFAC2000 also uses outdated information (from before EMFAC7f) for the typical driving pattern (average speed). Additionally, although some information was collected in El Dorado and Placer counties, none was inside the Basin. The data collected in this study will be able to supplement existing data on the driving patterns for the Tahoe Basin.

Nevada

Over forty hourly count locations and nine vehicle type count locations were identified to exist in the Nevada portion of the Tahoe Basin. Most of these counters provided hourly count data for a single week during 2001, and two counters at the state boundary line provided hourly counts for the entire year. This data also identifies the fraction of heavy duty traffic in many locations. Two of the three locations tested in this study could be matched to an operating count location for which data were provided. NDOT also provided the VMT by link within the boundaries of the Basin. Comparisons between the date collected in this study and the NDOT data will be made in the Results section.

Table 2.3.1. summarizes the existing data identified to be useful in this study. Most of the California data are developed from areas outside of the Basin and are quite dated. The remainder of the vehicle activity study is dedicated to the collection of Tahoe-specific information to supplement this existing data. This information can likely improve current estimates of vehicle emissions in the Basin.

Table 2.3.1. Summary of Traffic and Fleet Information Available

	California	Nevada	To Be Collected in the Current Study
Overall VMT	Best Estimate	Best Estimate	No
Driving Patterns	Speed data is from other areas in county	Reasonable estimate from speed data on roadways in the Basin	Speed, grade and VSP data to be collected
Seasonal Variation of Driving Patterns	No	Yes	Yes
Fleet Distribution (Vehicle Type)	Reasonable estimate from DMV database of registered vehicles within each zip code	Reasonable estimate from DMV database of registered vehicles within each zip code	Yes
Fleet Distribution (out-of-state)	County information exists from assumptions, no measurements specifically from the Basin	No	Yes
Seasonal Variation in Fleet Distribution	No	No	Yes

Collection of New Local Data

The field program was designed to gather information that will improve existing emissions estimates from on-road vehicles in the Lake Tahoe basin. Specifically, information on the fleet makeup, vehicle density, and vehicular driving patterns were determined to be the focus of the data collection. This small scoping study was not designed to collect a complete temporal and spatial vehicle emissions profile for modeling purposes. Instead, this information was intended to provide guidance on whether the existing data accurately characterize the current fleet in Tahoe.

Based on the indicated budget and the interests of the ARB, a total of twelve days of video collection and driving trace data were planned. This includes two separate trips to Tahoe, one in the summer and one in the winter season at three pre-determined locations (one in Nevada, two in California). Figure 2.3.1 shows the location of the vehicle activity tests. Each trip was scheduled to collect a total of six days of information, including weekday and weekend day for each location (Tables 2.3.2-2.3.3). Unfortunately, due to poor weather conditions, only a subset of the winter data could be collected (Table 2.3.4). The processed data are shown in Appendix B and C. All raw data will be provided to the ARB.

Figure 2.3.1. Location of Field Testing

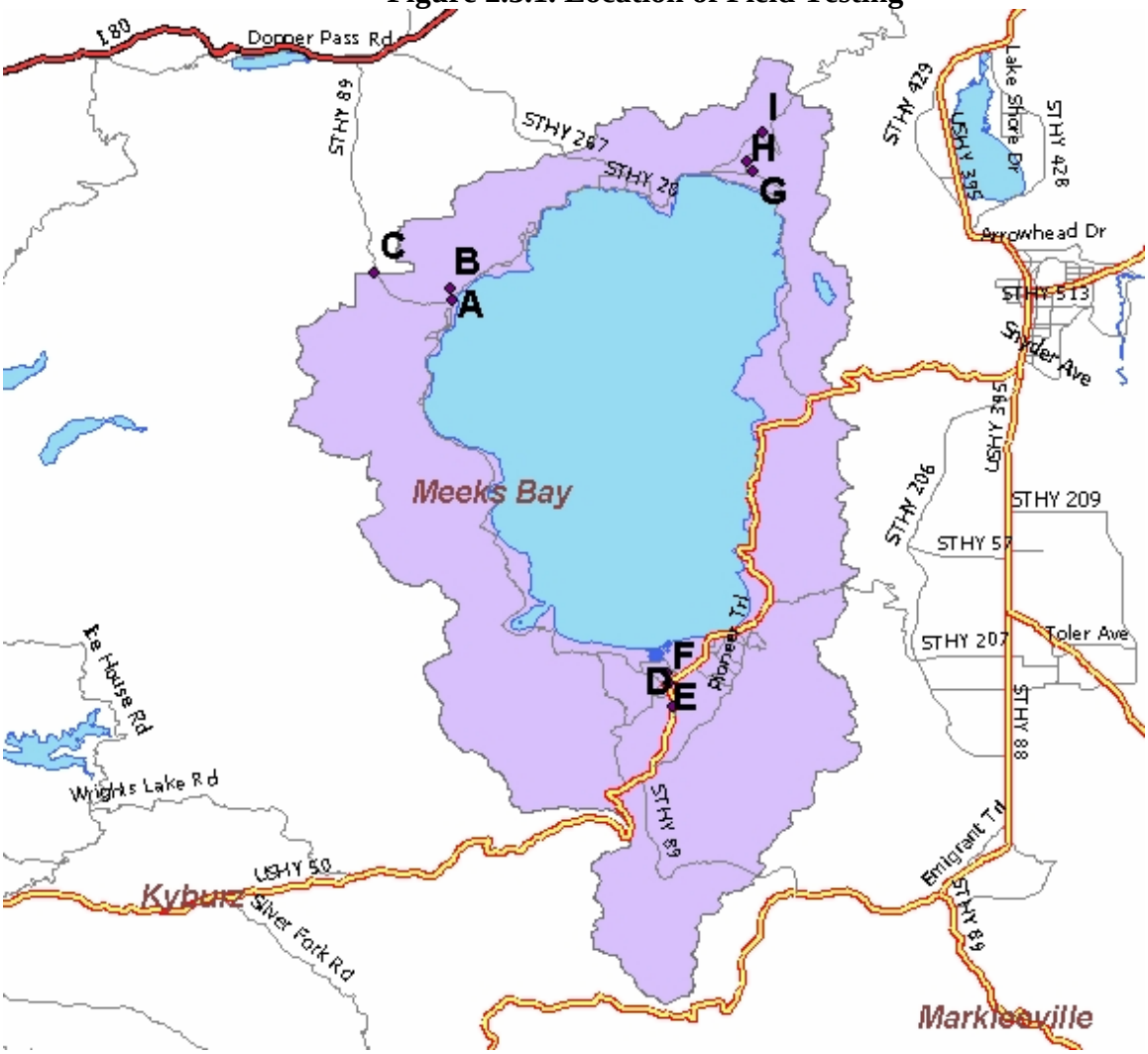


Table 2.3.2. Scheduled Dates, Times, and Locations of Summer Field Testing

Test Day	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
	15-Aug	16-Aug	17-Aug	18-Aug	19-Aug	20-Aug
	Thursday	Friday	Saturday	Sunday	Monday	Tuesday
Area	South Shore (Tahoe Valley)	North Shore (Tahoe City)	North Shore (Tahoe City)	North Shore (Incline Village)	South Shore (Tahoe Valley)	North Shore (Incline Village)
State	CA	CA	CA	NV	CA	NV
8:00 AM	E*	B	C	I	D	H
9:00 AM	F	A	B	H	E	G
10:00 AM	D	C	A	G	F	I
11:00 AM						
12:00 PM	F	A	B	H	E	G
1:00 PM	D	C	C	I	D	I
2:00 PM			A	G	F	
3:00 PM	E	B				H
4:00 PM	F	A	C	I	D	G
5:00 PM	D	C	A	G	F	I

*For the locations of the Lettered Sites, refer to Figure 2.3.1

Table 2.3.3. Scheduled Dates, Times, and Locations of Winter Field Testing

Test Day	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
	16-Dec	17-Dec	18-Dec	19-Dec	20-Dec	21-Dec
	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Area	South Shore (Tahoe Valley)	North Shore (Tahoe City)	North Shore (Tahoe City)	North Shore (Incline Village)	South Shore (Tahoe Valley)	North Shore (Incline Village)
State	CA	CA	CA	NV	CA	NV
8:00 AM	E*	*B*	*C*	*I*	*D*	*H*
9:00 AM	*F***	*A*	*B*	H	*E*	*G*
10:00 AM	*D*	*C*	A	G	F	*I*
11:00 AM						
12:00 PM	*F*	*A*	B	H	E	*G*
1:00 PM	*D*	*C*	C	I	D	*I*
2:00 PM			A	*G*	F	
3:00 PM	*E*	*B*				*H*
4:00 PM	*F*	*A*	C	*I*	D	*G*
5:00 PM	*D*	*C*	*A*	*G*	F	*I*

*For the locations of the Lettered Sites, refer to Figure 2.3.1
** Letters in italics were not completed due to poor weather conditions

Table 2.3.4. Weather Conditions and Vehicle Activity Collected During Winter Field Testing

Date	Location	Traffic Description	Data Collected
16-Dec	South Shore	Official Snow Day	No
17-Dec	Tahoe City	Official Snow Day	No
18-Dec	Tahoe City	Snowy	Yes
19-Dec	Incline Village	High Wind	Yes
20-Dec	South Shore	Snowy	Yes

21-Dec	Incline Village	Official Snow Day	No

Three roadway types were selected for analysis at each location. Two arterial roadways and a residential roadway were selected for each area. Table 2.3.5. contains details on each roadway. Figures 2.3.2, 2.3.3, and 2.3.4 show the driving trace for each roadway.

Table 2.3.5. Description of Testing Locations

Location	Tahoe City			Tahoe Valley			Incline Village		
Road	28	Res	431	89	Res	50	28	Res	431
Location on Map	A	B	C	D	E	F	G	H	I
Speed Limit	50	25	35	50	25	35	35	25	45
No. of Lanes (BD)	2	2	2	2	2	4	2	2	2
Road Type	Major Arterial	Residential	Arterial	Arterial	Residential	Major Arterial	Arterial	Residential	Major Arterial

Figure 2.3.2. Driving Routes in Tahoe City

Figure 2.3.3. Driving Routes in Tahoe Valley

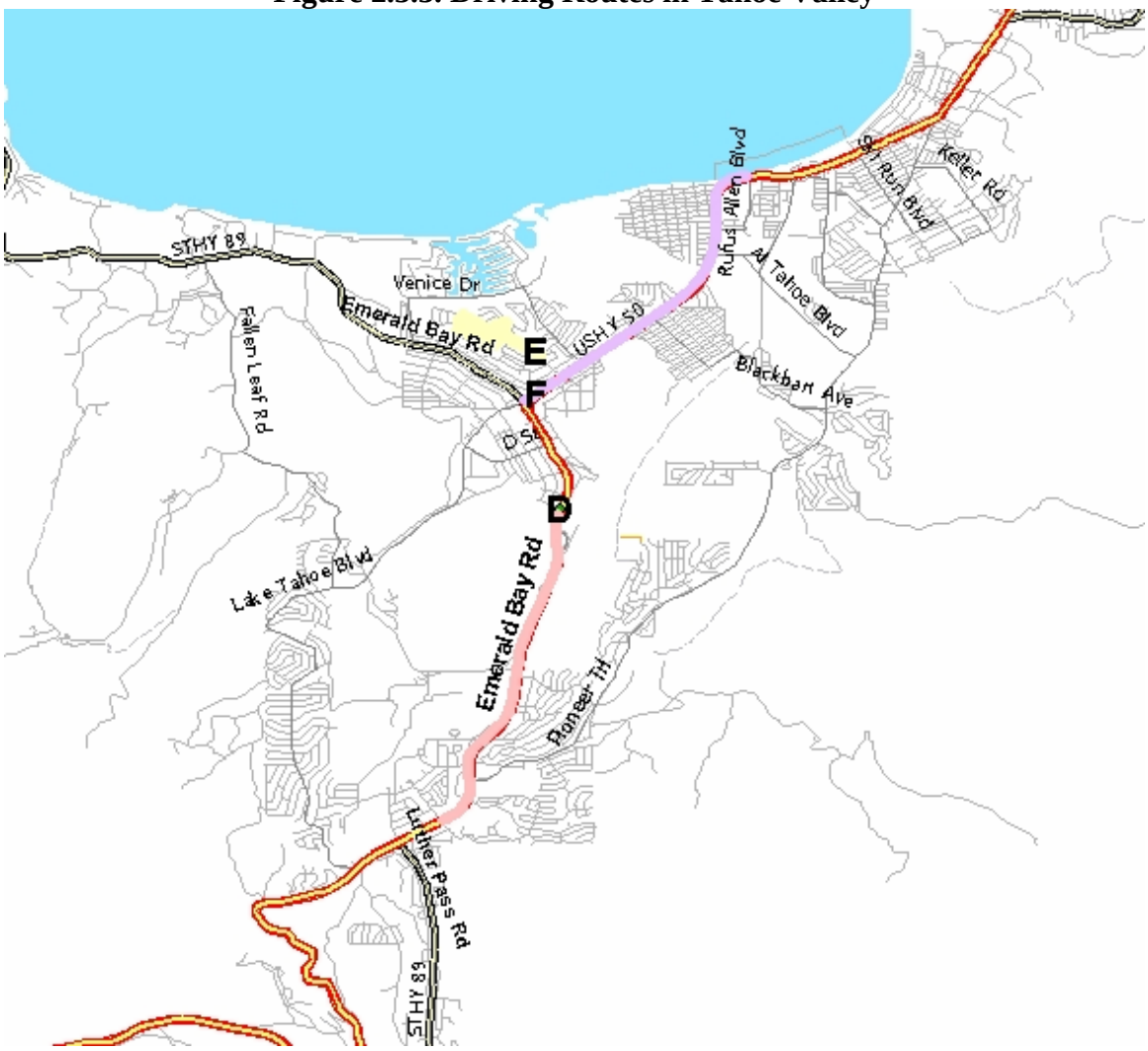
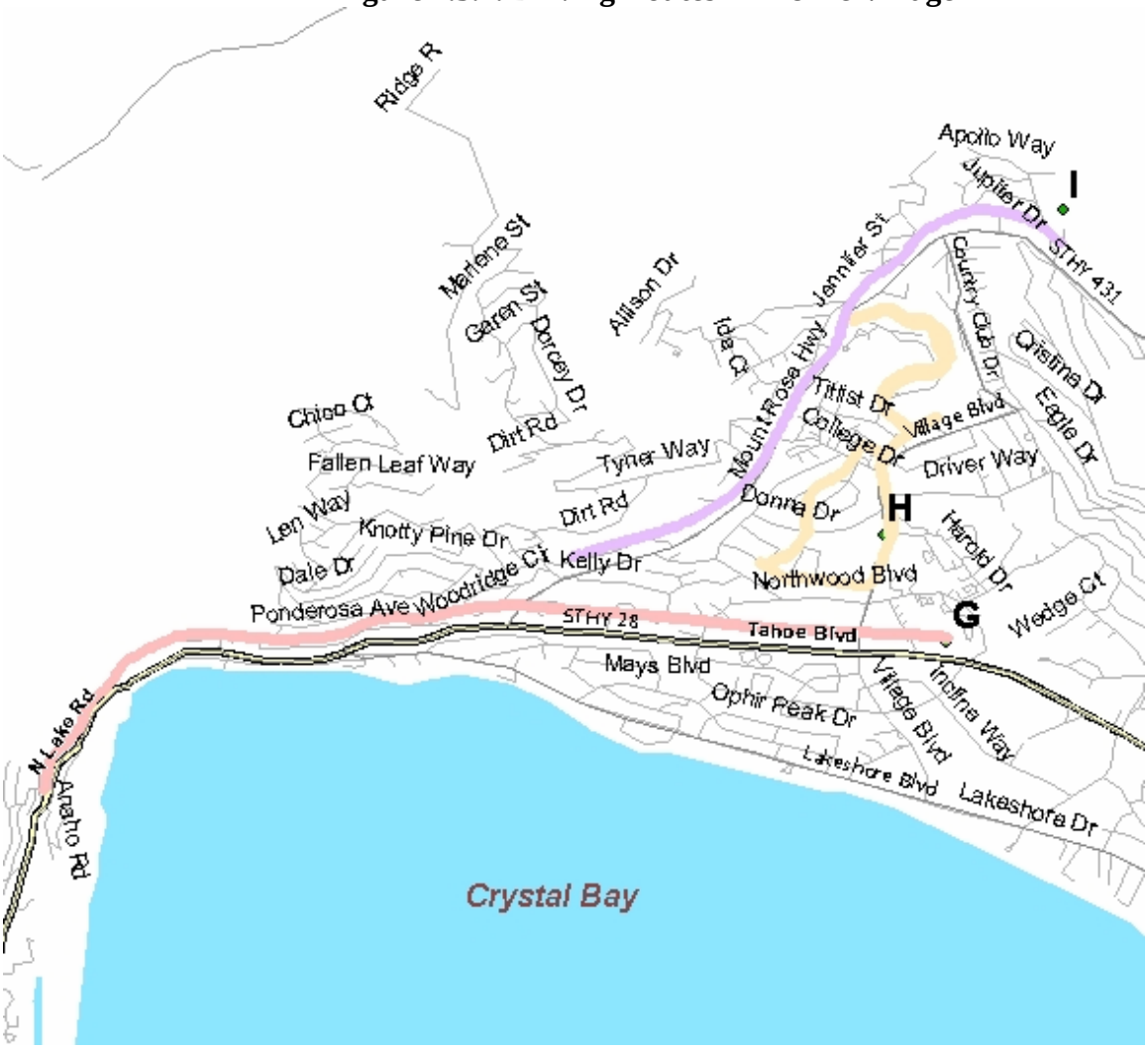


Figure 2.3.4. Driving Routes in Incline Village



As part of this testing, on-site digital video cameras were used to capture the fleet profile (Figure 2.3.5). The videos were reviewed using a software program and manual inspection to estimate the flow, speed, and size distribution (including fraction of heavy-duty vehicles) of the fleet. The percentage of out-of state license plates were also identified using the collected video images. The video data provides an additional data source to compare with existing information. The types of data collected and extracted from these tapes are listed in Table 2.3.6.

Figure 2.3.5. Cameras collecting fleet information

Table 2.3.6. Information obtained from fleet observation

Data	Description
Vehicle Type Distribution	Distribution of vehicles by class and weight category for each location and time.
State of Registration	Percentage of California-registered vehicles by location
Vehicle Count	Overall flow rate of vehicles by time and roadway

CE-CERT collected information on the local driving patterns, including speed and grade estimates, using a passenger vehicle and global positioning software (Figure 2.3.6). A representative sample of road types, including residential, arterial, and major arterials, were driven with the flow of traffic to estimate the driving behavior of the local fleet. This will supplement the "instantaneous" speed measurements recorded by the DOTs and video data collected in this study by providing the typical variations in velocity, accelerations, and road grade, which are important in properly estimating vehicle emissions. Table 2.3.7 lists the exact data collected in the driving pattern study.

Figure 2.3.3. Laptop recording driving pattern information in chase vehicle

Table 2.3.7. Information obtained from Driving Pattern Study

Data	Purpose
Velocity Distribution	Percentage of driving occurring in each velocity bin, used in the EMFAC2002 model
VSP Distribution	Percentage of driving occurring in each vehicle specific power (VSP) bin to be used in future models
Road Grade	Can be used in VSP distribution to account for emission effects from changes in engine load from variations in road grade.

Both the fleet data and driving patterns were successfully collected during this reporting period. All data has been transferred from the video cameras and the GPS log files into the computer system at CE-CERT. Average velocity by hour and road type were calculated, along with the VSP, engine stress, acceleration and other useful parameters for characterizing driving behavior with potential effects on emissions. The resulting driving traces have been processed to provide speed distributions and also have been aggregated into several representative driving cycles for the area. These results are presented in the next section.

3 Analysis and Results

3.1 Characterization Particulate Emissions from Prescribed Burns and Wood Burning Stoves and Fireplaces

Prescribed Burns

Table 3.1.1 summarizes the mass, organic carbon (OC), and elemental (EC) concentrations measured in µg/m^3. None have been corrected for the small and variable amount of filter blanks: (2 µg for mass, 16µg for OC and 0.5 µg for EC). All of the PM concentrations were much higher than the several µg/m^3 expected for the background. The filters also smelled of smoke. Appendix A contains the full data set. Note that carbon accounts for most of the weighed particulate mass, and in fact may be higher than the weighed mass due to collection of gases by the quartz filter.

Table 3.1.1 Summary of Mass and Carbon Concentrations Measured during Prescribed Burns

Site	PM	Date On	Time On	Date Off	Time Off	Mass	OC	EC
						µg/m^3	µg/m^3	µg/m^3
1	10	12/5/02	9:31	12/5/02	16:27	159	141	12
2	10	12/5/02	9:38	12/5/02	16:17	63	60	5
3	10	12/5/02	9:51	12/5/02	16:32	46	52	3
1	10	12/5/02	16:29	12/6/02	8:51	80	57	3
2	10	12/5/02	16:19	12/6/02	8:42	66	57	3
3	10	12/5/02	16:33	12/6/03	8:23	147	110	6
4	10	12/6/02	9:15	12/6/02	15:05	72	220	9
5A	TSP	12/6/02	10:44	12/6/02	13:32	879	394	21
5B	10	12/6/02	10:55	12/6/02	15:25	333	330	22
6	10	12/6/02	11:21	12/6/02	15:35	228	235	15
5A	TSP	12/6/02	15:35	12/7/02	8:40	188	176	8
5B	10	12/6/02	15:28	12/7/02	8:26	193	163	6
6	10	12/6/02	15:41	12/7/02	8:16	193	152	7

Wood Burning Stoves and Fireplaces

Table 3.1.2 summarizes the mass, organic carbon, and elemental concentrations measured. These were also not blank corrected. Most of the PM concentrations were significantly higher that the several µg/m^3 expected for the background, but much lower than the samples collected during prescribed burns. One of the samples visually looked lighter than that determined by the mass weighing and two looked heavier. These samples are therefore suspect. Many of the filters also smelled of smoke. Appendix B contains the full data set.

Table 3.1.2 Summary of Mass and Carbon Concentrations Measured While Characterizing Wood Burning Stoves and Fireplaces.

ID	Site	PM	Date On	Time On	Date Off	Time Off	Mass	OC	EC	Comments
							$\mu g/m^3$	$\mu g/m^3$	$\mu g/m^3$	
	Wood Burning Stove and Fireplace Characterization									
APL1628	1	TSP	12/29/02	18:00	12/29/02	23:00	24	19.5	2.0	
APL1623	1	PM10	12/29/02	18:00	12/29/02	23:00	20	17.2	3.6	
APL1625	1	PM2.5	12/29/02	18:00	12/29/02	23:00	17	13.3	2.1	
APL1633	1	TSP	12/30/02	18:00	12/31/02	*	18	16.1	3.7	
APL1612	1	PM10	12/30/02	18:00	12/31/02	*	24	22.2	5.6	
APL1624	1	PM2.5	12/30/02	18:00	12/31/02	*	24	14.8	3.7	
APL1629	2	TSP	12/30/02	18:00	12/31/02	*	7	5.5	1.3	
APL1615	2	PM10	12/30/02	18:00	12/31/02	*	8	6.5	1.7	
APL1611	2	PM2.5	12/30/02	18:00	12/31/02	*	8	4.2	1.1	
APL1630	3	TSP	12/30/02	18:00	12/31/02	*	27	15.7	5.1	
APL1620	3	PM10	12/30/02	18:00	12/31/02	*	24	17.9	6.5	
APL1613	3	PM2.5	12/30/02	18:00	12/31/02	*	24	13.2	3.9	
APL1622	4	TSP	12/30/02	18:00	12/31/02	*	18	11.2	5.0	
APL1616	4	PM10	12/30/02	18:00	12/31/02	*	18	16.0	5.2	
APL1631	4	PM2.5	12/30/02	18:00	12/31/02	*	17	8.1	4.0	
APL1632	5	TSP	12/30/02	18:00	12/31/02	*	17	10.5	2.2	
APL1619	5	PM10	12/30/02	18:00	12/31/02	*	15	11.8	3.2	
APL1642	5	PM2.5	12/30/02	18:00	12/31/02	*	18	7.4	1.8	
APL1636	1	TSP	1/1/03	18:00	1/1/03	**	23	12.1	4.4	
APL1635	1	PM10	1/1/03	18:00	1/1/03	**	26	19.2	6.4	
APL1634	1	PM2.5	1/1/03	18:00	1/1/03	**	21	11.4	4.0	
APL1621	2	TSP	1/1/03	18:00	1/1/03	23:00	26	12.3	3.1	
APL1618	2	PM10	1/1/03	18:00	1/1/03	23:00	14	15.4	3.3	
APL1640	2	PM2.5	1/1/03	18:00	1/1/03	23:00	18	8.8	2.4	
APL1606	3	TSP	1/1/03	18:00	1/1/03	23:00	59	28.2	12.5	
APL1592	3	PM10	1/1/03	18:00	1/1/03	23:00	54	37.5	17.2	
APL1577	3	PM2.5	1/1/03	18:00	1/1/03	23:00	5	29.9	10.3	Deposit looks lighter
APL1614	4	TSP	1/1/03	18:00	1/1/03	23:00	50	30.9	9.3	
APL1641	4	PM10	1/1/03	18:00	1/1/03	23:00	57	42.5	13.8	
APL1617	4	PM2.5	1/1/03	18:00	1/1/03	23:00	51	28.0	8.1	
APL1638	5	TSP	1/1/03	18:00	1/1/03	23:00	40	25.2	7.5	
APL1639	5	PM10	1/1/03	18:00	1/1/03	23:00	41	24.6	9.0	
APL1637	5	PM2.5	1/1/03	18:00	1/1/03	23:00	39	21.7	6.0	
APL1591	1	TSP	1/2/03	18:00	1/2/03	23:00	15	15.0	1.6	
APL1567	1	PM10	1/2/03	18:00	1/2/03	23:00	12	13.2	2.8	
APL1573	1	PM2.5	1/2/03	18:00	1/2/03	23:00	11	8.4	2.1	
APL1593	2	TSP	1/2/03	18:00	1/2/03	23:00	3	2.3	0.3	Deposit looks heavier
APL1568	2	PM10	1/2/03	18:00	1/2/03	23:00	4	4.2	0.3	
APL1598	2	PM2.5	1/2/03	18:00	1/2/03	23:00	3	2.3	0.7	
APL1569	3	TSP	1/2/03	18:00	1/2/03	23:00	3	3.1	0.4	
APL1604	3	PM10	1/2/03	18:00	1/2/03	23:00	6	2.9	0.2	
APL1561	3	PM2.5	1/2/03	18:00	1/2/03	23:00	1	1.6	0.4	
APL1564	4	TSP	1/2/03	18:00	1/2/03	23:00	31	7.5	2.1	
APL1603	4	PM10	1/2/03	18:00	1/2/03	23:00	37	23.1	8.3	
APL1575	4	PM2.5	1/2/03	18:00	1/2/03	23:00	54	18.0	6.5	
APL1574	5	TSP	1/2/03	18:00	1/2/03	23:00	108	27.6	9.3	Deposit looks heavier
APL1572	5	PM10	1/2/03	18:00	1/2/03	23:00	40	27.0	12.0	
APL1571	5	PM2.5	1/2/03	18:00	1/2/03	23:00	35	17.9	8.1	
	* Ran two consecutive nights									
	** Ran 276 minutes the next morning starting at 08:00									

3.2. Fuel Use Activity Determination

In conjunction with the local agencies, CE-CERT conducted a Residential Wood burning and Campfire Fuel Use Survey to estimate the type, quantity and timing of wood fuel used for recreational, heating, and cooking purposes.

Campfires

Of the surveys collected, it appears that most campers do make wood campfires every night they camp (94% of campers made fires in the areas surveyed). Details of the surveyed campers are shown in Table 3.2.1. The campers surveyed included both motorhome and tent campers, and sites with and without firepits.

Table 3.2.1 Statistics of Surveyed Campers and Campsites

Camper Details		Campsite Details	
Motorhome/Camper	65%	Firepit	72%
Tent	35%	No Firepit	28%

The amount of wood burned and type was estimated from the survey results (Table 3.2.2 and 3.2.3). Most campers made a campfire only in the evening hours an average of 2 hours, burning a total of 4 logs. Roughly 25% of campers also made a morning fire. A single camper made a fire for every meal. Other details on the wood burning activities of the campers survey can be found in Table 3.2.2. A combination of hard and soft wood, purchased and privately cut wood was being burned. Most (97%) of the wood used had been dried.

Table 3.2.2 Summary of Campfires Activity in the Tahoe Basin

Timing of Campfires		Quantity of Wood Burned		Duration of Campfires	
Evening Only	72%	Lower Quartile	1.3 logs/day	Lower Quartile	1.3 hours/day
Morning & Evening	24%	Average	4.0 logs/day	Average	2.0 hours/day
Morning, Midday, & Evening	4%	Upper Quartile	5 hours/day	Upper Quartile	2.8 hours/day

Table 3.2.3 Type of Firewood Burned in Campsites in the Tahoe Basin

Wood State		Wood Type		Wood Origin	
Dry Wood	97%	Hard Wood	44%	Cut their Own	39%
Green Wood	3%	Soft Wood	56%	Purchased	61%

TRPA estimates that on average, 1,667 campsite sites are occupied each day during the summer. This is roughly an 82% occupancy rate. Assuming that 94% of campers made fires an average of 2 hours per day, that would equal a total of 1600 campfires per summer day in the Tahoe Basin, and a total of 6400 logs/summer day, or roughly100 cords per day (assuming 64 logs/cord) (equations 3.2.1, 3.2.2).

$$1667\frac{campers}{summerday} * 0.94 * 2\frac{hours}{day} * 2.05\frac{\log s}{hour} = 6424\frac{\log s}{summerday} \qquad \text{Eq. 3.2.1}$$

$$6424\frac{\log s}{summerday} \Big/ 64\frac{\log s}{cord} = \frac{100 cords}{summerday} \qquad \text{Eq. 3.2.2}$$

Using an average hardwood density of 700 kg/m3 and a softwood density of 530 kg/m3 and a particulate emission factor of 12 g/kg, the emissions from campsite activity can be calculated as 1.46 tons PM_{10} /summer day (Houck, 2001) (Eq. 3.2.3, 3.2.4). Of course, these emission estimates will change with any variations in assumptions regarding activity and emission rates.

$$Average_Density = \left(700\frac{kg}{m^3} * 0.44 + 530\frac{kg}{m^3} * 0.56\right) * 0.0283\frac{m^3}{ft^3} = 17.13\frac{kg}{ft^e} \qquad \text{Eq. 3.2.3}$$

$$6424\frac{\log s}{summer} * 1\frac{ft^3}{\log} * 17.13\frac{kg}{ft^e} * 12\frac{gPM}{kg} * 907184.7\frac{g}{ton} = 1.46\frac{tonsPM}{summer} \qquad \text{Eq. 3.2.4}$$

Residential Wood burning

The statistics of the residents surveyed are listed in Table 3.2.4. The results of the residential wood burning survey are shown in Table 3.2.5. Virtually all of the wood burned was dried and natural (as opposed to artificial logs). The vast majority of those residents who use wood burning as their primary means of heating do so with a wood burning stove. The census data provided for individual counties indicates that single homes in counties around the basin range from 75-89 percent. This may indicate that there was a slight bias toward homeowners in this survey. However, because the census data provided was on a countywide basis, this cannot be confirmed.

Table 3.2.4 Information of Residents Surveyed in the Tahoe Basin

Resident Status		Type of Home		Primary Method of Heating		Percentage of Time Wood burning is used for Aesthetic Purposes	
Full Time Resident	92%	Single Residence Home	90%	Gas	74%	0% of the time	71%
Visitor	7%	Apartment	7%	Electricity	6%	50% of the time	25%
		Other	3%	Woodburning	16%	100% of the time	4%
				Other	4%		

Table 3.2.5 Details of Residential Woodburning in the Tahoe Basin

Quantity of Wood Burning Devices		Type of wood burning Device		Time of Day Used		Type of Wood Burned	
None	15%	Fireplace without insert	25%	Morning Or Midday	0%	Hard Wood	25%
1	76%	Fireplace with insert	10%	Evening	74%	Soft Wood	50%
2	8%	Wood burning Stove	59%	All Night or Day	15%	Both	25%
3 or more	1%	Pellet Stove	6%	24 hours	10%		

The quantity of wood burned by residents is shown in Table 3.2.6. Residents who use wood as their primary means of heating use 40% more wood per day and burn for over 12 hours per day, compared with only 6 hours per day for other residents. It is also noted that there are, on average, 1.7 cords of wood stored at the resident's homes at the beginning of the season. Overall, when residents with and without wood burning devices are combined, the average Tahoe resident burns 7.4 logs/ per day during the winter season for 6 hours each day. This is assuming that 15% of Tahoe residents do not use wood at all and 90% of the residents reside in single family dwellings.

Table 3.2.6 Average Residential wood burning Use in the Tahoe Basin

Type of Resident	Average Wood Use during Winter (Hours/day)	Average Wood Use during Winter (Logs/day)	% of Yearly WoodBurning that occurs in the Winter Season	% of Weekly Wood burning that occurs during the Weekend
Residents who use Wood As Primary Means of Heating	12.4	11.5	90%	40%
Residents who do not use Wood as Primary means of heating	5.9	8.2	89%	67%
Residents who use Wood (Eq. 2.3.5, Eq. 2.3.6)	7.0	8.7	89%	63%
Average of All Residence and Visitors (Eq.2.3.7, Eq. 2.3.8)	5.9	7.4		

$$12.4\frac{hours}{day} * 0.16 + 5.9\frac{hours}{day} * 0.84 = 7.0\frac{hours}{day} \qquad \text{Eq. 3.2.5}$$

$$11.5\frac{\log s}{day} * 0.16 + 8.2\frac{\log s}{day} * 0.84 = 8.7\frac{\log s}{day} \qquad \text{Eq. 3.2.6}$$

$$7.0\frac{hours}{day} * .85 = 5.9\frac{hours}{day} \qquad \text{Eq. 3.2.7}$$

$$8.7\frac{\log s}{day} * .85 = 7.4\frac{\log s}{day} \qquad \text{Eq. 3.2.8}$$

TRPA estimated there are 21,000 occupied housing units in the Basin. Using this number of housing units, and the study average of 7.4 logs/day, the Tahoe Basin would likely burn a total of 155,400 logs/winter day, or approximately 2428 cords (assuming 64 logs/cord) (Eq 2.3.9).

$$21{,}000 residents * 7.4\frac{\log s}{day} = 155{,}400\frac{\log s}{winterday} \qquad \text{Eq. 3.2.9}$$

Using an average hardwood density of 700 kg/m3 and a softwood density of 530 kg/m3 and a particulate emission factor of 12 g/kg, the emissions from campsite activity are estimated at 34 tons PM_{10} /winter day in the Tahoe Basin. These emission estimates are subject to change due to variations in the assumptions regarding activity and emission rates.

$$Average_Density = \left(700\frac{kg}{m^3} * 0.33 + 530\frac{kg}{m^3} * 0.66\right) * 0.0283\frac{m^3}{ft^3} = 16.45\frac{kg}{ft^e} \qquad \text{Eq. 3.2.10}$$

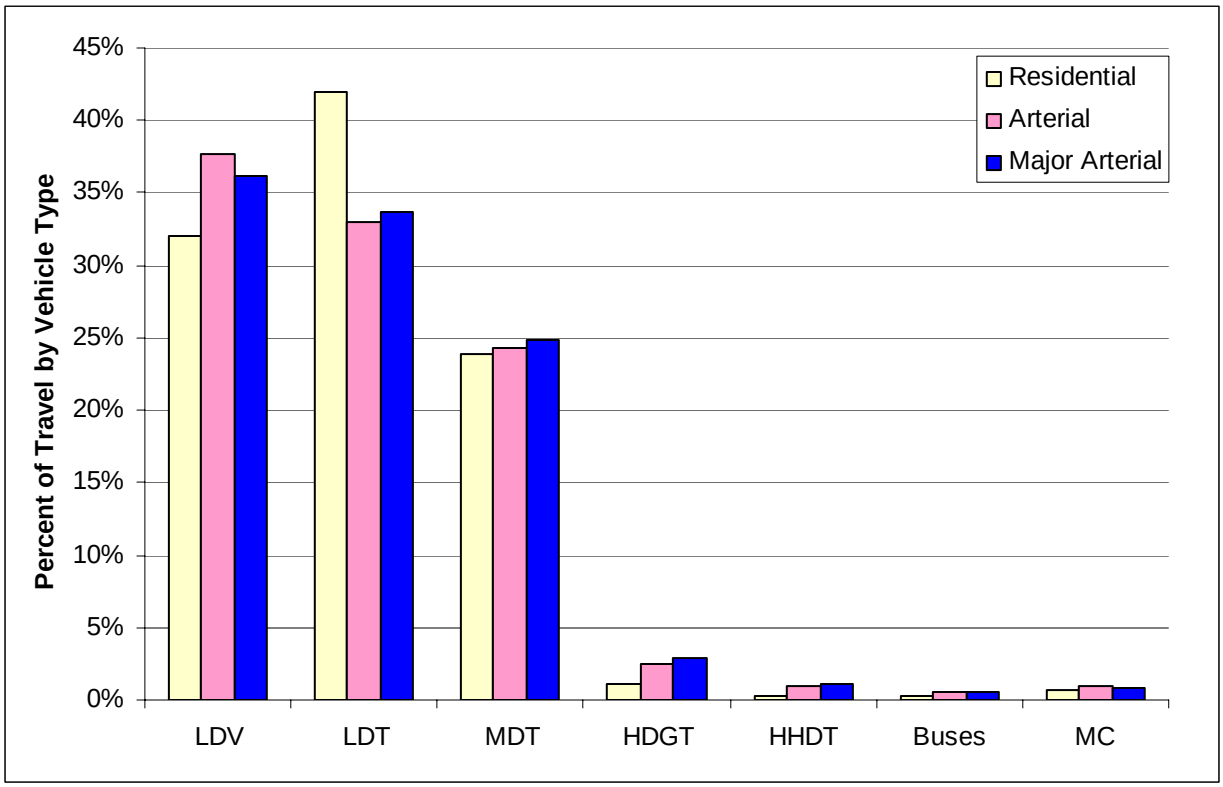
$$155{,}400\frac{\log s}{winterday} * 1\frac{ft^3}{\log} * 16.45\frac{kg}{ft^e} * 12\frac{gPM}{kg} * 907184.7\frac{g}{ton} = 33.8\frac{tonsPM}{winterday} \qquad \text{Eq. 3.2.11}$$

3.3. Vehicle Activity Determination

Fleet Distribution and Activity

The results of the observed travel by roadway type from this study for the Summer of 2002 is shown in Figure 3.3.1. Overall, the distribution of vehicle types is fairly similar for different roadway types. Residential roads show the most difference, with more light duty trucks than passenger cars and very few heavy duty vehicles. The majority of vehicles were made up of light duty trucks for residential roadways (42%), and light duty passenger vehicles for arterials (37%). This may indicate that residents tend to drive more light duty trucks than passenger vehicles compared with the rest of California (and other tourists). Typically, about 55% of California's VMT is made up from passenger cars, where on average only 37% of the VMT is from passenger vehicles in Tahoe. This also indicates that Tahoe residents and visitors more often use light duty trucks and SUVs compared with the rest of the state. Roughly 1% of the vehicles observed are HHDT (commercial truck and trailers) on arterials. This is significantly less than what is observed on a typical urban California roadways (5%).

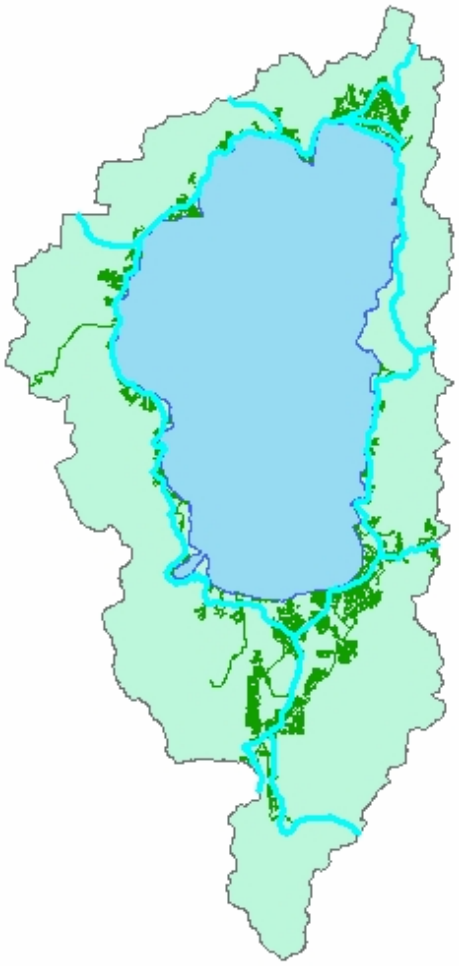
Figure 3.3.1. Fleet Distribution Observed during the Summer 2002 on Various Roadway Types in the Tahoe Basin



To compare the fleet distribution observed in this study with data currently used for emissions modeling, it is necessary to combine the residential and arterial data in some appropriate fashion. For this study, an assumed estimate of VMT by road type based on road lengths, observed and recorded vehicle flow, and data from other cities is used.

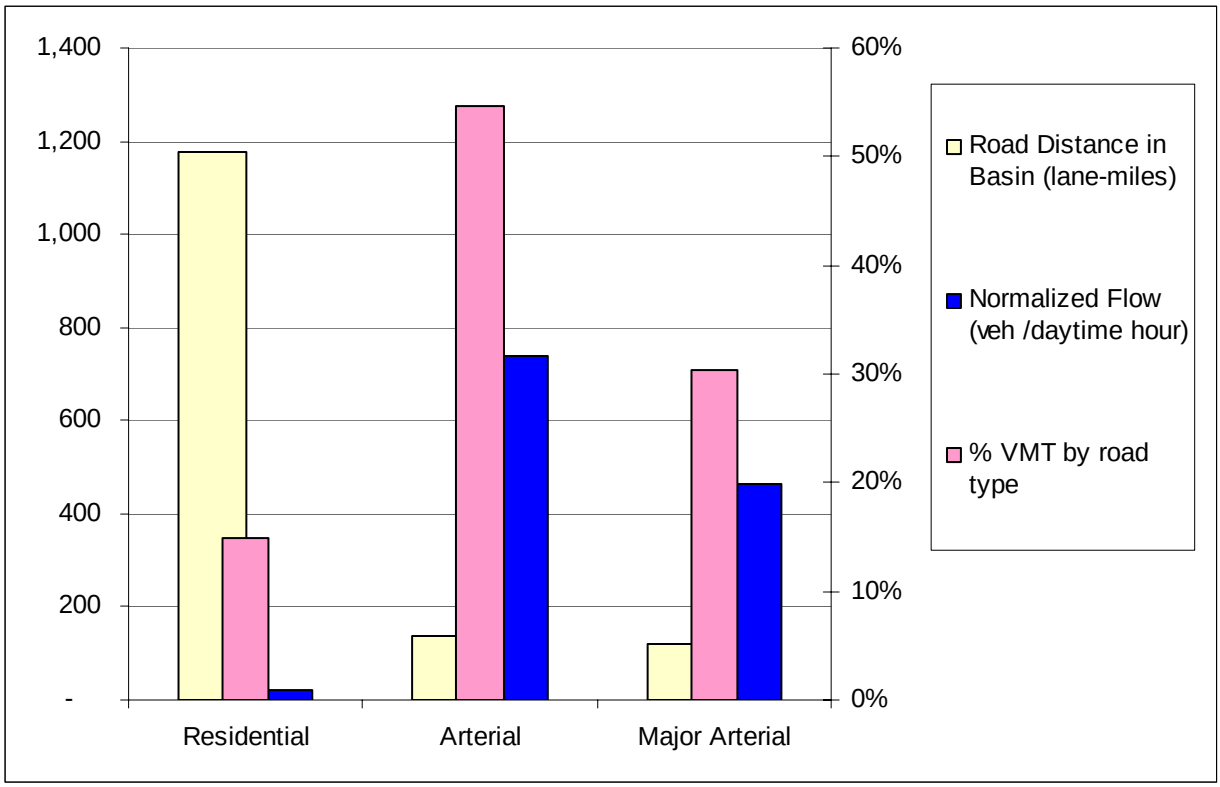
The length of each roadway type was estimated using ARCGIS software and shapefiles of the major and minor roadways and the TRPA Tahoe boundaries (Figure 3.3.2). There is an estimated 110 miles of arterial and major arterial/highways within the Tahoe Boundaries, and 620 miles of residential roadways.

Figure 3.3.2. Minor and Major Roadways in the Tahoe Basin



Although the lengths of residential roadways far outweigh the arterial (85% compared to 15%), the flow rate is much lower, resulting in a smaller contribution of daily VMT when combined. The normalized flow rate for each roadway is shown in Figure 3.3.3. While the flow on various types of minor and major arterials are fairly consistent within each category, the flow rate on residential roadways differ significantly depending upon their proximity to an arterial road, school, or church. Because many of the residential roadways do not see much traffic, "major" residential roadways were selected for the vehicle activity analysis. However, this means that the average flow recorded in this study must be modified before application to the entire set of residential roadways. It has been observed in other areas that approximately 10-15% of daily travel is spent on residential roadways. By decreasing the residential flow observed by a factor of three, the overall travel contribution of residential roadways becomes 15%. In reality, there will be a range of flow from less than 1 vehicle/hour on some residential roads to over 100 vehicles/hour. An average flow of 30 vehicles an hour is considered a reasonable assumption in this context and in light of the available information.

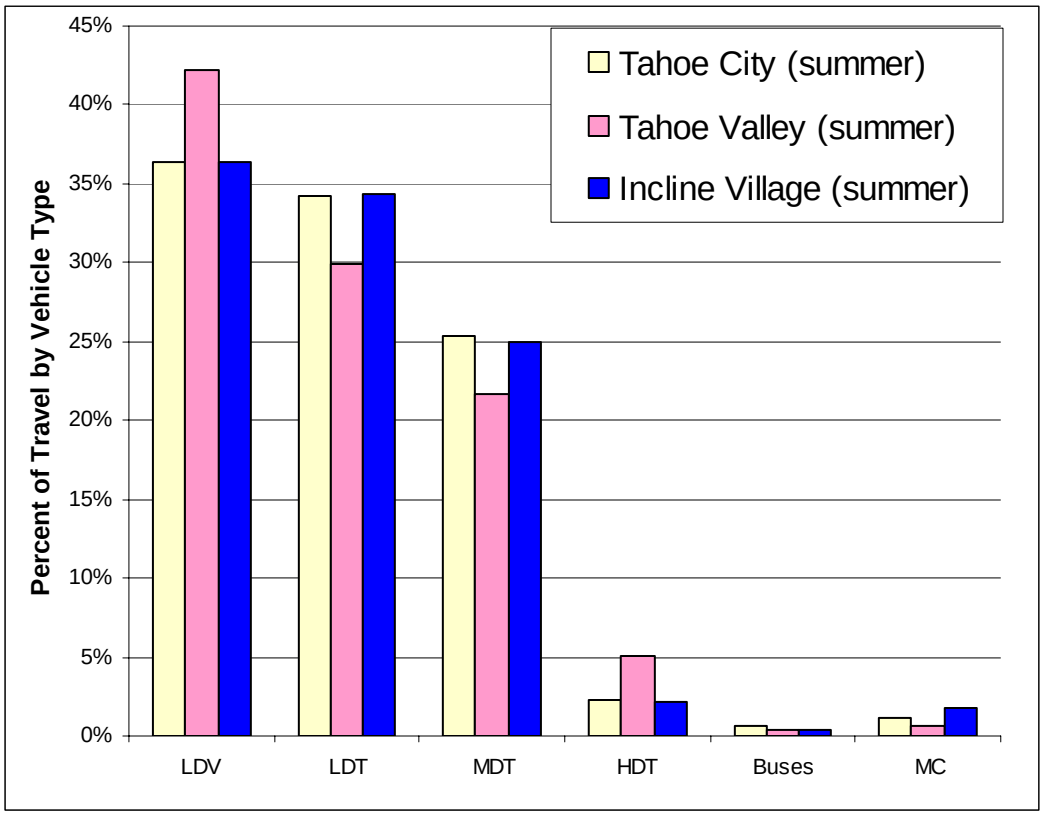
Figure 3.3.3. Observed Flow Rate on Various Roadways

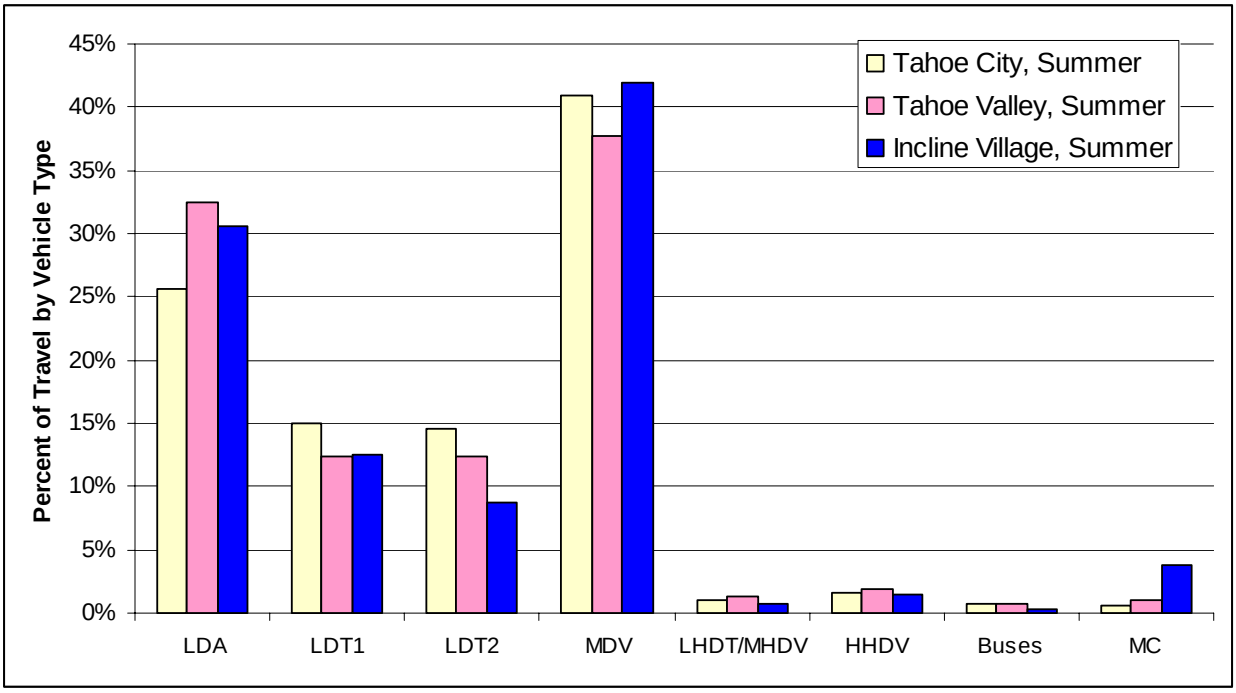


This approximate method of weighting travel results in about 15% of the VMT occurring on residential roads, 55% on arterial roads, and 30% on major arterial roads. These weighting factors were used to combine the fleet distributions into an "overall" fleet distribution for each area. Because of the similarities in the distributions in road types, this weighting does not have a large impact and the assumptions of the travel fraction in each road type can vary substantially without having a noticeable impact in the overall numbers.

Figure 3.3.4. shows the results of the combined fleet distribution from the vehicle activity study for the summer of 2002. Overall, all three regions show similar fractions of driving from each vehicle type. Tahoe City, which is located in Placer County, has the lowest fraction of passenger vehicles and highest fraction of light and medium duty trucks. This is consistent with the variation in the county data collected from ARB in Figure 3.3.5. For all of these comparisons, the distribution of residential, arterial and major arterial roadways was assumed to be 15%, 55%, and 30%, respectively. This distribution is described further in the VMT section.

Figure 3.3.4. Fleet Distribution Collected in the Vehicle Activity Study

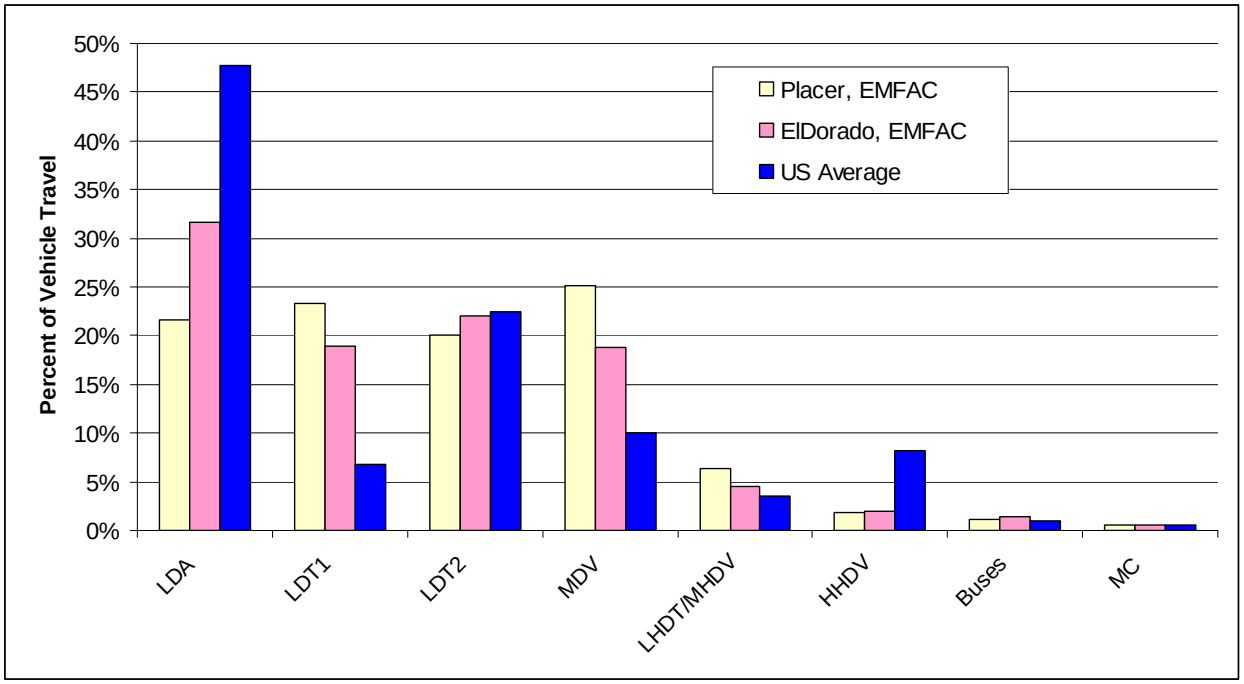




The distribution of travel by vehicle type used by the ARB in estimating vehicle emissions for the Tahoe Basin is shown in Figure 3.3.5. This data has been compiled from the DMV registration databases for each zip code and mileage accumulation reported by the Bureau of

Automotive Repair's smog check program. Also shown is the default US fleet distribution used in the MOBILE6 model. Both Lake Tahoe counties show a decrease in passenger vehicle travel and an increase in light duty and medium duty truck travel compared with state and national averages. Due to the rough terrain and weather conditions of the Lake Tahoe region, this increase is not surprising.

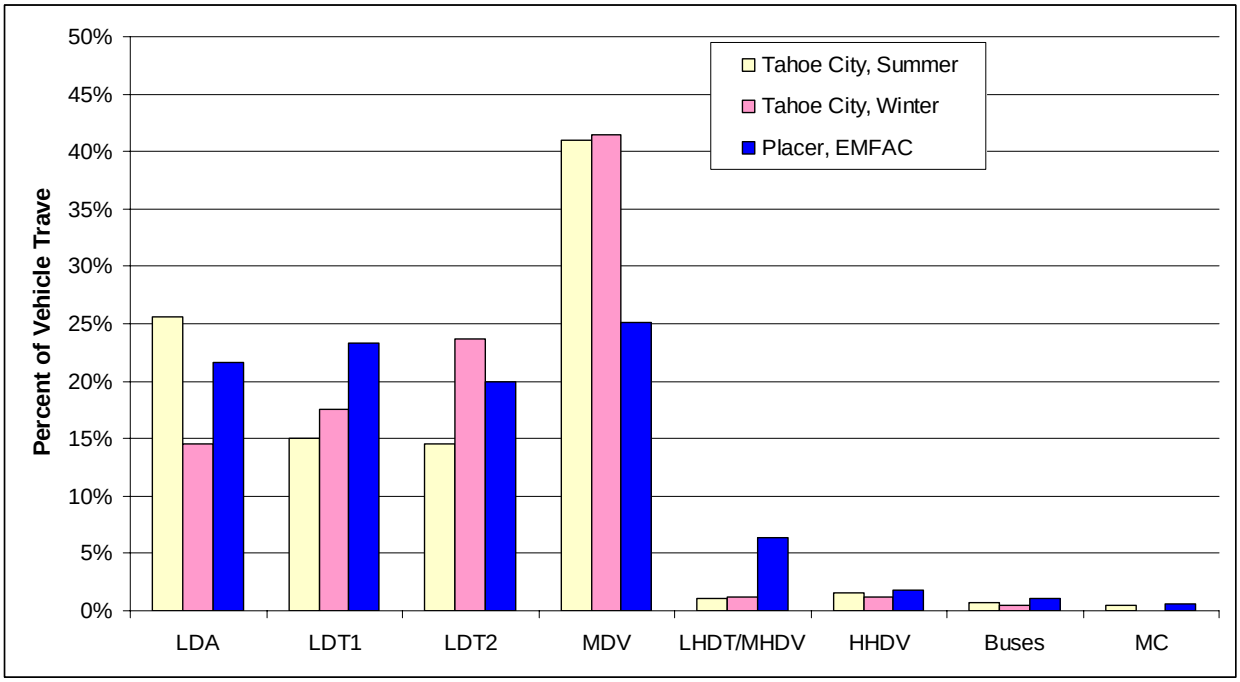
Figure 3.3.5. Fleet Distribution Used in Current Emission Models



Ideally, it would be useful to compare the light duty vehicle distribution with NDOT's estimate of vehicle type distribution, instead of simply the default MOBILE distribution. However, the data provided by NDOT does not distinguish between passenger vehicles and light trucks. The only comparison that can be made is for heavy duty trucks and buses. The same percentage of heavy duty vehicles (1.2%) and buses (~0.1%) are seen for the VA data collected in this study and the NDOT data.

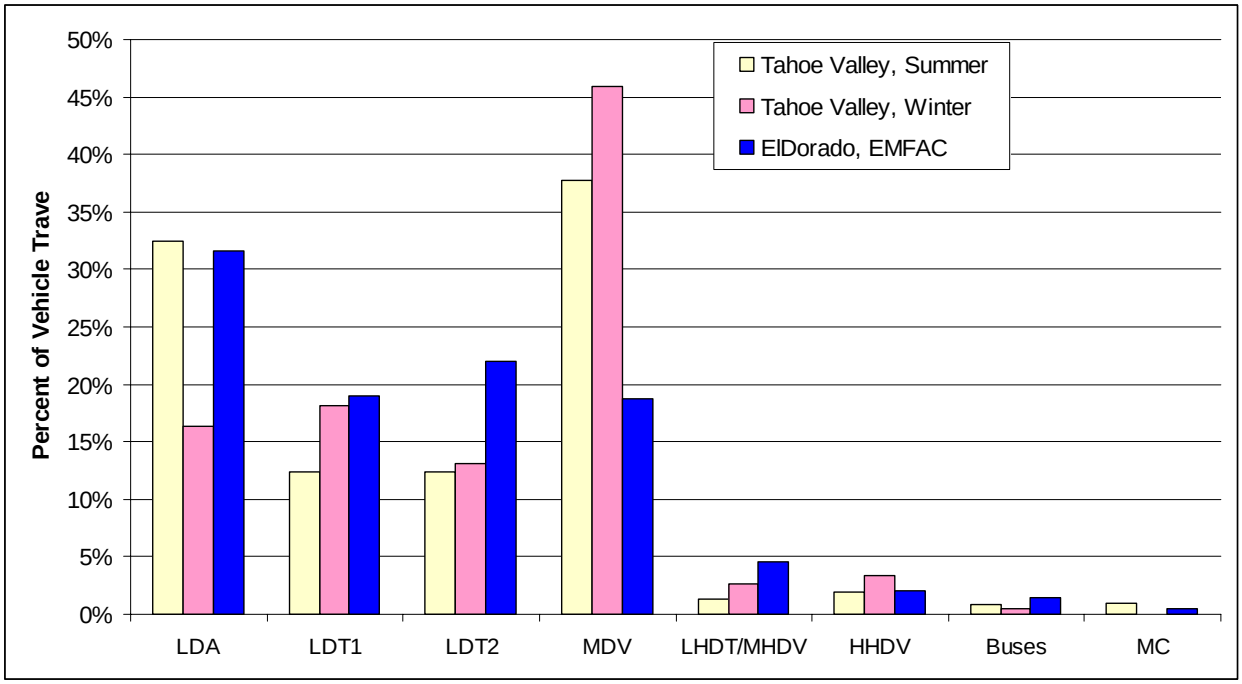
The combined data collected in Tahoe City is compared with the ARB Lake Tahoe portion of Placer County dataset in Figure 3.3.6. The first yellow bar represents data collected during the summer of 2002 and the pink bar represents data collected in the winter of 2002. The blue bar is the assumptions used in the EMFAC2002 model (there are no seasonal variations for the fleet distribution incorporated in the model). From the data collected in this study, it appears the existing county data may be underestimating medium duty vehicle travel. The ARB data also shows there is a slightly larger fraction of medium heavy duty traffic than observed in either season in this study. (A Chevrolet Tahoe or Ford 150 would be classified as a MDV, with a gross vehicle weight rating of between 5751 and 8500 pounds).

Figure 3.3.6. Fleet Distribution in Tahoe City in Comparison with Current Models



The data collected in this study is compared with the ARB best dataset in Figure 3.3.7 for Tahoe Valley, El Dorado County. The first yellow bar represents data collected during the summer of 2002 and the pink bar represents data collected in the winter of 2002. The blue bar is the assumptions used in the EMFAC2002 model (there are no seasonal variations for the fleet distribution incorporated in the model). From the data collected in this study, it appears the ARB data fall in between the summer and winter data collected in this study, therefore indicating the current data is reasonably accurate for a yearly fleet profile for this region. However, it does appear that the trucks observed are of a slightly higher weight category than assumed in EMFAC, by comparing the fraction of observed travel in the LDT2 and MDV categories. (A Ford Explorer would be classified as a LDT2, whereas a slightly heavier Chevrolet Tahoe or Ford 150 would be classified as a MDV).

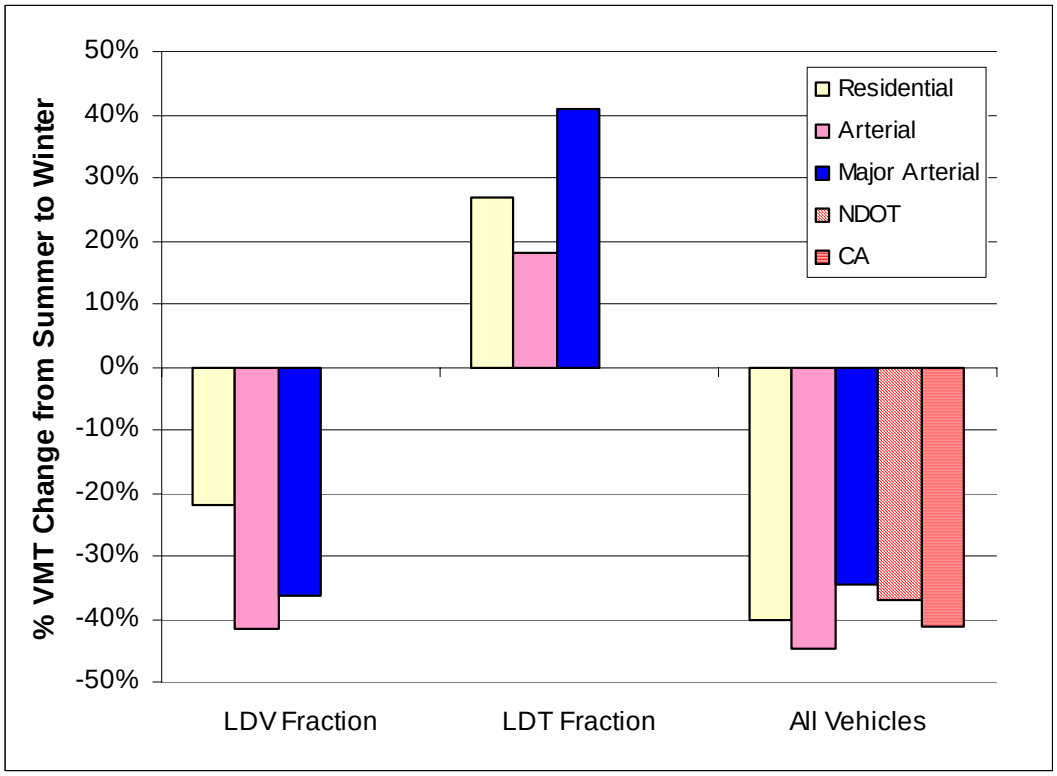
Figure 3.3.7. Fleet Distribution in Tahoe Valley in Comparison with Current Models



Seasonal Variation

As seen in the figures above, there are distinct differences between summer and winter vehicle activity, both in the overall amount of driving and the fraction of driving by cars versus light and medium duty trucks. Figure 3.3.8 specifically compares the differences between the fleet distribution and overall driving. In the winter, the fraction of travel by passenger vehicles was roughly 34% less than the summer. Most of this difference was counteracted by an increase in the light duty truck activity. Overall, there was approximately 40% less vehicle miles traveled per day during the winter test days. This seasonal difference is comparable to the differences observed by the NDOT and CalTrans counts for the Tahoe region (represented by the last two bars in Figure 3.3.8). Although the counts do show similar seasonal variations, there are no seasonal VMT and fleet distribution differences accounted for in the EMFAC modeling.

Figure 3.3.8. Seasonal Variation in Fleet Distribution and Overall Travel

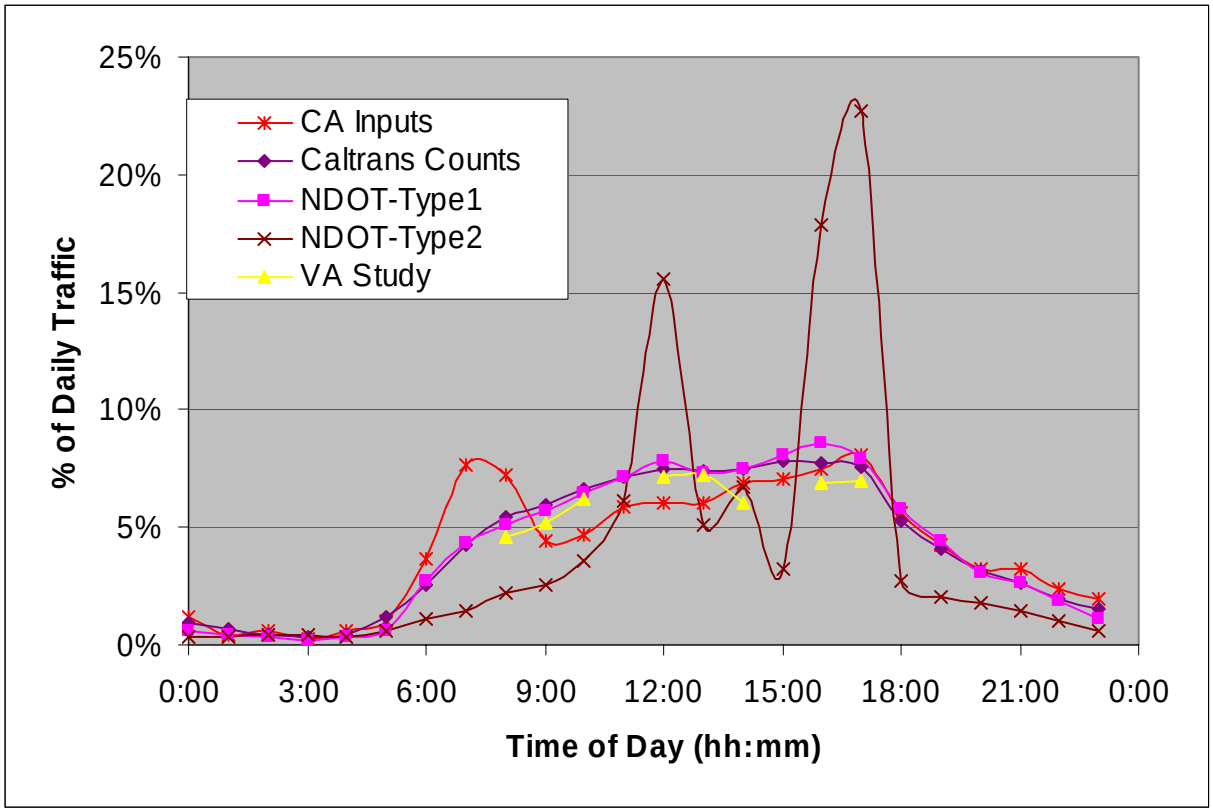


Temporal Variation

The California and Nevada vehicle hourly count data were compared with the data collected in this study and also the hourly VMT distribution used in the EMFAC model. The data from this study did not include a complete picture of the temporal variation by roadway, but did collect some information during the time of day when most traffic occurs. By assuming that the peak flow during the daytime hours collected in the VA study is equivalent to roughly 8% of the daily VMT on each roadway, as indicated by the hourly count information provided by the NDOT dataset and shown in Figure 3.3.9, the data collected in this study can be compared with existing hourly data.

The temporal profile of the Caltrans and NDOT traffic flow on selected arterial roadways is shown in Figure 3.3.9. The daily profile is similar on most roadways, with 72% of traffic occurring between 8 and 6 pm. On most roadways, traffic increases from 6 am to noon, and there is a slight decrease from noon till 2:00 pm, another increase until 5 pm, and then a steady decrease. One outlier was observed in the Nevada data. Typical hourly peak flows are approximately 8% of the total daily traffic, and occur in the afternoon. On the outlier, an hourly peak flow of 23% of daily traffic was observed in the afternoon. This data may indicate there are two types of daily patterns seen on arterial roadways, one with a more constant daily flow and one with a highly bimodal distribution. It does not appear that these differences are a function of total flow. Each individual roadway would need to be observed to determine its daily flow pattern.

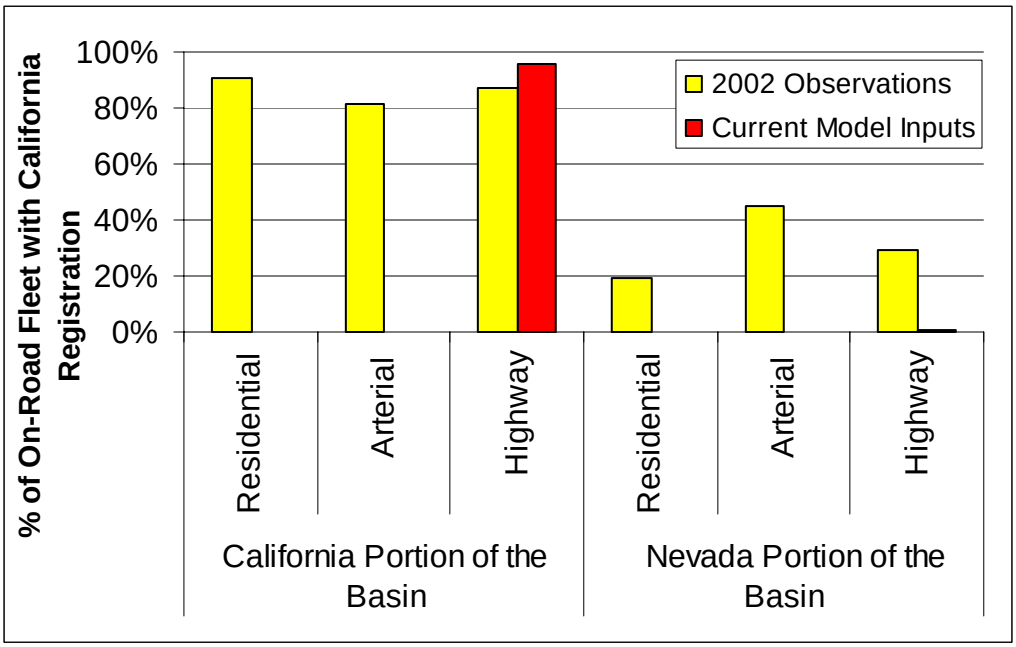
Figure 3.3.9. Hourly Flow Distribution on Arterial Roadways in the Tahoe Basin



Out-of-State Vehicles

Another important variation in the local fleet is the fraction of out-of-state vehicles. Because Lake Tahoe borders two states and it is a tourist destination, it is expected that the out-of-state fraction of vehicles are higher than average. For the state of California, average out-of-state percentage of vehicles on the road is 2% (Figure 3.3.10). For Placer and El Dorado counties, the ARB data indicates this percentage is 4% and 5%, respectively. The data collected in California in this study shows an out-of-state percentage of 9% for residential areas and approximately 15% for arterial roadways. This result is reasonable considering the close proximity to the state border compared to the rest of the county. It is also expected that the residential areas would have less out-of-state vehicles than arterial roadways. On the Nevada side, a significant fraction of California vehicles, up to 40% on arterial roadways, is observed. This high fraction may produce a significant change in emissions estimates for the Tahoe region, because many California vehicles have lower emissions than a 49-state comparable vehicle.

Figure 3.3.10. Percentage of Vehicles Registered in California in the Tahoe Basin



Driving Patterns

The average velocity of the vehicles measured in this study is shown in Figure 3.3.11 for each roadway type. Summertime driving was consistently greater by approximately 20% than wintertime driving on the same roadways. This was expected since the wintertime driving, as measured in this study, occurred during snowy conditions. The residential roadways are characterized by average velocities of less than 20 mph, arterials characterized by a velocity of between 18 and 24 mph, and major arterials have average velocities of between 25 and 40 mph. Figure 3.3.12 compares the average velocities measured in this study with some other similar studies conducted around the world. Typically, the summertime velocities look very similar to Los Angeles driving, except for the major arterial/freeway category. Because Lake Tahoe does not have major freeways and instead is characterized by mostly two-lane major arterials, the velocities are expected to be slower.

Figure 3.3.11. Average Velocity of Vehicles on Roadways Measured in VA study

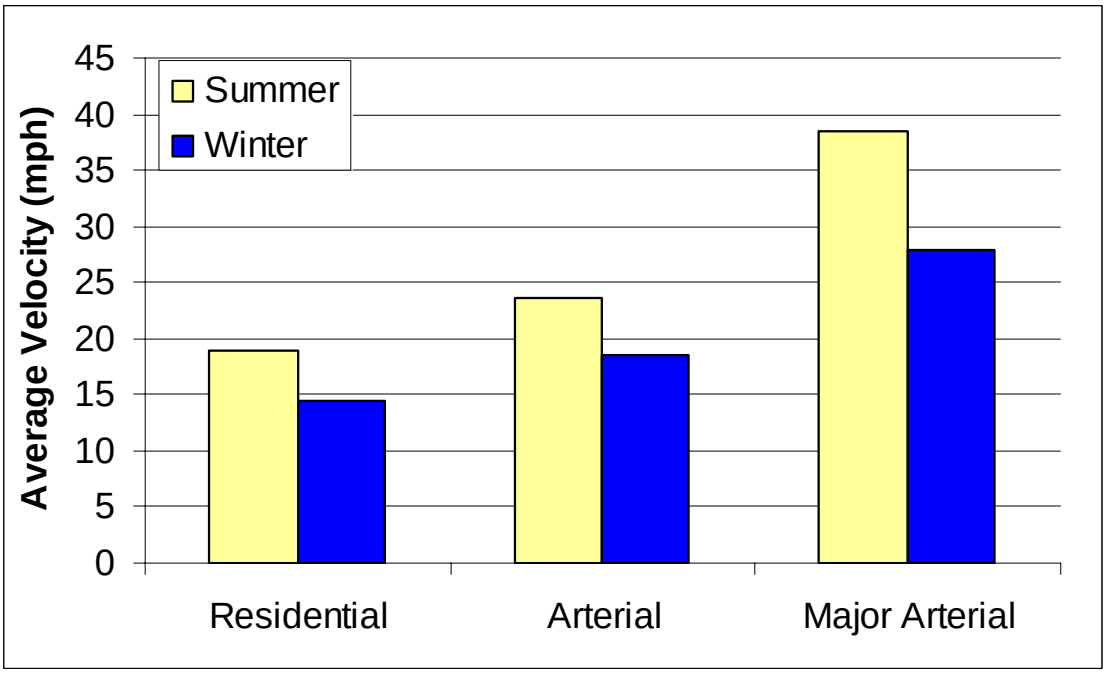
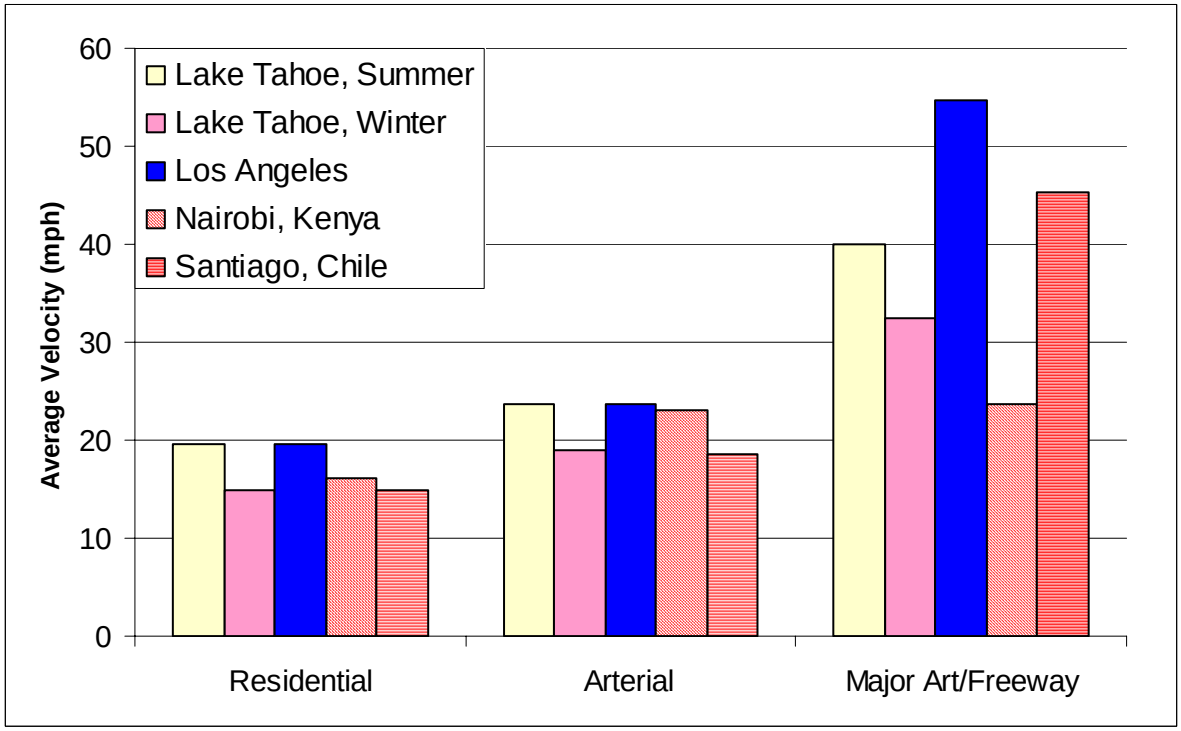


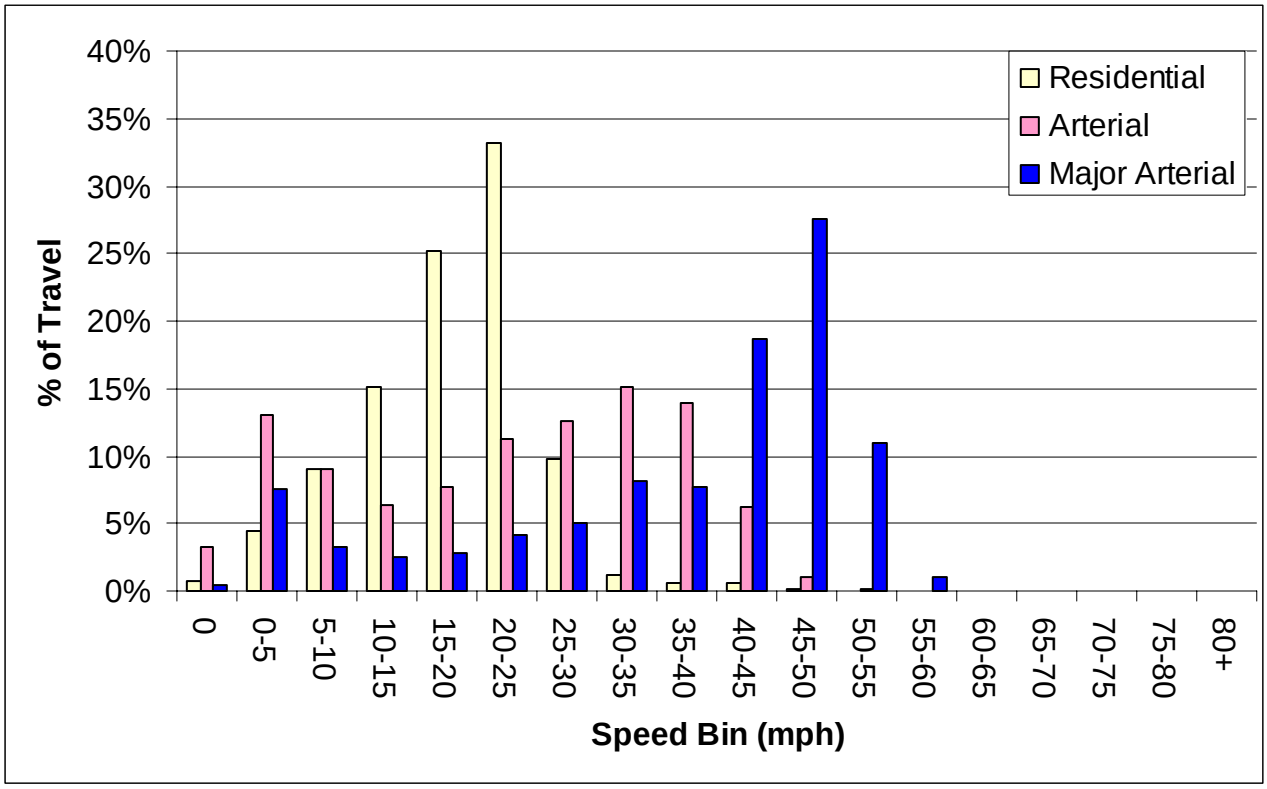
Figure 3.3.12. Comparison of Average Velocity of Vehicles in Lake Tahoe with Other Locations



A popular method of characterizing driving patterns is by binning the travel by speed category. The ARB uses this methodology in their EMFAC2002 model with speed bins in increments of 5 mph up to 80 mph (ARB, 2). This type of distribution can be created by simply counting the

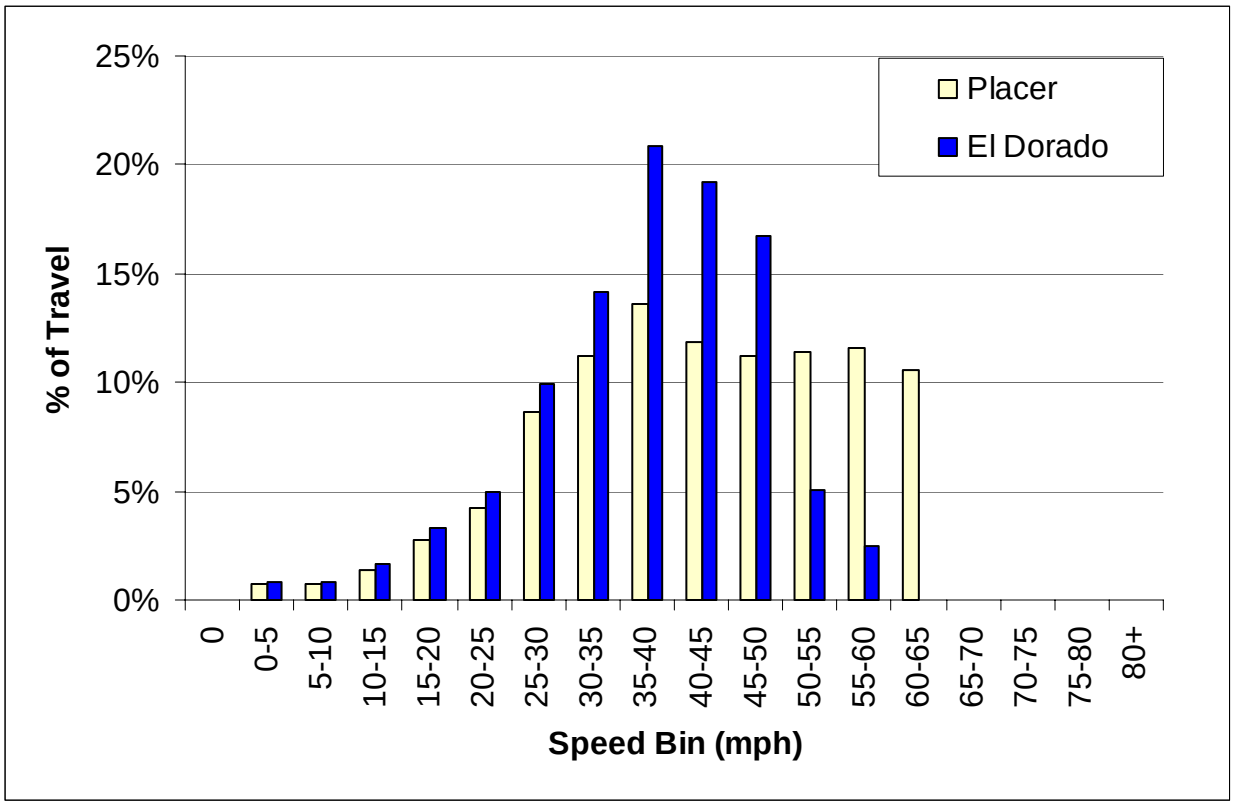
number of seconds of the driving trace that falls into each speed bin. The values in Figure 3.3.13 are the fraction of driving time spent in each of the speed bins for the different driving courses. These are for summer and winter combined. The residential course has a bell-shaped curve, while the two arterials have a bimodal distribution. This is consistent with driving patterns seen in other areas.

Figure 3.3.13. Velocity Profile for Driving Patterns Observed in the Tahoe Basin



The speed-binned distributions used in the EMFAC2002 model are shown in Figure 3.3.14. The distribution is slightly different for Placer and El Dorado counties. However, both have the majority of travel at 35 mph or greater. El Dorado is characterized by slightly higher speeds than Placer County. Driving patterns used in the EMFAC model do not differentiate between summer and winter season and do not explicitly break down the patterns for different roadways.

Figure 3.3.14. Velocity Profile of the Tahoe Basin Used in the EMFAC model



In order to compare the driving traces collected in this study with the values used in the California modeling, the residential, arterial, and major arterial traces were combined. The weighted VMT fraction as derived in the previous section of 15% residential, 55% arterial, and 35% major arterial were used. The results are shown in Figure 3.3.15, for Tahoe City and Figure 3.3.16 for Tahoe Valley. Also shown in these figures are the assumed values in used in the EMFAC model. By changing the speed distribution in EMFAC, this resulted in a 64 and 100% increase in the VOC light duty running emissions modeled in El Dorado and Placer County, respectively.

Figure 3.3.15. Velocity Profile Comparison of Measured and Current Modeling Inputs for Placer County, Tahoe Basin

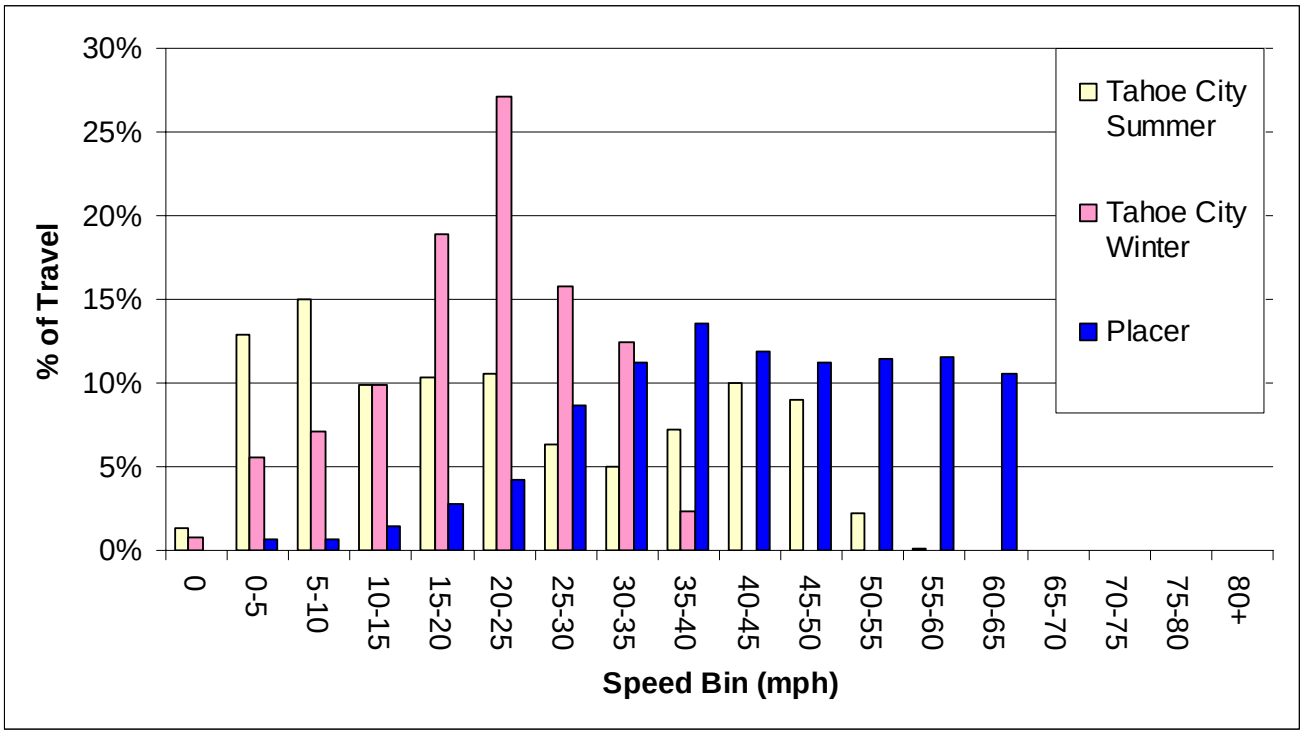
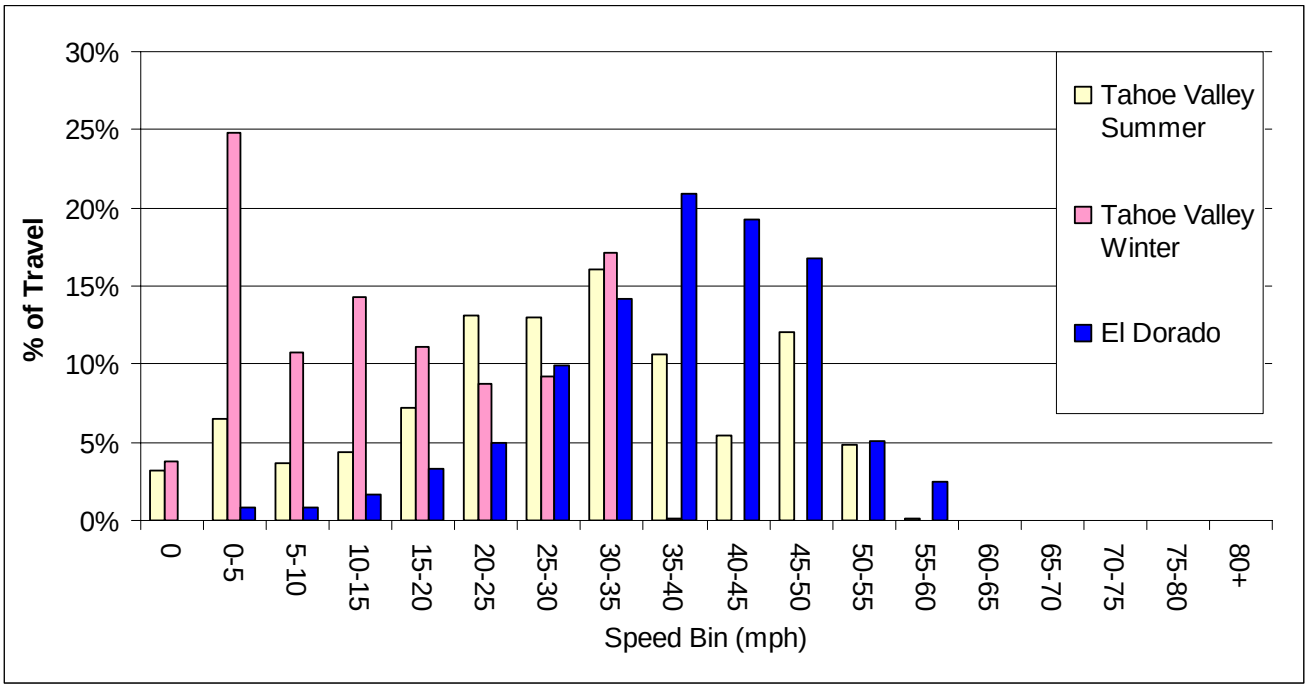


Figure 3.3.16. Velocity Profile Comparison of Measured and Current Modeling Inputs for El Dorado County, Tahoe Basin



Both locations have a higher observed percentage of travel spent in the lower speed bins than assumed in the modeling. These differences could produce significant changes in the emissions modeling results.

Another way to view driving pattern data is to use Vehicle Specific Power (VSP) binning. Although this method is not employed in the current emissions models, it will be used in the upcoming EPA's MOVES model and it is used in the International Emissions Model (IVE model) funded by the EPA (EPA, Lents). A useful aspect of incorporating VSP into the driving cycle is that road grade can explicitly be addressed and incorporated into the modeling. CE-CERT has developed a method to bin vehicle travel into VSP and engine stress bins from the collected GPS data. VSP (kW/ton) can be calculated for each second of data using the following equation (Jimenez-Palacios, 1999):

$$\text{VSP} = v[1.1a + 9.81\,(\text{atan}(\sin(\text{grade})))+0.132] + 0.000302v^3 \qquad \text{(Eq. 3.3.1)}$$

$\text{grade} = (h_{t=0} - h_{t=-1})/\, v_{(t=-1\text{to}0)}$
v = velocity (m/s)
a = acceleration (m/s^2)
h = Altitude (m)

Current research projects at CE-CERT have found that vehicle power-based emissions estimates perform quite well for CO_2, but improvements in predictive power for other emissions such as CO, HC, NO_x, and NH_3 may be achieved through the addition of one or more dimensions to the matrix binning approach. In this analysis, a parameter called engine stress is used in addition to VSP. Engine stress is related to vehicle power load requirements over the past 20 seconds of operation and engine RPM (Eq. 3.3.2, Table 3.3.1). Low engine stress refers to conditions in

which vehicle operation has encountered low speed and accelerations over the last 20 seconds of operation and the engine RPM is relatively low, and high engine stress occurs at high speed and accelerations over the most recent 20 seconds and engine RPM is high. A total of 60 bins for the VSP/stress categories were used for this analysis (Table 3.3.2).

Engine Stress *(unitless)* = *RPMIndex + (0.08 ton/kW)*PreaveragePower* (Eq. 3.3.2)

$$PreaveragePower = Average(VSP_{t=-5sec\ to\ -25\ sec})\ \ (kW/ton)$$
$$RPMIndex = Velocity_{t=0}/SpeedDivider\ \ (unitless)$$
$$Minimum\ RPMIndex = 0.9$$

Table 3.3.1. Cutpoints used in *RPMIndex* Calculations

Speed Cutpoints (m/s)		Power Cutpoints (kW/ton)		Speed
Min	Max	Min	Max	Divider (s/m)
0.0	5.4	-20	400	3
5.4	8.5	-20	16	5
5.4	8.5	16	400	3
8.5	12.5	-20	16	7
8.5	12.5	16	400	5
12.5	50	-20	16	13
12.5	50	16	400	5

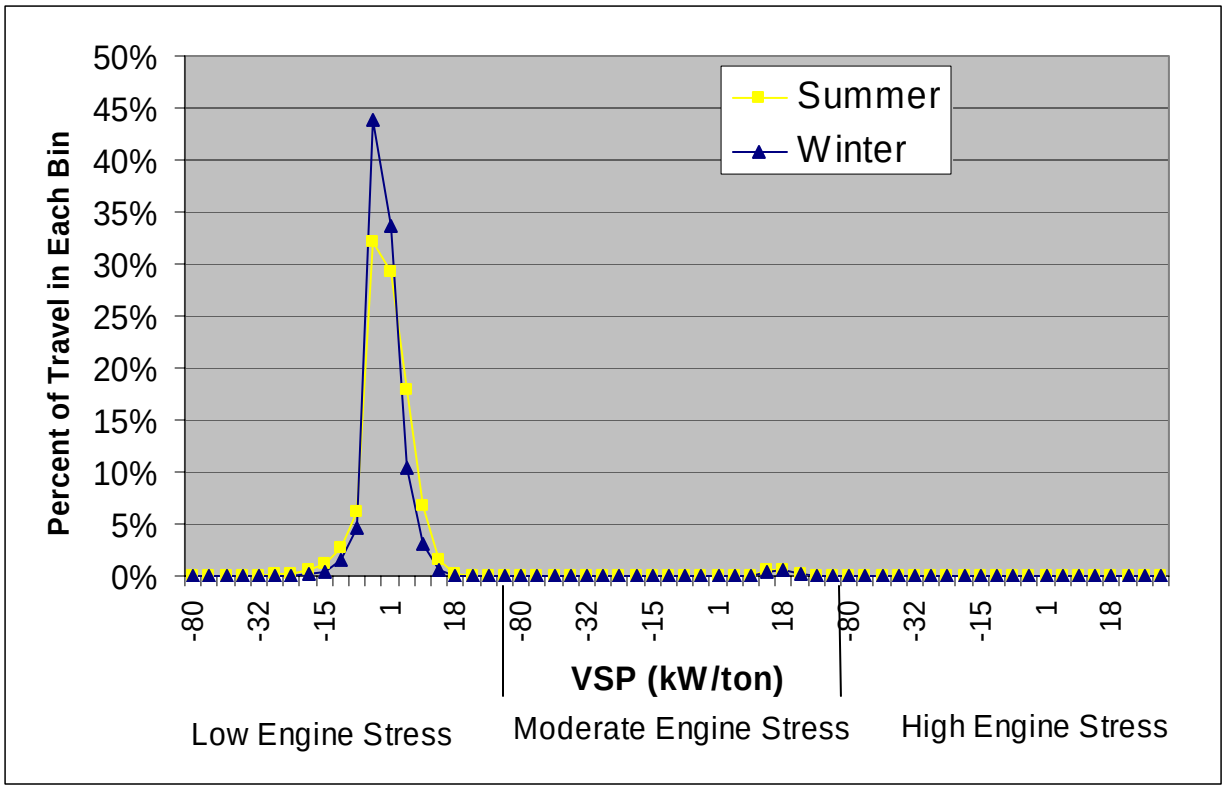
Table 3.3.2. Boundaries Assumed in VSP/Engine Stress Binning

	VSP (kW/Ton)		Engine Stress	
Bin	Lower	Upper	Lower	Upper
0	-80.0	-44.0	-1.6	3.1
1	-44.0	-39.9	-1.6	3.1
2	-39.9	-35.8	-1.6	3.1
3	-35.8	-31.7	-1.6	3.1
4	-31.7	-27.6	-1.6	3.1
5	-27.6	-23.4	-1.6	3.1
6	-23.4	-19.3	-1.6	3.1
7	-19.3	-15.2	-1.6	3.1
8	-15.2	-11.1	-1.6	3.1
9	-11.1	-7.0	-1.6	3.1
10	-7.0	-2.9	-1.6	3.1
11	-2.9	1.2	-1.6	3.1
12	1.2	5.3	-1.6	3.1
13	5.3	9.4	-1.6	3.1
14	9.4	13.6	-1.6	3.1
15	13.6	17.7	-1.6	3.1
16	17.7	21.8	-1.6	3.1
17	21.8	25.9	-1.6	3.1
18	25.9	30.0	-1.6	3.1
19	30.0	1000.0	-1.6	3.1
20	-80.0	-44.0	3.1	7.8
21	-44.0	-39.9	3.1	7.8
22	-39.9	-35.8	3.1	7.8

23	-35.8	-31.7	3.1	7.8
24	-31.7	-27.6	3.1	7.8
25	-27.6	-23.4	3.1	7.8
26	-23.4	-19.3	3.1	7.8
27	-19.3	-15.2	3.1	7.8
28	-15.2	-11.1	3.1	7.8
29	-11.1	-7.0	3.1	7.8
30	-7.0	-2.9	3.1	7.8
31	-2.9	1.2	3.1	7.8
32	1.2	5.3	3.1	7.8
33	5.3	9.4	3.1	7.8
34	9.4	13.6	3.1	7.8
35	13.6	17.7	3.1	7.8
36	17.7	21.8	3.1	7.8
37	21.8	25.9	3.1	7.8
38	25.9	30.0	3.1	7.8
39	30.0	1000.0	3.1	7.8
40	-80.0	-44.0	7.8	12.6
41	-44.0	-39.9	7.8	12.6
42	-39.9	-35.8	7.8	12.6
43	-35.8	-31.7	7.8	12.6
44	-31.7	-27.6	7.8	12.6
45	-27.6	-23.4	7.8	12.6
46	-23.4	-19.3	7.8	12.6
47	-19.3	-15.2	7.8	12.6
48	-15.2	-11.1	7.8	12.6
49	-11.1	-7.0	7.8	12.6
50	-7.0	-2.9	7.8	12.6
51	-2.9	1.2	7.8	12.6
52	1.2	5.3	7.8	12.6
53	5.3	9.4	7.8	12.6
54	9.4	13.6	7.8	12.6
55	13.6	17.7	7.8	12.6
56	17.7	21.8	7.8	12.6
57	21.8	25.9	7.8	12.6
58	25.9	30.0	7.8	12.6
59	30.0	1000.0	7.8	12.6

Road grade was estimated by taking a 5 second average road grade. Grades larger than 14% and road grades at velocities of less than 1 kph were filtered out. An estimate of VSP without using the measured road grade was also conducted. Figure 3.3.17 show the travel distribution results from binning by VSP and engine stress.

Figure 3.3.17. VSP Travel Distribution in Lake Tahoe Study



The change in VSP distribution from summer to winter could have a substantial impact in emissions. Using the IVE model and a typical fleet, it is estimated that PM emissions could increase as much as 15% from the summer to winter driving conditions. This is due to the increased time spent to travel the same distance and the acceleration profiles. Of course, this increase in emissions will be more than offset by a decrease in overall VMT. Also, not included here is a description of start emissions. Start emissions will be higher in the winter season also due to a higher fraction of cold starts.

4 Summary and Recommendations

Samples were collected from prescribed burns and in vicinities of wood burning stoves and fireplaces. Concentrations of mass, organic and elemental carbon, and elements by xrf were determined. These samples are now available for more detailed chemical analysis that may provide a phosphorus source profile for residential wood burning.

Wood used for campfire and residential wood burning activities in the Lake Tahoe Basin is a combination of hard and soft wood; both purchased and cut from private woods. The vast majority of wood burned was dry and natural (as opposed to artificial logs). The average camper has a campfire for 2 hours a day each evening, burning an average of 4 logs. Assuming 1667 campers per summer day throughout the basin and an emission factor of 12 g/kg dry wood, and a 96% campfire rate, this corresponds to 2.3 tons of PM10/summer day. Ninety percent of the residents surveyed have and use a wood burning device (either a fireplace or wood burning stove) during the winter season. The average resident surveyed burns wood 6 hours per winter

day and uses 7.4 logs per day. Most residents burn their wood during the weekend evenings. Sixteen percent of the residents surveyed use wood as their primary source of heating through the use of a wood burning stove. These residents, on average, burn wood twice as long and use 40% more wood, and burn a higher percentage (60%) during the weekdays. Assuming an occupied residence of 21,000, residential wood burning is estimated at 86 tons PM10/ winter day in the Tahoe Basin. Because the number of surveys in each estimate is less than two hundred, there is substantial uncertainty in these extrapolations to the entire community. The survey consisted of approximately 90% single family residents, whereas census data indicate the counties included in the Tahoe basin have a single family residency of 70 to 89%. If the survey did not collect an accurate ratio of single to multiunit residences, it could impact the average wood use per resident.

The results of the vehicle activity indicate there are some differences between measured values in the Basin and the values currently used in the mobile source emission inventory estimates. The most profound differences were the seasonal variations, with roughly 40% less traffic observed under winter conditions than summer, a 15% decrease in passenger car VMT fraction, and a 12% increase in medium duty truck VMT fraction. These seasonal differences are currently not applied in the vehicle modeling process. Observed driving patterns also differed by season, and from current inputs used in the models. Average winter velocities were 5 to 15 mph slower than summer, and the average velocity used in the ARB's modeling is 12 mph higher than the average velocity estimated from the summer data collected in this study. It must be noted that some assumptions on the percentage of travel on each road type were made and that the driving conditions noted in the winter were during very snowy conditions (rumored as the worst storm in a decade). It is anticipated that in winter conditions with clear roads, driving behavior would look more like measurements recorded during the summer season.

The vehicle fleet observed in the Tahoe Basin reflected a large fraction of out-of-state vehicles. In California, the observed out-of-state vehicle percentage was between 9% and 15%, compared with the 5% assumed in the California emission model for the Basin. The registration data used to define the fleet distribution for modeling purposed is based on data from each zip code. The current data reflects an increased percentage of light and medium duty trucks and SUVs and less passenger cars than the rest of the state. Observations made specifically in the Tahoe Basin in this study show similar results. The observed fleet makeup is highly dependent upon season, and somewhat dependent upon roadway type. Differences were also observed for the various counties, but concrete trends could not be distinguished based on the amount and variation of the data collected.

The vehicle activity data provided from this study offers an improved dataset that is locally specific and timely. The data can be used to with existing vehicle emissions models to create an alternate estimate of the contribution of vehicle emissions to the Basin-wide inventory. It is anticipated that the application of these data to the models will significantly change the emissions estimate for this region. However, caution must be used when applying these data, since it is a limited collection over a limited timeframe. Additionally, extrapolations to weight the various roadway types were used which may have considerable error. It is therefore recommended that this data be used in an exploratory manner.

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