Solicited Proposal

INVESTIGATION AND CHARACTERIZATION OF POLLUTION CONCENTRATIONS AND CONCENTRATION GRADIENTS IN WILMINGTON , CALIFORNIA, USING A MOBILE MEASUREMENT PLATFORM

Prepared for
California Air Resources Board

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STATEMENT OF SIGNIFICANCE

Widely-spaced monitoring stations in fixed locations have no capacity to characterize localized high concentrations and accompanying steep pollutant concentration gradients that can arise from specific stationary or mobile sources. Yet physical measurements, modeling studies, and epidemiological evidence continues to accumulate from all over the world that such high concentrations with sharp concentration gradients are critically important to characterize in order to accurately determine human exposures at the individual and sub-community levels, and that persons living within the sharp gradients of sources like busy roadways show significantly increased incidence of adverse health effects. The ARB is developing modeling approaches capable of assessing such pollutant concentration gradients at a fine resolution. For community-level localized assessments, ARB uses a combination of photochemical models to assess long-range regional transport and transformation of air pollutants, and local-scale models to assess direct transport of local pollutants to community receptors. ARB staff want to evaluate how well these models perform both individually and collectively when used to estimate cumulative air pollution impacts on a community such as Wilmington, CA. A second important ARB goal is to understand the relative importance of point sources versus local traffic versus transported regional background pollution at the local level.

Fortunately, new experimental approaches have become available that afford powerful capabilities for rapid investigation of air pollutant concentration gradients, especially those arising from vehicle emission impacts. Among the most powerful approaches is the use of a mobile platform equipped with state-of-the-art real-time and near real-time monitoring instruments that provide the necessary time resolution to identify high concentrations and sharp spatial gradients while traveling at normal vehicle speeds. The present study proposes to use such a mobile platform to generate critical data on vehicle and point source-related high concentrations and sharp pollutant gradients in Wilmington that can be used to address both of these important ARB goals.

ABSTRACT

The Wilmington, CA community is surrounded by some of the most heavily traveled freeways in southern California, includes the Alameda corridor, has several large refineries, and is located just north of the Ports of Los Angeles and Long Beach. Thus, Wilmington and its surrounding area constitutes arguably the most complex emission source scenario in California, and provides the potential for complex pollutant concentration gradients that cannot be readily identified by conventional monitoring approaches. Wilmington is also the focus of a major field study being developed by the ARB involving various measurement and modeling goals, including detailed characterization of vehicle and point source-related pollutant concentrations and gradients.

The overall objectives of this work are: to generate pollutant concentration grids for Wilmington, CA, in part to identify suitable locations for fixed site, passive monitors in the Wilmington “saturation” monitoring study; to investigate the identified locations of high concentrations and sharp concentration gradients in greater depth; to determine how such gradients are affected by key variables; and to obtain data relevant to resolving the relative importance of local point sources versus traffic-generated emissions versus transported regional background pollution.

In order to test our hypotheses, stated in section 1.4, and pursue the overall objectives stated in section 1.5, we will (1) Acquire a suitable non-polluting vehicle and outfit it with a set of real- and near real-time instruments capable of measuring key pollutants of interest which include CO, CO_2, NO_x, ultrafine particles, PM2.5, VOC, and black carbon; (2) Test and validate this mobile platform in a field study conducted in Sacramento, CA; (3) Conduct a pilot study in Wilmington using our mobile platform to generate a representative matrix of spatial pollutant concentrations and gradients; and (4) Conduct a main study consisting of mobile platform measurements in the warm and cool seasons in and around Wilmington, CA, investigating the identified locations of high pollution concentrations and sharp concentration gradients as a function of important variables such as traffic volume and composition, known stationary source emissions, meteorological factors, and weekday versus weekend influences.

1.0 INTRODUCTION AND BACKGROUND

1.1 Introduction

For many decades the standard approach for air monitoring in California and the U.S. consisted of a relatively limited number of fixed site monitoring stations placed across a given airshed, and focused primarily on the six criteria pollutants regulated under federal and state statutes. Within the past decade, however, it has been increasingly recognized that such widely-spaced monitoring stations in fixed locations have no capacity to characterize the localized high concentrations and steep pollutant concentration gradients that arise from specific stationary or mobile sources. Yet physical measurements, modeling studies and epidemiological evidence continues to accumulate from all over the world that such localized high concentrations and steep concentration gradients are critically important in determining human exposure at the individual and sub-community levels, and that persons living within the sharp gradients of sources like busy roadways show significantly increased incidence of adverse health effects.

Fortunately, new experimental approaches have become available, particularly in the past five years, that afford powerful capabilities for rapid investigation of air pollutant concentration gradients, especially those arising from vehicle emission impacts and point sources. Among the powerful and productive approaches is the use of a mobile platform equipped with state-of-the-art real-time monitoring instruments that provide the necessary time resolution to identify spatial gradients while traveling at normal vehicle speeds. In the work proposed below we describe how we will procure, instrument and apply such a platform concurrent with, and in support of, the Wilmington Saturation Monitoring Project, as well as to achieve other goals requiring spatially and temporally resolved measurements.

The Wilmington community (Figure 1) is surrounded by some of the most heavily traveled freeways in southern California, is home to multiple petroleum refineries and other industrial facilities, and is located just north of the Ports of Los Angeles and Long Beach. Many smaller industrial and commercial businesses are also located within the community. The Alameda Corridor runs through the eastern portion of the community. Thus, Wilmington and its surrounding area constitutes arguably the most complex emission source scenario in California, and provides the potential for complex pollutant concentration gradients and high exposure conditions that cannot be identified by conventional monitoring approaches.

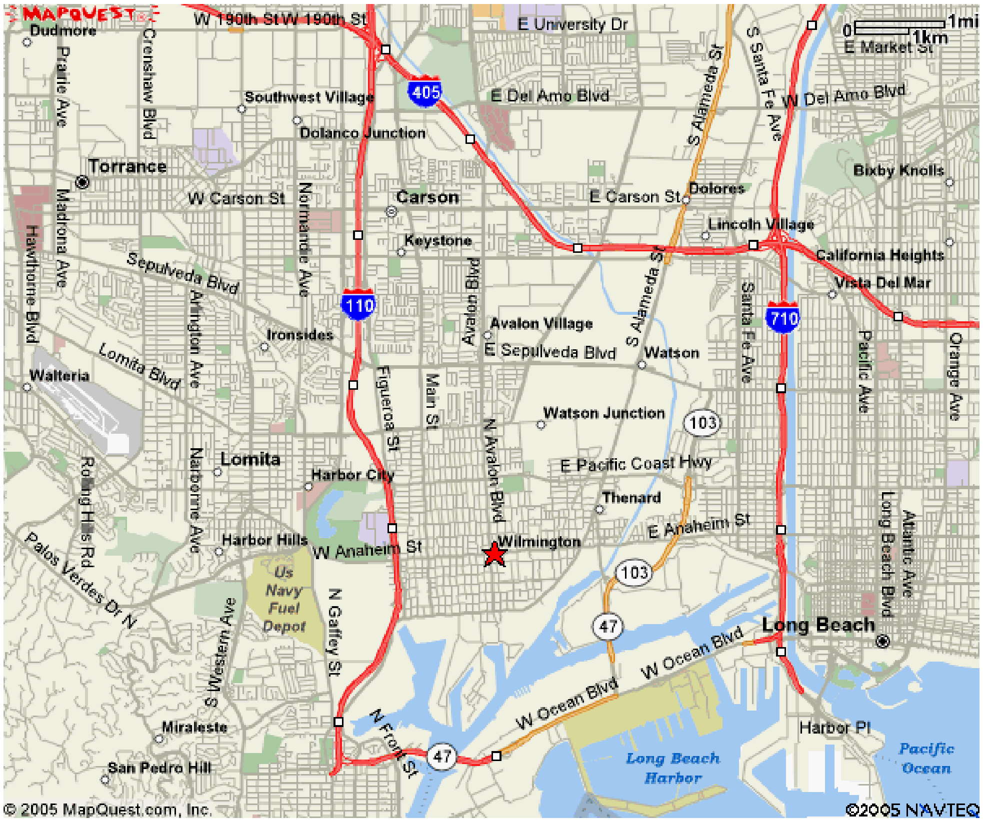

Figure 1. Wilmington Air Quality Study Modeling Domain

Wilmington is the focus of a major study being developed by ARB involving various measurement and modeling goals. Some of the objectives of this major ARB study include: (1) to complement the Pastor et al. (2004) project; (2) to measure micro-scale exposure to selected pollutants (PM and toxics) in Wilmington by collecting extensive spatial data and to identify hot spots and determine concentration gradients in the area from stationary sources (e.g., power plants, oil refineries, chemical plants), mobile sources (e.g., freeways) and area sources (e.g., docks); (3) to collect a subset of data of sufficient temporal resolution to allow comparison with previous near source modeling results; (4) to compare and contrast the ability of detailed emission inventories, modeling studies, and the data with sufficient temporal resolution (e.g., daily) to identify hot spots and to determine background air quality levels for power plant siting applications; (5) to demonstrate the usefulness of low-cost monitoring technologies (e.g., passive monitors).

Wilmington was chosen for this project because of the diversity and magnitude of air pollution sources and impacts in the community, and because the distribution of air pollution sources is much different than was encountered in the comprehensive measurement and modeling study conducted by ARB at Barrio Logan in San Diego. Although focused on Wilmington, the modeling domain for the present study will extend into surrounding communities including San Pedro, Harbor City, Carson, and Long Beach. The major pollutants of concern in this proposed study include CO, CO_2, NO_x, ultrafine particles, PM2.5, VOC, and black carbon.

1.2 Background

1.2.1 Modeling and Measurement Needs for Assessment of Localized Source Impacts

The ARB is continuing to develop modeling approaches capable of assessing pollutant concentration gradients at a fine resolution. For community-level localized assessments, ARB uses a combination of photochemical models to assess long-range regional transport and transformation of air pollutants, and local-scale models to assess direct transport of local pollutants to community receptors. One important goal of the new Wilmington monitoring project, including the study proposed here as well as the saturation monitoring project proposed to be conducted by Desert Research Institute (DRI), is to allow ARB staff to evaluate how well these models perform both individually and collectively when used to estimate cumulative air pollution impacts on the community. A second important goal is to determine the relative importance of point sources versus local traffic sources versus transported regional background pollution for a community such as Wilmington.

Wilmington was one of the six communities that were earlier chosen for preliminary monitoring as part of a larger statewide evaluation of the adequacy of the State's air quality monitoring network as required by the Children's Environment Health Protection Act (SB25). In 2001-2002, the ARB monitored for more than 50 toxic air pollutants at the Wilmington Park Elementary School. Monitoring results did not identify large differences for most pollutants between the Wilmington Park Elementary School and the permanent statewide monitoring site in Long Beach, located approximately 10 miles apart. However, local-scale modeling results indicated non-uniform spatial distribution of concentrations and strong spatial gradients: concentrations were much higher near the source, rapidly decreasing with distance. In addition, modeled levels of some pollutant concentrations were much lower than monitoring station observations for key vehicle-related pollutants such as CO, benzene and diesel PM (ARB, 2004).

1.2.2 Spatial Evaluation of Pollutant Concentrations Using Mobile Monitoring

The ARB has proposed to support innovative mobile-platform and fixed-site air monitoring in Wilmington to provide spatially and temporally resolved data to determine how various local sources impact community air. A central feature of this monitoring is the use of an electrically powered vehicle as a mobile platform, coordinated with fixed-site locations, to perform state-of-the-art, real-time measurements in urban communities where people are exposed to elevated levels of pollutants. Such vehicle-based measurements allow rapid and flexible spatial coverage of pollutant concentrations at the neighborhood and community scales.

1.2.3 Examples of Previous Mobile Platform Studies

Instrumented vehicles, or mobile platforms, began to be employed about 15 years ago, and have been used primarily for two main goals: (a) to measure pollutant levels on board vehicles (i.e., “in cabin” concentrations) under realistic driving conditions, and (b) to make mobile measurements of pollutant concentrations on roadways (rather than making measurements alongside roadways from fixed sites). These studies have focused on the influence of roadway concentrations per se as well as on the specific impacts of vehicles being followed closely by an instrumented platform. In the following sections we briefly cite examples of such studies, some of which represent antecedents to the study proposed here. This summary of earlier studies is meant to be illustrative and is not inclusive of all such studies.

A growing number of studies have characterized in-cabin conditions in passenger cars, school buses and transit buses. The earliest example of studies of this type in California was the pioneering study by Shikiya et al. (1989) in which they demonstrated for a passenger car that in-cabin concentrations of vehicle-related criteria pollutants such CO and NOx could be two to four times those measured at fixed site monitors. This work was confirmed by later passenger car studies showing that in-vehicle concentrations of CO and fuel-related VOCs were significantly higher than those in ambient air (Ptak and Fallon, 1994; Lawryk and Weisel, 1995; Jo and Park 1999; Alm et al., 1999).

In moderate to heavy traffic, vehicle occupants are primarily exposed to the exhaust of the vehicle being followed, as well as neighboring vehicles. A limited number of studies, most notably that of Rodes et al. (1998), have investigated the impacts of the exhaust location and type of vehicle on the exposure of occupants in the following vehicle. Fruin et al. (2004) analyzed the Rodes et al. data to show that for a typical California driver, one third to one half of their 24 hr exposure to diesel exhaust particulate came from the 6% of the time on average they spent in daily driving. As in the case of the earlier studies cited above, the Rodes et al. (1998) study also showed in general, VOC and CO concentrations measured inside or just outside their instrumented vehicles were four to ten times higher than those measured at the roadside or at the nearest ambient air stations.

To date half a dozen studies of pollutant concentrations aboard school buses, with a focus on diesel powered buses, have been conducted in North America (Brauer et al. 2000; Weir et al., 2002; Solomon et al., 2001; Wargo et al., 2002, Fitz et al. 2003; Maybee et al., 2004). Consistent with results from passenger car studies, these studies showed significantly elevated concentrations of diesel and gasoline exhaust pollutants relative to ambient air; large transient impacts of nearby diesel vehicles with windows open; and, in several of these studies, elevated concentrations above roadway concentrations primarily due to reentrainment of the bus's or vehicle's own emissions (Solomon et al., 2001; Wargo et al., 2002; Fitz et al., 2003; Chan et al., 1991; Fletcher and Saunders, 1994; Clifford et al., 1997).

A substantial number of studies have been conducted in Europe and Asia concerned with occupational exposure of transit bus and commercial truck drivers and some of these employed monitoring instruments aboard the buses or trucks. However, these studies are beyond the scope of the present project and will not be covered here.

Within the past five years there has been intense focus on measurement of ultrafine particles (UFP) since such particles are increasingly implicated in human health effects. To date, there have been relatively few measurements of UFP in vehicle cabins or on roadways, although seminal measurements conducted by Zhu et al. (2002a,b) adjacent to major freeways in Los Angeles, as well as studies by Hitchins et al. (2000) and Kittelson et al. (2004a) indicated high concentrations of UFP on roadways. Recently, several mobile monitoring studies that included UFP measurements have been conducted in Europe (Bukowiecki et al. 2002,a,b, 2003; Weijers et al. 2004; Pirjola et al. 2004) and in the eastern United States (Canagaratna et al. 2004; Kittelson et al. 2004a,b).

In California, Miguel and co-workers have conducted mobile monitoring using a passenger car equipped with a HEPA filter system, including measurement of in-cabin and roadway measurements for both freeways and surface streets (Miguel et al. 2005). In a study that serves as a direct antecedent for the present project, Westerdahl et al. (2005) utilized a non-polluting mobile platform to conduct measurements of UFP and associated pollutant concentrations on freeways and residential streets in Los Angeles with an emphasis on measurement of roadway concentrations. This study was unique in the United States in that it measured roadway concentrations during realistic driving; covered a wide range of traffic and diesel vehicle densities; used an electric vehicle; and employed a wide range of sophisticated instruments. The experience gained in that study will be directly useful in the design and conduct of the work proposed here.

1.2.4 Measurements of Vehicle-Related Concentration Gradients and Their Implications for Exposure

As noted earlier, studies such as those by Zhu et al. (2002a,b) have provided new physical evidence that vehicle-related pollutant concentrations spike dramatically near the downwind edges of major roadways but then fall off fairly rapidly with downwind distance (under conditions of steady, moderate winds) creating strong pollutant concentration gradients. Figure 2 shows data for black carbon, carbon monoxide and particle number obtained in by Zhu et al. (2002a) for the I-405 freeway.

As seen in Figure 2, pollutant concentrations were low on the upwind side of the freeway, increased dramatically at the freeway, and then fell to upwind levels within about 650 feet or so of the freeway on the downwind side. Similar results were found for the I-710 freeway (Zhu et al. 2002b). These results show clearly that locating homes, schools or other facilities within about 200 meters of freeways (and probably major arterial roads) can lead to elevated exposures to possibly deleterious particles and gases for “downwind” occupants. These physical measurements of vehicle-related pollutants also help to explain the health impacts observed in extensive epidemiological studies in Europe and the U.S. of subjects living, working or attending school near major roadways versus those spending their time well away from major roadways.

The implications of both these recent physical measurements of pollutants concentration gradients and the accumulating evidence of resulting health effects for people spending time in close proximity to major roadways are gaining the attention of regulators and legislators. Partly in response to these new findings, the California Legislature passed regulations preventing the siting of new schools in California any closer than 500 feet of a freeway, and attention is now being given to pre-school facilities concerning their proximity to major roadways.

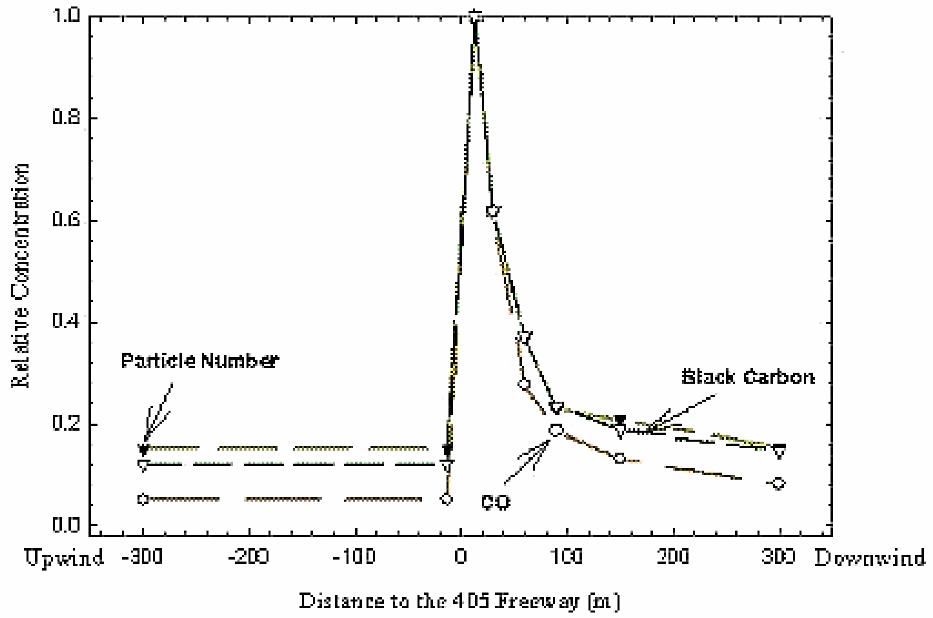

Figure 2. Relative concentrations of black carbon, CO and particle counts, upwind and downwind of the I-405 freeway in west Los Angeles (Zhu et al. 2002a).

The ARB recently sponsored a study session, and published a handbook, on the relationship between the location of sensitive receptors and air pollution sources. Agency officials and academic researchers have been increasingly interested in the broader societal implications of these health and physical measurement studies, in part because they raise local health disparity concerns that may be overlooked by the existing regional-scale air quality standards (AQS) "conformity" process. For instance, even though Southern California has met federal AQS for carbon monoxide and nitrogen dioxide on a regional basis, concentrations will be more elevated along heavily-traveled roadways leading to disproportionate exposure along such corridors.

Concerns that areas with high traffic densities are primarily minority and low-income have been raised by a study of traffic distribution in California that found non-white children were about three-to-four times more likely to live in areas with high traffic density than white children, and low-income children had a higher potential exposure to vehicle emissions (Gunier et al., 2003). Researchers at UCLA and elsewhere are attempting to quantify socioeconomic and demographic aspects of the health effects findings related to proximity to traffic, in particular identifying whether the search by low-income families for affordable housing in Los Angeles, and imposition of higher roadway densities in less affluent neighborhoods, lead to disproportionate vehicle pollution impacts on minority populations. Initial analyses show that while not necessarily benefiting from freeways, due to low vehicle ownership, minority and high poverty neighborhoods in Los Angeles bear over two times the traffic density of the rest of the southern California region (Houston et al., 2004).

1.3 Statement of the Problem

The relatively new concerns discussed above about localized vehicle and point source emission impacts characterized by localized high concentrations and sharp concentration gradients add to the recent concerns by ARB and others about disproportionate impacts of stationary sources (e.g. toxic release facilities) in minority communities as well as the potentially high exposures possible for all persons living close to sources such as busy roads. Although the SCAQMD and SCAG conduct sub-regional and socioeconomic assessments of air pollution, our growing understanding of the health risks for populations near major roadways and major point sources emphasizes the critical need to study the highly *localized* impacts of emission sources by mapping pollutant concentrations and concentration gradients over a much larger area. Clearly, extensive spatial monitoring is needed to identify locations of high concentration and sharp spatial gradients in the study area in support of the overall Wilmington project and to address other key scientific questions.

As discussed above, a critical and related question is how representative is one monitoring site in a study area such as the Wilmington community? While a single station of this kind cannot capture important spatial gradients in pollutant concentrations, it may be an adequate measure of regional contributions to local concentrations and may also be adequate over longer averaging periods, but evaluating this question also requires the kind of spatially and temporally resolved data the mobile platform can generate. At present there is little or no information on the range of spatial variability in vehicle-related or point source-related pollutants in this domain, or on the important variables affecting that spatial variability.

1.4. Hypotheses

Testable hypotheses for this project include the following:

1. There exist substantial spatial gradients in pollutant concentrations across a community such as Wilmington, CA., with statistically significant and important concentration differences between upwind and downwind locations for busy roadways and potentially for major point sources.
2. Vehicle-related pollutant concentration gradients can be predicted with reasonable accuracy (e.g., within a factor of two) as a function of measurable or previously-estimated variables such as average traffic volume, average fraction of diesel vehicles, adjustments to traffic volume or diesel fraction based on time of day or day of week, and meteorology.
3. A single monitoring station in a community such as Wilmington is incapable of providing any meaningful information concerning the potential for such spatial gradients, but does provide, over longer averaging periods, useful information about regionally-transported pollutant concentrations.
4. Regionally-transported pollution makes significant contributions to local pollutant concentrations, and these contributions can be estimated from lower confidence interval values from the concentrations distributions derived from spatially-resolved concentration grids.
5. Spatially-resolved concentrations grids determined from a mobile platform can be used to efficiently optimize the siting of stationary monitors, and reduce the required number of longer-term sampling devices such as passive samplers or canisters to produce a given spatial resolution.

1.5 Objectives

1.5.1 Overall Objectives

Our overall main objectives are to:

1. Generate a preliminary pollutant concentration map for Wilmington, CA. This concentration map will be helpful in finding suitable locations for fixed site, passive monitors in the "saturation" monitoring study.

2. Study identified gradients in greater depth to better characterize them, and determine how such localized high concentrations and sharp gradients are affected by key variables.
3. Obtain data relevant to resolving the relative importance of local point sources versus traffic-generated emissions versus transported regional background pollution.

1.5.2 Specific Objectives

In order to test our hypotheses and pursue our overall objectives we will carry out the following specific objectives:

1. Acquire a suitable non-polluting vehicle and outfit it with a set of real- and near real-time instruments capable of measuring the key vehicle-related pollutants of interest.
2. Test and validate this mobile platform in a field study conducted in Sacramento, CA.
3. Conduct a pilot study of spatially-resolved concentrations and concentration gradients in Wilmington using our mobile platform to generate a representative matrix of the Wilmington area, focusing on freeway underpasses and overpasses, as well as on a range of surface streets near refinery and port activities, to map concentrations.
4. Conduct a main study consisting of mobile platform measurements in the warm and cool seasons in and around Wilmington, CA. In this main study, we will investigate the identified pollution concentrations and gradients as a function of important variables, including traffic volume, traffic composition (i.e., fraction of heavy duty diesel vehicles), meteorological factors such as wind speed and direction, and weekday versus weekend influences on traffic volume and composition. Our measurements will be coordinated temporally and spatially with monitoring efforts by DRI, and will be complementary to their measurement program.

1.6 Project Oversight

Scott Fruin will act as the technical contract monitor for this project. Scott Fruin, Dane Westerdahl, Jorn Herner, and Alberto Ayala will provide technical guidance for the project. Kathleen Kozawa will work on site at the ARB's Sacramento facilities and will report to Scott Fruin and Alberto Ayala, Manager of the Emission Control Technology Research of ARB’s Research Division. Arthur Winer will participate with ARB staff in oversight of the experimental program, data analysis, and interpretation and especially the monitoring campaigns in southern California. Support for the field study phases of the project in Wilmington will be provided by Dr. Winer's laboratory in the UCLA School of Public Health.

2.0 APPROACH

2.1 Development of the Mobile Platform

2.1.1 Procurement of Vehicle

The vehicle to be employed in this study will be initially located in Sacramento, California. The design, construction, and validation of the instrument system in this vehicle will be conducted at this location.

The mobile sampling platform will be an electric Toyota RAV4 sub-SUV, if available. An electric vehicle (EV) is desired because of its non-polluting propulsion, and the RAV4 EV is capable of transporting substantial weight, and is easily modified to accommodate the instrument package (Westerdahl et al., 2005). This vehicle has a range of approximately 80 miles at speeds up to 70 miles per hour. Recharging of the RAV4 and the instrument battery pack during the southern California monitoring program will occur at the Particle Instrument Unit (PIU) of the Southern California Particle Center Supersite (SCPCS) located near downtown Los Angeles. The vehicle will be parked at this facility between sampling runs. A site at UCLA will be available as a backup location for parking and for recharging of the vehicle and instrument battery pack. If the RAV4 EV is not available, one alternative is a gasoline-powered RAV4, which has several of the same advantages as the RAV4 EV. In this case, the data analysis portion of the project will include an evaluation of possible RAV4 emissions impacts on the measurements during times the vehicle is stationary or slowly moving, and winds are from the vehicle exhaust pipe towards the instrument sampling manifold. Procedures to account for this phenomenon are discussed in Canagaratna et al. (2004) and Buckoweiki et al. (2002).

2.1.2 Selection of Measured Pollutants and Instruments

Table 1 presents a list of instruments from which the final instruments for this study will be selected. Table 1 also shows the parameters to be measured and the time resolution of the corresponding instrument. The instruments to be included on the mobile platform have been selected for their ability to report useful physical and chemical data at high time resolution, for their compact size and robust operation while on roadways, and for their low power consumption. Special emphasis will be placed on measurements of pollutants relating to emissions from diesel and gasoline powered vehicles.

Table 1. Potential Instruments and their Measurement Parameters

Instrument	**Measurement Parameter**	**Resolution**
TSI Portable CPC, model 3007, or, TSI Model 3785 CPC	UFP Count 10 nm-1um UFP Count 5-3000 nm	10 s 10 s
TSI Model 8520 DustTrak	PM2.5	10 s
TSI SMPS	UFP Size 3 nm	60 s
DMT Photoacoustic Spectrometer, or, Magee Scientific Aethalometer	Black Carbon	10 s 60 s
LI-COR, LI-820 CO_2 Gas Analyzer	CO_2	10 Hz
TSI Q-Trak Model 8554, or, Teledyne API 300e	CO	10 s (60 s response) 20 s
Teledyne-API NO_x analyzer, model 200e	NO, NO_x, NO_2	20 s
Synspec GC 855	VOC	
RAE Systems Model PGM-7240	VOC	5 s
Garmin GPSMAP 76CS	GPS	±3 meters
Cambell CSAT3, 3-D Sonic Anemometer	Local Wind Speed and Direction	10 Hz
Eurotherm Chessell Graphic DAQ Recorder	Data Logger	na
DCR-HC32 MiniDV Handycam®	Traffic Documentation	na
DryCal DC-lite, Model M	Gas Flow Calibrator	na

The pollutants selected for investigation in this study include ultra-fine particles (UFP), PM2.5, CO and CO_2, oxides of nitrogen and black carbon. Particulate matter (e.g. PM2.5) has been associated with mortality and a wide range of morbidity effects (Brunekreef, et al. 1995; Dockery, 2001; Dockery et al., 1993; Pope et al., 1995), while UFP are the subject of intense current investigation concerning their potential health effects (Hauser et al., 2001). Zhu et al (2002a,b) measured UFP, black carbon, and CO at various distances from two southern California freeways and demonstrated the existence of strong pollutant concentration gradients, with decreasing concentrations with increasing distance from the freeway. As discussed throughout this proposal, further characterization of these gradients by measuring UFP, CO, black carbon, nitrogen dioxide and other vehicle-related pollutants, is a central focus of the present work. However, such gradients were not found in earlier studies for PM2.5, and we recognize that PM2.5 is most properly classified as a regional "background" pollutant, with a large secondary formation contribution. Zhu et al. (2002a,b) and others have demonstrated that PM2.5 concentrations are not highly sensitive to line source emissions, in contrast to black carbon and CO concentrations or particle number. Thus, PM2.5 is not an obvious choice for measurement given that the focus of the present study is in large part on characterizing vehicle-related pollutant concentration gradients. However, PM2.5 is critically important from a regulatory standpoint and as noted above, PM 2.5 has been associated with both mortality and a wide range of morbidity effects. Thus, we feel that for completeness and to support the overall goals of the Wilmington study, including further model development and testing, PM2.5 should be measured in this work.

It is well established that CO_2, CO, black carbon, particulate-phase PAH and NO_x are associated with either diesel or gasoline vehicle exhaust, or both. Westerdahl et al. (2005) measured UFP and associated pollutants such as NOx and black carbon on southern California roads and freeways and found that average concentrations of UFP varied by location, road type and truck traffic volumes. Real-time measurements of black carbon and NOx were highly correlation with UFP number. Measurements of in-cabin CO_2 correlated reasonably well with UFP concentrations.

CO_2 concentration measurements will also serve to identify periods when our test vehicle is in its own exhaust plume (if a gasoline powered RAV 4 is employed), or the plume of another vehicle during mobile testing. CO emissions occur primarily from gasoline-powered vehicles and these measurements can be used, along with CO_2 and NOx values to help distinguish between gasoline and diesel vehicle influences (Westerdahl et al., 2005; Canagaratna et al., 2004; Buckoweiki et al., (2002).

2.1.3 Measurement Methods

2.1.3.1 Ultrafine Particles

The TSI Condensation Particle Counter Model 3007 is capable of measuring particle counts in the size range from 10 nm to 1 um. This instrument draws the aerosol sample continuously through a heated saturator, where alcohol is vaporized and diffuses into the sample stream. This mixture of aerosols passes into a cooled condenser where the alcohol becomes supersaturated. Particles present in the aerosol sample stream serve as condensation sites in the alcohol vapor, causing the particles to grow quickly into alcohol droplets. These droplets pass through an optical detector where they can be counted.

An alternative is to use a TSI Model 3785, water-based CPC. This CPC uses water instead of alcohol as the working fluid. It can detect particles down to 5 nm over a concentration range of $0\text{-}10^7$ particles/cm^3.

If available, ultrafine particle size distribution will be measured with a TSI SMPS System. This system consists of two components, a differential mobility analyzer (DMA) and a condensation particle counter (TSI Model 3025 CPC). Particles are separated according to their size (as determined by electrical mobility) by applying a variable voltage potential to the DMA. As charged particles pass through the DMA those with a narrow range of electrical mobility pass through a slit in the DMA to the CPC. The classifier unit controls the voltage ramping to the DMA and times when particles of given size are present at the CPC for counting. The model 3025 CPC is capable of detecting particles as small as 3 nm.

2.1.3.2 PM2.5 Mass

PM2.5 measurements will be made using a Thermo Systems Inc. Model 8520 DustTrak Aerosol Monitor. The DustTrak is a nephelometer that senses particle scattering of a laser beam and converts signals into a particle mass reading. Impactors will be used to perform the necessary size cuts. The PM concentration circumventing the impactor is determined by measuring the intensity of the 90° scattering of light from a laser diode. The instrument sample flow rate is 1.7 L/min. The averaging time is adjustable from 1 to 60 seconds, and an averaging time of 1 second will be used. The instruments are calibrated at the factory with Arizona road dust (NIST SRM 8632).

Our experience with this instrument during our previous school bus study (Fitz et al., 2003; Sabin et al., 2005) paralleled that of other investigators (Ramachandran et al., 2000; Yanosky et al., 2002; Chung et al., 2001). In particular, the greatest utility of the DustTrak is to obtain relative measurements of PM2.5 with high time resolution, rather than rely on this instrument for absolute PM2.5 mass. Instruments based on other methods such as beta attenuation (BAM monitors) or tapered element oscillation (TEOM monitors) do not have adequate time resolution for real-time measurements, although, if available, they may be used to provide site-specific calibrations for the DustTrak.

2.1.3.3 Black Carbon

Black carbon concentrations will be measured using one of two instruments: either a Magee Scientific aethalometer, or a photoacoustic spectrometer (Droplett Measurement Technologies). Both are real-time instruments.

The aethalometer draws sample air through a 0.5 cm^2 spot on a quartz fiber filter tape. Infrared light at 880 nm is transmitted through the quartz tape and detected on the back side of the tape using photodetectors (one detector senses the light transmitted through the spot where the air was drawn through and the second detected light transmitted though an unused section of tape in order to correct for changes in the light source intensity and changes in the tape characteristics). Decreases in the amount of light transmitted through the spot on the quartz tape are proportional to the amount of elemental carbon and "heavy" organic molecules collected. The instrument's response to the change in light transmittance is reported as "black carbon" (BC). The instrument's sample flow rate is maintained using mass flow controllers. The concentration of BC in units of mass of BC per volume of air (e.g. "ug/m^3") is determined by the instrument from the flow rate and change in light transmittance data. When the light transmittance through the collection spot on the quartz filter decreases by seventy-five percent, the quartz tape automatically advances to a fresh section of filter. Each time the filter tape automatically advances, the instrument recalibrates for approximately one minute prior to restarting sampling.

The photoacoustic spectrometer is another instrument that may be used to detect and quantify black carbon. The air sample is drawn into a chamber (acoustic resonator) where it is exposed to electromagnetic energy from a laser. The aerosol in the chamber absorbs the laser light energy and as the aerosol rapidly cools creates a pressure disturbance. This disturbance is amplified in the chamber and measured by a microphone as an acoustic signal. By tuning the laser to the resonance frequency of the compound of interest, in this case, black carbon, the sound pressure associated with aerosol light absorption can be used as a measure of black carbon mass. This instrument has a faster response and is more sensitive than the aethalometer, although as a new instrument it has not been as extensively used in mobile operations to date.

2.1.3.4 Oxides of Nitrogen

An API-Teledyne Model 200e instrument will be used to measure oxides of nitrogen. This device utilizes chemiluminesence to detect nitric oxide (NO). Other oxides of nitrogen (e.g. NO_2) are converted to NO for measurement. The instrument reports NO, total oxides of nitrogen (NOx), and calculates nitrogen dioxide by subtracting NO values from NOx. The Model 200e unit is an analyzer designed for routine ambient air monitoring applications that was shown by Westerdahl et al. (2005) to perform well in mobile operations

2.1.3.5 Carbon Dioxide, Carbon Monoxide

Carbon dioxide (CO_2) will be measured with a LI-COR CO_2 Gas Analyzer, Model LI-820. This instrument uses an absolute, non-dispersive, infrared (NIDR) gas analyzer based on a single path, dual wavelength, infrared detection subsystem. CO_2 measurement is a function of the absorption of IR energy as it travels through an optical path. The concentration measurements are based on the difference in ratio of IR absorption between the sample signal and reference signal. This instrument has an accuracy of between 2.5% using a 14 cm optical bench and 4% using a 5 cm optical bench. Output is provided in a digital format through an RS-232 interface.

CO will be measured with a TSI Q-Trak Model 8554 monitor. This small, portable unit uses an electrochemical cell to measure CO, and also records relative humidity and temperature. Data will be recorded at 10-second time resolution; however the response time of the CO channel is fairly slow, approximately 60 seconds. An alternate device is the API model 300e, an EPA approved CO monitor that will be altered to improve time resolution to approximately 20 seconds and to reduce power consumption.

2.1.3.6 Total VOC

A RAE Systems Model PGM-7240 (ppbRAE) portable PID monitor will be used to continuously monitor VOC levels. The monitor is equipped with a 10.6 eV photoionization (PID) detector and responds to certain organic and inorganic gases that have an ionization potential of less than 10.6 eV. These include aromatic hydrocarbons, olefins, and higher molecular weight alkanes. Lighter hydrocarbons such as methane, ethane, and propane or acetylene, formaldehyde or methanol are not detected. The monitor has a < 5-second response and lower detection limit of 1 ppb. Sample air is drawn through the instrument’s reaction chamber where it is continuously irradiated with high energy ultraviolet light. Compounds present that have a lower ionization potential than that of the irradiation energy (10.6 electron volts) are ionized. The ions formed are collected in an electrical field, producing an ion current that is proportional to total compound concentration.

2.1.3.7 VOC Speciation

A Synspec GC 855 gas chromatograph will be used for speciation of VOCs during our mobile monitoring. The sample of air is drawn into the instrument via a pump with a capacity of 1.5 L/min. The instrument works semi-continuously in two steps. The first step is the flushing of the probe-tubing by drawing sample gas through it with the pump. Second, the pump is switched off and with an indirect piston system, a volume of 18.5 ml GC855 sample gas is preconcentrated on a Tenax® or Carbograph column. This procedure can be repeated until enough material has been sampled. The preconcentration tube is purged with carrier gas to remove oxygen and water if desired. The sample is desorbed from the preconcentration-tube by heating the tube, while flushing it with carrier gas, and is sent through a separation column. The detection limit for the PID is 0.05 for benzene and the instrument has a range of 0-500 ppm for packed columns and 0-10 ppm for capillary columns.

2.1.4 Other Measurements

2.1.4.1 Meteorological Data

Local meteorological data conditions will be collected on-board the platform with a Campbell Scientific CSAT3 sonic anemometer. This instrument transmits three component (u, v and w) wind velocities and virtual temperature up to sixty times per second (60 Hertz). The sonic anemometer electronics conditions these signals (internal averaging) and outputs one-minute averaged data. For fast response, a fine wire thermocouple will be utilized. Measurement resolution for both the x and y directions is 1 mm s^{-1} rms and 0.5 mm s^{-1} for the z direction (values are for instantaneous measurements made on a constant signal). The operating range for this instrument is between -30° to $+50^{\circ}$ C, winds speeds below 30 m s^{-1}, and wind angles between $\pm 170^{\circ}$.

These measurements will be collected during the test runs by stopping for several minutes during runs to capture meteorological conditions at that particular location and time. Data from stationary monitoring stations will be used to supplement these data.

2.1.4.2 Verification of Vehicle Location using GPS

Vehicle location and speed will be determined with a Garmin GPSMAP 76CS global positioning system with a Wide Area Augmentation System (WAAS) corrections system. The system provides position accuracy of about 2-3 m and velocity accuracy of 0.05 m s^{-1} while moving at steady state. The GPS has a 12 parallel channel receiver to continuously track and use data from up to twelve satellites. The WAAS system is a broadcasted "signal integrity" signal that is determined by fixed ground-based reference stations. The GPS uses the WAAS correction information to increase the accuracy of the positioning information. In addition to horizontal position (e.g. latitude and longitude or UTM coordinates), the corrected GPS system also provides elevation and velocity data. These data will be displayed on a 256 color TFT display on the GPS and will be output digitally (RS-232) for logging along with the air quality data on the data logger.

The GPS unit will also be used as a time reference during this study. The clocks on all other devices will be set to the GPS time on a daily basis

2.1.4.3 Traffic Documentation

A Sony DCR-HC32 MiniDV Handycam® video camera will be mounted at the front of the vehicle to record traffic conditions in the lane in which the vehicle is traveling during all measurement periods, as well as the adjacent lanes. This camera has an IEEE 1394 Interface, and 500 lines of horizontal resolution. The camera will be set to a wide angle to view as much of the scene as possible. The camera includes a "time stamp" feature for adding date and time information to the video. The video camera will also serve to help identify emission sources and serve as an oral record of driver observations. The clock in the video camera will be synchronized with the GPS master clock time prior to each run.

2.1.4.4 Calibrations

Flow measurements will be made several times each week with a NIST traceable rotometer or a DryCal DC-lite flow meter. The DryCal DC-lite Model ML, has a flow range of 100 ml/min to 7 L/min, with an accuracy of ±1%.

The API NOx and API 300e CO analyzers will be connected to the calibrator system of the Particle Instrumentation Unit and will be challenged with zero and span gases at least twice weekly. The TSI Q-Traks will be calibrated at the start and end of the study with a series of four concentrations of CO generated from NIST traceable standards by MLD staff.

Zero and leak checks will be made on a weekly basis for the CPC, DusTrak, and other instruments. All instruments and data logging devices will be synchronized to the GPS clock.

2.1.5 Data Logger

A Eurotherm Chessell 5100V graphic data acquisition recorder will be used for data collection. The 5100V has a 5.5" color, 1/4 VGA TFT touch screen display, up to 12 input channels with a 125ms total sample rate, and 12 relay outputs. Universal input channels accept thermocouples, 2/3-wire RTD's, DC mA (w/shunt), DC millivolts and volts (-20 to +100), potentiometer and contact closure. Each channel is individually isolated channel-to-channel, channel-to-electronic common, and channel-to-ground (all 300V RMS).

The 12 input channels can be configured to be updated using Ethernet or Serial Modbus (no input channel hardware is required) and the 36 math channels can similarly be configured for a total of 48 points.

The 5100V has 8 MB of internal Flash memory for secure, short term, data storage and has a removable PC Flash Card slot accessible from the front. Data stored within the internal memory can be archived to the Flash card (or floppy) on demand or at preset intervals. The 5100V provides an indication of how long its internal memory and that of the removable media installed will last according to the configuration of the recorder. Data is stored in a tamper-proof binary format that can be used for secure, long term records.

2.1.6 Instrument Packaging and Power Supply

Instruments will be powered by a 2-kW/115-V inverter connected to sealed lead-acid batteries, providing for up to 6 hours of continuous instrument operation.

2.2 Application of Mobile Platform

2.2.1 Pilot Studies

2.2.1.1 Pilot Study I: Testing and Validation of Mobile Platform in Sacramento

The purpose of this pilot study is to conduct preliminary mobile monitoring test runs in the Sacramento metropolitan area. These tests will serve to validate QA/QC procedures for the instruments described in Section 2.1, to test instrument function in an in-vehicle setting and establish their measurement capabilities, to test time synchronization and data downloading procedures, and to diagnose and correct any malfunctions. The basic test route in Sacramento will be a representative driving matrix, including major and minor arterials, residential streets, and freeway segments.

Data from this pilot study will be evaluated prior to conducting a second pilot study in southern California. If necessary, modifications will be made to the vehicle and instrument package prior to moving the vehicle to the Wilmington area.

2.2.1.2 Pilot Study II: Investigation of Pollution Concentrations and Gradients Over a Wide Grid in Wilmington, CA

Once the mobile platform procedures and functions are shown to be satisfactory, preliminary mobile monitoring runs will be conducted in Wilmington, CA. The Wilmington area includes three major southern California freeways (I-405, I-710, and I-110) and the Ports of Los Angeles and Long Beach (see Figure 1). The pilot study grid route will be chosen based on careful study of freeway/surface street systems and the location of ports and refineries, and will include both Wilmington and portions of the surrounding communities.

The Wilmington pilot study presents an opportunity to optimize vehicle route selection, speed of driving, etc. and to observe the relative importance of various sources as well as the influence of factors such as weather conditions and traffic volumes. The test route will include many transects upwind and downwind of freeways such as the I-710, and busy arterials, as well as locations near the ports and refineries. Although we expect such locations to exhibit strong pollutant concentration gradients, we need to verify the relative importance of each source type. Various vehicle speeds under various wind conditions will be driven to determine the most appropriate speed and grid density for optimal gradient measurement. This evaluation is necessary in light of the inherent trade-off between good spatial coverage of a large area and the desire for a complete set of grid measurements to be taken under relatively constant meteorological and traffic conditions, both of which vary by time of day as discussed in more detail below.

The pilot study will also evaluate the effect of other nearby vehicles as possible interferences to measurement of “underlying” grid concentrations; earlier studies (e.g. Fruin et al. 2004) have shown that other vehicles traveling in the same direction can strongly affect the on-road concentrations measured by a mobile platform, particularly if the other vehicles are directly followed, or if they are high emitters. For example, other vehicles on the transect road during measurement of the downwind pollutant gradients from a freeway can interfere with measurements by superimposing their own emissions on the freeway concentrations. Special precautions may be necessary to reduce the effects of other vehicles, such as relying on measurements during off-peak hours, emphasizing streets with little traffic, and/or attempting to stay in upwind lane position. It may also be necessary to use data selection processes such as eliminating those readings accompanied by high CO_2 concentrations indicating direct vehicle plume impacts, or normalizing measurements for CO_2 or other co-pollutants.

For each run, pollution gradient maps will be produced. This will be made available to investigators in the Wilmington Saturation Monitoring Project to help optimize the placement of the fixed-site passive samplers.

2.2.2 Main Study: Wilmington

2.2.2.1 Detailed Investigation of Pollution Concentrations and Gradients as a Function of Important Variables

Once pollution concentrations and gradients in Wilmington are mapped in the second pilot study, we will use the resulting data to finalize the design of the main study. A principal goal of the main study will be to examine localized high concentrations and sharp concentration gradients as a function of the key variables described below. The main study will be conducted in the cool and warm season, and will consist of several weeks of data collection in each season.

2.2.2.1.1 Meteorology

The location and magnitude of a pollution concentration gradient, from either stationary point sources or vehicle line sources, depends on both wind speed and wind direction. Previous studies have demonstrated the importance of wind speed and direction in the characterization of particulate number with increasing distance from a line source when the wind was toward or away from the sampling location (Hitchins et al., 2000; Zhu et al., 2002a,b).

The meteorology of southern California is well characterized and varies diurnally as well as by season. We will exploit our detailed knowledge of meteorology in the Wilmington area, as well as our real-time measurements of wind speed and direction, to investigate the effects of meteorology on vehicle-related and point source-related pollution concentration gradients as discussed below.

Investigation of seasonal variations in meteorology is important and, as noted earlier, two testing periods are planned over the course of the study: one in the winter and another in the summer. These cool and warm season monitoring periods will capture the range of seasonal variation throughout the year, and will also coincide with other monitoring efforts during the overall Wilmington study. The warm season is characterized by calm mornings (little or no wind), followed by on-shore flow conditions and higher wind speeds in the afternoon. Little to no rain occurs during the warm season and clear skies predominate. The cool season is characterized by stronger meteorological events (e.g. the passage of storm fronts) and includes more variable wind conditions. In summary, meteorological conditions will have a significant impact on the presence of pollution concentration gradients near freeways, major arterials, point sources, or other sources and therefore will be a significant variable in this study.

2.2.2.1.2 Monitoring Periods

Time of day is expected to be another significant variable, especially affecting vehicle-related pollutant concentration gradients due to strong temporal variations in traffic densities and meteorology as discussed in the preceding sections. Daily monitoring will be split into three testing periods: early to mid-morning, mid-morning to late-morning, and mid-to-late afternoon. The purpose of three distinct testing periods is to (a) capture a wide range of traffic volumes ranging from relatively light traffic in the late morning, to heavy congestion during morning and afternoon "rush hours;" and (b) capture meteorological patterns ranging from little to no wind in the 6-9 am period, to light but well defined wind flow in the late morning, to strong on-shore flow (in the warm season). We hypothesize that pollution gradients from major line sources such as freeways and large surface arterials will vary substantially as a function of the superposition of these diurnal patterns in traffic density and wind speeds and direction.

The weekend/weekday variable is expected to have a significant impact on pollutant gradients in Wilmington as well, particularly because HDD truck traffic is dramatically reduced on the weekends. The Ports of Los Angeles and Long Beach are responsible for a dominant fraction of HDD trucks traffic on the I-710 freeway and presently, the ports operate HDD trucks primarily on weekdays. Thus, exhaust emissions from HDD trucks transporting cargo to and from the ports are currently minimized on weekends. Marr and Harley (2002) modeled these differences in motor vehicle emissions in central California while Chinkin et al. (2003) examined these differences in southern California. The major difference found between the weekday and weekend in both studies was the substantial decrease in NO_x emissions (30-40%) during the weekends which was attributed to the significant decrease in heavy duty diesel truck traffic during weekend days.

Pollution gradients from stationary sources (e.g., point sources) will also be inherently investigated during these monitoring periods as the routes will traverse areas where such sources are located. Emissions from point sources may also vary diurnally or by weekday versus weekend due to variation in hours and days of operation of retail businesses, such as a dry cleaner, or light and heavy industrial sources.

2.2.2.1.3 Traffic Volume and Composition

Traffic volume and composition (e.g., fraction of diesel trucks) data will be used to investigate the effect of heavy congestion during “rush hours” as well as the effect of the high numbers of heavy duty diesel vehicles. Both traffic volume and composition have large impacts on pollutant concentrations on roadways (Levy et al., 2001; Lena et al., 2002) and vary significantly by time of day (Marr and Harley 2002; Chinkin et al., 2003). Traffic volume and composition will be estimated by examination of vehicle traffic density data obtained from the California Department of Transportation (Caltrans) including hourly patterns derived from weigh-in-motion data. If greater accuracy is judged necessary, day- or hour-specific counts can be obtained through videotape records, as described by Zhu et al. (2002a,b)

Data on traffic volume and composition are available for all southern California freeways (including diesel/gasoline splits). For major arterials data are available for traffic volume but data for diesel gasoline splits are not reliable or not available . Annual average daily traffic (AADT) is the total volume for the year divided by 365 days (starting October 1st and ending September 30th). Except for freeways, many of which have in-road sensors, traffic counting is generally performed by electronic counting instruments moved from location to location throughout the State. The resulting counts are adjusted to estimate annual average daily traffic by compensating for seasonal influence, weekly variation and other variables. Using these data, we can relate traffic volume to measured pollution concentration gradients.

2.2.2.1.4 Heavy Duty versus Light Duty Traffic

It is well established that vehicle composition differs on different freeways, and this will be important for freeways in the Wilmington area. For example, on the I-710 freeway, 15-25% of vehicles are heavy duty diesel (HDD) trucks, compared to 5% and 10% on the I-405 and I-110 freeways respectively (Caltrans, 2003). Data of this kind can be obtained through annual average daily truck traffic (AADTT) information collected by Caltrans. AADTT is calculated in a similar manner as AADT and includes partial day and 24-hour counts made on high volume, urban highways; and 7-day and continuous counts usually taken on low volume rural highways. Data on traffic composition will characterize the fraction of heavy duty diesel trucks on freeways which can then be related to pollutant concentration gradients measured in the present study.

Zhu et al (2002a,b) examined the I-710 freeway and demonstrated concentrations of black carbon, an indicator for diesel exhaust, were higher compared to the I-405 freeway, which has a lower percentage of heavy duty diesel truck traffic. Other studies have also shown that pollutants associated with diesel exhaust, including black carbon, elemental carbon and PAH, have higher concentrations near freeways with a greater percentage of heavy duty diesel truck traffic (Levy et al., 2001; Lena et al., 2002; Westerdahl et al., 2005). Light duty and heavy duty traffic also show pronounced differences by hour of day on the I-710 freeway, with light duty traffic volume maximums occurring at rush hour peaks in the morning and late afternoon, and heavy duty vehicle traffic volume maximums occurring midday (Marr and Harley, 2002; Chinkin et al., 2003). We can exploit these temporal differences in vehicle traffic to investigate their relationship with measured pollutant concentration gradients.

2.2.3 Data Handling

2.2.3.1 Data Validation and Partial Data Validation

Data validation will follow guidelines described by the U.S. Environmental Protection Agency (U.S. EPA, 1978, 1980). This includes the following steps: (1) flag data when significant deviations from measurement expectations occur; (2) verify computer file entries; (3) eliminate values for measurements that are known to be invalid because of instrument malfunctions; (4) adjust measurement values for quantifiable calibration or interference biases. Data will not be removed unless there is an identifiable problem or the measurement result is physically impossible. Our extensive experience with validation of the voluminous real-time data from our two ARB-sponsored instrumented school bus studies will guide our validation and analysis in the present study.

Partial data validation will also be conducted between runs as a preliminary validation step. Partial data validation is the process of scanning data in real-time by plotting pollutant time series for each pollutant to be measured (e.g. CO_2, CO, black carbon, NO_x, PM2.5, and UFP).

Once these time series are plotted, patterns/trends in pollutant concentrations, or anomalous data will be noted. Performing these preliminary validation steps serves as a check to ensure the instruments are functioning correctly and also will allow us to develop an initial understanding of the data from our measurements in and around the Wilmington area, thus laying the groundwork for subsequent more detailed data analysis, as well as the possibility of "mid-course" corrections in our study design.

2.2.3.2 Data Analysis

We will generate several types of databases arising from the real-time data collection emphasis of this project. Time series analysis techniques as well as conventional statistical procedures will be used to analyze the data set.

Time series analysis can be used to accomplish two goals: identification of the nature of the phenomenon represented by the sequence, and the forecasting or prediction of future values of the time series variable. For the proposed study, the first objective will be our focus. When analyzing time series it is also important to consider autocorrelation (serial correlation), which is the statistic that measures the correlation of a variable with itself over time. Auto correlation can be measured by estimating the sample autocorrelation coefficients where values of $\pm {}^{2}\!/_{\sqrt{n}}$ (where n is effective sample size) denote autocorrelations significantly different from zero (Norusis, 2002). Cross correlation analyses will be used for the establishment of relationships between different time-series and to study the implications of such relationships.

Data from the mobile monitoring tests will be grouped run-by-run and basic descriptive statistics, such as the median and interquartile ranges, and the 95% confidence intervals, of pollutant concentrations will be calculated for the grouped data. Graphical representations will be used to describe the contrast between data sets, including cumulative frequency distributions and boxplots. Appropriate regression analysis will be conducted for pairs or groups of variables (e.g., pollutant concentrations). Plots of spatial concentration gradients, both concentration cross sections with respect to a given roadway and concentration surfaces for larger areas involving multiple roadways, will be constructed from our data. Comparisons for key variables identified above will be presented in appropriate tables and figures based on means and confidence intervals.

A wide range of specific examples of the types of data analyses, and presentations of the data, we will utilize in the present study can be found in our final report for our earlier ARB-sponsored school bus project (Fitz et al. 2003).

2.2.3.3 Video Record Data

As noted earlier, a Sony DCR-HC32 MiniDV Handycam® video camera will be mounted at the front of the vehicle to record traffic conditions and other events occurring in front of and adjacent to our test vehicle during measurement periods. All video camera records will be digitized into MPEG format, which is considered state-of-the-art for long-term preservation and future migration to new formats. Selected videotape records will be carefully examined to relate peaks in pollutant concentrations with several variables including traffic conditions, presence of diesel vehicles, and other variables that may affect pollution gradients. They may also be used, if necessary, to verify the presence of followed vehicle impacts that need to be adjusted for or removed.

2.4 Reporting

Quarterly progress reports will be written to review the work conducted and describe any problems encountered. A draft final report will be written in accordance with the ARB guidelines. This will consist of the following main components:

- Description of the objective and approach.
- A summary of the data collected and estimates of precision and accuracy.
- Summary and conclusions.

The final report will include a summary of all of the data. In addition all data will be provided on magnetic media in a format specified by the ARB.

The final report will incorporate the comments provided by the ARB after reviewing the draft final report.

3.0 PROPOSED SCHEDULE

	FIRST YEAR											
Activities	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8	Month 9	Month 10	Month 11	Month 12
Literature Search and Update	■	■	■	■	■	■	■	■	■	■	■	■
Procure Vehicle and Instruments	■	■	■									
Instrument Installation and Vehicle Setup		■	■	■								
Instrument QA/QC			■	■								
Pilot Study I Work Plan			■	■								
Pilot Study I: Testing and Validation				■	■	■						
Data QA/QC				■	■	■						
Pilot Study I Data Analysis					■	■						
Pilot Study II Work Plan						■	■					
Pilot Study II: Wilmington							■	■				
Data QA/QC							■	■				
Pilot Study II Data Analysis								■	■			
Summer Monitoring Work Plan									■	■		
Summer Monitoring in Wilmington										■	■	
Data QA/QC										■	■	
Data Analysis												■
Quarterly Reports			■			■			■			■

PROPOSED SCHEDULE (Cont.)

	SECOND YEAR											
Activities	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8	Month 9	Month 10	Month 11	Month 12
Literature Search and Update	■	■	■	■	■	■	■	■	■	■	■	■
Data Analysis	■											
Winter Monitoring Work Plan	■	■										
Winter Monitoring in Wilmington		■	■									
Data QA/QC		■	■									
Data Analysis	■	■	■	■	■	■	■	■	■	■	■	
Preparation of Draft Final Report						■	■	■	■	■	■	■
Quarterly Reports			■			■			■			■

	THIRD YEAR					
Activities	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6
Literature Search	■	■	■	■	■	
Submission of Draft Final Report	■					
Comments from ARB		■	■			
Revisions of Final Report				■	■	
Submission of Final Report						■
Quarterly Reports			■			

4.0 PROJECT MANAGEMENT PLAN

4.1 Key Personnel

The nature of this project is such that it must undertaken as a close collaborative effort. The Principal Investigator and Research Associate from UCLA (Dr. Arthur M. Winer and Ms. Kathleen Kozawa), in the course of the pilot studies and the main study, will participate with ARB staff (Dr. Alberto Ayala, Dr. Scott Fruin, Dr. Jorn Herner, and Mr. Dane Westerdahl) in designing a detailed and evolving sampling framework to achieve the objectives discussed in this proposal. Ms. Kozawa will be responsible for the development of the instrumented platform, running the experiments, as well as analyzing all acquired data. In the course of the project, all investigators will be responsible for the interpretation and implications of the results. Ms. Kozawa will be based on site at the ARB Headquarters in Sacramento and will report to Dr. Alberto Ayala, Manager of the Emission Control Technology Research (ECTR) of the ARB's Research Division. Dr. Scott Fruin from the ARB's ETCR Branch will act as the technical contract monitor for this project.

4.2 Qualifications

The UCLA investigators bring a complementary set of expertise, skills and experience to this project with a focus on the use of a wide range of real-time instrumentation in air pollution studies, as well as data management and analysis applications. The Principal Investigator has more than 30 years experience in the air pollution field with more than 200 peer reviewed journal articles and book chapters on air pollution topics. Both investigators had principal roles in a major ARB-funded study to characterize the range of children's pollutant exposure during school bus commutes, and a second field study to elucidate the mechanisms of vehicle exhaust intrusion into school buses. Many aspects of these previous studies are relevant to the project proposed here.

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