Estimating Statewide Vehicle Activity and Roadway Mileage for Unpaved Roads in California

Contract Number: 99-715

Research Assistant:
Jennifer E. Morey

GIS Support:
Thirayoot Limanond
Michael Nicholas

Principal Investigator:
Debbie A. Niemeier, Ph.D.
Dept. of Civil & Env. Engineering
University of California
One Shields Avenue
Davis, CA 95616

Final Report, October 31, 2002

Prepared for the California Air Resources Board
and the California Environmental Protection Agency

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 their use in connection with material reported herein is not to be construed as actual or implied endorsement of such products.

Acknowledgments

This report was submitted in fulfillment of ARB contract number 99-715, “Estimating Statewide Vehicle Activity and Roadway Mileage for Unpaved Roads in California,” by the Department of Civil and Environmental Engineering at the University of California, Davis under the sponsorship of the California Air Resources Board. Work was completed as of June 30, 2002. In addition we owe thanks to members of our field teams: Heather Huovinen, Megan Fidell, Shelby McCoy, Katherine Gilman, Daniel Dowling, and Timothy Duong and to Larry Brohman at Caltrans for the use of traffic counting equipment.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

Emissions of particulate matter with an aerodynamic diameter less than 10 μm (PM_{10}) are a great concern in California. Over 25% of California counties are nonattainment areas according to federal PM_{10} standards while over 90% are out of attainment by state standards. Areawide sources, which include unpaved roads, are a major contributor of primary PM_{10} emissions, however, vehicle activity data on unpaved roads is sparse. Currently, the California Air Resources Board (CARB) assumes daily vehicle activity on unpaved roads as equal 10 vehicle passes for each mile of nonagricultural unpaved road in the state and 4.375 vehicle passes per acre of farmland for agricultural unpaved roads. These estimates are based on conversations with experts.

The purpose of this study is to better characterize vehicle miles traveled (VMT) on unpaved roads in California and to provide a framework for updating VMT estimates. The primary goals of the study are to:

- Characterize the number of vehicle passes per day by land use type;
- Distinguish between VMT attributable to the hauling of harvested crops and VMT generated by nonharvest related activities; and,
- Produce county and statewide estimates of annual unpaved road VMT for 2001.

Spatial data play critical roles in the estimation procedure. Land use and road databases allow us to establish a sampling framework that includes prevailing statewide land uses and also allows us to efficiently apply our findings on a countywide and statewide basis.

Method

Total unpaved road VMT is estimated for two categories of activity: 1) VMT generated from hauling harvested crops (harvest VMT) and, 2) VMT generated from all other agricultural, recreational, residential and other unpaved road activities (nonharvest VMT). Harvest VMT (HVMT) estimates utilize more than 60 major crops described by the California Department of Food and Agriculture. Factors affecting VMT include yield per acre of a given crop, capacity of a harvest hauling vehicle, size of a harvested field, length of road driven by a hauling vehicle, and the proportion of unpaved roads abutting a field. We use a combination of published crop and yield data, survey responses from a previous pilot study, grower lists from the County Agricultural Commissioners, and satellite imagery to establish the HVMT framework. Additionally, we derive default HVMT per acre values that can be applied to areas with less refined field and crop information.

The nonharvest VMT (NVMT) framework is based on average daily vehicle passes on unpaved roads according to the type of land accessed by the road, the miles of unpaved road by land type, and the proportion of the unpaved road typically traveled during a trip. Average daily vehicle passes are established through observed traffic volumes at randomly selected sites within California, lengths of unpaved roads are established through GIS data and visual surveys, and the average proportion of unpaved road traveled during a single trip is established through on-site observations.

The HVMT framework was developed using data from 18 counties in major growing regions throughout the state and the nonharvest estimation is based on traffic volumes collected on roads in 39 counties.

Results

Harvest VMT results vary by crop and field size; detailed tables are presented in Section 8.0. Summary data in Table 1 show the default HVMT per acre values derived using newly proposed methods. Table 2 summarizes the average daily vehicle passes by land use derived using the nonharvest VMT framework. Table 2 includes agricultural and non-agricultural unpaved road activities; only vehicle passes resulting from harvest hauling activities are excluded.

Table 1. Default harvest VMT per acre by crop category

Crop Category	Unpaved Road HVMT/acre
Grain	0.0028
Field	0.0103
Tree fruit and nut	0.0011
Vine and berry	0.0259
Vegetable	0.1027

Table 2. Average nonharvest daily passes by land use type

Land use type	Average daily vehicle passes
Fruit and Nut	**3.0**
Truck, Berry, Nursery and Vine	**10.2**
Field and Pasture	**10.5**
Grasslands, Sand dunes and Scrubland	**9.0**
Forest and Woodlands	**17.0**
Urban Residential	**16.1**
Urban Industrial and Other (Urban Interface)	**2.5**

Study results indicate that CARB's current activity factor for nonagricultural unpaved roads underestimates vehicle activity for Forest and Woodland and Urban Residential areas, but overestimates vehicle activity in Grasslands, Sand dunes and Scrubland and Urban Interface areas. The addition of a spatial element to the estimation procedure allows for more regional refinement of VMT estimations.

Table 3 summarizes statewide results. Nonharvest traffic is clearly the dominant source of unpaved road VMT; statewide HVMT accounts for only about 1% of the annual total. The low HVMT suggests that changes in harvest hauling traffic patterns will not dramatically affect PM_{10} emissions from unpaved roads. It is important to note, however, that the HVMT calculation does not include any travel on agricultural fields, nor does it include agricultural traffic generated by activities other than harvest hauling. These activities are incorporated into the nonharvest estimate.

Table 3. Annual unpaved road VMT in California

Harvest VMT	Nonharvest VMT	Total Statewide VMT
4,945,329	468,023,838	472,969,167

1.0 INTRODUCTION

This report documents methodologies that have been developed for estimating vehicle miles traveled (VMT) on unpaved roads in California, a study sponsored by the California Air Resources Board (CARB). Section 1 begins with a brief review of relevant literature as well as an overview of the current project goals and deliverables. Section 2 briefly outlines the current method used by the CARB to estimate unpaved road VMT and identifies ways in which the current method can be improved. Section 3 provides a brief description of an initial pilot study conducted for the CARB in 1998-1999, demonstrating the potential for integrating Geographic Information System (GIS) technology into VMT estimation procedures. Major findings from the pilot study, as well as the final pilot study reports, are included in this report as Appendix E. Section 4 describes the new framework developed to estimate unpaved road VMT on a statewide basis. Sections 5 and 6 describe the data collection and modeling techniques used to develop VMT associated with hauling harvested crops ("Harvest VMT") and for all other activities ("Nonharvest VMT"), respectively. Section 7 briefly describes a GIS interface that estimates unpaved road VMT using the methods developed in this study and allows future users to update the data used in the estimation process. Section 8 highlights the results of the study, providing monthly and annual VMT estimations for both harvest and nonharvest VMT. Finally, Section 9 provides conclusions and discussion of issues for future research.

1.1 Overview

Ambient PM_{10} (particulate matter < 10μm in aerodynamic diameter) concentrations are a major air quality concern in California. Of California's 58 counties, 16 counties (portions of 6 air basins) are partially or entirely designated as nonattainment areas according to federal standards. The number jumps dramatically when considering California's PM_{10} standards; by California standards 54 of the 58 counties are designated nonattainment areas (CARB 2002).

Areawide sources of PM_{10} emissions[1] account for approximately 85% of all directly emitted PM_{10} emissions in the state (CARB 2000). Unpaved roads are generally considered an important contributor to these PM_{10} emissions (Moosmuller 1998). In fact, over one-fourth of primary PM_{10} emissions from all sources in California are currently estimated to come from unpaved roads (CARB 2000).

Since directly measuring PM_{10} emissions is difficult, PM_{10} inventories are generally calculated by multiplying an estimated emissions factor by an associated source activity factor. For unpaved roads, several physical attributes influence the emission factor including the silt content of the road surface, moisture, average vehicle weight, and average vehicle speed (USEPA 1998). Researchers have estimated PM_{10} emissions from unpaved roads to be from 0.25 to 3.04 lbs. PM_{10}/VMT depending, in part, on the speed of observed vehicles (Kantamaneni 1996, Gillies *et al*. 1999). Road emissions estimates have varied from the US Environmental Protection Agency's (EPA's) AP-42 model by as little as 1% and as much as 250% (Kantamaneni 1996). Because of the myriad factors and changing conditions on unpaved roads, there is inherently a high degree of uncertainty involved in estimating their PM_{10} emissions. The CARB uses an emission factor of 2.0 lbs. PM_{10}/VMT for unpaved roads, as established through a study of unpaved roads in the San Joaquin Valley (CARB 1997).

[1] Areawide sources include farming operations, construction and demolition, fugitive and windblown dust, waste burning, and emissions from paved and unpaved roads (CARB 2000).

Vehicle activity is assumed to be the primary source activity associated with PM_{10} emissions from unpaved roads (CARB 1997). The majority of research intended to improve PM_{10} emission inventories have focused more on accurately estimating PM_{10} emission factors as opposed to refining estimates of source activity (*e.g.,* Dyck and Stukel 1976, Claiborn *et al.* 1995, Kantamaneni *et al.* 1996, USEPA 1998, Gillies et al. 1999). However, recent, albeit limited research has been undertaken to better understand travel behavior on unpaved roads in California. One study, conducted for the CARB, observed average vehicle passes on unpaved roads in San Joaquin County of approximately 18 per day (Morey *et al*. 1999). Another recent study in the San Joaquin Valley undertaken by Sonoma Technology, Inc. also measured vehicular traffic on unpaved agricultural roads (Coe 2000). Using results of a survey of 93 row crop and vegetable growers in the San Joaquin Valley, they found that average vehicle passes during land preparation activities varied from a low of 2.2 vehicle passes per acre in Tulare County to a high of 13.0 vehicle passes per acre in Stanislaus County, with an overall mean of 5.7 vehicle passes per acre[2] when the whole Valley was considered (Coe 2000). Vehicle passes during harvest periods were not estimated.

1.2 Project Goals and Deliverables

The primary goal of this project is to improve upon the CARB's current method for estimating vehicle miles traveled (VMT) on unpaved roads in California. The study does not include estimating PM_{10} emissions generated per VMT beyond using CARB's current unpaved road PM_{10} emission rate for demonstrative purposes, nor is it within the study scope to evaluate dust remediation measures. As part of this study we have produced an updateable framework for the estimation of VMT on unpaved roads, that includes spatial and temporal refinement, packaged in a GIS format for ease of access, updating of information, and changing of policy variables. This project extends the 1998-1999 pilot study by expanding the geographical range of the framework, by including data for additional crops, expanded land use categories, and urban interface roads.

Included in this final report are the details of seven major tasks included in the workplan for the project. These seven tasks include:

- Compiling statewide unpaved road mileage, land use, and other GIS coverages,
- Conducting traffic counts on randomly chosen non-agriculture unpaved roads in California counties and developing methods for estimating vehicle miles traveled (VMT) for these roads,
- Developing relationships between land use and VMT on non-agriculture unpaved roads and deriving default VMT for unpaved road classes,
- Extending the agriculture VMT models to other counties in the state,
- Preparing the conceptual design of a GIS based model for estimating VMT on both non-agriculture and agriculture unpaved roads,
- Program development for an unpaved road VMT GIS model,
- Estimating statewide unpaved road VMT on a county-by-county basis for 2001.

Deliverables included in this report correspond to the tasks listed above and include:

[2] Average vehicle passes reported are the acreage-weighted average vehicle passes (Coe 2000, p. -12). Corresponding arithmetic means are reported by STI as well. Their values are 5.6, 6.9, and 7.7 for Tulare, Stanislaus and the total Valley, respectively.

- A listing of the GIS coverages needed for the project,
- A description of the coverages that could reasonably be obtained as well as limitations,
- A description of the methodology used for non-agricultural traffic count site selection and how traffic counts are performed,
- A listing of the sites sampled and traffic measured at each site,
- An analysis of sampled unpaved road VMT,
- Proposed relationships between non-agricultural unpaved road VMT and other factors,
- Assumptions and rationale used to develop the VMT relationships,
- Results of data collected for selected crops,
- Development of unpaved road VMT models for each major California crop, including a tabular listing of the unpaved road VMT assigned to each crop type (as VMT/acre),
- A description, for each major crop, of the data and assumptions used to produce the VMT estimates,
- A description of the values and rationale used for the generic default VMT values,
- A description of the model design, data used, concerns and potential limitations,
- A table displaying countywide and statewide unpaved road VMT estimates for 2001.

2.0 CURRENT METHODS

This section describes the CARB's current method for estimating VMT on unpaved roads in California. It is not a comprehensive survey of methods used in other states or by other agencies.

2.1 Overview

The CARB divides unpaved roads into 2 categories when estimating annual VMT: Farm Roads and Non-farm roads. Non-farm roads are then further divided into 3 subcategories: city and county roads, US Forest Service and Park roads, and Bureau of Land Management/Bureau of Indian Affairs (BLM/BIA) roads. For each subcategory, the estimation methodology is the same: a set number of vehicle passes is multiplied by the unpaved road mileage and also by 365 days of the year. The calculated VMT is then apportioned according to monthly precipitation statistics, so that, although the annual VMT does not change, each month reflects VMT corresponding to the weather experienced in the region. Summer months then have much higher VMT than winter months. The assumption behind the apportionment is that less travel occurs on unpaved roads during wetter times of the year. Since the VMT is used to estimate PM_{10} emissions from the roads due to travel, this assumption also serves to demonstrate the diminution of PM_{10} emissions when roads are wet (CARB 1997). Equation 1 illustrates CARB's current non-farm road model.

$$V = 365RM \tag{1}$$

where, V = annual non-farm unpaved road VMT,
R = number of vehicle passes per mile of unpaved road per day,
M = miles of unpaved road,
365 = number of days in the year.

For all classes of non-farm road, CARB assumes R = 10 vehicle passes. This factor was established by limited surveys of county traffic engineers and US Forest Service officials in the 1970s (CARB 1997). The most current estimate of miles of non-farm roads (M) uses the unpaved road mileage calculated from the California Department of Transportation's (Caltrans) 1993 "Assembly of Statistical Reports" (CARB 1997).

For farm roads the CARB uses a slightly different estimation method. Instead of using the daily passes on unpaved roads, they multiply an annual activity factor by acres of harvested land. Equation 2 summarizes the farm road estimation procedure:

$$T = AF \tag{2}$$

where, T = annual VMT on unpaved agricultural (farm) roads,
A = harvested acreage in California,
F = vehicle activity factor (VMT/Acre)

CARB currently assumes F = 4.375 VMT/Acre. This factor was established using informal surveys of county agricultural commissioners in 1976. For crop acreage, CARB relies on the harvested acreage reported by the California Department of Food and Agriculture (CDFA).

Travel activity on pastureland is assumed to be minimal and therefore is excluded from the estimation.

2.2 Summary of Major Issues

There are several elements missing from the CARB's current VMT estimation method. These include:

- CARB's assumption of 10 vehicle passes over every mile of unpaved road on every day of the year has not been substantiated empirically,
- CARB's unpaved farm road activity factor (4.375 VMT/Acre) has not been substantiated in the field and could benefit from additional data collection,
- CARB uses the California Department of Transportation's 1993 unpaved road mileage estimates in its calculations. Roads may have been paved or new unpaved roads created since the creation of this database,
- There is no spatial distinction between traffic volumes in the method. Traffic volumes on roads in one land use area are assumed to be the same as in any other,
- There is no distinction between traffic generation during harvest and nonharvest periods on agricultural roads,
- There are no distinctions between crop types or field sizes for traffic on farm roads,
- There are no regional distinctions in the estimations; all estimations are based on observations in the San Joaquin Valley,
- The temporal refinement of the estimates is rudimentary.

Although refinements could also be made to the CARB's PM_{10} emission factor (spatial refinement, vehicle size distinctions, dust control measures), these are beyond the scope of this study.

3.0 PILOT STUDY

In 1998-1999 a pilot study was undertaken to explore a new theoretical framework for estimating VMT on unpaved roads. Because components of the pilot study are utilized in this report, a brief summary of the pilot study is provided here prior to discussing the new study. Appendix E describes the major findings and final reports from the pilot study.

The pilot study focused on the San Joaquin Valley, and in particular, on San Joaquin County and was designed to distinguish between unpaved road vehicular traffic associated with harvest[3] and nonharvest activities and to replace the CARB's farm/non-farm road split method. To further experiment with the generalizability of the framework, the models specified using data from San Joaquin County were also applied to Fresno County.

3.1 Overview of Methods and Models

Three model specifications were used to estimate annual VMT on unpaved roads in the pilot study: 1) a logit model specifying the proportion of growers who hauled harvested crops via unpaved roads (positive VMT), 2) a regression model specifying the estimated harvest VMT (HVMT) on unpaved roads associated with harvest-hauling activities, and 3) a regression model that estimated VMT on unpaved roads not associated with harvest activities (NVMT).

For the harvest models, the amount of unpaved road vehicle activity was specified as a function of field and crop characteristics. Harvest vehicle data were collected as part of a mail-back survey completed by San Joaquin County growers, which specified the grower's typical field acreage and crop as well as annual yield from the field and details about vehicles used to transport the harvest. In specifying a logit model, we found that HVMT was log-linearly related to our independent variables. To use all the data collected through the grower surveys, and to preserve the valuable information provided by growers who reported zero VMT on unpaved roads, we first specified a binary logit model to estimate the proportion of growers with HVMT > 0 (Equation 3):

$$\mathrm{P}_n(i) = \frac{1}{1+e^{-\beta' x_n}} \qquad (3)$$

where, $\mathrm{P}_n(i)$ = the proportion of growers with HVMT > 0 miles on unpaved roads,
x_n = the vector of observed variables,
β' = the vector of estimated coefficients on the observed variables.

The logit model specification for the harvest VMT pilot study included the variables *res* (percent of township-range-section (TRS) location classified as residential by the California Department of Water Resources (DWR)), *PRD* (paved road density of the TRS location), and *resPRD* (an interaction effect of the percent of residential area and paved road density in each TRS location). The county was then divided into sectors of 36 square miles each. The logit model was applied to the defined sectors to determine the proportion of growers in each sector that reported hauling their harvests, at least in part, via an unpaved road. The proportion was then multiplied by the total number of growers in the sector to determine how many growers

[3] It is important to note that the harvest VMT model accounts only for VMT associated with harvest transport from the field to the nearest paved road, and does not include harvesting activities on the field itself.

were needed to adequately represent the sector's harvest travel activity in the second step of the harvest VMT estimation process. An estimate of the harvest-hauling VMT was found from

$$\ln(y) = \sum_{i=1}^{8} \beta_i X_i + \beta_9 (Ag) + \varepsilon \qquad (4)$$

where, y = the estimated VMT per acre of harvested farmland,
X_i = a binary indicator denoting each of eight crop types, *i,*
β_i = estimated constants for each crop type *i*,
Ag = the percent of land classified as agricultural, by TRS location,
β_9 = the estimated parameter on *Ag*.

Although the rate of increase in harvest VMT was kept constant, the magnitude of VMT was allowed to vary by crop type, capturing any systematic differences that existed between them. Annual VMT was then apportioned by month using crop calendars assembled from responses to the mail-back grower surveys.

In the nonharvest VMT model, vehicle activity was a function of surrounding land use characteristics and access to paved roads. To model nonharvest traffic, we collected volumes at locations where paved roads access unpaved roads and estimated the number of active unpaved roads using GIS coverages as well as field verifications. The estimation of unpaved road mileage according to our field verification procedure is described by

$$M = \sum_{j} \left(\mathrm{U}_j \sum_{i} l_i \right), \quad \forall i \in j \qquad (5)$$

where, M = total county unpaved road mileage,
U_j = proportion of class 4 roads in each land use category, *j*, estimated to be unpaved,
l_i = length of sampled road segment *i*.

Daily nonharvest vehicle counts were then estimated using

$$\mathrm{y}_i = \beta_0 + \beta_1 P_{TRS} + \varepsilon \qquad (6)$$

where, y_i = the estimated number of vehicle passes per day on road segment *i,*
P_{TRS} = density of paved roads according to the TRS location, in which road segment *i* lies,
i = any active, unpaved road segment.

Daily nonharvest vehicle passes were then multiplied by the adjusted total county unpaved road mileage (*M*) and by the days of the year to arrive at an estimation of annual unpaved road VMT. Two important departures from the CARB's current model should be noted in the nonharvest VMT estimation: 1) the days of the year did not equal 365, instead vehicle passes were not included for days that had recorded precipitation; precipitation statistics also provided the distribution of nonharvest VMT among the months of the year, and, 2) we assumed that, on average, only 0.5 of the road length was traveled by each vehicle on any given trip. This assumption was based upon the observation that there was typically a single destination along each road on which traffic volumes were recorded and that destinations were not typically located at the end of the roads.

Although the pilot study proposes a more statistically robust method for estimating vehicle activity on unpaved roads than that used by the CARB, it had several limitations and relies on several assumptions. First, the database used to specify the models was very small. It was restricted to only one county (San Joaquin County), which is not necessarily representative of unpaved road activity in other counties. Second, the road count data used to specify the nonharvest model in the pilot study were limited to 10 agricultural roads, with only one 24-hour count taken on each road. The data limit the models' generalizability to roads in other counties or on other land types. Third, as became evident in our application of the model to Fresno County, some major crops, such as cotton, were not accounted for in the San Joaquin County harvest model specification. Fourth, it has been noted that if we assumed drivers travel the entire length of the unpaved road (and return by the same path) rather than traveling half of the length (and returning by the same path) during a single trip, our findings would be very similar to those of the CARB. This assumption was not tested in the pilot study.

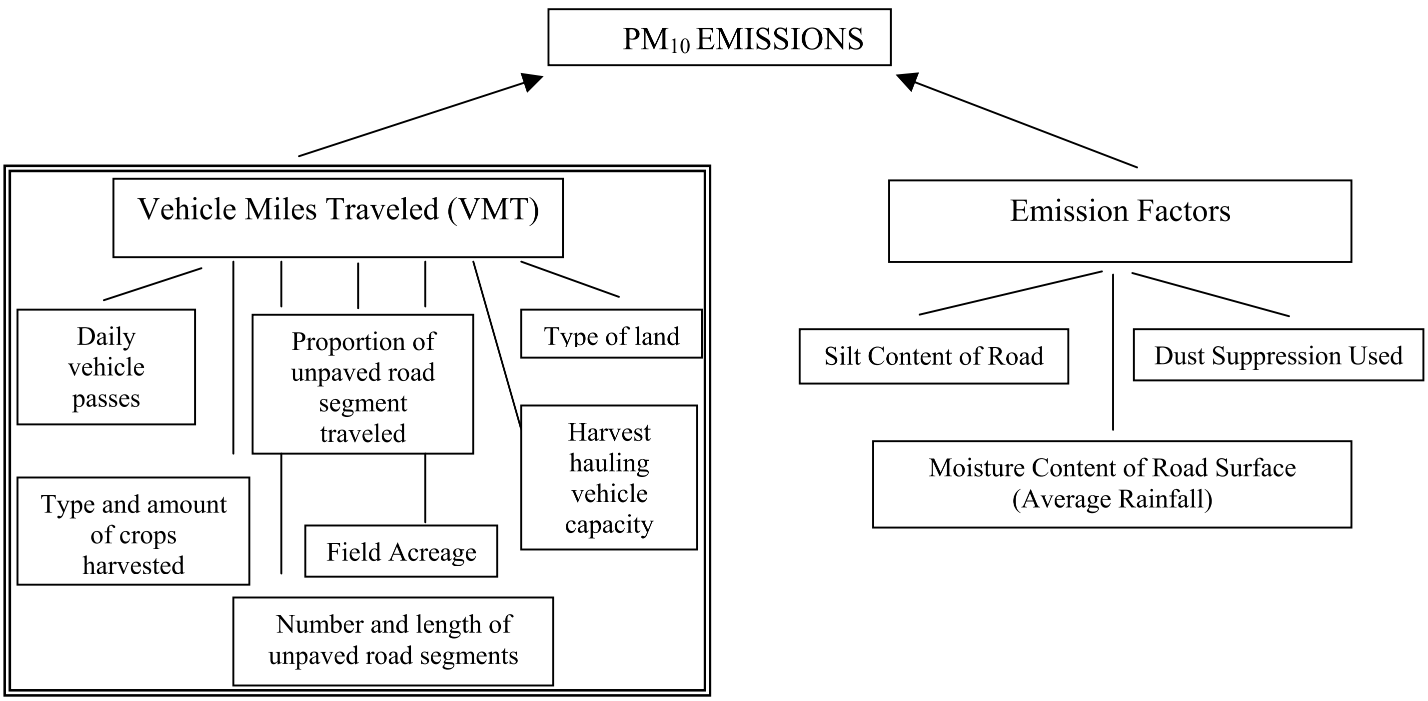
4.0 MODEL FRAMEWORK

This section broadly illustrates the structure of the current study and outlines departures from the pilot study. Both the harvest and nonharvest frameworks are generally discussed with additional details for each included in later sections.

4.1 Overview

Similar to the pilot study, the new framework distinguishes between harvest and nonharvest unpaved road VMT. In the present study, however, several major crops have been added to the harvest sampling framework, and several land use types to the nonharvest framework, to increase model applicability on a statewide basis.

Figure 1. General modeling framework



This study is concerned solely with the outlined portion of the illustration. Generally speaking, we propose that daily travel *not involved with hauling agricultural harvests* is a function of the length of the unpaved road segment, the average proportion of the road segment traveled by each vehicle during each trip, the number of two-way vehicle passes on each road per day, and the type of land accessed by the unpaved road segment. Since myriad activities take place on unpaved roads, and road users are not easily identified, we assume that land types such as scrubland, forest, urban industrial and others serve as sufficient surrogates for the activities that take place upon them.

Travel attributable to *hauling harvested crops* is a function of the capacity of the hauling vehicle(s), the yield per acre of the field, the field size (acreage), the type of crop harvested, the length of road traveled to haul the harvest away from the field, and the proportion of roads surrounding a field that are unpaved.

4.2 Harvest Vehicle Miles Traveled (HVMT)

According to recent figures, there are about 87,500 farms in California, accounting for 4% of US agricultural land and about 13% of US gross agricultural cash receipts (CDFA 2001). California leads the nation in production of many crops including lettuce, cantaloupe, tomatoes, almonds, strawberries, dates, grapes, lemons, olives, and pistachios. In 2000, there were approximately 27.8 million acres dedicated to farmland in the state with an average farm size equaling 318 acres (CDFA 2001). Table 4 shows the acreage of farmland, average farm size, and the percent of farmland harvested for selected counties in the state located in major growing regions. Major growing regions are illustrated in Figure 2.

Table 4. Farm acreage by region and county*

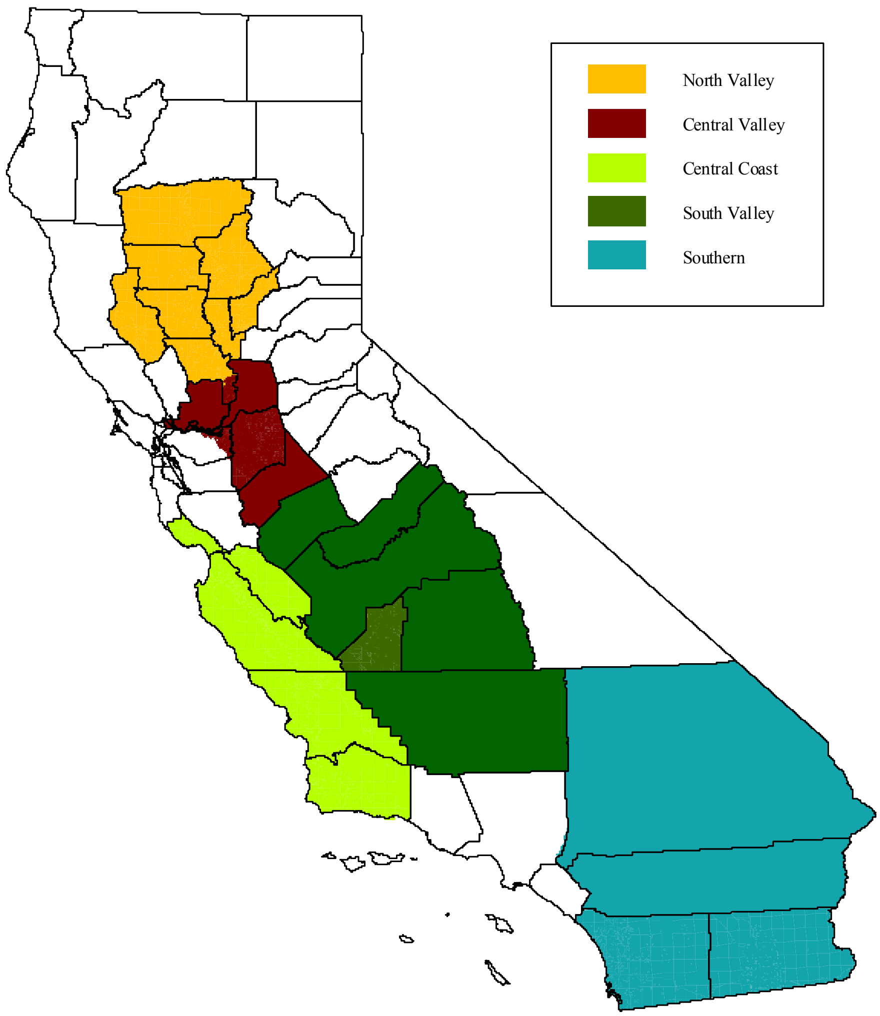
County	No. Farms	Acres	Average Farm Size	% County in Cropland**	Acres Harvested	% Cropland Harvested
CENTRAL COAST						
Monterey	980	388,633	1,277	18.3	286,426	73.7
San Benito	419	73,166	910	8.2	39,049	53.4
San Luis Obispo	1,511	280,524	679	13.2	105,237	37.5
Santa Barbara	1,169	157,213	563	8.9	107,519	68.4
Santa Cruz	637	27,776	98	9.9	22,229	80.0
NORTH VALLEY						
County	**No. Farms**	**Acres**	**Average Farm Size**	**% County in Cropland****	**Acres Harvested**	**% Cropland Harvested**
Butte	1,750	247,368	208	23.2	222,209	89.8
Colusa	759	316,756	532	42.8	287,630	90.8
Glenn	1,070	255,968	406	30.3	212,848	83.2
Lake	703	33,085	178	3.9	20,811	62.9
Sutter	1,259	297,107	265	76.5	266,399	89.7
Tehama	1,063	127,019	650	6.7	62,038	48.8
Yolo	832	380,700	581	57.5	324,291	85.2
Yuba	548	96,989	295	23.7	79,586	82.1
CENTRAL VALLEY						
County	**No. Farms**	**Acres**	**Average Farm Size**	**% County in Cropland****	**Acres Harvested**	**% Cropland Harvested**
Sacramento	986	159,059	239	24.5	120,220	75.6
San Joaquin	3,552	559,435	209	60.9	498,985	89.2
Solano	651	209,551	455	37.5	141,017	67.3
Stanislaus	3,481	381,601	183	37.3	315,978	82.8

Table 6. Acreage of Farmland by Region and County* (continued)

SOUTH VALLEY						
County	**No. Farms**	**Acres**	**Average Farm Size**	**% County in Cropland****	**Acres Harvested**	**% Cropland Harvested**
Fresno	6,005	1,250,984	285	32.6	1,157,357	92.5
Kern	1,522	1,054,228	1,428	20.2	893,221	84.7
Kings	935	526,132	609	57.3	445,537	84.7
Madera	1,400	332,617	383	24.2	294,706	88.6
Merced	2,485	532,327	311	41.4	434,074	81.5
Tulare	4,992	703,295	240	22.7	639,578	90.9
SOUTHERN						
County	**No. Farms**	**Acres**	**Average Farm Size**	**% County in Cropland****	**Acres Harvested**	**% Cropland Harvested**
Imperial	493	459,386	879	15.6	433,119	94.3
Riverside	2,367	279,806	167	6.0	245,446	87.7
San Bernardino	982	58,141	635	0.5	39,543	68.0
San Diego	5,474	112,974	80	4.1	77,574	68.7

* Adapted from USDA (1999). "No. Farms," "Acres," and "Acres Harvested" are based on values given for "Total cropland" and "Harvested cropland."
** "% County in Cropland" is calculated by area. Total area for each county was derived from the CSAC (2002).

Figure 2. Major growing regions in California



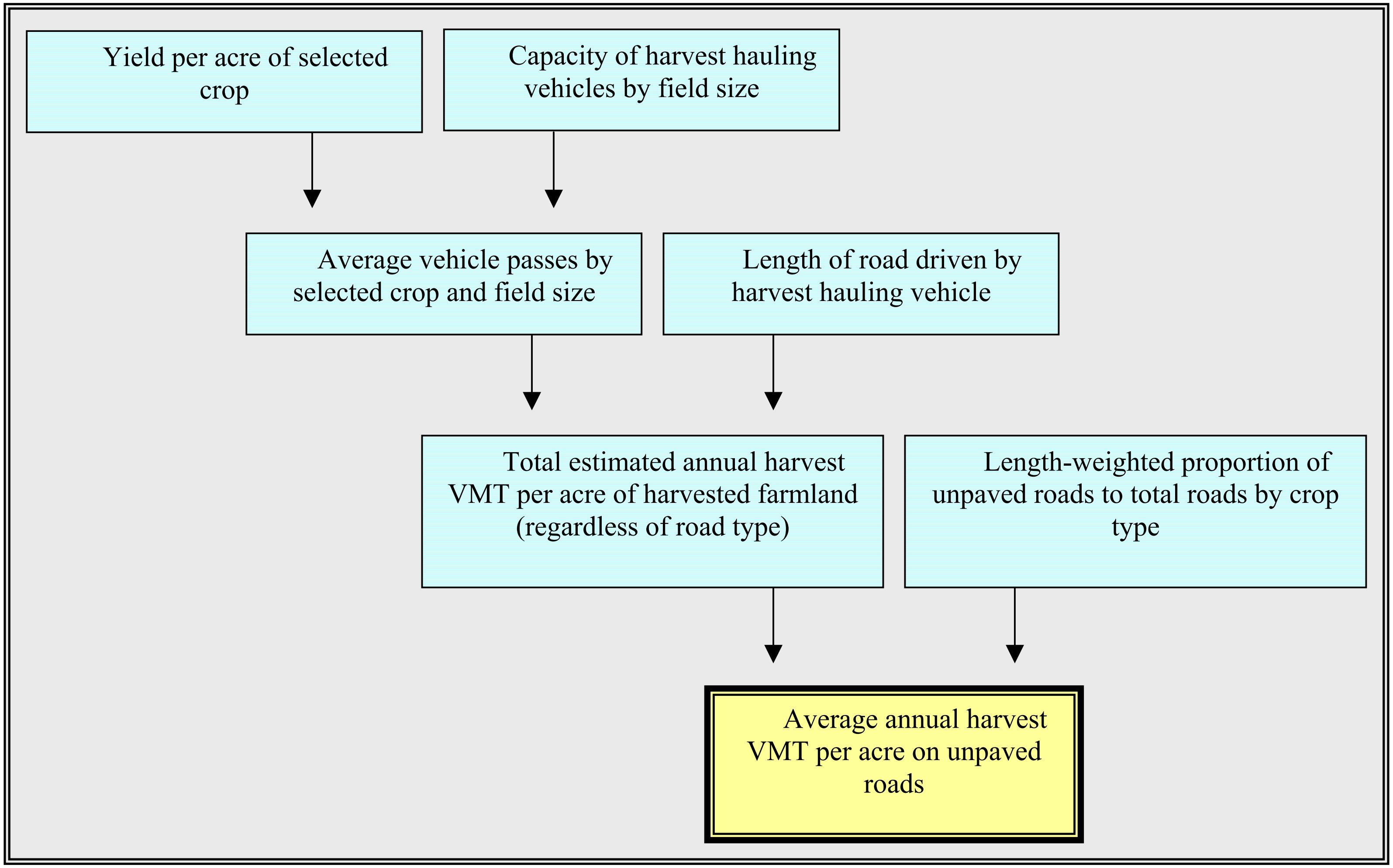
Fresno County leads the nation in terms of agricultural cash productivity, providing over $3.4 billion[4] in agricultural commodities in 2000. Its top commodities included grapes, cotton and tomatoes (CDFA 2001). Tulare, Monterey, Kern, and Merced Counties follow Fresno's lead, rounding out the top 5 agricultural counties in the state, producing approximately $3.1 billion, $2.4 billion, $2.1 billion, and $1.5 billion of agricultural commodities, respectively. Leading crops in these counties include oranges, grapes, plums, lettuce, broccoli, strawberries, cotton, and almonds (CDFA 2001). Nevada, Sierra, Trinity, San Francisco, and Alpine Counties ranked the lowest in the state in terms of agricultural production, each generating less than $7.1 million of agricultural commodities in 2000 (CDFA 2001).

A framework that can be used to estimate VMT per acre and VMT per acre by crop type is needed for major crops and major growing areas in the state to estimate agricultural harvest VMT. Because harvesting may sometimes occur when atmospheric conditions can lead to elevated PM levels, harvest related VMT was analyzed separately from other unpaved road VMT. In this method, VMT associated with agricultural harvests is a function of crop, crop yields, field size and the average capacity of equipment used to haul the harvest from the field to its next destination. VMT on *unpaved roads* is additionally a function of alternative transportation routes (*e.g.*, via paved roads).

Unlike the pilot study, we were unable to distribute a survey to California growers during the study period so we revised our approach for the harvest VMT framework. The pilot study survey results suggested that approximately 35% of growers in San Joaquin County did not carry their crops from fields via unpaved roads. Building on this observation, we based our new harvest framework on the assumption that growers may or may not have fields bordered by unpaved roads and that the presence or absence of unpaved roads abutting agricultural fields is important to estimating unpaved road VMT during harvest seasons. Figure 3 illustrates the structure of the new harvest framework.

[4] Dollar amounts include crops, livestock, and floriculture, but exclude timber.

Figure 3. Harvest VMT framework



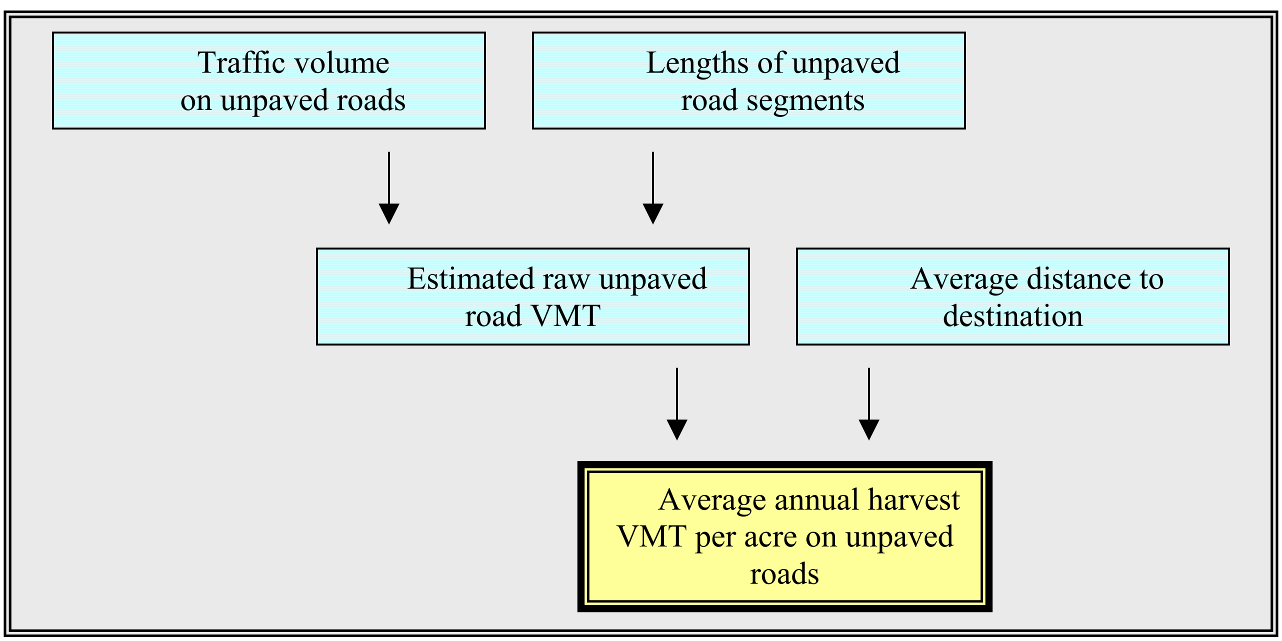
Crops and average yields per acre are derived from previous literature, while hauling capacities of harvest trucks are estimated using responses from the pilot study survey. The proportion of unpaved roads to total roads accessing agricultural fields is determined from satellite imagery. The new framework will provide the CARB with benefits including: 1) the ability to compare and test the results from the pilot study with results obtained from a different modeling structure, and 2) the ability to incorporate hypothetical policy alternatives in the VMT prediction.

4.3 Nonharvest Vehicle Miles Traveled (NVMT)

Nonharvest activities relevant to estimating VMT on unpaved roads take place on lands owned by the federal government (*e.g.*, Bureau of Land Management, US Forest Service, National Park Service), the state government (*e.g.*, California State Parks), counties, and private landholders. The Bureau of Land Management supervises approximately 14.7 million acres in California, the US Forest Service about 40.2 million acres and the National Park Service approximately 8.3 million acres. State parklands account for approximately 1.4 million acres. According to the 1997 Census of Agriculture, pastureland and rangeland constituted nearly 52% of land use in California, while cropland accounted for 39%, woodlands for about 4%, and "other" land for 5% (USDA 1999). Each of these managed areas support a variety of commodity- and recreation-based activities.

Unpaved road VMT associated with nonharvest activities is a function of land type, number of vehicle passes, length of unpaved roads, and the average proportion of road that is traveled during a single trip. Figure 4 illustrates the structure of the expanded nonharvest framework. Land use characteristics are used as a surrogate for the activities that take place on unpaved roads accessing those land use types.

Figure 4. Nonharvest VMT framework



The nonharvest model estimates unpaved road VMT accessing agricultural as well as non-agricultural lands and geographically encompasses a wide range of locations. Many different activities take place on each of these land types and the different activities can be expected to produce very different levels of travel activity. Potential activities include residential, commodity-based (such as timber or mining activities), agricultural (*e.g.*, transport to fields for preparation), and recreational (*e.g.*, all-terrain vehicle driving, driving to hiking trailheads). Because of the diversity of activities served and because of the many land uses involved, we expect that the vast majority of California's unpaved road travel will come from activities included in the nonharvest model.

5.0 METHODOLOGICAL FRAMEWORK FOR HARVEST VMT

Originally, the harvest framework was developed to follow the design developed in the pilot study. A plan was created to send a mail-back survey to 1600 growers in 5 representative counties to establish a database of vehicle capacities and unpaved road VMT for a wider variety of crops than were included in the pilot study. The survey would also serve to include additional geographical regions in the VMT estimation process. With the additional data, we planned to test and further generalize the pilot study harvest framework to be applicable on a statewide basis.

Near the end of the study period, the agricultural community expressed concerns to the CARB. The CARB indicated that the grower survey should not be distributed and the data collection approach should be modified. We subsequently modified the approach to utilize prior published materials and university extension services where available. Therefore, the framework presented here characterizes harvest-hauling traffic using limited empirical agriculture data and redirection very late in the study process.

5.1 Framework

Because of limited access, we chose an indirect method for our new approach to estimating harvest VMT (HVMT). The method is based on 4 primary steps:

1) Establishing the two-way harvest-hauling vehicle passes on agricultural roads,
2) Estimating the average lengths of roads that access agricultural fields (mile/acre),
3) Multiplying the average length of roads (established in Step 2) by vehicle passes (established in Step 1) to establish a raw HVMT that includes travel on both paved and unpaved roads,
4) Multiplying the estimated raw HVMT by the proportion of road segments estimated to be unpaved. This leads us to an estimated annual harvest-hauling unpaved road VMT.

These steps are summarized in Equation 7,

$$U_f = \frac{1}{2}\left(\frac{Y_i A_f}{T_j}\right)(L_c)(A_f)(P_c) \tag{7}$$

where,
- U_f = HVMT on unpaved roads for field *f*,
- Y_i = the average yield per acre or major crop *i*,
- A_f = the acreage of field *f*,
- T_j = the average hauling truck capacity used for field size *j*,
- L_c = the average length of roads per acre that access fields in crop type *c*,
- P_c = the average proportion of unpaved road lengths to total road lengths by crop type *c*.

The ½ in Equation 7 takes into account two pieces of the modeling procedure: 1) it accounts for both the inbound and outbound travel of the harvest vehicle by multiplying the equation by 2, and, 2) it incorporates an assumption that each hauling vehicle drives the equivalent of 1 road of the 4 segments surrounding a field during each hauling trip (dividing the equation by 4). Additional details regarding this assumption can be found in Section 5.1.2.

We hypothesized a strong correlation between crop type and the proportion of unpaved roads that access a given field. Results from the pilot study showed notable differences by crop type in the percentages of growers who reported zero VMT on unpaved roads. Of the approximately 35% of the growers who reported zero VMT on unpaved roads, roughly 31% were nut growers, followed by vine growers (25%), bean/legume growers (16%), fruit growers (13%), grain growers (6%), and the remaining 9% were comprised of tomato, vegetable, and oil-product growers. This led us to suspect, for instance, that vegetable crops would positively influence the proportion of unpaved roads (*i.e.*, a higher proportion of unpaved roads) while nuts and grapes would negatively influence the proportion (*i.e.*, a lower proportion of roads will be unpaved).

We also hypothesized that the carrying capacity of harvest vehicles would vary by field size. This hypothesis was based on two factors: 1) the pilot study survey responses showed a large variation in harvest equipment capacities reported by growers of the same crop, and 2) conversations with UC Davis Agricultural Extension advisors, when taken together, suggested that vehicle capacities were often the same for a variety of crops (*e.g.*, wheat, tomatoes, rice). For these reasons, we suspected that crops generally grown on large fields would utilize hauling vehicles with large capacities while crops generally grown on a smaller scale would utilize hauling vehicles with relatively smaller capacities.

There are distinct advantages and disadvantages to using this framework: 1) we can estimate HVMT at the field size or grid size, 2) we can aggregate HVMT by crop type, and location (*e.g.*, county, state), and, 3) as growers pave or de-pave roads, change their travel behavior, or add further roads to their property, the proportion of unpaved roads accessing agricultural fields and the distance driven on those roads can be altered as a policy variable. Similarly, as hauling vehicle capacities change, the number of vehicle passes needed to haul harvests can be altered. This allows the CARB to investigate potential PM_{10} control scenarios by allowing them to alter the proportions of unpaved roads (or vehicle capacities) in specific areas or for specific crops to predict the effectiveness of controlling PM_{10} emissions from unpaved roads by various hypothetical means.

The major disadvantages of the framework include a lack of available primary data, a lack of grower input in the formation of the framework or in data collection, and a limited number of crops and field sizes incorporated into the framework development process. Although the original project proposal included distributing grower surveys, the CARB modified this portion of the project due to concerns about distributing surveys to the agricultural community. While this method provides a stronger and more defensible design for estimating HVMT than the current approach, the framework can be further strengthened and enhanced through collecting and incorporating additional detailed activity information from farming industry representatives.

5.1.1 Estimating Harvest Traffic Volumes

Harvest traffic volumes included in this study do not include vehicle passes created by workers being transported to and from fields nor do they include vehicle passes generated by moving harvest equipment to and from or between fields. These are included in the nonharvest VMT estimates. Furthermore, harvest traffic volumes do not include any vehicle passes that take place on the field itself. Only the hauling of harvested crops from the field pick-up point to the nearest paved road on the vehicles' routes are considered in the estimation process. Because of the narrow scope of the harvest traffic volume, we can estimate vehicle passes using 3 essential components: the yield per acre of the crops we consider, the acreage of each crop in each region of interest, and the capacity of vehicles carrying each crop away from the field.

The first task is to define regions and crops of interest. Important agricultural counties can be defined in two ways: the amount of land dedicated to farm use within a county and the prevalence of key commercial crops in the county. In terms of acreage, the major counties include Fresno, Kern, Kings, Madera, Merced, Modoc, Monterey, San Joaquin, San Luis Obispo, Santa Barbara, San Bernardino, Stanislaus, Tulare, and Tehama[5] (USDA 1999). In terms of harvest, many of the same counties appear, including Fresno, Kern, Kings, Madera, Monterey, and Tulare (CDFA 2001). Since the two measures are similar in their results and we are most concerned about the harvests of significant crops, major growing regions in this study were chosen in accordance with the number of major crops that were produced in each county. The California Department of Food and Agriculture (CDFA) lists 350 crops recognized in the state (including seeds, flowers, and ornamentals). Of these, the statistics of 67 major crops (crops "grown on a large commercial scale") are reported in the CDFA Agricultural Resource Directory (CDFA 2001). The 67 crops include 13 field crops (*e.g.*, barley, cotton), 25 fruit and nuts (*e.g.*, avocados, strawberries, almonds, pistachios), and 29 vegetables (*e.g.*, asparagus, melons). Fresno County is a leading producer of 52% of these crops, Kern 34%, Merced 18%, Monterey 28%, and Tulare 32%. Major growing regions in this study include only counties that were reported as leading producers of 2 or more of the 67 crops included in the CDFA Agricultural Resource Directory for 2001.[6]

A summary of the CDFA's "major crops,"[7] their total harvested acreage, and their yields per acre for 2000 are shown in Table 5. In the case that a reported crop has more than one yield per acre value (*e.g.*, for freestone peaches versus clingstone peaches) one value is reported in the table with the other(s) contained in the table notes. In the future, better regional data for yields per acre can be acquired to produce more accurate local estimates of vehicle passes.

---

[5] "Important counties" are defined as those with a substantial amount of land in farms. Using categories set forth by the USDA, these include a minimum of 638,567 acres of the county land in farms (USDA 1999).

[6] The major crops described by the CDFA account for over 8 million harvested acres in the state, representing over 30% of all land in farms in the state and approximately 98% of harvested cropland (USDA 1999; CDFA 2001).

[7] Foliage, flower, and nursery products are not included in the HVMT framework.

Table 5. Major crops and harvested acreage in California*

CROP	HARVESTED ACRES*	YIELD PER ACRE (lbs.)	CROP	HARVESTED ACRES**	YIELD PER ACRE (lbs.)
Almond	500,000	1,410.0	Hay (all)	1,530,000	14,000.0
Apple	31,000	21,000.0	Honeydew	22,000	19,000.0
Apricot	19,000	9,680.0	Kale	2,000	27,500.0
Artichoke	9,500	11,500.0	Kiwifruit	5,300	12,840.0
Asparagus	37,000	3,200.0	Lemon	48,500	29,792.0
Avocado	59,000	5,460.0	Lettuce (all)***	221,500	37,000.0
Barley	85,000	3,260.0	Mushroom	537	240,800.0
Bean (snap)	5,500	10,000.0	Mustard Greens	1,500	14,000.0
Bean (dry)	112,000	1,880.0	Nectarine	35,500	15,040.0
Bell Pepper	29,200	30,500.0	Oat	25,000	2,400.0
Boysenberry	260	9,600.0	Olive	36,000	2,940.0
Broccoli	124,000	14,000.0	Onion	43,400	44,300.0
Brussels Sprout	2,900	16,000.0	Orange (all)	195,500	24,562.5
Cabbage	13,700	37,000.0	Peach (all)****	67,200	21,000.0
Cantaloupe	57,500	22,000.0	Pear (all)	19,300	32,400.0
Carrot*****	91,480	29,000.0	Pecan	2,600	1,310.0
Cauliflower	42,000	16,000.0	Pistachio	74,600	3,260.0
Celery	23,500	70,500.0	Plum******	124,000	10,360.0
Cherry	19,000	4,940.0	Potato (all)	43,000	25,000.0
Chili Pepper	3,900	23,000.0	Pumpkin	5,900	30,500.0
Collard Greens	500	20,000.0	Radish	1,500	25,000.0
Corn (fresh)	24,000	14,000.0	Raspberry	2,000	10,800.0
Corn (grain)	235,000	9,520.0	Rice (all)	548,000	7,950.0
Corn (silage)	300,000	52,000.0	Spinach (fresh)	17,000	18,500.0
Cotton (all)	914,000	1,342.0	Squash	8,600	16,000.0
Cucumber (fresh)	6,500	28,500.0	Strawberry (all)	27,600	55,000.0
Date	4,700	6,180.0	Sugar Beet	93,500	65,000.0
Eggplant	1,700	22,000.0	Sweet Potato	9,700	25,000.0
Escarole / Endive	2,000	15,500.0	Tangerine	8,600	21,825.0
Fig	15,000	7,340.0	Tomato (fresh)	42.800	26,000.0
Garlic	39,000	17,000.0	Walnut	193,000	2,480.0
Grapefruit (all)	16,600	29,078.0	Watermelon	12,300	19,000.0
Grape (all)	827,000	17,000.0	Wheat (all)	447,000	4,600.0
TOTAL HARVESTED ACRES: 7,523,620					

* All "Harvested Acre" and "Yield per Acre" values are derived from CDFA (2001) . Yield per acre is reported as the total yield (in lbs.) divided by the total harvested acreage.
**For tree fruit and nut crops (*e.g.*, grapefruit, peaches, walnut) this number reflects the "bearing acres" listed in the CDFA (2001).
***This yield per acre represents head lettuce. Leaf lettuce and romaine lettuce have yields of 23,500 lbs. per acre and 29,400 lbs. per acre, respectively.
****The yield per acre represents freestone peaches. The yield per acre for clingstone peaches is 37,700 lbs. per acre.
*****This yield per acre represents fresh carrots. The yield per acre for carrots for processing is 60,600 lbs. per acre.
******The "Plum" category includes harvested acres for fresh plums as well as plums used for prunes and the yield per acre represents the average yield per acre of the two plum types. The yield per acre for fresh plums is ___ lbs. per acre; for prune plums it is 5,100 lbs. per acre.

The second task was to determine the number and acreage of fields associated with each of these crops in each county. For most counties in major growing regions, County Agricultural Commissioners' Offices (CACs) were able to provide us with a list of growers from the Pesticide Use Permitting System. This list provided us with an inventory of commodities (crops) and field sizes (acreages) for each grower. The lists also included a variety of non-crop entries (*e.g.,* vertebrate control) and non-area unit sizes (*e.g.*, cubic feet) that were eliminated before any calculations were undertaken. Table 6 shows the CACs that provided grower lists. All grower lists are from 2000.

Table 6. Counties providing grower data

Counties		
Amador	Marin	San Luis Obispo
Butte	Merced	Santa Barbara
Colusa	Monterey	Santa Cruz
Contra Costa	Riverside	Stanislaus
Fresno	Sacramento	Sutter
Glenn	San Benito	Tulare
Kern	San Bernardino	Tuolumne
Kings	San Diego	Yolo
Madera	San Joaquin	Yuba

We believe that the grower lists may actually overestimate the harvested acreage in a county because it is likely that not all acreage farmed will also be harvested. However, since it provides the most disaggregate and complete data, in each county for which it was available, the grower lists were used as the primary data for all HVMT estimations. We aggregated agricultural acreage for other counties from harvest acreage reported in the 2000 County Agricultural Commissioners' Data (published August 2001).

The third and final task required for estimating harvest-hauling vehicle passes was to estimate the hauling capacity used to carry harvested crops away from the field. In lieu of new data from growers or agricultural experts, we drew upon the pilot study survey for vehicle capacity data. In the pilot study survey, growers reported the acreage of a "typical" field on their farm, the capacity of the vehicles used to haul the harvests away from fields, and the percentage of their harvest that was typically carried by each vehicle type. Using these figures, we calculated the average capacity of hauling vehicles by both crop type and by field size. Since there were limited responses to this portion of the survey (N=93), we could not use both crop type and field size simultaneously as determinants. Table 7 shows the decision rule and average capacities of hauling vehicles used during harvests according to field size.

Table 7. Average capacity of hauling vehicles used by field size

Field Size (acres)	N	Mean	Median	Mode	Skewness	SE of Skewness	z	α	Critical z	Capacity Chosen (lbs.)
0 to 2.99	4	1,000	1,000	500	1.19	1.014	1.17	0.0005	12.92	**1,000**
3 to 14.99	12	13,375	6,000	2,000	1.26	0.637	1.98	0.0005	4.44	**13,375**
15 to 49.99	45	25,783	12,000	2,000	1.035	0.354	2.92	0.0005	3.50	**25,783**
50 to 124.99	24	49,063	52,000	80,000	-0.205	0.472	-0.43	0.0005	3.77	**49,063**
> 125	8	54,492	51,000	5,940	1.498	0.752	1.99	0.0005	5.41	**54,492**

Although we are interested in using the most common vehicle hauling capacity for our estimates, using the mode to represent hauling capacities seemed unwise since there were such low numbers of vehicles reported. Instead we calculated both the mean and the median for each field size and used a skewness[8] test to indicate whether the mean or median better represented approximate vehicle capacity. Where $z < critical\ z$, we fail to reject the hypothesis that the data are normally distributed and accept the mean value as representative of the vehicle capacity. If $z > critical\ z$, we reject the hypothesis that the data are normally distributed and accept that they are significantly skewed. In this case, the median is chosen in place of the mean as representative of the vehicle capacity.

Data splits, including total aggregated data, field size, and crop type were investigated before making the determination that field size provided the most accurate split. We observed a slightly greater variation in vehicle hauling capacities within crop categories than within field size categories. Without additional information, the hauling capacities by field size were better suited to the data available to us. Therefore, we calculated our HVMT figures for each county using the average vehicle capacity according to field size.

5.1.2 Estimating Distance Traveled on Unpaved Roads

There are three major considerations which are taken into account in estimating the distance traveled by harvest-hauling vehicles: 1) the average length of roads accessing agricultural fields, 2) the average proportion of those roads that is unpaved, and 3) the number of roads traveled during any one trip by the harvest hauler. We analyze both the average length of roads and proportion of roads that are unpaved by crop type and make an informed assumption about the number of roads driven during any given trip.

The average lengths of roads (paved and unpaved) are determined through sampling a selection of fields by crop type, totaling the length of roads per crop type and dividing that sum by the total acreage sampled in that crop type. The result is an average length of road per acre per crop category. We then estimate the length-weighted proportion of unpaved roads that access the same sampled fields and multiply that proportion by the average length of total roads per acre of field. Last, we use one-quarter of the average length of all roads to represent the number of roads driven during a single trip. This proportion is based on the assumption that in hauling crops away from the field, the grower seeks to minimize the distance which hauling vehicles travel on unpaved roads and seeks to make harvested crops easier to reach using large vehicles. We also assume that the most direct and simplest route is the most likely for a hauling vehicle to follow, so during harvest, only 1 of the 4 roads bounding the harvest field would be used at any one time. These assumptions were substantiated through discussions with UC Davis Agricultural Extension farm advisors.

The average length of roads (paved as well as unpaved) accessing agricultural fields are shown in Table 8. Table 9 demonstrates the decision process for the proportion of roads that are unpaved and access agricultural fields. Several attempts were made to model this data using different data splits such as field size and crop category. The final selection was made according to Table 9. We used the same skewness test described in Section 5.1.1 to select the proportion of unpaved roads that characterizes fields of each crop type.

[8] The skewness measure indicates the shape of the reported data and its deviation from a normal distribution. The significance of the deviation from normal can be calculated by z = (Skewness – 0)/SE Skewness.

Table 8. Average road lengths per acre

Crop Type	All road length (mile/acre)	Unpaved road length (mile/acre)
Grain	0.020	0.016
Field	0.022	0.019
Tree Fruit & Nut	0.001	0.001
Vine & Berry	0.026	0.023
Vegetable	0.037	0.035

Table 9. Proportion of unpaved roads and decision rules

Crop Type	N	Mean	Median	Skewness	SE of Skewness	*z*	α	Critical *z*	Proportion Chosen
Grain	23	0.76	0.80	-1.834	0.481	-3.81	0.0005	-3.792	**0.80**
Field	15	0.81	1.00	-0.467	0.580	-0.81	0.0005	- 4.14	**0.81**
Tree Fruit and Nut	29	0.90	1.00	-3.245	0.434	-7.48	0.0005	-3.674	**1.00**
Vine and Berry	8	0.87	0.98	-1.534	0.752	-2.04	0.0005	-5.408	**0.87**
Vegetable	26	0.91	1.00	-1.712	0.456	-3.75	0.0005	-3.725	**1.00**

The unpaved road proportions matched our expectations to a large extent. We had expected vegetable crops to be associated with a higher proportion of unpaved roads and vine crops with a lower proportion of unpaved roads. However, we had expected nut fields to also be associated with a lower proportion. This did not turn out to be the case. This could be attributable to the fact that tree fruit fields are combined with nut fields in the present study while they were considered separate crop categories in the pilot study. It could also be attributable to the inclusion of a much wider geographical range in the data collection. It could also point to a misunderstanding of the questions asked in the pilot study survey, resulting in erroneous responses being reported.

5.2 Data Collection

We used a combination of satellite data, aerial photographs, grower lists, and California Department of Water Resources (DWR) land use data to identify fields of specified crops, record the approximate shape of the fields, and the number, types and lengths of roads in and around those fields. Considering our data constraints, to ensure that information could be collected for a representative portion of crop types in a variety of California locations, we utilized the major growing region as our main unit of study. Counties in each of the 5 major growing regions that had both DWR land use data and provided grower lists were included in the sampling frame. Table 10 lists the counties included in the sampling frame and the regions they represent.

Table 10. Regions and representative counties

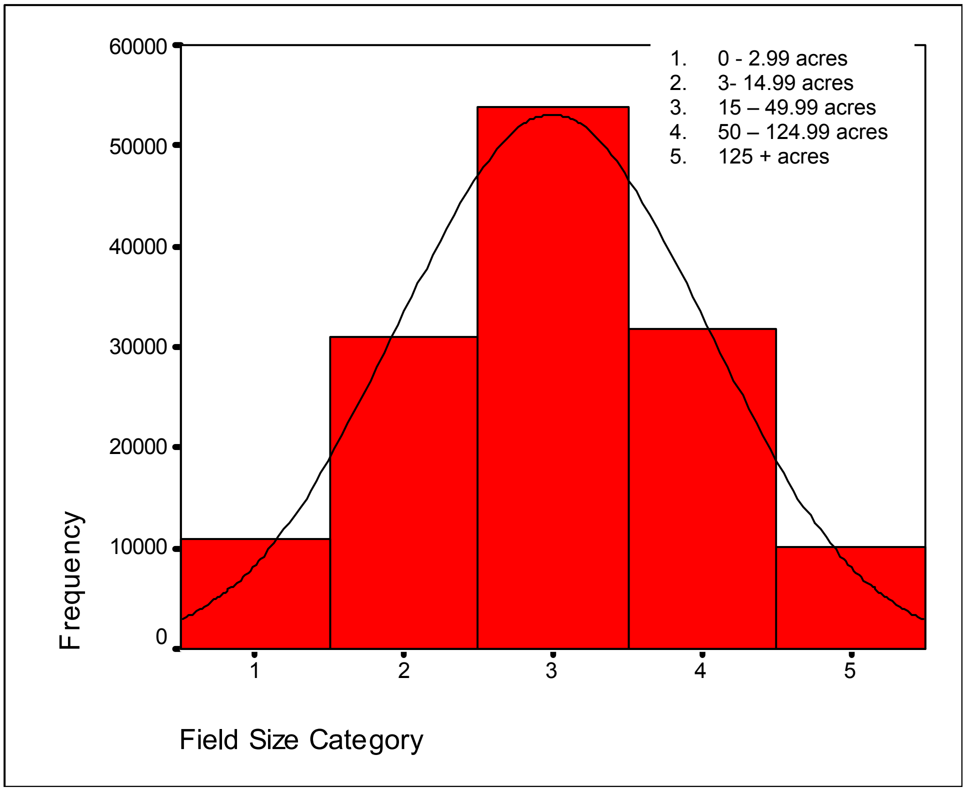
Region	Counties[9]
Central Coast	Monterey, San Luis Obispo, Santa Barbara
Central Valley	Sacramento, San Joaquin, Stanislaus
North Valley	Butte, Colusa, Glenn, Yolo, Yuba
South Valley	Fresno, Madera, Merced, Tulare
Southern	Riverside, San Bernardino, San Diego

Crops in each grower list were aggregated into 1 of 5 crop types: 1) Grain, 2) Field, 3) Tree fruit and nuts, 4) Vine and berry, or 5) Vegetable. The grain category includes crops such as barley, oats, and wheat; Field includes crops such as cotton, grain corn, and dry beans; Tree fruit and nuts include crops such as oranges, avocados, olives, and pecans; Vine and berry consist of crops such as strawberries, boysenberries, and grapes; and, Vegetable includes such crops as broccoli, squash, and watermelon. A complete list of included crops and their categories can be gleaned from Appendix D (statewide crop schedules). Crop categories were designated using a variation on the basic categories set forth by the CDFA and the DWR. The CDFA categories were altered to reflect hypothesized differences between how harvested produce would be carried from the field and the capacity of vehicles that would be used. DWR categories were used to separate field and grain crops.

Similarly, field size categories were established to take into account the differences in hauling harvests between fields of different sizes. Using a database that combined all the grower lists shown in Table 6 and preserved only fields that were represented in the 5 crop categories, field size category bins were established by adjusting the categories until they approximated a normal curve (Figure 5).

[9] Solano, and Imperial Counties have been dropped from the sampling frame due to a lack of grower information. Lake County, although originally part of the North Valley region is not a major growing area and could not provide us with a list of growers. Lake County has also been dropped.

Figure 5. Field size distribution



By establishing major growing regions, crop categories and field size categories we could ensure that our sampling plan could be generalized over a wide geographical area, many crops, and all field sizes included in the grower lists.

5.2.1 Data Sources

We used several databases in the development of the HVMT framework. These included:

- SPOT 10 Satellite Imagery (CARB),
- A GIS land use coverage for each county (DWR),
- Aerial photography (DWR),
- A GIS roads coverage for each county (Caltrans),
- A list of growers for each county in a major growing region (County Agricultural Commissioners).

The SPOT 10 satellite imagery consists of a collection of black and white images taken by satellite with a 10-meter resolution. The data were collected in 1998 for all of California. The data are also compatible with ArcView and can be uploaded into project files to be used in conjunction with other GIS databases. In lieu of mail-back survey responses and the ability to travel to each field to conduct visual surveys, we used the SPOT 10 data with other spatial data to identify the number and types of roads (paved or unpaved) accessing a given agricultural field.

Land use databases have been developed by the DWR for all or portions of 40 counties in the state and range in age, the earliest being developed in 1993 and the latest in 2000. At this time, there are also plans to develop land use databases for 6 additional counties. The databases contain a variety of useful information including field acreage and crop type, with varying degrees of specificity. For instance, although one field entry may specify an "oat" crop, another oat field may be simply listed as "grain." Land use surveys are incomplete in some counties, however they appear to contain data for the portions of the counties that are dedicated primarily to agriculture.

Aerial photographs are also available from the DWR in the form of JPEG files. Photos were taken in the same year as their accompanying land use databases, however photographs are only available for a fraction of the counties with land use databases and are sometimes incomplete. Photography is available for the full extent of the land use databases developed for Fresno, Kern, Kings, Sacramento, San Bernardino, San Joaquin, Sutter and Yolo Counties. It is available, in part, for Butte, Colusa, Glenn, Monterey, Santa Cruz, and Tulare Counties. The aerial photographs provided some advantages over the satellite imagery. Roads and road types are more easily distinguishable in the photographs because of differences in the colors of road surfaces and field types. However, since the aerial photography is not as geographically complete as the satellite imagery, photographs were used only to confirm road data recorded from the satellite images.

Road coverages for each county have been created by the California Department of Transportation (Caltrans) and include all known roads by service class. The database contains a series of arcs or road segments with unequal lengths that make up each county's road network. Table 11 shows the road classifications and contains a brief description of each.

Table 11. Road coverage service classes and descriptions

Service Class	Description
1	Primary route
2	Secondary route
3	Thoroughfares
4	Residential, unimproved and unpaved roads
5	Four wheel drive vehicle and other than four-wheel drive vehicle (*e.g*., hiking trail)
6	Own classification
7	USGS classification
9	Newly digitized roads or recoded as highway by Caltrans

For the harvest model data collection process, we concentrate on class 4 roads. The road coverage database has some flaws: although the status of paved roads has been recently updated, the status of class 4 roads has not. Some class 4 roads may now be paved or no longer exist while others may exist that have not yet been included in the database. Regardless of the flaws, the Caltrans road database provides the most thorough survey of roads in California available for this study.

Grower lists come from the Pesticide Use Permitting System and are available from most County Agricultural Commissioners' Offices in the state. The lists contain the permit number, permittee name, and a variety of location, crop, and acreage information for agricultural fields. In this study, the grower lists were useful in establishing a sampling frame and later in applying estimated VMT/acre on a countywide basis.

5.2.2 Sample Field Selection

Establishing a minimum sample size for the harvest framework was difficult because we had no prior data to suggest a standard deviation for the population of unpaved roads accessing agricultural fields in California. Therefore, our sampling scheme is based primarily on practical considerations. In attempting to strike a balance between representative samples and limited resources, we chose to visually survey a total of 20 fields in each major growing region. This resulted in a sample size of approximately 100 fields and was designed to reflect the relative proportions of crop types grown on a statewide scale. In each major growing region, the number of fields sampled in the crop type varies by the proportion of each crop type represented in the given growing region. In other words, if in the "Southern" growing region (Riverside, San Bernardino, and San Diego Counties) "Vegetable" crops account for 50% of all fields, while "Tree fruit and nut" crops account for only 5%, 10 "Vegetable" fields were surveyed in the "Southern" region while only 1 "Tree fruit and nut" field was surveyed. Table 12 shows the proportion of each crop type for each of the 5 growing regions.

Table 12. Representation of the 5 crop types in each growing region

	% Grain	% Field	% Tree Fruit and Nut	% Vine and Berry	% Vegetable	% Total*
Central Coast	7.1	2.8	9.0	11.3	69.8	100
Central Valley	22.6	21.7	31.1	9.9	15.0	100
North Valley	44.1	13.9	27.2	1.8	13.0	100
South Valley	17.6	19.4	44.1	13.7	5.2	100
Southern	20.8	9.1	39.3	4.1	26.7	100

* The columns do not sum to exactly 100% because of rounding error.

Within these areas, grower fields were chosen according to a stratified random sampling scheme for a visual review of fields containing specified crops. The lists of growers for each county in each growing region were aggregated to form 5 field databases for sampling, 1 representing each growing region. Rounding of crop proportions resulted in 1 extra field being chosen in the "Central Valley" growing region, for a total of 101 fields selected for visual inspection. Table 13 shows the field distribution in each county.

Table 13. Number of fields surveyed in each growing region

	Grain	Field	Tree Fruit and Nut	Vine and Berry	Vegetable	Total
Central Coast	1	1	2	3	13	20
Central Valley	5	4	6	2	4	21
North Valley	9	3	5	0	3	20
South Valley	4	4	8	3	1	20
Southern	4	2	8	1	5	20

Once we established the number of fields in each crop category, field sizes were randomly selected in accordance with their proportionate representation in the databases and were randomly matched with crop types. By sampling by both field size and crop type we incorporate any systematic differences that may exist between them into the modeling effort. Table 14 shows the final sampling frame of fields by growing region.

Table 14. Sampling frame by field size and crop categories

CENTRAL COAST						
	Grain	**Field**	**Tree fruit and Nut**	**Vine and Berry**	**Vegetable**	**Total**
0-2.99 acres	0	0	0	0	0	**0**
3-14.99 acres	1	0	0	0	3	**4**
15-49.99 acres	0	1	2	2	5	**10**
50-124.99 acres	0	0	0	1	2	**3**
>125 acres	0	0	0	0	3	**3**
CENTRAL VALLEY						
	Grain	**Field**	**Tree fruit and Nut**	**Vine and Berry**	**Vegetable**	**Total**
0-2.99 acres	0	1	1	0	1	**3**
3-14.99 acres	1	2	1	0	2	**6**
15-49.99 acres	2	1	3	2	0	**8**
50-124.99 acres	1	0	1	0	1	**3**
>125 acres	1	0	0	0	0	**1**
NORTH VALLEY						
	Grain	**Field**	**Tree fruit and Nut**	**Vine and Berry**	**Vegetable**	**Total**
0-2.99 acres	1	1	0	0	1	**3**
3-14.99 acres	3	2	1	0	0	**6**
15-49.99 acres	3	0	1	0	2	**6**
50-124.99 acres	2	0	2	0	0	**4**
>125 acres	0	0	1	0	0	**1**
SOUTH VALLEY						
	Grain	**Field**	**Tree fruit and Nut**	**Vine and Berry**	**Vegetable**	**Total**
0-2.99 acres	0	0	1	0	0	**1**
3-14.99 acres	2	0	1	0	0	**3**
15-49.99 acres	2	4	3	1	1	**11**
50-124.99 acres	0	0	3	1	0	**4**
>125 acres	0	0	0	1	0	**1**
SOUTHERN						
	Grain	**Field**	**Tree fruit and Nut**	**Vine and Berry**	**Vegetable**	**Total**
0-2.99 acres	0	0	1	0	0	**1**
3-14.99 acres	1	0	0	0	2	**3**
15-49.99 acres	1	1	3	0	2	**7**
50-124.99 acres	1	0	3	0	1	**5**
>125 acres	1	1	1	1	0	**4**
Total Fields	**23**	**14**	**29**	**9**	**26**	**101**

5.2.3 Survey Protocol

With the sampling frame set forth in Table 14, we conducted a visual survey of fields using the SPOT 10 satellite data overlaid with the Caltrans road network data. The satellite and road network data were used to:

- Determine the number of road segments that access a chosen field,
- Note the acreage of the field,
- Note the crop grown on the specified field,

- Measure a road segment lengths,
- Identify whether each road segment is paved or unpaved.

Briefly stated, once the fields had been selected using the DWR land use data and the satellite and road network data had been overlaid, researchers observed where roads intersected with the given field and whether the observed road segments were class 4 or from another service class. Class 4 roads intersecting fields were assumed to be unpaved, while all other classes were assumed to be paved. If a road did not exist in the road network coverage, but was clearly evident in the satellite data, the researcher decided whether the road was paved or unpaved by comparing the unknown road with known paved and unpaved roads in the satellite coverage. If a decision could not be easily arrived at, at least one other researcher was brought in to form a consensus. When possible, the status of any road in question was confirmed using DWR aerial photographs.

Data collected using this protocol were used to calculate the average road length per acre for all roads (paved and unpaved), the proportion or road lengths that were unpaved, and the approximate shape of the field so that the typical trip distances could be estimated for each crop type.

5.2.4 Limitations to Data Collection

Although we managed to include major crops and major growing areas in the HVMT estimation process, we were not able to include specialty crops or crops generally grown on a smaller scale. We attempted to compensate for this by considering field size in the framework, however, the HVMT associated with specialty crops may not be well represented by the framework. Similarly, crops that would typically fit well into one of the given crop categories were excluded from the estimation procedure if they were not listed by the CDFA in their Agricultural Resource Directory because of a lack of data. Additional crops can be added to the existing crop categories in the future to increase the representativeness of the HVMT estimation.

The number of fields surveyed also presents a limitation to the model. With such a short amount of time to conduct the sampling, we were unable to include additional fields. Also, since the data collection was performed in an indirect manner (through satellite and aerial imagery), there is a greater chance of error in identifying the surface of each road segment. Field verifications for at least a portion of surveyed fields are advisable.

5.2.5 Establishing Default Values

Since grower lists showing crop and field size are not available for all counties, we developed a default value that can be applied to any county by crop type. Equation 8 describes the process used to establish default VMT/acre values.

$$D_c = \frac{1}{2} X_c \left(\frac{P_f}{C_f} \right) (L_c)(U_c) \tag{8}$$

where, D_c = default HVMT per acre for each crop type, c,
X_c = average yield per acre by crop category, c,
P_f = proportion of fields in each field size category, f,
C_f = average hauling vehicle capacity by field size category, f,
L_c = average length of road segments per acre for each crop type, c,
U_c = length-weighted proportion of unpaved road segments for each crop type, c.

Using a sample of 144,724 fields distributed throughout California, we established the proportion of fields in each crop category that belong to each field size category. We use the mean yield per acre for each crop category derived from the yields per acre presented in Table 5. For each crop type, we then multiplied the average yield per acre by the proportion of fields represented by each field size category. We then use the average yield per acre for each crop type and the hauling capacities by field size (Table 7) to arrive at default vehicle pass values. The vehicle passes are then multiplied by 2 to account for both inbound and outbound traffic, then multiplied by the average road length by crop type and divided by 4 so that only 1 field road length per trip is included in the VMT estimation. As with the more specific VMT estimations, the raw HVMT is then multiplied by the proportion of road lengths estimated to be unpaved to arrive at an unpaved road HVMT estimate per acre of farmland.

Table 15 shows the default HVMT/Acre over the course of a year. These values can be multiplied by county or regional acreage of crops in each crop category and summed to estimate unpaved HVMT over all crop types.

Table 15. Default HVMT/Acre by crop type

Crop Category	**Raw HVMT/acre**	**Unpaved Road HVMT/acre**
Grain	0.0035	0.0028
Field	0.0128	0.0103
Tree fruit and nut	0.0011	0.0011
Vine and berry	0.0298	0.0259
Vegetable	0.1027	0.1027

6.0 METHODOLOGICAL FRAMEWORK FOR NONHARVEST VMT

The nonharvest framework was developed to enhance the results of the pilot study by widening the geographical range, adding further land use types to the sampling frame, and simplifying the estimation method. The framework was designed to estimate nonharvest VMT (NVMT) at the grid level or more aggregate levels such as the county or air basin, using land use types as the basis for variation between estimated NVMT.

6.1 Framework

Nonharvest VMT is estimated in 3 steps:

1) Calculating average two-way daily vehicle passes on unpaved roads, categorized by land use,
2) Multiplying the average two-way daily vehicle passes by the estimated miles of unpaved road, categorized by land use (producing a raw NVMT),
3) Multiplying raw NVMT by the average proportion of the unpaved road traveled on each trip.

Land uses are employed here as surrogates for activities that take place on the lands. For instance, recreational activities would be expected to take place in forest or scrubland areas while residential activities would be more likely at urban interfaces. To ensure that we would take into account the different land uses in the state, we divided California lands into 3 “primary” land use classes: Agricultural, Natural, and Developed. We then further divided the primary land uses into a group of “secondary” land use classes as demonstrated in Table 16.

Table 16. Land use classifications for nonharvest VMT framework

Primary Classification	Secondary classification
Natural Land*	Sand Dune and Scrubland
	Grassland and Wetland
	Forest and Woodland
Agricultural Land**	Pasture
	Field (Field crops, Grain and Hay Crops, Rice)
	Fruit and Nut (Citrus and Subtropical, Deciduous Fruit and Nuts)
	Vegetable (Truck, Nursery and Berry Crops)
	Vine
Developed Land	Urban Residential
	Urban Industrial/Commercial
	Urban Other (Urban Interface)

* Secondary classifications are based on vegetation classifications suggested by Holland (1986).
** Secondary classifications are based on the strata established for the harvest model sampling process in addition to pastureland.

Primary land use classifications are based on observations from land use databases while secondary land uses are derived from vegetation classifications for California suggested by Holland (1986) and from DWR land use classes. Specifically, secondary “Natural” land uses are derived from Holland (1986) while secondary uses for “Agricultural” and “Developed” lands come from the DWR land use databases used in the harvest VMT estimation process. Both primary and secondary land use classes are used in the selection of sample sites; primary land uses are used to estimate the proportion of unpaved road traveled during each trip, and secondary classes are used to calculate average daily vehicle passes on unpaved roads as well as to adjust the miles of unpaved roads used in the estimation process.

The steps of the nonharvest VMT estimation process can be summarized as

$$V_s = D_s L_s M_p \quad (9)$$

where, V_s = the estimated nonharvest VMT by secondary land use type, s,
D_s = the estimated two-way daily vehicle passes by secondary land use type, s,
L_s = length of unpaved road segments by secondary land use type, s,
M_p = the multiplier that estimates the proportion of the unpaved road actually traveled during a single trip, by primary land use type, p.

We hypothesized that secondary land uses would be strong indicators of average unpaved road NVMT. Although we would expect activities to be similar within primary land use classes, the additional variability allowed by using secondary land classes was expected to lead to more precision in our estimations. For instance, although we would expect hiking traffic in a Forest and Woodland area, we would more likely expect vehicle passes by all-terrain vehicles to occur on Sand Dune and Scrubland roads. Furthermore, the significant predictor of NVMT in the pilot study was paved road density, which we also would expect to vary within primary land use types. A forested area may have a greater paved road density than a scrubland area, and therefore more accessibility.

This framework has 3 distinct advantages over the pilot study and the current CARB model: 1) it incorporates geographic variation in the sampling framework, 2) it distinguishes between VMT occurring on different land types, and 3) as land uses or road surfaces change, the framework can be updated to reflect the those changes.

6.1.1 Estimating Nonharvest Traffic Volumes

To obtain traffic counts from unpaved roads representative of the variety of activities supported by unpaved road travel in the state, we chose a single unpaved road within sites selected according to the sampling scheme presented in Section 6.2.2. In the pilot study, sample areas were restricted only to agricultural lands and were chosen according to crop types representative of the county. In this case, the traffic counts are representative of a wider variety of activities, terrains, and land usage. The counties sampled for traffic counts include: Fresno, Imperial, Inyo, Kern, Kings, Modoc, Marin, Mendocino, Monterey, Riverside, Sacramento, San Diego, San Joaquin, Santa Barbara, Siskiyou, Solano, Stanislaus, Sutter, Tulare, Tuolumne, and Yolo, as well as others.

The first task was to choose locations such that they were representative of California's land uses and geographical areas. Site selection is further discussed in Section 6.2.2. The second task was to set, and successfully retrieve, automated traffic counters that recorded vehicle passes on a given road. Within each chosen sample site, the field team member selected one unpaved road on which to place a traffic counter. Sites were only dismissed from the list if they were not accessible or did not actually support any unpaved roads. We used Nu-Metrics NC-30x countcards to record traffic volumes at chosen locations. Countcards are small, credit card-sized counters that use magnetic imaging technology to record vehicle passes that occur over or near the counter. The cards were programmed in the count only mode to record vehicles traveling between 8 and 50 miles per hour in 60-minute increments. The cards were then placed in a protective metal sheath, provided by Nu-Metrics, and buried ¼" to ½" beneath the surface of the unpaved road at a sufficient distance from the nearest intersection that a minimum speed of 8 miles per hour would likely be reached prior to encountering the device. Each countcard was placed on the chosen road for a period of 7 consecutive days so that differences between days in each land-use category would be captured.

All road counts were completed between July 02, 2001 and December 01, 2001. The sampling effort resulted in 7-day samples from 90 roads dispersed throughout the state, resulting in nearly 15,000 hours of traffic volume data. Road locations and raw vehicle counts can be found in Appendix A. Table 17 shows the number of sampled roads in each land use category.

Table 17. Number of roads sampled from each land use type

Primary Land Use	Roads	Secondary classification	Roads
Natural Land	36	Sand Dune and Scrubland	8
		Grassland and Wetland	6
		Forest and Woodland	21
Agricultural Land	32	Pasture	3
		Field	12
		Fruit and Nut	11
		Vegetable	2
		Vine	4
Developed Land	22	Urban Residential	6
		Urban Industrial/Commercial	1
		Urban Other (Urban Interface)	16
Total	**90**	**Total**	**90**

Traffic volumes collected at 5 sites were subsequently excluded from the analysis due to equipment malfunctions and operator error. Excluded counts came from 2 Forest and Woodland sites, 2 Field sites, 1 Fruit and Nut site, and 1 Grassland and Wetland site. Table 18 elaborates.

Table 18. Excluded data

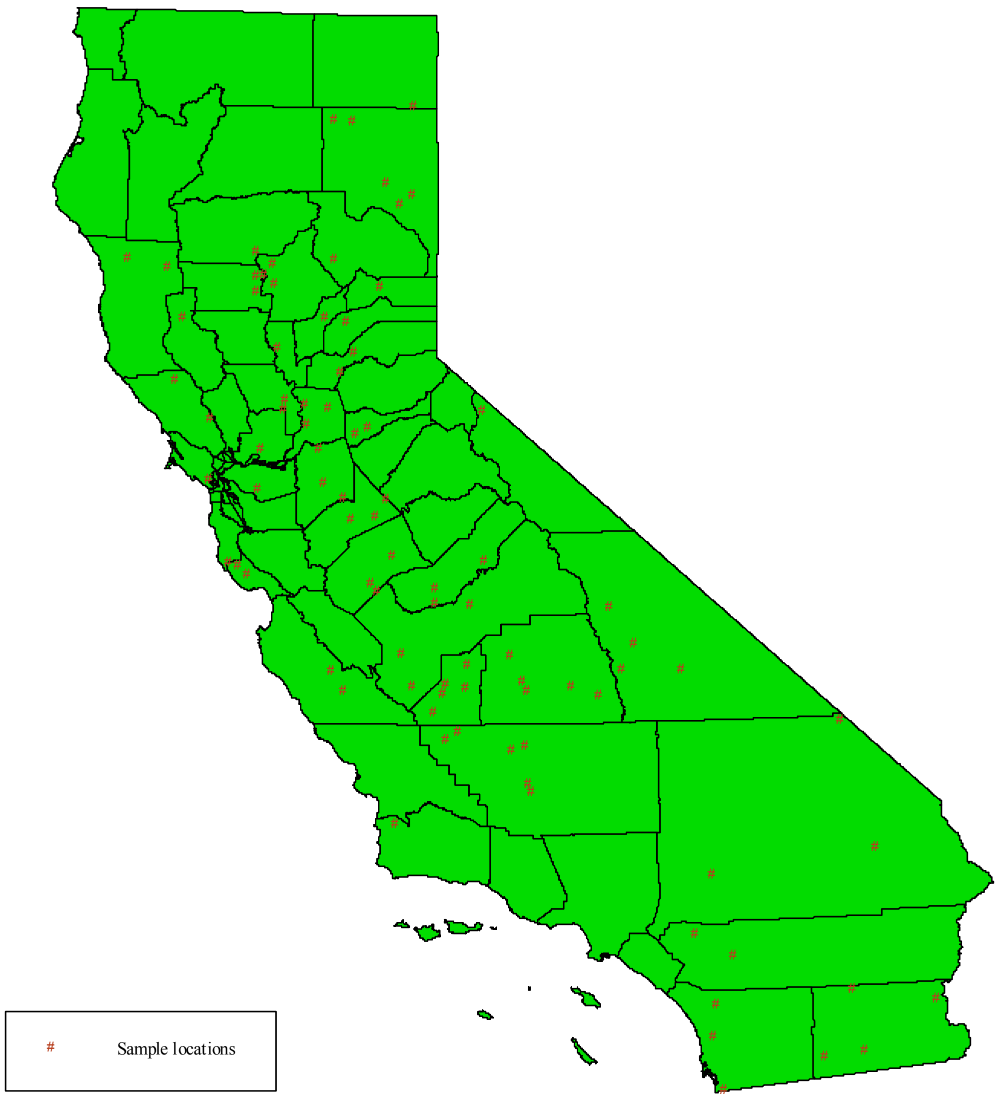
Site Number	County	Count dates	7-day Traffic Count	Reason eliminated
1-11	San Diego	8/23/01 – 8/30/01	0	Counter malfunction
3-15	Colusa	7/23/01 – 7/30/01	443	Operator error
4-18	Alameda	7/12/01 – 7/19/01	1322	Counter malfunction
5-20	Tulare	7/14/01 – 7/21/01	11	Operator error
5-21	Plumas	7/12/01 – 7/19/01	10	Operator error

The counts from site 1-11 were excluded because the traffic counter used at the site was tested subsequent to its retrieval and did not register any vehicle passes during the test procedure (see Section 6.2.4 for details). The counts from site 3-15 were excluded because the operator placed a traffic counter on a road that was grated while the counter was in place. Therefore, although counts were recorded, they were deemed unreliable. The count at site 4-18 was unusual in that it recorded not only very high vehicle volumes, but recorded them at unexpected times of day. For instance, it recorded 277 vehicle passes between the hours of 1:00 and 2:00 am and 200 vehicle passes between the hours of 2:00 and 3:00 am on Thursday, July 19, 2001. We excluded the data because the road appeared to be a service road with no residences or businesses along it and because of the unusually high traffic volumes during non-peak hours. Counts from sites 5-20 and 5-21 were removed from the analysis because operators programmed the countcards incorrectly.

Counts from three roads, taken from a previous study in San Bernardino County[10], were subsequently added to our traffic volume data and included in the analysis. These 3 counts represented roads in quads that had been selected during the site selection procedure, but had not been sampled due to time and equipment constraints. After excluding the suspect traffic counts and adding in counts from San Bernardino County, we had traffic volume data from 88 roads with which to establish average daily vehicle passes. Figure 6 shows the approximate locations of the sampled sites.

[10] Counts were taken from the November 17, 1994 San Bernardino County Traffic ADT printout.

Figure 6. Counter locations



We use the same measure of data skewness presented in Section 5.1.1 to choose the representative average vehicle passes by secondary land use. Table 19 shows the decision rule and results.

Table 19. Average daily vehicle counts by secondary land use

Secondary Land Use	N	# Roads	Skewness	SE of Skewness	*z*	α	Critical *z*	Value Chosen
Fruit and Nut	70	10	4.301	0.287	14.98606	0.0005	3.4	**3.0**
Truck, Berry, Nursery and Vine	42	6	0.452	0.365	1.238356	0.0005	3.6	**10.2**
Field and Pasture	98	14	1.51	0.244	6.188525	0.0005	3.4	**10.5**
Grasslands, Sand dunes and Scrubland	119	17	2.334	0.222	10.51351	0.0005	3.3	**9.0**
Forest & Woodlands	133	19	1.637	0.21	7.795238	0.0005	3.3	**17.0**
Urban Residential	42	6	0.856	0.365	2.345205	0.0005	3.6	**16.1**
Urban Industrial & Other	112	16	2.73	0.228	11.97368	0.0005	3.3	**2.5**

For nearly every land use class, the data were very significantly skewed and the median value was chosen as representative. There were 2 exceptions, neither the "Truck, Berry, Nursery and Vine" nor the "Urban Residential" data was significantly non-normal, therefore mean vehicle passes were chosen as representative of unpaved roads in these land use types. Figure 7 a - g demonstrates the level of skewness in the data for each land use classification. Figure 8 shows the scatter of daily vehicle passes around the mean by land use.

Figure 7. Data skewness by secondary land use class

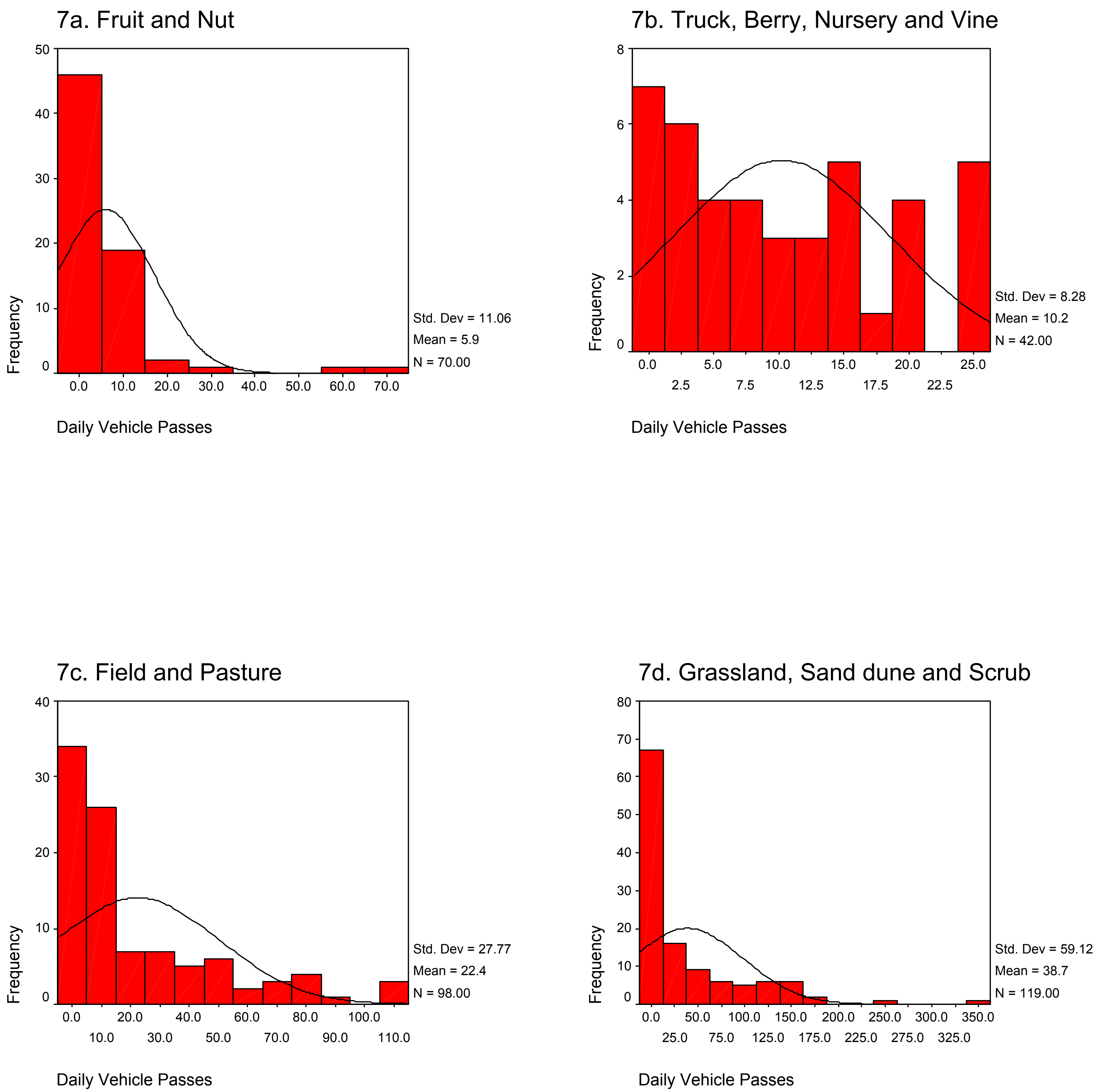
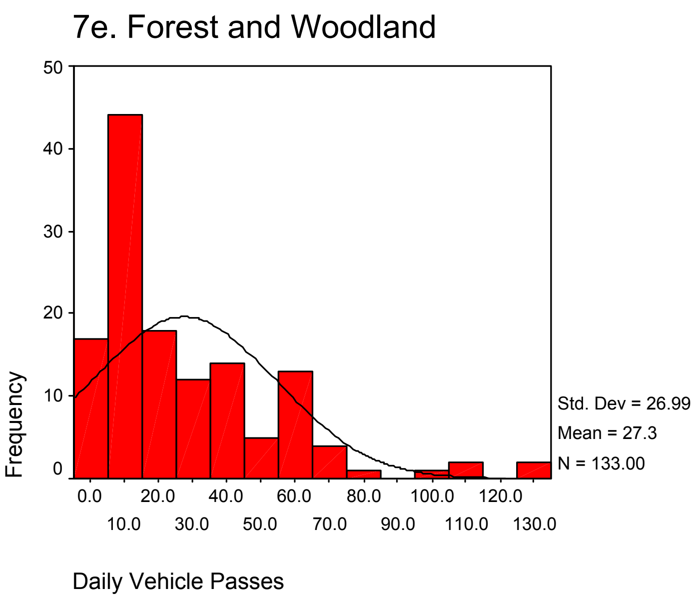
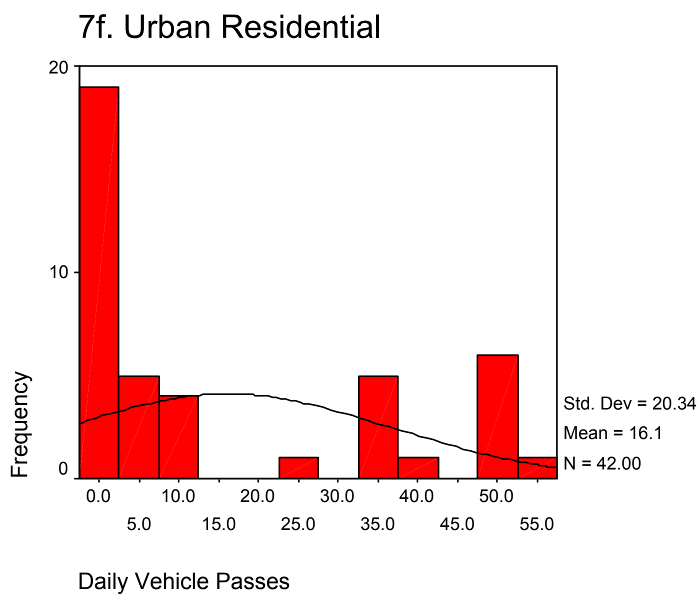


Figure 7. Data skewness by secondary land use class (continued)





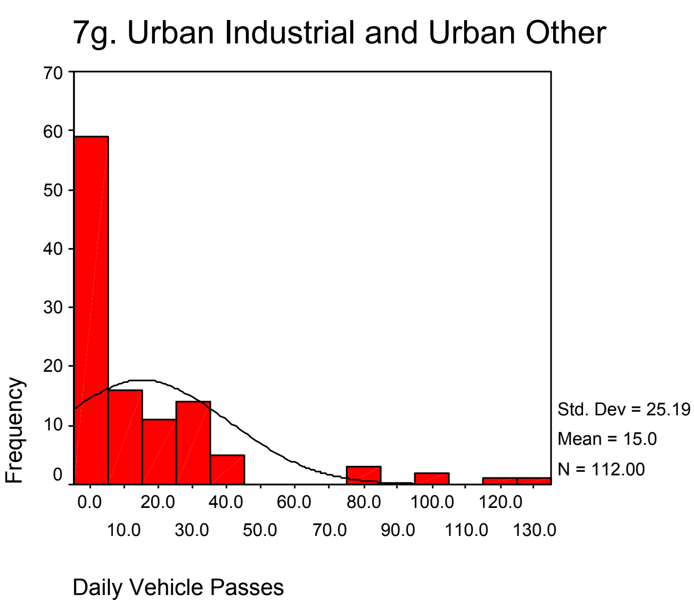
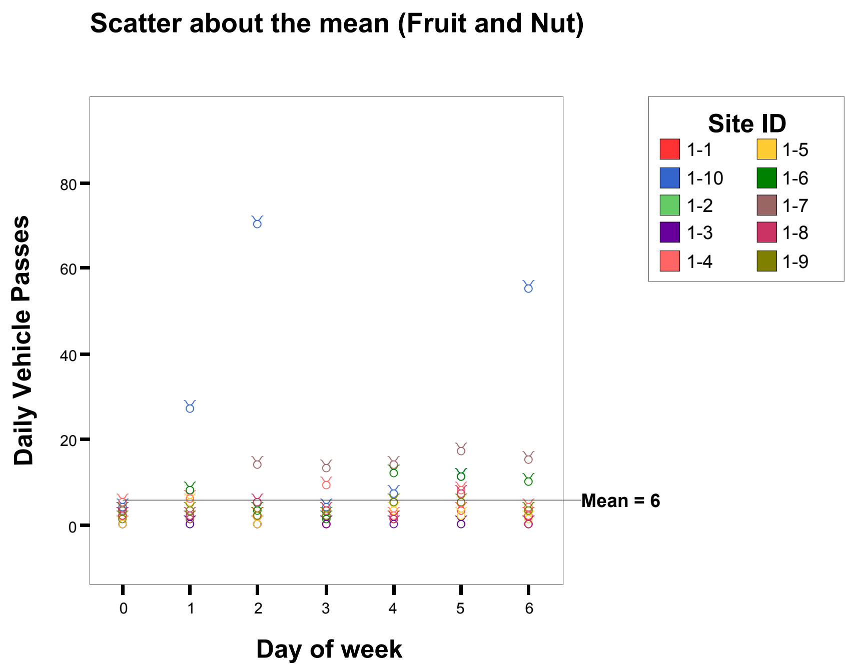


Figure 8. Daily vehicle pass scatter around the mean

Day of Week	0	1	2	3	4	5	6
	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday



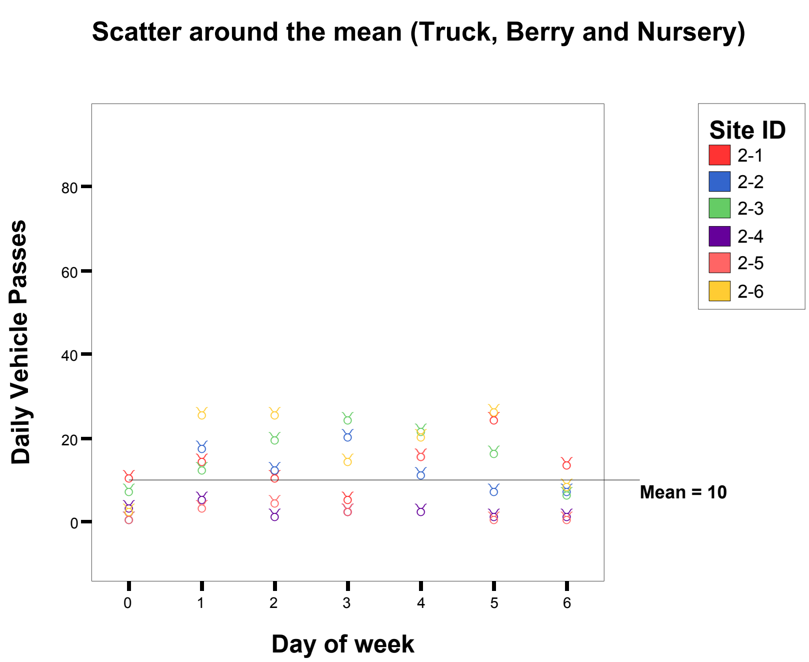
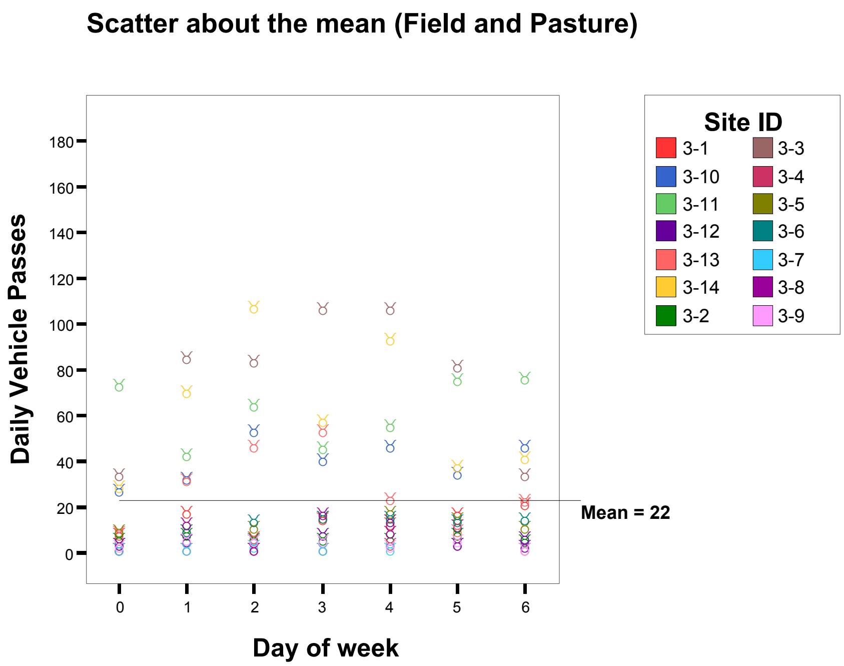


Figure 8. Daily vehicle pass scatter around the mean (continued)



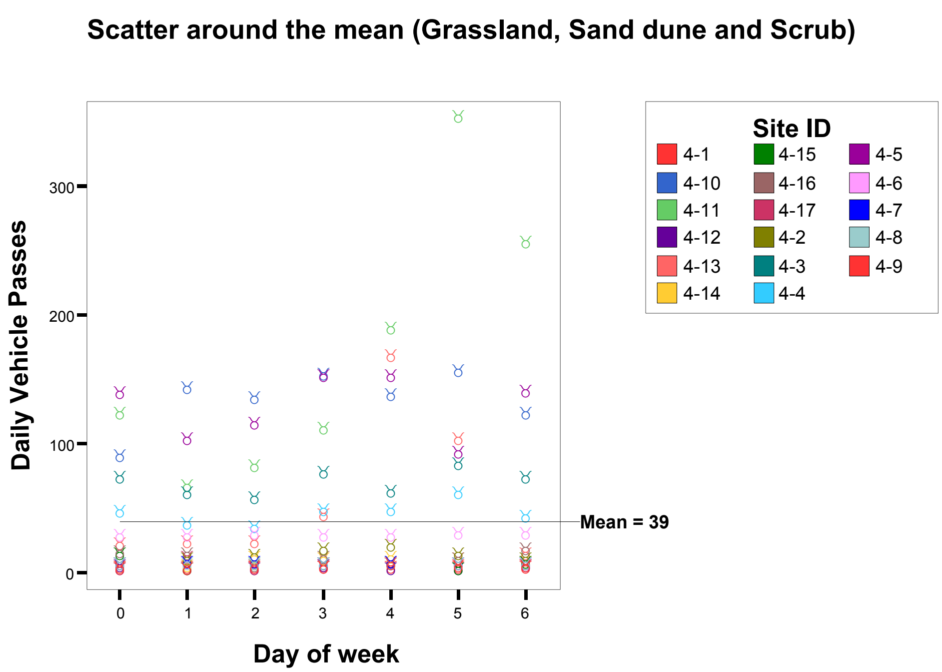
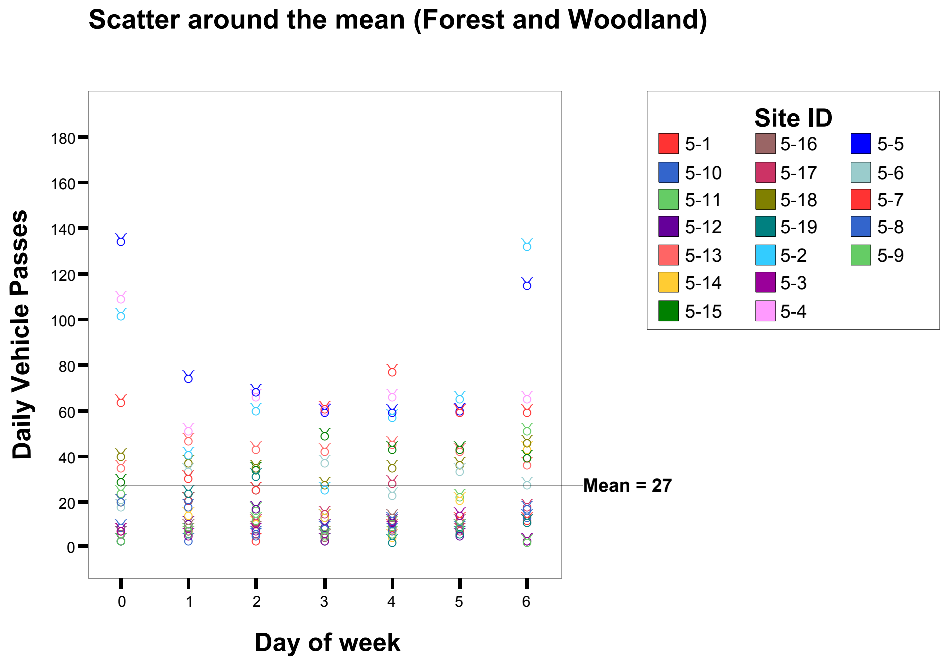


Figure 8. Daily vehicle pass scatter around the mean (continued)



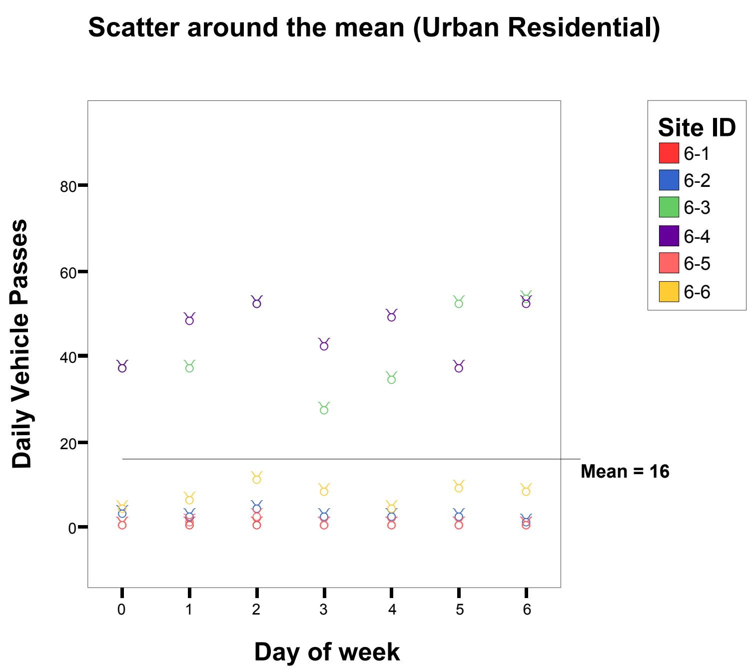
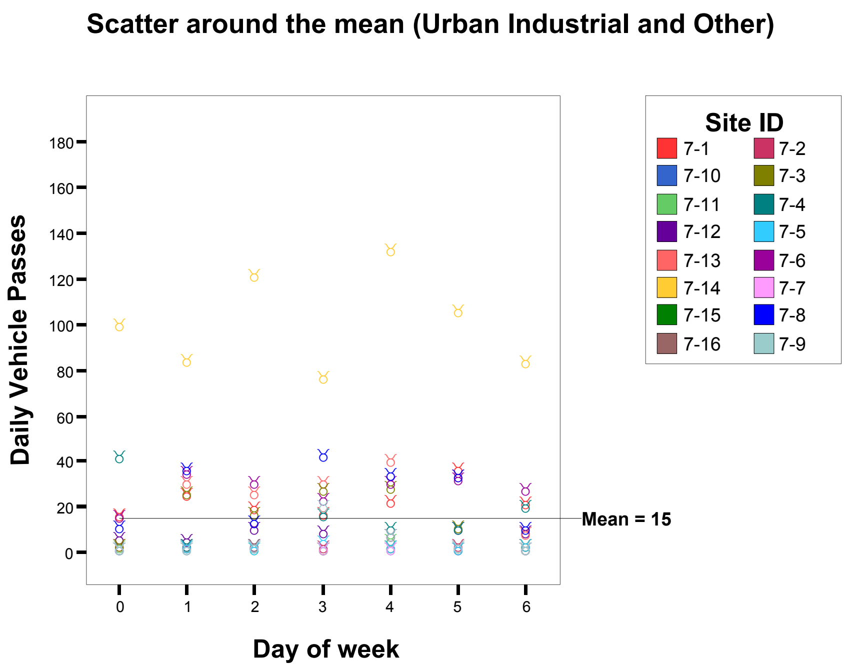


Figure 8. Daily vehicle pass scatter around the mean (continued)



6.1.2 Estimating Miles of Unpaved Roads

It was also necessary to update the miles of unpaved road included in the Caltrans road database for the purposes of this study. As mentioned in Section 5.2.1, paved road indicators are reasonably up-to-date in the Caltrans road coverage, however surveying and digitizing of unpaved roads in the coverage can be as much as 20 years old. A more accurate inventory of unpaved road mileage was needed for the nonharvest model. This was accomplished by verifying that the roads identified as unpaved in the GIS road coverage were indeed unpaved and active and by adjusting the miles of unpaved road based on these visual surveys.

The methodological framework for estimating the miles of unpaved road for the nonharvest framework is fairly straightforward. Sampled sites were visually surveyed to ascertain how many roads identified as class 4 or class 5 roads[11] were in actuality unpaved within the site boundaries. For each identified site, the field team member numbered each road on a paper map, which was later correlated with the roads on the GIS road network. Roads within the defined site were then visually surveyed on-site and identified as:

- Unpaved Active: Any road consisting of dirt, gravel, or other earthen surface material that appears to be used. This can be evidenced by road maintenance (little to no vegetative overgrowth), and/or tire-track marks.
- Unpaved Inactive: An earthen surfaced road (dirt, gravel, other earthen surface) that, by all appearances has had no activity for an indefinite period of time. This can be evidenced by severe vegetative overgrowth and/or the absence of tire-track marks.
- Paved: Any road that has a contiguously solid surface made up of materials other than dirt, gravel or other earthen surfaces.
- Other: Any path investigated that has not been previously defined.

The field-verified road segment classifications were used to find the percent of miles of class 4 and class 5 unpaved roads in each secondary land use category observed to be unpaved using Equation 10,

$$U_j = \frac{\sum_i (l_i * x_u)}{\sum_i l_i}, \quad \forall i \in j \tag{10}$$

where, U_j = percent of class 4 and 5 roads in each land use classification, j, estimated to be unpaved,

x_u = binary indicator of surveyed unpaved roads: 1 if field verified unpaved active, 0 if otherwise,

l_i = length of sampled road segment i.

This resulted in a percentage of unpaved roads across sampled areas for each secondary land use class as shown in Table 20, where $\mathbf{P_w}$ is the length-weighted proportion of class 4 and class 5 roads that were observed to be unpaved in each land use class.

[11] The only class 5 roads included in the study were those classified as four-wheel drive unpaved roads. These are distinguished from hiking trails and other class 5 roads through subclasses in the Caltrans coverage.

Table 20. Proportion of class 4 and class 5 roads that are unpaved

Secondary Land Use	N	P_w
Fruit & Nut	53	**0.79**
Truck, Berry, Nursery & Vine	41	**0.93**
Field & Pasture	63	**0.92**
Grasslands, Sand dune & Scrubland	76	**0.86**
Forest & Woodland	76	**0.65**
Urban Residential	27	**0.72**
Urban Industrial & Other	24	**0.58**
Total	360	**--**

The percentages of unpaved roads shown in Table 20 were then multiplied by the total miles of class 4 and class 5 roads in each land use category for each county. The procedure, performed with GIS, yielded countywide estimates of unpaved road mileage for each of the secondary land use categories. Finally, these estimates were summed to define a total unpaved road mileage that could be used in the NVMT procedure for each county (Equation 11),

$$M_j = \sum_j \left(U_j \times \sum_i l_i \right), \quad \forall i \in j \tag{11}$$

where, M_j = miles of unpaved road in land use, j,
U_j = percent of class 4 and class 5 road segments, i, observed to be unpaved,
l_i = length of road segment, i.

Summary values of M_j are provided in Appendix B (Table 33), U_j values are taken from Table 20, and l_i is based on Caltrans digitized road length data. This procedure could also be performed on a smaller scale, for instance at the grid level, to produce more resolved estimates of unpaved road mileage.

6.1.3 Estimating Distance Traveled on Unpaved Roads

The final step in the NVMT framework was establishing a multiplier that indicated the average proportion of an unpaved road traveled during a single trip. We suspected that the multiplier would be highly dependent on the predominant activity that a given road supported. For instance, if a road led to a particular recreational attraction (*e.g.*, all-terrain vehicle track, hiking trailhead), the entire length of the road might be traveled. However, if a house or agricultural field were located along the road at some point, the multiplier might be some fraction of the actual length of the road. In the pilot study, the multiplier was assumed to be the length of the road divided by 2. However, because of limited resources, no measurements were taken to justify its use. In this study, we attempted to better establish the multiplier.

At each site, a field team member was asked to drive the length of the unpaved road prior to setting a traffic counter and was further asked to note the most prominent destination and the mileage of the unpaved road from the nearest paved intersection to that destination. For the cases in which more than 1 primary destination was identified, each distance was recorded and average distances were computed. Selected road segments were later located in the GIS road database and each of their lengths recorded. The proportion of unpaved road then was equal to the average observed distance (recorded by the field member) divided by the total length of the road segment. Equation 12 describes the process and Table 21 shows the results.

$$R_p = \sum \frac{O_{ip}}{S_{ip}} \qquad (12)$$

where, R_p = proportion of unpaved road segment traveled during a single trip for primary land use, *p,*
O_{ip} = observed unpaved road to the identified destination for road segment, *i,* in primary land use *p*,
S_{ip} = road segment length measured in the GIS roads database for road segment, *i*, in primary land use *p*.

Table 21. Average proportion of unpaved road segment traveled during a single trip

Primary Land Use	N	Mean Proportion	Std. Deviation
Agricultural Land	29	**0.58**	0.36
Natural Land	29	**0.84**	0.28
Developed Land	17	**0.79**	0.32

The results indicate that our pilot study assumption (road segment length/2) was reasonable for agricultural lands, although it does not appear to characterize travel on other land uses as well. The standard deviations for each primary land use category, however, indicate some overlap between the proportion of unpaved road traveled in each land use category, most significantly between natural and developed lands.

6.2 Data Collection

Our sample size was defined by practical and fiscal constraints: the equipment available to us and the resources and time frame available for sampling. Expecting to have 10-15 traffic counters available, and approximately 10-15 weeks in which to take 7-day traffic counts, we estimated that traffic counts could be taken on a maximum of 150 unpaved roads, giving us at most 1050 sample days of data.

6.2.1 Data Sources

Three GIS coverages were needed to carry out the sampling plan and applying average nonharvest traffic volumes to road segments on a statewide basis. These included:

- ♦ A GIS road coverage for each county (Caltrans),
- ♦ A GIS land use coverage for each county (DWR)
- ♦ A GIS Gap Analysis coverage for California (UC Santa Barbara/USGS)

Land-use coverages from two different sources were needed to account for the 3 primary land uses in the state: countywide land use databases provided by the DWR and a statewide GAP Analysis database. While the DWR land-use databases are more recent (1993-2000) and have a greater level of detail in both the agricultural and developed categories, the DWR provides coverages for only 40 counties in the state and are incomplete or lack sufficient detail for natural areas. The GAP Analysis coverage contains sufficient detail and geographical coverage for the missing natural areas. However, it does not contain the desired level of detail for agricultural or urban areas. Since the DWR coverages are more recent, they were considered the primary land use information source. Where no DWR data were available, GAP Analysis data were used in their place. The land use coverages were joined so that they did not overlap.

The GIS coverages were used in 3 ways: 1) identifying land use types in California and categorizing each road segment according to the land use type on which it lay, 2) choosing sample sites, and 3) calculating NVMT on a countywide and statewide basis. First, land use coverages for each county were overlaid with their corresponding road use coverages. Each class 4 or class 5 road segment was classified according to its secondary land use, based on the midpoint of the road segment. For example, if the midpoint of the road segment were on forestland, the road was considered representative of forest unpaved road traffic. Second, land use coverages were overlaid with a digital map of USGS quadrangles (quads) for selection of sample sites within which to place traffic counters. Last, an Avenue script, run in ArcView using the GIS coverages described above was used to calculate the NVMT for class 4 and class 5 road segments for each county of the state.

6.2.2 Site Selection

Sites were selected for the purpose of: 1) observing traffic volumes on unpaved roads, 2) updating the mileage of unpaved road by land type, and 3) estimating the proportion of unpaved road that would likely be traveled during a given trip. To accomplish these tasks we took into account the diversity of landscapes, the diversity of uses, and the potential geographical differences that could affect VMT on unpaved roads. We chose sites based on a stratified, nested sampling plan.

California consists of approximately 2900 quadrangles (quads) according to the mapping system employed by the US Geological Survey (USGS). These 3 classes were used to separate quads into 3 groups (agricultural land, natural land, developed land) from which to choose sample sites.[12] By separating the land uses, we ensured that no one category would be underrepresented.

All quad numbers from each primary land use category were separately placed in a spreadsheet and 50 were randomly selected from each population. Each quad was then individually located on a GIS coverage and overlaid with the relevant land use coverage. The predominant secondary land use (Table 16) in the quad was then used to define the boundaries of the site to be sampled. In other words, if the largest contiguous area in the quad appeared to be a Forest and Woodland area, roads within the Forest and Woodland area of the quad were chosen for survey and traffic counts.

The quad and land use coverages were then overlaid with the relevant road coverages and class 4 and 5 roads were identified within the chosen site. If class 4 or class 5 roads did not exist within the chosen site, the site was discarded and an adjacent quad with the same secondary land use, and containing class 4 or class 5 roads within it, was chosen in its place. Even though a secondary land uses sometimes extended beyond the boundaries of the chosen quad, sites did

[12] The 3 lists of quads were not mutually exclusive since some quads contained more than one primary land use type. The criterion for inclusion in a land use classification was that a quad must contain at least 1 contiguous square mile of the given primary land use.

not. Only that part of the secondary land use that lay within the randomly chosen quad was included as a sample site. Figure 9 shows primary and secondary land uses and class 4 and 5 roads to help illustrate the process.

After sites were selected, they were identified on a highly resolved paper map and given to a field team member. If upon surveying the chosen site, the field team member found either no unpaved roads or no accessible unpaved roads, the traffic counter could be placed on a road adjacent to, but outside the site boundaries as long as it had the same secondary land use as the original site.

6.2.3 Limitations to Data Collection

Traffic counts and visual surveys were taken on a fairly large number of roads over a widely dispersed geographical area and 2 seasons (summer and fall). However, this resulted in a typically low number of roads being sampled in any one county. A larger number of traffic counters on a year-round basis could provide more conclusive regional data and could incorporate much needed seasonality (winter and spring counts) in the NVMT estimation procedure.

6.2.4 Data Quality Assurance/Quality Control

Quality assurance/quality control measures were conducted to test the precision and consistency of the traffic counters. Specifically, the measures were undertaken to determine if traffic counters correctly registered vehicle passes and to confirm that counts represented 2-way, rather than 1-way, vehicle passes.

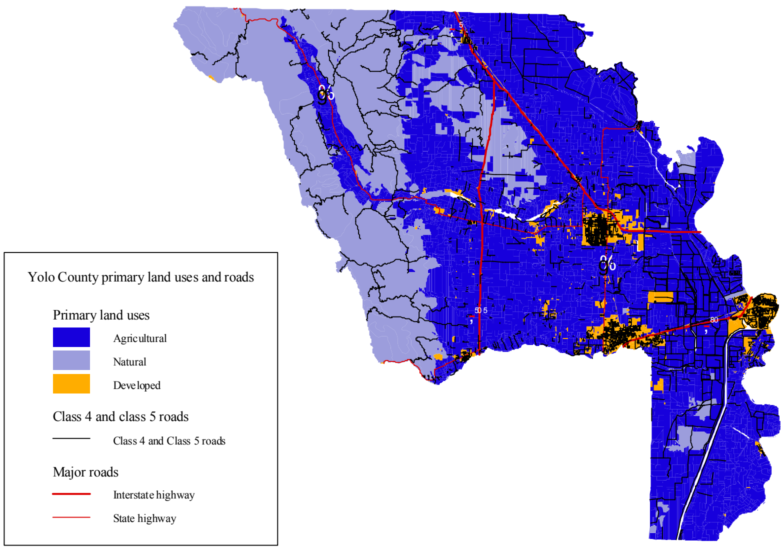
Counters were programmed in exactly the same manner as in the field study except they were set to record in 15 minute intervals for 1-hour periods rather than 1-hour intervals for 7-day periods. They were then placed within a metal sheath consistent with the study protocol.

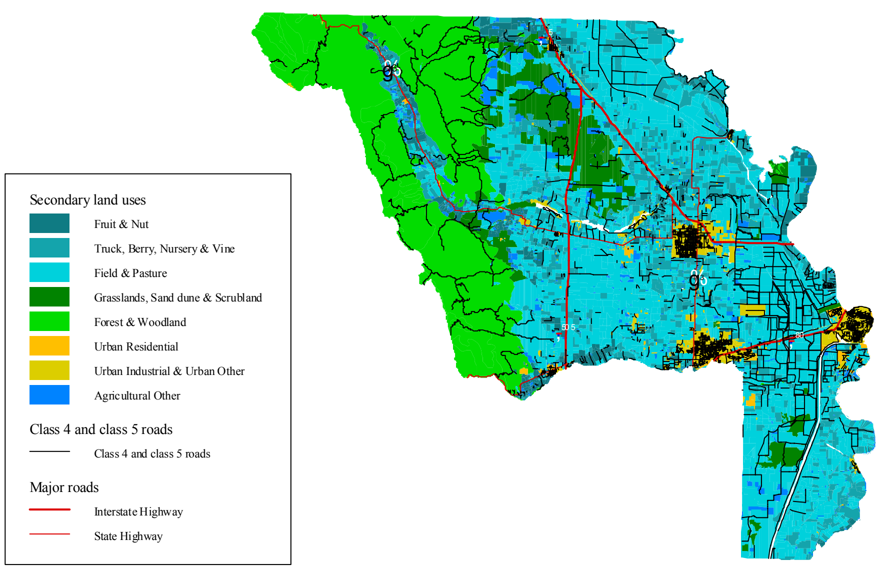
Counters were arranged in a forward direction at a distance of approximately 10 feet from one another. A passenger vehicle then made 5 passes directly over each line of counters during 4, 15-minute periods, for a total of 20 vehicle passes. After an hour, when the counters had automatically turned off, the counters were collected and their vehicle passes recorded. One counter was found to have registered zero vehicle passes, while the remaining counters perfectly recorded 5 vehicle passes in each of the 15-minute intervals.

Half of the counters were then switched so that they faced the reverse direction. Again, a passenger vehicle was driven so that it traveled over both the forward and then the reverse positioned counters 5 times in 4, 15-minute periods, for a total of 20 passes. All the counters in both the forward and reverse position accurately recorded all 20 vehicle passes.

The experiment confirmed that the counters registered vehicle passes in both the forward and reverse direction with the same precision and that each counter recorded vehicle passes in each direction with the same precision, with the exception of counter #11289. This counter never registered a vehicle pass. Since this held true over multiple trials, and the one road on which the counter was placed also returned zero counts, the road was dropped from the analysis.

Figure 9. Primary land use classes, secondary land use classes and roads in Yolo County





7.0 GIS INTERFACE

The GIS interface structure allows VMT estimates to be updated as additional data are developed or existing data are revised. The interface is designed to accommodate two types of updates: 1) a quick update where the user can change values at the grid level, and, 2) a more extensive update that changes values in larger geographical areas, such as multiple grid locations, counties or the state. At the grid level, updates take place within the GIS software, so attribute tables have to be manipulated manually. For small changes, this is not a time-consuming endeavor, but requires careful attention. For extensive updates, Avenue scripts have been written to assist with updating input data.

All inquiries into VMT through the GIS interface must be viewed in data attribute tables and requires knowledge of GIS software and commands. Details concerning the GIS interface and user instructions are provided in a technical document accompanying the final GIS package.

8.0 RESULTS

8.1 Harvest VMT

To estimate countywide and statewide HVMT for 2001, we use GIS tools in conjunction with factors estimated using the Harvest VMT framework established in Section 5.0. Using an Avenue script (ArcView), we apply the Harvest VMT framework (Equation 7) to all counties for which we received grower databases (Table 6). The script incorporates yield per acre values for the major crops listed in the CDFA (2001) (Table 5), the average capacity of hauling vehicles by field size (Table 7), the average road length per acre (Table 8), the proportion of field roads estimated to be unpaved (Table 9), and field acreages reported in the provided grower databases. The script is used for all counties in the sampling frame (Table 10) and for 7 additional counties that provided grower lists but were outside the identified major growing regions (Figure 2). HVMT for all other counties were estimated using the default unpaved road HVMT/acre by crop type values established in Section 5.2.5 and crop and acreage information provided in the 2000 County Agricultural Commissioners' Data (published August 2001).[13] The acreages of published crops were averaged according to crop type and then multiplied by the corresponding unpaved road HVMT/acre by crop type value (Table 15).

8.1.1 Annual Harvest VMT Estimations

Annual unpaved road VMT estimations for counties included in the sampling frame are presented in Table 22. Annual results for all counties are included in Table 23. Figure 10 displays annual statewide HVMT densities for counties whose grower databases provided Township-Range-Section (TRS) location information. The figure does not depict the total HVMT for Monterey, Santa Barbara, and San Diego counties. In these counties, respectively, about 38%, 18%, and 3% of estimated HVMT were unaccounted for due to a lack of TRS information. These counties were retained in the figure to give a general idea of the spatial distribution of HVMT in each. For all other counties included in the figure, greater than 99% of the estimated HVMT correspond to the TRS locations provided. Densities are displayed in 3 x 3 mile grids.

[13] Acreages for Alpine and Trinity Counties were derived from USDA 1999.

Table 22. Annual unpaved road Harvest VMT for sampled regions and counties

Region	County	N	Unpaved Road HVMT
Central Coast	Monterey	7,455	1,195,658
	San Benito	740	73,720
	San Luis Obispo	2,552	33,885
	Santa Barbara	5,479	1,649,996
	Santa Cruz	801	4,510
	Total	**17,027**	**2,957,769**
Central Valley	Sacramento	3,659	66,699
	San Joaquin	12,163	421,133
	Stanislaus	10,293	134,257
	Total	**26,115**	**622,089**
North Valley	Butte	3,568	18,067
	Colusa	3,997	58,927
	Glenn	3,637	42,447
	Sutter	3,186	45,866
	Yolo	4,557	111,695
	Yuba	1,325	8,599
	Total	**20,270**	**285,601**
South Valley	Fresno	13,620	161,768
	Kings	4,117	94,942
	Madera	5,495	87,919
	Merced	9,177	120,814
	Tulare	22,244	104,164
	Total	**54,653**	**569,607**
Southern	Riverside	10,722	121,505
	San Bernardino	1,442	25,252
	San Diego	4,725	13,892
	Total	**16,889**	**160,649**
	Grand Total	**134,954**	**4,595,715**

The results for Monterey, San Benito and Santa Barbara Counties were unexpectedly high. In examining the data, we found that the total HVMT in these counties is strongly influenced by the presence of a small number of very large fields. We suspect that in these grower lists, not all growers reported their field size for each crop, but rather the size of their farming operations. As a result, we also calculated HVMT for these 3 counties using aggregated acreages and the default values established in Section 5.2.5. Using this alternative calculation, we estimate HVMT to be 38,264, 2,747, and 45,854 for Monterey, San Benito, and Santa Barbara Counties, respectively. Although these numbers appear to be reasonable, they are based on less refined data than that obtained from the grower lists. Since field size is a sensitive variable in the harvest framework, field size data should be double-checked to support the accuracy of the calculated HVMT in these counties.

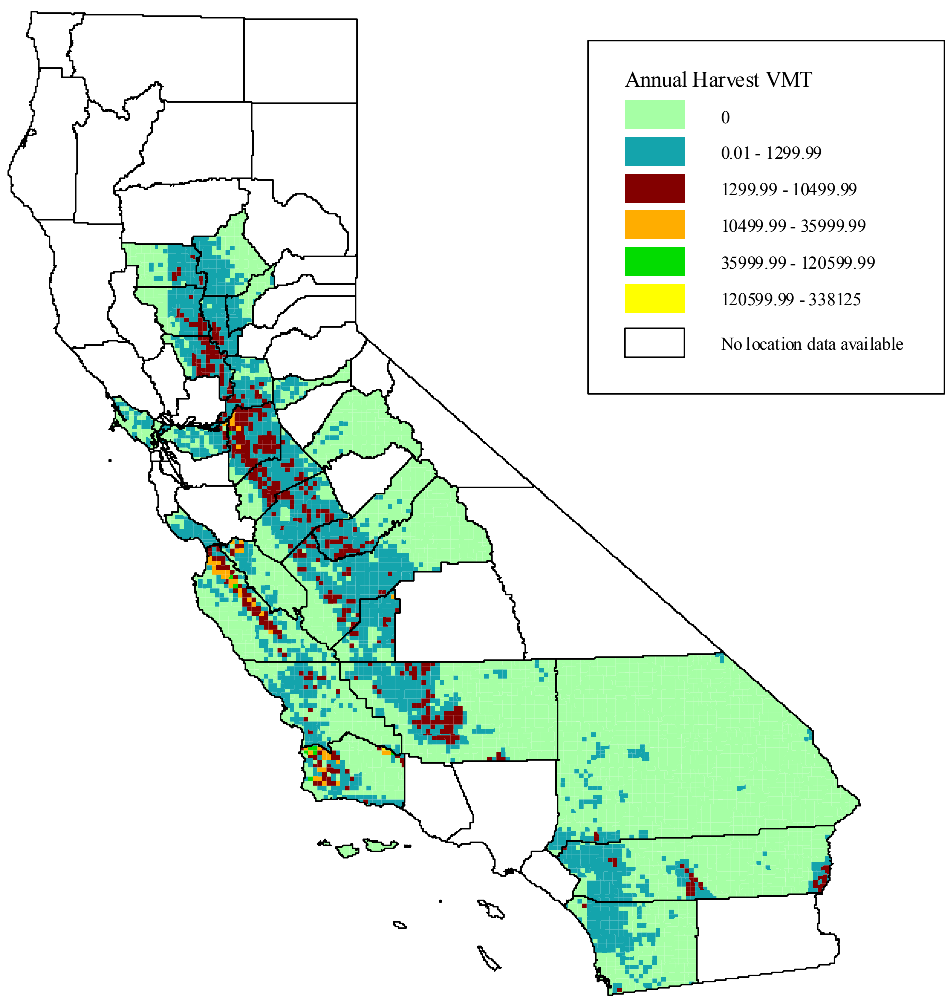
Table 23. Annual unpaved road HVMT by county

County	Annual Unpaved Road HVMT	County	Annual Unpaved Road HVMT
Alameda	102	Orange	588
Alpine*	-	Placer	64
Amador	1,280	Plumas	36
Butte	18,067	Riverside	121,505
Calaveras	72	Sacramento	66,699
Colusa	58,927	San Benito	73,720
Contra Costa	40,237	San Bernardino	25,252
Del Norte	781	San Diego	13,892
El Dorado	33	San Francisco	-
Fresno	161,768	San Joaquin	421,133
Glenn	42,447	San Luis Obispo	33,885
Humboldt	9	San Mateo	265
Imperial	13,947	Santa Barbara	1,649,996
Inyo	28	Santa Clara	1,233
Kern	276,863	Santa Cruz	4,510
Kings	94,942	Shasta	74
Lake	125	Sierra	13
Lassen	257	Siskiyou	1,008
Los Angeles	1,182	Solano	2,921
Madera	87,919	Sonoma	1,237
Marin	310	Stanislaus	134,257
Mariposa	11	Sutter	45,866
Mendocino	372	Tehama	153
Merced	120,814	Trinity*	14
Modoc	1,679	Tulare	104,164
Mono	174	Tuolumne	5
Monterey	1,195,658	Ventura	3,692
Napa	841	Yolo	111,695
Nevada	8	Yuba	8,599
Total	**2,118,853**	**Total**	**2,826,476**
GRAND TOTAL FOR CALIFORNIA			**4,945,329**

* County Agricultural Commissioners for Alpine and Trinity Counties did not report any agricultural acreage for 2000. The acreage for these counties is taken from USDA 1999.

All HVMT is assumed to take place on dry days, therefore no precipitation adjustments have been made to the annual results. Some growers voluntarily water roads during harvest periods, which might mimic precipitation in the suppression of PM_{10} emissions. With additional grower data, future emissions estimations could incorporate an adjustment specific to road watering or other dust suppression methods.

Figure 10. Statewide densities of annual Harvest VMT



8.1.2 Monthly Harvest VMT Estimations

To arrive at monthly unpaved road HVMT, we apportioned the estimated annual HVMT among months of the year according to crop calendars that characterize harvests in the state. We multiplied the annual unpaved road HVMT for each county by the proportion of each crop harvested during each month of the year. This provided us with a monthly profile of HVMT for each county in the state. Table 24 shows these monthly profiles. Crop calendars for the state are also included in Appendix D.

Table 24. Monthly HVMT by county and statewide

County	January	February	March	April	May	June	July	August	September	October	November	December	Total*
Alameda	3	3	5	5	7	8	10	11	16	16	13	6	102
Alpine	-	-	-	-	-	-	-	-	-	-	-	-	-
Amador	-	-	10	10	11	17	20	201	304	309	290	108	1,280
Butte	3	3	124	130	194	297	313	378	5,573	5,712	5,327	10	18,067
Calaveras	2	2	4	4	5	8	9	8	10	9	6	4	72
Colusa	1	1	183	253	2,459	4,801	4,965	5,368	12,061	12,562	11,925	4,346	58,927
Contra Costa	2	80	705	705	1,026	1,364	1,273	1,433	11,171	11,518	10,671	289	40,237
Del Norte	31	30	49	50	67	71	86	86	103	96	67	44	781
El Dorado	0	0	1	1	1	8	5	4	5	5	2	1	33
Fresno	827	763	1,727	5,826	9,580	13,770	14,353	23,035	26,684	27,980	24,366	12,838	161,768
Glenn	11	10	357	816	1,180	1,707	1,790	2,035	11,373	11,657	10,896	612	42,447
Humboldt	-	-	0	0	0	1	1	1	2	2	2	0	9
Imperial	445	432	711	785	1,050	1,142	1,385	1,445	2,088	2,103	1,570	792	13,947
Inyo	1	1	1	1	2	3	4	4	4	3	2	1	28
Kern	6,739	6,096	9,565	13,208	15,558	18,138	19,190	34,686	45,112	47,928	40,593	20,040	276,863
Kings	320	292	3,902	5,013	6,925	9,663	9,991	10,274	14,388	17,149	12,798	4,226	94,942
Lake	0	1	4	3	5	28	20	17	18	17	9	4	125
Lassen	1	1	7	7	17	35	42	43	48	30	23	3	257
Los Angeles	46	45	73	75	100	108	131	131	158	147	102	65	1,182
Madera	30	27	1,051	1,211	1,617	2,116	2,268	14,125	19,417	20,057	18,499	7,496	87,919
Marin	0	1	32	31	32	34	38	43	44	40	12	3	310
Mariposa	0	0	0	0	0	1	1	1	2	3	2	1	11
Mendocino	2	4	12	12	13	85	58	47	50	51	27	12	372
Merced	657	606	2,737	3,569	5,892	8,182	8,740	11,310	24,642	25,435	22,807	6,228	120,814
Modoc	26	25	65	67	125	209	255	257	283	188	138	41	1,679
Mono	6	6	10	10	15	17	21	21	24	21	14	8	174
Monterey	88,593	81,215	93,062	90,907	95,901	94,745	98,403	114,742	114,214	115,515	108,972	99,381	1,195,658
Napa	0	6	24	24	24	205	136	108	112	116	59	25	841
Nevada	-	0	0	0	0	2	1	1	1	1	1	0	8

Table 24. Monthly HVMT by county and statewide (continued)

County	January	February	March	April	May	June	July	August	September	October	November	December	Total*
Orange	21	20	34	35	46	61	66	65	79	77	52	32	588
Placer	0	0	2	2	4	10	12	12	12	6	5	0	64
Plumas	-	-	1	1	3	6	7	7	7	3	3	-	36
Riverside	3,662	3,311	6,051	6,743	8,776	11,945	13,270	16,396	16,440	16,219	12,387	6,286	121,505
Sacramento	48	57	315	773	2,260	2,837	2,993	9,312	14,531	14,827	13,788	4,959	66,699
San Benito	3,904	3,546	4,198	5,449	6,147	6,557	7,940	8,332	8,191	8,071	6,219	5,166	73,720
San Bernardino	566	521	2,017	1,784	2,400	2,332	3,210	2,988	3,777	3,160	1,772	722	25,252
San Diego	216	216	361	501	895	1,620	2,155	2,163	2,110	1,435	1,179	1,015	13,892
San Francisco	-	-	-	-	-	-	-	-	-	-	-	-	-
San Joaquin	879	1,248	4,257	8,622	12,302	16,513	16,633	26,801	108,235	110,978	101,007	13,647	421,133
San Luis Obispo	162	159	896	868	911	908	956	5,876	6,817	7,031	6,189	3,111	33,885
San Mateo	10	10	16	17	23	24	29	29	35	33	23	15	265
Santa Barbara	92,055	84,299	118,247	137,952	166,887	146,095	178,397	164,359	181,476	165,573	113,789	100,867	1,649,996
Santa Clara	47	46	75	77	103	119	139	137	164	153	105	67	1,233
Santa Cruz	70	189	437	402	416	486	497	555	542	559	278	80	4,510
Shasta	0	0	2	2	5	11	13	13	14	8	6	0	74
Sierra	-	-	0	0	1	2	2	2	2	1	1	-	13
Siskiyou	26	26	47	51	76	98	119	122	158	138	102	45	1,008
Solano	73	72	119	144	188	226	258	278	476	516	399	172	2,921
Sonoma	3	11	37	37	41	279	191	155	171	176	97	41	1,237
Stanislaus	535	485	1,728	2,035	4,665	7,589	8,205	11,280	31,113	31,328	28,887	6,389	134,257
Sutter	8	8	144	220	1,170	2,671	2,764	2,857	11,453	11,761	11,114	1,695	45,866
Tehama	2	2	2	4	7	11	11	15	30	33	27	8	153
Trinity	1	1	1	1	1	1	2	2	2	2	1	1	14
Tulare	398	365	3,077	3,182	4,278	6,320	6,762	14,964	20,048	20,827	17,780	6,130	104,164
Tuolumne	-	-	-	-	0	0	0	1	1	1	1	0	5
Ventura	139	136	222	229	303	360	411	408	493	468	321	203	3,692
Yolo	7	7	1,276	1,857	5,525	10,128	10,663	11,796	21,133	21,740	19,864	7,695	111,695
Yuba	3	3	28	27	62	130	161	308	2,698	2,646	2,473	58	8,599
STATEWIDE	**200,579**	**184,388**	**258,011**	**293,737**	**359,302**	**374,099**	**419,375**	**499,048**	**718,116**	**716,437**	**607,064**	**314,989**	**4,945,329**

*For some counties, the total annual unpaved road VMT may not equal the sum of monthly values due to rounding error.

8.2 Nonharvest VMT

Similar to the HVMT model, applying the nonharvest model to California counties required an Avenue script to process the data. Each road segment in the Caltrans road coverage was identified with a primary and secondary land use class according to the land use surrounding the midpoint of the road segment. The average values calculated for each land use were applied to the entire road database and the results returned for each county with one exception.

Recall that class 4 roads include residential, unpaved and unimproved roads, a portion of which are paved. Although the percentage of class 4 and class 5 roads that are unpaved was previously estimated for urban areas and the mileage of unpaved urban roads was calculated from that estimate, the data used in the estimation did not include data from core urban areas where unpaved roads are virtually nonexistent. Most urban unpaved class 4 roads exist at the edge of urban areas, at the urban-rural interface. By applying the calculated average daily vehicle passes for "Urban Industrial and Other" roads (see Table 19) to core urban areas we would be severely overestimating the unpaved road VMT generated in these areas.

To apply the average value appropriately, we applied "Urban Industrial and Other" average daily vehicle passes only to those class 4 road segments that existed within a township-range-section (TRS) location that had a paved road density of less than 2 miles/mile^2. This density threshold was determined from the average paved road density in the TRS locations of sampled urban industrial and urban other roads. In limiting the application region to urban areas with low paved road densities we lessen the chance of applying the average daily vehicle passes on unpaved roads to paved class 4 roads in core urban areas.

There was also a small portion of land that did not fit within our designated secondary land use categories. These include semi-agricultural land, idle agricultural land, and other land uses (*e.g.*, "Outside Area" or "Unknown" land uses). For the sake of completeness, these categories were included in the final NVMT estimation for 2001 and are reflected in the total. Semi-agricultural and idle agricultural land, were assumed to have 6.0 vehicle passes per mile of unpaved road per day, a proportion of class 4 and class 5 roads equal to 0.88, and a proportion of the unpaved road actually traveled of 0.58. These numbers represent the respective averages for the primary land use class, "Agriculture." Similarly, for the "Others" land use category we assumed 8.0 vehicle passes per mile of unpaved road per day, a proportion of class 4 and class 5 roads equal to 0.81, and a proportion of the unpaved road actually traveled of 0.73. These represent the respective averages over all land use types included in the analysis. NVMT and road mileage for the "Others" land use category are not included in the tables, but represent approximately 0.3% of the total estimated NVMT.

8.2.1 Annual Nonharvest VMT Estimation

Annual NVMT estimations for 2001 were calculated for each county and are displayed in Table 25. The NVMT for each county were multiplied by the number of dry days occurring in that county during each month of the year. This adjustment accounts not only for a lower number of vehicles traveling on unpaved roads during wet days, but also accounts for the fact that less PM_{10} is emitted from an unpaved road when the road is wet. Annual NVMT was also calculated without the rain day adjustment and can be seen in Appendix B. Precipitation data are derived from data collected by the Statewide Integrated Pest Management Project for 2001.

Table 26 shows the estimated annual NVMT by county and primary land use class. Figures in the table suggest that NVMT in developed (urban) areas may be overestimated by the method for highly urbanized counties. This suggests that a top paved road density value of 2 miles/mile^2 may not be an adequate threshold in counties such as Los Angeles, San Francisco, Orange and Alameda. In the future, the threshold value can be altered to reflect local conditions.

Estimated miles of unpaved road by county and primary land use class can be found in Appendix B. Figure 11 illustrates the annual NVMT densities statewide. Densities are displayed in 3 x 3 mile grids.

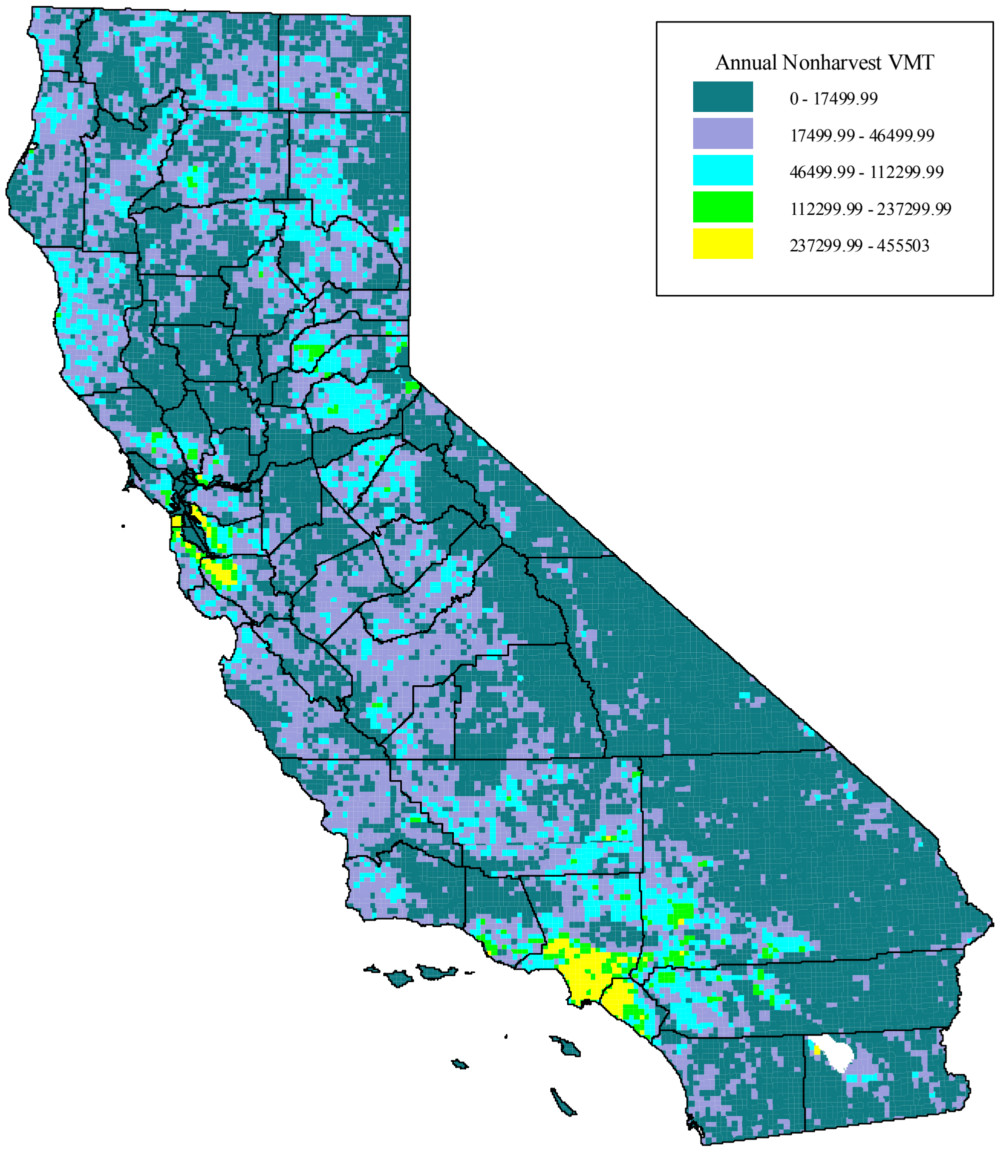
Table 25. Annual unpaved road NVMT by county

County	Annual Unpaved Road NVMT	County	Annual Unpaved Road NVMT
Alameda	8,976,103	Orange	17,100,259
Alpine	837,323	Placer	5,931,637
Amador	544,098	Plumas	10,641,580
Butte	5,017,180	Riverside	16,694,060
Calaveras	5,669,411	Sacramento	1,478,402
Colusa	1,628,476	San Benito	3,281,500
Contra Costa	2,563,887	San Bernardino	41,431,739
Del Norte	3,376,900	San Diego	7,097,980
El Dorado	9,555,894	San Francisco	1,785,024
Fresno	14,553,888	San Joaquin	2,352,629
Glenn	2,319,629	San Luis Obispo	9,276,502
Humboldt	10,784,934	San Mateo	4,529,171
Imperial	6,649,497	Santa Barbara	6,381,084
Inyo	8,046,783	Santa Clara	10,210,510
Kern	28,618,955	Santa Cruz	1,999,049
Kings	4,086,490	Shasta	12,254,706
Lake	1,654,957	Sierra	2,957,074
Lassen	14,582,774	Siskiyou	17,246,530
Los Angeles	47,516,925	Solano	3,127,560
Madera	7,197,594	Sonoma	4,942,219
Marin	2,450,789	Stanislaus	2,957,643
Mariposa	3,849,395	Sutter	921,089
Mendocino	14,515,806	Tehama	7,514,675
Merced	5,602,982	Trinity	9,273,344
Modoc	11,637,520	Tulare	6,666,995
Mono	4,318,772	Tuolumne	5,997,087
Monterey	9,058,089	Ventura	7,142,722
Napa	2,259,369	Yolo	1,506,549
Nevada	5,458,383	Yuba	1,991,715
Total	**243,332,803**	**Total**	**224,691,035**
GRAND TOTAL FOR CALIFORNIA			**468,023,838**

Table 26. Annual Nonharvest VMT by primary land use class and county

County	NVMT Agricultural	NVMT Developed	NVMT Natural	County	NVMT Agricultural	NVMT Developed	NVMT Natural
Alameda	41,166	6,982,935	1,936,921	Orange	13,217	15,524,852	1,504,877
Alpine	12,333	28,198	791,226	Placer	320,176	764,495	4,840,232
Amador	9,098	50,397	480,106	Plumas	149,263	337,876	10,134,147
Butte	507,753	502,403	3,986,693	Riverside	1,068,500	8,717,272	6,885,519
Calaveras	3,801	218,369	5,438,341	Sacramento	325,042	522,539	595,440
Colusa	716,093	6,766	897,279	San Benito	338,458	119,591	2,788,413
Contra Costa	223,305	772,270	1,531,756	San Bernardino	410,232	10,900,726	30,021,014
Del Norte	258	48,838	3,324,993	San Diego	560,389	1,661,953	4,867,767
El Dorado	65,934	689,437	8,780,527	San Francisco	--	1,785,024	--
Fresno	7,261,388	881,533	6,375,408	San Joaquin	1,251,766	202,878	855,628
Glenn	419,489	10,040	1,889,426	San Luis Obispo	1,131,510	510,118	7,612,551
Humboldt	163,971	362,653	10,234,891	San Mateo	23,533	3,419,250	1,084,706
Imperial	2,437,903	839,815	3,369,074	Santa Barbara	812,957	527,237	4,966,165
Inyo	4,587	35,971	7,932,219	Santa Clara	248,753	7,334,922	2,548,003
Kern	4,965,327	1,979,494	21,582,900	Santa Cruz	284,585	334,091	1,370,161
Kings	2,792,926	138,915	1,130,538	Shasta	188,298	819,136	11,205,817
Lake	27,373	99,631	1,520,587	Sierra	42,542	--	2,913,141
Lassen	993,678	408,808	13,123,039	Siskiyou	604,774	291,043	16,320,772
Los Angeles	373,835	38,196,918	8,881,486	Solano	403,059	1,640,591	1,054,903
Madera	2,269,544	623,733	4,280,308	Sonoma	328,208	1,410,594	3,192,498
Marin	78,370	1,361,521	996,290	Stanislaus	1,054,342	158,561	1,710,206
Mariposa	16,085	275,330	3,533,373	Sutter	678,366	53,658	180,521
Mendocino	259,113	92,322	14,130,728	Tehama	428,290	188,162	6,896,489
Merced	2,838,963	216,708	2,530,966	Trinity	9,436	272,636	8,947,610
Modoc	1,106,028	231,738	10,239,629	Tulare	2,113,646	330,058	4,179,873
Mono	83,797	--	4,206,055	Tuolumne	9,814	647,416	5,313,054
Monterey	1,525,186	988,336	6,308,677	Ventura	526,531	3,482,759	3,100,113
Napa	65,331	609,424	1,561,750	Yolo	867,552	128,131	496,331
Nevada	7,809	341,310	5,090,430	Yuba	314,194	169,226	1,470,973
Total	**29,270,445**	**56,993,810**	**156,085,616**	**Total**	**14,507,433**	**62,254,795**	**147,056,924**
STATEWIDE GRAND TOTAL					**43,777,878**	**119,248,605**	**303,142,539**

Figure 11. Statewide densities of annual Nonharvest VMT



8.2.2 Monthly Nonharvest VMT Estimation

Rain adjusted annual NVMT were apportioned according to the proportion of dry days each month. For each county, annual NVMT was multiplied by the number of dry days each month and divided by the total dry days in the year to produce a monthly profile of NVMT. Precipitation data for 2001, recorded at weather monitors in most California counties, were obtained from the Statewide Integrated Pest Management Project.[14] Table 27 shows the adjusted monthly and annual NVMT for each county.

[14] Precipitation data were not available for Marin, San Francisco and Alpine Counties. Precipitation statistics from Alameda County were used for Marin and San Francisco Counties and data from El Dorado County were used for Alpine in this study.

Table 27. Monthly Nonharvest VMT by county and statewide*

County	January	February	March	April	May	June	July	August	September	October	November	December	Total
Alameda	619,042	481,477	687,824	550,259	894,171	894,171	997,345	1,031,736	894,171	928,562	653,433	343,912	8,976,103
Alpine	59,385	41,569	62,354	65,323	92,046	80,169	92,046	92,046	80,169	86,108	56,415	29,692	837,323
Amador	-	-	-	-	-	86,740	197,137	197,137	47,313	15,771	-	-	544,098
Butte	363,841	248,944	382,991	421,290	593,636	517,038	593,636	593,636	536,187	497,888	210,645	57,449	5,017,180
Calaveras	433,211	282,529	452,046	433,211	583,893	546,222	583,893	583,893	546,222	546,222	414,376	263,694	5,669,411
Colusa	119,821	81,696	130,714	147,053	168,839	152,499	163,392	168,839	157,946	157,946	108,928	70,803	1,628,476
Contra Costa	178,631	126,093	241,678	210,155	325,740	220,662	294,217	325,740	136,601	304,724	126,093	73,554	2,563,887
Del Norte	245,593	168,845	245,593	199,544	414,438	353,040	383,739	399,088	383,739	337,690	199,544	46,049	3,376,900
El Dorado	677,723	474,406	711,609	745,495	1,050,471	914,926	1,050,471	1,050,471	914,926	982,698	643,837	338,861	9,555,894
Fresno	659,044	604,124	1,263,168	1,263,168	1,647,610	1,592,690	1,592,690	1,702,530	1,373,008	1,537,769	713,964	604,124	14,553,888
Glenn	164,451	103,864	164,451	190,417	268,315	242,349	268,315	268,315	242,349	242,349	112,519	51,932	2,319,629
Humboldt	576,734	403,714	749,755	288,367	1,499,510	1,384,163	1,557,183	1,499,510	1,268,816	1,268,816	288,367	-	10,784,934
Imperial	488,036	447,367	569,376	610,046	589,711	569,376	569,376	528,706	549,041	589,711	549,041	589,711	6,649,497
Inyo	154,153	493,289	770,765	770,765	832,426	863,256	832,426	924,918	894,087	493,289	678,273	339,136	8,046,783
Kern	1,754,419	1,425,465	2,302,675	2,302,675	3,399,186	3,179,884	2,960,582	2,850,930	3,179,884	3,070,233	1,096,512	1,096,512	28,618,955
Kings	314,345	142,884	342,922	271,480	442,941	428,653	414,364	442,941	428,653	414,364	271,480	171,461	4,086,490
Lake	135,261	95,478	183,000	167,087	246,652	222,783	246,652	246,652	87,522	23,870	-	-	1,654,957
Lassen	1,289,633	793,620	992,025	1,041,627	1,537,639	1,438,437	1,438,437	1,488,038	1,388,836	1,488,038	892,823	793,620	14,582,774
Los Angeles	3,670,006	2,124,741	4,249,481	3,863,165	5,215,272	4,249,481	4,635,798	5,987,905	5,408,431	4,828,956	2,704,215	579,475	47,516,925
Madera	487,579	441,143	603,669	557,233	719,759	696,541	696,541	719,759	673,323	673,323	534,015	394,707	7,197,594
Marin	80,354	120,531	187,492	214,277	281,238	267,846	415,161	415,161	93,746	361,592	13,392	-	2,450,789
Mariposa	283,233	193,113	296,107	308,982	399,101	386,227	373,353	399,101	373,353	360,478	257,485	218,862	3,849,395
Mendocino	995,035	702,378	1,170,630	819,441	1,755,944	1,580,350	1,814,476	1,814,476	1,580,350	1,638,881	526,783	117,063	14,515,806
Merced	357,637	298,031	476,850	417,243	615,931	596,062	615,931	576,193	556,324	596,062	298,031	198,687	5,602,982
Modoc	844,659	703,882	938,510	610,031	1,360,839	1,032,361	1,173,137	1,407,765	1,126,212	1,220,063	610,031	610,031	11,637,520
Mono	325,678	226,559	396,477	339,838	410,637	424,797	311,518	424,797	382,318	410,637	339,838	325,678	4,318,772
Monterey	690,871	345,436	614,108	652,489	1,151,452	1,036,307	959,543	921,162	806,016	959,543	575,726	345,436	9,058,089
Napa	118,914	109,767	192,092	219,534	256,123	228,681	283,565	283,565	256,123	265,270	45,736	-	2,259,369
Nevada	361,356	266,263	475,469	418,413	589,581	513,506	589,581	589,581	551,544	532,525	342,338	228,225	5,458,383

Table 27. Monthly Nonharvest VMT by county and statewide (continued)*

County	January	February	March	April	May	June	July	August	September	October	November	December	Total
Orange	1,177,395	728,863	1,289,528	1,233,461	1,569,860	1,625,926	1,738,059	1,738,059	1,681,993	1,738,059	1,345,594	1,233,461	17,100,259
Placer	362,726	256,042	469,410	469,410	661,442	597,431	661,442	661,442	597,431	597,431	362,726	234,705	5,931,637
Plumas	534,133	575,221	821,744	739,569	1,191,528	1,068,267	1,068,267	1,273,703	1,109,354	1,191,528	657,395	410,872	10,641,580
Riverside	1,063,837	818,336	-	1,227,504	1,554,839	1,964,007	1,309,338	1,882,173	2,045,841	2,209,508	1,309,338	1,309,338	16,694,060
Sacramento	63,587	74,185	121,875	121,875	164,267	148,370	164,267	164,267	153,669	153,669	95,381	52,989	1,478,402
San Benito	205,898	154,424	231,635	231,635	398,927	257,373	386,059	386,059	373,190	373,190	128,686	154,424	3,281,500
San Bernardino	2,399,522	1,919,617	3,679,266	159,968	4,319,139	4,639,075	4,159,171	4,159,171	4,639,075	4,639,075	3,359,330	3,359,330	41,431,739
San Diego	514,346	445,767	582,926	342,898	445,767	685,795	685,795	960,113	925,824	582,926	514,346	411,477	7,097,980
San Francisco	143,139	109,459	176,818	134,719	25,260	218,918	218,918	143,139	193,658	227,338	117,879	75,779	1,785,024
San Joaquin	173,930	128,159	219,701	192,238	283,780	247,163	283,780	283,780	256,318	64,079	146,467	73,234	2,352,629
San Luis Obispo	640,922	337,327	708,387	674,655	1,045,715	1,011,982	1,011,982	1,045,715	978,249	910,784	472,258	438,526	9,276,502
San Mateo	363,188	277,732	448,644	341,824	64,092	555,464	555,464	363,188	491,372	576,828	299,096	192,276	4,529,171
Santa Barbara	423,640	185,343	529,551	344,208	476,595	767,848	741,371	767,848	767,848	476,595	503,073	397,163	6,381,084
Santa Clara	694,315	530,947	939,367	775,999	1,266,103	1,061,893	1,102,735	1,225,261	653,473	1,184,419	408,420	367,578	10,210,510
Santa Cruz	130,206	99,570	153,184	153,184	206,798	222,117	237,435	191,480	206,798	206,798	107,229	84,251	1,999,049
Shasta	882,339	539,207	1,029,395	882,339	1,372,527	1,274,489	1,421,546	1,519,583	1,225,471	1,372,527	441,169	294,113	12,254,706
Sierra	212,017	133,905	200,858	200,858	334,763	312,446	334,763	345,922	301,287	323,604	167,382	89,270	2,957,074
Siskiyou	1,464,328	894,867	650,812	732,164	2,196,492	1,952,437	1,789,734	2,359,195	1,871,086	2,115,140	976,219	244,055	17,246,530
Solano	146,253	168,753	202,504	292,506	348,757	315,006	337,506	348,757	315,006	315,006	202,504	135,003	3,127,560
Sonoma	162,040	243,060	378,093	432,107	567,140	540,133	837,206	837,206	189,047	729,180	27,007	-	4,942,219
Stanislaus	174,583	164,313	246,470	225,931	318,357	287,549	318,357	318,357	287,549	308,088	205,392	102,696	2,957,643
Sutter	65,558	36,057	78,670	72,114	101,615	88,503	101,615	101,615	91,781	95,059	59,002	29,501	921,089
Tehama	540,829	426,970	711,617	512,364	825,476	768,546	882,405	882,405	740,082	797,011	426,970	-	7,514,675
Trinity	703,033	468,689	736,511	569,122	1,004,333	903,900	1,004,333	1,037,811	970,856	903,900	535,644	435,211	9,273,344
Tulare	528,328	251,585	578,645	503,169	754,754	754,754	754,754	779,913	754,754	729,596	50,317	226,426	6,666,995
Tuolumne	384,155	298,787	448,181	405,497	661,600	618,916	576,233	661,600	618,916	618,916	426,839	277,445	5,997,087
Ventura	592,981	296,490	-	592,981	700,795	781,656	781,656	835,564	808,610	727,749	592,981	431,259	7,142,722
Yolo	91,653	68,740	126,023	131,751	171,850	114,566	177,578	177,578	160,393	160,393	91,653	34,370	1,506,549
Yuba	146,245	97,497	167,137	146,245	215,885	194,993	215,885	215,885	194,993	201,957	125,353	69,640	1,991,715
Grand Total	**31,433,772**	**22,677,119**	**35,780,782**	**30,940,901**	**50,591,559**	**48,678,743**	**49,962,158**	**53,601,380**	**48,521,131**	**49,363,736**	**27,419,491**	**19,053,066**	**468,023,838**

*Monthly NVMT were calculated using the precipitation adjusted annual NVMT.

8.3 Total Statewide Unpaved Road VMT

Statewide unpaved road VMT estimates simply equal the sum of the harvest and nonharvest VMT estimations. Table 28 summarizes statewide unpaved road VMT for 2001 by county. Table 29 summarizes harvest, nonharvest and total unpaved road VMT for 2001 by month. Monthly and annual estimates for individual counties can be found in Appendix C.

Table 28. Unpaved road VMT by county *

County	HVMT	NVMT	Total
Alameda	102	8,976,103	8,976,205
Alpine	-	837,323	837,323
Amador	1,280	544,098	545,378
Butte	18,067	5,017,180	5,035,247
Calaveras	72	5,669,411	5,669,483
Colusa	58,927	1,628,476	1,687,402
Contra Costa	40,237	2,563,887	2,604,124
Del Norte	781	3,376,900	3,377,681
El Dorado	33	9,555,894	9,555,927
Fresno	161,768	14,553,888	14,715,656
Glenn	42,447	2,319,629	2,362,076
Humboldt	9	10,784,934	10,784,943
Imperial	13,947	6,649,497	6,663,444
Inyo	28	8,046,783	8,046,811
Kern	276,863	28,618,955	28,895,818
Kings	94,942	4,086,490	4,181,432
Lake	125	1,654,957	1,655,082
Lassen	257	14,582,774	14,583,031
Los Angeles	1,182	47,516,925	47,518,108
Madera	87,919	7,197,594	7,285,513
Marin	310	2,450,789	2,451,099
Mariposa	11	3,849,395	3,849,406
Mendocino	372	14,515,806	14,516,178
Merced	120,814	5,602,982	5,723,796
Modoc	1,679	11,637,520	11,639,199
Mono	174	4,318,772	4,318,946
Monterey	1,195,658	9,058,089	10,253,747
Napa	841	2,259,369	2,260,210
Nevada	8	5,458,383	5,458,391

Table 28. Unpaved road VMT by county (continued)*

County	HVMT	NVMT	Total
Orange	588	17,100,259	17,100,847
Placer	64	5,931,637	5,931,701
Plumas	36	10,641,580	10,641,616
Riverside	121,505	16,694,060	16,815,564
Sacramento	66,699	1,478,402	1,545,101
San Benito	73,720	3,281,500	3,355,221
San Bernardino	25,252	41,431,739	41,456,990
San Diego	13,892	7,097,980	7,111,872
San Francisco	-	1,785,024	1,785,024
San Joaquin	421,133	2,352,629	2,773,762
San Luis Obispo	33,885	9,276,502	9,310,387
San Mateo	265	4,529,171	4,529,436
Santa Barbara	1,649,996	6,381,084	8,031,080
Santa Clara	1,233	10,210,510	10,211,743
Santa Cruz	4,510	1,999,049	2,003,559
Shasta	74	12,254,706	12,254,779
Sierra	13	2,957,074	2,957,087
Siskiyou	1,008	17,246,530	17,247,539
Solano	2,921	3,127,560	3,130,481
Sonoma	1,237	4,942,219	4,943,456
Stanislaus	134,257	2,957,643	3,091,900
Sutter	45,866	921,089	966,955
Tehama	153	7,514,675	7,514,828
Trinity	14	9,273,344	9,273,358
Tulare	104,164	6,666,995	6,771,158
Tuolumne	5	5,997,087	5,997,092
Ventura	3,692	7,142,722	7,146,414
Yolo	111,695	1,506,549	1,618,244
Yuba	8,599	1,991,715	2,000,314
STATEWIDE TOTALS	**4,945,329**	**468,023,838**	**472,969,167**

*Monthly NVMT is calculated using the adjusted annual NVMT.

Table 29. Monthly harvest, nonharvest and total unpaved road VMT

TOTALS FOR THE ENTIRE STATE			
Month	**Harvest VMT**	**Nonharvest VMT**	**Total Unpaved Road VMT**
January	200,579	31,433,772	31,634,351
February	184,388	22,677,119	22,861,507
March	258,011	35,780,782	36,038,793
April	293,737	30,940,901	31,234,638
May	359,302	50,591,559	50,950,861
June	374,099	48,678,743	49,052,842
July	419,375	49,962,158	50,381,533
August	499,048	53,601,380	54,100,428
September	718,116	48,521,131	49,239,246
October	716,437	49,363,736	50,080,173
November	607,064	27,419,491	28,026,555
December	314,989	19,053,066	19,368,055
Annual *	**4,945,329**	**468,023,838**	**472,968,984**

*Annual VMT totals may not equal the sum of monthly values due to rounding error.

The model results show us that annual harvest VMT make up only about 1% of the total unpaved road VMT generated each year. This does not mean that agricultural VMT on unpaved roads is necessarily insignificant because agricultural VMT for purposes other than harvest are included in the nonharvest model. However, from Table 19 we see that even the agricultural land with the highest daily vehicle passes are substantially lower than those for urban residential and forested areas.

Although harvest VMT does not appear to have a great impact on an annual time scale, it may be important for meeting the 24-hour standard for PM_{10}. HVMT is concentrated during short periods of time in any given area and may play a factor in increased concentrations of PM_{10} episodes in these areas.

Figure 12 and Figure 13 illustrate the densities of statewide HVMT during the peak harvest month of September and the densities of statewide NVMT during the peak nonharvest month of August, respectively. Figure 14 illustrates the densities of annual total statewide unpaved road VMT for 2001.

Figure 12. Statewide Harvest VMT during the peak harvest month (September)

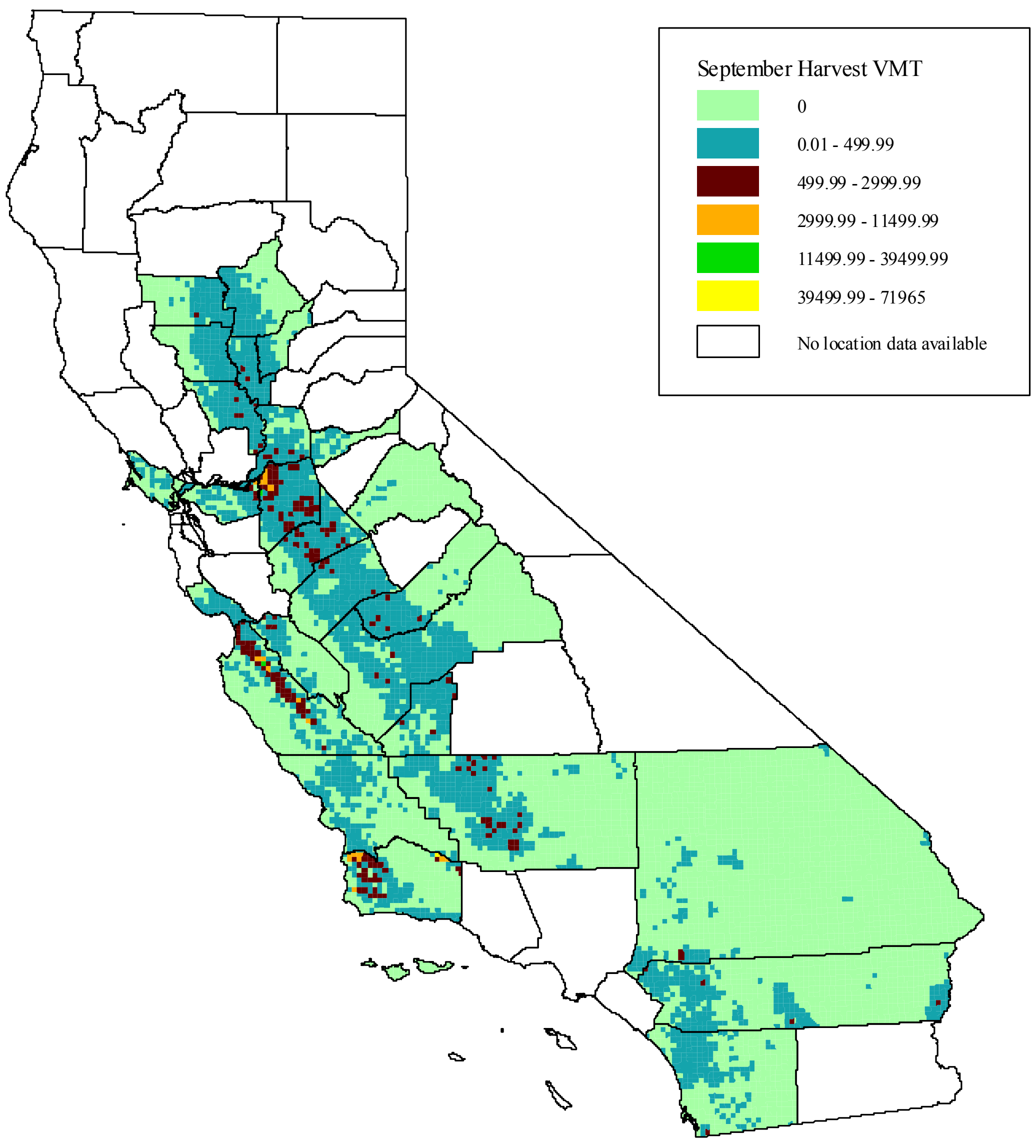


Figure 13. Statewide Nonharvest VMT during the peak nonharvest month (August)

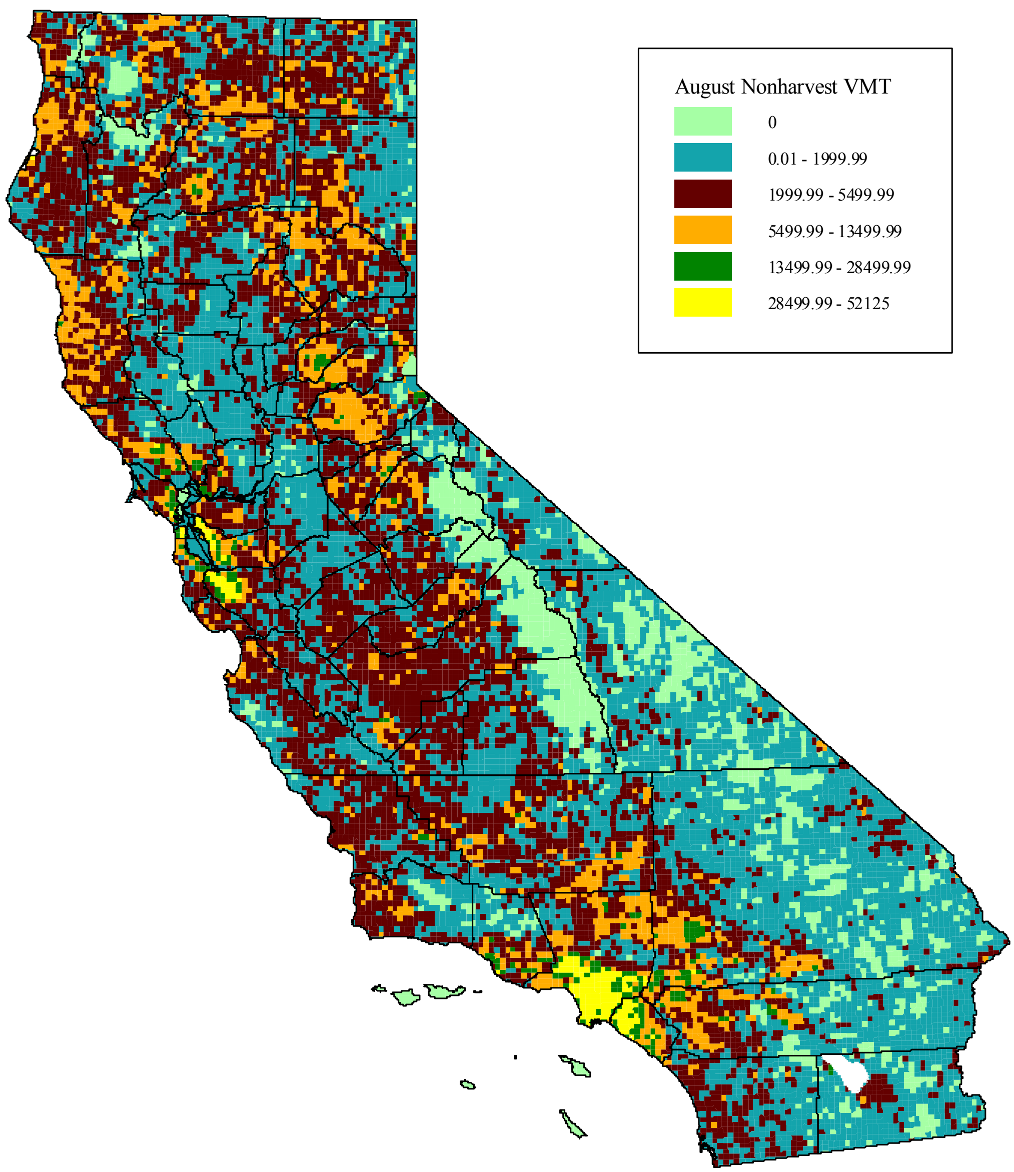
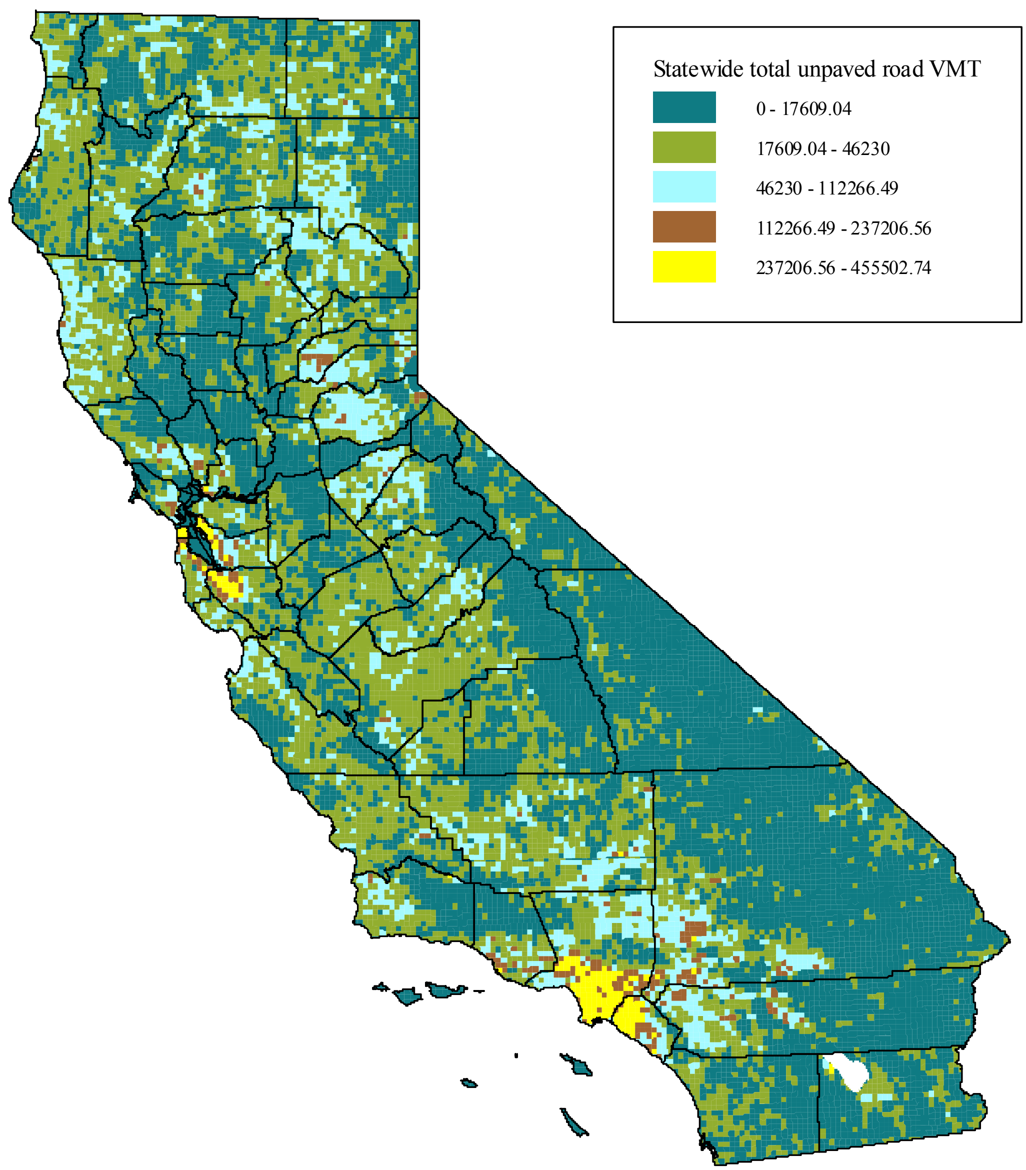


Figure 14. Statewide total annual unpaved road VMT



9.0 CONCLUSIONS AND FUTURE RESEARCH

The purpose of this study was to produce a framework for estimating VMT on unpaved roads in California using real-world data and a finer spatial resolution than is available in the current CARB estimation procedure. It was also the purpose of this study to estimate statewide unpaved road VMT for 2001 using the new method. In the course of developing the method we compiled several databases, recorded traffic counts on agricultural as well as nonagricultural unpaved roads and characterized the vehicle passes generated as a result of both harvest and nonharvest activities on these roads. In addition to spatial distinctions, we incorporated differences between crop types and differences in harvest travel according to field sizes into the VMT estimation. We also expanded data collection to areas outside the San Joaquin Valley to more completely characterize statewide unpaved road VMT.

CARB's current method for estimating unpaved road VMT is based on multiplying the estimated miles of unpaved road in the state by a standard 10 vehicle passes per day for nonagricultural roads. Based on study results, we find that the 10 vehicle passes per day characterize vehicle passes on some agricultural and natural land roads fairly well (*i.e*., Truck, Berry, Nursery and Vine roads, Field and Pasture roads, and Grasslands, Sand dunes and Scrubland roads), however it does not well characterize travel for other land use categories (*i.e*., Fruit and nut roads, Forest and Woodland roads, Urban Residential or Urban Industrial and Other roads). The differences in these numbers result in an unpaved road VMT underestimation in some areas, and overestimation in others. More spatial refinement, such as that presented in this study, improves these VMT estimations on the county and regional levels. Looking at Table 29, we also see that nonharvest vehicle activity far outweighs harvest vehicle activity regardless of the county. Even in very heavily agricultural counties such as Fresno or Kern, HVMT is small compared to the NVMT. This suggests that PM_{10} control measures may be best concentrated on recreational, residential and other nonharvest agricultural users.

Although the new framework presented in this document represents advancement in characterizing annual unpaved road VMT, there are still improvements that should be considered. Additional traffic counts on a year-round basis could be used to better characterize temporal changes (e.g., winter and spring) in unpaved road traffic volumes. Data from a wider network of traffic counters would improve the reliability of the estimates. Furthermore, refining the GIS roads database to more clearly distinguish urban unpaved roads from other urban class 4 roads would improve the unpaved road VMT estimates for developed areas, particularly for highly urbanized counties.

In terms of the harvest model, data used to perform estimates should be improved in the future. Specific suggestions include: regionalizing the yield per acre data to obtain more accurate local HVMT estimates, regionalizing crop calendars to more accurately apportion HVMT per month, and improving the estimated average road lengths traveled during a single harvest-hauling trip. Because some fields directly access paved roads and others do not, hauling from some fields may not utilize an unpaved road, while others travel more than the side of a single field to transport crops from the field to their next destination. GIS data are also being refined on a field level basis by the Department of Pesticide Management. As these data becomes available, it will allow for more refined VMT estimates to be generated, possibly on a field-by-field basis.

In addition to data improvements, PM_{10} emission estimates would benefit from a better understanding of the influence of rain or dust suppression measures undertaken by growers. Although rain and road watering diminish PM_{10} emissions, the relationship between the amount of precipitation and the diminution of emissions should be quantified to improve emissions estimates.

REFERENCES

California Air Resources Board (CARB). 2002. http://www.arb.ca.gov/desig/adm/adm.htm. Last updated: May 13, 2002.

California Air Resources Board (CARB). 2000. "Public Meeting to Consider Revisions to the State's On-Road Mobile Source Emissions Inventory." May 25, 2000.

California Air Resources Board (CARB). 1997. "Emission Inventory Procedural Manual, Volume III: Methods for Assessing Area Source Emissions." Sections 7.10 and 7.11, (Revised 2000).

California Department of Food and Agriculture (CDFA). 2001. "2001 Agricultural Resource Directory."

California State Association of Counties (CSAC). 2002. "Square Mileage by County." http://www.csac.counties.org/counties_close_up/county_web/county_mileage.html.

Claiborn, C., A. Mitra, G. Adams, L. Bamesberger, G. Allwine, R. Kantamaneni, B. Lamb, and H. Westberg. 1995. "Evaluation of PM10 Emissions Rates from Paved and Unpaved Roads Using Tracer Techniques." *Atmospheric Environment*. Vol. 29, No. 10, pp. 1075-1089.

Coe, Dana L., Lyle R. Chinkin, and Patrick A Ryan. "Identification of Selected Agricultural Practices that Reduce PM10 Emissions within the San Joaquin Valley, Final Report." *Report # STI-999681-1978-FR*. Prepared for the San Joaquin Valley Unified Air Pollution Control District, Fresno, CA, August 2000.

Dyck, R. and J. Stukel. 1976. "Fugitive Dust Emissions from Trucks on Unpaved Roads." *Environmental Science & Technology*. Vol. 10, No. 10, pp. 1046-1048.

Gillies, J.A., J.G. Watson, C.F. Rogers, D. DuBois, J.C. Chow, R. Langston, and J. Sweet. 1999. "Long-Term Efficiencies of Dust Suppressants to Reduce PM_{10} Emissions from Unpaved Roads." *Journal of the Air & Waste Management Association*. Vol. 49, pp. 3-16.

Holland, R.F. (1986). Preliminary Descriptions of the Terrestrial Natural Communities of California. Sacramento. California Department of Fish and Game.

Kantamaneni, R., G. Adams, L. Bamesberger, E. Allwine, H. Westberg, B. Lamb, and C. Claiborn. 1996. "The Measurement of Roadway PM_{10} Emission Rates Using Atmospheric Tracer Techniques." *Atmospheric Environment*. Vol. 30, No. 24, pp. 4209-4223.

Moosmuller, H., J.A. Gillies, C.F. Rogers, D.W. DuBois, J.C. Chow, and J.G. Watson. 1998. "Particulate Emission Rates for Unpaved Shoulders along a Paved Road." *Journal of the Air & Waste Management Association*. Vol. 48, pp. 398-407.

Morey, J., D. Niemeier, J.P. Franklin, T. Limanond, and K. Lakshminarayanan. 1999. "An Exploratory Study: A New Methodology for Estimating Unpaved Road Miles and Vehicle Activity on Unpaved Roads." Final Report, Vol. I. Institute of Transportation Studies, University of California, Davis, California, February 1999.

United States Department of Agriculture (USDA). 1999. *1997 Census of Agriculture*. Published by the National Agricultural Statistics Service, February 1999.

United States Environmental Protection Agency (USEPA). 1998. *Compilation of Air Pollutant Emission Factors*. AP-42, 13.2.2., Fifth Edition.

10.0 APPENDIX A: TRAFFIC COUNTS AND COUNTER LOCATIONS

Table 30. Count dates and raw data

		Day of Week									
Site No.	**Count Dates**	**Sunday**	**Monday**	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**	**7-day Total**	**Average Daily Vehicle Passes**	**Standard Deviation**
1-1	08/01/01 - 08/08/01	2	1	2	0	1	3	2	**11**	**1.6**	**0.98**
1-2	11/21/01 - 11/28/01	0	0	0	2	5	0	3	**10**	**1.4**	**1.99**
1-3	08/23/01 - 08/30/01	0	0	0	0	0	0	0	**0**	**0.0**	**0.00**
1-4	07/24/01 - 07/31/01	5	6	2	9	2	8	4	**36**	**5.1**	**2.73**
1-5	07/26/01 - 08/02/01	0	5	0	3	3	2	1	**14**	**2.0**	**1.83**
1-6	08/17/01 - 08/24/01	3	8	3	1	12	11	10	**48**	**6.9**	**4.45**
1-7	09/12/01 - 09/19/01	3	1	14	13	14	17	15	**77**	**11.0**	**6.30**
1-8	08/30/01 - 09/06/01	2	2	5	3	1	7	0	**20**	**2.9**	**2.41**
1-9	08/02/01 - 08/09/01	1	3	2	2	5	5	3	**21**	**3.0**	**1.53**
1-10	08/30/01 - 09/06/01	4	27	70	4	7	11	55	**178**	**25.4**	**26.86**
2-1	07/12/01 - 07/19/01	10	14	10	5	15	24	13	**91**	**13.0**	**5.89**
2-2	07/12/01 - 07/19/01	0	17	12	20	11	7	7	**74**	**10.6**	**6.71**
2-3	10/29/01 - 11/05/01	7	12	19	24	21	16	6	**105**	**15.0**	**6.93**
2-4	10/29/01 - 11/05/01	3	5	1	2	2	1	1	**15**	**2.1**	**1.46**
2-5	08/06/01 - 08/13/01	0	3	4	2	15	0	0	**24**	**3.4**	**5.35**
2-6	10/22/01 - 10/29/01	2	25	25	14	20	26	8	**120**	**17.1**	**9.42**
3-1	07/26/01 - 08/02/01	6	16	5	13	11	15	20	**86**	**12.3**	**5.41**
3-2	08/25/01 - 09/01/01	4	6	4	4	4	6	3	**31**	**4.4**	**1.13**
3-3	07/20/01 - 07/27/01	32	84	82	105	105	80	32	**520**	**74.3**	**30.69**
3-4	08/15/01 - 08/22/01	0	0	0	0	2	2	0	**4**	**0.6**	**0.98**
3-5	10/29/01 - 11/05/01	8	8	9	14	16	13	9	**77**	**11.0**	**3.27**
3-6	08/15/01 - 08/22/01	2	8	12	14	14	12	13	**75**	**10.7**	**4.35**
3-7	08/02/01 - 08/09/01	0	0	1	0	0	2	1	**4**	**0.6**	**0.79**
3-8	08/02/01 - 08/09/01	2	11	0	15	7	2	1	**38**	**5.4**	**5.74**
3-9	08/23/01 - 08/30/01	1	4	3	3	1	3	0	**15**	**2.1**	**1.46**
3-10	07/02/01 - 07/09/01	26	31	52	39	45	33	45	**271**	**38.7**	**9.21**
3-11	10/17/01 - 10/24/01	72	41	63	44	54	74	75	**423**	**60.4**	**14.29**
3-12	08/23/01 - 08/30/01	0	3	3	6	12	10	5	**39**	**5.6**	**4.20**
3-13	08/09/01 - 08/16/01	7	30	45	52	22	8	21	**185**	**26.4**	**17.21**
3-14	07/23/01 - 07/30/01	27	69	106	56	92	36	40	**426**	**60.9**	**29.71**
4-1	10/29/01 - 11/05/01	0	1	1	2	1	1	1	**7**	**1.0**	**0.58**
4-2	08/30/01 - 09/06/01	4	8	10	15	18	12	8	**75**	**10.7**	**4.72**
4-3	08/08/01 - 08/15/01	71	59	55	74	60	81	70	**470**	**67.1**	**9.37**
4-4	07/27/01 - 08/03/01	44	35	32	45	45	59	40	**300**	**42.9**	**8.75**
4-5	08/14/01 - 08/21/01	136	101	113	149	149	90	138	**876**	**125.1**	**23.76**
4-6*	11/94	--	--	--	--	--	--	--	**--**	**27.0**	**--**
4-7*	11/94	--	--	--	--	--	--	--	**--**	**4.0**	**--**
4-8*	11/94	--	--	--	--	--	--	--	**--**	**3.0**	**--**
4-9	11/11/01 - 11/18/01	1	0	1	1	3	2	2	**10**	**1.4**	**0.98**
4-10	08/23/01 - 08/30/01	88	141	133	151	135	153	121	**922**	**131.7**	**22.17**
4-11	11/20/01 - 11/27/01	121	64	80	109	187	351	254	**1166**	**166.6**	**104.47**
4-12	07/02/01 - 07/09/01	2	0	0	2	0	0	2	**6**	**0.9**	**1.07**

Table 30. Count dates and raw data (continued)

		Day of Week									
Site No.	Count Dates	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	7-day Total	Average Daily Vehicle Passes	Standard Deviation
4-13	09/07/01 - 09/14/01	19	20	21	42	165	101	11	**379**	**54.1**	**57.73**
4-14	09/12/01 - 09/19/01	1	2	9	7	9	8	5	**41**	**5.9**	**3.29**
4-15	11/11/01 - 11/18/01	11	0	4	4	4	0	5	**28**	**4.0**	**3.70**
4-16	11/11/01 - 11/18/01	13	11	2	9	5	8	15	**63**	**9.0**	**4.51**
4-17	11/11/01 - 11/18/01	0	9	0	1	3	4	4	**21**	**3.0**	**3.16**
5-1	11/20/01 - 11/27/01	6	6	2	5	8	11	11	**49**	**7.0**	**3.27**
5-2	07/07/01 - 07/14/01	101	40	59	24	56	64	131	**475**	**67.9**	**36.56**
5-3	11/19/01 - 11/26/01	6	4	6	2	7	13	2	**40**	**5.7**	**3.77**
5-4	07/14/01 - 07/21/01	108	50	65	59	65	58	64	**469**	**67.0**	**18.85**
5-5	07/14/01 - 07/21/02	133	73	67	58	58	59	114	**562**	**80.3**	**30.53**
5-6	09/16/01 - 09/23/01	17	32	24	36	22	32	26	**189**	**27.0**	**6.66**
5-7	07/23/01 - 07/30/01	63	29	24	60	76	58	58	**368**	**52.6**	**18.90**
5-8	10/15/01 - 10/22/01	19	17	5	7	6	8	16	**78**	**11.1**	**5.93**
5-9	09/12/01 - 09/19/01	2	6	11	4	5	8	1	**37**	**5.3**	**3.45**
5-10	10/18/01 - 10/25/01	8	2	4	12	11	7	12	**56**	**8.0**	**3.96**
5-11	07/15/01 - 07/2/01	23	5	15	5	9	21	50	**128**	**18.3**	**15.73**
5-12	09/23/01 - 09/30/01	5	9	16	8	10	4	2	**54**	**7.7**	**4.65**
5-13	11/02/01 - 11/09/01	34	46	42	41	44	41	35	**283**	**40.4**	**4.43**
5-14	07/14/01 - 07/21/01	19	13	9	12	3	20	42	**118**	**16.9**	**12.51**
5-15	07/02/01 - 07/09/01	28	20	33	48	42	42	38	**251**	**35.9**	**9.56**
5-16	07/02/01 - 07/09/02	5	8	7	3	12	10	10	**55**	**7.9**	**3.13**
5-17	07/02/01 - 07/09/03	2	20	10	14	27	6	17	**96**	**13.7**	**8.54**
5-18	09/07/01 - 09/14/01	39	36	34	26	34	35	45	**249**	**35.6**	**5.74**
5-19	07/14/01 - 07/21/01	2	23	30	2	1	5	10	**73**	**10.4**	**11.56**
6-1	08/06/01 - 08/13/01	0	0	0	0	0	0	0	**0**	**0.0**	**0.00**
6-2	10/29/01 - 11/05/01	3	2	4	2	2	2	1	**16**	**2.3**	**0.95**
6-3	10/15/01 - 10/22/01	37	37	52	27	34	52	53	**292**	**41.7**	**10.48**
6-4	11/01/01 - 11/08/01	37	48	52	42	49	37	52	**317**	**45.3**	**6.58**
6-5	08/18/01 - 08/25/01	0	1	2	0	0	0	0	**3**	**0.4**	**0.79**
6-6	10/29/01 - 11/05/01	4	6	11	8	4	9	8	**50**	**7.1**	**2.61**
7-1	11/21/01 - 11/28/01	15	24	18	16	21	35	20	**149**	**21.3**	**6.78**
7-2	08/23/01 - 08/30/01	2	2	1	1	6	2	2	**16**	**2.3**	**1.70**
7-3	09/07/01 - 09/14/01	2	25	16	26	27	10	2	**108**	**15.4**	**11.01**
7-4	07/28/01 - 08/04/01	40	2	1	15	9	9	19	**95**	**13.6**	**13.32**
7-5	10/29/01 - 11/05/01	0	1	0	3	1	0	2	**7**	**1.0**	**1.16**
7-6	09/25/01 - 10/02/01	14	34	29	22	29	31	26	**185**	**26.4**	**6.66**
7-7	09/12/01 - 09/19/01	0	0	1	0	0	1	0	**2**	**0.3**	**0.49**
7-8	10/13/01 - 10/20/01	10	35	12	41	33	32	9	**172**	**24.6**	**13.65**
7-9	08/23/01 - 08/30/01	6	0	0	1	19	1	0	**27**	**3.9**	**7.01**
7-10	11/21/01 - 11/28/01	0	0	2	0	0	0	0	**2**	**0.3**	**0.76**
7-11	08/15/01 - 08/22/01	1	0	0	0	4	1	2	**8**	**1.1**	**1.46**
7-12	11/20/01 - 11/27/01	5	4	9	8	6	9	8	**49**	**7.0**	**2.00**
7-13	07/24/01 - 07/31/01	0	29	25	29	39	32	7	**161**	**23.0**	**14.13**
7-14	11/02/01 - 11/09/01	98	83	120	75	131	104	82	**693**	**99.0**	**20.87**
7-15	09/28/01 - 10/05/01	0	1	1	0	1	1	0	**4**	**0.6**	**0.54**
7-16	08/30/01 - 09/06/01	0	1	2	0	1	0	0	**4**	**0.6**	**0.79**

* Data for these sites were taken from the November 17, 1994 San Bernardino County ADT printout. The data were expressed as "average daily traffic"; traffic counts for individual days were not provided.

Table 31. Counter locations

Site Number	County	Location	Latitude	Longitude
1-1	Tehama	Off Stevens Rd., south of intersection of Stevens Rd. and South Ave.	39.92149	-122.05617
1-10	Kern	Off Kimberlina Rd., west of the intersection of Kimberlina Rd. and Highway 99	35.56656	-119.21344
1-2	Riverside	Off Stetson Ave., west of the intersection of Fairview Ave. and Stetson Ave.	33.73773	-116.90104
1-3	San Diego	Off Courser Canyon Rd., west of the intersection of Courser Canyon Rd. and Camino Del Venado	33.30894	-117.09418
1-4	San Joaquin	Off S. Sexton Rd., south of the intersection of Sexton Rd. and Highway 120	37.77780	-121.02295
1-5	Glenn	Off Road 23 east of the Sacramento River	39.71511	-121.96512
1-6	Butte	Off Troxel Rd., north of the intersection of Troxel Rd. and Duncan Rd.	39.63244	-121.83223
1-7	Tulare	Avenue 336 between Road 164 and Road 168	36.40755	-119.19663
1-8	Tulare	Road 298 off of Highway 65	36.16092	-119.08915
1-9	Kern	Off Highway 33 between Twisselman Rd. and Highway 46	35.66627	-119.91121
2-1	Merced	Off of west end of Aqua Vista St.	36.96126	-120.66182
2-2	Stanislaus	Off of Roen Rd., south of Lake Rd.	37.61747	-120.69039
2-3	Madera	Off of Avenue 7 between Road 281 and road 28	36.84530	-120.02718
2-4	Monterey	Parids Valley Rd. east of El Camino Real	36.08974	-121.00069
2-5	San Joaquin	Off E. Jahant Rd., east of the intersection of E. Jahant and north of Bender Rd.	38.21184	-121.30790
2-6	Monterey	Off Metz Rd., north of the intersection of Metz Rd. and Airport Rd.	36.26426	-121.14358
3-1	Glenn	County Road VV	39.70450	-122.05710
3-10	Lassen	Off Standish Buntingville Rd., south of Highway 395	40.34441	-120.42693
3-11	Lassen	Horse Lake Rd., at intersection of Horse Lake Rd. and Highway 139	40.53228	-120.59254
3-12	Kern	Off Highway 223, east of the intersection with Union Ave.	35.20225	-118.99339
3-13	Yolo	Oakside Dr. south of Montgomery Ave.	38.53983	-121.70303
3-14	Sutter	Oswald Rd. at the corner of Oswald Rd. and Progress Rd	39.07828	-121.80866
3-2	Glenn	County Road 41 east of County Road W	39.57497	-122.05418
3-3	Yolo	Off of County Road 27, near the intersection of County Road 27 and Road 104	38.61263	-121.70063
3-4	Kings	26th Ave., north of Nevada Ave.	36.14605	-119.91346
3-5	Fresno	Off Jayne Ave., east of the intersection of Jayne Ave. and Highway 33	36.13081	-120.26205
3-6	Kings	11th Ave., south of Newton Ave.	36.11703	-119.68808
3-7	Kings	Paris Ave., west of Highway 41	36.07331	-119.93981
3-8	Kings	Off Highway 44, northeast of the intersection of Highway 44 and Highway 33	35.91434	-120.02980
3-9	Kern	Off Twisselman Rd. between the California Aquaduct and Interstate 5	35.73988	-119.78628

Table 31. Counter locations (continued)

Site Number	County	Location	Latitude	Longitude
4-1	Fresno	Off S. Derrick Blvd. just before Coalinga-Mendota Rd.	36.42229	-120.40146
4-10	San Diego	Black Mountain Rd., east of Camino San Bernardino	33.03019	-117.12584
4-11	Imperial	Painted Gorge Rd., near Highway 580	32.82112	-115.97616
4-12	Lassen	Road to Shaffer Mt. Trailhead, west of Highway 395	40.43267	-120.27694
4-13	Mendocino	Newhouse Ridge Rd., north of Etsel Ridge Rd.	39.76492	-123.0688
4-14	Merced	Off Brito Rd., north of the intersection of Brito Rd. and Eucalyptus Rd.	37.01951	-120.71631
4-15	Inyo	Mazourka Canyon Rd., east of Owenyo Lone Pine Rd.	36.80583	-118.11972
4-16	Inyo	Cerro Gordo Rd., east of Highway 136	36.48571	-117.86415
4-17	Inyo	Minietta Rd., west of Panamint Valley Rd.	36.25481	-117.35787
4-2	Kern	Off Famosa Woody Rd. beween Highway 65 and Woody Rd.	35.61093	-119.05355
4-3	Butte	Oasis Dr., east of Hicks Lane	39.80570	-121.87122
4-4	Sacramento	Jaeger Rd., at the corner of Douglas Rd. and Jaeger Rd.	38.56253	-121.2144
4-5	Solano	Off Grizzly Island Rd. near the bridge over the Montezuma Slough	38.19333	-121.96004
4-6	San Bernardino	Valle Vista (Twentynine Palms)	34.45114	-117.0938
4-7	San Bernardino	Japatul Road (Apple Valley)	34.63819	-115.34539
4-8	San Bernardino	Mountain Springs Road (Helendale)	35.75871	-115.65375
4-9	Inyo	Walker Creek Rd., south of Shop St.	36.25414	-118.01042
5-1	Imperial	Milipitas Wash Rd., north of Highway 78	33.27878	-114.78207
5-10	San Mateo	Gazas Creek Rd., south of Pescadero Rd.	37.19487	-122.28635
5-11	Tulare	Forest Rte. 34E27, Sequoia National Forest south of Troy Meadows Campground	36.03973	-118.25680
5-12	Sonoma	Off of Abobe Canyon Rd. east of the Ranger Station	38.43776	-122.54677
5-13	Santa Cruz	Off of Big Basin Way south of Via Paloma	37.16751	-122.17878
5-14	Tulare	Forest Rte. 20581 toward Clicks Creek Trailhead	36.11943	-118.54362
5-15	Modoc	Off of Jess Valley Rd. near Patterson Campground	41.20229	-120.27511
5-16	Lassen	Muck Valley Rd., south of Highway 299	41.07521	-121.18995
5-17	Lassen	Across the street from Center School House Road, Forest Rte. 54	41.07448	-120.97897
5-18	Mendocino	Off Spy Rock Rd., south of Registered Guest Rd.	39.84041	-123.50265
5-19	Plumas	Off Butte Co. Rd., south of Bucks Lake	39.86276	-121.16356
5-2	Sierra	Packer Lake Rd., south of Primrose Mine Rd.	39.61489	-120.65082
5-3	Lake	Forest Rte. 18N04, east of Forest Rte. M3	39.32827	-122.85716
5-4	Nevada	Trinity Dr., west of Boogie Hill Rd.	39.30845	-121.02889
5-5	Placer	Porcupine Ridge Rd., east of Yankee Jims Rd.	39.05090	-120.94114
5-6	Sonoma	Off of Highland Ranch Rd. east of Giorgi Rd.	38.77254	-122.92421
5-7	Mono	Mill Canyon Rd., north of Highway 395	38.53951	-119.49296
5-8	Tuolumne	Rock River Rd., east of Williams Rd.	37.76468	-120.55762
5-9	Madera	Douglas Ranger Station Rd., north of Road 225	37.23525	-119.48091

Table 31. Counter locations (continued)

Site Number	County	Location	Latitude	Longitude
6-1	Sacramento	Off Elk Grove Blvd. between Interstate 5 and Franklin Blvd.	38.41706	-121.4537
6-2	Fresno	Off E. Herndon Ave. east of N. De Wolf Ave.	36.84561	-119.64690
6-3	Amador	Running Gold Run Rd., south of Highway 104	38.38889	-120.76994
6-4	Yuba	Arganow Rd., south of Rices Texas Hill Rd.	39.34695	-121.26800
6-5	Marin	East end of Taylor Rd.	37.92269	-122.53208
6-6	Madera	Ellis St., off Road 281	36.99003	-120.02757
7-1	Imperial	Coachella Canal Rd., north of Hot Mineral Spa Rd.	33.40592	-115.65472
7-10	Riverside	Off Sycamore Canyon Rd. near Alessandro Rd.	33.92495	-117.28685
7-11	Kings	Robin Ct. off of Hanford Armona Rd.	36.32173	-119.66292
7-12	Imperial	P St., between Berioni Rd. and Neckel Rd.	32.84755	-115.56319
7-13	San Joaquin	Off Arch Airport Rd. between Alitalia Way and E St.	37.90603	-121.24642
7-14	Santa Cruz	Love Creek Rd., near Ben Lomand	37.09238	-122.08518
7-15	Contra Costa	Off Stone Valley Rd. near Green Valley Rd.	37.84592	-121.97768
7-16	Tulare	Off W. Mulberry Way near N. Wisconsin Way	36.08852	-119.04324
7-2	San Diego	Off east Beyer Rd. near Beyer Middle School	32.55590	-117.04010
7-3	Amador	Off Highway 104 south of Old Ione-Jackson Rd.	38.34784	-120.91777
7-4	Placer	Near Indian Hill Rd. and Dillon Rd.	38.87744	-121.08873
7-5	Stanislaus	Blaker Rd., south of Service Rd.	37.57429	-120.96515
7-6	Sacramento	Off 25th St. between C St. and D St.	38.57634	-121.47318
7-7	Merced	Off Highway 59 between Vassar Ave. and Dickson Ferry Rd.	37.26689	-120.47782
7-8	Santa Barbara	Off W. Bettervia Rd. near Blosser Rd.	34.91753	-120.44398
7-9	Kern	Cerro Dr., north of Highway 119 at Pumpkin Center	35.27510	-119.02919

The site number is comprised of two numbers; the first represents the land use category and the second represents the individual site within which a road was selected. For example, site 1-1 is the first site in the Fruit and Nut category.

11.0 APPENDIX B: NONHARVEST VMT BY COUNTY (UNADJUSTED) AND ESTIMATED COUNTY UNPAVED ROAD MILEAGE BY PRIMARY LAND USE

Table 32. Nonharvest VMT by county before and after applying the rain adjustment factor

County	Unadjusted Annual NVMT	Rain Adjusted Annual NVMT
Alameda	12,552,788	8,976,103
Alpine	1,083,769	837,323
Amador	2,878,200	544,098
Butte	6,989,583	5,017,180
Calaveras	6,874,867	5,669,411
Colusa	1,987,938	1,628,476
Contra Costa	3,835,323	2,563,887
Del Norte	5,602,584	3,376,900
El Dorado	12,368,444	9,555,894
Fresno	20,045,921	14,553,888
Glenn	3,159,197	2,319,629
Humboldt	21,050,806	10,784,934
Imperial	7,422,222	6,649,497
Inyo	11,253,165	8,046,783
Kern	40,022,677	28,618,955
Kings	5,215,275	4,086,490
Lake	2,904,131	1,654,957
Lassen	18,104,464	14,582,774
Los Angeles	70,502,755	47,516,925
Madera	8,474,586	7,197,594
Marin	4,888,186	2,450,789
Mariposa	4,699,094	3,849,395
Mendocino	21,363,989	14,515,806
Merced	7,252,087	5,602,982
Modoc	17,127,802	11,637,520
Mono	5,168,366	4,318,772
Monterey	14,009,332	9,058,089
Napa	3,338,744	2,259,369
Nevada	6,941,846	5,458,383

Table 32. Nonharvest VMT by county before and after applying the rain adjustment factor (continued)

County	Unadjusted Annual NVMT	Rain Adjusted Annual NVMT
Orange	20,464,244	17,100,259
Placer	7,787,940	5,931,637
Plumas	14,996,821	10,641,580
Riverside	29,869,273	16,694,060
Sacramento	1,934,110	1,478,402
San Benito	4,697,050	3,281,500
San Bernardino	58,388,357	41,431,739
San Diego	12,515,763	7,097,980
San Francisco	3,073,272	1,785,024
San Joaquin	3,341,283	2,352,629
San Luis Obispo	12,312,449	9,276,502
San Mateo	7,797,865	4,529,171
Santa Barbara	9,664,297	6,381,084
Santa Clara	14,907,345	10,210,510
Santa Cruz	2,795,605	1,999,049
Shasta	17,891,870	12,254,706
Sierra	4,072,951	2,957,074
Siskiyou	29,693,319	17,246,530
Solano	4,106,329	3,127,560
Sonoma	9,857,430	4,942,219
Stanislaus	3,748,402	2,957,643
Sutter	1,196,432	921,089
Tehama	10,389,608	7,514,675
Trinity	12,219,389	9,273,344
Tulare	9,182,842	6,666,995
Tuolumne	7,789,811	5,997,087
Ventura	9,838,089	7,142,722
Yolo	2,090,838	1,506,549
Yuba	2,541,874	1,991,715
TOTAL	**676,283,000**	**468,023,838**

Table 33. Estimated unpaved road mileage by county and primary land use class

County	Agricultural	Natural	Developed (Urban)	County	Agricultural	Natural	Developed (Urban)
Alameda	33.49	797.19	2,103.51	Orange	12.45	641.60	4,001.98
Alpine	12.57	240.71	7.86	Placer	270.52	1,281.92	258.95
Amador	29.83	544.86	84.15	Plumas	108.30	2,894.21	118.81
Butte	489.05	1,140.96	302.47	Riverside	1,434.87	4,108.78	3,564.24
Calaveras	4.09	1,383.10	57.04	Sacramento	221.11	234.27	438.11
Colusa	441.29	246.20	5.60	San Benito	286.09	1,162.44	69.27
Contra Costa	200.29	714.96	981.62	San Bernardino	411.80	14,665.75	3,546.02
Del Norte	0.19	1,080.19	17.45	San Diego	933.37	2,877.11	2,525.48
El Dorado	67.19	2,306.20	192.22	San Francisco	--	--	662.00
Fresno	5,203.46	2,351.88	844.75	San Joaquin	946.82	380.54	243.16
Glenn	310.23	575.85	16.34	San Luis Obispo	858.77	3,098.29	474.55
Humboldt	143.98	3,931.05	152.47	San Mateo	31.90	501.90	1,268.07
Imperial	1,323.43	1,155.18	271.66	Santa Barbara	738.33	2,340.33	669.54
Inyo	4.42	3,902.99	10.84	Santa Clara	296.47	951.46	2,306.76
Kern	3,987.75	9,931.34	881.17	Santa Cruz	247.53	426.48	419.75
Kings	1,814.61	518.67	146.51	Shasta	138.38	3,248.14	257.61
Lake	35.15	555.13	49.36	Sierra	33.76	833.21	--
Lassen	573.63	3,961.55	129.15	Siskiyou	526.71	5,646.51	107.94
Los Angeles	436.70	4,466.25	12,213.50	Solano	349.79	420.89	643.98
Madera	1,547.10	1,088.86	275.35	Sonoma	489.41	1,392.65	606.04
Marin	114.96	549.60	643.05	Stanislaus	814.33	647.64	236.54
Mariposa	9.86	1,026.32	78.09	Sutter	481.28	64.48	51.91
Mendocino	302.14	4,157.69	29.27	Tehama	411.84	2,044.09	97.14
Merced	2,047.80	1,118.41	259.09	Trinity	5.59	2,290.71	77.38
Modoc	763.60	3,493.87	86.37	Tulare	1,973.15	1,236.11	341.96
Mono	75.51	1,391.70	--	Tuolumne	7.66	1,404.03	209.96
Monterey	1,205.39	2,836.40	761.82	Ventura	689.93	1,420.28	1,033.30
Napa	76.57	489.50	193.99	Yolo	591.20	152.58	83.07
Nevada	7.82	1,298.04	93.50	Yuba	268.06	421.09	88.73
Total	**21,262**	**57,255**	**1,049**	**Total**	**9,901**	**17,141**	**9,217**
STATEWIDE GRAND TOTAL					**31,163**	**74,396**	**10,267**

12.0 APPENDIX C: MONTHLY HARVEST, NONHARVEST AND TOTAL UNPAVED ROAD VMT BY COUNTY

TOTALS FOR THE ENTIRE STATE			
Month	**Harvest VMT**	**Nonharvest VMT**	**Total Unpaved Road VMT**
January	200,579	31,433,772	31,634,351
February	184,388	22,677,119	22,861,507
March	258,011	35,780,782	36,038,793
April	293,737	30,940,901	31,234,638
May	359,302	50,591,559	50,950,861
June	374,099	48,678,743	49,052,842
July	419,375	49,962,158	50,381,533
August	499,048	53,601,380	54,100,428
September	718,116	48,521,131	49,239,246
October	716,437	49,363,736	50,080,173
November	607,064	27,419,491	28,026,555
December	314,989	19,053,066	19,368,055
Annual *	**4,945,329**	**468,023,838**	**472,969,167**

*Annual VMT totals may not equal the sum of monthly values due to rounding error.

ALAMEDA COUNTY[*]			
Month	**Harvest VMT**	**Nonharvest VMT**	**Total Unpaved Road VMT**
January	3	619,042	619,044
February	3	481,477	481,479
March	5	687,824	687,829
April	5	550,259	550,264
May	7	894,171	894,178
June	8	894,171	894,179
July	10	997,345	997,355
August	11	1,031,736	1,031,747
September	16	894,171	894,187
October	16	928,562	928,579
November	13	653,433	653,445
December	6	343,912	343,918
Annual [**]	**102**	**8,976,103**	**8,976,205**

[*]Harvest VMT was calculated using default HVMT/Acre values (Table 14).

[**]Annual VMT totals may not equal the sum of monthly values due to rounding error.

ALPINE COUNTY*			
Month	**Harvest VMT**	**Nonharvest VMT**	**Total Unpaved Road VMT**
January	0	59,385	59,385
February	0	41,569	41,569
March	0	62,354	62,354
April	0	65,323	65,323
May	0	92,046	92,046
June	0	80,169	80,169
July	0	92,046	92,046
August	0	92,046	92,046
September	0	80,169	80,169
October	0	86,108	86,108
November	0	56,415	56,415
December	0	29,692	29,692
Annual **	**0**	**837,323**	**837,323**

*Harvest VMT was calculated using default HVMT/Acre values (Table 14).

**Annual VMT totals may not equal the sum of monthly values due to rounding error.

AMADOR COUNTY			
Month	**Harvest VMT**	**Nonharvest VMT**	**Total Unpaved Road VMT**
January	0	0	0
February	0	0	0
March	10	0	10
April	10	0	10
May	11	0	11
June	17	86,740	86,757
July	20	197,137	197,157
August	201	197,137	197,337
September	304	47,313	47,617
October	309	15,771	16,080
November	290	0	290
December	108	0	108
***Annual** *	**1,280**	**544,098**	**545,378**

*Annual VMT totals may not equal the sum of monthly values due to rounding error.

BUTTE COUNTY

Month	Harvest VMT	Nonharvest VMT	Total Unpaved Road VMT
January	3	363,841	363,844
February	3	248,944	248,947
March	124	382,991	383,115
April	130	421,290	421,420
May	194	593,636	593,829
June	297	517,038	517,335
July	313	593,636	593,948
August	378	593,636	594,014
September	5,573	536,187	541,760
October	5,712	497,888	503,600
November	5,327	210,645	215,972
December	10	57,449	57,458
Annual *	**18,067**	**5,017,180**	**5,035,247**

*Annual VMT totals may not equal the sum of monthly values due to rounding error.

CALAVERAS COUNTY*			
Month	**Harvest VMT**	**Nonharvest VMT**	**Total Unpaved Road VMT**
January	2	433,211	433,213
February	2	282,529	282,531
March	4	452,046	452,050
April	4	433,211	433,215
May	5	583,893	583,898
June	8	546,222	546,231
July	9	583,893	583,901
August	8	583,893	583,901
September	10	546,222	546,232
October	9	546,222	546,232
November	6	414,376	414,382
December	4	263,694	263,697
Annual **	**72**	**5,669,411**	**5,669,483**

*Harvest VMT was calculated using default HVMT/Acre values (Table 14).

**Annual VMT totals may not equal the sum of monthly values due to rounding error.

COLUSA COUNTY			
Month	**Harvest VMT**	**Nonharvest VMT**	**Total Unpaved Road VMT**
January	1	119,821	119,822
February	1	81,696	81,697
March	183	130,714	130,896
April	253	147,053	147,306
May	2,459	168,839	171,298
June	4,801	152,499	157,300
July	4,965	163,392	168,357
August	5,368	168,839	174,207
September	12,061	157,946	170,007
October	12,562	157,946	170,507
November	11,925	108,928	120,854
December	4,346	70,803	75,149
Annual *	**58,927**	**1,628,476**	**1,687,402**

*Annual VMT totals may not equal the sum of monthly values due to rounding error.

CONTRA COSTA COUNTY			
Month	**Harvest VMT**	**Nonharvest VMT**	**Total Unpaved Road VMT**
January	2	178,631	178,633
February	80	126,093	126,173
March	705	241,678	242,383
April	705	210,155	210,860
May	1,026	325,740	326,765
June	1,364	220,662	222,026
July	1,273	294,217	295,489
August	1,433	325,740	327,173
September	11,171	136,601	147,771
October	11,518	304,724	316,242
November	10,671	126,093	136,764
December	289	73,554	73,843
Annual *	**40,237**	**2,563,887**	**2,604,124**

*Annual VMT totals may not equal the sum of monthly values due to rounding error.

DEL NORTE COUNTY[*]			
Month	**Harvest VMT**	**Nonharvest VMT**	**Total Unpaved Road VMT**
January	31	245,593	245,624
February	30	168,845	168,875
March	49	245,593	245,642
April	50	199,544	199,594
May	67	414,438	414,505
June	71	353,040	353,110
July	86	383,739	383,825
August	86	399,088	399,175
September	103	383,739	383,842
October	96	337,690	337,786
November	67	199,544	199,611
December	44	46,049	46,092
Annual [**]	**781**	**3,376,900**	**3,377,681**

[*] Harvest VMT was calculated using default HVMT/Acre values (Table 14).

[**] Annual VMT totals may not equal the sum of monthly values due to rounding error.

EL DORADO COUNTY*			
Month	**Harvest VMT**	**Nonharvest VMT**	**Total Unpaved Road VMT**
January	0	677,723	677,723
February	0	474,406	474,406
March	1	711,609	711,610
April	1	745,495	745,496
May	1	1,050,471	1,050,472
June	8	914,926	914,934
July	5	1,050,471	1,050,476
August	4	1,050,471	1,050,475
September	5	914,926	914,931
October	5	982,698	982,703
November	2	643,837	643,839
December	1	338,861	338,863
Annual **	**33**	**9,555,894**	**9,555,927**

*Harvest VMT was calculated using default HVMT/Acre values (Table 14).

**Annual VMT totals may not equal the sum of monthly values due to rounding error.

FRESNO COUNTY			
Month	**Harvest VMT**	**Nonharvest VMT**	**Total Unpaved Road VMT**
January	827	659,044	659,870
February	763	604,124	604,887
March	1,727	1,263,168	1,264,895
April	5,826	1,263,168	1,268,993
May	9,580	1,647,610	1,657,190
June	13,770	1,592,690	1,606,460
July	14,353	1,592,690	1,607,043
August	23,035	1,702,530	1,725,566
September	26,684	1,373,008	1,399,693
October	27,980	1,537,769	1,565,749
November	24,366	713,964	738,330
December	12,838	604,124	616,962
***Annual** **	**161,768**	**14,553,888**	**14,715,656**

*Annual VMT totals may not equal the sum of monthly values due to rounding error.

GLENN COUNTY			
Month	**Harvest VMT**	**Nonharvest VMT**	**Total Unpaved Road VMT**
January	11	164,451	164,463
February	10	103,864	103,874
March	357	164,451	164,808
April	816	190,417	191,233
May	1,180	268,315	269,496
June	1,707	242,349	244,056
July	1,790	268,315	270,106
August	2,035	268,315	270,350
September	11,373	242,349	253,722
October	11,657	242,349	254,007
November	10,896	112,519	123,415
December	612	51,932	52,544
Annual*	**42,447**	**2,319,629**	**2,362,076**

*Annual VMT totals may not equal the sum of monthly values due to rounding error.

HUMBOLDT COUNTY*			
Month	**Harvest VMT**	**Nonharvest VMT**	**Total Unpaved Road VMT**
January	0	576,734	576,734
February	0	403,714	403,714
March	0	749,755	749,755
April	0	288,367	288,367
May	0	1,499,510	1,499,510
June	1	1,384,163	1,384,163
July	1	1,557,183	1,557,184
August	1	1,499,510	1,499,510
September	2	1,268,816	1,268,818
October	2	1,268,816	1,268,818
November	2	288,367	288,369
December	0	0	0
Annual **	**9**	**10,784,934**	**10,784,943**

*Harvest VMT was calculated using default HVMT/Acre values (Table 14).

**Annual VMT totals may not equal the sum of monthly values due to rounding error.

IMPERIAL COUNTY*			
Month	**Harvest VMT**	**Nonharvest VMT**	**Total Unpaved Road VMT**
January	445	488,036	488,481
February	432	447,367	447,799
March	711	569,376	570,087
April	785	610,046	610,830
May	1,050	589,711	590,760
June	1,142	569,376	570,517
July	1,385	569,376	570,761
August	1,445	528,706	530,151
September	2,088	549,041	551,129
October	2,103	589,711	591,814
November	1,570	549,041	550,611
December	792	589,711	590,503
Annual **	**13,947**	**6,649,497**	**6,663,444**

*Harvest VMT was calculated using default HVMT/Acre values (Table 14).

**Annual VMT totals may not equal the sum of monthly values due to rounding error.

INYO COUNTY*

Month	Harvest VMT	Nonharvest VMT	Total Unpaved Road VMT
January	1	154,153	154,154
February	1	493,289	493,290
March	1	770,765	770,766
April	1	770,765	770,766
May	2	832,426	832,428
June	3	863,256	863,260
July	4	832,426	832,430
August	4	924,918	924,922
September	4	894,087	894,091
October	3	493,289	493,292
November	2	678,273	678,275
December	1	339,136	339,137
Annual **	**28**	**8,046,783**	**8,046,811**

*Harvest VMT was calculated using default HVMT/Acre values (Table 14).

**Annual VMT totals may not equal the sum of monthly values due to rounding error.

KERN COUNTY			
Month	**Harvest VMT**	**Nonharvest VMT**	**Total Unpaved Road VMT**
January	6,739	1,754,419	1,761,158
February	6,096	1,425,465	1,431,561
March	9,565	2,302,675	2,312,240
April	13,208	2,302,675	2,315,882
May	15,558	3,399,186	3,414,744
June	18,138	3,179,884	3,198,021
July	19,190	2,960,582	2,979,771
August	34,686	2,850,930	2,885,616
September	45,112	3,179,884	3,224,996
October	47,928	3,070,233	3,118,160
November	40,593	1,096,512	1,137,105
December	20,040	1,096,512	1,116,552
Annual *	**276,863**	**28,618,955**	**28,895,818**

*Annual VMT totals may not equal the sum of monthly values due to rounding error.

KINGS COUNTY			
Month	**Harvest VMT**	**Nonharvest VMT**	**Total Unpaved Road VMT**
January	320	314,345	314,665
February	292	142,884	143,177
March	3,902	342,922	346,824
April	5,013	271,480	276,493
May	6,925	442,941	449,867
June	9,663	428,653	438,316
July	9,991	414,364	424,355
August	10,274	442,941	453,215
September	14,388	428,653	443,041
October	17,149	414,364	431,513
November	12,798	271,480	284,278
December	4,226	171,461	175,687
Annual *	**94,942**	**4,086,490**	**4,181,432**

*Annual VMT totals may not equal the sum of monthly values due to rounding error.

LAKE COUNTY*			
Month	**Harvest VMT**	**Nonharvest VMT**	**Total Unpaved Road VMT**
January	0	135,261	135,261
February	1	95,478	95,479
March	4	183,000	183,004
April	3	167,087	167,090
May	5	246,652	246,657
June	28	222,783	222,811
July	20	246,652	246,672
August	17	246,652	246,669
September	18	87,522	87,540
October	17	23,870	23,886
November	9	0	9
December	4	0	4
Annual **	**125**	**1,654,957**	**1,655,082**

*Harvest VMT was calculated using default HVMT/Acre values (Table 14).

**Annual VMT totals may not equal the sum of monthly values due to rounding error.

LASSEN COUNTY*			
Month	**Harvest VMT**	**Nonharvest VMT**	**Total Unpaved Road VMT**
January	1	1,289,633	1,289,634
February	1	793,620	793,621
March	7	992,025	992,032
April	7	1,041,627	1,041,634
May	17	1,537,639	1,537,657
June	35	1,438,437	1,438,471
July	42	1,438,437	1,438,479
August	43	1,488,038	1,488,081
September	48	1,388,836	1,388,884
October	30	1,488,038	1,488,068
November	23	892,823	892,846
December	3	793,620	793,624
Annual **	**257**	**14,582,774**	**14,583,031**

*Harvest VMT was calculated using default HVMT/Acre values (Table 14).

**Annual VMT totals may not equal the sum of monthly values due to rounding error.

LOS ANGELES COUNTY*			
Month	**Harvest VMT**	**Nonharvest VMT**	**Total Unpaved Road VMT**
January	46	3,670,006	3,670,053
February	45	2,124,741	2,124,785
March	73	4,249,481	4,249,554
April	75	3,863,165	3,863,240
May	100	5,215,272	5,215,373
June	108	4,249,481	4,249,589
July	131	4,635,798	4,635,929
August	131	5,987,905	5,988,037
September	158	5,408,431	5,408,589
October	147	4,828,956	4,829,103
November	102	2,704,215	2,704,318
December	65	579,475	579,540
Annual **	**1,182**	**47,516,925**	**47,518,108**

*Harvest VMT was calculated using default HVMT/Acre values (Table 14).

**Annual VMT totals may not equal the sum of monthly values due to rounding error.

MADERA COUNTY			
Month	**Harvest VMT**	**Nonharvest VMT**	**Total Unpaved Road VMT**
January	30	487,579	487,609
February	27	441,143	441,170
March	1,051	603,669	604,720
April	1,211	557,233	558,444
May	1,617	719,759	721,377
June	2,116	696,541	698,657
July	2,268	696,541	698,809
August	14,125	719,759	733,884
September	19,417	673,323	692,740
October	20,057	673,323	693,381
November	18,499	534,015	552,514
December	7,496	394,707	402,203
Annual *	**87,919**	**7,197,594**	**7,285,513**

*Annual VMT totals may not equal the sum of monthly values due to rounding error.

MARIN COUNTY

Month	Harvest VMT	Nonharvest VMT	Total Unpaved Road VMT
January	0	80,354	80,354
February	1	120,531	120,531
March	32	187,492	187,524
April	31	214,277	214,308
May	32	281,238	281,270
June	34	267,846	267,880
July	38	415,161	415,199
August	43	415,161	415,204
September	44	93,746	93,790
October	40	361,592	361,631
November	12	13,392	13,404
December	3	0	3
Annual *	**310**	**2,450,789**	**2,451,099**

*Annual VMT totals may not equal the sum of monthly values due to rounding error.

MARIPOSA COUNTY*			
Month	**Harvest VMT**	**Nonharvest VMT**	**Total Unpaved Road VMT**
January	0	283,233	283,233
February	0	193,113	193,113
March	0	296,107	296,107
April	0	308,982	308,982
May	0	399,101	399,101
June	1	386,227	386,228
July	1	373,353	373,353
August	1	399,101	399,102
September	2	373,353	373,355
October	3	360,478	360,481
November	2	257,485	257,487
December	1	218,862	218,863
Annual **	**11**	**3,849,395**	**3,849,406**

*Harvest VMT was calculated using default HVMT/Acre values (Table 14).

**Annual VMT totals may not equal the sum of monthly values due to rounding error.

MENDOCINO COUNTY*			
Month	**Harvest VMT**	**Nonharvest VMT**	**Total Unpaved Road VMT**
January	2	995,035	995,037
February	4	702,378	702,382
March	12	1,170,630	1,170,642
April	12	819,441	819,452
May	13	1,755,944	1,755,957
June	85	1,580,350	1,580,435
July	58	1,814,476	1,814,534
August	47	1,814,476	1,814,523
September	50	1,580,350	1,580,399
October	51	1,638,881	1,638,932
November	27	526,783	526,810
December	12	117,063	117,075
Annual* *	**372**	**14,515,806**	**14,516,178**

*Harvest VMT was calculated using default HVMT/Acre values (Table 14).

**Annual VMT totals may not equal the sum of monthly values due to rounding error.

MERCED COUNTY			
Month	**Harvest VMT**	**Nonharvest VMT**	**Total Unpaved Road VMT**
January	657	357,637	358,294
February	606	298,031	298,637
March	2,737	476,850	479,587
April	3,569	417,243	420,813
May	5,892	615,931	621,822
June	8,182	596,062	604,244
July	8,740	615,931	624,671
August	11,310	576,193	587,503
September	24,642	556,324	580,966
October	25,435	596,062	621,497
November	22,807	298,031	320,838
December	6,228	198,687	204,916
Annual *	**120,814**	**5,602,982**	**5,723,796**

*Annual VMT totals may not equal the sum of monthly values due to rounding error.

MODOC COUNTY*			
Month	**Harvest VMT**	**Nonharvest VMT**	**Total Unpaved Road VMT**
January	26	844,659	844,685
February	25	703,882	703,908
March	65	938,510	938,574
April	67	610,031	610,098
May	125	1,360,839	1,360,964
June	209	1,032,361	1,032,570
July	255	1,173,137	1,173,393
August	257	1,407,765	1,408,022
September	283	1,126,212	1,126,495
October	188	1,220,063	1,220,250
November	138	610,031	610,170
December	41	610,031	610,072
Annual **	**1,679**	**11,637,520**	**11,639,199**

*Harvest VMT was calculated using default HVMT/Acre values (Table 14).

**Annual VMT totals may not equal the sum of monthly values due to rounding error.

MONO COUNTY*			
Month	**Harvest VMT**	**Nonharvest VMT**	**Total Unpaved Road VMT**
January	6	325,678	325,684
February	6	226,559	226,564
March	10	396,477	396,487
April	10	339,838	339,848
May	15	410,637	410,652
June	17	424,797	424,815
July	21	311,518	311,539
August	21	424,797	424,818
September	24	382,318	382,342
October	21	410,637	410,658
November	14	339,838	339,852
December	8	325,678	325,686
Annual **	**174**	**4,318,772**	**4,318,946**

*Harvest VMT was calculated using default HVMT/Acre values (Table 14).

**Annual VMT totals may not equal the sum of monthly values due to rounding error.

MONTEREY COUNTY			
Month	**Harvest VMT**	**Nonharvest VMT**	**Total Unpaved Road VMT**
January	88,593	690,871	779,464
February	81,215	345,436	426,650
March	93,062	614,108	707,169
April	90,907	652,489	743,396
May	95,901	1,151,452	1,247,353
June	94,745	1,036,307	1,131,052
July	98,403	959,543	1,057,947
August	114,742	921,162	1,035,904
September	114,214	806,016	920,231
October	115,515	959,543	1,075,058
November	108,972	575,726	684,698
December	99,381	345,436	444,816
Annual *	**1,195,658**	**9,058,089**	**10,253,747**

*Annual VMT totals may not equal the sum of monthly values due to rounding error.

NAPA COUNTY*			
Month	**Harvest VMT**	**Nonharvest VMT**	**Total Unpaved Road VMT**
January	0	118,914	118,914
February	6	109,767	109,773
March	24	192,092	192,116
April	24	219,534	219,557
May	24	256,123	256,147
June	205	228,681	228,886
July	136	283,565	283,701
August	108	283,565	283,673
September	112	256,123	256,235
October	116	265,270	265,386
November	59	45,736	45,795
December	25	0	25
Annual **	**841**	**2,259,369**	**2,260,210**

*Harvest VMT was calculated using default HVMT/Acre values (Table 14).

**Annual VMT totals may not equal the sum of monthly values due to rounding error.

NEVADA COUNTY[*]			
Month	**Harvest VMT**	**Nonharvest VMT**	**Total Unpaved Road VMT**
January	0	361,356	361,356
February	0	266,263	266,263
March	0	475,469	475,469
April	0	418,413	418,413
May	0	589,581	589,582
June	2	513,506	513,508
July	1	589,581	589,583
August	1	589,581	589,582
September	1	551,544	551,545
October	1	532,525	532,526
November	1	342,338	342,338
December	0	228,225	228,225
Annual [**]	**8**	**5,458,383**	**5,458,391**

[*]Harvest VMT was calculated using default HVMT/Acre values (Table 14).

[**]Annual VMT totals may not equal the sum of monthly values due to rounding error.

ORANGE COUNTY[*]			
Month	**Harvest VMT**	**Nonharvest VMT**	**Total Unpaved Road VMT**
January	21	1,177,395	1,177,415
February	20	728,863	728,884
March	34	1,289,528	1,289,562
April	35	1,233,461	1,233,496
May	46	1,569,860	1,569,906
June	61	1,625,926	1,625,987
July	66	1,738,059	1,738,125
August	65	1,738,059	1,738,124
September	79	1,681,993	1,682,072
October	77	1,738,059	1,738,136
November	52	1,345,594	1,345,647
December	32	1,233,461	1,233,493
Annual **	**588**	**17,100,259**	**17,100,847**

*Harvest VMT was calculated using default HVMT/Acre values (Table 14).

**Annual VMT totals may not equal the sum of monthly values due to rounding error.

PLACER COUNTY[*]			
Month	**Harvest VMT**	**Nonharvest VMT**	**Total Unpaved Road VMT**
January	0	362,726	362,726
February	0	256,042	256,042
March	2	469,410	469,412
April	2	469,410	469,412
May	4	661,442	661,446
June	10	597,431	597,441
July	12	661,442	661,453
August	12	661,442	661,453
September	12	597,431	597,443
October	6	597,431	597,437
November	5	362,726	362,731
December	0	234,705	234,705
Annual [**]	**64**	**5,931,637**	**5,931,701**

[*]Harvest VMT was calculated using default HVMT/Acre values (Table 14).

[**]Annual VMT totals may not equal the sum of monthly values due to rounding error.

PLUMAS COUNTY*			
Month	**Harvest VMT**	**Nonharvest VMT**	**Total Unpaved Road VMT**
January	0	534,133	534,133
February	0	575,221	575,221
March	1	821,744	821,745
April	1	739,569	739,570
May	3	1,191,528	1,191,531
June	6	1,068,267	1,068,272
July	7	1,068,267	1,068,274
August	7	1,273,703	1,273,709
September	7	1,109,354	1,109,361
October	3	1,191,528	1,191,532
November	3	657,395	657,397
December	0	410,872	410,872
Annual **	**36**	**10,641,580**	**10,641,616**

*Harvest VMT was calculated using default HVMT/Acre values (Table 14).

**Annual VMT totals may not equal the sum of monthly values due to rounding error.

RIVERSIDE COUNTY			
Month	**Harvest VMT**	**Nonharvest VMT**	**Total Unpaved Road VMT**
January	3,662	1,063,837	1,067,499
February	3,311	818,336	821,647
March	6,051	0	6,051
April	6,743	1,227,504	1,234,247
May	8,776	1,554,839	1,563,615
June	11,945	1,964,007	1,975,952
July	13,270	1,309,338	1,322,608
August	16,396	1,882,173	1,898,569
September	16,440	2,045,841	2,062,281
October	16,219	2,209,508	2,225,727
November	12,387	1,309,338	1,321,725
December	6,286	1,309,338	1,315,624
Annual*	**121,505**	**16,694,060**	**16,815,564**

*Annual VMT totals may not equal the sum of monthly values due to rounding error.

SACRAMENTO COUNTY			
Month	**Harvest VMT**	**Nonharvest VMT**	**Total Unpaved Road VMT**
January	48	63,587	63,635
February	57	74,185	74,242
March	315	121,875	122,190
April	773	121,875	122,648
May	2,260	164,267	166,527
June	2,837	148,370	151,207
July	2,993	164,267	167,260
August	9,312	164,267	173,578
September	14,531	153,669	168,200
October	14,827	153,669	168,496
November	13,788	95,381	109,169
December	4,959	52,989	57,949
Annual *	**66,699**	**1,478,402**	**1,545,101**

*Annual VMT totals may not equal the sum of monthly values due to rounding error.

SAN BENITO COUNTY			
Month	**Harvest VMT**	**Nonharvest VMT**	**Total Unpaved Road VMT**
January	3,904	205,898	209,802
February	3,546	154,424	157,970
March	4,198	231,635	235,834
April	5,449	231,635	237,084
May	6,147	398,927	405,075
June	6,557	257,373	263,929
July	7,940	386,059	393,998
August	8,332	386,059	394,391
September	8,191	373,190	381,381
October	8,071	373,190	381,261
November	6,219	128,686	134,905
December	5,166	154,424	159,590
Annual *	**73,720**	**3,281,500**	**3,355,221**

*Annual VMT totals may not equal the sum of monthly values due to rounding error.

SAN BERNARDINO COUNTY			
Month	**Harvest VMT**	**Nonharvest VMT**	**Total Unpaved Road VMT**
January	566	2,399,522	2,400,087
February	521	1,919,617	1,920,138
March	2,017	3,679,266	3,681,283
April	1,784	159,968	161,753
May	2,400	4,319,139	4,321,539
June	2,332	4,639,075	4,641,407
July	3,210	4,159,171	4,162,380
August	2,988	4,159,171	4,162,158
September	3,777	4,639,075	4,642,852
October	3,160	4,639,075	4,642,235
November	1,772	3,359,330	3,361,102
December	722	3,359,330	3,360,052
Annual *	**25,252**	**41,431,739**	**41,456,990**

*Annual VMT totals may not equal the sum of monthly values due to rounding error.

SAN DIEGO COUNTY			
Month	**Harvest VMT**	**Nonharvest VMT**	**Total Unpaved Road VMT**
January	216	514,346	514,562
February	216	445,767	445,983
March	361	582,926	583,287
April	501	342,898	343,399
May	895	445,767	446,662
June	1,620	685,795	687,415
July	2,155	685,795	687,950
August	2,163	960,113	962,277
September	2,110	925,824	927,933
October	1,435	582,926	584,361
November	1,179	514,346	515,525
December	1,015	411,477	412,492
Annual *	**13,892**	**7,097,980**	**7,111,872**

*Annual VMT totals may not equal the sum of monthly values due to rounding error.

SAN FRANCISCO COUNTY*			
Month	**Harvest VMT**	**Nonharvest VMT**	**Total Unpaved Road VMT**
January	0	143,139	143,139
February	0	109,459	109,459
March	0	176,818	176,818
April	0	134,719	134,719
May	0	25,260	25,260
June	0	218,918	218,918
July	0	218,918	218,918
August	0	143,139	143,139
September	0	193,658	193,658
October	0	227,338	227,338
November	0	117,879	117,879
December	0	75,779	75,779
Annual **	**0**	**1,785,024**	**1,785,024**

*Harvest VMT was calculated using default HVMT/Acre values (Table 14).

**Annual VMT totals may not equal the sum of monthly values due to rounding error.

SAN JOAQUIN COUNTY			
Month	**Harvest VMT**	**Nonharvest VMT**	**Total Unpaved Road VMT**
January	879	173,930	174,809
February	1,248	128,159	129,407
March	4,257	219,701	223,957
April	8,622	192,238	200,860
May	12,302	283,780	296,082
June	16,513	247,163	263,677
July	16,633	283,780	300,414
August	26,801	283,780	310,581
September	108,235	256,318	364,552
October	110,978	64,079	175,057
November	101,007	146,467	247,474
December	13,647	73,234	86,880
Annual *	**421,133**	**2,352,629**	**2,773,762**

*Annual VMT totals may not equal the sum of monthly values due to rounding error.

SAN LUIS OBISPO COUNTY			
Month	**Harvest VMT**	**Nonharvest VMT**	**Total Unpaved Road VMT**
January	162	640,922	641,084
February	159	337,327	337,486
March	896	708,387	709,284
April	868	674,655	675,523
May	911	1,045,715	1,046,626
June	908	1,011,982	1,012,890
July	956	1,011,982	1,012,938
August	5,876	1,045,715	1,051,590
September	6,817	978,249	985,067
October	7,031	910,784	917,815
November	6,189	472,258	478,447
December	3,111	438,526	441,637
Annual *	**33,885**	**9,276,502**	**9,310,387**

*Annual VMT totals may not equal the sum of monthly values due to rounding error.

SAN MATEO COUNTY*			
Month	**Harvest VMT**	**Nonharvest VMT**	**Total Unpaved Road VMT**
January	10	363,188	363,199
February	10	277,732	277,742
March	16	448,644	448,661
April	17	341,824	341,841
May	23	64,092	64,115
June	24	555,464	555,489
July	29	555,464	555,494
August	29	363,188	363,218
September	35	491,372	491,408
October	33	576,828	576,861
November	23	299,096	299,119
December	15	192,276	192,291
Annual **	**265**	**4,529,171**	**4,529,436**

*Harvest VMT was calculated using default HVMT/Acre values (Table 14).

**Annual VMT totals may not equal the sum of monthly values due to rounding error.

SANTA BARBARA COUNTY			
Month	**Harvest VMT**	**Nonharvest VMT**	**Total Unpaved Road VMT**
January	92,055	423,640	515,695
February	84,299	185,343	269,642
March	118,247	529,551	647,797
April	137,952	344,208	482,160
May	166,887	476,595	643,483
June	146,095	767,848	913,944
July	178,397	741,371	919,768
August	164,359	767,848	932,208
September	181,476	767,848	949,325
October	165,573	476,595	642,168
November	113,789	503,073	616,862
December	100,867	397,163	498,029
Annual *	**1,649,996**	**6,381,084**	**8,031,080**

*Annual VMT totals may not equal the sum of monthly values due to rounding error.

SANTA CLARA COUNTY*			
Month	**Harvest VMT**	**Nonharvest VMT**	**Total Unpaved Road VMT**
January	47	694,315	694,362
February	46	530,947	530,992
March	75	939,367	939,442
April	77	775,999	776,076
May	103	1,266,103	1,266,206
June	119	1,061,893	1,062,012
July	139	1,102,735	1,102,874
August	137	1,225,261	1,225,399
September	164	653,473	653,637
October	153	1,184,419	1,184,573
November	105	408,420	408,526
December	67	367,578	367,646
Annual **	**1,233**	**10,210,510**	**10,211,743**

*Harvest VMT was calculated using default HVMT/Acre values (Table 14).

**Annual VMT totals may not equal the sum of monthly values due to rounding error.

SANTA CRUZ COUNTY			
Month	**Harvest VMT**	**Nonharvest VMT**	**Total Unpaved Road VMT**
January	70	130,206	130,276
February	189	99,570	99,758
March	437	153,184	153,621
April	402	153,184	153,586
May	416	206,798	207,214
June	486	222,117	222,602
July	497	237,435	237,932
August	555	191,480	192,035
September	542	206,798	207,340
October	559	206,798	207,358
November	278	107,229	107,506
December	80	84,251	84,331
Annual *	**4,510**	**1,999,049**	**2,003,559**

*Annual VMT totals may not equal the sum of monthly values due to rounding error.

SHASTA COUNTY*			
Month	**Harvest VMT**	**Nonharvest VMT**	**Total Unpaved Road VMT**
January	0	882,339	882,339
February	0	539,207	539,207
March	2	1,029,395	1,029,397
April	2	882,339	882,341
May	5	1,372,527	1,372,532
June	11	1,274,489	1,274,500
July	13	1,421,546	1,421,559
August	13	1,519,583	1,519,597
September	14	1,225,471	1,225,485
October	8	1,372,527	1,372,535
November	6	441,169	441,176
December	0	294,113	294,113
Annual **	**74**	**12,254,706**	**12,254,779**

*Harvest VMT was calculated using default HVMT/Acre values (Table 14).

**Annual VMT totals may not equal the sum of monthly values due to rounding error.

SIERRA COUNTY*			
Month	**Harvest VMT**	**Nonharvest VMT**	**Total Unpaved Road VMT**
January	0	212,017	212,017
February	0	133,905	133,905
March	0	200,858	200,858
April	0	200,858	200,858
May	1	334,763	334,764
June	2	312,446	312,448
July	2	334,763	334,766
August	2	345,922	345,924
September	2	301,287	301,289
October	1	323,604	323,606
November	1	167,382	167,382
December	0	89,270	89,270
Annual **	**13**	**2,957,074**	**2,957,087**

*Harvest VMT was calculated using default HVMT/Acre values (Table 14).

**Annual VMT totals may not equal the sum of monthly values due to rounding error.

SISKIYOU COUNTY*			
Month	**Harvest VMT**	**Nonharvest VMT**	**Total Unpaved Road VMT**
January	26	1,464,328	1,464,354
February	26	894,867	894,893
March	47	650,812	650,859
April	51	732,164	732,215
May	76	2,196,492	2,196,568
June	98	1,952,437	1,952,535
July	119	1,789,734	1,789,854
August	122	2,359,195	2,359,318
September	158	1,871,086	1,871,244
October	138	2,115,140	2,115,278
November	102	976,219	976,321
December	45	244,055	244,100
Annual **	**1,008**	**17,246,530**	**17,247,539**

*Harvest VMT was calculated using default HVMT/Acre values (Table 14).

**Annual VMT totals may not equal the sum of monthly values due to rounding error.

SOLANO COUNTY*			
Month	**Harvest VMT**	**Nonharvest VMT**	**Total Unpaved Road VMT**
January	73	146,253	146,326
February	72	168,753	168,825
March	119	202,504	202,623
April	144	292,506	292,649
May	188	348,757	348,945
June	226	315,006	315,232
July	258	337,506	337,764
August	278	348,757	349,035
September	476	315,006	315,482
October	516	315,006	315,523
November	399	202,504	202,903
December	172	135,003	135,175
Annual **	**2,921**	**3,127,560**	**3,130,481**

*Harvest VMT was calculated using default HVMT/Acre values (Table 14).

**Annual VMT totals may not equal the sum of monthly values due to rounding error.

SONOMA COUNTY*

Month	Harvest VMT	Nonharvest VMT	Total Unpaved Road VMT
January	3	162,040	162,043
February	11	243,060	243,071
March	37	378,093	378,130
April	37	432,107	432,143
May	41	567,140	567,180
June	279	540,133	540,412
July	191	837,206	837,397
August	155	837,206	837,362
September	171	189,047	189,217
October	176	729,180	729,356
November	97	27,007	27,104
December	41	0	41
Annual **	**1,237**	**4,942,219**	**4,943,456**

*Harvest VMT was calculated using default HVMT/Acre values (Table 14).

**Annual VMT totals may not equal the sum of monthly values due to rounding error.

STANISLAUS COUNTY			
Month	**Harvest VMT**	**Nonharvest VMT**	**Total Unpaved Road VMT**
January	535	174,583	175,118
February	485	164,313	164,799
March	1,728	246,470	248,199
April	2,035	225,931	227,966
May	4,665	318,357	323,022
June	7,589	287,549	295,138
July	8,205	318,357	326,563
August	11,280	318,357	329,637
September	31,113	287,549	318,661
October	31,328	308,088	339,416
November	28,887	205,392	234,279
December	6,389	102,696	109,085
Annual *	**134,257**	**2,957,643**	**3,091,900**

*Annual VMT totals may not equal the sum of monthly values due to rounding error.

SUTTER COUNTY			
Month	**Harvest VMT**	**Nonharvest VMT**	**Total Unpaved Road VMT**
January	8	65,558	65,566
February	8	36,057	36,065
March	144	78,670	78,814
April	220	72,114	72,333
May	1,170	101,615	102,785
June	2,671	88,503	91,174
July	2,764	101,615	104,379
August	2,857	101,615	104,472
September	11,453	91,781	103,234
October	11,761	95,059	106,820
November	11,114	59,002	70,116
December	1,695	29,501	31,196
Annual *	**45,866**	**921,089**	**966,955**

*Annual VMT totals may not equal the sum of monthly values due to rounding error.

TEHAMA COUNTY*			
Month	**Harvest VMT**	**Nonharvest VMT**	**Total Unpaved Road VMT**
January	2	540,829	540,831
February	2	426,970	426,972
March	2	711,617	711,619
April	4	512,364	512,368
May	7	825,476	825,483
June	11	768,546	768,557
July	11	882,405	882,416
August	15	882,405	882,420
September	30	740,082	740,112
October	33	797,011	797,044
November	27	426,970	426,997
December	8	0	8
Annual **	**153**	**7,514,675**	**7,514,828**

*Harvest VMT was calculated using default HVMT/Acre values (Table 14).

**Annual VMT totals may not equal the sum of monthly values due to rounding error.

TRINITY COUNTY*[*]			
Month	**Harvest VMT**	**Nonharvest VMT**	**Total Unpaved Road VMT**
January	1	703,033	703,034
February	1	468,689	468,689
March	1	736,511	736,512
April	1	569,122	569,123
May	1	1,004,333	1,004,334
June	1	903,900	903,901
July	2	1,004,333	1,004,335
August	2	1,037,811	1,037,813
September	2	970,856	970,857
October	2	903,900	903,902
November	1	535,644	535,646
December	1	435,211	435,212
Annual [**]	**14**	**9,273,344**	**9,273,358**

[*]Harvest VMT was calculated using default HVMT/Acre values (Table 14).

[**]Annual VMT totals may not equal the sum of monthly values due to rounding error.

TULARE COUNTY			
Month	**Harvest VMT**	**Nonharvest VMT**	**Total Unpaved Road VMT**
January	398	528,328	528,726
February	365	251,585	251,950
March	3,077	578,645	581,722
April	3,182	503,169	506,351
May	4,278	754,754	759,032
June	6,320	754,754	761,074
July	6,762	754,754	761,516
August	14,964	779,913	794,877
September	20,048	754,754	774,802
October	20,827	729,596	750,423
November	17,780	50,317	68,097
December	6,130	226,426	232,556
Annual *	**104,164**	**6,666,995**	**6,771,158**

*Annual VMT totals may not equal the sum of monthly values due to rounding error.

TUOLUMNE COUNTY			
Month	**Harvest VMT**	**Nonharvest VMT**	**Total Unpaved Road VMT**
January	0	384,155	384,155
February	0	298,787	298,787
March	0	448,181	448,181
April	0	405,497	405,497
May	0	661,600	661,600
June	0	618,916	618,917
July	0	576,233	576,233
August	1	661,600	661,601
September	1	618,916	618,918
October	1	618,916	618,918
November	1	426,839	426,840
December	0	277,445	277,446
Annual *	**5**	**5,997,087**	**5,997,092**

*Annual VMT totals may not equal the sum of monthly values due to rounding error.

VENTURA COUNTY*			
Month	**Harvest VMT**	**Nonharvest VMT**	**Total Unpaved Road VMT**
January	139	592,981	593,120
February	136	296,490	296,627
March	222	0	222
April	229	592,981	593,210
May	303	700,795	701,098
June	360	781,656	782,016
July	411	781,656	782,067
August	408	835,564	835,971
September	493	808,610	809,103
October	468	727,749	728,217
November	321	592,981	593,302
December	203	431,259	431,462
Annual **	**3,692**	**7,142,722**	**7,146,414**

*Harvest VMT was calculated using default HVMT/Acre values (Table 14).

**Annual VMT totals may not equal the sum of monthly values due to rounding error.

YOLO COUNTY			
Month	**Harvest VMT**	**Nonharvest VMT**	**Total Unpaved Road VMT**
January	7	91,653	91,660
February	7	68,740	68,747
March	1,276	126,023	127,299
April	1,857	131,751	133,608
May	5,525	171,850	177,375
June	10,128	114,566	124,694
July	10,663	177,578	188,241
August	11,796	177,578	189,374
September	21,133	160,393	181,526
October	21,740	160,393	182,133
November	19,864	91,653	111,517
December	7,695	34,370	42,065
Annual *	**111,695**	**1,506,549**	**1,618,244**

*Annual VMT totals may not equal the sum of monthly values due to rounding error.

YUBA COUNTY			
Month	**Harvest VMT**	**Nonharvest VMT**	**Total Unpaved Road VMT**
January	3	146,245	146,248
February	3	97,497	97,500
March	28	167,137	167,165
April	27	146,245	146,272
May	62	215,885	215,947
June	130	194,993	195,123
July	161	215,885	216,047
August	308	215,885	216,193
September	2,698	194,993	197,692
October	2,646	201,957	204,603
November	2,473	125,353	127,826
December	58	69,640	69,698
Annual*	**8,599**	**1,991,715**	**2,000,314**

*Annual VMT totals may not equal the sum of monthly values due to rounding error.

13.0 APPENDIX D: STATEWIDE CROP SCHEDULES

Grain and field crops

CROP*	January		February		March		April		May		June		July		August		September		October		November		December	
Barley																								
Beans																20								
Corn, grain																								
All Cotton																								
Hay/alfalfa/other																					5			
Oats																								
Potatoes																								
Rice																								
Sugar Beets																							10	
Sweet Potatoes																								
Wheat, All										20														

*All crop calendars are derived from CDFA (2001) unless otherwise noted.

Fruit crops

CROP*	January		February		March		April		May		June		July		August		September		October		November		December	
Apples																								
Apricots																								
Avocados																								
Boysenberries																								
Cherries (sweet)										20		25												
Dates																								
Figs												10												
Grapefruit (All)																								
Grapes (All)															5									
Kiwifruit																								
Lemons																								
Nectarines												10					5							
Olives																		25						
Oranges (All)																						25		
Peaches (All)										10														
Pears (All)															5				5					
Plums										25					20									
Prunes																			10					
Raspberries																								
Strawberries (All)				20																				
Tangerines, etc.																								

*All crop calendars are derived from CDFA (2001) unless otherwise noted.

Nut crops

CROP*	January		February		March		April		May		June		July		August		September		October		November		December	
Almonds																								
Pecans																								
Pistachios																							10	
Walnuts																	5				10			

*All crop calendars are derived from CDFA (2001) unless otherwise noted.

Vegetable crops

CROP[*]	January		February		March		April		May		June		July		August		September		October		November		December	
Artichoke	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Asparagus				■	■	■	■	■	■	■	■	■												
Beans, Snap								■ 20	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	
Broccoli	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Brussel Sprouts	■	■	■	■	■										■	■	■	■	■	■	■	■	■	■
Cabbage	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Carrots	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Cauliflower	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Celery	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Chili Pepper[**]																	■	■	■	■	■	■	■	■
Corn (fresh)									■	■	■	■	■	■	■	■	■	■	■	■	■	■	■ 10	
Cucumbers (All)						■ 20	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■ 10			
Eggplant													■	■	■	■	■	■	■	■				
Escarole/Endive[**]	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Garlic							■	■	■	■	■	■	■	■	■	■	■							
Greens					■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		
Lettuce (All)	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Pumpkin																	■	■	■	■				
Cantaloupe										■	■	■	■	■	■	■	■	■	■	■	■	■		
Honeydew											■	■	■	■	■	■	■	■	■	■	■	■		
Watermelon										■ 25	■	■	■	■	■	■	■	■	■					
Mushrooms	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Onions							■	■	■	■	■	■	■	■	■	■	■	■	■	■				
Radish					■	■			■	■			■	■			■	■						
Bell Peppers													■	■	■	■	■	■	■	■	■	■	■ 10	
Spinach	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Tomatoes (All)										■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Squash	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■

[*] All crop calendars are derived from CDFA (2001) unless otherwise noted.
[**] Source: California Pest Management Center (www.wrpmc.ucdavis.edu/ca/cacrops/region10a.html)

14.0 APPENDIX E: PILOT STUDY MAJOR FINDINGS AND FINAL REPORTS

SUMMARY OF PILOT STUDY MAJOR FINDINGS

For San Joaquin County, CARB's unpaved road VMT estimate was about 3.7 million. For Fresno County the estimate was approximately 11.6 million. By comparison, the pilot study estimated roughly 2.6 million VMT in San Joaquin County and 6.9 million VMT in Fresno County. Table 34 shows the monthly harvest, nonharvest and total unpaved road VMT estimated using the pilot study method.

Table 34. Pilot study harvest versus nonharvest VMT in San Joaquin and Fresno Counties

Month	Harvest VMT	Nonharvest VMT	Total Unpaved Road VMT
SAN JOAQUIN COUNTY			
January	154	185,076	185,230
February	189	168,251	168,440
March	391	185,076	185,467
April	1251	210,313	211,564
May	3559	243,963	247,522
June	2461	243,963	246,424
July	1898	260,788	262,686
August	4316	260,788	265,104
September	10132	243,963	254,095
October	4207	235,551	239,758
November	190	193,488	193,678
December	69	193,488	193,557
Annual	**28,817**	**2,624,710**	**2,653,527**
FRESNO COUNTY			
Month	**Harvest VMT**	**Nonharvest VMT**	**Total Unpaved Road VMT**
January	264	494,107	494,371
February	313	451,142	451,455
March	614	494,107	494,721
April	2564	558,556	561,120
May	8210	623,005	631,215
June	5655	623,005	629,660
July	3814	665,971	669,785
August	9300	665,971	675,271
September	22,029	623,005	645,034
October	6283	623,005	629,288
November	267	515,590	515,857
December	119	515,590	515,709
Annual	**59,435**	**6,853,056**	**6,912,491**

Table 34 highlights the dominance of nonharvest VMT in estimating the county annual total. Even in the peak harvest month of September, harvest VMT only accounts for about 4% of total VMT for the month in San Joaquin County. This suggests that sources other than crop transport may be more significant in determining the PM_{10} inventory. However, it is important to recall that these findings do not incorporate harvesting activities that take place in the fields or the transport of personnel to and from the fields during harvest periods; they only reflect the harvest transport from the field to the nearest paved road.

Since CARB did not differentiate between harvest and nonharvest vehicle activity, a direct comparison between the two methods was not performed. However, in comparing the monthly profiles of total VMT, we found substantial differences not only between the annual VMT estimates, but also between the proportions of VMT per month estimated by each method. Table 35 depicts the monthly and annual VMT estimates according to each method and the corresponding PM_{10} emissions generated.

Table 35. VMT and PM_{10} estimates using the pilot study method and CARB's method, San Joaquin and Fresno Counties

SAN JOAQUIN COUNTY						
Month	***VMT New Method***	***Proportion of Total VMT***	***PM_{10}* (tons)***	***VMT CARB Method*****	***Proportion of Total VMT*****	***PM_{10}* (tons)***
January	185,230	0.070	210	89,584	0.024	102
February	168,440	0.063	191	91,049	0.026	110
March	185,467	0.070	211	93,317	0.025	106
April	211,564	0.080	240	298,613	0.080	339
May	247,522	0.093	281	358,336	0.096	407
June	246,424	0.093	280	515,108	0.138	585
July	262,686	0.099	298	515,108	0.138	585
August	265,104	0.100	301	515,108	0.138	585
September	254,095	0.096	288	515,108	0.138	585
October	239,758	0.090	272	384,465	0.103	436
November	193,678	0.073	220	190,366	0.051	216
December	193,557	0.073	220	160,505	0.043	182
Annual	**2,653,527**	**1.000**	**3012**	**3,732,667**	**1.000**	**4237**
FRESNO COUNTY						
Month	***VMT New Method***	***Proportion of Total VMT***	***PM_{10}* (tons)***	***VMT CARB Method*****	***Proportion of Total VMT*****	***PM_{10}* (tons)***
January	494,371	0.072	561	347,425	0.030	394
February	451,455	0.065	512	382,167	0.033	434
March	494,721	0.072	562	301,101	0.026	342
April	561,120	0.081	637	1,146,501	0.099	1301
May	631,215	0.091	716	1,401,279	0.121	1590
June	629,660	0.091	715	1,401,279	0.121	1590
July	669,785	0.097	760	1,401,279	0.121	1590
August	675,271	0.098	766	1,401,279	0.121	1590
September	645,034	0.093	732	1,401,279	0.121	1590
October	629,288	0.091	714	1,204,405	0.104	1367
November	515,857	0.075	585	671,688	0.058	762
December	515,709	0.075	585	532,718	0.046	605
Annual	6,912,491	1.000	7847	11,592,400	1.001	13,155

*PM_{10} (tons) = VMT x (1.135×10^{-3} tons/VMT) (CARB 1997).
**Monthly VMT and the proportion of total VMT were derived from calculations presented in CARB 1997.

PM_{10} emissions from December through March are estimated to be substantially larger using the pilot study methodology, while they are substantially smaller during the summer months. Although clearly the lower summer VMT is due to the overall lower VMT estimation, the higher winter VMT might be, in part, the result of using a long-term average number of rain days in the new methodology to apportion the nonharvest VMT among the months of the year. In any case, the PM_{10} emissions estimated from the new methodology are more evenly distributed over the months of the year and are approximately 29% lower than CARB's estimates for San Joaquin County (40% lower for Fresno County).

Volume I

AN EXPLORATORY STUDY:

A NEW METHODOLOGY FOR ESTIMATING UNPAVED ROAD MILES AND VEHICLE ACTIVITY ON UNPAVED ROADS

Final Report, February 1999

by

Debbie Niemeier, Ph.D.
Principal Investigator
Department of Civil and Environmental Engineering

Institute of Transportation Studies
University of California, Davis

Research Assistants:

Methodology Framework

Joel P. Franklin
Thirayoot Limanond
Jennifer E. Morey

Study Implementation

Jennifer E. Morey
Thirayoot Limanond

GIS Analysis

Thirayoot Limanond
Kishore Lakshminarayanan

Submitted to:

California Air Resources Board
Sacramento, CA

TABLE OF CONTENTS

ABSTRACT

The object of this pilot study is to propose a new methodology for estimating the miles of unpaved road in California Counties and the annual vehicular traffic as measured in vehicle miles traveled (VMT) on these unpaved roads. The methods incorporate three separate estimations. These consist of: 1) An estimate of Miles of Unpaved Road, 2) An estimate of VMT associated with harvest activities, and 3) An estimate of VMT not associated with harvest ("non-harvest" VMT). GIS data, on-site observations and land-use information were used to estimate the miles of unpaved road within each county in the study. Grower surveys and land-use characteristics were used to develop the model of harvest traffic. A system of traffic counts, weather statistics and land-use characteristics were used to specify the model for estimating non-harvest traffic.

The method previously employed by the California Air Resources Board (CARB) resulted in lower estimates of miles of unpaved road and higher estimates of annual VMT on unpaved roads than those yielded by the methods developed in this study. Using 1993 numbers, including both farm and non-farm roads, CARB estimates the miles of unpaved road in San Joaquin County (SJC) to be roughly 1022. The method presented in this study yields an estimate of approximately 1437 miles of unpaved roads. Using CARB's previous method, San Joaquin County's VMT was estimated to be approximately 3,732,667. The results obtained using the new methodology presented in this report result in a VMT estimate of approximately 2,653,527 per year.

The methods described in this document were developed using data from San Joaquin County. They were then applied to data from Fresno County in order to illustrate the methods' application in calculating both miles of unpaved road and predicting VMT in other California counties. Results from SJC from the proposed study methodology, show both harvest and non-harvest models to be significant at a 99 percent level of confidence. Although the models are statistically significant, it is recommended that a further, larger study be undertaken to test the veracity of these models and under which conditions they remain consistent. Specifically, we recommend more extensive survey data be collected from growers, further unpaved road traffic counts be collected, and additional counties with a diversity of crop types be included in the analysis.

1. INTRODUCTION

This document contains methodologies that have been developed for estimating road miles and mileage traveled on unpaved roads as requested by the California Air Resources Board (CARB). Section 1 begins with a brief review of the formerly used method and a full statement of the current project's objectives. Section 2 describes field study areas and research performed to assess mileage of unpaved roads in San Joaquin County. Section 3 presents the statistical frameworks proposed for VMT estimations and the results produced for San Joaquin County. It also describes data collection procedures to calibrate and test the proposed methodologies. Section 4 summarizes the steps necessary to perform these analyses on other counties. Section 5 gives the results of the method when applied to Fresno County. A companion document (Volume II) summarizes the Geographic Information System (GIS) data. These data include a Road Coverage Database obtained from the California Department of Transportation (Caltrans), a Land Use Coverage Database from the California Department of Water Resources (CDWR) and the Public Land Survey System Database (PLSS) obtained from the Stephen P. Teale Data Center. Volume II of this report also describes data processing steps performed using GIS analysis techniques.

1.1. Previous Estimation Method

The previous method employed by CARB used simple multiplication to estimate the annual number of vehicle miles traveled (VMT) on unpaved roads. Based on 1976 and 1979 surveys of county traffic engineers, CARB set the average number of daily passes for one mile of unpaved road in Fresno County at 10 vehicles. This number was then multiplied by the unpaved road mileage as determined from the 1987 Maintained Public Road Mileage report furnished by the California Department of Transportation (Caltrans) and summed for each day of the year (Section 7.9—Road Dust, Unpaved Road Travel—Non-Farm Roads, February 1990). This method did not differentiate between harvest and non-harvest seasonal traffic levels, nor did it account for any general traffic variability that might exist on unpaved roads.

1.2. Present Estimation Project

Two primary objectives were defined for this project. As stated in the initial project proposal, these objectives were:

- To develop a new methodology for estimating miles of unpaved road within a given jurisdiction, and
- To develop a methodology for estimating the type (harvest versus non-harvest) and amount of vehicle activity on these roads, as measured in vehicle-miles traveled (VMT).

The methodologies described were developed using data specific to San Joaquin County (SJC). The sampling data and statistical frameworks developed for SJC were then used to estimate the total unpaved road miles using a combination of information from GIS databases and a visual survey of sample agricultural areas. Annual VMT on unpaved roads within the county was then calculated by employing two different methods, one for modeling traffic associated with harvest activities and one for modeling non-harvest traffic activity.

Harvest VMT estimates were computed using data obtained from grower surveys designed by this research team, and land-use characteristics from GIS databases provided by the CDWR via CARB. Non-harvest traffic was estimated using traffic counter data, information from on-site visual road surveys and the miles of unpaved road estimated within the county. The VMT models were developed using logistic and simple linear regression methods. Model parameters estimated using SJC data were then applied to Fresno County as an illustration of the proposed methodology.

These case studies represent an exploratory analysis and results should not be interpreted as definitive. For certain steps in the analysis, the sample sizes were limited due to both time and cost restrictions. These small samples may cause the statistical significance of results to be less than certain, however these results provide strong support for the validity of the study methodology, which can be incrementally improved as funding becomes available. For instance, the scope of this exploratory study is such that year-round surveys of vehicle-counts were impractical. A follow-up study could expand on the present methodology to account for seasonal variation using more extensive data collection.

2. SAMPLE AREAS

2.1. Purpose

A record of all known roads by service class is available in the form of a GIS database from Caltrans (received via CARB). Because the database includes some residential roads (presumably most of which are paved) in the same service class (Class 4) as unpaved roads, it was necessary to estimate the percentages of Class 4 roads that were in actuality unpaved. In order to update the database and to confirm the proportion of Class 4 roads that were unpaved, all residential Class 4 roads were assumed to be paved and sub-areas were chosen for on-site verification of the remaining roads' pavement status. These sub-areas also represent sites where traffic counters were placed to collect data for developing the non-harvest traffic estimation model (Section 3.2.3, Vol. I).

2.2. Sub-Areas

From the GIS database, land uses in SJC could be divided into six predominant land-use categories (Table 1). When combined with urban areas, these six categories comprise a total of 92.08 percent of the land area in the county. The goal was to investigate a total of 18 sub-areas, 3 sub-areas in each land use category, for verification of pavement status. Each chosen sub-area was roughly four contiguous square miles in size and represented within only one land-use category. For each of "Grain Crop," "Pasture," "Fruit Crop" and "Vegetable Crop" categories, three representative sub-areas were selected for field classification. Due to access problems with private property, however, it was only feasible to investigate two of the three chosen sub-areas in the "Natural Conditions" category. Likewise, only two sub-areas were investigated in the "Vineyards" category due to a lack of sites four contiguous square miles in area. This resulted in a total of 16 of the proposed 18 sub-areas being used to confirm pavement status. The sub-areas are depicted in Figure 1.

Table 1. San Joaquin County Land Use Categories

Category Identification Number*	Category	County Area (%)	Number of Sub-Areas
4	Natural Conditions	24.06	2
2	Grain Crop	22.53	3
5	Pasture	11.75	3
1	Fruit Crop	10.79	3
8	Vegetable Crop	8.10	3
10	Vineyard	6.91	2
	Urban	7.94	-
	Total	**92.08**	**16**

*The Category Identification Number is used in Figure 1 to identify the sub-areas chosen for visual verification of road pavement status. For instance, in Figure 1, the section labeled "4-1" is the first sample area chosen in the "Natural Conditions" category. "4-2" is the second sample in the "Natural Conditions" category and so on.

2.3. Data

Non-urban Class 4 roads within the chosen sub-areas in SJC were then field verified into one of four classes:

- Paved Roads – any contiguously solid surface, not including dirt, gravel, or other earthen surfaces.
- Unpaved Inactive – any remaining road that by all appearances has had no activity for an indefinite period of time, as evidenced by vegetative overgrowth and/or absence of tire-track marks.
- Unpaved Active Private – any remaining road that is posted as private property at its point of access from a paved road.
- Unpaved Active Public – any remaining road.

The roads listed as "unpaved active private" and "unpaved active public" were used to estimate the miles of unpaved road in SJC. From this point forward, "Unpaved roads" refer to only private, and public, actively used unpaved roads.

3. METHODOLOGICAL FRAMEWORK

3.1. Estimating Miles of Unpaved Road

The methodological framework for estimating the miles of unpaved roads is shown in Figure 2. The first two steps were described in the previous chapter. Here, we outline the basic analytical framework for estimating actual mileage.

The field-verified road segment classifications were used to find the percent of miles of unpaved roads in each land-use category using Equation 1,

$$\%Unpaved_j = \frac{\sum_i \left(l_i * x_{unpaved}\right)}{\sum_i l_i}, \quad \forall i \in j \qquad (1)$$

where, $\%Unpaved$ = Percent of Class 4 roads in each land use category estimated to be unpaved.
$x_{unpaved}$ = binary indicator: 1 if field verified unpaved active, 0 if paved or unpaved inactive.
l_i = length of sampled road segment *i.*
j = land-use category.

This results in the percentage of unpaved roads across sub-areas for each land-use category. These percentages of unpaved roads by land-use category were then multiplied by the total miles of non-urban Class 4 roads by land-use categories as represented in the county (See Section 3.1, Vol. II). The procedure, performed with GIS, yielded countywide estimates of actual unpaved road mileage in each of the six predominant land-use categories. Percentages of unpaved roads for individual sub-areas along with the average percentage for each land-use category are presented in Table 7 of Volume II. Percentage of unpaved roads for portions of the county that lay outside of the sampled land-use categories (7.92 percent of the land area), including idle, other-agricultural, and unknown land-use types were inferred by using the average percentage of unpaved roads in the sampled categories. Finally, these estimates were summed to find a total estimate of unpaved road mileage in the county, using Equation 2.

$$E\begin{pmatrix} \text{Miles of} \\ \text{Unpaved Road} \end{pmatrix} = \sum_j \left(\%Unpaved_j * \sum_i l_i \right), \quad \forall i \in j \qquad (2)$$

It should be noted that this estimate also assumes that all Class 4 roads lying within urban areas are residential and paved.

3.1.1. Results for San Joaquin County

Table 2, shown below, presents the estimates of unpaved road lengths in San Joaquin County (SJC) categorized by land use.

Table 2. Estimated Miles of Unpaved Road

Crop Type	Land Use Code	Measured Meters	% Unpaved	Estimated Meters	Estimated Miles
Fruits	1	245,428.7	68.78	168,805.9	104.9
Grains	2	520,486.5	98.15	510,857.5	317.4
Natural	4	977,688.3	93.81	917,169.4	569.9
Pasture	5	300,577.1	64.10	192,669.9	119.7
Vegetable	8	259,076.1	100.00	259,076.1	161.0
Vine	10	65,830.5	58.52	38,524.0	23.9
Others	(0,3,6,7,9,11)	232,963.4	84.84	197,655.5	122.8
Total		**2,602,050.6**		**2,284,758.3**	**1419.7**

The "measured meters" represent the lengths of roads in each land-use category digitized as Class 4 roads in the GIS Database obtained from Caltrans.

Since the six crop categories listed in Table 2 had relatively distinct divisions in the computed percentages of unpaved roads, it was possible to estimate the miles of unpaved road by collapsing the categories from six down to two[1]. Since the sample size (number of sub-areas) for each land-use was small, aggregating the land-use data into two distinct groups also increased the sample size and thus the statistical power of the analysis. Table 3 illustrates the estimates of unpaved road lengths using two groups instead of the original six.

Table 3. Estimated Miles of Unpaved Road with Land Use Categories Combined into Two Groups

Group	Crop Type	Average % Unpaved	Land Use Code	Measured Meters	Estimated Meters	Estimated Miles
1	***Fruits***	64.61	1	245,428.7	158,571.5	98.5
	Pasture		5	300,577.1	194,202.9	120.7
	Vine		10	65,830.5	42,533.1	26.4
2	***Grains***	97.83	2	520,486.5	509,191.9	316.4
	Natural		4	977,688.3	956,472.5	594.3
	Vegetable		8	259,076.1	253,454.1	157.5
	Others	84.84	(0,3,6,7,9,11)	232,963.4	197,646.1	122.8
	Total			**2,602,050.6**	**2,312,072.1**	**1436.7**

[1] The *Others* category was not collapsed because its percentage of unpaved roads is the average of all the other crop types. As such, it did not distinctly belong in either of the two newly defined groups.

An ANOVA analysis revealed no significant difference in estimates produced using the collapsed versus the originally grouped data, but a significant difference in estimates between the two groups. For estimating non-harvest VMT (Section 3.2.3, Vol. I), the miles of unpaved road showed in Table 3 were used.

3.2. Estimating Vehicle-Miles Traveled

Two independent methods have been employed in order to estimate total VMT on unpaved roads. Since a relatively large amount of travel is expected to be generated in a short period of time by seasonal harvesting, it was decided that VMT associated with harvest should be calculated separately from VMT created by non-harvest activities. At the beginning of this study, several crops were not yet being harvested. Because any data collected during this period would be unrepresentative of peak-harvest activity, it was decided that the estimation of harvest traffic would be modeled using field-specific characteristics, such as crop type and field acres as independent factors. Non-harvest activity is estimated using a combination of road network characteristics, traffic counters, surrounding land-use characteristics, and weather statistics.

3.2.1. Estimating Harvest Traffic

The process for estimating harvest VMT is illustrated in Figure 3. We take advantage of defined 36 square-mile sectors (SMS)[2] to compute the annual number of vehicle miles of travel (VMT), which is then disaggregated by month. This was accomplished by first estimating the amount of travel expected to be generated by each acre of cropland in each SMS and distributing the estimate among months according to harvest information obtained from survey responses.

Essential to this estimation was the use of information obtained from a grower survey. To estimate VMT per acre due to harvest activity, a sampling frame was developed from records maintained by the San Joaquin County Agriculture Commissioner's Office (SJCAC). These records listed each crop grown by each grower in SJC. Information concerning harvest VMT and harvest periods for sample fields were collected using a mail survey and discussed in detail in the next section.

---

[2] We define each SMS to be 36 square miles in area. Each SMS has a corresponding Township and Range Location and contains 36 Township-Range-Sections (TRS's) within them. (See Section 3.3 of Volume II for details on TRS Locations). Definition of the SMS was necessary to ensure an adequate population from which to build the harvest traffic model.

3.2.1.a. Survey

The SJCAC database contained the acreage of each crop grown by each grower as well as mailing addresses and phone numbers for each grower within SJC. Growers included in the sample were sent a one-page, two-sided mail survey. The survey asked the grower to identify a typical field for a specified crop and to provide the following information as it relates to the identified field:

- Acreage of the field
- Average annual yield from the field (lbs/tons/kg/Mg)
- Vehicle types used to pick up crops from this field. For each vehicle type:
    - Vehicle Name or Brief Description
    - Number of Wheels
    - Weight (lbs./tons/kg/Mg)
    - Capacity (lbs./tons/kg/Mg)
    - Estimated % of total trips for which vehicle type is used
    - Average off-road speed (mph)
- Distance from the typical pick-up point to the nearest paved road access (ft/miles)
- Typical beginning and end of the harvest season (month & day)
- Permission for researchers to contact the grower for more information if needed at a later date

The survey was distributed to a random sample of grower-crop combinations, stratified by the crop categories listed in Table 4. The stratification was necessary to sufficiently represent the diverse types of crops grown within the county. The sample size was chosen based on the expected variance within each crop category plus a safety margin. Grower-crop combinations were selected at the sample sizes shown in Table 4, while ensuring that no grower was selected more than once (*i.e.,* for two different crop types).

Table 4. Crop Stratification Categories and Sample Sizes

Crop Category	No. of Grower-Crop Combinations (Sampling Frame Size)	Sample Size
Bean / Legume	1564	70
Fruit	1296	70
Grain	3123	70
Sugar / Honey / Oils	225	70
Nut	2461	70
Tomato Processing	457	70
Vegetable	1793	70
Vine	1798	70
Herbs / Spices	16	-
Total	**12,679**	**560**

Of the 560 surveys sent to growers, 119 were returned, yielding a response rate of 21.3 percent. Of the 119 returned surveys, 89 had sufficient information to make them usable, yielding an effective response rate of approximately 16 percent. Growers who returned surveys concerning crops other than those specified by the researchers from the list of growers were excluded from the sample. This was necessary because no additional field characteristics or information were available for grower-crop combinations not included in the list of growers and because of the stratification structure used in the original sample design of the Grower Survey. The response rates categorized by crop were somewhat variable, with vine growers representing the high of 21.3 percent of returned surveys and Sugar/Honey/Oils growers representing the low of only 4.5 percent. Harvest traffic estimates were created based on the 89 surveys returned by growers in SJC. Table 5 displays the response rates by crop category.

Table 5: Frequency of Survey Responses by Crop Type

Crop Type	Frequency	Percent Total
Bean / Legume	12	13.5
Fruit	9	10.1
Grain	10	11.2
Sugar / Honey / Oils	4	4.5
Nut	15	16.9
Tomato Processing	11	12.4
Vegetable	9	10.1
Vine	19	21.3
Total	**89**	**100.0**

Using the grower provided information the annual VMT per acre could be computed using Equation 3.

$$\left[\frac{VMT}{year \cdot acre}\right]_f = 2 \times \frac{d_f \times y_f}{a_f} \times \sum_v \frac{\%Crop_v}{C_v} \qquad (3)$$

where, d_f = Distance (miles) harvest vehicles travel from crop pick-up to the nearest paved road.

y_f = Annual yield (tons) of crop from field *f*.

$\%Crop_v$ = Percentage of annual crop carried by vehicle type *v*.

C_v = Capacity (tons) of vehicle type *v*.

a_f = Size of field *f* (acres).

v = Vehicle type used to transport harvest.

The output of the above equation is the annual VMT/acre due to the harvest of each crop, calculated for each field in the sample. The figure is multiplied by two in order to account for both in-bound and out-bound trips to the field. All of the distance input figures were collected for the sample fields using the mail-back surveys.

As can be seen in Table 6, although the remaining categories were similar in response rates, vegetable growers had the largest total annual VMT per acre, representing 27 percent of total reported VMT. Growers of tomatoes for processing represented the opposite extreme. It should be noted that these VMT estimates do not reflect actual harvesting performed on the field, only transport to and from the field to the nearest paved road.

Table 6: Reported VMT by Crop Type

Crop Category	% Total Responses	% Annual VMT / Acre
Bean / Legume	13.5	21
Fruit	10.1	13
Grain	11.2	3
Sugar / Honey / Oils	4.5	10
Nut	16.9	4
Tomato Processing	12.4	1
Vegetable	10.1	27
Vine	21.3	21

The difference between grower response rates indicates that vine growers may be over-represented while Sugar/Honey/Oils growers are under-represented relative to their representation within the county. Thus, VMT estimates may actually be different (slightly lower or higher) than reported here. A larger grower survey would make the grower VMT estimates more robust.

3.2.1.b. Model Step 1

With annual VMT per acre as the dependent variable, we first attempted to use a general linear model analysis that combined the following categorical and continuous factors associated with each field:

- *Paved Road Density* (*PRD*), for the Township-Range-Section (TRS) Location in which the field's centroid lies, calculated in miles/mile^2 using the GIS database provided by Caltrans. *PRD* is used in lieu of unpaved road density. *PRD* is hypothesized a predictor using the logic that areas with a higher *PRD* will produce less VMT on unpaved roads . The average *PRD* for a given TRS was assigned to each crop field within that TRS.
- *Land Use Factors (L/U)*, includes:
  - %*Ag* = Percent of TRS Location's Land Use zoned as Agricultural.
  - %*Re* = Percent of TRS Location's Land Use zoned as Residential.
  - %*Com* = Percent of TRS Location's Land Use zoned as Commercial.
  - *%Pub/Fac* = Percent of TRS Location's Land Use occupied by Public Facilities.
  - *Crop Type^i* = Binary Indicator that field *f* grows crop type *i*, as recorded in the List of Growers provided by SJCAC.

Returned surveys revealed no public facilities (*%Pub/Fac*) and only one commercial zone (*%Com*) located in the same TRS as the field cited in each survey. These variables were therefore ignored in the analysis. The remaining characteristics were then associated with each grower-crop combination through the List of Growers obtained from SJCAC, listing the Public Land Survey System (PLSS) grid locations of each grower-crop combination. Refer to Section 4.2 of Volume II for details on collection of these data.

We explored several models that included the land-use variables hypothesized above. None of the proposed land-use variables were significant in the model. The linear regression model, shown in Equation 4, was first used to model the data.

$$E\left(\left[\frac{VMT}{year \cdot acre}\right]_f\right) = b_{CropType^i} + b_1 \times PRD_{TRS} \tag{4}$$

where, $b_{CropTypei}$ = Constant Parameter for Crop Category grown in field *f*.
PRD = Paved Road Density for the TRS Location in which the field's centroid lies.
TRS = Township-Range-Section Location of the field.
j = Land-Use Factor as described above.

An analysis of the model residuals suggested that it did not adequately fit the sample data. The residuals indicated the need for a natural log (*ln*) transformation in the dependent variable. Since a substantial number of the 89 returned surveys revealed that growers traveled zero miles on unpaved roads during harvest, a *ln* transformation was not possible without losing valuable information from the data set. The zero miles reported do not mean that growers were not traveling during harvest season, but rather that they were likely traveling by pathways other than unpaved roads (*i.e.,* paved roads). Other transformations of the dependent variable were attempted, however none yielded satisfactory results. The modeling process was then revised to instead use two-steps to model harvest VMT. In the first step, we employed a logistic regression model, shown in Equation 5:

$$logit(+VMT) = 3.2203 - 0.9129 \times \%res_{SMS} - 0.5308 \times PRD_{SMS} + 0.1705 \times \%res_{SMS} * PRD_{SMS} \tag{5}$$

where, $logit(+VMT)$ = Log Odds that growers have harvest VMT greater than zero on unpaved roads.
PRD = Paved Road Density (miles/mile^2).
$\%res_{SMS}$ = Percent of the SMS Location's land use zoned as residential.
$\%res*PRD$ = Interaction effect between the two variables.
SMS = 36 Square Mile area consisting of 36 Contiguous Township-Range-Section Locations.

The logistic regression estimates the probability that growers in each SMS will have a positive unpaved roads VMT during the harvest season. This probability was then used to determine the proportion of growers used for the second step in the estimation process.

The probabilities can be computed as,

$$\Pr(+VMT) = \frac{e^{(3.2203 - 0.9129\times\%res_{SMS} - 0.5308\times PRD_{SMS} + 0.1705\times\%res_{SMS} * PRD_{SMS})}}{1 + e^{(3.2203 - 0.9129\times\%res_{SMS} - 0.5308\times PRD_{SMS} + 0.1705\times\%res_{SMS} * PRD_{SMS})}} \quad (6)$$

Diagnostics on this model revealed that it correctly predicted 91.23 percent of the observed incidences of positive VMT. The model does not fair nearly as well in predicting zero VMT when VMT is observed to be zero; it is correct only 12.50 percent of the time (See Table 7). Since this method will be used in estimating the amount of PM_{10} generated by harvest activities, under-predicting the probability of positive VMT could have more severe consequences than a slight over-prediction. Therefore, slightly over-predicting the probability of positive VMT is preferable to under-prediction.

Table 7. Logistic Regression Diagnostics

Observed ↓ / Predicted →

	VMT = 0	***VMT > 0***	***Percent Correct***
VMT = 0	4	28	12.50
VMT > 0	5	52	91.23

3.2.1.c. Applying Model Step 1 to the Entire Grower Database

The objective in Step 1 of the modeling process was to determine the probability that growers from each SMS had harvest VMT greater than zero on unpaved roads. These probabilities then define the sample size of growers used in Step 2 of the process. According to each SMS's probability of positive VMT, we randomly choose a sample of growers to use in the proposed linear regression model (Equation 4) with the necessary *ln* transformation in the dependent variable. This transformed linear regression model in turn yields annual harvest VMT per acre.

In order to apply the results of the logistic model to the second step of the estimation process, several modifications to the grower database provided to us by SJCAC were necessary. The information received from SJCAC was arranged by grower. Because of this, the list of growers needed to be re-ordered so that groups were based on TRS Location rather than crop type. As mentioned in footnote 2, 36 contiguous TRS Locations comprise one SMS. Since some SMS's contained relatively few growers, it was decided that a minimum criterion of 100 growers for any given SMS was necessary in order have an adequate pool of growers from which to randomly sample in Step 2 of the harvest estimation. Since we did not want to exclude any potentially important data from the set, it was decided that a "combined" group of growers from SMS's with fewer than 100 growers would be created. If a SMS had fewer than 100 growers, it was merged with other SMS's with fewer than 100 growers that had similar percentages in terms of agriculture, residential area and paved road densities. It was felt that the similarities in these characteristics were necessary because they were hypothesized to be important to determining harvest VMT. The total number of growers in the county equals 12,675 with an average of 379 growers per SMS. The combined "fewer than 100" group contained 562 growers. It was felt that this was reasonably close to the average number of growers per SMS and was therefore acceptable for the analysis. The average percentage of each land use characteristic (percent agriculture, percent residential area, paved road density) then was calculated for each low-grower SMS. The average for each characteristic across these SMS's was then used in the logistic regression model to determine the probability of positive VMT for this "combined" group. Including the "combined" group, 34 SMS's were defined for SJC.

Growers of an SMS (or the "combined" group) were then eligible to be selected according to the sector's individual probability of having an annual VMT greater than zero. Growers were then randomly chosen from each SMS according to the corresponding probabilities of positive VMT from that sector. Table 8 provides an illustration of this.

Table 8. Random Sampling Example

SMS ID Number	Number of Growers	Prob(VMT > 0)	Random Sample Size
146	404	0.574	232

3.2.1.d. Model Step 2

Using these random samples we were then able to utilize our originally proposed linear regression model (Equation 4) with a *ln* transformation in the dependent variable. The transformed best-fit model, representing Step 2 in our harvest traffic modeling procedure, is shown in Equation 7. The variable included in this model was determined based on the original 57 survey results that reported positive VMT.

$$E\left[\ln\left(\frac{VMT}{acre \bullet year}\right)\right] = \sum_{i=1}^{8} b_i X_{croptype_i} + b_9 \% Ag_{TRS} \qquad (7)$$

where, b_i is a binary indicator approximating constants in the model for each of the eight crop types used and $E\left[\ln\left(\frac{VMT}{acre \bullet year}\right)\right]$ is the expected value of the natural log of the dependent variable, $\left[\left(\frac{VMT}{acre \bullet year}\right)\right]$. It was felt that using crop types to approximate model constants would provide a more accurate estimate than using an overall constant. Although the rate of increase in harvest VMT is constant, the magnitude of VMT is allowed to vary between crop types, capturing any systematic difference that may exist between them. The numerical parameters describing the relationship of the constants and variables are shown in Table 9.

Table 9. Harvest VMT Linear Regression Model Coefficients

Model	B	Standard Error	Significance
b_1 *(Bean)*	-4.102	1.361	0.004
b_2 *(Fruit)*	-2.578	1.341	0.060
b_3 *(Grain)*	-5.679	1.113	0.000
b_4 *(Sugar / Honey / Oils)*	-2.915	1.679	0.089
b_5 *(Nut)*	-3.990	1.444	0.008
b_6 *(Tomato Processing)*	-6.382	1.291	0.000
b_7 *(Vegetable)*	-4.971	1.339	0.001
b_8 *(Vine)*	-3.664	1.184	0.003
b_9 *(%Ag_{TRS})*	0.0183	0.013	0.168

Table 10. Diagnostics

$R^2_{adjusted}$	F	p
0.757	16.651	0.000

All of the constants were significant in the model, thus all crop types investigated in the study are significantly represented. The variable *%Ag* (b_9), representing the percent of land use zoned as agricultural, appears to be a reasonably, although not an exceptionally strong indicator of harvest VMT. Because it was the best indicator variable hypothesized and because the variable is a logical indicator of harvest VMT, *%Ag* (b_9) was retained. Although the variable does not appear significant here, we feel that this may be the effect of the small sample size rather than actual variable significance. We would expect *%Ag* to be significant given a larger sample. After estimating the parameters, our expectation that the value of b_9 would be positive, since with a higher percentage of agricultural land, a higher number of unpaved roads would be expected, was met. This provided us with additional justification for retaining this variable.

The $R^2_{adjusted}$ criterion (0.757) suggests a good fit of the model to the data and the model appears to be a better predictor of VMT than the mean VMT by crop type.

3.2.1.e. Annual Harvest VMT Estimation Results for San Joaquin County

The two-step modeling procedure described above was used to estimate annual VMT for each SMS and the average VMT for the SMS's included in the "combined" group. The results were then summed across all sectors to arrive at total annual harvest VMT. For SJC, the random sampling procedure was performed twice and entered into the model to ensure consistency in results. Between the two trials there was a difference in countywide annual VMT of 4.57 percent. For all subsequent analyses using the annual VMT estimate, such as determination of monthly VMT estimates, only the results from the first trial were utilized. Numerical results of annual harvest VMT for SJC are presented in Table 11.

Table 11. Harvest VMT Estimates, San Joaquin Co.

Trial	N Growers	**Sum Annual VMT**
1	8295	**28,816.83**
2	8295	**27,557.50**

3.2.2. Monthly Harvest Estimates

Annual VMT estimates were also used to calculate monthly VMT estimates for each SMS. The sector's total harvest VMT includes all crops, with monthly distributions for each crop found using harvest calendars developed from the grower survey responses, and all grower-crop-locations that fall within the given sector. These harvest calendars indicate the amount of each crop harvested during each month of the year according to the survey data (See Appendix A for harvest calendars). The annual VMT was weighted by the percentage of each crop harvested by each grower during that month to find the monthly VMT. Finally, for each month and for each sector, the monthly VMT for all crops in a harvest period was totaled, resulting in a profile of monthly harvest VMT across all sectors in the county. These calculations are summarized in Equation 8.

$$\mathbf{VMT} = \sum_{f} \mathbf{VMT}_f = \sum \left[a_f \times E\left(\frac{VMT}{year \cdot acre} \right)_f \times \mathbf{H}_{c(f)} \right] \qquad (8)$$

where, $\mathbf{VMT}$ = Vector of monthly vehicle-miles traveled for the county.
f = Grower field.
$c(f)$ = Crop grown in field f.
$\mathbf{VMT}_f$ = Vector of monthly vehicle-miles traveled due to harvest of f.
$\mathbf{H}_{c(f)}$ = Vector of reported % of annual harvest occurring during each month.
$E\left(\frac{VMT}{year \cdot acre} \right)_f$ = Estimated annual VMT generated by harvest activities for f.
a_f = Total acreage of f.

The percentages of the crop harvest occurring in each month of the year were found for each crop represented in the grower survey. The final vector of percentages corresponds to the proportion of total yield of harvest that is typically produced during each month of the year. The results were then imported back to GIS for graphical representation.

3.2.2.a. Monthly Harvest Estimates for San Joaquin County

Using the method described above, monthly harvest traffic for San Joaquin County was estimated as shown in Table 12. See Figure 4 for a graphical illustration of the distribution of peak harvest month traffic (September).

Table 12. Estimated Monthly Harvest VMT

Month	Estimated VMT
January	154
February	189
March	391
April	1251
May	3559
June	2461
July	1898
August	4316
September	10132
October	4207
November	190
December	69
Total	**28,817**

It should be noted when using this method for other counties that proportions of monthly VMT will change depending on the typical crops grown in the given county.

3.2.3. Estimating Non-Harvest Traffic

The process for estimating non-harvest VMT is illustrated in Figure 5. Non-harvest traffic refers to consistent traffic levels that occur during the non-harvest as well as the harvest season, but that are not associated with harvest activities. Non-harvest traffic therefore includes agricultural traffic involved with non-harvest agricultural activities such as land preparation and field fertilization. A useful way to think about non-harvest traffic is as a baseline, or as the amount of traffic that would occur regardless of harvest activities in the area. In accordance with current procedures at CARB for estimating non-farm-road particulate matter, it was assumed in the model for non-harvest activity that only days without rainfall during a month would be used (Section 7.9, Road Dust, Unpaved Road Travel—Non-Farm Roads, February 1990). This is consistent with the proposed future use of this model since PM_{10} dispersion is minimized on days with precipitation.

At the outset, a distinction between weekdays and weekends was considered for this model since previous studies have indicated a possible difference in VMT between these times. Ultimately, it was decided, however, that this was beyond the scope of this pilot study. In order to estimate weekly VMT, random samples over all days of the week were used, resulting in a model that does not incorporate the possibility of differences based on day of the week. The same GIS road coverage, provided by Caltrans, was used for both harvest and non-harvest VMT estimations.

3.2.3.a. Data Collection

The collection of non-harvest data consisted of two stages: 1) randomly sampled road segments, stratified by land-use category, used to determine the proportion of roads in that category that are abandoned, active private, and active public; and 2) out of the active roads identified, a sample of segments were selected for 24-hour traffic counts. (See Section 2 for further information on sampling sites).

Both private and publicly maintained unpaved roads were represented in the GIS database provided by Caltrans. Most of the data collected in this study came from counts on private unpaved roads. Traffic counts over 24-hour periods were collected at unpaved segments' access points to paved roads, such that incursion on private property was unnecessary. To further avoid such incursion, at each site a tube-style traffic counter was placed in the arrangement shown in Figure 6. Using this arrangement, a 24-hour record of the car-passes and a time-stamp of each pass were collected. After data were collected, the distribution of passes on the two tubes was collected; for every pass on one tube that does not have a counterpart on the other tube at nearly the same time stamp, we count an entrance or exit to the unpaved road.

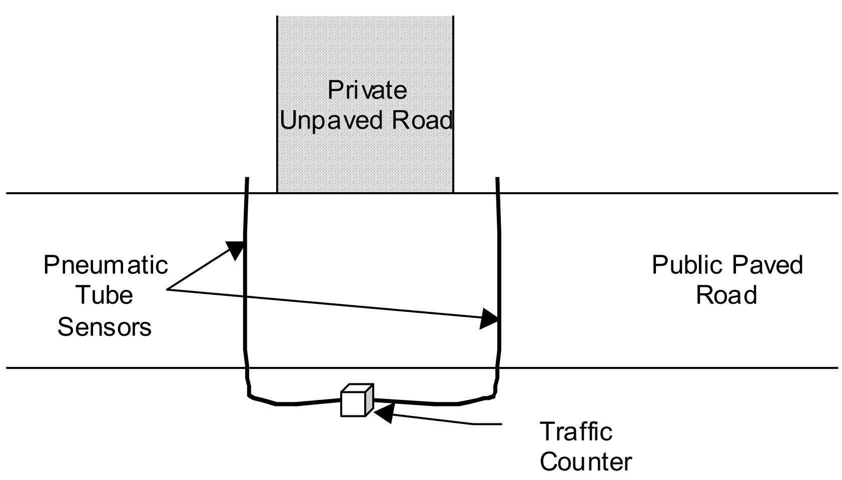


Figure 6. Traffic Counter Tubes Arrangement

The counts provided an estimate of the number of trips generated on the unpaved road. This figure was then converted into an estimate of miles traveled. Because nearly all unpaved roads are private in nature, it is reasonable to assume that there is typically a single destination located somewhere along each road segment that is served by that road, rather than a large distribution of destinations. Given this assumption, we make the additional assumption that half the length of the current segment is traveled by each car counted as entering or exiting the unpaved road. This assumption will likely underestimate the miles traveled on the studied segments, since in many cases the single destination will be located at the end of the road segment. However, this underestimation counteracts the under-sampling of unpaved roads that are not directly accessible by paved roads, and which likely carry less travel than roads that have direct connections to paved roads. Additional counts are recommended for future research.

The counts in this exploratory study were conducted from May 31 to June 15, 1998. In recording count data, each site was assigned a day-of-week such that every day of the week was sampled an equal number of times. The traffic counters collected the following attributes.

- Day ID
- Count of Vehicles at Paved Access Point

Next, additional attributes were assigned to each road segment on the basis of network and land use characteristics. These characteristics include road density for the TRS in which the segment's length-center resides. The section-based calculations are discussed in Volume II, Section 4.2.

Originally, segments in the 16 sub-areas used to estimate miles of unpaved road (Section 3.1) were selected as potential sites for traffic counters. From these 16, only 13 proved to have suitable road segments. The remaining three were infeasible either because paved roads connecting to the unpaved roads were too large in size (*e.g.,* a 4-lane arterial) or there was no area where an unpaved road was connected to a paved road. One active unpaved road from each of the 13 suitable sites was chosen and fitted with a traffic counter. A description of the sample sites and their location is contained in Table 13. Figure 7 graphically displays the sample site locations.

Table 13. Sample Site Locations and Time Frames

Site Code	Lane Use	Road Name	Cross Street	Sampling Period (1998)			
				Start		End	
				Date	*Time*	*Date*	*Time*
*101	Pasture	Forest Lake Blvd.	Lower Sacramento Rd.	05/31	1200	06/01	1100
*201	Natural	Mackville Rd.	Liberty Rd.	06/01	1630	06/02	1130
*401	Vine	Fine Ave.	Flood Rd.	06/02	1330	06/03	1330
551	Vegetable	Bacon Island Rd.	**Middle River	06/14	1230	06/15	1130
651	Vegetable	Tracy Blvd.	California Delta Hwy.	06/13	1000	06/14	1000
701	Grain	Roberts Rd.	Matthews Rd.	06/03	1300	06/04	1100
901	Pasture	Carter Rd.	Escalon-Bellota Rd.	06/04	1730	06/05	1530
1001	Grain	Clifton Court Rd.	Calpack Rd.	06/12	1200	06/13	0900
1101	Vegetable	Finck Rd.	Tracy Blvd.	06/11	1700	06/12	1100
1201	Fruit	Louise Ave.	Wagner Rd.	06/07	1330	06/08	1330
1301	Fruit	Sexton Rd.	River Rd.	06/06	1400	06/07	1230
1401	Pasture	Crichett Rd.	Kasson Rd.	06/10	1830	06/11	1530
1501	Fruit	West Ripon Rd.	Manteca Rd.	06/08	1700	06/09	1630

* Traffic count data was not usable due to mechanical error.
** The name of a river in lieu of an existing cross street.

From the 13 chosen sites, daily count data were successfully retrieved from 10. The remaining three counters yielded no usable data due to mechanical error; the data from the counters is contained in Table 14.

Table 14. Traffic Counter Data

Time		**Location**										**Avg**
From	***To***	***551***	***651***	***701***	***901***	***1001***	***1101***	***1201***	***1301***	***1401***	***1501***	**-**
12:00AM	12:30AM	0	0	0	0	0	0	0	0	0	0	0
12:30AM	1:00AM	0	0	0	0	0	0	0	0	0	0	0
1:00AM	1:30AM	0	0	0	0	0	0	0	0	0	0	0
1:30AM	2:00AM	0	1	0	0	0	0	0	0	0	0	0
2:00AM	2:30AM	0	0	0	0	0	0	0	0	0	0	0
2:30AM	3:00AM	0	0	0	0	0	0	0	0	0	0	0
3:00AM	3:30AM	0	0	0	0	0	0	0	0	0	0	0
3:30AM	4:00AM	0	0	0	0	0	0	0	0	0	0	0
4:00AM	4:30AM	0	0	0	1	0	0	0	0	0	0	0
4:30AM	5:00AM	0	0	0	0	0	0	0	0	0	0	0
5:00AM	5:30AM	0	0	0	0	0	0	0	0	0	0	0
5:30AM	6:00AM	0	0	0	0	0	0	1	0	0	0	0
6:00AM	6:30AM	0	1	3	0	0	1	2	0	0	0	1
6:30AM	7:00AM	0	0	2	0	0	0	0	0	0	0	0
7:00AM	7:30AM	13	1	1	0	0	0	3	0	0	0	2
7:30AM	8:00AM	3	0	1	0	0	0	0	0	0	0	0
8:00AM	8:30AM	10	1	0	0	0	0	1	0	0	0	1
8:30AM	9:00AM	2	2	0	0	0	0	0	0	0		0
9:00AM	9:30AM	6	1	0	0	1*	0	1	0	0	0	1
9:30AM	10:00AM	5	1	1	0	1*	0	0	0	0	0	1
10:00AM	10:30AM	2	0	0	0	0*	0	0	0	0	0	0
10:30AM	11:00AM	2	0	0	0	1*	0	4	1	0	0	1
11:00AM	11:30AM	0	1	0*	1	0*	0*	0	0	0	0	0
11:30AM	12:00PM	0*	0	0*	0	0*	0*	1	0	0	0	0
12:00PM	12:30AM	2*	0	2*	0	12	0* (2)	0	0	0	0	2
12:30PM	1:00PM	0	1	1*	1	0	1*	3	1*	0	0	1
1:00PM	1:30PM	0	0	0	1	0	0*	0	0*	0	0	0
1:30PM	2:00PM	0	0	1	0	0	0*	1	0*	0	0	0
2:00PM	2:30PM	0	5	0	1	0	0* (1)	4	0	0	0	1
2:30PM	3:00PM	0	0	0	0	0	0*	0	0	0	0	0
3:00PM	3:30PM	0	0	0	0	0	0*	0	0	0	0	0
3:30PM	4:00PM	0	2	4	1*	0	1*	0	0	0* (1)	0	1
4:00PM	4:30PM	0	2	3	1*	0	0* (1)	0	0	0* (1)	0	1
4:30PM	5:00PM	0	1	0	0*	1	0*	0	0	0*	0*	0
5:00PM	5:30PM	0	0	2	0*	0	1	0	0	0*	0	0
5:30PM	6:00PM	0	1	1	3	0	0	2	0	0* (1)	0	1
6:00PM	6:30PM	0	0	8	0	3	0	1	0	0* (1)	0	1
6:30PM	7:00PM	0	2	2	0	1	0	0	0	0	0	1
7:00PM	7:30PM	0	1	1	0	0	0	0	0	0	0	0
7:30PM	8:00PM	0	2	2	0	0	0	0	0	0	0	0
8:00PM	8:30PM	0	0	2	0	0	0	1	4	0	0	1
8:30PM	9:00PM	0	1	1	0	0	0	0	0	0	0	0
9:00PM	9:30PM	0	1	1	0	0	0	1	0	0	0	0
9:30PM	10:00PM	0	0	1	0	0	0	0	2	0	0	0
10:00PM	10:30PM	0	0	1	0	0	0	0	0	0	0	0
10:30PM	11:00PM	0	1	0	0	0	0	0	0	0	0	0
11:00PM	11:30PM	0	1	0	0	0	0	0	0	0	0	0
11:30PM	12:00AM	0	0	0	0	0	0	0	0	0	0	0
	TOTAL	**43**	**30**	**38**	**8**	**17**	**2**	**26**	**7**	**0**	**0**	
Control 1	**Allw Inc.**	**5**	**0**	**9**	**2**	**6**	**2**	**0**	**1**	**0**	**0**	
Control 2	**Allw Max.**	**48**	**30**	**47**	**10**	**23**	**4**	**26**	**8**	**0**	**0**	
	Final Est.	**45**	**30**	**41**	**10**	**20**	**4**	**26**	**8**	**0**	**0**	

* Asterisks indicate missing data points. Numbers adjacent to asterisks indicate the average number of trips across the sampled sites for the given time period that were used to calculate the final estimate. Numbers in parentheses represent the average across sites during the indicated time period that were not used in the final estimate.

Data were collected over a 24-hour period with missing data points being inferred from others occurring during the same half-hour interval. Missing data points were entered as the average number of vehicle passes occurring across all other sample sites during the half-hour interval in which the data were missing. However, not all inferred points were used in the *Final Estimate;* the procedure used to determine the validity of including inferred points is described below.

First, the total number of passes was calculated for each site, without incorporating the missing data points. *Control 1*, the *"Allowable Increment"* was then calculated as *2 x (the average number of passes occuring each half-hour during the most probable travel time periods (6:00 AM to 10:00 PM)*). Twice the average number of passes was an arbitrary, but reasonable choice for this determination. *Control 2*, the *"Allowable Maximum"* was calculated by adding the actual *Total* to the *Allowable Increment*. The *Allowable Maximum* was treated as the uppermost boundary for the *Final Estimate*.

Two decision rules were employed to determine whether values inferred for the missing data points would be used: 1) If including the inferred values raised the total value above the *Allowable Maximum*, the inferred values were ignored and the *Allowable Maximum* for the site was used as the *Final Estimate*; 2) If including the inferred values was less than or equal to the *Allowable Maximum*, the inferred values were added to the actual *Total* to arrived at the *Final Estimate* used to build the model.

From the GIS road coverage, all digitized unpaved roads were separated into two or more segments such that each segment lay in only one particular TRS. For each segment, the actual length of the unpaved road used was as determined under Section 3.1.

The 10 sampled sites were associated with their respective TRS codes. This allowed us to identify the percentage of agriculture, residential area and paved road density contained within the TRS associated with the sample data points.

3.2.3.b. Model for Daily Non-Harvest Traffic

The estimation of non-harvest traffic counts on selected unpaved road segments uses the best fitting linear regression model shown in Equation 9. This model was created using the sample data from the traffic counters and land use characteristics associated with the counter locations (See Table 15).

$$E(DailyCount_i) = 2.181 + 3.277 \times PRD_{TRS} \qquad (9)$$

where, E(Daily Count$_i$)	=	The estimated number of vehicle passes per day on road segment *i*.
PRD	=	Density of paved roads within the section *s*, in which the segment *i* lies.
i	=	Any given active, unpaved, accessible road segment.
TRS	=	Township-Range-Section location in which segment *i* lies.

This model results in an estimated daily vehicle count for each sample road segment included in the analysis.

Table 15. Non-Harvest Traffic Variable Values

Site ID	Traffic Count	PLSS	% Agriculture	% Residential	% Paved Road
501	45	11414	100.0	0.0	6.94
601	30	11530	94.2	0.0	9.09
701	41	21605	100.0	0.0	11.32
901	10	21903	57.0	0.0	1.00
1001	20	21413	94.8	0.0	3.06
1101	4	21531	96.7	0.0	4.71
1201	26	21834	96.0	0.0	6.00
1301	8	22907	99.0	0.0	1.03
1401	0	22634	95.9	0.0	0.33
1501	0	22728	90.0	0.0	6.01

Table 16. Diagnostics

$R^2_{adjusted}$	F	p
0.460	8.664	0.019

We expected the coefficient associated with PRD_{TRS} in Equation 9 to be negative since a higher density of paved roads should result in fewer trips on unpaved roads. However, this was not found to be true. This conclusion could be an artifact of the traffic sampling technique employed. Because of the traffic counter technology used, unpaved roads could only be sampled if they attached to a paved road, hence an increase in paved road density might be correlated to an increase in daily counts. It may, on the other hand, be a true depiction of the use of unpaved roads. The greater the access (*i.e.,* the greater the density of paved roads in the vicinity), the more likely the use of an intermediate unpaved roadway. An analysis of the residuals did not reveal any pattern.

Once vehicle counts had been estimated for each road segment, the total daily non-harvest VMT was calculated by multiplying the estimated daily count by 0.5 x (*length of road segment$_i$*) where the length of the road segment is as determined in Section 3.1 of this report. These results were then summed over all road segments in the county as shown in Equation 10. This reflects our assumption that daily traffic is consistent throughout the year and that the sample period is representative of this consistent daily traffic.

$$E(DailyVMT) = \sum_i E(DailyCount_i) * 0.5 * (LengthRoadSegment_i) \quad (10)$$

where, *E(DailyVMT)* = The estimated non-harvest VMT per day for the county.
E(Daily Count$_i$) = The estimated non-harvest vehicle counts per day on road segment *i*.
Length of Road Segment$_i$ = The length of road segment *i* as determined in Section 3.1 of this report.
i = Any unpaved road segment.

By using 0.5 x (*length of road segment*), we assume that each vehicle entering an unpaved road will travel half the length of the road and will return by the same path. If this is true, the vehicle will be counted twice and the total VMT for that road segment will be accounted for. If, however, a vehicle enters an unpaved road, travels the full length and exits at a paved road that is not outfitted with a traffic counter, VMT will be underestimated. The assumption that most vehicles return along the same path as they entered appears reasonable by the logic presented in Section 3.2.3.a.

3.2.3.c. Model for Annual Non-Harvest Traffic

Rainfall data provided the information needed for annual non-harvest VMT. In accordance with past CARB practices, only days without precipitation were used to calculate the final estimate of non-harvest VMT on unpaved roads. The average number of dry days, defined by CARB in their previous method as less than 0.01 inches, was multiplied by the non-harvest VMT per day to estimate the total non-harvest traffic per year (Section 7.9 Unpaved Road Dust, February 1990).

Using the daily counts produced in Equation 10, monthly estimate of VMT on unpaved roads in the county can be found by multiplying the estimated daily VMT by the number of dry days in a given month, as shown in Equation 11. The monthly VMT estimates can then be summed in order to determine the annual VMT as shown in Equation 12.

$$\mathrm{VMT}_m = \mathrm{D}_m * E(DailyVMT) \quad (11)$$

$$\mathrm{VMT}_a = \sum_{m=1}^{12} \mathrm{VMT}_m \quad (12)$$

where, VMT_m = VMT on unpaved roads within the county for each month of the year, *m*.
D_m = Expected number of dry days in each month of the year, *m*.
VMT_a = Annual VMT.
E(*DailyVMT*) = Estimated daily count of trips over all road segments in the county.
i = Any given unpaved road segment.

The variable D_m distributes annual VMT among the twelve months of the year, weighting each month in proportion to the average number of days without rainfall in it. Annual VMT then is simply the sum of the monthly VMT, VMT_m. Average rainfall figures should be used when predicting VMT for a future year.

3.2.3.d. Results for San Joaquin County

Weather statistics obtained from the Statewide Integrated Pest Management Project (UC Davis) for 1961-1997 showed the average number of dry days for SJC to equal 312. It was deemed necessary to use a long-term average for precipitation for two reasons: first, the road count data for the study were obtained in 1998 and the year is not yet at an end and, second, because the first part of 1998 was under an "El Nino" condition, it is dubious to assume that rainfall in this year is "typical" for the area. Precipitation measures used in estimating non-harvest VMT are shown in Table 16.

Table 16. Dry Days, San Joaquin County

Month	Total Number of Days each Month	Average Number of Dry Days
January	31	22
February	28	20
March	31	22
April	30	25
May	31	29
June	30	29
July	31	31
August	31	31
September	30	29
October	31	28
November	30	23
December	31	23

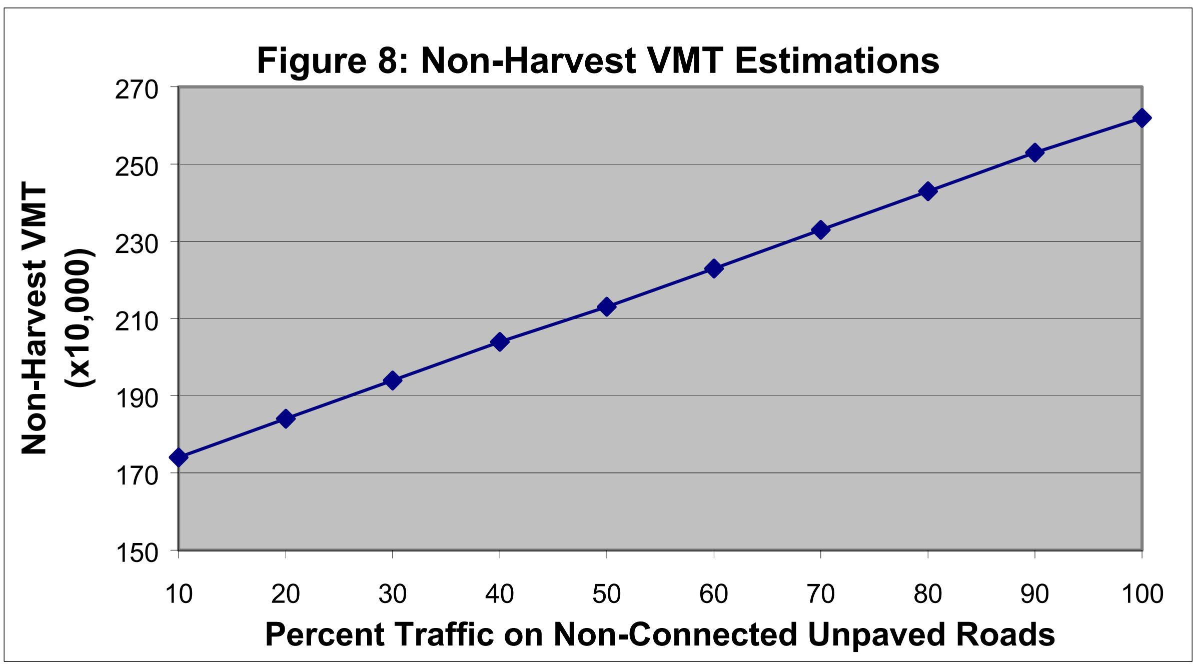
Using the methods described in this Section, total daily non-harvest VMT was calculated using 0.5 x (*length of road segment*$_i$) for the county's 14,278 road segments identified in the GIS database. This result was then multiplied by the long-term average number of dry days (312) expected for a given year. Because we suspect that unpaved roads not connected to paved roads may have less traffic than unpaved roads connected to paved roads, a sensitivity analysis was then performed. The sensitivity analysis assumed that unpaved road segments not connected to paved roads have lower traffic levels than those connected to paved road segments. For our analysis, we reduced traffic levels on "non-connected" roads in intervals of 10 percent. The results are shown in Table 17.

Table 17. Non-Harvest VMT Estimations

Percentage Traffic of Unpaved Roads (UPRs)	Total Annual Non-Harvest VMT
All Traffic on UPR Segments Regardless of Connection	2,624,710
All Traffic on *Connected Segments + 90% Traffic on **Not Connected Segments	2,526,437
All Traffic on Connected Segments + 80% Traffic on Not Connected Segments	2,428,164
All Traffic on Connected Segments + 70% Traffic on Not Connected Segments	2,329,891
All Traffic on Connected Segments + 60% Traffic on Not Connected Segments	2,231,619
All Traffic on Connected Segments + 50% Traffic on Not Connected Segments	2,133,345
All Traffic on Connected Segments + 40% Traffic on Not Connected Segments	2,035,073
All Traffic on Connected Segments + 30% Traffic on Not Connected Segments	1,936,800
All Traffic on Connected Segments + 20% Traffic on Not Connected Segments	1,838,527
All Traffic on Connected Segments + 10% Traffic on Not Connected Segments	1,740,255

* "Connected" designates that an unpaved road is connected to a paved road.
** "Not Connected" means that an unpaved road does not directly meet with a paved road.

Figure 8 depicts the results of the sensitivity analysis graphically.



The analysis reveals a 4-5 percent change in estimated annual non-harvest VMT for every 10 percent change in traffic levels on non-connected unpaved roads. A larger study could determine whether significant differences exist between traffic levels on "Connected" versus "Not Connected" unpaved roads and could incorporate their possible differences in non-harvest traffic estimations.

Monthly non-harvest VMT was calculated by the same method as described in Section 3.2.3.c. (See Table 18 for results). It should be noted that the apparent diminution of non-harvest VMT in the winter months is due to the presence of precipitation during these months. Although the method discounts these days because of rainfall, there may actually be vehicles on unpaved roads.

Table 18. Estimated Monthly Non-Harvest VMT

Month	Estimated VMT
January	185,076
February	168,251
March	185,076
April	210,313
May	243,963
June	243,963
July	260,788
August	260,788
September	243,963
October	235,551
November	193,488
December	193,488
Total	***2,624,710**

*Summing the monthly estimates will not yield the estimated total due to rounding error.

Figure 9 provides a graphical illustration of the distribution of non-harvest VMT across the county during the peak non-harvest traffic month of July.

3.2.4. Estimating Total County VMT

The total estimate of a given month's VMT equals the sum of the Sector's estimated harvest VMT for the given month and its estimated non-harvest VMT for the same month.

Results are shown in Table 19.

Table 19. Total Annual VMT

Month	Estimated Harvest VMT	Estimated Non-Harvest VMT	Total San Joaquin VMT
January	154	185,076	185,230
February	189	168,251	168,440
March	391	185,076	185,467
April	1251	210,313	211,564
May	3559	243,963	247,522
June	2461	243,963	246,424
July	1898	260,788	262,686
August	4316	260,788	265,104
September	10132	243,963	254,095
October	4207	235,551	239,758
November	190	193,488	193,678
December	69	193,488	193,557
Total	**28,817**	**2,624,710**	**2,653,527**

4. SUMMARY OF STEPS FOR ESTIMATIONS

Steps for estimating and applying the models described in the previous section follow.

Estimate of County Miles of Unpaved Roads

- *Databases Required*
  - GIS Road Coverage (Caltrans)
  - GIS Land Use Coverage (CDWR)
- *Steps*

1) Specify classes of land use for each polygon in the Land Use Coverage (See Task 1, Section 4.1, Vol. II).
2) Overlay the Land Use Coverage with the Road Coverage to define the pavement status for each road segment in the Road Coverage (See Task 2, Section 4., Vol. II).
3) Using the Land Use Coverage and the Road Coverage, compute the length of digitized unpaved roads for each land use type (See Task 3, Section 4., Vol. II).
4) Use the data from previous step to estimate Miles of Unpaved Road in a county (See Section 3.1.1 and Table 3, Vol. I).

Estimate of Unpaved Road Vehicle Mile Travel in a County

- *Database Required*
  - List of Growers (SJCAC)
  - GIS Road Coverage (Caltrans)
  - GIS Land Use Coverage (CDWR)
  - Public Land Survey System (PLSS) Coverage (Stephen P. Teale Data Center)

Estimate of County Harvest Vehicle Mile Travel

- *Steps*

1) Use the Road, Land Use, and PLSS coverages to estimate the percentages of agriculture and residential area, and the paved road density for each PLSS location (See Section 4.2, Vol. II).
2) In the list of growers, keep only those attributes necessary for the estimation: land_ID, ‘quantity’ (in acres), ‘commodity name’, township, range, and sections.
3) Of each piece of land, based on Township, Range, and Sections, create a single numeric code designating all information of Township, Range, and Sections. (See Section 3.3.1, Vol. II).
4) Categorize pieces of land into 8 main groups (See Table 3, Vol. I) based on type of crops (commodity name), and discard pieces of land that are not used for growing these crops.
5) Associate each piece of land to the percentages of land-use factors and the paved road densities based on its PLSS location.
6) Group the pieces of land by their locations to form SMS’s; Check to see if there are 100 growers in each SMS. If not, combine “low grower” SMS’s into groups based on the similarity of their land-use factors and paved road densities (See Section 3.2.1.c, Vol. I).

7) Estimate the percentages of residential land use and paved road density of each SMS using data from Step 1.
8) Apply the Logistic Regression Model (Equations 5 and 6, Vol. I) to each SMS to generate the probabilities used to determine the sample size necessary to generate harvest traffic estimates.
9) Randomly select sample pieces of land from each SMS.
10) Discard pieces of land that were not selected.
11) Apply the Linear Regression Model (Equation 7, Table 9, Vol. I) to estimate the Annual VMT per acre for each piece of land.
12) Multiply the estimated Annual VMT per acre with 'quantity' (in acres) to estimate Annual VMT each selected piece of land generates. The sum of this column will result in total annual harvest VMT for the entire county.
13) Apply Equation 8 to estimate monthly harvest VMT for each month.
14) Save the results into a database file and transfer the file to GIS in order to display the results on a coverage (See Section 4.5, Vol. II).

Estimate of Non-Harvest Vehicle Mile Travel in a County

♦ *Steps*

1) Prepare the data from the GIS Road Coverage (See Section 4.4, Vol. II), and transfer the database file to statistical software (SPSS was used in this analysis).
2) On statistical software, associate each segment to the percentage of paved road density according to its PLSS location. The average paved road density for each TRS is associated with each unpaved road segment.
3) Convert the unit of the length of each segment from meters to miles, and also discount the percentage of the length of digitized unpaved roads that are actually unpaved according to the land use classes that segment lies on (See Table 3, Vol. II).
4) Set up traffic counters to collect data regarding the number of passes on each unpaved road during the non-harvest season.
5) Apply Equation 9, Vol. I to estimate daily counts for each road segment.
6) Apply Equation 10, Vol. I to estimate daily non-harvest VMT for each road segment.
7) Multiply estimated daily VMT to the number of dry days in the year to estimate annual non-harvest VMT for each road segment. Sum this column to get the total annual non-harvest VMT for the entire county.
8) Multiply estimated daily VMT to the numbers of dry days of each month (Equation 11, Vol. I) to estimate monthly non-harvest VMT of each road segment. Sum up these columns, we will get the total monthly non-harvest VMTs for each month of the county (Equation 12, Vol I).
9) Perform the sensitivity analysis to calculate non-harvest VMT if we assumed that traffic on "Not Connected" unpaved roads were approximately 10%, 20%, ..., 90% of the traffic on "Connected" unpaved roads. (See Objective 3, Section 2, Vol. II).
10) Save the results into a database file and transfer the file to GIS in order to display the results on a coverage (See Section 4.5, Vol. II).

Estimate of Unpaved Road Vehicle Mile Travel in a County

♦ *Steps*

1) Combine harvest VMT and non-harvest VMT, both annually and monthly, to estimate the total unpaved road VMT for the county.

2) Save the results into a database file and transfer the file to GIS in order to display the results on a coverage (See Section 4.5, Vol. II).

5. RESULTS FOR FRESNO COUNTY

Using the proposed methodology on Fresno County (FC) presented some unforeseen challenges. For instance, crops such as cotton that are prevalent in FC did not fit conveniently into the categories designed for SJC. Listed simply as a "field crop" by the California Agricultural Statistics Handbook, it was decided that cotton would be grouped with "Grain Crops" for our analysis. The assumption here was that unpaved road networks and VMT for cotton would approximate those for grains. Assumptions such as these may be necessary for use of this method in other counties or further generalization of crop categories may be necessary to include the great diversity of crops grown throughout California.

Table 20, shown below, presents the estimates produced by the study methodology of the lengths of unpaved road in FC associated with land use. This estimation uses methods described in Section 3.1.

Table 20: Estimates of Meters of Unpaved Road

Crop Type	Land use code	Measured Meters
Fruits	1	865,191
Grains	2	3,258,890
Natural	4	5,777,622
Pasture	5	562,064
Vegetable Crops	8	923,343
Vine	10	1,377,131
Others	(0,3,5,6,7,11)	284,748
Total	--	**13,048,990**

Table 21 presents the estimated miles of unpaved road in FC using methods described in Section 3.1 of this report.

Table 21. Estimated Miles of Unpaved Road with Land Use Categories Combined into Two Groups

Group	Crop Type	Average% Unpaved	Land Use Code	Measured Meters	Estimated Meters	Estimated Miles
1	***Fruits***	64.61	1	865,191	559,000	347
	Pasture		5	562,064	363,150	226
	Vine		10	1,377,131	889,765	553
2	***Grains***	97.83	2	3,258,890	3,188,172	1981
	Natural		4	5,777,622	5,652,248	3512
	Vegetable		8	923,343	903,307	561
	Others	84.84	(0,3,6,7,9,11)	284,748	241,580	150
	Total			**13,048,990**	**11,797,221**	**7331**

Table 22 shows the VMT estimate for FC associated with harvest activities. This estimate was found using methods described in Section 3.2.1.

Table 22. Harvest VMT Estimates, Fresno County

N Growers	**Sum Annual VMT**
15271	**59,434.55**

Table 23 reveals monthly VMT estimates associated with harvest activities in Fresno County. These estimates were made using methods described in Section 3.2.2. See Figure 10 for a graphical depiction of the countywide distribution harvest VMT during the peak traffic month in FC (September).

Table 23. Estimated Harvest VMT per Month

Month	**Estimated Harvest VMT**
January	264
February	313
March	614
April	2564
May	8210
June	5655
July	3814
August	9300
September	22,029
October	6283
November	267
December	119
Total	***59,435**

*Summing the monthly estimates will not yield the estimated total due to rounding error.

Non-harvest VMT for FC was calculated using the precipitation statistics shown in Table 24. These statistics were used as described in Section 3.2.3.c.

Table 24. Dry Days, Fresno County

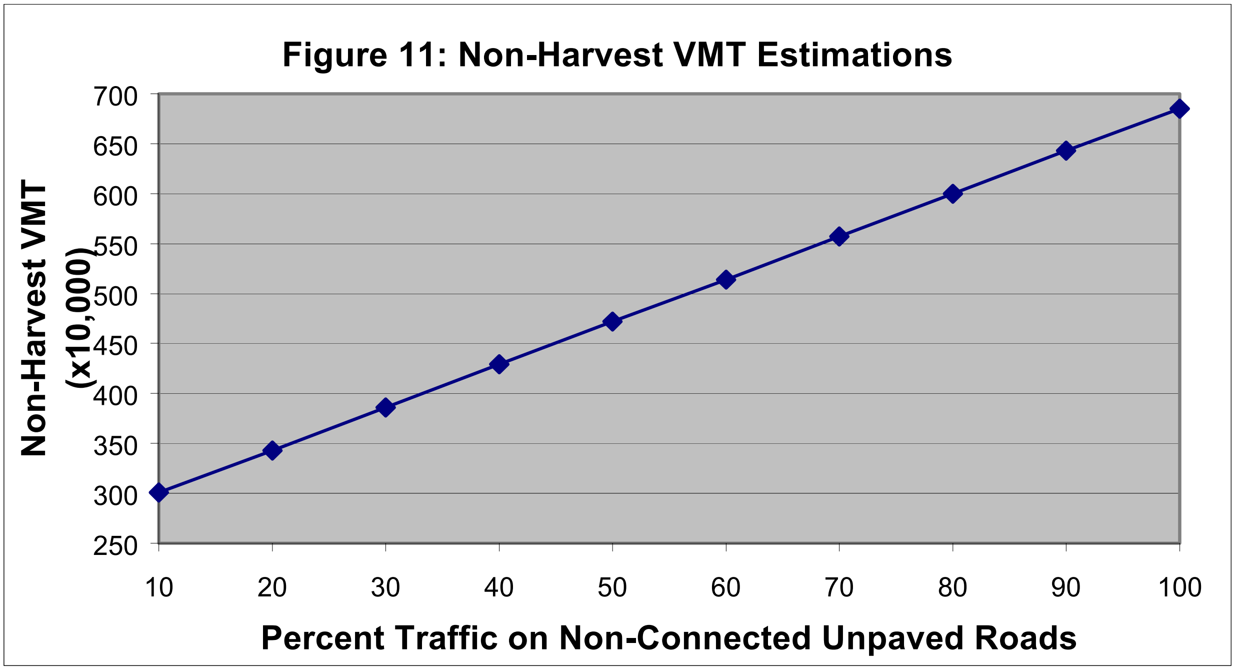
Month	Total Number of Days each Month	Average Number of Dry Days
January	31	23
February	28	21
March	31	23
April	30	26
May	31	29
June	30	29
July	31	31
August	31	31
September	30	29
October	31	29
November	30	24
December	31	24

The total non-harvest VMT on unpaved roads and the sensitivity analysis performed for FC are shown in Table 25. Methods used are described in Section 3.2.3.c. See Figure 11 for a graphical depiction of the results of the sensitivity analysis.

Table 25. Non-Harvest VMT Estimations for Fresno County

Percentage of Unpaved Roads (UPRs)	Total Annual Non-Harvest VMT
All Traffic on UPR Segments Regardless of Connection	6,853,056
All Traffic on *Connected Segments + 90% Traffic on **Not Connected Segments	6,425,740
All Traffic on Connected Segments + 80% Traffic on Not Connected Segments	5,998,424
All Traffic on Connected Segments + 70% Traffic on Not Connected Segments	5,571,109
All Traffic on Connected Segments + 60% Traffic on Not Connected Segments	5,143,793
All Traffic on Connected Segments + 50% Traffic on Not Connected Segments	4,716,477
All Traffic on Connected Segments + 40% Traffic on Not Connected Segments	4,289,162
All Traffic on Connected Segments + 30% Traffic on Not Connected Segments	3,861,846
All Traffic on Connected Segments + 20% Traffic on Not Connected Segments	3,434,530
All Traffic on Connected Segments + 10% Traffic on Not Connected Segments	3,007,214

* “Connected” designates that an unpaved road is connected to a paved road.
** “Not Connected” means that an unpaved road does not directly meet with a paved road.



Monthly non-harvest VMT for FC is shown in Table 26, below. These estimations were determined by methods described in 3.2.3.c. Figure 12 provides a graphical depiction of the distribution of non-harvest VMT in the county for the peak non-harvest traffic month of July.

Table 26. Estimated Monthly Non-Harvest VMT

Month	Estimated VMT
January	494,107
February	451,142
March	494,107
April	558,556
May	623,005
June	623,005
July	665,971
August	665,971
September	623,005
October	623,005
November	515,590
December	515,590
Total	***6,853,056**

*Summing the monthly estimates will not yield the estimated total due to rounding error.

Table 27 shows the annual total VMT for FC as determined by methods described in Section 3.2.4.

Table 27. Total Annual VMT for Fresno County

Month	Estimated Harvest VMT	Estimated Non-Harvest VMT	Total Fresno County VMT
January	264	494,107	494,371
February	313	451,142	451,455
March	614	494,107	494,721
April	2564	558,556	561,120
May	8210	623,005	631,215
June	5655	623,005	629,660
July	3814	665,971	669,785
August	9300	665,971	675,271
September	22,029	623,005	645,034
October	6283	623,005	629,288
November	267	515,590	515,857
December	119	515,590	515,709
Total	**59,435**	**6,853,056**	**6,912,491**

In comparison, using CARB's previous method and 1993 numbers, total Fresno County VMT was estimated to be 11,580,820.

6. CONCLUSIONS AND FUTURE RESEARCH

6.1. Conclusions

In this document, we have proposed a new methodology for estimating the miles of unpaved roads and for determining the VMT on those roads. The methodology consists of three separate, but interrelated estimations: 1)An estimate of the Miles of Unpaved Road, 2) An estimate of VMT associated with agricultural harvest activities, and 3) An estimate of VMT associated with non-harvest activities. In providing separate estimates for the type (harvest versus non-harvest) of vehicle activity on unpaved roads, the methodology allows one to distinguish the relative importance of these sources as contributors of PM_{10}. Data from San Joaquin County were used to specify the models. The models were then used to estimate VMT in Fresno County.

The methodology presented in this study provides a more statistically robust method to estimate unpaved road mileage and vehicle activity on unpaved roads than that previously employed by CARB. It must be stressed, however, that the results of this study should be considered preliminary. Future research should enlarge the database used to specify the models and to determine under which conditions they are applicable.

6.2. Future Research

There are several areas in which this method could be refined. In general, to increase the generalizability of the methods for use on a statewide basis, future research should include several different thrusts. The remainder of this section outlines data needs and concerns specific to each estimation incorporated in the new methodology.

6.2.1. Estimate of Miles of Unpaved Road

It would be advantageous to define additional study sub-areas for verification of road pavement status, both within the counties already observed in this pilot study and in counties representative of other parts of the state.

6.2.2. Estimate of Harvest VMT

It would be advantageous to refine the grower survey questions and to expand the survey area in order to address a larger population of growers, including additional counties. As illustrated by our encounter with a major crop in Fresno County (cotton) that did not fit in our defined crop categories, the crop categories also need to be modified. Finally, it would be interesting to relax our assumption that harvest vehicles haul crops at full capacity in order to presumably more fully capture harvest VMT.

6.2.3. Estimate of Non-Harvest VMT

The most urgent need in validating this model is the retrieval of additional traffic counter data. In accordance with this, collection of traffic counts in a wider variety of agricultural areas would be preferable. It would be valuable as well to have access to areas where unpaved roads join other unpaved roads instead of relying solely on data collected from paved-unpaved road intersections. This data would eliminate the sensitivity analysis and would substantially improve the model.

APPENDIX A: HARVEST SCHEDULES

The harvest schedules used in this analysis were compiled from growers' survey responses and were used to compute monthly harvest VMT (Section 3.2.2). The black bars indicate each grower's stated harvest period. "ID" indicates each grower's survey identification number. Numbers at the left edge of a black bar indicate the starting date reported for each grower's harvest; numbers at the right edge indicate the ending date reported for the harvest. "Traffic Allocation," at the bottom of each schedule, apportions the percentages of crop harvested to the months in which they were harvested. These percentages were then used in Equation 8 to determine monthly harvest estimates.

Sampled Harvest Period (Fruits)

Id	January		February		March		April		May		June		July		August		September		October		November		December		
2							15																		
3							12																		
6									3			20													
11																	8		10						
14																	10								
21									5		1														
38										18	5														
52										20	10														
62																									
64													10	30											
65															8	16									
67																20	10								
Traffic Allocation																									Sum
Days	0	0	0	0	0	0	5	30	54	90	61	35	21	31	23	13	24	30	25	16	0	0	0	0	458
%15	0.00	0.00	0.00	0.00	0.00	0.00	1.09	6.55	11.79	19.65	13.32	7.64	4.59	6.77	5.02	2.84	5.24	6.55	5.46	3.49	0.00	0.00	0.00	0.00	100.00
%M	0.00		0.00		0.00		7.64		31.44		20.96		11.35		7.86		11.79		8.95		0.00		0.00		100.00

Sampled Harvest Period (Nuts)

Id	January		February		March		April		May		June		July		August		September		October		November		December		
75															15										
77															15										
80																									
93																	15								
96																20									
97																			1						
99																25									
104																			10	20					
105																		20		18					
106																			1-3						
110																	15	17							
118																	15								
119																			6						
123																			1						
140																	15	17							
Traffic Allocation																									Sum
Days	0	0	0	0	0	0	0	0	0	0	0	0	0	0	17	67	109	151	132	8	0	0	0	0	484
%15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.51	13.84	22.52	31.20	27.27	1.65	0.00	0.00	0.00	0.00	100.00
%M	0.00		0.00		0.00		0.00		0.00		0.00		0.00		17.36		53.72		28.93		0.00		0.00		100.00

Id	January		February		March		April		May		June		July		August		September		October		November		December		
	Sampled Harvest Period (Misc.)																								
143									15	20															
176																									
187																			10	20					
188																			8						
189																			15		1				
Traffic Allocation																									Sum
Days	0	0	0	0	0	0	0	0	1	5	0	0	0	0	0	0	15	15	8	21	1	0	0	0	66
%15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.52	7.58	0.00	0.00	0.00	0.00	0.00	0.00	22.73	22.73	12.12	31.82	1.52	0.00	0.00	0.00	100.00
%M	0.00		0.00		0.00		0.00		9.09		0.00		0.00		0.00		45.45		43.94		1.52		0.00		100.00

Sampled Harvest Period (Vegetable)

Id	January		February		March		April		May		June		July		August		September		October		November		December		
211														20			1								
217																	15			29					
218								30																	
224																	15					20			
259																									
266			10						10																
267					5					20															
272									10		10														
273																			15	18					
277																	15			30					
Traffic Allocation																									Sum
Days	0	0	6	13	41	48	45	46	61	53	25	15	15	28	30	32	19	60	61	64	30	5	0	0	697
%15	0.00	0.00	0.86	1.87	5.88	6.89	6.46	6.60	8.75	7.60	3.59	2.15	2.15	4.02	4.30	4.59	2.73	8.61	8.75	9.18	4.30	0.72	0.00	0.00	100.00
%M	0.00		2.73		12.77		13.06		16.36		5.74		6.17		8.90		11.33		17.93		5.02		0.00		100.00

Sampled Harvest Period (Bean/Legume)

Id	January		February		March		April		May		June		July		August		September		October		November		December		
282																				30					
288																									
289							15																		
307							10													20					
310																									
312																				30					
314								28																	
316							15																		
317							15																		
318																									
341																									
343							15																		
349																			1						
350						31	3																		
	Traffic Allocation																								Sum
Days	0	0	0	0	0	1	43	138	165	192	180	180	180	192	180	192	180	180	166	35	0	0	0	0	2204
%15	0.00	0.00	0.00	0.00	0.00	0.05	1.95	6.26	7.49	8.71	8.17	8.17	8.17	8.71	8.17	8.71	8.17	8.17	7.53	1.59	0.00	0.00	0.00	0.00	100.00
%M	0.00		0.00		0.05		8.21		16.20		16.33		16.88		16.88		16.33		9.12		0.00		0.00		100.00

Sampled Harvest Period (Grains)

Id	January		February		March		April		May		June		July		August		September		October		November		December		
355																			15	20					
361																			10-15						
369																	1								
375									12																
381																									
408																	1-6								
410																	1-8								
414																									
417								20-21																	
418																								18	
	Traffic Allocation																								Sum
Days	15	16	15	13	15	16	15	17	34	48	30	30	30	32	30	16	15	0	22	21	15	0	0	14	459
%15	3.27	3.49	3.27	2.83	3.27	3.49	3.27	3.70	7.41	10.46	6.54	6.54	6.54	6.97	6.54	3.49	3.27	0.00	4.79	4.58	3.27	0.00	0.00	3.05	100.00
%M	6.75		6.10		6.75		6.97		17.86		13.07		13.51		10.02		3.27		9.37		3.27		3.05		100.00

Sampled Harvest Period (Tomato Process)

Id	January		February		March		April		May		June		July		August		September		October		November		December		
422																		20-23							
423																	15	18							
443																		25	10						
448																	15	21							
449															[redacted]										
457															[redacted]			25							
461															[redacted]										
462																	10	18							
465																	5-7								
466																	10	17							
475																		20	4						
477																	15	25							
479															15	20									
485																24	12								
Traffic Allocation																									Sum
Days	0	0	0	0	0	0	0	0	0	0	0	0	0	0	46	61	75	84	14	0	0	0	0	0	280
%15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	16.43	21.79	26.79	30.00	5.00	0.00	0.00	0.00	0.00	0.00	100.00
%M	0.00		0.00		0.00		0.00		0.00		0.00		0.00		38.21		56.79		5.00		0.00		0.00		100.00

Volume II

USING GIS TO ESTIMATE UNPAVED ROAD MILES AND VEHICLE ACTIVITY ON UNPAVED ROADS

Final Report, February 1999

by

Debbie Niemeier, Ph.D.
Principal Investigator
Department of Civil and Environmental Engineering

Institute of Transportation Studies
University of California, Davis

Research Assistants:

GIS Analysis

Thirayoot Limanond
Kishore Lakshminarayanan

Methodology Framework

Joel P. Franklin
Thirayoot Limanond
Jennifer E. Morey

Study Implementation

Jennifer E. Morey
Thirayoot Limanond

Submitted to:

California Air Resources Board
Sacramento, CA

TABLE OF CONTENTS

1. INTRODUCTION

This document describes the GIS analysis techniques used to extract data, perform spatial analysis, and display results for the purposes of estimating unpaved road miles and vehicle activity. It is the companion document to Volume I, "An Exploratory Study: A New Methodology for Estimating Unpaved Road Miles and Vehicle Activity on Unpaved Roads." Both Arc/INFO and ArcView software were used. Arc/INFO was used mostly to perform spatial analysis, while ArcView was used to extract and update data, and to display results. Without the use of the GIS and GIS databases, this research would be intensively time consuming if not infeasible.

Volume II is organized into four sections. Following the introduction, five main goals of using the GIS for this study are specified in Section 2. Section 3, "Data Collection and Preparation" describes the GIS coverages required for our GIS analysis. Section 4, "Methodologies" explains how the five main goals stated in Section 2 were implemented using the GIS.

2. OBJECTIVES

The GIS was used to achieve the following five main objectives:

i) Estimate the length of digitized unpaved roads and the percentages of the digitized unpaved roads that are actually unpaved

GIS provides an efficient means for rapidly inventorying a given analysis area's total miles of unpaved road. Digitized road coverages are frequently available from a number of sources, both proprietary and non-proprietary. However, because these coverages were often created without significant field verification, some previously unpaved roads may actually now be paved or out of service. Thus, we developed a methodology using GIS land use coverages to better refine estimates of total unpaved road mileage.

ii) Estimate land use factors and paved road density for each Township-Range-Section location

Both harvest and non-harvest models proposed for estimating vehicle activity on unpaved roads contain several variables including the percentages of agriculture, residential, commercial, and public/facility and the paved road density of each Township-Range-Section (TRS) location (See Section 3.2.1.b. and 3.2.3.b. of Vol. I). Here the GIS was used to extract the four land use factors of each TRS from the land use coverages, and extract the paved road density of each TRS from the road coverage. These data were then saved and transferred to statistical software in which the estimate of vehicle activity was performed.

iii) Specify unpaved roads that connect to paved roads

Traffic counts were required as a part of the unpaved road model development. Because we wanted to avoid intrusion to private properties, we measured vehicle counts only on unpaved roads that were connected to paved roads. It is likely that these roads have more traffic than do unpaved roads connected to unpaved roads. Therefore it is also likely that our traffic count data overestimate overall unpaved road traffic. To address this, we performed a sensitivity analysis that illustrates how much overall unpaved road traffic would be reduced if "unpaved-road-connected" unpaved road traffic was approximately 10%, 20%, …, 90% of traffic on "paved-road-connected" unpaved roads (Section 3.2.3.d., Volume I). In order to do this, we needed to specify unpaved roads that were connected to paved roads and those that were not. We used the GIS to make this distinction. A future study that measures the difference between the amounts of traffic on these two types of unpaved roads would provide better estimates of overall traffic on unpaved roads.

iv) Prepare the database for the estimate of non-harvest traffic

Here we discuss steps necessary for preparing the database for the estimate of non-harvest traffic. In this project non-harvest traffic was estimated using the data extracted from GIS road coverages. The GIS seems to be less efficient in producing estimations than do other statistical software, so we decided to extract the data from the road coverages, and transfer them to statistical software in order to estimate non-harvest traffic.

Before we extracted the data, it was necessary to divide all road segments by TRS location so that we could associate each road segment with the independent factors required by our models. In short, this objective involves two tasks: dividing road segments by TRS, and extracting the data from the road coverages.

v) Display the results

Since most of the data analysis, model development, mileage estimation, and traffic estimation were done using statistical software, the results are more difficult to understand and compare between areas. Displaying the results geographically provides clearer insight into the results. The GIS has excellent capabilities for displaying data in the form of coverages; it allows users to change legends in several ways according to the user's definitions. Because of this, we displayed the results of the estimations on GIS coverages.

3. DATA COLLECTION AND PREPARATION

This project focused on two counties of California: San Joaquin and Fresno. For each county, the coverages required for data analysis were:

- Land use coverage
- Road coverage
- Public Land Survey System (PLSS) coverage

3.1. Land use coverage

The land use coverages were obtained from the California Department of Water Resources (CDWR), via the California Air Research Board (CARB). Each coverage consists of tiny irregularly shaped polygons encompassing an entire county. Each polygon on the coverage represents a piece of land with homogeneous land use. The important attributes available in the coverage are polygon-ID, area and land use code. The land use code is an alphanumeric code that is associated with the classes or subclasses of land use as shown in Table 1 below.

Table 1. Land Use Classification

Land use class	Land use subclass
Agricultural	• Grain and Hay Crops (G) • Rice (R) • Field Crops (F) • Pasture (P) • Truck, Nursery and Berry Crops (T) • Deciduous Fruits and Nuts (D) • Citrus and Subtropical (C) • Vineyards (V) • Idle (I) • Semi-Agricultural & Incidental to Agriculture (S)
Urban	• Urban (U) • Residential (UR) • Commercial (UC) • Industrial (UI) • Urban Landscape (UL) • Vacant (UV)
Native	• Native Classes Unsegregated (NC) • Native Vegetation (NV) • Riparian Vegetation (NR) • Water Surface (NW) • Barren and Wasteland (NB)
Unclassified	• Not Surveyed (NS) • Entry Denied (E) • Outside (Z)

Most of the codes appearing on the coverages are further divided into sub-subclasses using a number following the subclass letter. For example, G1 (Barley), G2 (Wheat), G3 (Oats) and G6 (Miscellaneous and mixed grain and hay) are four sub-subclasses categorized under the same subclass (Grain and Hay Crops (G)). For a complete discussion of coding, please refer to the “Standard Land Use Legend, Department of Water Resources, State of California” (July 1993). Note that not all of the sub-subclasses listed in the “Standard” are present in every county. Appendix A shows a list of all land use codes that exist for San Joaquin and Fresno Counties.

In order to make the GIS process more efficiently we developed a numerical coding system to replace the existing alphanumeric coding system. The numeric codes that we assigned are listed in the last column of Appendix A in this report. For example, the numeric code “20” indicates the crop “Sugar beets” (F5) in the subclass of Field Crops (F).

Redefining the land use code was done using ArcView by adding a new field named ‘code’ to the land use coverage table. The commands `query` and `calculate` were used to acquire and assign a new numeric code to each individual sub-subclass. After recoding all of the land use codes, the coverage table was saved. The land use coverage then had a new field named ‘code,’ which contained numeric designations referring to land use.

3.2. Road coverage

The road coverages were received from the California Department of Transportation (Caltrans) via CARB. Each coverage consists of arcs of unequal lengths comprising the entire road network of a county. An arc is the fundamental unit of linear data, so each arc is assumed to be homogeneous throughout its entire length in terms of road classification and physical appearance. The main attributes available in the coverages are Arc-ID, length and road-classification code. The road-classification code is a two-digit numerical code associated to one of the road classes as shown in Table 2.

Table 2. Road Classification

Class	Numeric code	Description of Class
1	10	Primary route - Undivided
	11	Primary route - Divided by centerline
	12	Primary route - Divided, lanes separated
	13	Primary route - One way, other than divided highway
2	20	Secondary route - Undivided
	21	Secondary route - Divided by centerline
	22	Secondary route - Divided, lanes separated
	23	Secondary route - One way, other than divided highway
3	30	Thoroughfares - County roads, mostly paved
	31	Thoroughfares - County roads - divided by centerline
	32	Thoroughfares - County roads - divided, lanes separated
	33	Thoroughfares - County roads - one way
4	40	Residential roads, Unimproved and Unpaved roads
	43	Residential roads, Unimproved, Unpaved roads - one way
	49	Originally not coded; assumed to be class 4 based on neighboring arcs
5	50	Other than 4-wheel drive vehicle: ex : hiking trail
	51	Four wheel drive vehicle
	59	Originally not coded; assumed to be class 5 based on neighboring arcs
6	60	Own classification
7	70	USGS classification
9	90	Newly digitized roads or recoded as highway by Caltrans

The first digit refers to the class and the second digit gives more detailed specifications. For example, an arc with code 40 is either a residential, unimproved or unpaved road. An arc with code 43 is the same as code 40 but represents a one-way road segment. Note that there is no need to recode the classes because they are already numeric.

3.3. Public Land Survey System (PLSS) coverage

The Public Land Survey System (PLSS) coverages were provided by the Stephen P. Teale Data Center via the Department of Environmental Science and Policy at the University of California, Davis. Each coverage consists primarily of several small square polygons sized 1 x 1 square mile, with a few irregularly shaped polygons around the county boundary. The main attributes available from the coverages include polygon-ID, area, Township, Range and Section. Townships are roughly six-mile intervals, and are numbered north and south from the baseline of the reference point[1]. Likewise, Ranges are numbered east and west from the meridian of the reference point. Each Township-Range area is

[1] The reference point for both San Joaquin and Fresno counties is Mount Diablo.

further divided into sections, which are one square mile in dimension. Thus 36 sections make up one Township–Range polygon. Metadata of PLSS coverages is provided in Appendix B of this report.

Two manipulations were required to facilitate use of this database. First, we created a numeric code designating Township, Range and Section called 'TRS_code.' This coding is necessary in order to associate land use factors and paved road density with growers' fields for the harvest traffic estimation. It is also necessary in determining the locations of unpaved road segments for estimating non-harvest traffic. Second, we created a numeric code designating Township and Range, called 'SMS_code.' "SMS" is an abbreviation of 'thirty-six Square Mile Section' as mentioned in Vol. I. This code was used for the purpose of displaying the results of the analysis.

3.3.1 Create a single numeric code designating Township Range and Section

To facilitate subsequent analysis tasks, a numerical code was constructed in such a way that the code could denote Township, Range, and Section for each individual polygon. For the PLSS coverage of San Joaquin County all polygons have a one digit Township associated with either north or south (from 1N to 5N and from 1S to 5S), a one digit Range associated with east (from 4E to 9E), and a two-digit Section (from 01 to 36). A five-digit numerical code, the 'TRS_code,' was designed for San Joaquin County in which the first two digits refer to the Township, the third to Range, and the last two to the Section. The first digit of the code is either a 1 or 2; 1 denotes north while 2 denotes south. The second digit falls in the range of 1 to 5 based on the polygon's Township code. The third digit falls in the range of 4 to 9 depending on the polygon's Range[2] code. The forth and fifth digits fall in the range of 01 to 36 based on the polygon's Section code. For example, TRS designation 15724 refers to a polygon at Township 5N, Range 7E and Section 24.

It should be noted that typically the designed 5-digit numerical coding would be unique to a specific county. For example, all of the PLSS polygons in Fresno County have a two-digit Township associated with only south (from 10S to 35S), a two-digit Range associated with east (from 10E to 24E) and a two-digit Section (from 01 to 36). Here we can ignore the direction parts for both Township and Range because we already know that the entire Fresno area is southeast of the reference point.

[2] We ignored the direction of Range here because they are all east.

The numerical coding frame designed for Fresno County is six-digit. The first two digits refer to the Township code, the second two refer to the Range code, and the last two refer to Section code. For example, TRS designation 131415 infers a polygon at Township 13S, Range 14E and Section 15. The recoding process was performed using ArcView resulting in a PLSS coverage with a new attribute, called 'TRS_code.'

One difficulty that was encountered during formulation of the framework is that large portions in the west and southwest of the PLSS coverage of San Joaquin were not defined with Townships, Ranges, and Sections. It was necessary therefore to define Townships, Ranges, and Sections on all undefined areas before further analysis could be performed. The methods used to alter the PLSS coverage are described in Appendix C of this report. The PLSS coverage for Fresno County exhibited the same problem but for a much smaller area. The same procedure was also applied to this coverage.

3.3.2 Create a single numeric code designating Township and Range

This objective of this manipulation was to create a numerical coding and, subsequently, a coverage that could be used as the base coverage for displaying results. For the purpose of displaying results for specific Township-Range (36 square miles) areas, a numerical code was constructed to denote both Township and Range of each particular polygon. From the PLSS coverage of San Joaquin County, all polygons have a one digit Township associated with either north or south (from 1N to 5N and from 1S to 5S), and have a one digit Range associated with only east (from 4E to 9E). A three-digit numerical coding, called 'SMS_code,' was designed for San Joaquin County in which the first two digits refer to Township and the last to Range. The first digit of the constructed coding may be either 1 or 2; one denotes north and two denotes south. The second digit ranges from 1 to 5 based on the polygon's Township code. The third digit ranges from 4 to 9 depending on the polygon's Range code. For example, SMS designation 157 means that polygon is at Township 5N and Range 7E.

Again, it should be noted that, usually, the designed three-digit numerical SMS coding might not be applicable to other counties in California depending on the Township and Range codes a particular county contains. For example, all of the polygons in Fresno County have a two-digit Township associated with only south (from 10S to 35S) and have a two-digit Range associated with only east (from 10E to 24E). The numerical SMS code designed for Fresno County has four digits. The first two numbers refer to the Township code and the last two refer to the Range code. For example, SMS designation 1314 infers a polygon at Township 13S and Range 14E. The recoding process was again performed using ArcView resulting in a PLSS coverage with a new attributes called 'SMS_code.'

To create a base coverage to use for displaying the results, the PLSS coverage was modified.
All polygons in the PLSS coverage having the same SMS codes were aggregated into one Township-Range polygon. This was done using the command `dissolve` in Arc/INFO with 'SMS code' as the dissolve item. The modified PLSS coverage, called MPLSS, encompasses all of San Joaquin County and primarily consists of several medium-sized square polygons (36 square miles each), with a few irregularly shaped polygons along the county's boundary. The MPLSS was used to achieve Objective 5 (Displaying the results) in this report.

4. METHODOLOGIES

This section describes the methodologies for all of the GIS tasks performed to accomplish each of the five objectives listed in Section 2.

4.1. Estimate the length of digitized unpaved roads and the percentages of the digitized unpaved roads that are actually unpaved

The purpose of this objective is to estimate the length of digitized unpaved roads and the percentages of the digitized unpaved roads that are actually unpaved. The two coverages required for achieving this objective are the road coverage obtained from the California Department of Transportation (Caltrans) and the land use coverage obtained from the California Department of Water Resources (CDWR). In summary, the tasks involved here are as follows: First, in the land use coverage, all land use sub-subclasses were grouped into twelve land use categories. After overlaying the road coverage on the land use coverage, all of the Class 4 roads were specified as to whether or not they intersected urban areas; those that intersected with urban areas were assumed to be paved, while those that did not were assumed to be potentially unpaved. ArcView was then used to extract the data of the lengths of digitized unpaved roads in each land use category. Finally, based on the data from field-verifications, ArcView was used to extract the data to estimate, on different non-urban land use categories, the percentages of digitized unpaved road lengths that are actually unpaved. The length of digitized unpaved roads and the percentages of digitized unpaved road lengths that are actually unpaved, obtained here, were used to estimate the miles of unpaved roads in the entire county as describe in Section 3.1.1 of Vol. I. Each task is discussed in more detail as follows.

Task 1. Specifying categories of land use for each polygon in the land use coverage

In the CDWR land use coverage, land uses were categorized into too many specific sub-subclasses. In order to make data manageable, we grouped land uses into twelve main categories instead. Table 3 shows the twelve land use categories and their corresponding codes. The third column shows the classification of the different sub-subclass codes into each of these major land use categories.

Table 3. Specification of major land use categories

Land Use Class Code	Land Use Class	Land Use Code
0	Others	0
1	Fruits	1–17, 103–106
2	Grains	18 – 29, 46, 107-108
3	Idle	30-31, 109
4	Natural	32-40, 124
5	Pasture	41 – 45
6	Other Agriculture	50 – 54
7	Unknown	55 – 62
8	Vegetable Crops	65 – 80, 110 – 111
9	Urban	47 – 49, 63-64,81-100,112-123
10	Vine	101
11	Outside study area	102

In San Joaquin County, it was found that the land use classes 1, 2, 4, 5, 8, and 10 plus the urban class (9) cover more than 90 percent of the county area (see Section 2.2 of Vol. I). Hence for the following stages we focused only on the six[3] predominant land use categories: Fruits, Grains, Natural, Pasture, Vegetable, and Vines. The other six classes including the urban class were put into a single group, called 'Others.'

Task 2. Defining pavement status for road segments in the road coverage

The purpose of this task is to determine the pavement status for each road segment in the road coverage. This task was necessary because the road coverage obtained from Caltrans was not detailed enough to provide this information. Class 4 roads include not only unpaved roads, but residential and unimproved roads as well. Pavement status was determined in order to ensure that a road that was later denoted "unpaved" really was unpaved.

As mentioned before Class 4 roads include residential, unimproved and unpaved roads. Although it would be very difficult to eliminate unimproved roads, we can eliminate residential roads by adopting the following procedure. The road coverage was overlaid on the land use coverage. All Class 4 roads intersecting urban areas (Land use code 9) were then specified and assumed to be paved. The assumption here is that all those Class 4 roads that lie in urban areas are residential and hence likely to be paved. The

[3] The urban class was ignored here because it is irrelevant to unpaved roads according to the assumption mentioned previously.

entire identification and coding processes were performed using ArcView resulting in a road coverage with a paved-unpaved indicator added to each road segment.

Task 3. Computing lengths of digitized unpaved road for each land use category

The purpose of this task was to compute the total lengths of unpaved roads in each of the twelve land use categories listed in Table 3. A new attribute 'landuse_code' was created on the INFO table of the road coverage. The 'landuse_code' specifies a category of land use where the center of a particular road segment lies. This process was performed on ArcView by overlaying the road coverage on the land use coverage and using the command `select by theme`. After specifying land use categories to all road segments, lengths of digitized unpaved segments were summed by land use categories. The results are shown in Table 4.

Table 4. Digitized unpaved road meters

Crop Type	Land use Code	Measured Meters
Fruits	1	245,428.7
Grains	2	520,486.5
Natural	4	977,688.3
Pasture	5	300,577.1
Vegetable-crops	8	259,076.1
Vine	10	65,830.5
Others	0, 3, 6, 7, 9, 11	232,963.4
	Total	2,602,050.6

Task 4. Estimating the percentages of digitized unpaved roads that are actually unpaved

In order to obtain the percentage of digitized unpaved roads that were actually unpaved, three sample regions[4] were selected from each of the six predominant land use categories. The sizes of the sample regions were chosen such that they contained a sufficient number of unpaved road segments for field verification. The 17 sample regions initially selected are shown in Figure 1. All of the road segments in the selected regions were field inspected to determine if they were actually unpaved. Sample region 3 of the "Natural" category covers mostly private or government agency properties. Because of this, we were not able to obtain valid data in this region. Therefore, we finally used the field-verification data from 16 sample regions.

[4] It was our goal to select three sample regions for each of the six predominant land use categories, but only two regions could be selected for "Vine." No other Vine regions were suitable for field-verification.

In ArcView, the segments that are actually unpaved were specified and the lengths of these actual unpaved segments were summed up to determine the miles of actual unpaved roads for each sample region of each land use category. These figures were compared with the digitized unpaved road miles to estimate the percentages of digitized unpaved roads that are actually unpaved. Table 5 shows the results of this task. Finally, the results from *task 3* and *task 4* were processed together to estimate the miles of unpaved roads for all of San Joaquin County as discussed in Section 3.1 of Vol. I.

4.2. Estimate land use factors and paved road density for each Township-Range-Section location

The objective here is to estimate the percentages of agriculture, residential, commercial and public/facility land use and the paved road density for each Township-Range-Section (TRS) location. Table 6 shows how land use sub-subclasses were grouped into each of these four categories. Note that these categories are mutually exclusive, but not exhaustive.

Table 6. Land use classes and their codes

Land Use	Land use code identification
Agriculture	1 - 31, 41 – 49, 65 – 80, 101, 103 – 109, 111
Commercial	96, 118 – 122
Public/Facility	82 – 83, 88
Residential	84 – 87, 112

The three coverages needed for accomplishing this objective are the CDWR land use, the Caltrans road, and the Public Land Survey System (PLSS) coverages. The land use and the PLSS coverages were processed together to estimate the land use factors for each TRS, while the road and the PLSS coverages were processed together to estimate the paved road density.

To accomplish this objective, we started by converting the land use coverage into a grid-based coverage (simply called 'grid'). The percentages of agriculture land use of each cell of the grid were estimated in Step 2 and Step 3. Step 4 and Step 5 were mainly repeats of the previous steps, but with the purpose of determining the percentages of residential, commercial and public/facility land use and the paved road density in each cell. We then converted the PLSS coverage into a grid, called 'PLSSG,' in Step 6. The PLSSG coverage was then processed with each of the output grids obtained from Steps 3, 4, and 5 to estimate the percentages of the four different land uses and the paved road density for each TRS location. The output grids from Step 7 were prepared and extracted for the land use factors and the paved road density in Steps 8, 9 and 10. As the following discussion illustrates, performing a spatial analysis on grids is the most appropriate way to extract all these factors from the database coverages:

Step 1. Convert the land use coverage into a grid-based coverage and assign a land use code to each cell

The purpose of this step is to convert the land use polygon coverage to a grid. The fundamental unit of a grid is a cell, which in GIS parlance is a small square area of user defined dimensions. In this project, we specified the cell size to be 50 x 50 square meters, so the entire grid-based coverage for San Joaquin County contains approximately 4.5 million tiny cells. Each cell was assigned with a pre-specified attribute; the attribute used was the sub-subclass code. Note that for the case in which a cell covers two or more types of land use, the code of land use that occupies the majority of the cell is assigned to that cell. The land coverage was converted into a grid using the command `polygrid` in Arc/INFO.

Next we estimated the percentages of different types of land use: agriculture, residential, commercial and public/facility for each cell. It is necessary to estimate these percentages separately for each land use category, resulting in four output grids. Step 2 and Step 3 below show how the percentage of 'agriculture' land use for each cell was estimated. These two steps were repeated again to estimate the percentage of commercial, residential, and public/facility land use for each cell.

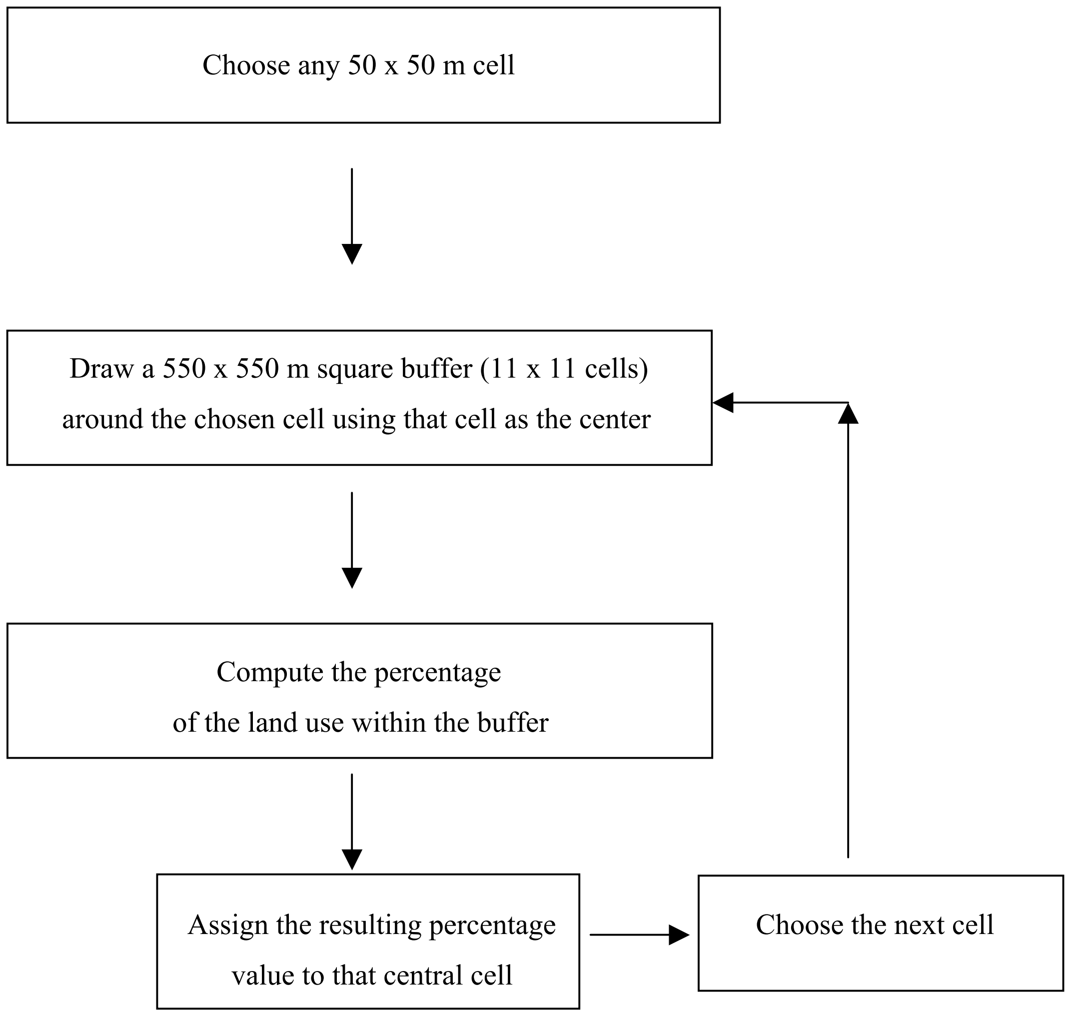
Step 2. Based on the land use code, test whether or not each cell contains agriculture land use

This step assigns an indicator, to each cell, showing whether it is used for agriculture. Those cells that are 'agricultural' (having land use codes corresponding to 'agriculture' category as mentioned in Table 6) were assigned the number 1; all others were assigned the number 0. The function `test` in the grid module of the GIS was used to evaluate and assign the indicator to each cell. Each cell of the output coverage from this step has a value of either 0 or 1 (implying 0 or 100 percent agriculture).

Step 3. Computing the percentages of agriculture land use of each cell

In the previous step the percentage value of each cell was assigned to be either 0 or 100 percent. In order to calculate the actual percentage of the agricultural land use, it was not possible to confine the computation within a single cell, since there is no variation within it. Therefore, a bigger square frame encompassing 11 x 11 cells (121 cells) was chosen around each cell. The average percentage of agricultural land use of the 121 cells were estimated and assigned to the center cell. This was accomplished using the function focalmean. The buffer that this function creates moves cell by cell. At each move, the function averages the agricultural percentages of all of the 11 x 11 cells within that square buffer and assigns the average value to the cell at the center. The flowchart for calculating and assigning percentages is depicted in Figure 2. The output grid 'Finalagri' would now have its cell values ranging from 0 to 100 percent.

Figure 2. Percent Land Use Computation



Step 4. Computing the percentages of residential, commercial and public/facility land use of each cell

The tasks outlined in Step 2 and Step 3 were performed for the other three predominant land use categories: residential, commercial and public/facility resulting in three additional output grids: 'Finalcom', 'Finalpfac' and 'Finalres,' respectively. The four output grids are summarized as follows:

a. Finalagri : Cells containing the percentage of agricultural area.

b. Finalcom : Cells containing the percentage of commercial area.

c. Finalpfac : Cells containing the percentage of public-facilities area.

d. Finalres : Cells containing the percentage of residential area.

Step 5. Computing the paved road density of each cell

A similar procedure was adopted to determine the percentage of paved road for each cell. It should be noted that although a road in reality is of linear dimension, it becomes an 'area' attribute when converted into a grid. The only difference between the road grid and the land use grid is in the way that cell values (*i.e.,* the binary indicator) are generated. The cell values of the resulting grid depend on two things: 1) if a road exists at that location, and 2) the type of road that exists. If the cell contains a paved road segment, then it takes the value of 1, otherwise it takes the value 0.

The steps we applied to the land use coverage for calculating the percentages of different land use were also applied to the road coverage in order to calculate the paved road density for each cell. The same functions `test` and `focalmean` were used, resulting in the fifth output grid:

e. Finalroad : Cells containing the percentage of paved roads.

Step 6. Converting PLSS coverage into a grid and assigning numeric TRS codes to each cell

In this step the Public Land Survey System (PLSS) coverage was transformed into a grid in which each cell contains its TRS code. In order to perform this conversion, the PLSS coverage already being prepared for an attribute of 'TRS code' is needed (see Section 3.3.1.). The command `polygrid` in Arc/INFO was used to convert this coverage into a grid, and 'TRS_code' was assigned to each cell. The cell size of this grid was set up to be 50 x 50 square meters. The output grid is called 'PLSSG.'

Step 7. Computing the percentages of land use categories and paved road density for each TRS location

The output grids from Steps 4, 5 and 6 were utilized to compute the percentages of different types of land use and the paved road densities for each TRS location. In the PLSSG coverage, the fundamental unit is a cell of size 50 x 50 square meters, whereas the fundamental unit of the PLSS coverage is a TRS section of 1 x 1 square mile dimensions. A TRS polygon (1 x 1 square mile) is much bigger than a cell (50 x 50 square meters) and hence a TRS polygon contains many cells within it. Other GIS functions were used to compute the average land use factors and the average paved road density for TRS polygons.

This task required the use of the grid coverages Finalagri, Finalres, Finalcom, Finalpfac, Finalroad and PLSSG. The command `zonalmean` in the grid module of Arc/INFO was used to determine the mean of the value from 'value_grid' (each of the first five grids mentions above) for those cells that share the same zones in 'zone_grid' (the PLSSG coverage). Again the process must be done separately to estimate each of land use factors and the paved road density. For example, using the command `zonalmean` with Finalagri as a 'value_grid,' and PLSSG as a 'zone_grid', gives an output grid showing the percentage of agriculture land use for each TRS polygon. This procedure was repeated for the other four 'value_grids.' Finally the following 5 grids were obtained:

- z_agri
- z_res
- z_com
- z_pfac
- z_road

Note that the output grids are still comprised of 50 x 50 meter^2 cells, but each cell now contains either the average percentage of a land use or the average paved road density of its corresponding TRS code. So neighbor cells located in the same TRS have the same value.

Step 8. Convert the output grids back to polygon coverages

The purpose of this step is to prepare the database for extracting data from the coverage. The five output grids and PLSSG were converted back to polygon coverages using the command `gridpoly` in Arc/INFO. Note that Arc/INFO usually can not perform the conversion for floating-point grids, so before the command `gridpoly` can be issued, each of the output grids above must be transformed into integer grids by using the command `int` in the grid module. Each integer grid can then be transformed to polygon coverages. Six output polygon coverages were obtained:

- Agripol
- Respol
- Commpol
- Pfacpol
- Roadpol
- Plsspol (The polygon version of PLSSG)

Step 9. Combine the coverages into a single coverage

For convenience in transferring and managing data, we decided to combine the five output coverages to a base coverage, PLSSPOL. The command `identity` in Arc/INFO was used to combine coverages one-by-one, starting from PLSSPOL and Agripol. The output was then combined with Commpol, and so on. The final output will be a PLSSPOL coverage that contains the percentage of agriculture, residential, commercial and public/facility land use and the paved road density of each TRS location.

Step 10. Load the data from PLSSPOL

The purpose of this step is to load data from PLSSPOL into a text file so that we can transfer the data into statistical software where the traffic estimations were generated. This step was done using the command `unload` in the table module in Arc/INFO. The feature attributes needed for traffic estimation are 'TRS_code', the percentages of agriculture, residential, commercial and public/facility land use, and the paved road density. After completing this step, a text file with all the information was transferred to statistical software for further analysis.

4.3. Specify unpaved roads that connect to paved roads

Specifying all unpaved roads that connect to paved roads by hand is tedious and time-consuming, especially when a geographic region has a complicated road network. Because of this, we decided to perform a GIS analysis using the command `buffer` in Arc/INFO to create buffer areas around all of the paved roads. Those unpaved segments that intersect the buffer areas were selected and specified as 'paved-roads-connected unpaved.' All of the other unpaved road segments were specified as 'unpaved-roads-connected unpaved.' The assumption used for this analysis is that all of the unpaved road segments that have any portion of their lengths within 100 meters of paved roads are paved-road-connected. To determine how each road segment should be categorized, the following steps were undertaken.

Step 1. Create a buffer area sized 100 meters around all of the paved roads

To create buffer areas around paved roads, but not unpaved roads requires the construction of an INFO table, 'Road.lut.' This table shows how we specified buffer distances for each road class. A 100 meter buffer around every paved road was created This included road Classes 1, 2, 3, 6, 7, and 9. No buffer was created around unpaved roads (classes 4 and 5). The content of 'Road.lut' is the following:

```
CLASS DIST
10    100
11    100
12    100
13    100
20    100
21    100
22    100
23    100
30    100
31    100
32    100
33    100
40    0
43    0
49    0
50    0
51    0
59    0
60    100
70    100
90    100
```

The command `buffer` was issued with the buffer_table ' road.lut.' The output coverage (buffer coverage) is a polygon coverage made up of a virtual 200-meter-wide paved road network (100-meter on each side) and several irregularly-shape polygons bounded by the virtual paved roads and the unpaved road arcs. The attribute 'Inside' of the output coverage can take values of either 1 or 100 where 100 denotes a 100-meter buffer polygon and 1 denotes those bounded by buffer polygons.

Step 2. Specify those unpaved roads that intersect with the paved buffered roads

To assign connector indicators, the areas that have the attribute 'Inside' equal to 100, on the buffer coverage, were selected. Then in the road coverage, only those segments that were unpaved were selected and the command `Select by Them...` was issued. Next, 'select features of active themes that `intersect` the selected features of `buffer coverage`' was chosen. On the road coverage table a new attribute called 'pavecon_idct' (abbreviated from a paved-connected indicator) was added and assigned all selected segments with 1. All other segments were assigned zero. The road coverage now had a new feature attribute, the "paved-connected" indicator.

4.4. Prepare the database for the estimate of non-harvest traffic

We needed to divide road segments so that each individual segment lies on only one Township-Range-Section location. Two coverages were required to accomplish this: the Caltrans road coverage and the Public Land Survey System (PLSS) coverage. Note that all segments in the road coverage, including both paved and unpaved roads, were processed together. Paved road segments were discarded later, after the database was transferred to the statistical software. The following two tasks were performed in order to accomplish this objective.

Task 1. Disaggregate road segments into shorter segments by TRS locations

When the road coverage was laid over the PLSS coverage, some road segments transected one or more Township-Range-Section (TRS) polygons. This task broke segments that lie across TRS polygons. Once this task was completed those segments overlaying more than one TRS polygon were subdivided into several shorter segments according to the number of TRS polygons they crossed.

In Arc/INFO the command `identity` with the line option can create intersected segments in the arc coverage (the road coverage) based on the intersect coverage (the PLSS coverage). The output coverage looks exactly the same as the road coverage, but contains more road segments. Each segment in the output coverage transects only one TRS polygon. The feature attributes of the output coverage will be the combination of the feature attributes from the road and the PLSS coverage.

Task 2. Save data into a database file for transferring into statistical software

The goal here is to save those feature attributes necessary for further analysis from the road coverage into a text file. The essential attributes are Segment ID, length, the unpaved road indicator (1-unpaved, 0-paved), land use code, the paved-road-connected indicator (1-connect, 0-not connect), and the Township-Range-Section code (TRS code). Note that the third, fourth, fifth, and sixth attributes are the additional attributes obtained from Task 2 of Section 4.1, Task 3 of Section 4.1, Step 2 of Section 4.3, and Task 1 of Section 4.4, respectively.

The command `unload` in the table module of Arc/INFO has a capability to write the records into an ASCII file. The output ASCII file contains all records of road segments including the six attributes mentioned above. The information is then available for transfer to statistical software.

4.5. Displaying the results

Once the results from the analysis were produced in statistical software (*e.g.,* SPSS) and saved as database files (.dbf), these files were transferred to ArcView. In Arcview, the database files were joined with the attribute table of the Modified Public Land Survey System coverage (MPLSS; Section 3.3.2). The results of the analysis were then displayed on ArcView.

The following three database files were transferred into ArcView for result display[5]:

1) harvest.dbf: this file contains the estimated harvest traffic for the county. It includes the total number of Growers, total acreage of agriculture land, estimated annual harvest vehicle miles travel (VMT), and estimated monthly harvest VMTs for each month of the year for each Township-Range designation (SMS_code).

2) nharvest.dbf: this file contains the estimated miles of unpaved roads and the estimated non-harvest traffic in the county. It includes the estimated miles of unpaved roads, the estimated annual non-harvest VMT, and the estimated monthly non-harvest VMTs for each Township-Range designation (SMS_code).

3) vmt.dbf: this file contains the estimated total traffic (harvest + non-harvest) on unpaved roads in the county including the total number of growers, the total acreage of agriculture land, the estimated miles of unpaved roads, the estimated total annual VMT on unpaved roads, the estimated monthly VMTs for each Township-Range (SMS_code).

To join the attribute table of the MPLSS coverage with each of these three files, the following steps needed to be employed. As an example, assume we are joining 'harvest.dbf' to the MPLSS coverage.

1. Open a view and a table of the MPLSS coverage.
2. Open 'harvest.dbf' on the Table window.
3. Highlight the attribute 'SMS_code' of 'harvest.dbf.'

---

[5] Users may alter the structures of the files, and may need more or less number of files depending on how much information is to be displayed.

4. Make the MPLSS table active, and highlight the attribute of 'SMS_code.'
5. Use the command `join`.

The data in 'harvest.dbf' will then be joined with the MPLSS attribute table based by the related item 'SMS code.' 'Harvest.dbf' can be displayed on the MPLSS view in several useful patterns depending on the users' desires. Perform the same procedure twice to join 'nharvest.dbf' and 'vmt.dbf' to the coverage.

Note that in using the command `join` on ArcView, the data files were virtually joined, so the current project needs to be saved. If it is not saved, all steps will have to be performed again the next time the information is needed.

An example of the graphics that can be displayed by the output coverage is shown in Figure 3. This figure illustrates the estimated annual unpaved road VMT for different regions of San Joaquin County. From this figure, we can perceive which areas have heavy unpaved road traffic and which areas do not.

APPENDIX A

APPENDIX A: LIST OF LAND USE

Alphanumeric Code	Description of land use	User-defined numeric code
C2	Lemons	1
C6	Olives	2
C7	Miscellaneous subtropical fruits	3
C8	Kiwis	4
D	Deciduous fruits and nuts	5
D1	Apples	6
D2	Apricots	7
D3	Cherries	8
D5	Peaches and Nectarines	9
D6	Pears	10
D7	Plums	11
D8	Prunes	12
D9	Figs	13
D10	Miscellaneous deciduous	14
D12	Almonds	15
D13	Walnuts	16
D14	Pistachios	17
F1	Cotton	18
F2	Safflower	19
F5	Sugar beets	20
F6	Corn	21
F7	Grain Sorghum	22
F8	Sudan	23

F10	Beans(dry)	24
F11	Miscellaneous Field	25
F12	Sunflowers	26
G	Grain and Hay crops	27
G3	Oats	28
G6	Miscellaneous and mixed grain and hay	29
I	Idle	30
I1	Land not cropped, but cropped within the past three years	31
NB	Barren and Wasteland	32
NB2	Mine trailing	33
NR	Riparian vegetation	34
NR1	Marsh lands, Tules and Sedges	35
NR2	Natural High water table meadow	36
NR3	Trees, Shrubs or stream side vegetation	37
NR5	Permanent Duck marsh, flooded during summer	38
NV	Native vegetation	39
NW	Water surface	40
P1	Alfalfa and alfalfa mixtures	41
P2	Clover	42
P3	Mixed pasture	43
P4	Native Pasture	44
P7	Turf farms	45
R	Rice	46
RC	Commercial area within a primary recreational area	47
RR	Residential	48
RT	Recreational vehicle and camp sites	49
S1	Farmsteads	50

S2	Livestock feedlots	51
S3	Dairies	52
S4	Poultry farms	53
S5	Cemeteries	54
S6	Unknown	55
S7	Unknown	56
S8	Unknown	57
S9	Unknown	58
S10	Unknown	59
S11	Unknown	60
S12	Unknown	61
S13	Unknown	62
SR1	Suburban residential(large % in lawns and high water use)	63
SR2	Suburban residential(large % in non-irrigated native plants and low water use)	64
T2	Asparagus	65
T3	Beans(green)	66
T4	Cole crops	67
T6	Carrots	68
T8	Lettuce	69
T9	Melons, Squash and Cucumber	70
T10	Onions and Garlic	71
T11	Peas	72
T12	Potatoes	73
T15	Tomatoes	74
T16	Flowers, nursery and Christmas tree farms	75
T18	Miscellaneous truck crops	76
T19	Bushberries	77

T20	Strawberries	78
T21	Peppers(Chilli, bell etc..)	79
T22	Broccoli	80
U	Urban	81
UC	Commercial	82
UC1	Offices, retailers	83
UC5	Institutions(having 24 hr resident popln)	84
UC6	Schools	85
UC7	Municipal auditoriums, theaters, churches, stadiums etc	86
UC8	Misc. high water use	87
UC12	Two storied offices , retailers	88
UI	Industrial	89
UI1	Manufacturing, assembling and general processing	90
UI2	Extractive industries (oil fields, quarries etc..)	91
UI3	Storage and distribution	92
UI11	Fruit and Vegetable canneries and general food processing	93
UI12	Misc. high water use	94
UI13	Sewage treatment plants	95
UR	Urban Residential	96
UV1	Unpaved areas	97
UV3	Railroad right of way	98
UV4	Paved areas	99
UV6	Airport runways	100
V	Vineyards	101
Z	Outside of study area	102
--	Others	0
C1	Grapefruit	103

C3	Oranges	104
C5	Avocados	105
C10	Eucalyptus	106
F	Field Crops	107
F9	Castor beans	108
I2	New lands being prepared for crop production	109
T13	Sweet potatoes	110
T17	Mixed (four or more)	111
UC4	Recreation vehicle parking, camp sites	112
UL	Urban Landscape	113
UL1	Lawn area – irrigated	114
UL2	Golf course – irrigated	115
UL4	Cemeteries – irrigated	116
UL5	Cemeteries – not irrigated	117
UR1	Residential (Single family dwelling with lot sizes greater than 1 acre up to 5 acres)	118
UR2	Residential (Single family dwelling with a density of 1 unit/acre up to 8+ units/acre)	119
UR3	Multiple family (apartments, condos, etc.)	120
UR11	Multiple family with water use factor of 0% to 25% of area irrigated	121
UR14	Multiple family with water use factor of 0% to 25% of area irrigated	122
UV	Vacant	123
NV1	Grass land	124

APPENDIX B

APPENDIX B: METADATA OF PLSA[6]

LIBRARY	:	COUNTY
LAYER NAME	:	PLS
COVERAGE NAME	:	PLSA

COVERAGE DESCRIPTION:

The 'PLS' layer is a polygon coverage depicting the Township, Range and Sections contained in the Public Land Survey System (PLSS) grid for the State of California. Townships are roughly six miles square and are numbered north and south from an established baseline. Likewise, ranges are numbered east and west from an established meridian. California uses three baseline/meridians, these being Humboldt, Mt. Diablo, and San Bernardino, abbreviated HB&M, MDB&M, and SBB&M. Township and Range values are combined in the redefined item TOWN-RANGE to facilitate use of the “dissolve” and “dropline” functions.

Many places in the State are not gridded into sections. Most of these cases involve Spanish and Mexican land-grant areas that were honored by the government of the United States when California became a State and were subsequently excluded from the section survey process. Names of land grants may be found under the item LANDGRANT. Other areas were not sectioned because of difficulties in surveying wetlands and mountainous terrain. These areas are identified in the item COMMENTS as ‘wetlands’ or ‘not sectioned.’

The PLS layer can be of help in defining position and scale on small-scale plots. It is of course irreplaceable if the user is locating other features by means of Township/Range/Section identifiers. There is also a centroid (point) coverage available that is not in the library. This represents each section as a point and carries all the township/range/section info as well as X and Y coordinates.

6 Source : Metadata was obtained along with the PLSS coverage from the Stephen P. Teale Data Center via the Department of Environmental Science and Policy at University of California, Davis.

VITAL STATISTICS:

Datum	:	NAD 27
Projection	:	Albers
Units	:	Meters
1st Std. Parallel	:	34 00 00 (34.0 degrees N)
2nd Std. Parallel	:	40 30 00 (40.5 degrees N)
Longitude of Origin	:	-120 00 00 (120.0 degrees W)
Latitude of Origin	:	00 00 00 (0.0 degrees)
False Easting (X shift)	:	0
False Northing (Y shift)	:	-4,000,000
Source	:	US Geological Survey
Source Media	:	Magnetic tape (digital file); mylar maps
Source Projection	:	Geographic (latitude/longitude)
Source Units	:	Degrees minutes seconds
Source Scale	:	1:100,000
Capture Method	:	Scanned/digitized
Conversion Software	:	ARC/INFO rev. 5.0.1
Data Structure	:	Vector

ARC/INFO Coverage Type	:	Polygon
ARC/INFO Precision	:	Single
ARC/INFO Tolerances	:	1 meter
Number of Features	:	146,151
Layer Size	:	74.904 MB
Data Updated	:	November 1993

(Coding errors corrected in 5 counties)

DATA DICTIONARY:

DATAFILE NAME	:	PLSA.PAT
RECORD LENGTH	:	138

COLUMN	ITEM NAME	WIDTH	OUTPUT	TYPE	`N.DEC
1	AREA	4	12	F	3
5	PERIMETER	4	12	F	3
9	PLSA#	4	5	B	-
13	PLSA-ID	4	5	B	-
17	SECTION	2	2	I	-
19	MERIDIAN	10	10	C	-
29	TOWNSHIP	5	5	C	-
34	RANGE	5	5	C	-
39	SOURCE	15	15	C	-
54	COMMENT	25	25	C	-
79	LANDGRANT	60	60	C	-
29	TOWN-RANGE	10	10	C	-

AREA	:	The area of the polygon in square coverage units.
PERIMETER	:	The length of the polygon perimeter of the polygon in coverage units.
PLSA#	:	The software-assigned unique integer identification number.
PLSA-ID	:	A user-assigned identification number.
SECTION	:	Section number (less than 36).
MERIDIAN	:	Name of the baseline and meridian.
TOWNSHIP	:	Township number and ordinal direction (N = north, S = south).
RANGE	:	Range number and ordinal direction (E=east, W=west).
SOURCE	:	Unused at this time.
COMMENT	:	Description of the polygon if not a surveyed section or landgrant.
LANDGRANT	:	Name of the landgrant, if any.
TOWN-RANGE	:	Concatenation of Township followed by Range.

DATA QUALITY ASSESSMENT:

The following are subjective comments regarding these data.
The layer is as complete as the USGS 100K quad sheets. The PLS coverage does not include 'projected' sections into land-grant, wetland, or unsectioned areas. The feature accuracy is good and attribute accuracy is very good. It also has all pertinent section information.

APPENDIX C

APPENDIX C: ALTERING THE PLSS COVERAGE FOR SAN JOAQUIN COUNTY

The PLSS coverage for San Joaquin County received from the Stephen P. Teale Data Center is incomplete. On the coverage, Townships, Ranges and Sections for approximately one-third of the county in the west and southwest regions were undefined. For further analysis, the coverage had to be altered so that the entire San Joaquin County was defined with the Township, Range and Sections.

The PLSS coverage of San Joaquin County was converted into a shapefile using the command "`convert to shapefile…`" in ArcView. Before start editing, set general snapping environment to ensure that the polygons that we are creating would be perfectly aligned with each other, i.e., no gaps or overlapping areas will be generated. The shapefile was edited by adding undefined PLSS 1-mile^2 polygons based on the alignments of the existing PLSS-defined polygons. The shapefile table was then opened to specify Township, Range and Section of the newly created polygons. Once the entire county area was completely defined, the edited shapefile was saved and converted back into coverage using the command `shapearc` in Arc/INFO. Finally, the command `clean` was issued to create the topology of the new coverage. The coverage was then ready to use.