West Oakland Monitoring Study

DRAFT REPORT

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EXECUTIVE SUMMARY

The West Oakland Monitoring Study (WOMS) was conducted to provide supplemental air quality monitoring that will be used by the Bay Area Air Quality Management District to evaluate local-scale dispersion modeling of diesel emissions and other toxic air contaminants (TAC) for the area within and around the Port of Oakland. These measurements and modeling results are being used by the District to assess population exposures to TAC and associated health risks in the Bay Area. The WOMS was conducted by Desert Research Institute (DRI) during two seasonal periods of four weeks in summer 2009 (7/30/09-8/27/09) and winter 2009/10 (12/9/09-12/23/09 and 1/6/10-1/20/10). The WOMS consisted of a high density ("saturation") air monitoring network and mobile sampling along routes within the Port and West Oakland Community. This report describes and evaluates the methods used by DRI and summarizes the study results and findings.

Project Objectives and Questions

The WOMS measurement program was designed to determine the spatial and seasonal variations in the ambient concentrations of TACs and other air pollutants within West Oakland. The spatial variations of pollutant concentrations were determined on time scales ranging from seasonal averages to a resolution necessary to examine their associations with proximity to emission hot spots. Diesel particulate matter (DPM) concentrations were estimated and compared to emission inventory estimates and to a receptor modeling approach. Because no method exists to directly measure ambient concentrations of DPM, aerosol light absorption or elemental carbon was used as a surrogate for DPM. Results of the study will be used by the BAAQMD to address the following specific questions.

1. Do gradients in pollutant concentrations exist within the West Oakland that can be related to the community's proximity to emissions from the Port of Oakland and related heavy-duty vehicle traffic?
2. Is the existing air quality monitoring in the area adequate to characterize the spatial variations in cumulative exposure within the community?
3. Are seasonal mean pollutant concentrations higher in West Oakland than elsewhere in the urban areas of the San Francisco Bay Area?
4. Are the concentrations and spatial variations in the DPM estimated from the WOMS saturation monitoring consistent with the modeled results from the ARB and BAAQMD health risk assessment for diesel PM emissions?

Overview of the HCMS Saturation Monitoring

The term "saturation monitoring" refers to ambient air monitoring for the purpose of establishing detailed spatial variations in pollutant concentrations at the community scale. The saturation monitoring network consisted of 7-day time-integrated sampling for four weeks in two seasons during 2009/10 (Summer – 7/30/09 to 8/27/09, Winter – 12/9/09 to 12/23/09 and 1/6/10 to 1/20/10) at 16 locations within the Port of Oakland and communities of West Oakland and Alameda (Figure 3-1 and Table 3-1). The core set of measurements at the eight sites indicated in Figure ES-1 as diamonds included 7-day integrated oxides of nitrogen (NOx), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), BTEX (benzene, toluene, ethylbenzene and xylenes), and carbonyl compounds (formaldehyde and acetaldehyde) using passive samplers. Additionally, 7-day

integrated Teflon and quartz filters were collected and analyzed for $PM_{2.5}$ mass and organic carbon (OC) and elemental carbon (EC). NOx and NO_2 were also measured at eight more locations indicated as orange circles ("gradient sites"). With the exception of one upwind site, all gradient sites were intended to determine NOx concentrations gradients near major roadways. The contributions of DPM to ambient levels of $PM_{2.5}$ in West Oakland were determine by applying the Chemical Mass Balance receptor model to ambient PM speciation data obtained at the three location shown in Figure ES-1 as white diamonds with red vertical line. DPM at the 8 core sites was also estimated from EC using the correlation between EC and TC at a diesel exhaust dominated location (site POC2).

Table ES-1. WOMS saturation monitoring site locations and descriptions[1].

Site ID	Site Name	Location	latitude	longitude
POU	Site 7 - Upwind Site	Residence, 1321 Crown Drive, Alameda	37.7694	-122.2814
G1	Gradient Site 1	Middle Harbor Shoreline Park	37.7997	-122.3252
POC	Site 6 - Port of Oakland Central (summer)	Port of Oakland maintenance yard, near west edge of yard ~120m from Maritime St.	37.8072	-122.3142
POC2	Site 6 - Port of Oakland Central (winter)	Port of Oakland maintenance yard, southeast corner of yard ~30 m from Maritime St.	37.8057	-122.3126
G2	Gradient Site 2	10th St. and Midway, between Maritime St. & I-880	37.8124	-122.3079
G3	Gradient Site 3	Bay St. north of 7th (W edge of I-880)	37.8080	-122.3064
G5	Gradient Site 5	Frontage Rd., N of 7th St (E edge of I-880)	37.8114	-122.3033
G7	Gradient Site 7	Adeline, E side between 7th St and I-880	37.8037	-122.2883
G4	Gradient Site 4	Shorey St. at Pine (E of I-880 north of 7th St)	37.8085	-122.3041
G6	Gradient Site 6	24th St. and Wood (E of I-880)	37.8204	-122.2921
G8	Gradient Site 8	1086 8th St (btwn Adeline and Filbert)	37.8046	-122.2869
NR1	Site 2 - Near Road	Residence, 924 Pine St.	37.8107	-122.3018
WO1	Site 3 - West Oakland - SW	Oakland Technology Exchange, 1680 14th St.	37.8130	-122.2965
WO3	CASS upwind/WOMS Site 5 West Oakland - NW	Cypress Auto Salvage 2717 Peralta St.	37.8213	-122.2867
WO2	Site 4 - West Oakland - SE	Residence, 1111 Filbert St.	37.8064	-122.2839
EMUD	Site 1 - EBMUD	EBMUD District air monitoring station, 1100 21st St.	37.8148	-122.2825
CFDW	CASS far downwind	Excel High School HS, 2607 Myrtle St.	37.8198	-122.2802

[1] Note the change in location from summer to winter study for the POC site. Sampling location was closer to Maritime Street during winter resulting in greater contributions of heavy-duty diesel traffic to the measured pollutant concentrations.

Figure ES-1. HCMS saturation monitoring sites relative to monitoring sites operated by the SCAQMD, Port of Los Angeles and Port of Long Beach.

A van-mounted monitoring system was used to determine the variations in O_3, NO, NOx, CO, VOC , black carbon and $PM_{2.5}$ mass concentrations and ultrafine particle number concentrations relative to the BAAQMD air quality monitoring station in the study area and WOMS saturation monitoring sites. The mobile monitoring also provided snapshots in time of gradients in pollutant concentration that may be useful in interpreting the saturation monitoring data.

Finding and Conclusions

WOMS was conducted to characterize the magnitude and spatial variations in concentrations of toxic air contaminants within the Port of Oakland and the adjacent community of West Oakland and was designed to address four questions.

Question #1. *Do gradients in pollutant concentrations exist within the West Oakland that can be related to the community's proximity to emissions from the Port of Oakland and related heavy-duty vehicle traffic?*

The mobile monitoring data showed spatial patterns of higher pollutant concentrations that were generally consistent with proximity to vehicle traffic. Concentrations of directly emitted pollutants were highest on heavily traveled roads with consistently lower concentrations away from the roadway. Pollutants that have higher emission rates from diesel trucks (NO, BC) tended to exhibit sharper gradients than pollutants that are largely associated with gasoline vehicles (CO and VOC, including BTEX). While automobiles are ubiquitous and distributed throughout the city, most diesel truck traffic tends to be concentrated along well-established truck routes. The observed spatial patterns were consistent with these differences. BC and NO concentrations were higher on the main truck routes within the Port, on the frontage road along the east edge of I-880, and on several of the major arterial streets in West Oakland (e.g., 7th Street, and Grand Ave.). Pollutant concentrations were about a factor of 2 to 5 lower for most pollutants within the residential areas of West Oakland that are at least a city block off the main arterial streets. The higher pollutant concentrations were also measured near the entrance to the port near I-880 at 7th Street, Grand Avenue and Adeline Street. $PM_{2.5}$ and CO concentrations were more uniform spatially than BC and NO. With the exception of higher values at WO3, BTEX mixing ratios were relatively uniform spatially. The higher levels at WO3 may be related to local emissions near this sampling location or from nearby freeway traffic.

The spatial variations observed with the 7-day passive and active aerosol filter samples were generally consistent with the mobile monitoring results. The passive samples on the east edge of I-880 (G5) had average NO values about five times higher than at the residential community sites during summer and about 2.5 times higher during winter. Atmospheric mixing is generally stronger during summer due to greater surface heating resulting in larger gradient in pollutant concentrations with proximity to major sources of emissions. Other sampling sites near I-880 also had higher NO and NO_2 values than residential sites, but much lower than at G5. The observed gradient in NOx levels is generally consistent with past studies that have shown that traffic-related pollutants disperse rapidly downwind of the roadway (Zhu et al., 2002). NOx levels were uniformly low at the neighborhood-scale sites. The spatial variations of EC (also DPC and DPM) were qualitatively similar to NO during the summer study with concentrations increasing with greater proximity to traffic. Average EC concentrations were about two times higher during the summer period at sampling locations near I-880 (NR1, WO1, WO2 and WO3) compared to locations further downwind of I-880 (EMUD and CFDW). The EC and NO values at the central port site (POC) were comparable during the summer period to levels at the EMUD and CFDW core sites.

Both OC and $PM_{2.5}$ exhibited less spatial variations than EC due to contributions of secondary pollutants from the atmospheric transformations of directly emitted (primary) pollutants. Secondary organic aerosols (SOA) are typically larger components of particulate organic matter during summer and secondary nitrate and sulfate particles are major components

of $PM_{2.5}$. Secondary pollutants have more uniform spatial distributions over a larger area than directly emitted pollutants. NO_2 levels similarly showed a smaller range of values than NO and lower NO_2/NOx ratios at roadway and near-road sites. NO_2 levels were uniformly lower during the winter study than in summer due to slower conversion of NO to NO_2. Concentrations were lower during the afternoon compared to morning and during weekdays compared to Sunday.

During summer, the mean concentration of DPM at the four community sampling sites near I-880 (NR1, WO1, WO2 and WO3) was 0.9 $\mu g/m^3$ compared to 0.4 at POU, 0.6 at POC and 0.7 at the downwind community site (CFDW). During winter, the mean concentration of DPM at the four sites near I-880 was 2.0 $\mu g/m^3$ compared to 1.8 at POU, 2.7 at POC2 and 2.0 at CFDW and EMUD. The fractions of TC and $PM_{2.5}$ attributed to diesel exhaust at the West Oakland community sampling sites were 30-40% and 10-12%, respectively during summer and 50-60% and 17-19 %, respectively during winter. These ratios are reasonably consistent with the source contribution estimates obtained from the Chemical Mass Balance (CMB) receptor modeling analysis considering the uncertainties of the methods. The estimated DPM concentrations for the WOMS community sampling sites were also comparable to similar estimates derived from the San Jose PM speciation monitoring data.

Diesel exhaust accounted for 70-90% of the ambient EC based on the CMB analysis. Vehicle exhaust accounted for about half of the ambient concentrations of TC during the winter period with a factor of three higher contributions of diesel (35%) relative to gasoline (11%) exhaust. Wood combustion (32%) and meat cooking (20%) accounted for the remainder. Only 2% of the TC, on average, was unidentified indicating insignificant contributions of SOA during the winter period. During the summer period, vehicle exhaust accounted for about a third of the ambient concentration of TC with the same factor of three higher contribution of diesel (22%) relative to gasoline (8%) exhaust. Wood combustion (17%), meat cooking (29%) and unidentified sources (23%) accounted for the remainder. The greater proportion of unidentified TC during summer is assumed to be SOA due to greater photochemical activity compared to winter.

Question # 3. *Is the existing air quality monitoring in the area adequate to characterize the spatial variations in cumulative exposure within the community?*

The BAAQMD EBMUD monitoring station adequately represents pollutant concentrations within West Oakland except within 200-300 m of major roadways. On-road concentrations of DPM along I-880 and other truck routes within the Port of Oakland may be over a factor of five higher than the community average and BTEX and CO may be factors of 2-3 higher. The higher concentrations on-road decrease sharply away from the roadway. Although none were definitively identified by the mobile surveys, localized 'hot-spots' due to commercial activities within the community such as auto wrecking or metal working may exist and these would also not be identified by routine monitoring.

Question #3. *Are seasonal mean pollutant concentrations higher in West Oakland than elsewhere in the urban areas of the San Francisco Bay Area?*

The seasonal mean concentrations of BTEX measured at the BAAQMD monitoring station at the EBMUD are generally comparable are similar to those measured at the three air toxics monitoring network sites in the Bay Area (San Francisco, Fremont and San Jose). Aldehyde levels are higher in Fremont and San Jose than in West Oakland reflecting greater contributions of atmospheric formation of aldehydes from photooxidation of hydrocarbons in downwind area of the Bay Area. The mass concentrations of EC (the primary surrogate for DPM) in West

Oakland were similar to San Jose. However fractions of EC relative to TC and $PM_{2.5}$ were higher in West Oakland than San Jose because sources other than diesel vehicle exhaust may account for a greater proportion of ambient TC and $PM_{2.5}$ in San Jose.

As described in Section 2.5, DPM values were estimated from the correlations of elemental or black carbon with total carbon measured at locations near diesel traffic. This methods assumes that diesel exhaust is the main source of EC or BC in urban areas, which has been supported by past source apportionment studies. However, DPM estimates from this method are upper limits of the true DPM concentrations to the extent that other combustion sources (e.g., gasoline vehicles, wood burning and meat cooking) contribute to the ambient EC or BC concentrations.

Another potential uncertainty in these comparisons is whether four weeks of WOMS data are representative of the seasonal averages and whether the combined WOMS summer and winter study are valid annual averages. The two-month WOMS averages and 2005 – 2007 annual averages from long-term monitoring site in the SF Bay Area agree to within 10 percent and any differences due to averaging periods are comparable to uncertainty of the measurements. The annual average pollutant concentrations have been essentially flat from 2005 to 2008 so that comparisons of the averages over these years with WOMS data are reasonable valid.

Question #4. *Are the concentrations and spatial variations in the DPM estimated from the WOMS saturation monitoring consistent with the modeled results from the ARB and BAAQMD health risk assessment?*

We examined whether the concentrations and spatial variations in the DPM estimated from the WOMS saturation monitoring data are consistent with modeled results from the recent health risk assessment conducted by the California Air Resources Board and the District (CARB, 2008). The spatial variations in modeled concentrations of DPM in $\mu g/m^3$ were estimated by dividing the modeled potential cancer risk isopleths values by 318. The model estimates of DPM were consistently higher that the estimated concentrations of DPM at the WOMS community sampling sites by about a factor of 2.3. However, significant reductions in DPM emissions were estimated by the ARB and BAAQMD for the period between 2005, the base year of the HRA, and the 2009-2010 WOMS. We adjusted the annual average HRA estimates to reflect changes in distributions and volumes of truck traffic provided by the Truck Survey conducted by the BAAQMD and projected impact of mitigation measures that have been implementation since 2005. The combined decrease in DPM emissions is estimated by the BAAQMD to be in the range of 40 to 60%. Using these corrections the average estimated West Oakland DPM concentrations would range between about 1.2 and 1.9 $\mu g/m^3$ in 2010, compared to 1.4 $\mu g/m^3$ estimated from WOMS measurements.

1. INTRODUCTION

The Bay Area Air Quality Management District (BAAQMD) sponsored the West Oakland Monitoring Study (WOMS) to provide supplemental air quality monitoring that will be used by the District to evaluate local-scale dispersion modeling of diesel emissions and other toxic air contaminants (TAC) for the area within and around the Port of Oakland. Additionally, the supplemental monitoring data will be used to characterize pollutant levels in emission hotspots that modeling may not accurately represent. The WOMS was conducted during two seasonal periods of four weeks in summer 2009 (7/30/09-8/27/09) and winter 2009/10 (12/9/09-12/23/09 and 1/6/10-1/20/10). These measurements and modeling results are being used by the District to assess population exposures to TAC and associated health risks in the Bay Area. This report summarizes the WOMS data from the two seasonal field measurement periods.

The BAAQMD is also conducting a parallel year-long air monitoring project to characterize ambient concentrations of metals near the Custom Alloy Scrap Sales (CASS) facility in West Oakland. DRI is providing laboratory support for the CASS PM and metals monitoring project. The CASS project began concurrently with the summer WOMS and will continue through the end of July 2010. The samples collected for WOMS were also analyzed for metals that are potentially toxic or may serve as emission tracers of emission sources (e.g., aluminum, mercury, lead, chromium, manganese, vanadium, nickel, and cadmium). Data for metals obtained during WOMS are summarized in this report. The CASS data will be summarized in a separate report prepared by the BAAQMD.

1.1 Background

Urban and regional air monitoring programs typically consist of a relatively limited number of widely spaced monitoring stations within a given airshed. While these monitoring networks are generally adequate to characterize the spatial variations of secondary pollutants such as ozone, nitrogen dioxide, and nitrate and sulfate particles, they are less effective for determining the spatial variability in concentrations of directly emitted pollutants such as CO, diesel PM and other toxic air contaminants. The costs of traditional monitoring technologies also pose limitations on the number of monitoring locations that can be established for special studies to assess community level exposures to toxic air contaminants (TAC). This raises concerns about the adequacy of such assessments because exposure concentrations can vary substantially in space and time due to variations in proximity to sources of emissions, magnitude and specific mix of emissions and meteorological conditions.

Annual average outdoor concentrations of air toxic contaminants in the Bay Area have been obtained by the California Air Resources Board (ARB) since 2001 at three sites (San Francisco, San Jose and Fremont). Samples are collected for 24 hours every 12th day, and are analyzed for volatile air toxics (e.g., BTEX, 1,3-butadiene, aldehydes, and halogenated hydrocarbons). Additionally, metals and particulate polyaromatic hydrocarbons are measured at San Jose. The BAAQMD also measures gaseous hydrocarbon toxic air contaminants at twenty monitoring sites located throughout the Bay Area. Several special studies have been conducted in the Bay Area by both the ARB and BAAQMD to provide more detailed estimates of ambient levels and potential health risks of air toxics. Other studies have characterized higher exposures on and near roadways.

1.1.1 Community Air Risk Evaluation (CARE) program

The BAAQMD initiated a Community Air Risk Evaluation (CARE) program to estimate health risks associated with exposure to toxic air contaminants (TACs) within the nine counties of the San Francisco Bay Area. Its objectives are to identify high risk communities – those with high toxic emissions and sensitive populations, and to use the information to help the BAAQMD establish policies on incentive funding, regulation development, and other programs to reduce toxic emissions in high risk communities (BAAQMD, 2006). The CARE program consists of three phases beginning in July 2004. A preliminary gridded (2x2 km) emissions inventory of TAC was developed for the year 2000 in Phase I, and demographic and health-statistics data were compiled to help identify high risk communities. Based upon toxicity-weightings of these emissions, diesel particulate matter (DPM) accounts for about 80% of the cancer risk from airborne toxics in the Bay Area and acrolein is the major contributor to both acute and chronic non-cancer health effects. This inventory was evaluated by comparing the source attributions of PM in the emissions inventory to the proportions of contemporary carbon and fossil carbon measured in the ambient air by isotopic ^{14}C analysis, ambient source apportionments by Chemical Mass Balance (CMB) receptor modeling, and comparing estimated to measured toxic VOC.

Key components in the CARE program include regional modeling by the BAAQMD to estimate the spatial and seasonal variations in ambient TAC concentrations throughout the Bay Area and local-scale modeling by ARB as part of a Health Risk Assessment (HRA) study of diesel emissions at and near the Port of Oakland. In Phase II of the CARE program, the District updated the year-2000 annual TAC emissions to 2005 (on a 1x1 km grid) and began regional modeling to estimate concentrations of TAC throughout the Bay Area. As part of the HRA study, an inventory of diesel emissions for the Port of Oakland, the Union Pacific (UP) rail yard, and surrounding West Oakland community was developed. Figure 1-1 shows the source areas for DPM emissions used for modeling in the West Oakland HRA. A summary report of the HRA findings and conclusions was released in September 2008 (ARB, 2008). In Phase III, the regional modeling of TAC concentrations will be refined and more detailed assessments of exposure will be made using measurements, surveys and modeling. The findings from these studies will be used to help design mitigation measures to reduce exposure to toxic compounds, especially for sensitive populations.

Both regional- and local-scale modeling have uncertainties that result from their formulation and inputs (i.e., emissions, source characteristics, upwind background concentrations and meteorology). Dispersion modeling results also can be uncertain due to random variability such as atmospheric turbulence and population activity patterns. Ambient measurements are used to estimate annual average exposure concentrations and can be used to evaluate modeled air toxic concentrations. However, the existing network is intended to provide a general representation of large-scale population exposure. As a result, it does not always accurately reflect more localized exposures such as near heavily traveled roadways and other emission hotspots.

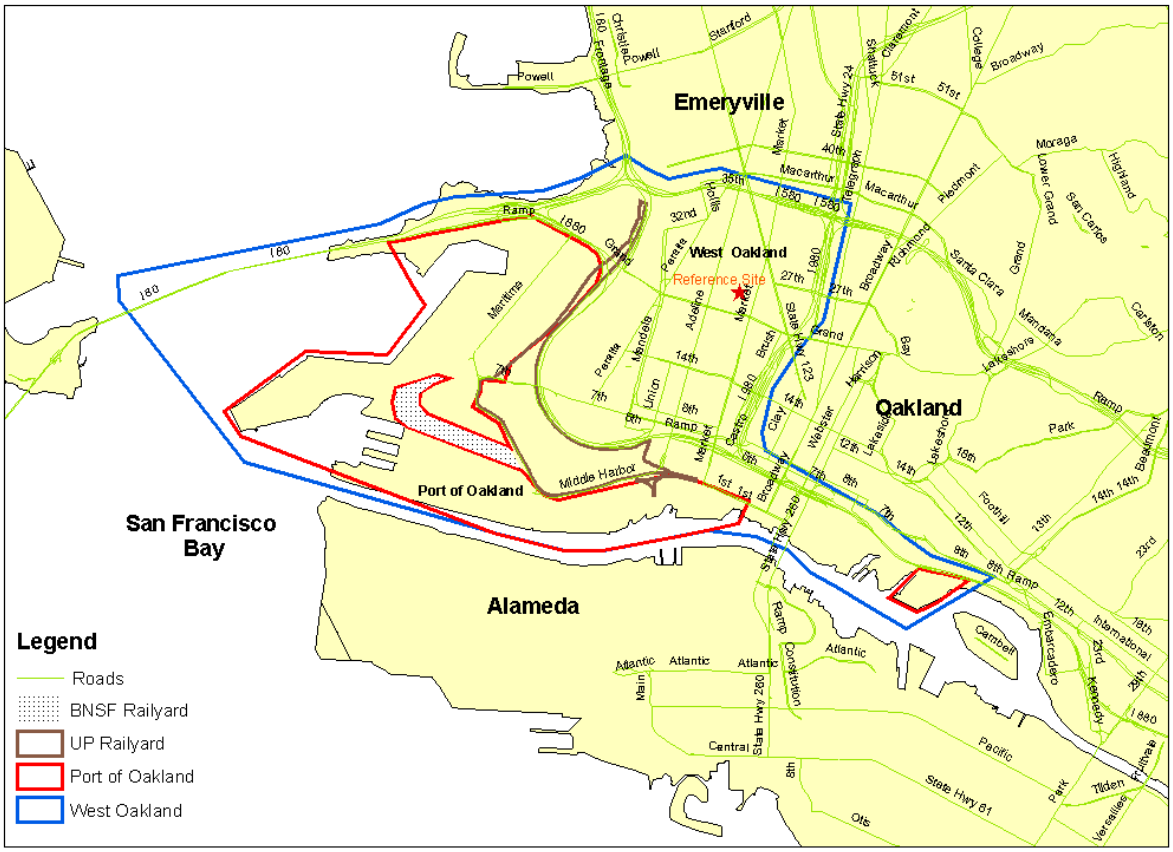

Figure 1-1. Bold colored lines demark boundaries of source areas for health risk assessment modeling of diesel PM in West Oakland. The red star indicates the Reference Site monitoring location.

1.1.2 Community-Scale Exposure and Risk Assessment Studies in the Bay Area and other relevant studies

Special monitoring programs have been conducted in California to characterize the ambient air toxic concentrations and potential exposures to certain susceptible populations and within communities that may experience disproportionate impacts due to their proximity to pollutant sources. The California Air Resources Board (ARB) conducted an 18-month (November 2001 through April 2003) special air quality monitoring study in the communities of Crockett in Contra Costa (ARB, 2004) and Fruitvale in Oakland (ARB, 2005) to investigate the impact of traffic and other industrial sources on children's exposure to air pollution. The studies were conducted as part of a larger statewide evaluation of the adequacy of the State's air quality monitoring network as required by SB 25 (Children's Environmental Health Protection Act). The Cal EPA's Office of Environmental Health Hazard Assessment conducted a study in 2001 to explore associations between respiratory symptoms and exposures to traffic-related air pollutants

among children living and attending schools near busy roads. The Pacific Institute conducted studies of the impact of diesel emissions associated with port activities in West Oakland and West Contra Costa. Both studies were conducted with active community involvement. The ARB and the Bay Area AQMD recently completed a health risk assessment study for the community adjacent to the Port of Oakland. The objectives of these and other related monitoring programs and research studies are to characterize the ambient air toxic concentrations within communities and potential exposures to certain susceptible populations.

ARB Community Monitoring in the Bay Area at Crockett (Contra Costa)

Monitoring in the Crockett community was conducted at John Swett High School from October 2001 to May 2003. Average levels of criteria air pollutants in Crockett were comparable to measurements from the nearest long-term monitoring sites located in Vallejo and San Pablo. The average PM_{10} concentration at the Crockett site was 19 $\mu g/m^3$ from October 2001 to May 2003 with a maximum of 70 $\mu g/m^3$. The State PM_{10} standard (50 $\mu g/m^3$) was exceeded on two occasions. The State carbon monoxide, ozone and nitrogen dioxide standards were not exceeded during the study. Monitoring of TACs included 1,3-butadiene, benzene, formaldehyde, acetaldehyde, several halogenated compounds, polycyclic aromatic hydrocarbons and several metals. The average concentrations of benzene and 1,3-butadiene during the monitoring period were 0.24 and 0.05 ppb, similar to the risks at the nearest long-term toxics site, at Crockett. Thus, ambient air quality levels at the school were reasonably well represented by existing monitoring sites.

ARB Community Monitoring in the Bay Area at Fruitvale (Oakland)

Fruitvale lies between two major East Bay freeways, and is surrounded by industrial sources in the vicinity of the Port of Oakland, Oakland International Airport, and numerous distribution centers and transportation-related businesses. Monitoring was conducted a few miles south of downtown Oakland at Lockwood Elementary School. Average levels of criteria air pollutants in Fruitvale were comparable to measurements from the nearest long-term monitoring sites in Oakland (located six miles north) and Fremont (located 23 miles south). The average PM_{10} concentration at the Fruitvale site was 24 $\mu g/m^3$ from November 2001 to February 2003 with a maximum of 70 $\mu g/m^3$. The State PM_{10} standard (50 $\mu g/m^3$) was exceeded on two occasions. The State carbon monoxide, ozone and nitrogen dioxide standards were not exceeded during the study. Monitoring of TACs included 1,3-butadiene, benzene, formaldehyde, acetaldehyde, several halogenated compounds, polycyclic aromatic hydrocarbons and several metals. The cancer risk associated with air pollution in Fruitvale was found to be among the highest among Bay Area sites, but comparable to the risk measured at the downtown Oakland (Filbert Street) monitoring site. Benzene and 1,3-butadiene accounted for most of the calculated cancer risk in Fruitvale and Fremont. The average concentrations of benzene and 1,3-butadiene during the monitoring period were 0.62 and 0.18 ppb. Because motor vehicles are the primary source of both these pollutants, heavy traffic near the two sites is probably the main source of these pollutants. Air quality concentrations at the school were reasonably well represented by nearby established monitoring sites.

OEHHA East Bay Children's Respiratory Health Study

The Office of Environmental Health Hazard Assessment (OEHHA) conducted the East Bay Children's Respiratory Health Study to determine whether exposures to traffic-related air pollutants are associated with increased respiratory symptoms and disease in children, such as asthma and bronchitis (Kim et al. 2004). The study was conducted as a school-based, cross-sectional study in Alameda County in 2001. The study area was comprised of ten neighborhoods and involved a total of 1,109 students between the 3rd and 5th grades. School sites were selected to represent a range of locations upwind and downwind from major roads. In addition, schools were selected to have similar demographic characteristics, such as race/ethnicity and indicators of socioeconomic status, so that the effects of traffic exposures would not be confounded by these factors. The investigators obtained information on bronchitis symptoms and asthma, demographics, home environmental factors, and activity factors using parental questionnaires. Air quality parameters included PM_{10}, $PM_{2.5}$, NOx, NO_2, NO, and black carbon. The investigators assumed that traffic-related pollutants measured at the neighborhood schools would be a good proxy for the children's overall exposure to these pollutant.

Although pollutant concentrations were relatively low, differences were observed in concentrations between schools nearby versus those more distant (or upwind) from major roads. For children residing at their current address for at least 1 year, the investigators found a modest but significant increase of 5 to 8 % in bronchitis symptoms and asthma symptoms in children in neighborhoods with higher concentrations of traffic pollutants. The concentrations of NOx, NO and black carbon were highly correlated. However, the relative effects of diesel truck traffic to total vehicular traffic were not studied. The results of the East Bay Children's Respiratory Health Study helped support the passage of SB 352, which amended the education code to ensure that new school sites are prohibited within 500 feet from the edge of the closest traffic lane of a freeway of other busy traffic corridors.

Pacific Institute - West Oakland Diesel Emission Inventory and Air Quality Monitoring Study

The objectives of this study were to develop an inventory of diesel exhaust emissions in West Oakland and to conduct an exploratory study of the levels of black carbon in homes in West Oakland. The study was conducted by the Pacific Institute, a nonprofit research center located in the Bay Area, with funding from the California Department of Health Services, U.S. Environmental Protection Agency and several foundations (Wu, 2003). TIAX LLC was contracted by Pacific Institute to perform a truck count and idling study focusing on container trucks servicing the Port of Oakland (Buchan et al., 2003). Container truck activity at the Port was estimated to have generated 8 tons of diesel particulate matter in 2002. These emissions were projected to triple as traffic at the Port of Oakland expands to 22,000 truck trips per day. The study reviewed several mitigation options including truck traffic reduction measures through West Oakland, technologies to reduce DPM emission from trucks, and policy changes to mitigate the impacts of diesel exhaust to the West Oakland Community.

The Pacific Institute measured ambient concentrations of black carbon for four weekdays in two homes in West Oakland using an Aethalometer. Average concentrations of black carbon were 2.1 $\mu g/m^3$. An average concentration of DPM of 2.9 $\mu g/m^3$ was estimated using BC as a surrogate. Using the California Air Resources Board's risk factor, lifetime exposures at this level of DPM would result in 1201 excess cancers per 1 million people (assuming a 95th percentile breathing rate). Measurements were also made for two weekdays in an Oakland home four miles

from the West Oakland site, and the average concentration of BC was found to be 0.37 $\mu g/m^3$ or about a fifth of the levels measured near the port.

Pacific Institute – Assessment of Diesel Pollution in Inner West Contra Costa County

In a study similar to the one in West Oakland, the Pacific Institute measured black carbon with an Aethalometer at three Inner West Contra Costa County homes located in North Richmond, Parchester Village, and San Pablo and a control home outside of Inner West County in Lafayette (Kamakate, 2005). Each home was monitored for five days in March and April 2005. On average, four times higher levels of black carbon were found on weekdays in the air in Inner West County homes (0.38 to 0.70 $\mu g/m^3$) than in the control home (0.11 $\mu g/m^3$). While Inner West County homes had almost double the levels of black soot on weekdays compared to Sunday, the control home had very little difference from weekdays to Sunday. The study also reviewed a range of mitigation measures. The study was funded by the U.S. Environmental Protection Agency Region IX.

ARB/BAAQMD Wesk Oakland Health Risk Assessment

The ARB and the BAAQMD conducted a health risk assessment (HRA) for diesel particulate matter (PM) in West Oakland (ARB, 2008). This study was a cooperative effort between the ARB and the Bay Area Air Quality Management District (BAAQMD). Both the Port and the Union Pacific (UP) Railroad assisted by providing information on their local marine and rail operations located near the West Oakland community. The study evaluated the current and future contributions of diesel PM emissions from sources at the Port, the Union Pacific Railyard, local freeways and other sources of diesel PM near the West Oakland community on the potential health impacts for people living in the West Oakland community.

Modeling results from the HRA showed that the West Oakland community is exposed to diesel PM ambient concentrations that are almost three times the average background diesel PM ambient concentrations in the BAAQMD. The estimated lifetime potential cancer risk for residents of West Oakland from exposure to diesel PM emissions is about 1,200 excess cancers per million (assuming an 80^{th} percentile breathing rate). This estimate assumes residents are exposed to the year 2005 levels of diesel PM emissions (Port and UP operations, and non-Port/non-UP marine and land-based diesel sources) continuously for 70 years. Diesel PM emissions from operations at the Port operations and UP Railyard result in an estimated lifetime potential cancer risk of 200 and 40 excess cancers per million in the West Oakland, respectively. Non-Port and non-UP emission sources account for about 950 excess cancers per million. Emissions from on-road heavy-duty trucks result in the largest contribution (over 80%) to the overall potential cancer risks levels in the West Oakland community, followed by OGV (combined transiting, maneuvering, anchoring, and hotelling emissions), harbor craft, locomotives, and cargo handling equipment.

On a regional basis, diesel PM emissions from Port operations potentially impact an area of about 550,000 acres. More than 3 million people live in this area and as a result of the diesel PM emissions from the Port, have potential elevated cancer risks of more than 10 excess cancers per million. Overall, the Port emissions result in a regional population-weighted potential cancer risk of about 27 in a million. OGV emissions are the largest contributor to the regional risk due

to Port-related activities, responsible for about 85 percent of overall average potential cancer risks. On a regional basis, diesel PM emissions also result in non-cancer health impacts. Due to diesel PM from Port operations, there are an estimated 18 premature deaths per year, 8 hospital admissions for respiratory and cardiovascular problems, about 290 cases of asthma-related and other lower respiratory symptoms, and 15,000 minor restricted activity days.

BAAQMD West Oakland Truck Survey

The West Oakland HRA raised questions about the volume of heavy-duty truck traffic in West Oakland and about the fraction of those trucks whose activities were related to the Port of Oakland. A major goal of the West Oakland Truck Survey (BAAQMD, 2009) was to address these questions in order to apportion the health risk to the appropriate source by estimating (1) the volume of medium heavy-duty (MHD) and heavy heavy-duty (HHD) truck traffic on the freeways and surface streets of West Oakland; (2) the primary routes of truck travel; (3) the locations and duration of truck idling activity; (4) the vehicle miles travelled for trucks within the study area; (5) the age distribution of trucks in West Oakland; and (6) the fraction of trucks transporting goods and passing through West Oakland in services related to the Port of Oakland.

To achieve these goals, the District collaborated with the members of the West Oakland community to survey surface streets in 2008 and estimate traffic volumes, routes, and speeds of medium heavy duty and heavy, heavy duty trucks along surface streets and freeways in West Oakland in order to improve the spatial representation of roadway emissions and differentiate the contribution of Port versus non-Port trucks. Select local businesses were also surveyed regarding their idling activity and truck licenses were recorded to develop a current truck age distribution for West Oakland. The HRA assumptions were then compared to the survey results and health risks were adjusted accordingly to derive new risk estimates that approximately reflect the findings of this survey.

One of the main findings of the Truck Survey was that, compared to the HRA, there were significantly fewer MHD and HHD trucks on surface streets in West Oakland overall but a higher percentage of the trucks that were on the surface streets were servicing the Port of Oakland. Relative to the HRA, the survey also found fewer trucks on freeways bounding West Oakland to the east (I-980) and north (I-580), but a somewhat higher number of Port and non-Port trucks on freeway I-880, which bounds West Oakland on the west and south. By linearly scaling risk to reflect the changes in truck activity and emissions, the study estimated the overall cancer risk levels from DPM in West Oakland to be about 75% of that estimated by the HRA, but that the Port of Oakland contribution to the risk was found to be 80% greater than estimated by the HRA.

The survey supported earlier findings on the age-distribution of trucks in West Oakland. The median and average model year for all trucks and diesel-powered trucks identified during the West Oakland truck survey was 1997, which was consistent with the emissions inventory used for the HRA. Approximately 85% of the trucks had model year of 1994 or newer. 49% of the trucks were registered in the Bay Area; 27% were registered in non-Bay Area California cities; and 24% were either registered out of state or no longer in use since the data were recorded. Idling survey responses, confirmed through curbside observations, indicated that a

majority of local businesses are complying with the five minute idling restriction required by CARB regulations.

Harbor Community Monitoring Study (HCMS)

The Harbor Community Monitoring Study (HCMS) was conducted to characterize the spatial variations in concentrations of toxic air contaminants (TACs) and their co-pollutants within the communities of Wilmington, West Long Beach, and San Pedro in California's South Coast Air Basin (SoCAB). These communities were chosen for this study because of the high density of emission sources in the area and close proximity of residents to these emission sources. These sources include the Ports of Los Angeles and Long Beach, petroleum refineries, intermodal rail facilities and diesel trucks (high traffic volumes associated with the movement of goods from one of the busiest port complexes in the world). The study objectives of the HCMS were similar to those of WOMS and used many of same sampling methods, which were extensively evaluated as part of the study.

Saturation monitoring consisting of 7-day time-integrated sampling at 23 locations was conducted as part of the HCMS by the Desert Research Institute. Samples were collected for four consecutive weeks in four seasons during 2007. Measurements at twenty sites included oxides of nitrogen (NOx) and sulfur dioxide (SO_2) using Ogawa passive samplers, and benzene, toluene, ethylbenzene, and xylenes (BTEX), formaldehyde and acetaldehyde using Radiello passive diffusive samplers. Additionally, 7-day integrated Teflon and quartz filters were collected with portable mini-volume samplers and analyzed for $PM_{2.5}$ mass and organic carbon (OC) and elemental carbon (EC). Nitrogen dioxide (NO_2) and hydrogen sulfide (H_2S) were also measured at three of the sites using Ogawa and Radiello passive samplers, respectively, and full sets of passive measurements (including NO_2 but not H_2S) were made at three additional near-roadway locations. Diesel particulate matter (DPM) concentrations were estimated at each site from the EC concentrations times the slope of the correlation between total carbon and EC at the near road sampling locations.

The annual average DPM concentrations were higher near diesel truck traffic but were comparable to the MATES-III fixed monitoring sites at sampling locations 300m or more from traffic. Results are qualitatively consistent with the ARB's modeling estimates of DPM concentrations. Higher average SO_2 levels were measured at the east boundary of a refinery and in the port area, but corresponding increases in BTEX were not observed near the refinery. Results from the HCMS are compared to similar data for other areas of the South Coast Air Basin using data from the Third Multiple Air Toxics Evaluation Study (MATES-III). Average BTEX levels in the Harbor Communities were generally comparable or less than at other air monitoring locations in the basin. Formaldehyde and other carbonyl compounds that are formed in the atmosphere were lower in the Harbor Communities than inland areas of the basin. Week-to-week variations were higher than site-to-site variability in concentrations of most pollutants.

1.1.3 On-Road and Near-Road Exposure Studies

Several studies (Wallace, 1987; Chan et al., 1991; Weisel et al., 1992; Jo and Choi, 1996; Duffy and Nelson, 1997; Jo and Park; 1999; Leung and Harrison, 1999) have found that individuals are exposed while commuting to levels of VOC several fold higher than the

corresponding ambient concentrations measured at nearby traditional (neighborhood-scale) monitoring sites. In a study of ozone precursors in the South Coast Air Basin, Fujita et al. (2003a) found that concentrations of black carbon[1] (BC) and nitrogen oxides (NO_x) were about ten times higher on roadways than at regional air monitoring sites, and that volatile organic compounds (VOC) and carbon monoxide (CO) were factors of two to four higher on roadways. Westerdahl et al. (2005) also found that concentrations of ultrafine PM (< 100 nm), nitrous oxide (NO), BC and CO on freeways were frequently ten times higher than on residential streets. Others have shown that traffic-related pollutants disperse rapidly downwind of the roadway (Zhu et al., 2002). These results suggest that the exposure to air pollutants for commuters and urban pedestrians would be underestimated by using fixed-site monitoring data or predicted concentrations from grid-based air quality simulation models.

Investigators from the Desert Research Institute measured on-road concentrations of volatile air toxics, $PM_{2.5}$ mass, black carbon, and polycyclic organic matter (POM) in California's South Coast Air Basin during summer 2004 and winter 2004/5 (Fujita et al., 2006). An important impetus for this study was to conduct the measurements during the MATES-III field study. The average and upper range of black carbon concentrations were highest on those routes with a higher proportion of truck traffic. The concentration ranges for BC show as much as an order of magnitude higher average concentration on the road than at three near-road residential neighborhood sites, and the peak 1-minute averages on roadways with high amounts of truck traffic can be as much as two orders of magnitude higher than peak neighborhood concentrations. The average 1-minute $PM_{2.5}$ mass concentrations for on-road exposures are about 2-6 times higher than at the three near-traffic residential sites. The spatial patterns of on-road pollutant concentrations indicated that gasoline vehicles were the predominant source of volatile mobile source air toxics (MSAT) such as 1,3-butadiene and BTEX (sum of benzene, toluene, ethylbenzene and xylenes).

1.1.4 Contributions of Gasoline and Diesel Exhaust to Ambient PM

The Gasoline/Diesel PM Split Study, sponsored by the U.S. Department of Energy, was conducted to assess the sources of uncertainties in using an organic compound-based chemical mass balance (CMB) receptor model to quantify the relative contributions of emissions from gasoline (or spark ignition, SI) and diesel (or compression ignition, CI) engines to the ambient concentrations of fine particulate matter ($PM_{2.5}$) (Fujita et al., 2007a; Fujita et al., 2007b; Lough et al., 2007a; Lough et al., 2007b). In this study, several groups worked cooperatively on sample collection and quality assurance aspects of the study. The Desert Research Institute and the University of Wisconsin worked independently to perform chemical and data analysis and source apportionment. Source testing included 59 light-duty vehicles (including two diesel vehicles) and 34 heavy-duty diesel vehicles. Ambient sampling included daily 24-hour $PM_{2.5}$ samples for twenty-eight days during summer 2001 at two air quality monitoring stations in the SoCAB plus samples at several regional urban locations and along freeway routes and surface streets with varying proportions of automobile and truck traffic.

[1] In this report BC refers to light absorbing carbon determined by methods such as an aethalometer, photoacoustic, or other instruments that measure light absorption that can be interpreted as BC when divided by assumed mass absorption efficiency. Elemental carbon (EC) refers to refractory carbon determined by thermal evolution methods.

On-road measurements of $PM_{2.5}$ mass (gravimetric) concentrations were consistently lower on Sundays and were very similar to levels measured on Sundays at the monitoring stations in Los Angeles and Azusa and an upwind background location in Venice. On-road levels of $PM_{2.5}$ were about 2 to 2.5 times higher on weekdays than on Sundays. The weekday-weekend differences are more apparent with total carbon and even more so for elemental carbon. On-road concentrations of total carbon were 3-4 times higher than ambient concentrations at the Los Angeles and Azusa monitoring stations. Furthermore, on-road concentrations of elemental carbon were about an order of magnitude higher than at the monitoring stations. While CI engine exhaust was the dominant source of total carbon (TC) and EC at the air monitoring stations at Azusa and downtown Los Angeles, samples from a regional park in the central part of the South Coast Air Basin showed nearly equal apportionment of CI and SI. About 70 percent of organic carbon in the ambient samples collected at the two fixed monitoring sites could not be apportioned to directly-emitted PM emissions.

1.2 Research Objectives

WOMS provides supplemental air monitoring data to determine the spatial and seasonal variations in the ambient concentrations of TACs and other air pollutants within West Oakland. The spatial variations of pollutant concentrations were determined on time scales ranging from seasonal averages to a resolution necessary to examine their associations with proximity to emission hot spots. DPM concentrations were estimated and compared to emission inventory estimates and to a receptor modeling approach. Because no method exists to directly measure ambient concentrations of DPM, black carbon or elemental carbon was used as a surrogate for DPM. Results of the study will be used by the BAAQMD to evaluate the local-scale dispersion modeling of diesel emissions for the area directly downwind of the Port of Oakland and regional scale modeling of diesel particulate matter and other toxic air contaminants. The field study had the following technical objectives.

a) Conduct saturation monitoring to determine the spatial variations in seasonal average ambient concentrations of toxic air contaminants and co-pollutants within West Oakland relative to the Port of Oakland, proximity to roadways, and nearby fixed monitoring sites. The saturation monitoring program by Desert Research Institute was primarily designed to characterize the spatial variations in seasonal (summer and winter) average concentrations of selected pollutants with long-term exposure impacts (e.g., selected TACs and criteria pollutants) within the study area. Measurements included oxides of nitrogen (NOx), nitrogen dioxide (NO_2) and sulfur dioxide (SO_2), VOC (benzene, toluene, ethylbenzene, and xylenes), and aldehydes (formaldehyde and acetaldehyde) using passive samplers. Additionally, Teflon and quartz filters were collected with portable Airmetrics MiniVol samplers and analyzed for $PM_{2.5}$ mass and organic carbon (OC) and elemental carbon (EC).

b) Use a van-mounted mobile monitoring system to determine the spatial and temporal variations in O_3, NO, NOx, CO, VOC[2], black carbon and $PM_{2.5}$ mass concentrations[3] and

[2] VOC was measured with a RAE Systems ppbRAE, which records the bulk response of a photo-ionization detector (PID) to ambient organic chemical concentrations. The response of PIDs varies for different chemical compounds

ultrafine particle number concentrations relative to nearby fixed location monitoring sites and to identify emission hotspots.

c) Estimate the contributions of diesel particulate matter (DPM) to ambient levels of $PM_{2.5}$ in West Oakland by collecting ambient speciation data suitable for use in source attribution and reconcile the results with corresponding emission inventory data.

These technical objectives were designed to answer the following specific questions.

1. Do gradients in pollutant concentrations exist within the West Oakland that can be related to the community's proximity to emissions from the Port of Oakland and related heavy-duty vehicle traffic?

2. Is the existing air quality monitoring in the area adequate to characterize the spatial variations in cumulative exposure within the community?

3. Are seasonal mean pollutant concentrations higher in West Oakland than elsewhere in the urban areas of the San Francisco Bay Area?

4. Are the concentrations and spatial variations in the DPM estimated from the WOMS saturation monitoring consistent with the modeled results from the ARB and BAAQMD health risk assessment?

found in the ambient air. The response is calibrated to a typical mixture of pollutants found in motor-vehicle exhaust. The actual relationship between PID signal and concentration in different microenviroments may vary.

[3] PM2.5 mass concentrations were measured with a TSI DustTrak, which measures light-scattering and converts the result internally using a calibration based on response to a dust standard. The accuracy of the calibration is variable since light-scattering is a function of both particle size distribution and composition.

2. EXPERIMENTAL

The West Oakland Monitoring Study (WOMS) was conducted during two seasonal periods of four weeks in summer 2009 (7/30/09-8/27/09) and winter 2009/10 (12/9/09-12/23/09 and 1/6/10-1/20/10). The monitoring in each season included the following three components.

- Saturation monitoring to determine spatial variations of $PM_{2.5}$ mass, OC and EC, selected volatile air toxics, and related air pollutants (NO, NO_2 and SO_2) using 7-day integrated sampling at multiple fixed sampling locations.

- Mobile monitoring of NO, CO, volatile organic compounds (VOC), $PM_{2.5}$ mass and black carbon, and ultrafine particles to characterize the spatial variations in pollutant concentrations within West Oakland and the Port of Oakland.

- Collection and analysis of PM samples for chemical speciation of particulate and semi-volatile alkanes, polycyclic aromatic hydrocarbons, hopanes, steranes, and polar compounds for application in Chemical Mass Balance (CMB) receptor modeling to estimate the source contributions of diesel particulate matter and other combustion sources in the study area.

2.1 Saturation Monitoring

Saturation monitoring refers to ambient air monitoring for the purpose of establishing spatial variations in pollutant concentrations at a community scale. The objectives of this type of monitoring in the context of health risk assessments is to determine the seasonal or annual average air toxics concentrations at a sufficient number of locations within a community to: 1) establish the spatial variations in air toxic concentrations; 2) identify air toxic emission hotspots; and 3) characterize the gradients in air toxic concentrations from these hotspots.

2.1.1 Saturation Monitoring Network Design and Objectives

The WOMS saturation monitoring consisted of the 16 sampling locations listed in Table 2-1 and shown in Figure 2-1. Additionally two CASS project sites were operated on the WOMS sampling schedule during the two seasonal field studies. Appropriate sampling sites were selected based upon locations of emission sources and typical patterns of pollutant transport. Winds in the area are almost exclusively from the northwest to southwest throughout the year based on data collected at the East Bay Municipal Utility District (EBMUD) sewage treatment plant from 1998 to 2000. Sampling sites were therefore aligned from the Middle Harbor area in the west to a cluster of sites near I-880 and 7th Street, and to sites fanning eastward within the community of West Oakland. The network included sites representing varying spatial scales relative to emission sources. Neighborhood-scale sampling sites represent an area of the community with relatively uniform land use within 0.5 to 4 kilometers. Microscale sampling sites characterize higher roadside exposures within several meters to 100 meters of highways and major arterial streets. Middle scale (100 m to 0.5 km) sampling sites characterize near-road exposures and higher exposures that may be observed near major stationary sources.

Table 2-1. WOMS sampling locations and measurements.

				7-day Samples During WOMS 4-Week Intensives							24-hr WOMS		
				Passive					Mini-Vol		SFS		SVOC
Project	Site ID	Site Name	Location	NOx	NO2	SO2	BTEX	Carb	Tef	Qtz	Tef	Qtz	TIGF/ XAD
WOMS	POC	Site 6 - Port of Oakland Central	Port of Oakland maintenance yard[1]	1	1	1	1	1	1	1	1	1	1
WOMS	G1	Gradient Site 1	Middle Harbor Shoreline Park	1	1								
WOMS	G2	Gradient Site 2	Former Army Base between Maritime St. & I-880	1	1								
WOMS	G3	Gradient Site 3	north of 7th St. near west edge of I-880	1	1								
WOMS	G4	Gradient Site 4	NE of 7th St and Frontage Rd.	1	1								
WOMS	NR1	Site 2 - Near Road	Residence, 924 Pine St.	1	1	1	1	1	1	1	1	1	1
WOMS	WO1	Site 3 - West Oakland - SW	Oakland Technology Exchange, 1680 14th St.	1	1	1	1	1	1	1			
WOMS	G5	Gradient Site 5	East edge of I-880 north of 7th St.	1	1								
WOMS	G6	Gradient Site 6	Near east edge of I-880 north of Grand Ave.	1	1								
CASS/WOMS	CUPW/WO3	CASS upwind/WOMS Site 5 West Oakland - NW	Cypress Auto Salvage 2717 Peralta St.	1	1	1	1	1	1	1			
CASS	CFDW	CASS far downwind	Excel High School HS, 2607 Myrtle St.	1	1	1	1	1	1	1			
WOMS	EMUD	Site 1 - EBMUD	EBMUD District air monitoring station, 1100 21st St.	3	3	3	3	3	1	1	1	1	1
WOMS	WO2	Site 4 - West Oakland - SE	Residence, 1111 Filbert St.	1	1	1	1	1	1	1			
WOMS	G8	Gradient Site 8	Between Sites G7 and C5	1	1								
WOMS	G7	Gradient Site 7	SW of 7th St. and Adeline, north of I-880	1	1								
WOMS	POU	Site 7 - Upwind Site	Residence, 1321 Crown Drive, Alameda	1	1	1	1	1	1	1			
TOTALS				18	18	10	10	10	8	8	3	3	3

[a] Sampling on Teflon impregnated glass fiber filter with backup XAD cartridge.
[b] BAAQMD Measurements include NOx, NO_2, CO, SO_2, $PM_{2.5}$ mass, black carbon, SASS speciation sampler and met data.
[1] Locate during summer at west side of the Building. Site was moved during winter to east side of building in closer proximity to Maritime Street.

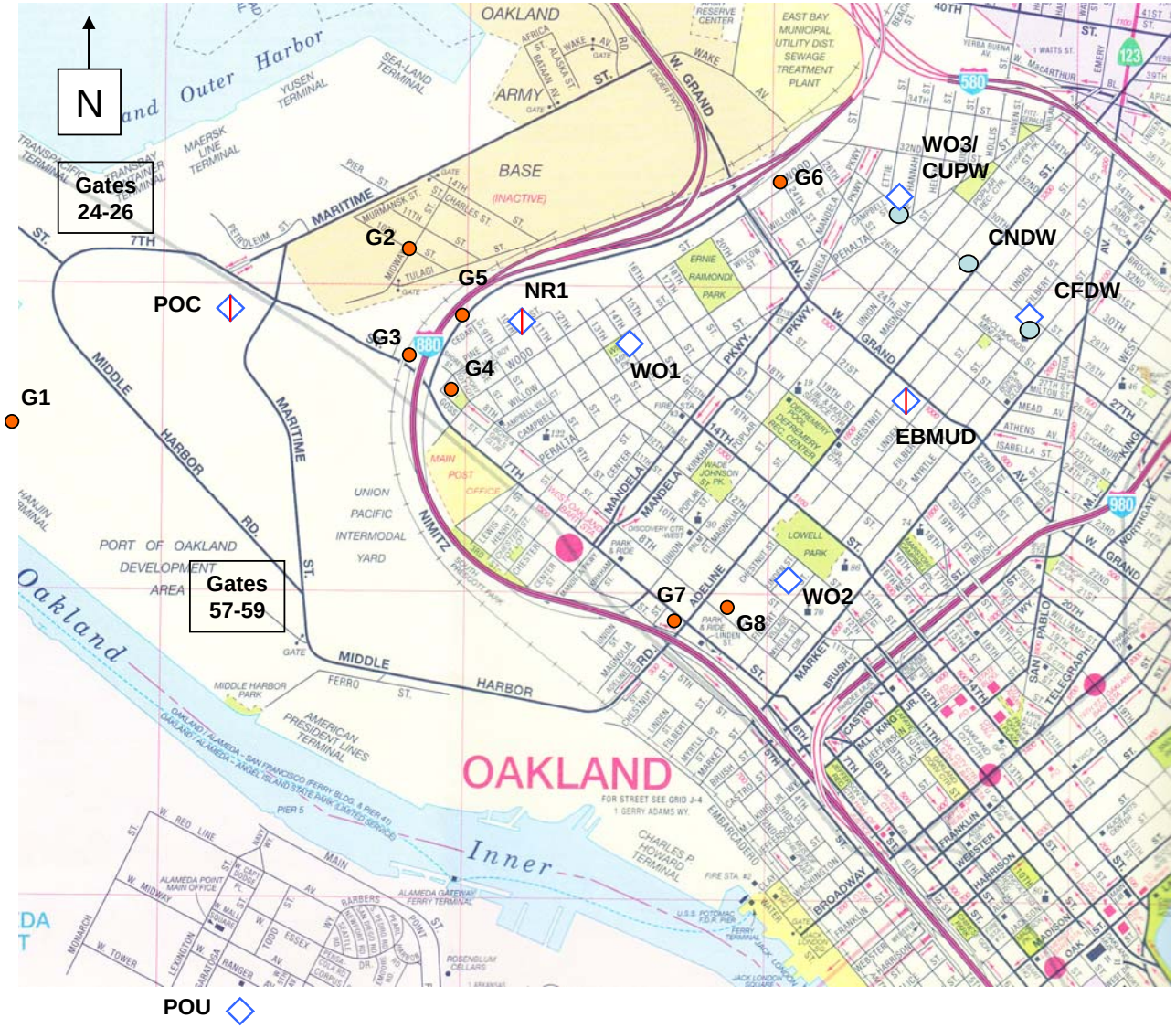

Figure 2-1. WOMS and CASS sampling locations.

2.1.2 Port Operations during Study

The Port of Oakland is the fifth busiest container port in the United States and handles 99 percent of the containerized goods moving through Northern California. There were 1,897 cargo vessel arrivals at the Port of Oakland in 2009 with total throughput[1] of 2,045,211 "Twenty-Foot Equivalent Units" (TEU) (Port of Oakland, 2010). The numbers of vessel calls and total throughput during WOMS were: 152 vessels and 169,016 TEU during the summer study (7/30/09 to 8/27/09); 88 vessels and 92,309 TEU during the first half of the winter study (12/9/09 to 12/23/09); and 75 vessels and 80,997 TEU during the second half (1/6/10 to 1/20/10) (Leong, 2010). Activity levels at the port during the WOMS summer and second half of the winter monitoring periods were comparable to 4-week average of the total 2009 annual vessel calls (146) and container throughput (157,323 TEU). Activity levels during the first winter period were about 20% higher than average.

Port activity levels in 2009 were about 10% lower than in 2005, the base emissions year for the CARE health risk assessment. Container throughput declined to 2004 levels from the 2006 peak, presumably as a consequence of the world economic downturn. While this may have some influence on the comparison between WOMS results and prior modeling estimates, the decrease is not substantial relative to the uncertainty of the estimates.

2.1.3 Meteorological Conditions during Study

In addition to the spatial and temporal patterns of pollutant emissions, changes in meteorological conditions are a dominant factor in the diurnal, day-to-day and seasonal variations in pollutant concentrations. The effect of meteorological conditions on air pollutant levels within the Bay Area have been extensively studied by District meteorologists. The following summary is based upon their analysis of past meteorological data and specific periods during WOMS (Cordova, 2010)

The summer climate of the West Coast is dominated by a semi-permanent high pressure centered over the northeastern Pacific Ocean. Because this high pressure cell is quite persistent, storms rarely affect the California coast during the summer. Conditions that persist along the coast of California during summer are a northwest air flow and negligible precipitation. Air that approaches the coast, already cooled and moisture-laden from its long trajectory over the Pacific, is further cooled by the cold water along the Central and Northern California coast that is upwelled from the deep ocean. This cooling is often sufficient enough to produce condensation, leading to a high incidence of fog and stratus clouds near the coast. A low pressure area over the interior of California, caused by heating near the surface, helps to draw the northwesterly flow onshore over the Bay Area for much of the summer. These onshore winds, or sea breezes, turn westerly as the flow enters through the Golden Gate and the various overland gaps in the Coastal Range. As the flow enters the interior of the Bay Area, local terrain features block and steer the winds.

[1] The twenty-foot equivalent unit (often TEU or teu) is a loosely defined unit used to describe the capacity of container ships based on the volume of a 20-foot-long (6.1 m) intermodal container. For a more detailed discussion see http://en.wikipedia.org/wiki/Twenty-foot_equivalent_unit.

In the winter, as the semi-permanent northeastern Pacific high weakens and shifts southward, the Bay Area experiences periods of moderate-to-strong winds, storminess, and periods of stagnation. Most of the Bay Area's annual precipitation occurs from the winter storms. Stagnation episodes are often characterized by winds that flow out of the Central Valley into the Bay Area and, sometimes, out through the Golden Gate and overland terrain gaps. These periods can also exhibit weak or nonexistent onshore flows in the afternoon, nighttime drainage flows in the coastal valleys, and periods of light and variable winds.

Wind data collected at the Oakland Sewage Treatment Plant are summarized for the three WOMS measurements periods in Figure 2-2, for July 30, 2009 to August 27, 2009, Figure 2-3 for December 8, 2009 to December 23, 2009, and Figure 2-4 for December 8, 2009 to December 23, 2009. The Oakland Sewage Treatment Plant meteorological station (OST) is located approximately ten miles almost due east of the Golden Gate Bridge (see Figure 2-1). In this area, marine air intrusion through the Golden Gate, across San Francisco, and through the San Bruno Gap is a dominant weather factor, particularly in the summer months. The Oakland-Berkeley Hills, east of OST, causes a split of the westerly flow in the vicinity of Oakland, with southerly winds observed over the San Francisco Bay north of the Golden Gate and northwesterlies over the bay to the south of the Golden Gate. Figure 2-2 illustrates the summertime split of the westerly winds at OST, as the wind directions vary from northwesterly to southwesterly.

In the winter, with the strong sea breezes diminished, storms and local influences have a larger influence on the wind patterns at OST. Figure 2-3 shows a northwesterly to southeasterly pattern, with a northeasterly spike. The northeasterly spike was mostly due to consistent light to gentle (4 -12 mph) offshore flow that occurred over the entire Bay Area on December 9, 2009 and December 10, 2009. The southeasterly flow was due to the passage of several winter storms and light offshore flow out of the Hayward gap to the southeast of the station. The dominant and stronger northwesterly flow was due to a combination of light onshore bay breezes, light winds out of San Pablo Bay to the north, and the passage of low pressure from over the Pacific Northwest towards Nevada from December 21, 2009 through December 23, 2009. Figure 2-4 exhibits a similar northwesterly to southeasterly wind pattern, with the northwesterly once again dominant, as in the December period. Unlike the December period, the stronger winds were from the southeast due to the passage of several storms from January 17, 2010 through January 20, 2010.

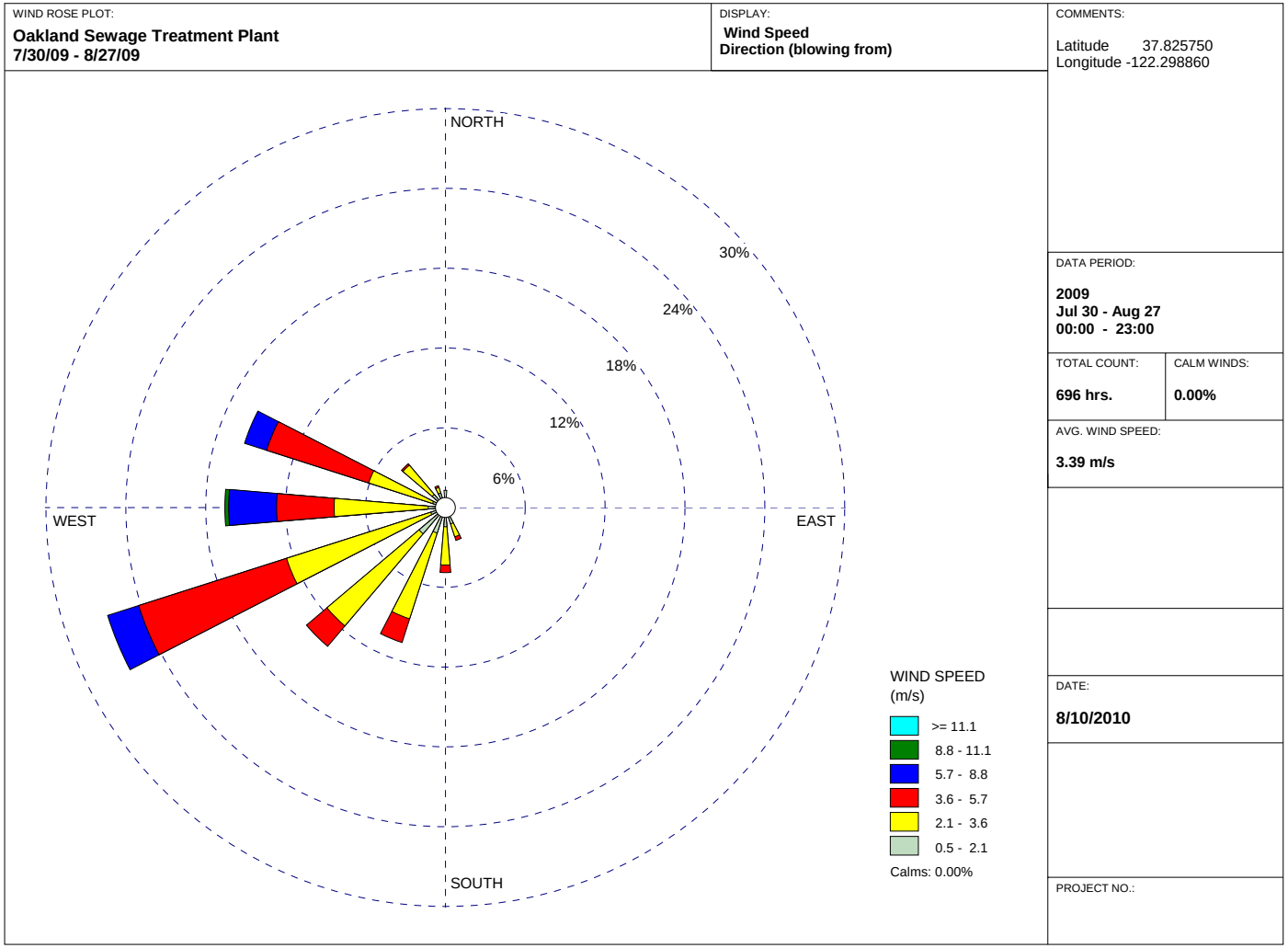

Figure 2-2. Summary of wind data collected at the Oakland Sewage Treatment Plant from July 30, 2009 to August 27, 2009.

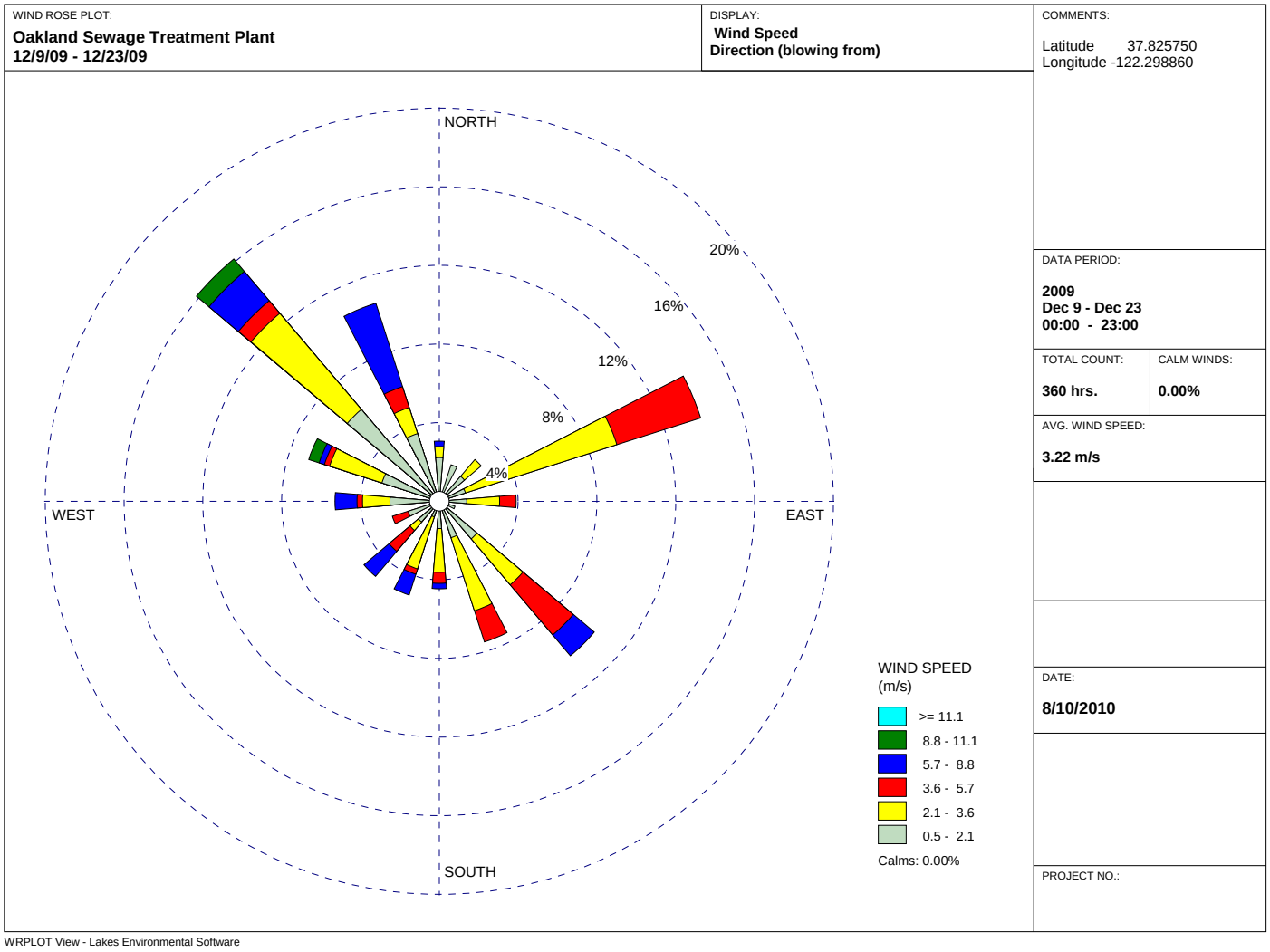

Figure 2-3. Summary of wind data collected at the Oakland Sewage Treatment Plant from December 8, 2009 to December 23, 2009.

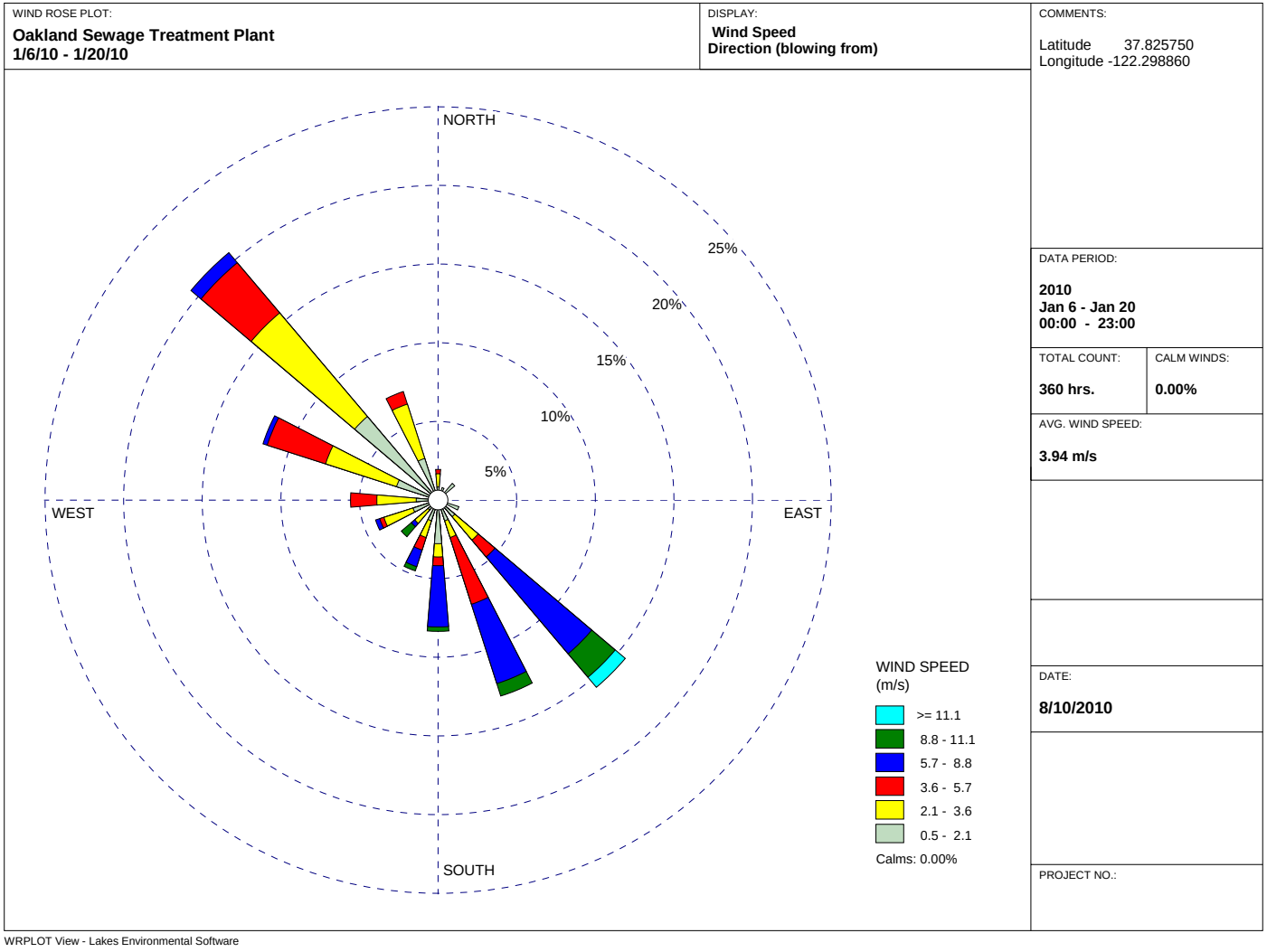

Figure 2-4. Summary of wind data collected at the Oakland Sewage Treatment Plant from January 6, 2010 to January 20, 2010.

2.1.4 Measurement Methods

Measurements at the eight core sites, shown as open blue diamonds in Figure 2-1, included 7-day integrated passive samples for nitrogen dioxide (NO_2), oxides of nitrogen (NOx), sulfur dioxide (SO_2), BTEX (benzene, toluene, ethylbenzene and xylenes) and carbonyl compounds (formaldehyde, acetaldehyde and acrolein) using the passive samplers shown in Figure 2-5 and described in Table 2-2. Additionally, 7-day Teflon and quartz filter samples were collected at core sites with portable Airmetrics MiniVol samplers and analyzed for $PM_{2.5}$ mass, organic carbon (OC), elemental carbon (EC) and metals. NO_2 and NOx were measured with Ogawa passive samplers at eight additional locations (shown as orange dots in Figure 2-1) to provide information on gradients near NO (also suspected DPM) hotspots. Passive samples were collected in triplicate at the BAAQMD monitoring station at the East Bay Municipal Utility District site (EMUD) to determine measurement precision and to compare the passive NOx and NO_2 measurements with the District's continuous NOx monitors. District staff collected the CASS samples during the two WOMS four-week intensives and during other times of the year. The analyses of the Teflon filters collected at the CASS sampling sites included gravimetric mass and metals by X-ray fluorescence. The applicable sampling and analytical methods are described in Appendix A.

Assessment of data quality is essential for proper interpretation of the WOMS data. This is especially important for passive measurements, which are not routinely used in national and local air quality monitoring programs. These passive measurements were evaluated by DRI during the recently completed Harbor Communities Monitoring Study (HCMS). The HCMS was conducted to characterize the spatial variations in concentrations of toxic air contaminants and their co-pollutants within the communities adjacent to the Ports of Los Angeles and Long Beach (Fujita et al., 2009), and had study objectives similar to WOMS. DRI evaluated the accuracy, sampling rates, and precision of the passive sampling methods in the laboratory using a flow-through chamber and in the field by comparing the passive measurements with collocated continuous NO/NOx and SO_2 monitors and time-integrated samples collected by active sampling methods (i.e., canisters and chemically-impregnated cartridges). Measurement precision was also established by collecting passive samples in triplicate at one of the HCMS sampling sites. The applicable hypothesis was that passive methods can be used to measure 1-week average ambient concentrations of selected pollutants with sensitivity and precision comparable to conventional monitoring methods averaged over the same period.

The above hypothesis was found to be generally true with a few exceptions. The replicate precisions for the HCMS were better than 10 percent for compounds with ambient levels greater than five times the limit of detection. Passive measurements of BTEX were generally within ± 15% of corresponding samples collected by active sampling methods that are commonly used in state and local monitoring programs. The passive samples for all BTEX were stable for storage times of up to 14 days at -18º C. The experimentally determined sampling rates for toluene and xylenes were within 10% of those published by Radiello. Our experimentally determined sampling rates for benzene and ethylbenzene of 22.4 and 37.4 ml/min, respectively, rather than 27.8 and 25.7 ml/min published by Radiello result in concentrations that are a factor of 1.24 higher for benzene and 0.69 lower for ethylbenzene.

AirMetricMinivol Aerosol Sampler
(20" long by 7" in diameter)

Ogawa passive samplers for NOx and SO2
(thumb size in protective cup shield)

Radiellopassive samplers for VOC, and aldehydes
(size of a roll of pennies)

Figure 2-5. Passive and mini-volume aerosol samplers used in the WOMS.

Table 2-2. Diffusive samplers and analytical methods with manufacturer supplied minimum detection limits for 7-day exposures.

Pollutant	Diffusive Body	Adsorbent	Analytical Method	MDL (168 hours exposure)
NO_2	Ogawa 3300 Sampler	Triethanolamine	Colorimetry for nitrite	0.32 ppb
NOx	Ogawa 3300 Sampler	Triethanolamine + PTIO	Colorimetry for nitrite	0.32 ppb
SO_2	Ogawa 3300 Sampler	Triethanolamine	Ion Chromatography for sulfate	0.54 ppb
VOC	Radiello 120-2, polycarbonate and yellow microporous polyethylene cylindrical diffusive body	Radiello 145, ss net cylindrical cartridge, o.d. 4.8 mm packed with 350 mg of 35-50 mesh graphitic charcoal (Carbograph 4)	Thermal Desorption GC/MS	benzene 0.05 etbenzene 0.02 toluene 0.02 xylenes 0.02 (ug/m^3)
Carbonyl Compounds	Radiello 120-1, polycarbonate and blue microporous polyethylene cylindrical diffusive body	Radiello 165, ss net cylindrical cartridge, o.d. 5.9 mm with 900 mg of 35-50 mesh DNPH coated florisil	HPLC-UV	formaldehyde 0.1 acetaldehyde 0.1 acrolein 0.3 (ug/m^3)

Notes: PTIO (2-phenyl-4,4,5,5-tetramethylimidazoline-3-oxide-1oxyl); ss net (stainless steel net)

Passive measurements of formaldehyde and acetaldehyde were in good agreement with diluted standards for the laboratory evaluations. Acetaldehyde measured by the passive sampler was 43% lower than values obtained by active sampling on DNPH cartridges. Acetaldehyde had poor accuracy probably due to low collection efficiencies over extended sampling times, which may also apply to "reference" samples collected actively on DNPH cartridges. The accuracy of passive measurements of acrolein could not be evaluated during the HCMS as their ambient concentrations were often below the limits of detection. The results for 1,3-butadiene from passive samplers with Carbograph 4 were not quantitative due to back diffusion and were not reported in the HCMS and will not be reported in WOMS. Results of HCMS evaluations are summarized in greater detail in Appendix A. The final report for the HCMS provides more detailed descriptions of the methods evaluations and summaries of the results (Fujita et al. 2009).

2.1.5 Evaluation of Passive Measurements during WOMS

Review of the passive sampling data after the initial summer intensive identified two problems that occurred with the Radiello VOC measurements, one during collection of the triplicate samples and a second, separate problem during thermal desorption analysis of the samples. The following describes the data anomalies, our explanation of the probable cause, and corrective measures that were implemented. These included both adjustments to the summer sampling data and changes to the sampling and analytical protocols so as to eliminate or minimize the problems during the winter sampling period.

The Radiello VOC samplers were applied in the HCMS with a high level of precision, as demonstrated described in Appendix A. However, results from the triplicate samples collected at the EMUD monitoring site during the summer WOMS were inconsistent. Results for the primary sample (top set of the three sets aligned vertically on a mast) during the three subsequent weeks were all within the range of values obtained at the other sites. However, the values obtained for the second and third replicates for the remaining three weeks were zero or nearly zero. These results were most likely related to a problem during sample collection.

The Radiello VOC passive sampler consists of a 4.8 mm (o.d.) stainless steel cylindrical cartridge packed with 350 mg of 35-50 mesh (~0.3-0.5 mm) graphitic carbon (Carbograph 4). The adsorbent cartridge is housed in a microporous polyethylene cylindrical diffusive body, which screws onto a support plate. Because the adsorbent cartridge is porous, a small amount of the carbon is lost to the outer walls of the cartridge or to the inner lining of the diffusive body. Carbon may accumulate inside the diffusive body over time, especially when the sampler is buffeted by high winds, clogging the micropores and preventing diffusion of ambient air to the adsorbent cartridge. This may have been the case for the diffusive bodies for the second and third replicate samples. We implemented the following modification to the sampling protocol for the Radiello VOC passive sampler for the winter phase of WOMS.

- The diffusive bodies were cleaned by sonication prior to use.
- Outsides of the adsorbent cartridges were wiped and cartridges weighed to ensure a minimum of 300 mg of carbon.
- Diffusive bodies were replaced with a clean one with each sample change.
- Provided increased protection of the samplers from the effects of strong winds.

The Radiello passive cartridges were analyzed by thermal desorption (Gerstel TDSA-3 unit) of the sample to a Varian 3800 gas chromatograph with a Saturn 2000 mass spectrometer. Anomalous values were obtained for toluene during the initial summer phase of WOMS and traced to contamination of the thermal desorption unit. This system was used for another project during the second and third week of August 2009. In the prior project, quartz filter samples were thermally desorbed and the calibration standards were diluted in toluene, which was adsorbed on the Viton seals of the Gerstel autosampler. During the thermal desorption analysis of the WOMS Radiello cartridges in the last week of August 2009, toluene slowly desorbed while the cartridges were loaded into the autosampler awaiting analysis. The amount of toluene that desorbed was different for different position of the autosampler making background subtraction problematic. However, since sample sets were small, the last four position of the autosampler were never used for holding quartz filter sample media, and thus had never been exposed to toluene. We noticed that the samples run from these positions did not show any evidence of excessive toluene concentrations.

Analysis of summer WOMS passive VOC cartridges occurred over the course of 4 days in the last week of August, with each day having another calibration sequence. Overall, the degree of toluene contamination decreased with each successive sample set as the toluene off-gassing from the Viton plugs was scavenged by the VOC sampling media. The ratio of toluene to ethylbenzene is known to be essentially constant in the absence of significant non-mobile sources of these species (e.g. industrial solvent use), so we used the uncontaminated samples to

determine this ratio then estimate the toluene concentrations for all highly contaminated samples using the equation y=3.49 x (where y= unknown toluene concentration and x=ethylbenzene concentration). To prevent this from happening again during the winter phase, we replaced all Viton plugs in the autosampler and used standards prepared in methanol, acetonitrile, or some other suitable solvent that is not quantified on this instrument.

Replicate precisions of the WOMS passive measurements are given in Table 2-3 through Table 2-5. The results include seasonal means of the four 7-day samples at the EMUD site and the mean % relative differences between the individual replicates and mean of the three replicates. With the exceptions described above, the replicate precisions of the passive measurements are generally consistent with the estimates of precision obtained during the HCMS, which are also presented for comparison in the tables. The mean ambient concentrations measured during the WOMS summer sampling period were well above the detection limits for all compounds with the exception of SO_2 and acrolein. The replicate precisions of the passive measurements for WOMS were better than 10 percent for compounds with ambient concentrations greater than five times the limit of detection. The practical consequence of these results is that any spatial differences in pollutant concentrations within the WOMS monitoring network that are greater than two times the mean relative difference between replicates are significant with respect to the precision of the measurement.

Table 2-3. Replicate precision of passive NO_2, NOx and SO_2 measurements at EMUD site during summer and winter WOMS compared to results from the HCMS.

	MDL [1]	4-wk Mean	Differences of Replicates	
	ppb	ppb	Mean (ppb) [2]	%RD [3]
WOMS Summer				
Nitorgen Dioxide (NO_2)	0.32	9.0	1.3	14.0%
Nitrogen Oxides (NOx)	0.32	17.5	0.7	4.2%
Sulfur Dioxide (SO_2)	0.54	0.09	0.03	33.9%
WOMS Winter				
Nitorgen Dioxide (NO_2)	0.32	5.7	0.1	1.7%
Nitrogen Oxides (NOx)	0.32	25.9	0.8	3.1%
Sulfur Dioxide (SO_2)	0.54	1.0	0.8	81.5%
HCMS Summer				
Nitorgen Dioxide (NO_2)	0.32	19.5	1.0	4.9%
Nitrogen Oxides (NOx)	0.32	29.4	0.6	2.2%
Sulfur Dioxide (SO_2)	0.54	1.0	0.2	19.8%
HCMS Winter				
Nitorgen Dioxide (NO2)	0.32	28.5	1.5	5.3%
Nitrogen Oxides (NOx)	0.32	73.0	2.0	2.8%
Sulfur Dioxide (SO2)	0.54	1.1	0.1	9.8%

[1] Minimum detection limits (MDL) are based upon manufacturer's specification for 7-day exposure.
[2] Mean of the absolute differences between mean of the triplicates and individual sample (up to 12 values per season).
[3] Mean of the absolute differences normalized to mean of the triplicate in percent.

Table 2-4. Replicate precision of passive BTEX measurements at EMUD sites and during summer and winter WOMS compared to results from the HCMS.

	MDL [1]	4-wk Mean	Differences of Replicates	
	ppb	ppb	Mean (ppb) [2]	%RD [3]
WOMS Summer				
benzene	0.015	0.16		
toluene	0.002	0.19	Not Available.	
ethylbenzene	0.002	0.08	See text for explanation.	
xylenes	0.002	0.36		
WOMS Winter				
benzene	0.015	0.26	0.02	7.8%
toluene	0.002	0.78	0.04	5.1%
ethylbenzene	0.002	0.15	0.01	5.1%
xylenes	0.002	0.63	0.03	5.0%
HCMS Summer				
benzene	0.015	0.35	0.03	7.5%
toluene	0.002	1.05	0.04	4.2%
ethylbenzene	0.002	0.21	0.01	6.7%
xylenes	0.002	0.69	0.06	9.2%
HCMS Winter				
benzene	0.015	0.61	0.01	2.3%
toluene	0.002	1.73	0.04	2.3%
ethylbenzene	0.002	0.34	0.01	2.4%
xylenes	0.002	1.41	0.03	2.2%

[1] Minimum detection limits (MDL) are based upon manufacturer's specification for 7-day exposure.

[2] Mean of the absolute differences between average of the triplicates and individual sample (up to 12 values per season).

[3] Mean of the absolute differences normalized to mean of the triplicate in percent.

Table 2-5. Replicate precision of passive aldehyde measurements at EMUD sites and during summer and winter WOMS compared to results from the HCMS.

	MDL [1]	4-wk Mean	Differences of Replicates	
	ppb	ppb	Mean (ppb) [2]	%RD [3]
WOMS Summer				
Formaldehyde	0.07	1.4	0.03	1.8%
Acetaldehyde	0.05	0.55	0.03	4.7%
Acrolein	0.12	0.009	0.005	57.7%
WOMS Winter				
Formaldehyde	0.07	1.3	0.1	5.1%
Acetaldehyde	0.05	0.5	0.1	18.9%
Acrolein	0.12	0.028	0.009	65.5%
HCMS Summer				
Formaldehyde	0.07	1.76	0.12	6.7%
Acetaldehyde	0.05	0.73	0.03	4.7%
Acrolein	0.12	0.010	0.005	47.4%
HCMS Winter				
Formaldehyde	0.07	2.65	0.06	2.2%
Acetaldehyde	0.05	1.88	0.05	2.8%
Acrolein	0.12	0.028	0.015	52.0%

[1] Minimum detection limits (MDL) are based upon manufacturer's specification for 7-day exposure.
[2] Mean of the absolute differences between average of the triplicates and individual sample (up to 12 values per season).
[3] Mean of the absolute differences normalized to mean of the triplicate in percent.

2.1.6 Community Outreach and Participation

The Bay Area Air Quality Management District held several meetings with the local community to publicize the objectives and scope of the proposed study. The following meetings sorted by date were held with representatives of the Port of Oakland, Community Members, and the CARE Task Force.

West Oakland Measurement Study Meeting
Port of Oakland/BAAQMD
Port of Oakland, Oakland
September 17, 2007

CARE Task Force Meeting
Bay Area Air Quality Management District
San Francisco, CA
December 12, 2007

Community Air Quality Input Meeting
West Oakland Public Library
Oakland, CA
April 10, 2008

CARE Task Force Meeting
Bay Area Air Quality Management District
San Francisco, CA
September 17, 2008

CARE Task Force Meeting
Bay Area Air Quality Management District
San Francisco, CA
November 18, 2008

West Oakland Measurement Studies Meeting
Willie Keyes Recreation Center
Oakland, CA
January 22, 2009

West Oakland Measurement Study Meeting
West Oakland Environmental Indicators Project (WOEIP)/BAAQMD
WOEIP Office, Oakland
June 30, 2009

The saturation monitoring relied greatly on community volunteers that offered their residences or businesses for many of our sampling sites. We gratefully acknowledge the following contributors and participants: Margaret Gordon (Co-Director, West Oakland Environmental Indicators Project), Brian Beveridge, Co-Director West Oakland Environmental Indicators Project), Ina Bendich (Teacher, EXCEL High School), Sharon Parker (Executive Director, ASA Academy and Community Science Center), Mike Percey (Business Owner, Cypress Auto Salvage), Jeff Jones (Port Environmental Compliance Supervisor, Port of Oakland), Bruce Buckelew (Founder/Director, Oakland Technology Exchange), Marcel Diallo (Oakland Resident/Chief Creative Officer, Black Dot Artists, Inc.), Letitia Ntofon (Oakland Resident/Artist, Black Dot Artists, Inc.), Oscar Martinez (Oakland Resident), Raymond Riley (Oakland Resident), Charles J. Murphy (Alameda Resident), Michael Murphy (Alameda Resident/District Employee).

2.2 Mobile Measurements

The surveys of pollutant concentrations were conducted to characterize the spatial variations in pollutant concentrations and to identify hotspots in pollutant concentrations. Spatial surveys of the variations in pollutant concentrations at the Port of Oakland and within West

Oakland were conducted with the BAAQMD mobile monitoring van following the measurement protocol outlined in the WOMS study plan. The instrument platform is a 2008 Ford E-350 cargo van modified by E-N-G Mobile Systems, Inc. to include an instrument rack, desk/workbench, calibration gas cylinder rack, and 100VAC and 12VDC power system that can operated off of on-board batteries or line power. The continuous instruments used in the surveys included O_3, NO, CO, VOC (est.), black carbon, $PM_{2.5}$ mass (est.), and ultrafine particle counts with time resolution of 10 seconds (Table 2-6).

The surveys determined spatial variations in pollutant concentrations within the Port of Oakland and West Oakland relative to the WOMS fixed monitoring sites and potential emission hotspots ("stops"). Figure 2-6 shows one of the spatial plots (10-second average NO) from the pilot study conducted prior to the summer 2009 WOMS (Fujita et al., 2009). Results of the pilot study showed that the spatial patterns of higher pollutant concentrations were generally consistent with proximity to vehicle traffic. NO, PM and UFP concentrations were higher on the main truck routes within the Port, on the frontage road along the west edge of I-880, and on several of the major arterial streets in West Oakland (e.g., 7th Street, Grand Ave. and Mandela Pkwy. Pollutant concentrations were about a factor of 2 to 5 lower for most pollutants within the residential areas of West Oakland that are at least a city block off the main arterial streets. The higher pollutant concentrations were also measured near the entrances to the port near I-880 at 7th Street, Grand Avenue and Adeline Street. Concentrations of black carbon were highest in close proximity to diesel trucks. However, the spatial pattern was less obvious in the spatial plots of BC because the effective resolution of the photoacoustic instrument was limited to 1-2 ug/m^3 by baseline drift. The mini Photoacoustic instrument for measuring black carbon was modified to reduce baseline drift (see Appendix A for details).

Measurements were made along the same prescribed route, which started and ended at the Port of Oakland maintenance yard near the intersection of 7th Street and Maritime Street. The route took approximately two hours to complete and included the sequence of survey areas shown in Table 2-7. Measurements were made during different times of the day and day of week because pollutant concentrations vary due to temporal variations in both emissions and meteorological conditions (see Figure 2-7). Concentrations of primary pollutant at EMUD during the summer study were highest during the early morning and secondary pollutants were highest during the afternoon and evenings. While NOx, BC and SO_2 are higher during the middle of the week, CO and PM were higher during the weekends.

Measurements were made twice per day (morning and afternoon) for four days on Tuesday 8/11, Wednesday 8/12, Wednesday 8/19, and Sunday 8/23/2009. These measurements were repeated during the winter field study during morning and midday runs on 1/14/2010 (with partial data recovery due to malfunctions of the NO and CPC instruments), late morning on Friday Jan 29, 2010, and late morning (9:30 AM - 12:30 PM) on Saturday 1/30/2010. Stationary measurements were made at each stop for 5 to 15 minutes and mobile measurements were made between stops. Measurements were also made on roadways with varying mix of diesel and gasoline vehicles and in residential areas during times with probable impact from residential wood combustion. The slopes of the regressions of $PM_{2.5}$ to BC concentrations measured in locations dominated by diesel exhaust emissions, gasoline exhaust and residential wood combustion were subsequently examined to evaluate the use of BC as a surrogate for diesel particulate matter (DPM).

Table 2-6. Continuous instruments operated in the BAAQMD mobile van.

Parameters measured:	**Ozone**	**NO**	**CO**	**"VOC"**	**PM2.5 Mass**	**Ultra-fine particles**	**light-absorbing carbon**
Manufacturer:	2B Technologies	2B Technologies	TEI	RAE Systems	TSI	TSI	Pat Arnott, UNR
Model:	202	400	48	ppbRAE 3000	8530 DustTrak	3007	mini-PA
Method:	UV absorption (254 nm)	Ozone depletion by NO measured by UV (254 nm)	infrared energy absorption	photo-ionization detector	Light scattering	CPC, isopropanol	photoacoustic
Lower Detectable Limit:	1.5 ppb	2 ppb	0.2 ppm	~30 ppb (1)	~ 1 ug/m3	< 1 particle/cm3	0.2 ug/m3 for 1 min
Range :	up to 100 ppm	up to 200 ppm	0-1,000 ppm	1 ppb to 10,000 ppm	0.001 to 100 mg/m3	0.015 - 1 um, 0 - 10^5 particles/cm^3	
Resolution:	0.1 ppb	0.1 ppm	0.01 ppm	1 ppb	0.1% + 0.001 mg/m3		0.1 ug/m3
Min sampling interval:	10 sec	10 sec	10 sec	1 sec	1 sec	9 sec	1 sec
Response Time:	20 sec		<40 secs	2 sec			1 sec
Linearity:	1% FS		1% FS			100±20% efficiency (>50% at 15 nm)	
Precision:	2%+1.5 ppb	3%+2 ppbv	0.50%	10%+20 ppb	1 ug/m3		<10%
Span Drift (24 hour):	<1%		<0.5%				
Zero Drift (24 hour):	1 ppb/hr		<0.1 ppm				
Interferences:	aromatic HC	aromatic HC?	0.05% per oC, 4x10-5 H20, 8x10-5 CO2				
Sample Flow Rate:	1 l/min	1 l/min	0.8 l/min	0.4 l/min		Aerosol Flow: 100cc/min, Total Flow: 700cc/min	1 l/min
Data Storage (1' logging)	84 days	84 days	none	10.4 days		10,000 measurements	Unlimited
Output:	RS232, 0-2.5 V Analog, LCD Display	RS232, 0-2.5 V Analog, LCD Display	RS232, 0-10 VDC Analog, LCD Display	RS232, 0-10 VDC Analog, LCD Display		LCD display, USB interface	Datalogging to system PC, Excel or text file formats
Power Requirements:	12 VDC or 110/220 VAC, 4.2 watt at 12 V (2.9 watt in low power mode)	11-14 W DC, nominally 0.9 A at 12 W, 11 Watts - we have AC adapter	120 AC	4.2 V/3300 m AH rechargeable battery or AC (100W @ 110VAC) or DC	Rechargeable batteries or AC adapter	6 AA-size batteries (5-8 hrs run time), or AC adapter (100 – 240V)	150 W at 110VAC, plus pump (<100W @ 12VDC)
Operating Temp/RH:	0-60C	0-60C	5 - 40C	-20 C to 50 C		10 to 35 C	
Dimensions:	front 17 in, depth 13 in, height 4 in	front 8.3 in, 11.6 in depth, 3.5 in height	17 in front x 7 in height x 23.5 in depth	9.25 in length, 3.6 in width x 2.9 in height		11.5 in x 5.5 in x 5.5 in	10" x 6" x 12"
Weight:	4.7 lb	6.4 lbs	40 lbs	1.25 lbs		3.8 lb with batteries	5 lbs
Installation	Rack mounted	Rack mounted	Rack mounted	handheld		handheld	
Span Gas Required?	Superblend gas	Superblend gas	Superblend gas				

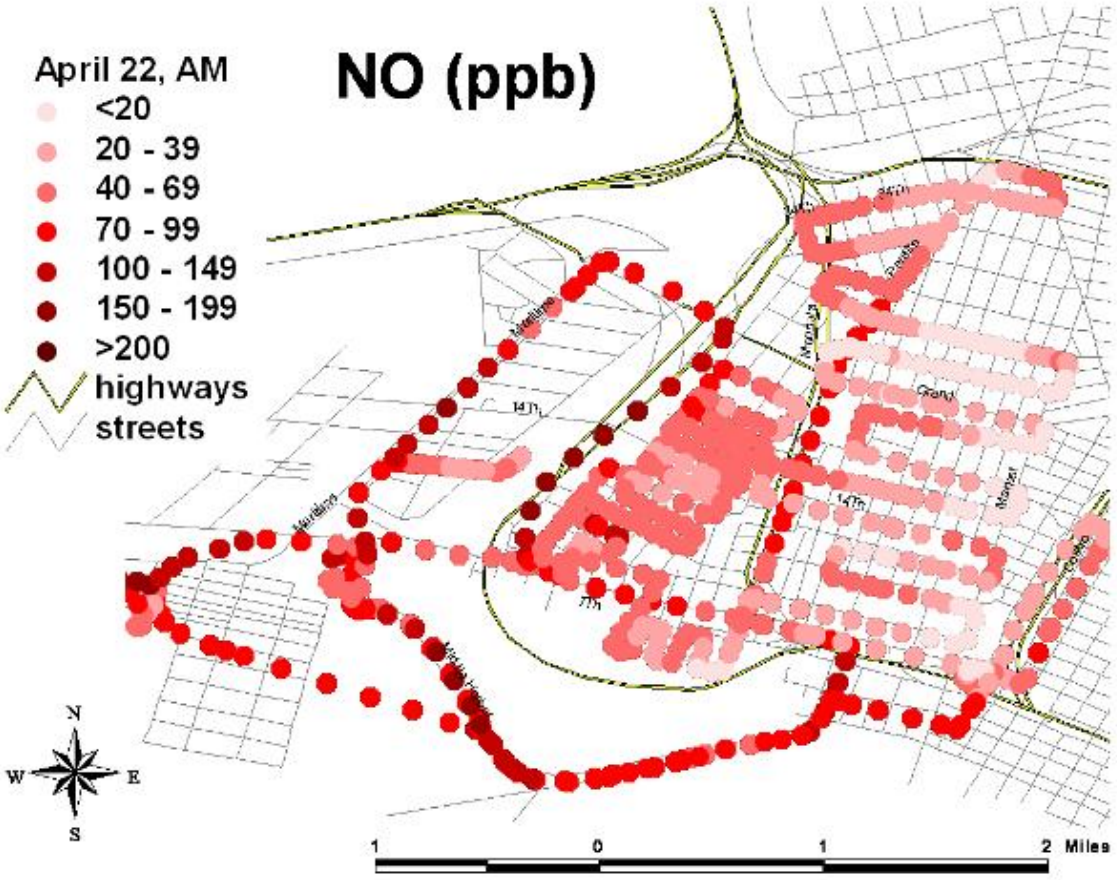

Figure 2-6. Spatial variation in NO concentration (10 second averages) during morning (NO analyzer malfunctioned during April 23 morning run).

Table 2-7. Example of mobile measurement schedule.

		Early AM Run		Late AM Run		PM Run			
Sampling Mode	Location or Route	Dur (min)	Start Time	Dur (min)	Start Time	Dur (min)	Start Time	Location ID	Site Name
Stationary	**Port of Oakland maintenance yard - base location**	0:10	7:20	0:10	10:00	0:10	13:20	POC	Site 6 - Port of Oakland Central
Mobile	N on Maritime, W on 7th to next stop.	0:05	7:30	0:05	10:10	0:05	13:30		
Stationary	Port of Oakland adjacent to active terminal: near east end of Transbay Container Terminal (Berths 26, 25) off of 7th St. Drive slowly by this location without stopping if no activity at terminal.		7:35		10:15		13:35		
Mobile	Middle Harbor Shoreline Parkat - park at south end near lookout tower, drive slowly at parking lot and head for exit.	0:05	7:35	0:05	10:15	0:05	13:35		Gradient Site 1
Stationary	Port of Oakland at east end of Oakland Int'l Container Terminal (Berths 57-59) off of Middle Harbor Rd. Drive slowly by this location if no acitvity at terminal	0:10	7:40	0:10	10:20	0:10	13:40		
Mobile	E on Middle Harbor Rd to Adeline, W on 7th St, S on Henry, E on 5th St, S on Center St, W on 3rd St, N on Peralta, W on 8th, S on Pine, E on Goss, S on Wood, W on 7th.	0:08	7:50	0:08	10:30	0:08	13:50		Gradient Sites 7 and 5
Mobile	W on 7th, drive slowly by gradient site 3, N on Maritime, drive slowy by gradient site 2, E on Grand, S on Frontage Rd, drive by gradient site 4, E on 7th, N on Wood to next stop.	0:08	7:58	0:08	10:38	0:08	13:58		Gradient Site 5
Stationary	**Residence, 1026 Pine St.**	0:10	8:06	0:10	10:46	0:10	14:06	NR1	Site 2 - Near Road
Mobile	S on Pine, E on Goss, N on Wood, E on 17th, S on Willow, E on 8th, N on Campbell to next stop.	0:05	8:16	0:05	10:56	0:05	14:16		
Stationary	Oakland Technology Exchange, 1680 14th St.	0:05	8:21	0:05	11:01	0:05	14:21	WO1	Site 3 - West Oakland - SW
Mobile	N on Campbell, E on 20th, S on Peralta, E on 8th, N Mandela Pkwy, W on Grand, N on Willow, W on 24th, N on Wood, E on 26th, N on Campbell, E on 28th to next stop.	0:08	8:26	0:08	11:06	0:08	14:26		Drive by G6 (near east edge of I-880 north of Grand)
Stationary	Cypress Auto Salvage 2717 Peralta St.	0:05	8:34	0:05	11:14	0:05	14:34	CUPW/WO3	CASS upwind/WOMS Site 5 West Oakland - NW
Mobile	E on 28th passing CASS and ASA Academy to Excel High	0:05	8:39	0:05	11:19	0:05	14:39		
Stationary	Excel High School HS, 2607 Myrtle St.	0:05	8:44	0:05	11:24	0:05	14:44	CFDW	CASS far downwind
Mobile	E on 28th, S on Market, W on 26th, S on Poplar, E on 24th, S on Market, W on Grand, S on Poplar, E on 21st to next stop.	0:07	8:49	0:07	11:29	0:07	14:49		
Stationary	**EBMUD District air monitoring station, 1100 21st St.**	0:10	8:56	0:10	11:36	0:10	14:56	EMUD	Site 1 - EBMUD
Mobile	E on 21st, S on Market, W on 18th, S on Poplar, E on 16th, S on Market, W on 14th, S. on Union, E on 12th, S on Filbert to next stop.	0:07	9:06	0:07	11:46	0:07	15:06		
Stationary	Residence, 1111 Filbert St.	0:05	9:13	0:05	11:53	0:05	15:13	WO2	Site 4 - West Oakland - SE
Mobile	N on Filbert, E on 12th, S on Market, W on 10th, S on Union, E on 8th, S on Market, W on 7th, S on Adeline, E on 5th, S on Market, W on 3rd, W on Middle Harbor Rd, N on Martime back to Base.	0:10	9:18	0:10	11:58	0:10	15:18		Drive by G8 and G7
End Time			9:28		12:08		15:28		
Total Time		2:08		2:08		2:08			

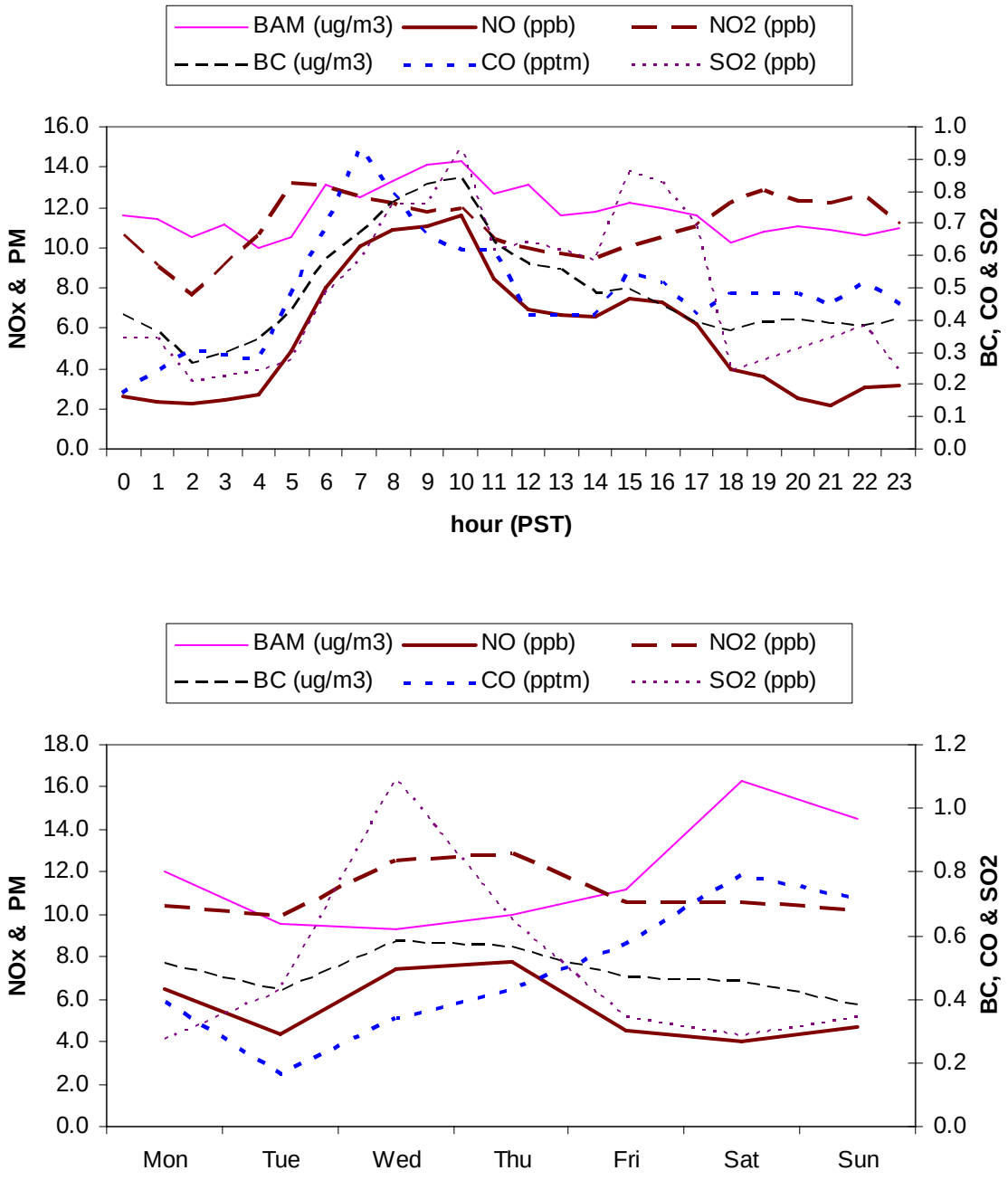

Figure 2-7. Diurnal (top) and day-of-week (bottom) patterns of pollutant concentrations measured by the BAAQMD at EMUD during WOMS 4-week summer study period.

2.3 Chemical Speciation for Source Attribution

DRI collected pairs of 24-hour Teflon and quartz filters with DRI medium volume (55 lpm) sequential filter samplers (SFS) on 14 consecutive days during the summer (8/7/09 to 8/20/09) and winter (1/6/10 to 1/19/10) at three sites (EMUD, Port of Oakland maintenance yard, and the West Oakland site E of I-880 - Sampling Location NR1). The Teflon filters were analyzed for $PM_{2.5}$ mass and elements by XRF and quartz filters analyzed by Thermal Optical Reflectance (TOR) for organic and elemental carbon using the IMPROVE protocol. The averages of the seven 24-hour Teflon and quartz samples were compared to the corresponding data from the 7-day integrated mini-vol samples. 24-hour samples were also collected for speciation of particulate and semi-volatile organic compounds on Teflon-impregnated glass fiber filters (TIGF) with XAD resin backup cartridges at the same three sites on a Sunday and three weekdays. The 12 samples plus 2 field blanks were analyzed by gas chromatography and mass spectrometry for polycyclic aromatic hydrocarbons, alkanes, hopanes, steranes, and polar compounds.

The Chemical Mass Balance receptor model was applied to the speciated particulate-phase organic compounds using appropriate source composition profiles to determine the source contributions of DPM, gasoline vehicles, wood smoke, and cooking emissions. The contributions of diesel particulate matter (DPM) to ambient levels of $PM_{2.5}$ were also determined by applying ratios of $PM_{2.5}$ to BC measured in locations dominated by diesel exhaust emissions to the BC or EC concentrations measured at the three aerosol speciation sites.

2.4 Source Apportionment Method and Procedures

Version 8 of the DRI/EPA Chemical Mass Balance (CMB) receptor model (Watson et al., 1997) was used to apportion ambient total carbon (TC) to the primary sources of carbonaceous particles (gasoline vehicle exhaust, diesel vehicle exhaust, wood combustion, and meat cooking). The source composition profiles were normalized to TC (in weight fractions) and composite profiles were derived by averaging weight fractions rather than emission rates. The former approach gives equal weight to all members of the composite while the latter method gives greater weight to high-emitters. The uncertainties were set to the analytical uncertainties or one σ variability in species abundances among members of a composite.

Total carbon (TC) and OC are key parameters for receptor modeling because they are used to both normalize species abundances in the source profiles and determine the relative source contributions of primary emissions and determine the residual unexplained carbon (i.e., not attributed to primary sources), which is typically interpreted as the upper bound of the contribution of Secondary Organic Aerosols (SOA). The following measurement variation and uncertainty need to be carefully considered when comparing source and receptor modeling results:

- EC and OC are operationally defined by the method, the specific instrument used (Watson et al., 2005), details of its operation, and choice of thermal evolution protocol (Chow et al., 2005), and filter handling.

- Sampling of OC on quartz filters is prone to both negative and positive artifacts. These artifacts vary by site and season and may be significant relative to the filter mass loadings of ambient samples.

- The phase distributions of various semi-volatile organic compounds in ambient samples may differ from source samples resulting in varying ratios of marker compounds to TC.

- Source models predict the mass of organic matter (OM) which differs from measured OC by factors that vary for specific sources and change with time due to atmospheric transformations.

Elemental carbon (EC) is dominant in diesel exhaust, but is less abundant in emissions from newer technology diesel engines and at lower engine load. EC abundances in PM emissions of gasoline vehicles are very low but can be higher during hard accelerations and during cold starts and for high emitters that emit black smoke. Hopanes and steranes are present in lubricating oil with similar composition for both gasoline and diesel vehicles. While hopanes and steranes are useful markers for motor vehicle emissions, they cannot be used to distinguish between gasoline and diesel exhaust. Gasoline vehicles, whether low or high emitter, emit greater abundances of high molecular-weight particulate PAHs (e.g., benzo(b+j+k)fluoranthene, benzo(ghi)perylene, ideno(1,2,3-cd)pyrene, and coronene) relative to other PAHs than do diesel vehicles. Diesel vehicles also emit particulate PAHs, but in lower relative proportions relative to other PAHs, especially the semi-volatile methylated PAHs.

Particulate carbon emissions from vegetative burning are predominantly organic with OC/EC ratios for softwood of about 4 compared to 8 to 9 for hardwood. The unaltered resin acids, such as dehydroabietic, abietic or pimaric acid were found in coniferous (mostly pine) wood smoke but are not detected in deciduous tree wood smoke (Rogge et al., 1993). Guaiacol (2-methoxyphenol), syringol (2,6 dimethoxyphenols) and their derivatives are commonly found in wood burning emissions. The guaiacol series are fairly consistent no matter what type of wood was being burned, while the syringol series are almost two orders of magnitude higher in hardwoods. These wood lignin pyrolysis products are emitted in distinctive amounts and constitute as much as 21 percent of the total fine particle mass emissions (McDonald et al., 2000). Levoglucosan (1,6-anhydro-β-D-glucose) is a product of the decomposition of cellulose with emission rates substantially higher than other organic species and is very stable in the atmosphere. However, the abundance of levoglucosan is substantially higher for pine needles and grasses than for wood (Mazzoleni et al., 2007) and higher in hardwood combustion that softwood combustion (Fine et al., 2002). Using profiles for residential softwood combustion in CMB may lead to significant overestimation of the contributions of biomass combustion emissions in ambient samples affected by wildland fires or prescribed burns. The hardwood profile contains abundances of levoglucosan that are comparable to those reported for wildland fires (Mazzoleni et al., 2007). Therefore both softwood and hardwood profiles were included in the default set of source profiles in the CMB calculations.

Meat cooking profiles include charbroiled hamburger and chicken separately and combined composite with 50:50 weighting. The emissions from meat cooking depend strongly on the cooking method used, fat content of the meat, and the type of grease eliminator used in the

cooking facilities. The identified compounds belong to the following compound classes: alkanes, alkanoic and alkenoic acids, dicarboxylic acids, alkanals and alkenals, ketones, alkanols, furans, lactones, amides, nitriles, polycyclic aromatic hydrocarbons, pesticides, and steroids. However, fatty acids can be emitted from other sources in addition to meat cooking. Among these compound classes, alkanoic and alkenoic acids (normal and unsaturated fatty acids) are the most abundant. Hexadecanoic (palmitic) and octadecanoic (stearic) are the most abundant alkanoic acids and 9-hexadecenoic (palmitoleic) and cis-9-octadecenoic (oleic) acids are the most abundant alkenoic acids. Cholesterol is a specific organic marker for meat cooking, but it typically accounts for negligible fraction (less than 0.1 percent) of particulate OC.

In addition to emissions from combustion sources, OC can be directly entrained into the atmosphere by abrasion of leaf and plant wax (during summer months) and decomposition of vegetative detritus (fall). High molecular n-alkanes with strong odd carbon number predominance may serve as marker for this source. It has been reported (Rogge et al., 1993) that the carbon preference index (CPI) is a measure of biologically synthesized compounds. Rogge et al. (1993) suggest that the groups of n-alkanes in the range of C27 to C33 with their strong odd carbon number predominance may serve as markers for green and dead leaf abrasion products released to the atmosphere. Gasoline and diesel powered vehicles emit n-alkanes mainly in the carbon range <C27 with no odd/even carbon number predominance, so no interference is expected from these sources. However, the odd carbon number n-alkanes ranging from C27 to C33 are found in cooking vegetable oil and in resuspended soil (from the dead and degraded plant material) so the vegetative detritus apportioned by using C27-C33 alkanes would represent the upper range of their contribution to ambient PM.

The default chemical profiles were selected based upon best CMB model performance among the alternative source profile. However, it must be recognized that variations in contributions with alternative source profiles often exceeds the uncertainties yielded by the CMB model based on analytical uncertainties alone. Therefore, the uncertainties were set to the analytical uncertainties or one σ variability in species abundances among members of a composite. The larger of the two uncertainties were used. A set of default chemical profiles was selected based upon best CMB model performance among the alternative source profiles. The ambient samples were applied in CMB to the default profiles using 18 to 20 fitting species: EC, 3 PAHs, 4 hopanes and steranes, wood and meat cooking markers, and high molecular weight alkanes.

2.5 Elemental Carbon as a Surrogate for Diesel Particulate Matter

Diesel particulate matter (DPM) is composed of a center core of elemental carbon (EC) coated with organic compounds, as well as small amounts of sulfate, nitrates, metals, and other trace elements. There is no direct method for measuring DPM in ambient air as it contains many of the chemical components that are also emitted by other combustion sources (e.g., gasoline vehicles). Ambient concentrations of EC in the South Coast Air Basin have been primarily attributed to diesel exhaust (Fujita et al., 2007b, Lough et al., 2007b). Surrogate calculations of DPM have been based on the fraction of ambient EC attributed to diesel engine exhaust by source apportionment methods and the fraction of the total mass of diesel particles determined to be EC in direct source measurements. In the Multiple Air Toxics Exposure Study in the South

Coast Air Basin (MATES-II, SCAQMD, 2000), EC measurements were used to estimate DPM concentrations using the following relationships: approximately 67% of EC in the ambient air in the Los Angeles area originates from diesel engine exhaust (Gray, 1986), and the average EC fraction of diesel particles was 64%. Therefore, in the MATES-II study, the South Coast Air Quality Management District calculated DPM concentrations from EC measurements by multiplying a measured EC concentration by 67% and dividing by the fraction of DPM mass accounted for by EC (64%), that is, DPM concentration = (EC * 0.67)/0.64, or DPM = EC * 1.04. Using a 1998 emissions inventory for the South Coast Air Basin, the conversion from EC to DPM is a factor of 1.24 (MATES-II, SCAQMD, 2000).

The estimation of DPM from EC was recently updated for the Harbor Communities Monitoring Study (HCMS) (Fujita et al., 2009). In this study, diesel particulate carbon (DPC) concentrations were estimated at each site from the measured EC concentrations times the slope of the correlation between total carbon and EC at the near road sampling locations for each season. TC and EC were well correlated (R^2 between 0.8 and 0.9) with slopes between 1.5 and 2.2. The upper-bound ambient concentrations of DPC were estimated using these regression results and the average EC concentrations at each site. Diesel particulate matter (DPM) was estimated from the following relationship:

Diesel Particulate Matter (DPM) = EC + 1.46 (DPC-EC)

where 1.46 is the ratio of diesel particulate organic matter (DPOM) to DPC from the Gasoline/Diesel PM Split dynamometer testing of diesel trucks in the Riverside, CA area (Fujita et al., 2007, El-Zanan et al., 2008). Metals have a minor contribution to DPM and can be excluded in the above calculation. The estimated annual average concentrations of DPM (from the EC surrogate method) at the HCMS residential sampling sites were similar to those determined in MATES-III at the West Long Beach and North Long Beach monitoring sites using Chemical Mass Balance receptor model (SCAQMD, 2008, Fujita et al., 2009).

The EC surrogate approach applied in the HCMS was used in WOMS to estimate ambient concentrations of DPM from measured EC concentrations at the eight WOMS PM sampling sites. The EC to TC correlations were derived specifically for WOMS using the 24-hour quartz filters collected on 14 consecutive days during the summer (8/7/09 to 8/20/09) and winter (1/6/10 to 1/19/10) at three sites (EBMUD, Port of Oakland maintenance yard, and the West Oakland site E of I-880 - Sampling Location NR1).

2.6 WOMS Data Validation

An assessment of the quality of the data produced by these samplers was critical to the objectives of the WOMS. The BAAQMD East Bay Municipal Utility District (EMUD) monitoring site was used in the WOMS as a quality assurance site. In addition to the primary passive samples (7-day Ogawa samplers for NO_2, NOx, SO_2 and Radiello samplers for BTEX, 1,3-butadiene, formaldehyde, acetaldehyde and acrolein) and 7-day mini-volume aerosol samples for $PM_{2.5}$ mass and OC and EC, DRI collected two additional sets of replicate samples during the winter and summer sampling periods to establish the precision of the passive measurements. The EMUD site was selected as the quality assurance site in order to utilize the District's routine criteria pollutants and air toxics measurements which are collected with traditional methods.

Preliminary data for NO, NOx, CO, SO_2, $PM_{2.5}$ mass and black carbon were provided by the BAAQMD and compared with corresponding WOMS data.

The BAAQMD data were used for initial review of the WOMS data to identify and diagnose potential problems in the monitoring program. Results are shown in Figure 2-8. Correlations were excellent for both daily and 7-day PM measurements although there were indications of bias, particularly for the gravimetric mass vs. BAM. We suspect the BAM was out of calibration, since same relationship existed to both SFS and miniVols and the daily SFS agreed well with the 24-hour gravimetric mass concentrations measured simultaneously for the CASS project. NO and NO_2 from the passive samplers was strongly correlated with the reference measurements with only a small bias of about 10%, despite very low average concentrations. SO_2 concentrations were too low for meaningful comparison.

The 24hr and 7-day long $PM_{2.5}$ filter data were compared by averaging the daily sample results for the weeks corresponding to the speciation sampling (Figure 2-9). Both sets began on the same day, however the daily samples began at midnight while the 7day samples started between 8AM and 4PM. Comparisons are generally good. Higher OC concentrations were measured by the SFS, which is attributable to larger positive artifact for 7 filters versus 1. Higher soils were also measured by the SFS during the summer, possibly due to lower inlet height, but not during winter. The improvement may be related to relocation of the samplers at the port site, since much higher inorganic mass was measured at that site than the others during summer. Agreement between the two sampling methods was achieved for mass, EC, and abundant elements like sulfur, however, so the difference is not due to volumetric sampling errors. Measured concentrations of many elements of interest were generally below XRF detection limits. Metals detected above analytical uncertainty for most samples were Fe and V during summer and Al, Ti, V, Cr, Mn, Fe, Cu, Zn, Se, Br, Sr, Zr, Sn, Pb during winter.

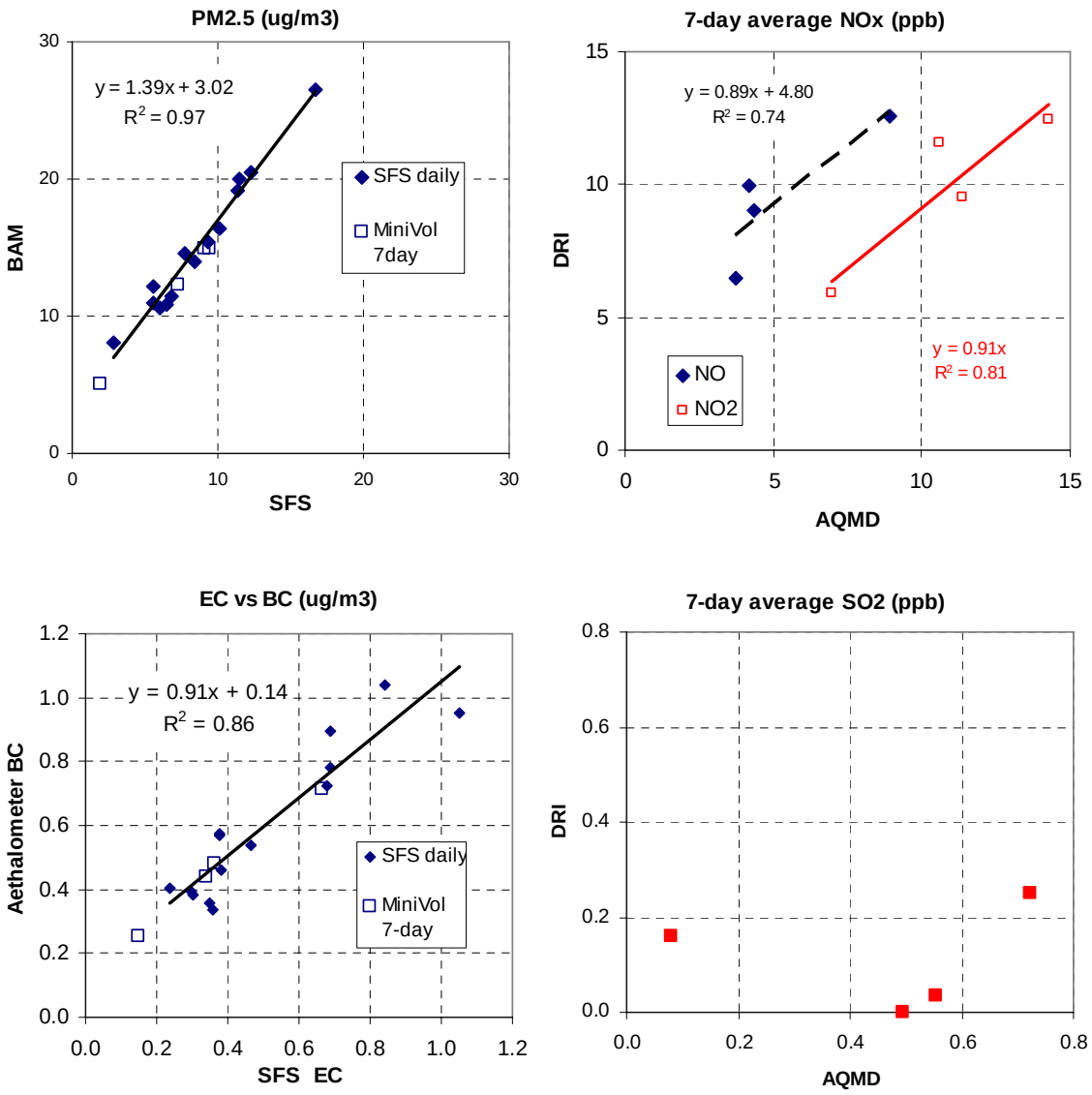

Figure 2-8. Comparison of daily and weekly DRI measurements at EMUD site to time-averages of continuous analyzer data collected by BAAQMD. Note that the 7-day minivol $PM_{2.5}$ mass values are averages of all WOMS sites with valid data for the week.

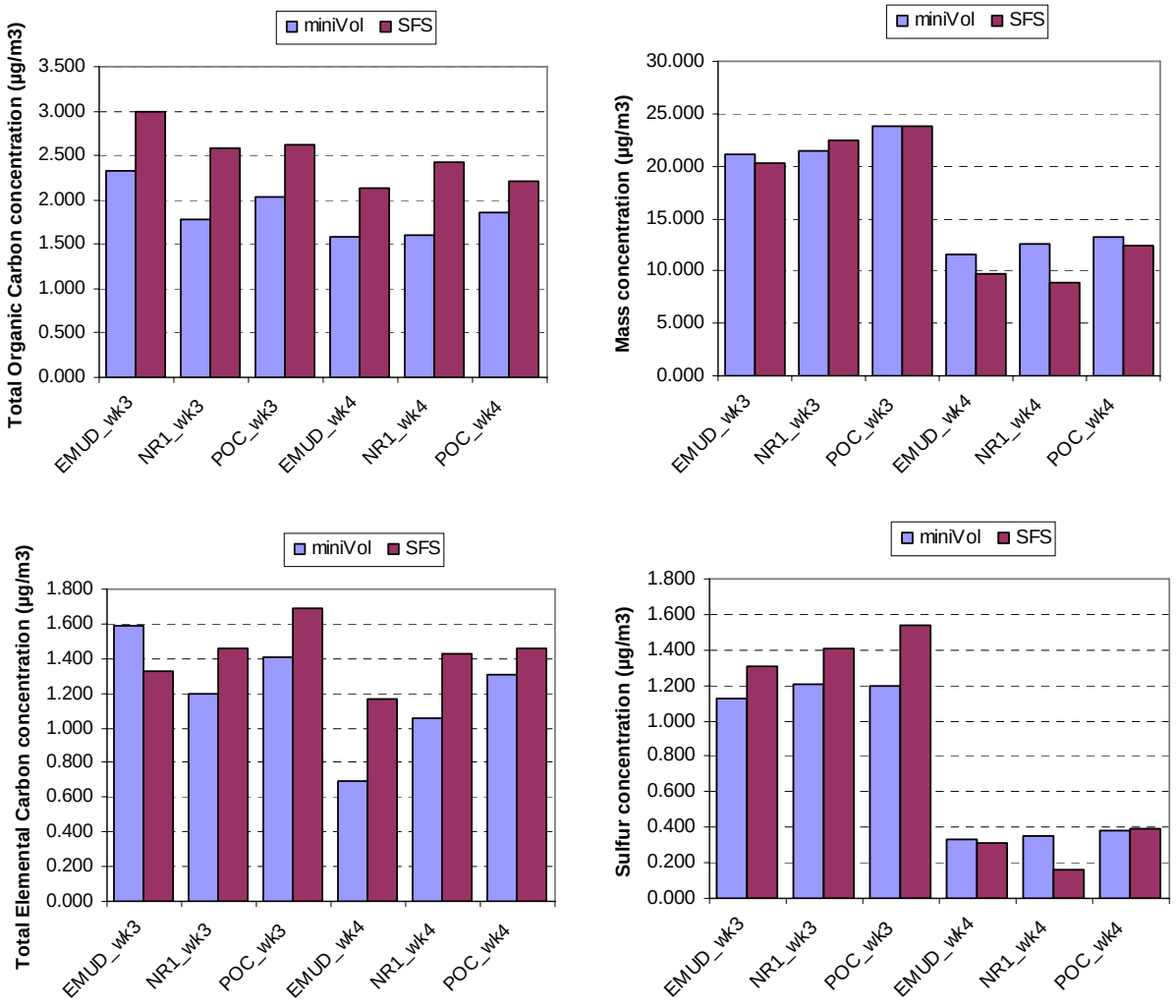

Figure 2-9. Comparison of data from week-long MiniVol and average of 7 24-hour medium volume filter samples, for winter study period.

3. RESULTS

This section presents the estimated seasonal mean concentrations of TACs and related air pollutants from the WOMS saturation monitoring as well as the spatial surveys and source apportionment analysis. WOMS was conducted to characterize the magnitude and spatial variations in concentrations of toxic air contaminants relative to emission sources in order to address the following questions of interest to the District and the Community of West Oakland.

1. Do gradients in pollutant concentrations exist within the West Oakland that can be related to the community's proximity to emissions from the Port of Oakland and related heavy-duty vehicle traffic?

2. Is the existing air quality monitoring in the area adequate to characterize the spatial variations in cumulative exposure within the community?

3. Are seasonal mean pollutant concentrations higher in West Oakland than elsewhere in the urban areas of the San Francisco Bay Area?

4. Are the concentrations and spatial variations in the DPM estimated from the WOMS saturation monitoring data consistent with modeled results from the recent health risk assessment conducted by the California Air Resources Board and the District?

3.1 Spatial Variations in Seasonal Mean Concentrations of Air Toxic Contaminants and Related Pollutants

The saturation monitoring network consisted of 7-day time-integrated sampling for four weeks in two seasons during 2009/10 (Summer – 7/30/09 to 8/27/09, Winter – 12/9/09 to 12/23/09 and 1/6/10 to 1/20/10) at 16 locations within the Port of Oakland and communities of West Oakland and Alameda (Figure 3-1 and Table 3-1). Sampling sites were aligned from the Middle Harbor area in the west to a cluster of sites near I-880 and 7th Street, and to sites fanning eastward within the community of West Oakland. The upwind background site was located on Alameda Island (POU) and the Port of Oakland Central (POC) site was located at the Port of Oakland maintenance yard at the southwest corner of the intersection of 7th and Maritime Streets. The POC sampling site was located near the west edge of the maintenance yard during the summer study with a two-story building between the sampling site and Maritime Street located approximately 120 m from the site. There was a large vacant lot west of the yard during the summer study. After the summer study, this lot filled up with storage containers stacked three high near the POC sampling site. Due to this unexpected obstruction, the site was moved to the nearest location with available power, at the east side of the yard within 30 m of Maritime Street. The relocated winter site is designated POC2 to distinguish it from the summer location.

Figure 3-1. Map of the WOMS monitoring sites.

Table 3-1. Location of saturation monitoring sites[1].

Site ID	Site Name	Location	latitude	longitude
POU	Site 7 - Upwind Site	Residence, 1321 Crown Drive, Alameda	37.7694	-122.2814
G1	Gradient Site 1	Middle Harbor Shoreline Park	37.7997	-122.3252
POC	Site 6 - Port of Oakland Central (summer)	Port of Oakland maintenance yard, near west edge of yard ~120m from Maritime St.	37.8072	-122.3142
POC2	Site 6 - Port of Oakland Central (winter)	Port of Oakland maintenance yard, southeast corner of yard ~30 m from Maritime St.	37.8057	-122.3126
G2	Gradient Site 2	10th St. and Midway, between Maritime St. & I-880	37.8124	-122.3079
G3	Gradient Site 3	Bay St. north of 7th (W edge of I-880)	37.8080	-122.3064
G5	Gradient Site 5	Frontage Rd., N of 7th St (E edge of I-880)	37.8114	-122.3033
G7	Gradient Site 7	Adeline, E side between 7th St and I-880	37.8037	-122.2883
G4	Gradient Site 4	Shorey St. at Pine (E of I-880 north of 7th St)	37.8085	-122.3041
G6	Gradient Site 6	24th St. and Wood (E of I-880)	37.8204	-122.2921
G8	Gradient Site 8	1086 8th St (btwn Adeline and Filbert)	37.8046	-122.2869
NR1	Site 2 - Near Road	Residence, 924 Pine St.	37.8107	-122.3018
WO1	Site 3 - West Oakland - SW	Oakland Technology Exchange, 1680 14th St.	37.8130	-122.2965
WO3	CASS upwind/WOMS Site 5 West Oakland - NW	Cypress Auto Salvage 2717 Peralta St.	37.8213	-122.2867
WO2	Site 4 - West Oakland - SE	Residence, 1111 Filbert St.	37.8064	-122.2839
EMUD	Site 1 - EBMUD	EBMUD District air monitoring station, 1100 21st St.	37.8148	-122.2825
CFDW	CASS far downwind	Excel High School HS, 2607 Myrtle St.	37.8198	-122.2802

[1] Note the change in location from summer to winter study for the POC site. Sampling location was closer to Maritime Street during winter resulting in greater contributions of heavy-duty diesel traffic to the measured pollutant concentrations.

The saturation monitoring results are presented in series of tables and bar plots showing the seasonal means, and line plots showing the individual weekly measurements. Mean values are not shown for sites with less than 3 of 4 possible valid samples per season. Sampling sites are listed in the tables approximately from west to east and similarly arranged in the charts from left to right. The range bars are estimates of replicate precision based on the average absolute difference of individual samples and means of the triplicate samples collected at the EMUD monitoring station normalized to the mean of the triplicates. The precision estimates from the Harbor Communities Monitoring Study (Fujita et al., 2009) were used for the WOMS summer VOC data since replicate precision of the Radiello VOC measurements could not be determined as explained in Section 2.1.3. Replicated precisions were successfully determined for the winter WOMS VOC samples and are similar to those from the HCMS winter field sampling. The weekly variations in pollutant concentrations due to variations in meteorological conditions are generally larger than measurement precision. However, the measurement precision is a more appropriate benchmark of meaningful spatial variations in pollutant concentrations, which is the main objective of WOMS. It should be noted that seasonal average pollutant concentrations do not reflect peak concentrations that occur on shorter time periods of hours and minutes.

3.1.1 Seasonal Mean NO, NO_2 and SO_2

Data for each of the 7-day passive NO (derived from differences of NOx and NO_2 samples), NO_2 and SO_2 samples are shown in Figures 3-2a and 3-2b for the summer and winter measurement periods, respectively. The corresponding seasonal averages are shown in Figures 3-3a and 3-3b and in Table 3-2. The passive samples on the east edge of I-880 (G5) had average NO values about five times higher than at the residential community sites during summer and about 2.5 higher during winter. Other sampling sites near I-880 also had higher NO and NO_2 values than residential sites, but much lower than at G5. The observed gradient in NOx levels is generally consistent with past studies that have shown that traffic-related pollutants disperse rapidly downwind of the roadway (Zhu et al., 2002). NOx levels were uniformly lower at the neighborhood-scale sites. As expected for a pollutant that has a large secondary component, NO_2 levels showed a smaller range of values than NO and lower NO_2/NOx ratios at roadway and near-road sites. NO_2 levels were uniformly lower during the winter study than in summer due to slower conversion of NO to NO_2.

During summer, SO_2 mixing ratios were all below 0.5 ppb with higher values downwind of I-880. Values were substantially greater during the winter, especially during the fourth week of sampling at WO2 and EMUD. Despite the apparent higher values, the replicate precision of the EMUD triplicate samples were inexplicably poor during the winter sampling period with high variability during all four weeks. High humidity and precipitation may be a contributing factor for the variability as moisture may leach material off the sampling pads or interfere with the diffusive sampling. Higher SO_2 levels appear to be associated with closer proximity to I-880. However, ambient SO_2 levels were generally low, particularly during summer, and have high relative uncertainty.

Table 3-2. Seasonal mean mixing ratios of NO, NOx and SO_2 during summer and winter WOMS and comparable data from the air toxic monitoring network (ATMN)[1] sites.

	NO	NO_2	SO_2
Summer			
POU	4.0 ± 0.6	5.1 ± 1.5	0.07 ± 0.04
G1	6.6 ± 1.0	6.6 ± 1.5	
POC	10.7 ± 1.2	8.5 ± 1.8	0.08 ± 0.02
G2	16.7 ± 3.8	7.6 ± 1.0	
G3	13.9 ± 1.5	14.3 ± 2.1	
G5	46.6 ± 1.5	21.9 ± 3.1	
G7	25.3 ± 0.6	15.6 ± 1.2	
G4	15.5 ± 3.4	14.3 ± 1.8	
G6	10.3 ± 1.3	13.0 ± 1.3	
G8	10.2 ± 1.0	13.7 ± 1.8	
NR1	10.9 ± 1.6	11.6 ± 1.7	0.12 ± 0.11
WO1	8.7 ± 2.5	10.2 ± 1.7	0.34 ± 0.12
WO3	12.2 ± 2.6	11.3 ± 1.4	0.27 ± 0.07
WO2	8.2 ± 1.5	10.4 ± 1.5	0.12 ± 0.07
EMUD	9.4 ± 1.3	9.7 ± 1.4	0.11 ± 0.06
CFDW	8.0 ± 1.0	9.2 ± 1.2	0.12 ± 0.05
Winter			
POU	14.7 ± 3.5	4.5 ± 0.4	0.95 ± 0.20
G1	12.5 ± 2.5	4.6 ± 0.4	
POC2	28.5 ± 2.6	6.2 ± 0.6	0.58 ± 0.27
G2	19.5 ± 6.2	6.3 ± 1.9	
G3	25.5 ± 4.3	9.2 ± 1.6	
G5	54.7 ± 4.9	9.2 ± 0.4	
G7	25.1 ± 2.4	6.7 ± 0.4	
G4	23.8 ± 3.1	6.7 ± 0.3	
G6	19.1 ± 2.8	6.0 ± 0.3	
G8	21.2 ± 2.7	6.2 ± 0.5	
NR1	21.5 ± 3.2	5.8 ± 0.3	0.67 ± 0.10
WO1	20.7 ± 3.7	5.1 ± 1.0	0.63 ± 0.25
WO3	23.6 ± 3.9	6.0 ± 0.7	0.86 ± 0.32
WO2	16.5 ± 2.7	5.7 ± 0.4	1.83 ± 0.92
EMUD	19.7 ± 3.5	5.7 ± 0.4	1.34 ± 1.21
CFDW	20.3 ± 2.7	5.9 ± 0.4	0.73 ± 0.33

[1] Average of reported daily values for WOMS study periods from December 2005 to August 2008.

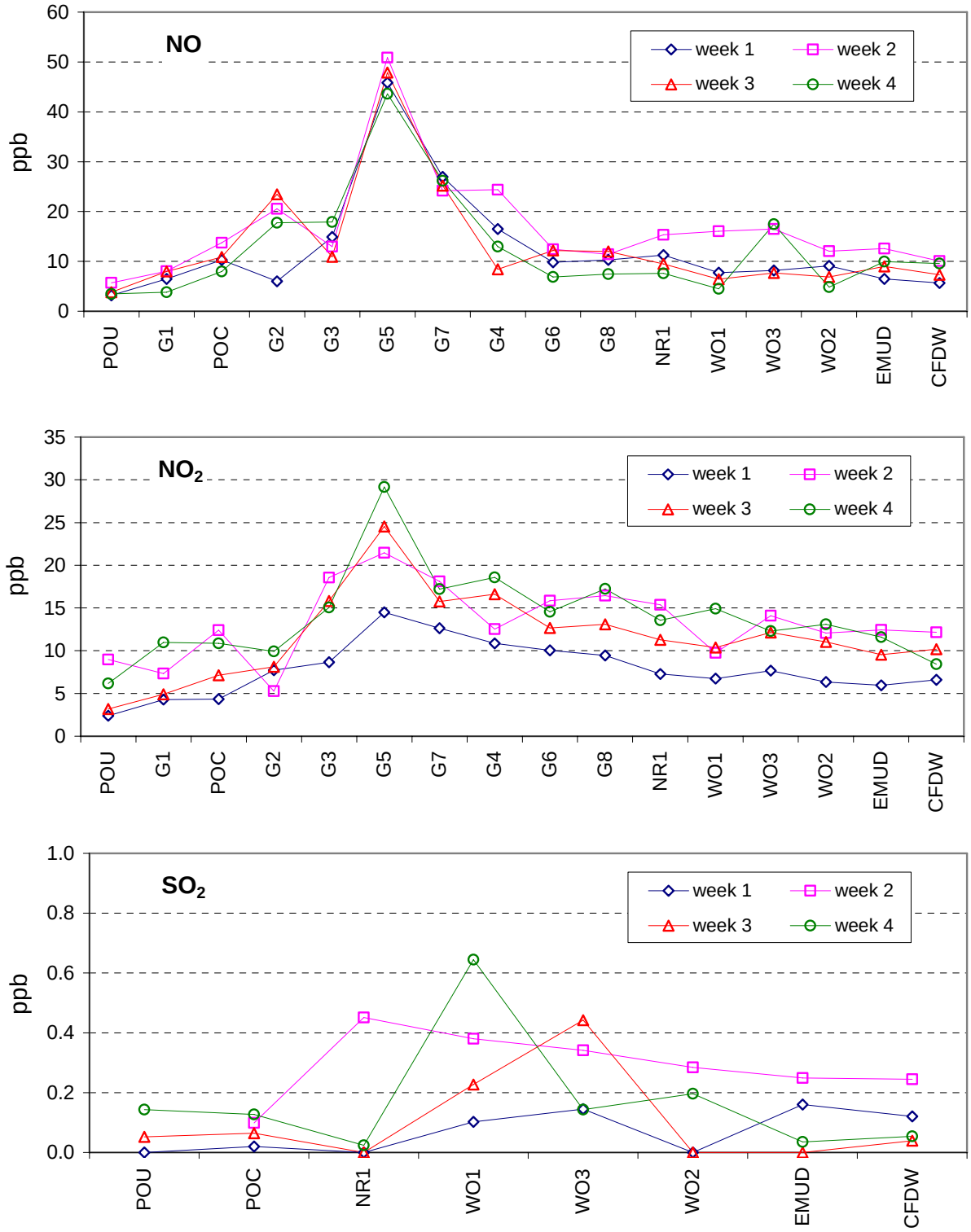

Figure 3-2a. 7-day average NO, NO_2, and SO_2 during the WOMS summer 2009 field study. Sites are ordered approximately from west to east in the plots from left to right.

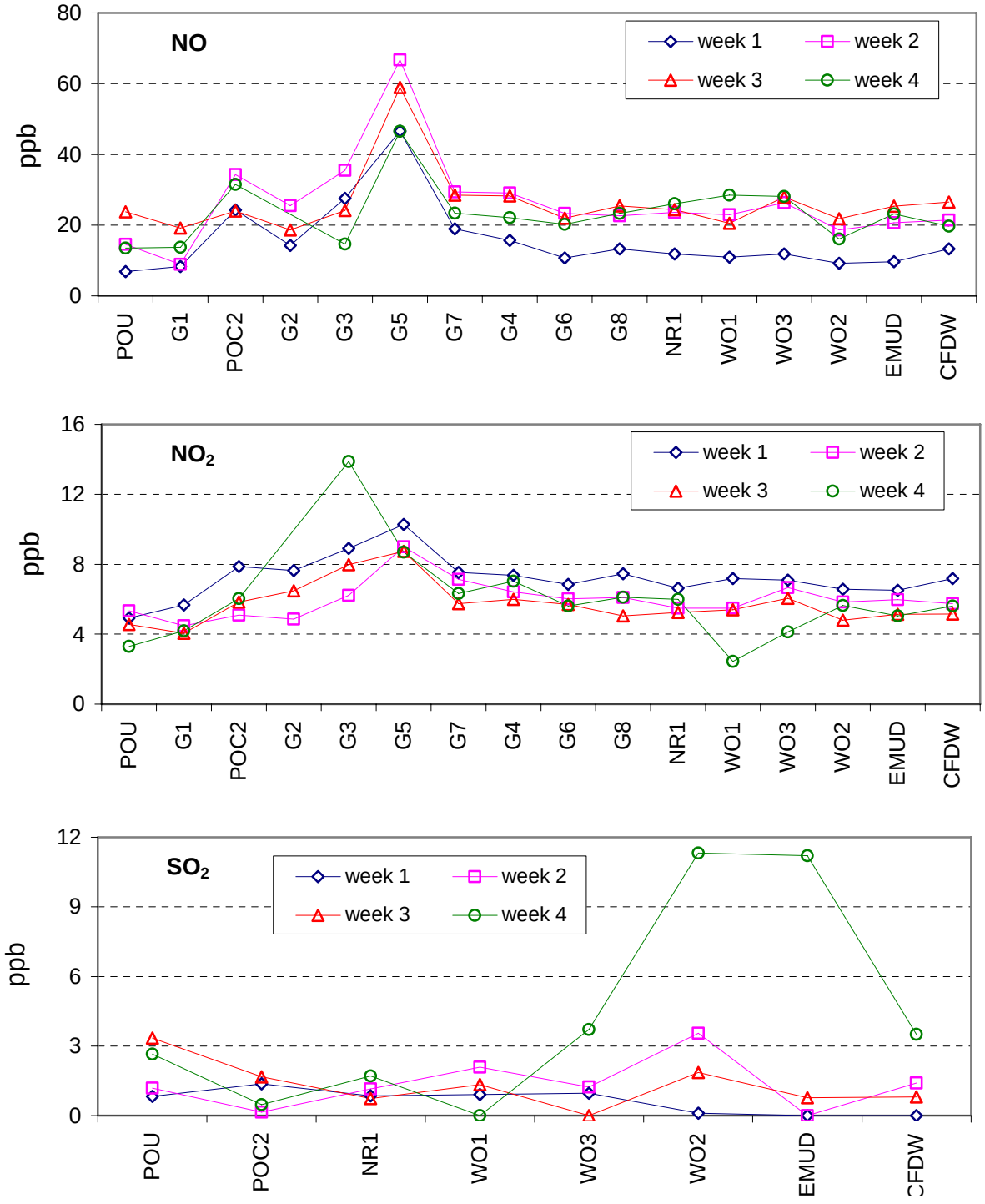

Figure 3-2b. 7-day average NO, NO_2, and SO_2 during the WOMS winter 2010 field study. Sites are ordered approximately from west to east in the plots from left to right.

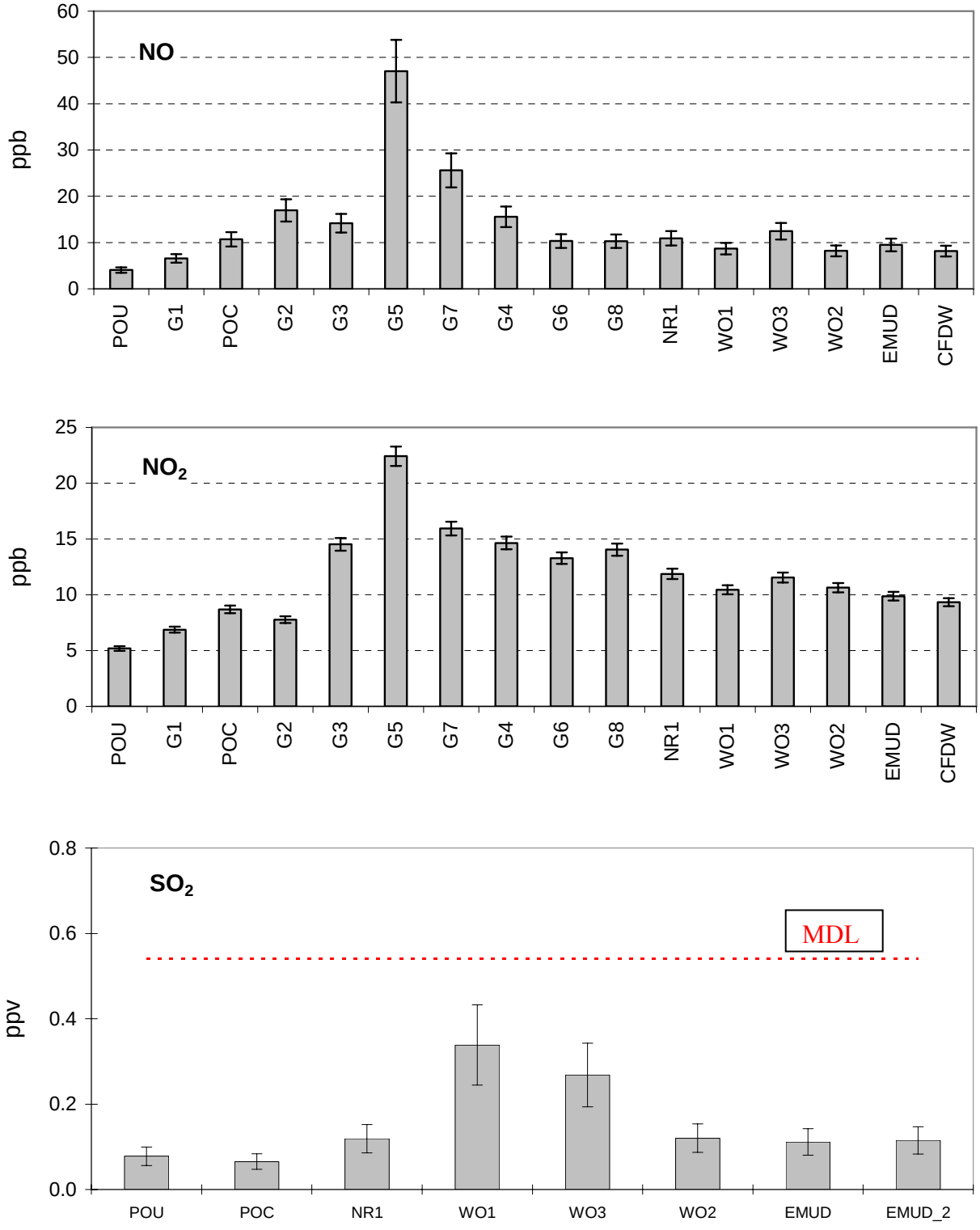

Figure 3-3a. 28-day average NO, NO_2, and SO_2 during the WOMS summer 2009 field study. Sites are ordered approximately from west to east in the plots from left to right. Uncertainties are values multiplied by the mean fractional relative differences of triplicate samples at EMUD.

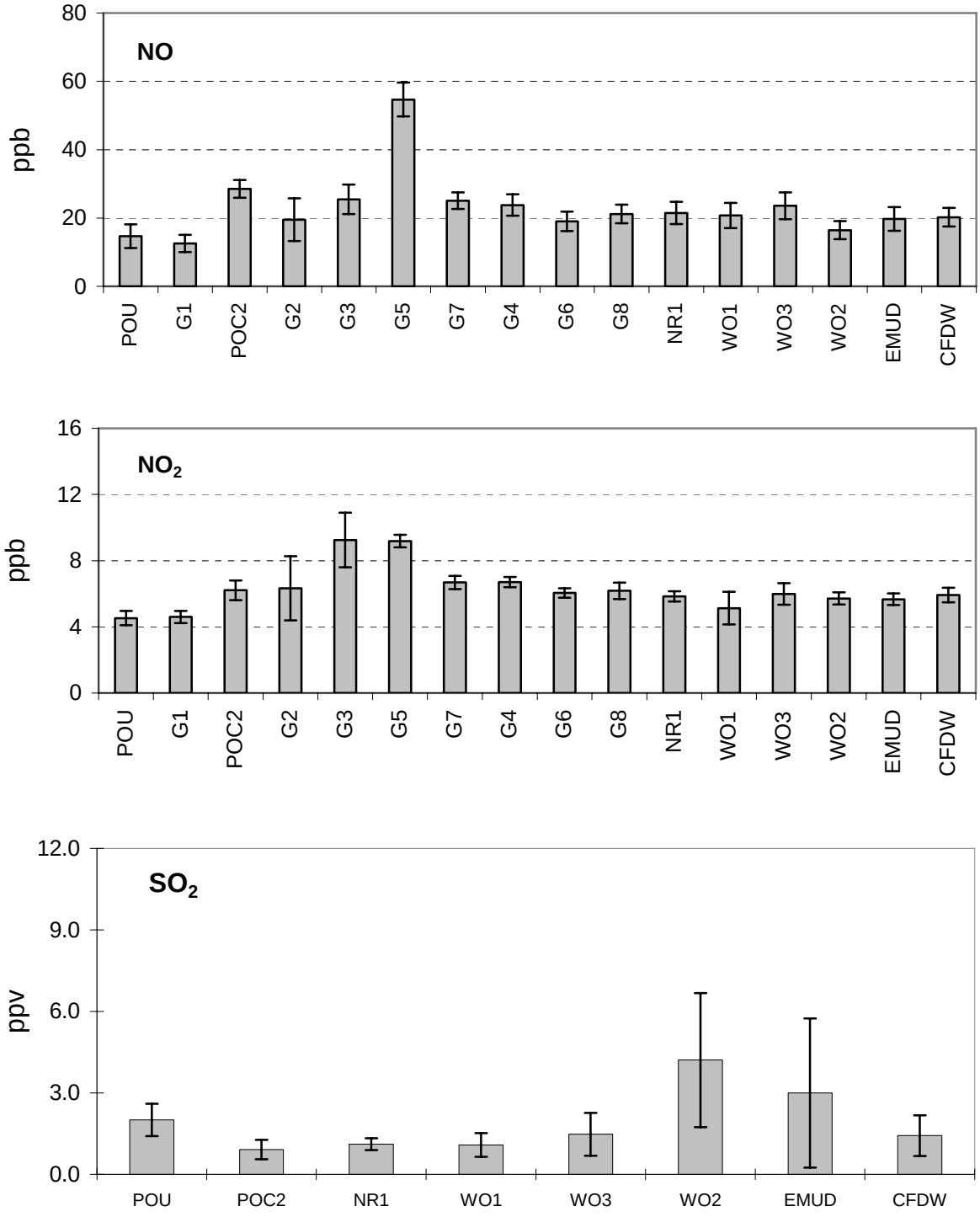

Figure 3-3b. 28-day average NO, NO_2, and SO_2 during the WOMS winter 2010 field study. Sites are ordered approximately from west to east in the plots from left to right. Uncertainties are values multiplied by the mean fractional relative differences of triplicate samples at EMUD.

3.1.2 Seasonal Mean Concentrations of $PM_{2.5}$ mass, OC, EC, DPM and metals

Data for each of the 7-day integrated $PM_{2.5}$ samples are shown in Figures 3-5a and 3-5b for the summer and winter measurement periods, respectively. Corresponding seasonal averages are shown in Figures 3-6a and 3-6b and in Table 3-3. The table includes estimates of diesel particulate carbon (DPC) and diesel particulate matter (DPM) using the EC surrogate method described in Section 2.5 in which DPC is estimated from the correlation of TC with EC, shown in Figure 3-4. All EC and TC values used in the linear regressions were background subtracted using data from the POU upwind site. The DPC estimates are based on data from the winter POC2 (Port of Oakland - Central) site, which were similar to those obtained using winter data from all eight WOMS PM sampling sites. The correlation statistics for the regression shown in Figure 3-4 yield a margin of error for the estimated concentrations of DPC equal to 17% + 0.1 $\mu g/m^3$, but this does not account for more fundamental sources of error inherent in the method assumptions. The relationship between EC and DPC can be affected by variations in the composition of diesel exhaust particles, sampling and analytical protocols for measuring EC from filters, or interferences from other sources of light absorbing aerosol. Since all EC measurements for WOMS used the same field and laboratory protocols, the data can be considered to be consistent so the third source of error would only affect the comparison to data from other sources. Considering the very small amount of particulate typically emitted by gasoline powered vehicles, and the low automobile traffic volume in West Oakland, it is unlikely that EC from cars would present a significant contribution (this is supported by the results of source attribution by Chemical Mass Balance receptor modeling). Also, chemical speciation analysis of filter samples does not indicate any significant presence of weakly light-absorbing minerals such as iron oxides in the urban aerosol. Therefore, the only likely source of uncharacterized uncertainty in the DPC estimates is due to differences in exhaust composition. If the diesel vehicle fleet at other locations is substantially different than that at the central port site (POC2) this could be significant.

The spatial variations of EC (also DPC and DPM) were qualitatively similar to NO during the summer study with concentrations increasing with greater proximity to traffic. The apparent larger spatial gradients for NO are the result of having eight additional passive samplers in mostly near-road locations. Average EC concentrations were about two times higher during the summer period at sampling locations near I-880 (NR1, WO1, WO2 and WO3) compared to locations further downwind of I-880 (EMUD and CFDW). The EC and NO values at the central port site (POC) were comparable during the summer period to levels at EMUD and CFDW. This spatial pattern indicates that the main source of EC is truck traffic associated with port operations. The lowest concentrations of $PM_{2.5}$, OC and EC were measured at the upwind sampling location on Alameda Island. Both OC and $PM_{2.5}$ exhibit less spatial variations than EC due to contributions of secondary pollutants from the atmospheric transformations of directly emitted (primary) pollutants. Secondary organic aerosols (SOA) are typically larger components of particulate organic matter during summer and secondary nitrate and sulfate particles are major components of $PM_{2.5}$. Secondary pollutants have more uniform spatial distributions over a larger area than directly emitted pollutants.

The seasonal average TC and $PM_{2.5}$ concentrations were about twice as high during the winter with more uniform spatial distributions than during the summer study. The concentrations

of primary components of PM are higher during winter due to meteorological conditions that favor accumulation of directly emitted pollutant closer to the source of emissions. The primary component is also proportionally greater than SOA, nitrate and sulfate during winter relative to summer due to lower photochemical activity. The ratios of EC to TC were greater during the winter study indicating greater relative contributions of diesel exhaust to TC and $PM_{2.5}$ during winter. During summer, the mean concentration of DPM at the four community sampling sites near I-880 (NR1, WO1, WO2 and WO3) was 0.9 $\mu g/m^3$ compared to 0.4 at POU, 0.6 at POC and 0.7 at the downwind community site (CFDW). During winter, the mean concentration of DPM at the four sites near I-880 was 2.0 $\mu g/m^3$ compared to 1.8 at POU, 2.7 at POC2 and 2.0 at CFDW and EMUD. The DPC/TC and DPM/$PM_{2.5}$ ratios at the West Oakland community sampling sites were 30-40% and 10-12%, respectively during summer and 50-60% and 17-19 %, respectively during winter. These ratios are reasonably consistent with the source contribution estimates obtained from the Chemical Mass Balance (CMB) receptor modeling analysis in Section 3.3 considering the uncertainties of the methods. The estimated DPM concentrations for the WOMS community sampling sites were also comparable to similar estimates derived from the San Jose PM speciation monitoring data.

The ambient concentrations of metals that are associated with specific sources (e.g., vanadium as a tracer of oil combustion) or concerns to human health were mostly below the limits of detection during the summer study. Vanadium was the only metal of interest that was quantitatively measured during both summer and winter periods. As shown in Figure 3-7, vanadium concentrations were slightly higher near I-880. Most metals of interest (Al, Pb, Cr, and Mn) were quantitatively measured during the winter period with higher concentrations at the central port site and upwind of the CASS facility at an auto salvage yard (Figure 3-8).

Table 3-3. Seasonal mean $PM_{2.5}$ mass, OC, EC and DPC concentrations ($\mu g/m^3$) and DPC/TC and DPM/$PM_{2.5}$ ratios during summer and winter WOMS and comparable data from the San Jose Speciation Trends Network (STN) site.

	$PM_{2.5}$ mass	OC	EC	DPC	DPM	DPC/TC	DPM/$PM_{2.5}$
Summer							
POU	6.18 ± 1.70	1.08 ± 0.41	7.89 to 10.35	0.35 ± 0.09	0.44 ± 0.11	28.3%	7.1%
POC	6.48 ± 1.62	1.30 ± 0.47	0.31 ± 0.07	0.53 ± 0.10	0.64 ± 0.12	33.3%	9.9%
NR1	9.16 ± 0.71	1.67 ± 0.29	0.50 ± 0.06	0.79 ± 0.08	0.92 ± 0.10	36.5%	10.1%
WO1	6.92 ± 1.68	1.35 ± 0.39	0.42 ± 0.09	0.69 ± 0.13	0.81 ± 0.16	38.8%	11.7%
WO3	7.16 ± 1.75	1.48 ± 0.40	0.48 ± 0.07	0.76 ± 0.09	0.89 ± 0.11	38.7%	12.4%
WO2	6.91 ± 1.68				0.84 ± 0.10		12.1%
EMUD		1.37 ± 0.39	0.38 ± 0.11				
CFDW	6.97 ± 1.75	1.50 ± 0.39	0.32 ± 0.07	0.56 ± 0.09	0.66 ± 0.12	30.5%	9.5%
Community Mean	7.43 ± 0.18	1.47 ± 0.02	0.42 ± 0.01	0.70 ± 0.01	0.82 ± 0.01	36.8%	11.1%
STN San Jose	9.97	3.90	0.51	0.80	0.93	17.2%	9.3%
Winter							
POU	13.91 ± 2.71	1.76 ± 0.14	1.07 ± 0.18	1.55 ± 0.24	1.77 ± 0.30	55.1%	12.7%
POC2	16.59 ± 2.57	2.10 ± 0.15	1.68 ± 0.19	2.35 ± 0.25	2.66 ± 0.31	62.5%	16.0%
NR1	15.15 ± 2.21	1.82 ± 0.10	1.26 ± 0.09	1.79 ± 0.12	2.03 ± 0.15	58.5%	13.4%
WO1	15.45 ± 5.01	1.82 ± 0.53	1.27 ± 0.39	1.80 ± 0.55	2.05 ± 0.68	58.8%	13.3%
WO3	15.11 ± 2.38	1.81 ± 0.08	1.28 ± 0.16	1.82 ± 0.21	2.06 ± 0.27	54.3%	13.7%
WO2	13.53 ± 1.85	2.09 ± 0.24	1.13 ± 0.13	1.63 ± 0.17	1.85 ± 0.25	55.7%	13.7%
EMUD	15.50 ± 5.04	2.00 ± 0.18	1.19 ± 0.40	1.70 ± 0.57	1.93 ± 0.69	53.8%	12.5%
CFDW	12.36 ± 3.68	1.99 ± 0.60	1.22 ± 0.20	1.74 ± 0.27	1.98 ± 0.33	54.4%	16.0%
Community Mean	14.52 ± 0.58	1.92 ± 0.09	1.22 ± 0.06	1.74 ± 0.08	1.98 ± 0.10	55.9%	13.7%
STN San Jose	17.26	7.21	1.60	2.24	2.54	25.5%	14.7%

Note: Community mean includes NR1, WO1, WO2, WO3, EMUD and CFDW.

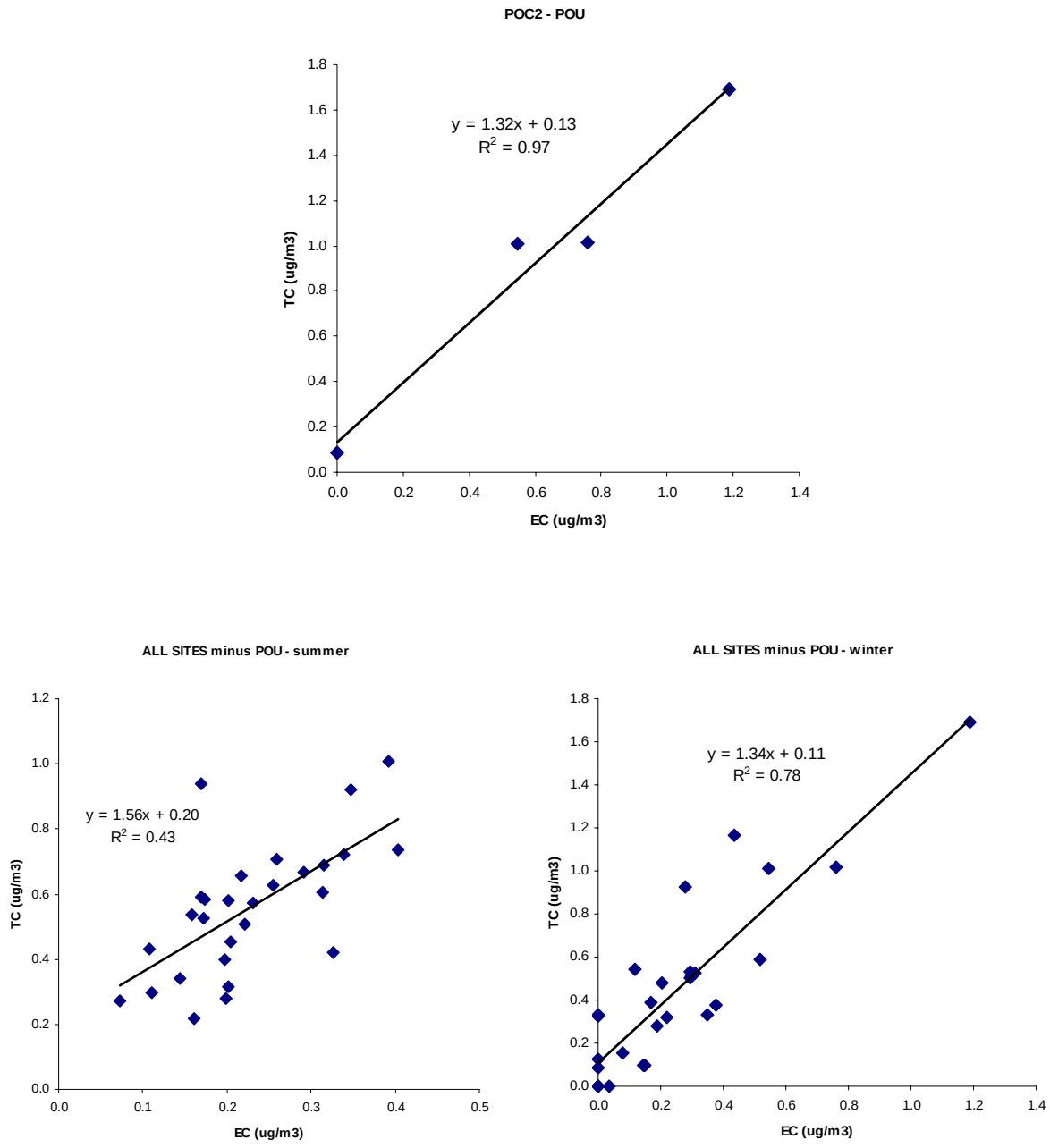

Figure 3-4. Correlation of EC with TC for POC2 site (top) and for all sites in summer and winter (bottom). All EC and TC values are background subtracted using values at the POU upwind site.

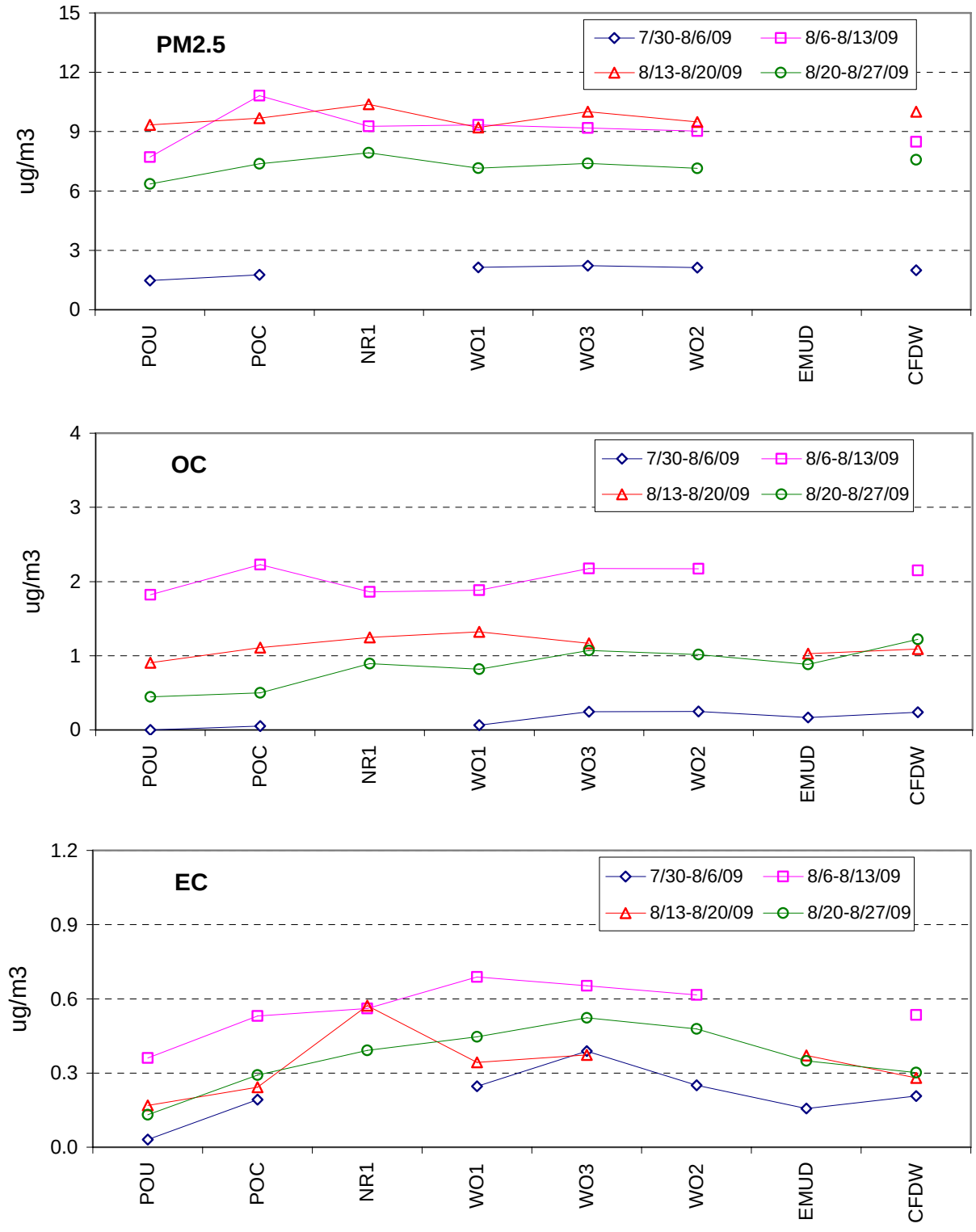

Figure 3-5a. 7-day average $PM_{2.5}$ mass, OC and EC during the WOMS summer 2009 field study. Sites are ordered approximately from west to east in the plots from left to right.

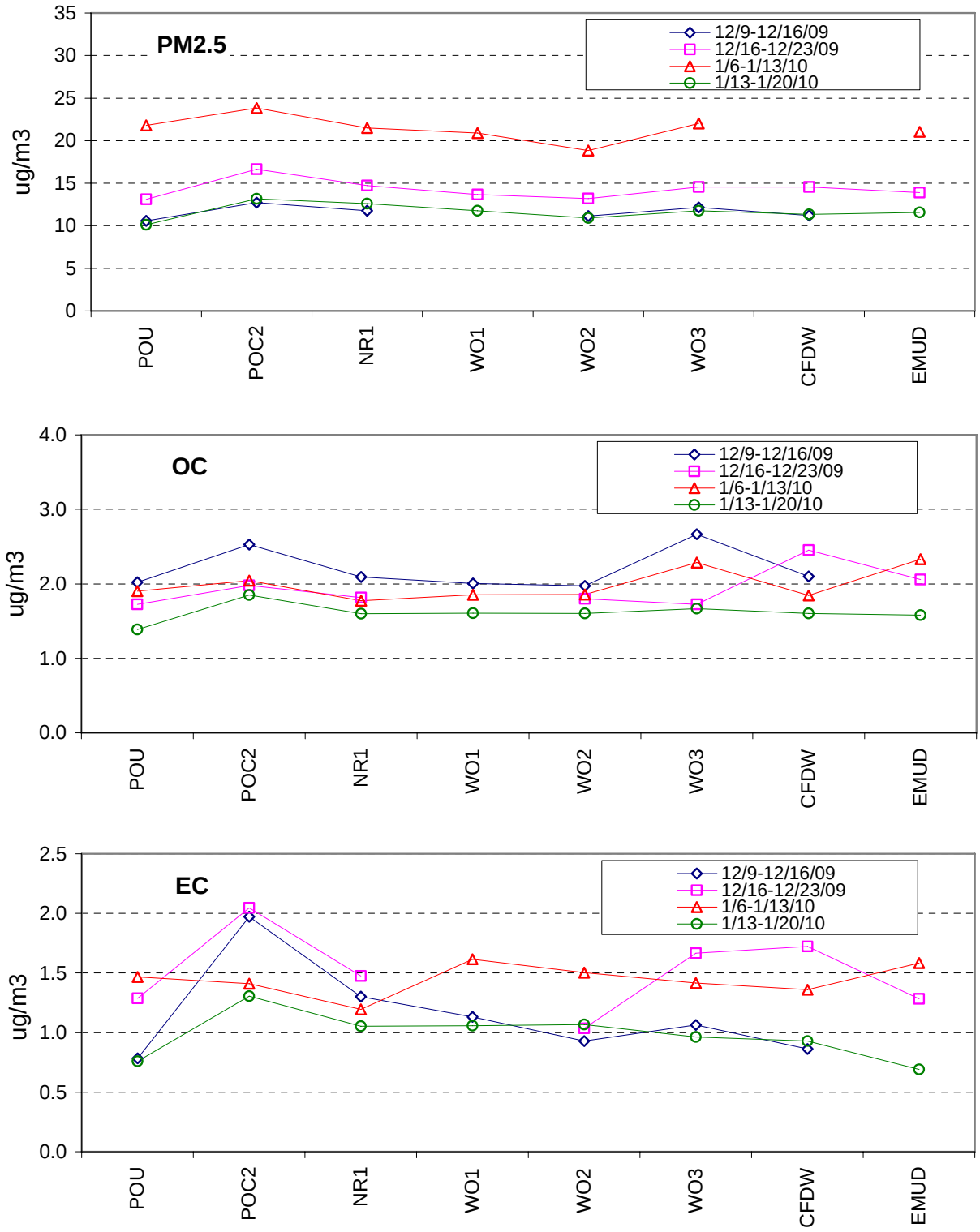

Figure 3-5b. 7-day average $PM_{2.5}$ mass, OC and EC during the WOMS winter 2010 field study. Sites are ordered approximately from west to east in the plots from left to right.

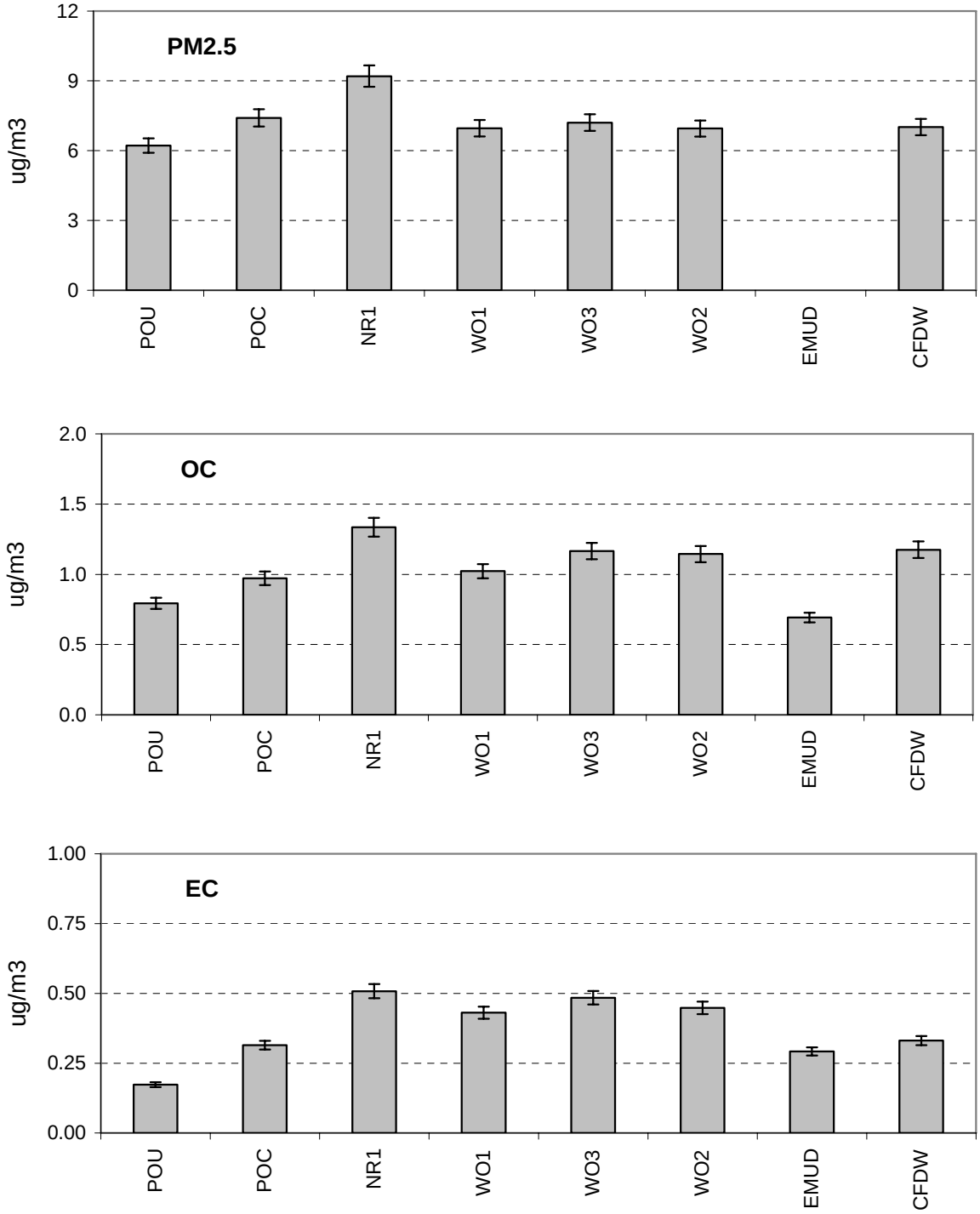

Figure 3-6a. 28-day average $PM_{2.5}$ mass, OC and EC during the WOMS summer 2009 field study. Sites are ordered approximately from west to east in the plots from left to right. Note that the average concentrations at EMUD are lower during the summer period due to a missed sample during the week with highest PM concentrations.

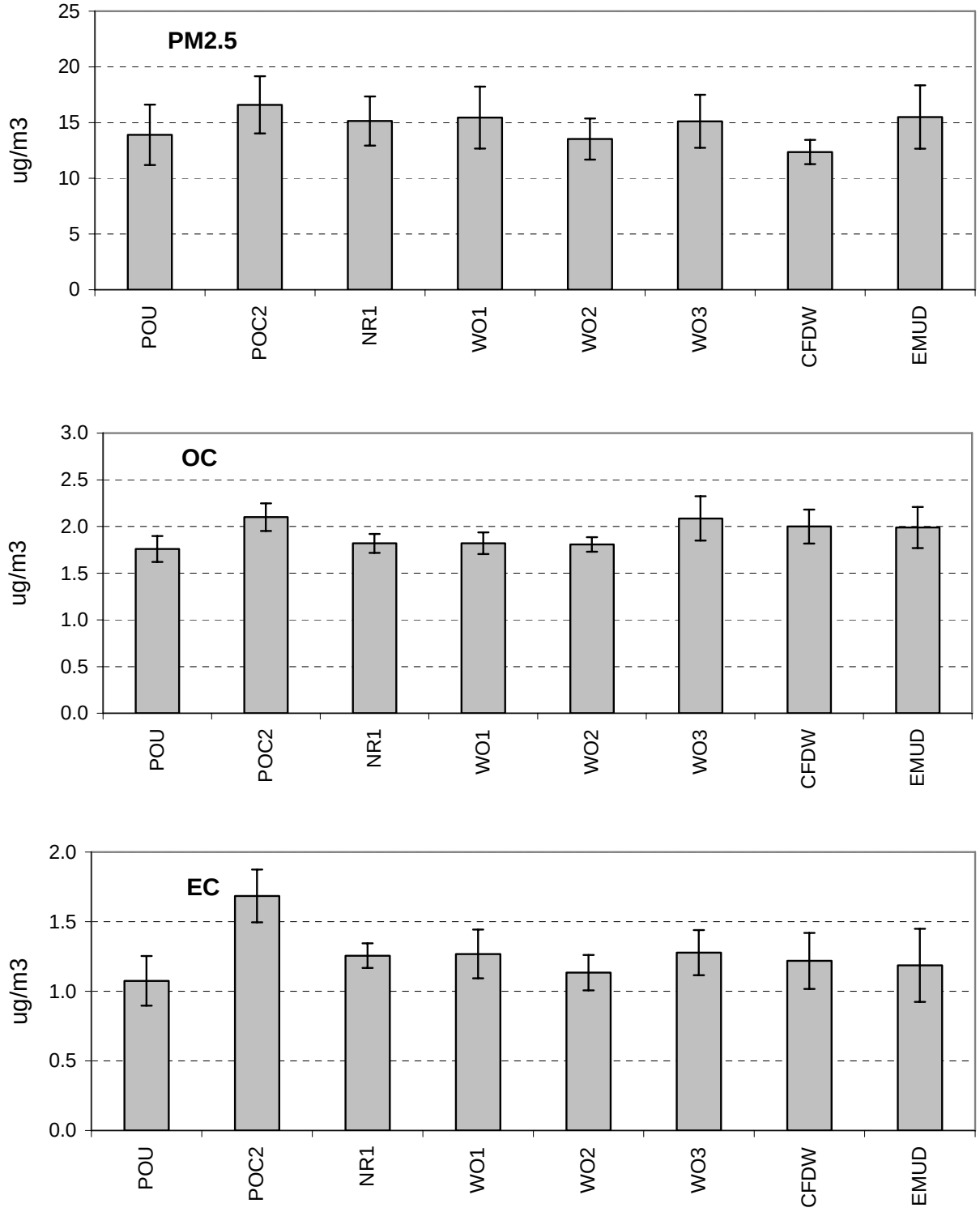

Figure 3-6b. 28-day average $PM_{2.5}$ mass, OC and EC during the WOMS winter 2010 field study. Sites are ordered approximately from west to east in the plots from left to right.

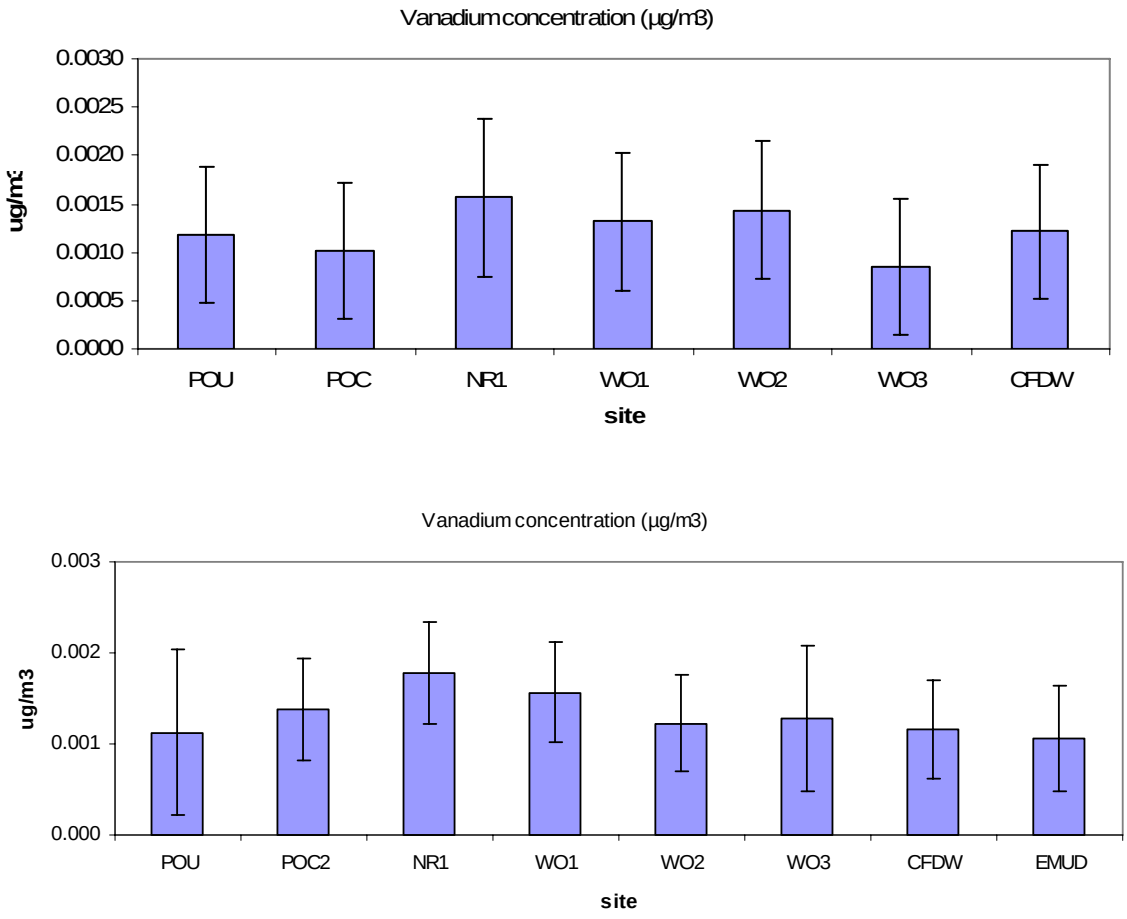

Figure 3-7. Vanadium concentrations during summer (top) and winter (bottom).

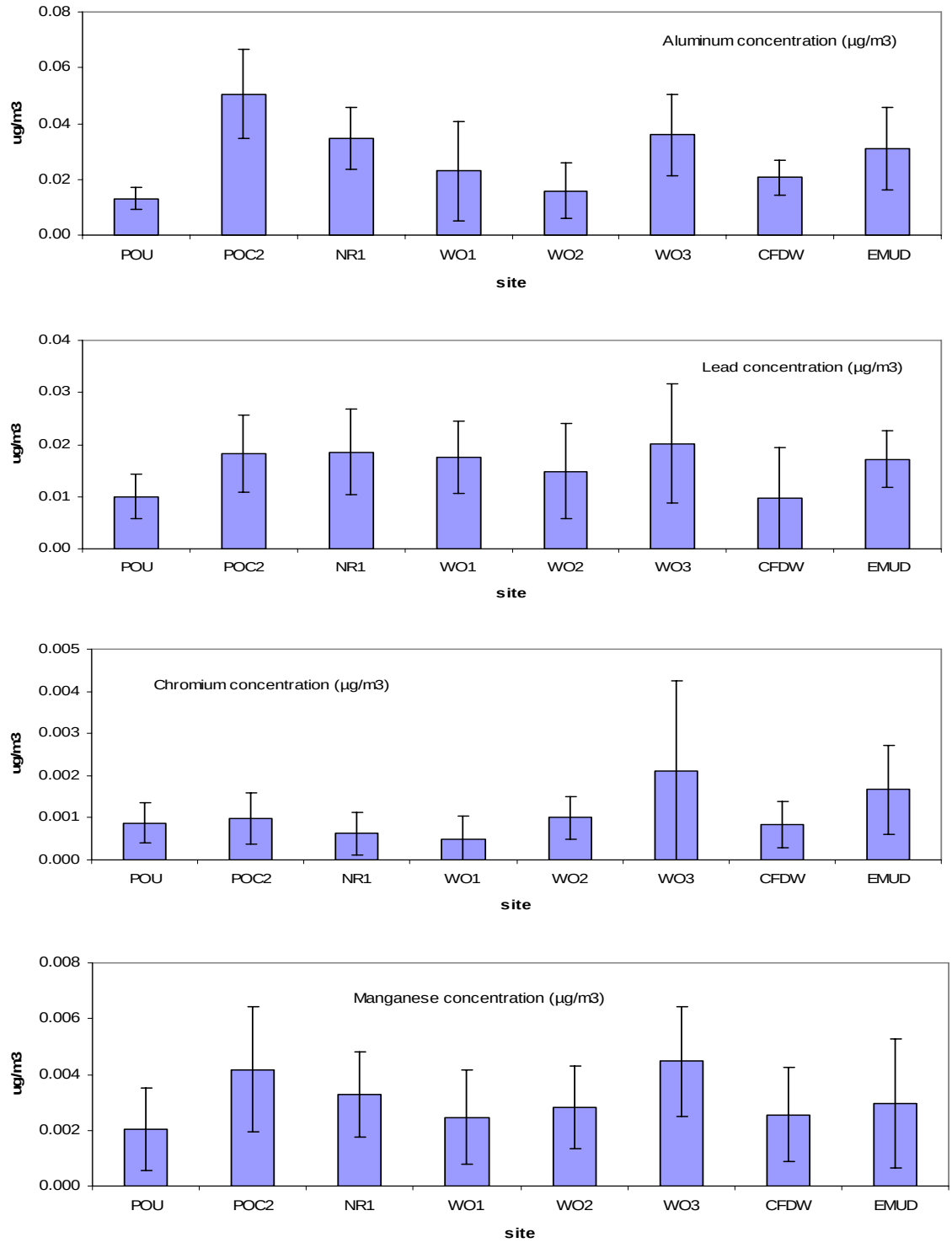

Figure 3-8. Ambient concentrations of Al, Pb, Cr and Mn during winter WOMS. All other potentially toxic metals were at or near detection limits.

3.1.3 Seasonal Mean Mixing Ratios of Volatile Organic Toxic Air Contaminants

Data for each of the 7-day integrated BTEX samples are shown in Figures 3-9a and 3-9b for the summer and winter measurement periods, respectively. Corresponding seasonal averages are shown in Figures 3-10a and 3-10b and in Table 3-4. BTEX levels were consistently highest at WO3 and generally higher within West Oakland relative to the port during the summer period. With the exception of the higher values at WO3, BTEX mixing ratios were relatively uniform spatially during the winter period. The higher levels level at WO3 may be related to local emissions from the auto salvage operations that are superimposed on emissions from local traffic. The mean values for the WOMS community sampling sites are either comparable or lower than the seasonal BTEX values measured at the three air toxic maintaining network sites (San Francisco, San Jose and Fremont).

Data for each of the 7-day integrated aldehyde samples are shown in Figures 3-11a and 3-11b for the summer and winter measurement periods, respectively. Corresponding seasonal averages are shown in Figures 3-12a and 3-12b and in Table 3-5. Although formaldehyde and acetaldehyde are directly emitted in vehicle exhaust, a large fraction of these aldehydes in the ambient air are formed by photochemical transformations of hydrocarbons. Consequently, their concentrations vary less spatially than directly emitted pollutants. Note that the ambient levels of aldehydes at the background site (POU) are comparable to most other sites. Acrolein is also directly emitted and is formed in the atmosphere from reaction of ozone and 1,3-butadiene. In contrast to formaldehyde and acetaldehyde, the spatial variations for acrolein appear to be more similar to that of BTEX. However, the values for acrolein are below detection limits. In contrast, the acrolein values reported at the three air toxics monitoring sites were at least ten times higher. Acrolein is measured in the air toxic monitoring program by the California Air Resources Board using EPA Method TO-15, in which sample air is collected in a stainless steel canister and analyzed by thermal desorption gas chromatography with mass spectrometry. Other investigators have also obtained much lower measurements of acrolein compared to measurements by the ARB (Cahill et al., 2010).

Table 3-4. Seasonal mean mixing ratios of BTEX (ppb) during summer and winter WOMS and comparable data from the air toxics monitoring network (ATMN)[1].

	Benzene	Toluene	Ethylbenzene	Xylenes
Summer				
POU	0.08 ± 0.01	0.04 ± 0.01	0.03 ± 0.01	0.10 ± 0.01
POC	0.12 ± 0.01	0.06 ± 0.01	0.04 ± 0.01	0.20 ± 0.02
NR1	0.15 ± 0.01	0.13 ± 0.01	0.06 ± 0.01	0.28 ± 0.03
WO1	0.17 ± 0.01	0.15 ± 0.02	0.07 ± 0.01	0.31 ± 0.03
WO3	0.18 ± 0.01	0.27 ± 0.03	0.10 ± 0.01	0.45 ± 0.05
WO2	0.18 ± 0.01	0.23 ± 0.02	0.10 ± 0.01	0.42 ± 0.04
EMUD	0.16 ± 0.01	0.19 ± 0.02	0.08 ± 0.01	0.36 ± 0.04
CFDW	0.12 ± 0.01	0.18 ± 0.02	0.08 ± 0.01	0.37 ± 0.04
Community Mean	0.16 ± 0.00	0.19 ± 0.00	0.08 ± 0.00	0.37 ± 0.00
ATN San Francisco	0.13	0.46	0.10	0.30
ATN San Jose	0.18	0.56	0.10	0.40
ATN Fremont	0.20	0.61	0.11	0.45
Winter				
POU	0.20 ± 0.01	0.31 ± 0.03	0.10 ± 0.01	0.42 ± 0.04
POC2	0.22 ± 0.01	0.34 ± 0.03	0.09 ± 0.01	0.33 ± 0.03
NR1	0.31 ± 0.02	0.49 ± 0.05	0.14 ± 0.01	0.58 ± 0.06
WO1	0.21 ± 0.01	0.35 ± 0.04	0.12 ± 0.01	0.48 ± 0.05
WO3	0.41 ± 0.03	0.79 ± 0.08	0.23 ± 0.02	0.88 ± 0.09
WO2	0.32 ± 0.02	0.47 ± 0.05	0.12 ± 0.01	0.45 ± 0.05
EMUD	0.25 ± 0.02	0.52 ± 0.05	0.15 ± 0.01	0.62 ± 0.06
CFDW	0.27 ± 0.02	0.45 ± 0.05	0.14 ± 0.01	0.59 ± 0.06
Community Mean	0.30 ± 0.00	0.51 ± 0.01	0.15 ± 0.00	0.60 ± 0.01
ATN San Francisco	0.51	1.42	0.20	1.17
ATN San Jose	0.87	2.22	0.31	1.79
ATN Fremont	0.47	1.04	0.19	1.00

[1] Air toxic network data are averages for years 2005-07.

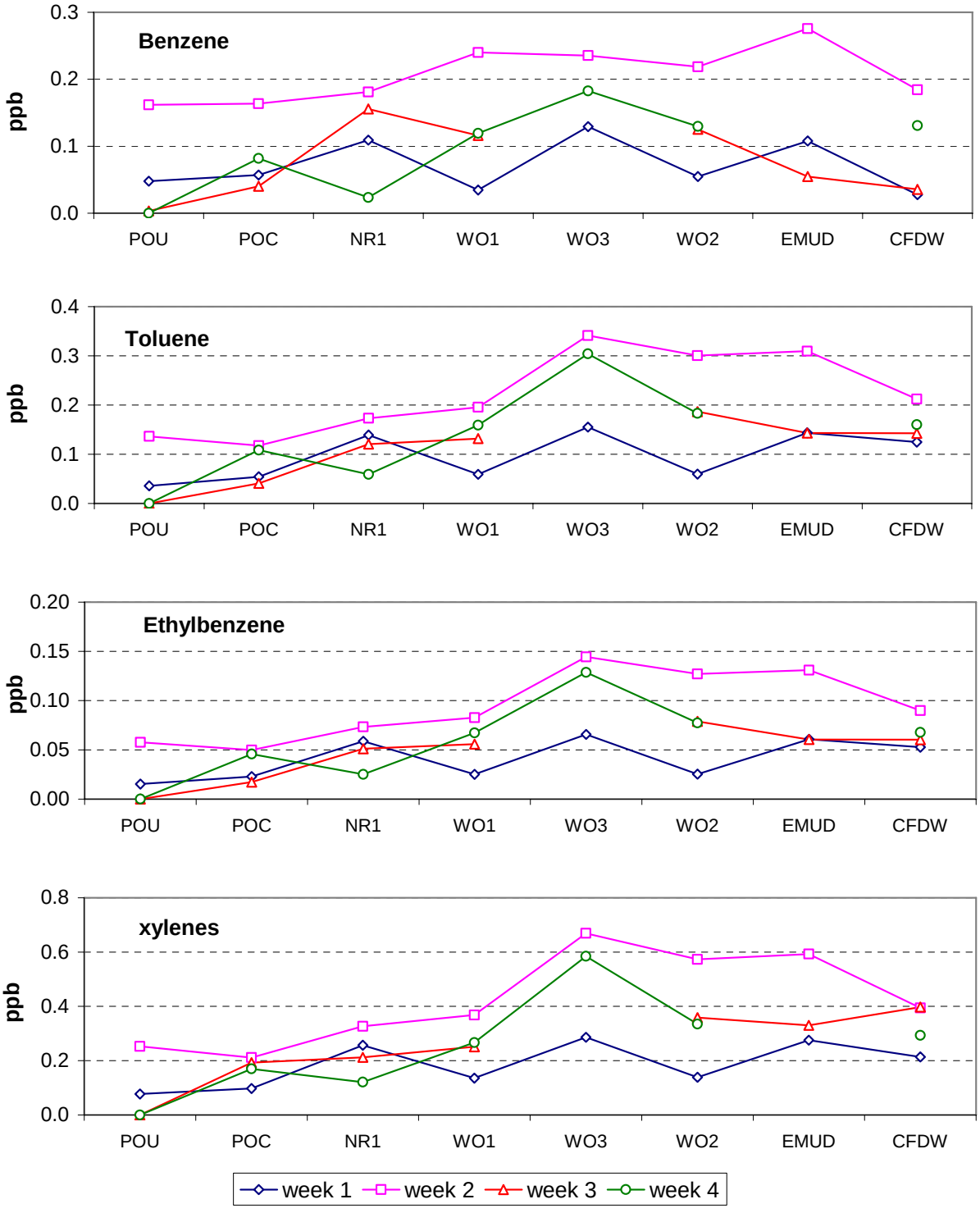

Figure 3-9a. 7-day average BTEX (ppbv) during the WOMS summer 2009 field study. Sites are ordered approximately from west to east in the plots from left to right. Toluene values with evidence of contamination are estimated from correlations of ethylbenzene to toluene values without contamination.

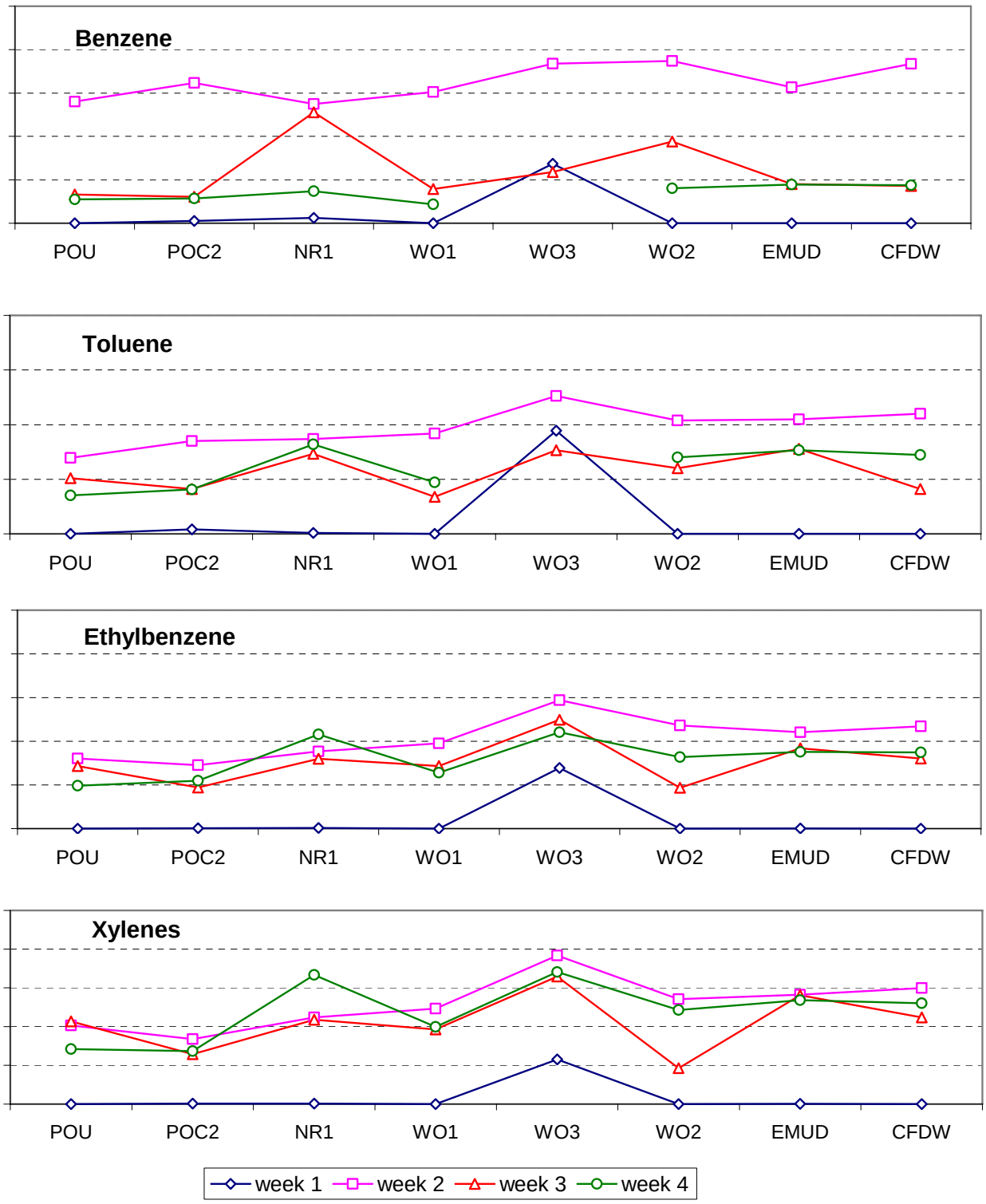

Figure 3-9b. 7-day average BTEX (ppbv) during the WOMS winter 2010 field study. Sites are ordered approximately from west to east in the plots from left to right.

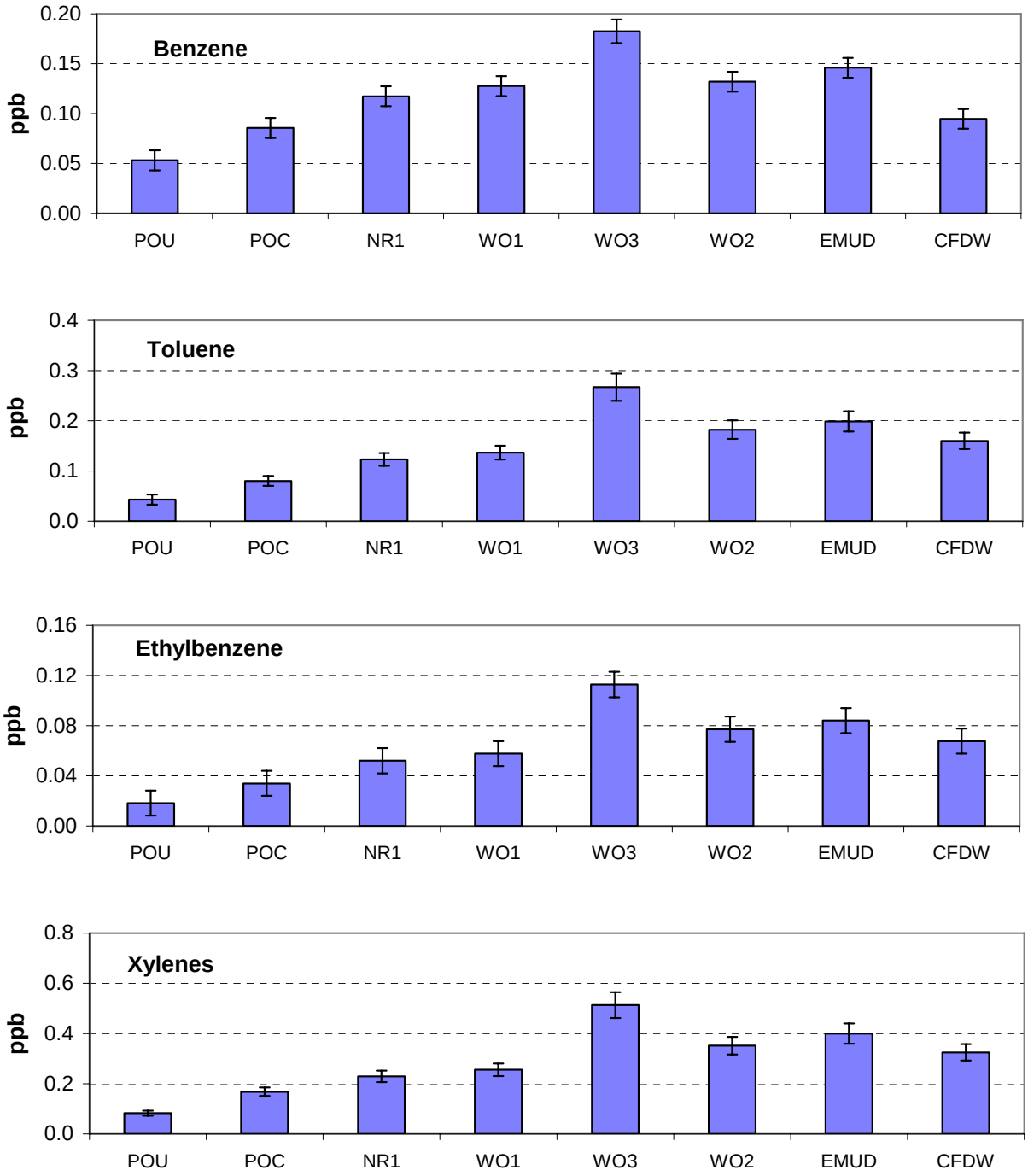

Figure 3-10a. 28-day average BTEX during the WOMS summer 2009 field study. Sites are ordered approximately from west to east in the plots from left to right. Uncertainties are values multiplied by the mean fractional relative differences of triplicate samples from EMUD.

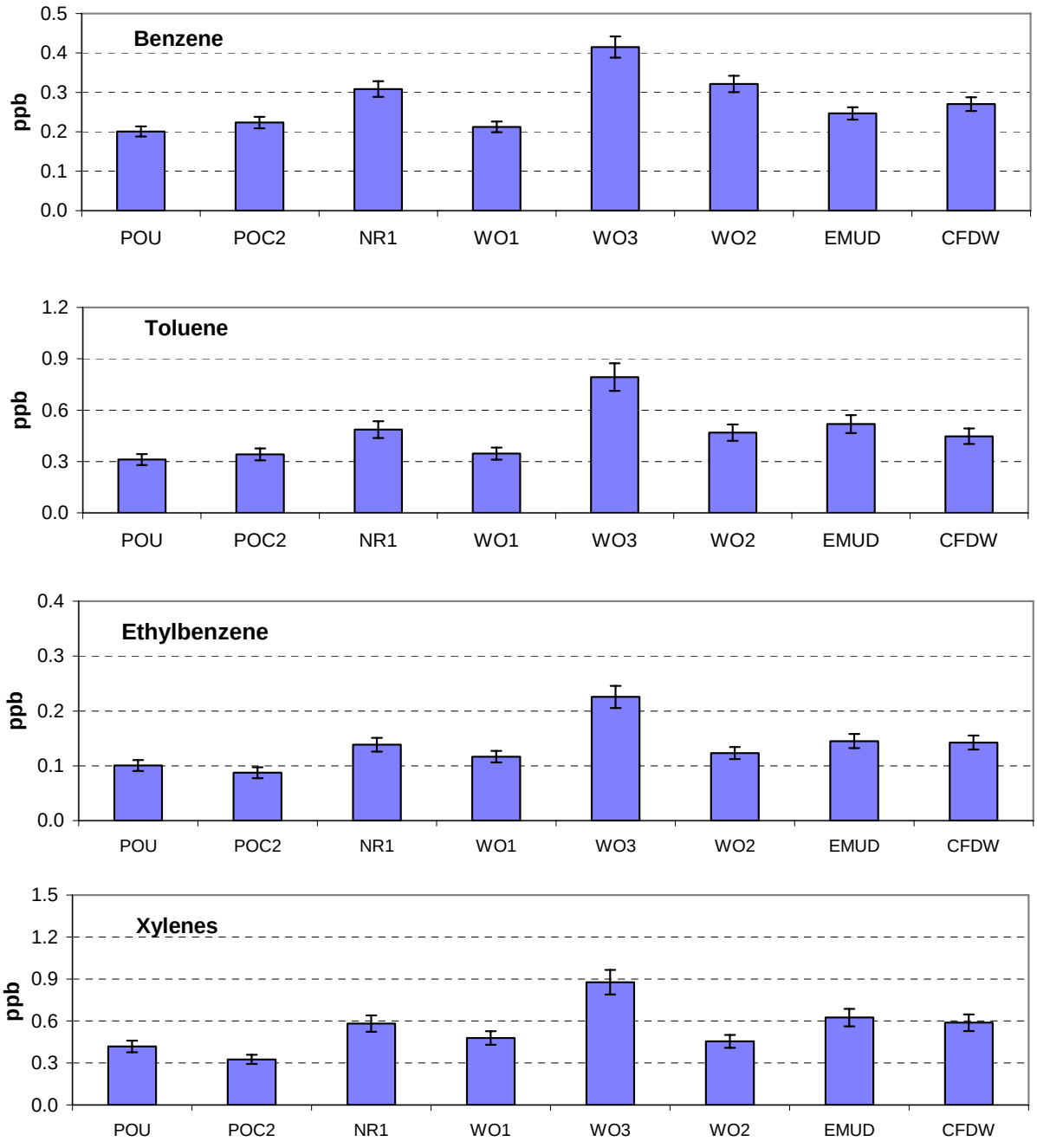

Figure 3-10b. 28-day average BTEX during the WOMS winter 2010 field study. Sites are ordered approximately from west to east in the plots from left to right. Uncertainties are values multiplied by the mean fractional relative differences of triplicate samples from EMUD.

Table 3-5. Seasonal mean mixing ratios of aldehydes during summer and winter WOMS and comparable data from the BAAQMD air toxics network.

	Formaldehyde	Acetaldehyde	Acrolein
Summer			
POU	1.23 ± 0.01	0.53 ± 0.04	0.01 ± 0.01
POC	1.12 ± 0.01	0.39 ± 0.03	0.01 ± 0.01
NR1	1.27 ± 0.02	0.52 ± 0.04	0.00 ± 0.01
WO1	1.14 ± 0.01	0.57 ± 0.04	0.02 ± 0.01
WO3	1.66 ± 0.02	0.56 ± 0.04	0.01 ± 0.01
WO2	1.19 ± 0.01	0.55 ± 0.04	0.01 ± 0.01
EMUD	1.38 ± 0.02	0.56 ± 0.04	0.01 ± 0.01
CFDW	1.32 ± 0.02	0.39 ± 0.03	0.02 ± 0.01
Community Mean	1.33 ± 0.00	0.52 ± 0.00	0.01 ± 0.00
ATN San Francisc	1.10	0.38	0.42
ATN San Jose	2.47	0.64	0.67
ATN Fremont	1.78	0.68	0.56
Winter			
POU	0.98 ± 0.08	0.35 ± 0.01	0.02 ± 0.01
POC2	1.14 ± 0.09	0.37 ± 0.01	0.04 ± 0.01
NR1	1.11 ± 0.09	0.44 ± 0.02	0.02 ± 0.01
WO1	1.11 ± 0.09	0.44 ± 0.02	0.04 ± 0.01
WO3	1.46 ± 0.12	0.50 ± 0.02	0.04 ± 0.01
WO2	1.10 ± 0.09	0.38 ± 0.02	0.04 ± 0.01
EMUD	1.32 ± 0.11	0.46 ± 0.02	0.03 ± 0.01
CFDW	1.36 ± 0.11	0.41 ± 0.02	0.03 ± 0.01
Community Mea	1.24 ± 0.01	0.44 ± 0.00	0.03 ± 0.00
ATN San Francis	1.54	0.70	0.36
ATN San Jose	2.32	0.97	0.52
ATN Fremont	1.60	0.63	0.56

Air toxic network data are averages for years 2005-07.

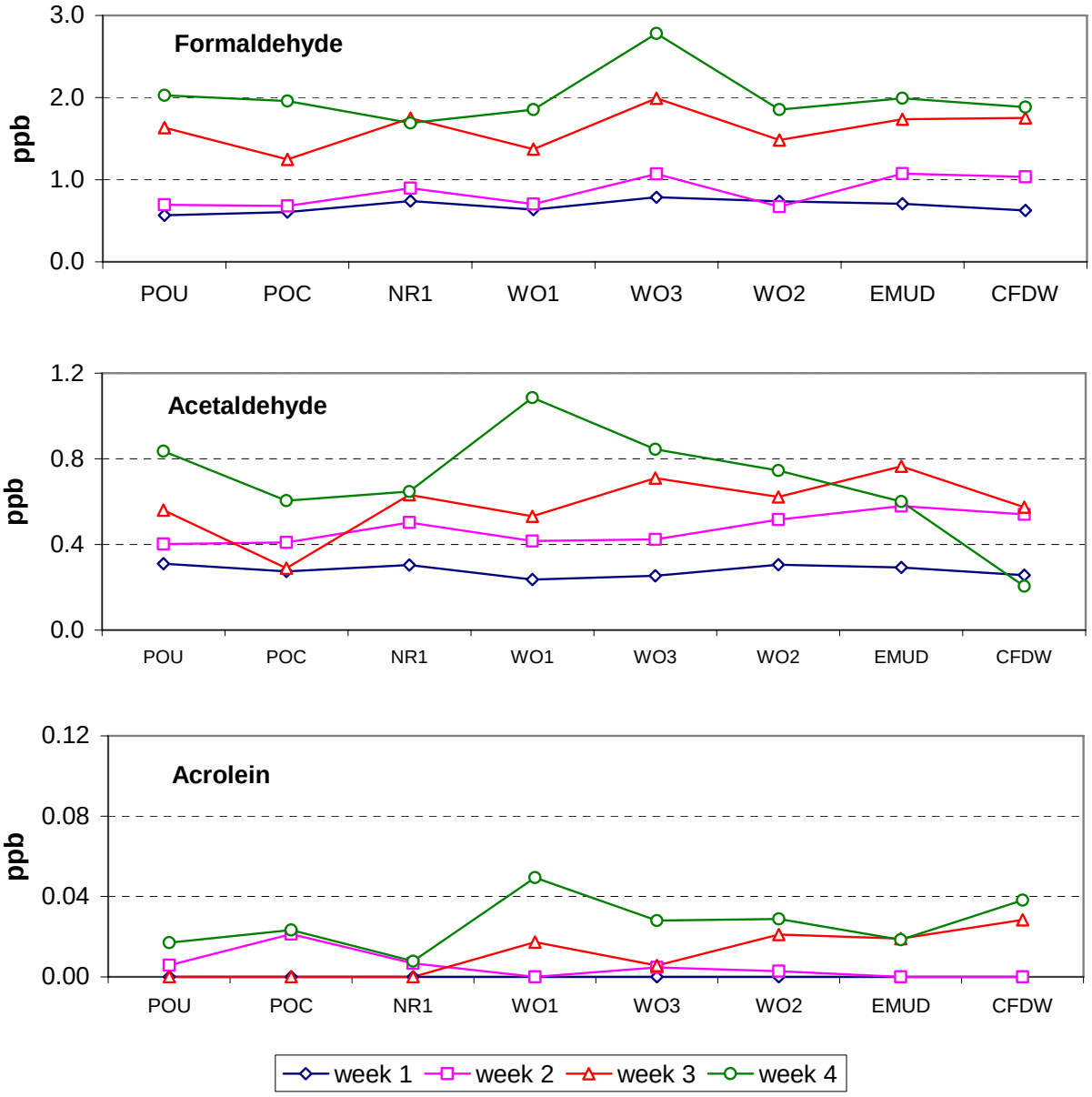

Figure 3-11a. 7-day average aldehydes (ppbv) during the WOMS summer 2009 field study. Sites are ordered approximately from west to east in the plots from left to right.

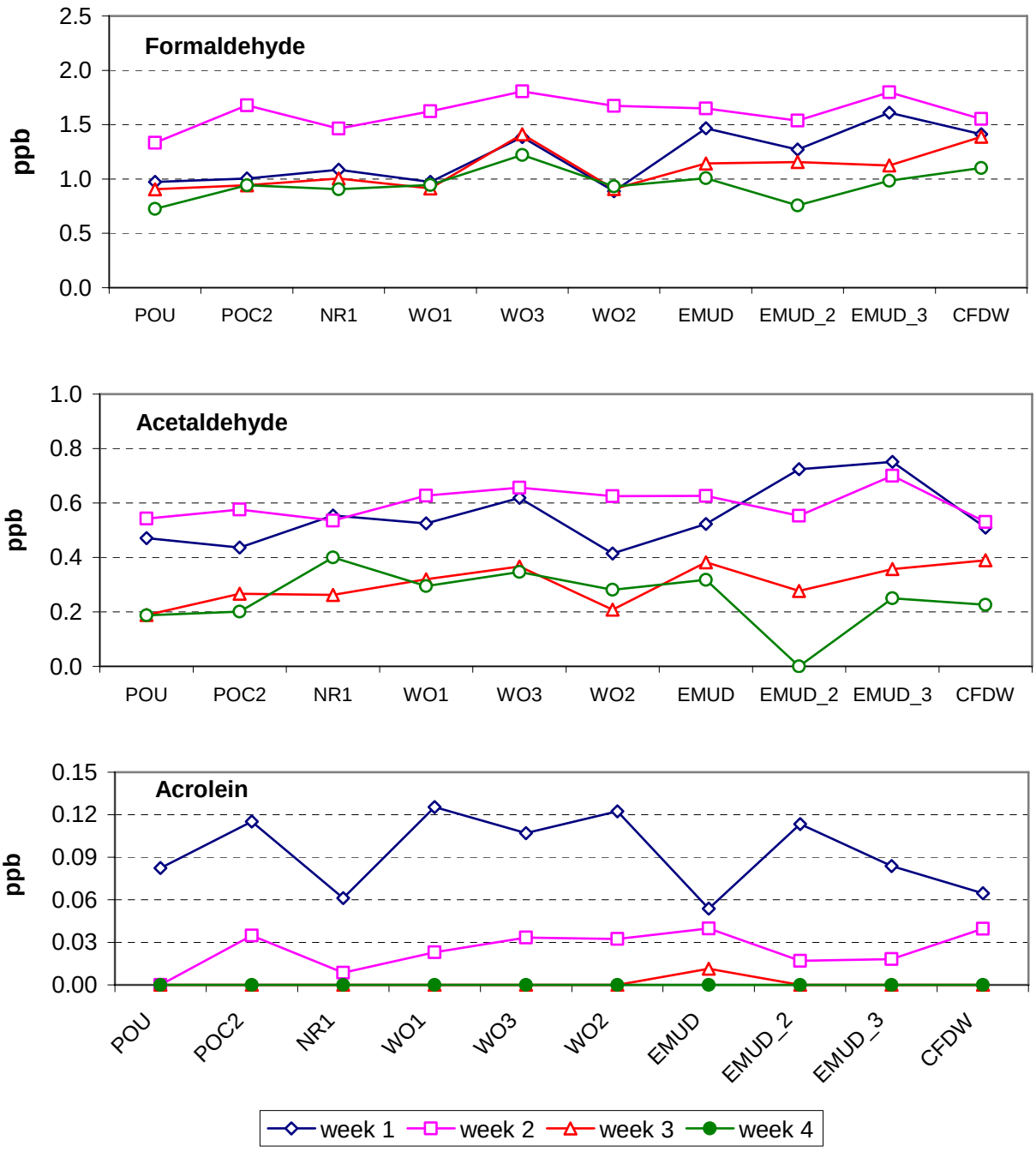

Figure 3-11b. 7-day average aldehydes (ppbv) during the WOMS winter 2010 field study. Sites are ordered approximately from west to east in the plots from left to right.

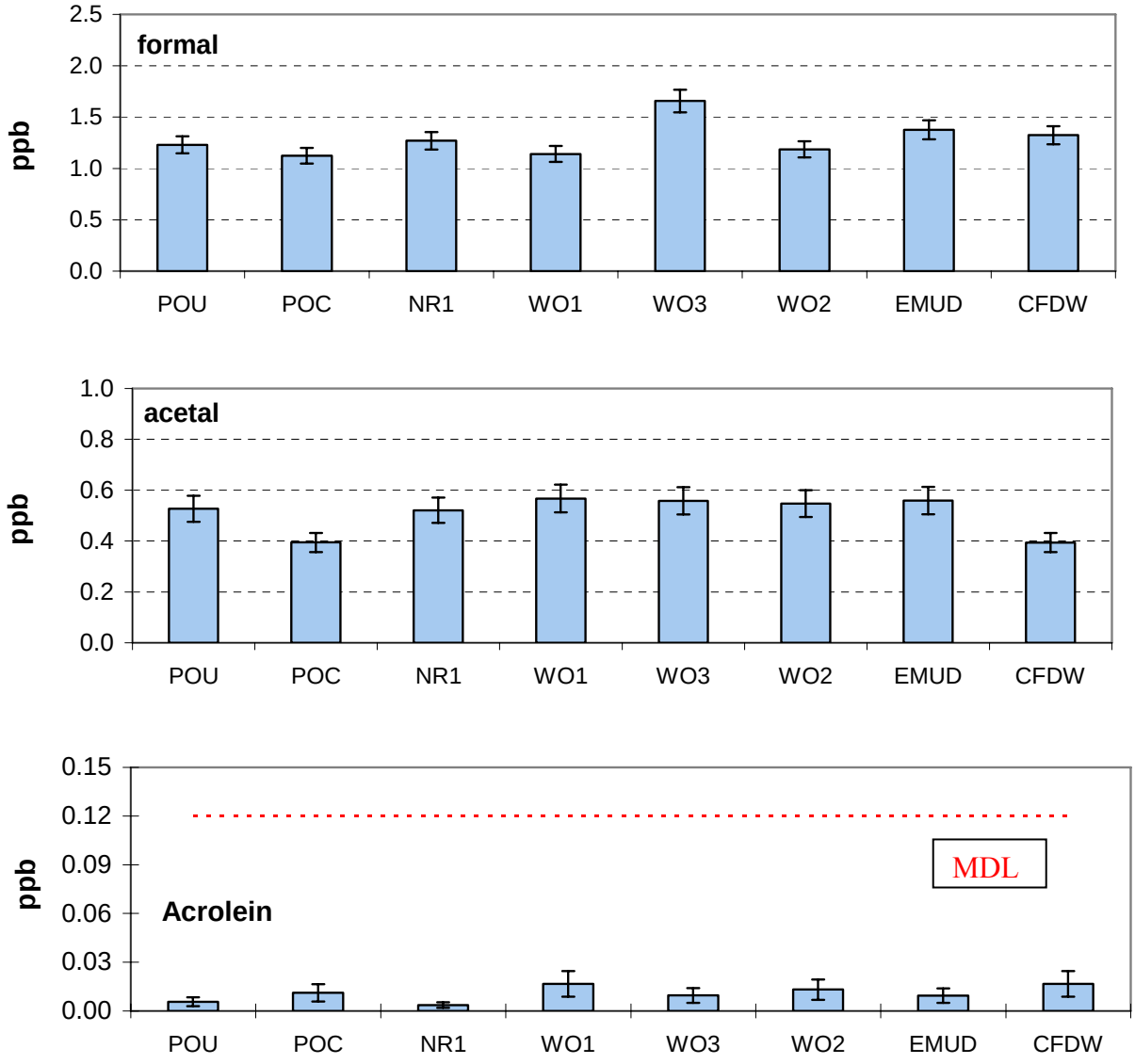

Figure 3-12a. 28-day average aldehydes (ppbv) during the WOMS summer 2009 field study. Sites are ordered approximately from west to east in the plots from left to right. Uncertainties are values multiplied by the mean fractional relative differences of triplicate samples from EMUD.

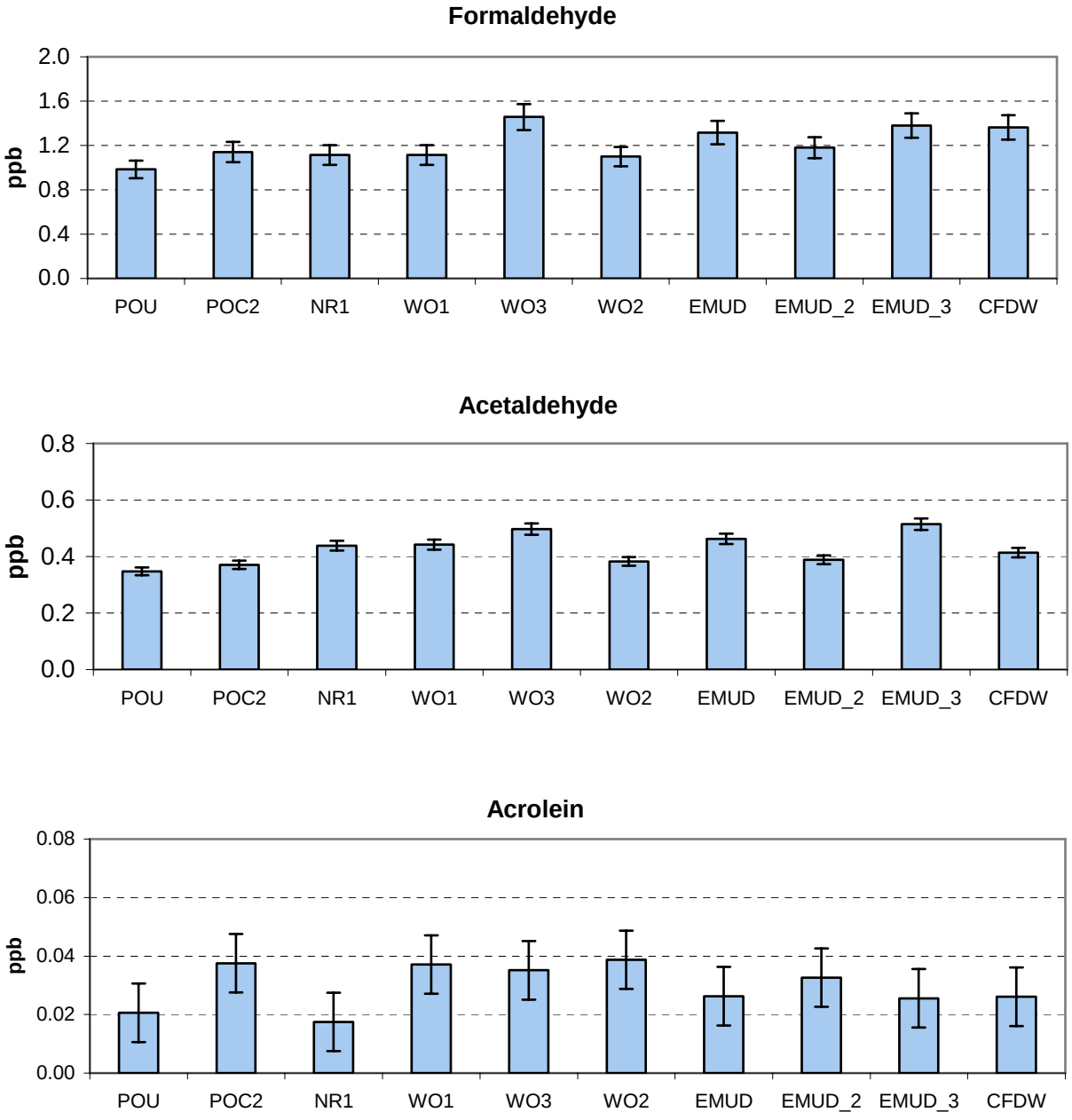

Figure 3-12b. 28-day average aldehydes (ppbv) during the WOMS winter 2010 field study. Sites are ordered approximately from west to east in the plots from left to right. Uncertainties are values multiplied by the mean fractional relative differences of triplicate samples from EMUD.

3.2 Mobile Monitoring

The van-mounted monitoring system described Appendix C was used to determine the variations in O_3, NO, NOx, CO, VOC , black carbon and $PM_{2.5}$ mass concentrations and ultrafine particle number concentrations relative to the BAAQMD air quality monitoring station in the study area and WOMS saturation monitoring sites. The mobile monitoring also provided snapshots in time of gradients in pollutant concentration relative to emission sources that may be useful in interpreting the saturation monitoring data.

Spatial plots of the 10-second average BC ($\mu g/m^3$), NO (ppb), $PM_{2.5}$ mass ($\mu g/m^3$) and CO (ppm) concentrations are shown in Appendix B for each of the mobile surveys. The spatial patterns of higher pollutant concentrations were generally consistent with proximity to vehicle traffic. BC and NO concentrations were higher on the main truck routes within the Port, on the frontage road along the east edge of I-880, and on several of the major arterial streets in West Oakland (e.g., 7th Street, Grand Ave. and Mandela Pkwy). Pollutant concentrations were about a factor of 2 to 5 lower for most pollutants within the residential areas of West Oakland that are at least a city block off the main arterial streets. The higher pollutant concentrations were also measured near the entrance to the port near I-880 at 7th Street, Grand Avenue and Adeline Street. $PM_{2.5}$ and CO concentrations were more uniform spatially than BC and NO. These results are generally consistent with the spatial variations observed with the 7-day passive and mini-volume aerosol samples. Concentrations were lower during the afternoon compared to morning and during Sunday compared to other days of the week.

In addition to mapping the continuous data we also examined the average values measured during the various stops along the route near the saturation monitoring sites, since those 5 to 15 minute averages are less affected by the momentary influence of passing vehicles. In addition to the scheduled stops, we also calculated run averages for three ranges of vehicle speed that generally corresponded to travel through intersections and parking areas (5-15 mph), neighborhood streets (15-25 mph), and port and arterial roads (25-35 mph). The box and whisker plots in Figure 3-13 and Figure 3-14 summarize the survey data according the above groupings for summer and winter.

Concentrations of directly emitted pollutants are highest on heavily traveled roads with consistently lower concentrations away from the roadway. Pollutants that have higher emission rates from diesel trucks (NO, BC) exhibit sharper gradients near such roadways relative to pollutants those are largely associated with gasoline vehicle (CO and VOC). These spatial patterns are likely due to differences in pollutant emission rates and spatial distributions of diesel trucks and gasoline-powered light-duty vehicles. While automobiles are ubiquitous and distributed throughout the city, most diesel truck traffic tends to be concentrated along well-established truck routes. The mobile monitoring data are consistent with sharp gradients in pollutant concentrations near highways, especially those associated with diesel exhaust, and rapid dispersion and mixing of these emissions with the existing background levels that may consist of substantially upwind contributions as shown by measurements at the POU site.

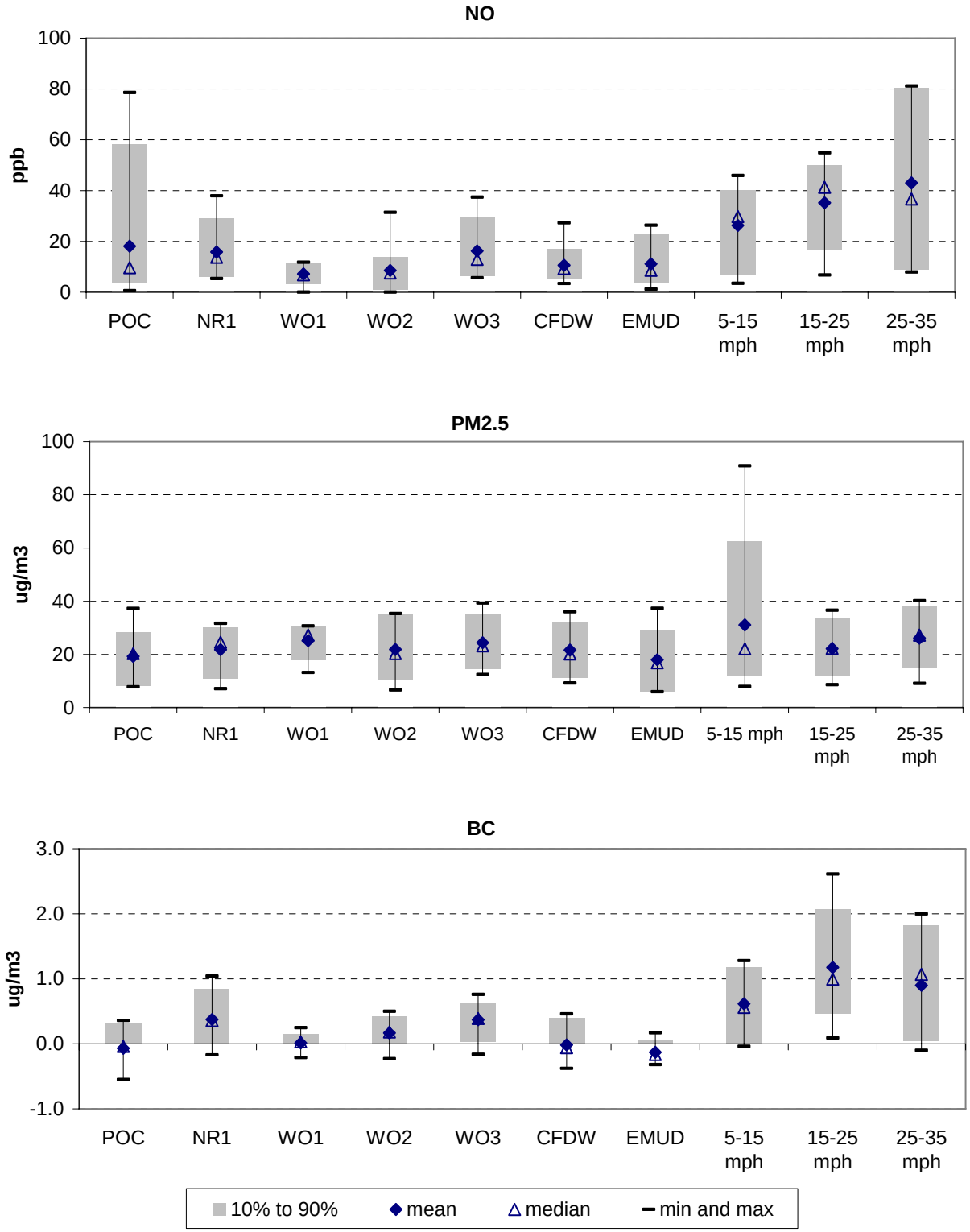

Figure 3-13a. Spatial surveys of NO, $PM_{2.5}$ and black carbon during WOMS summer field study.

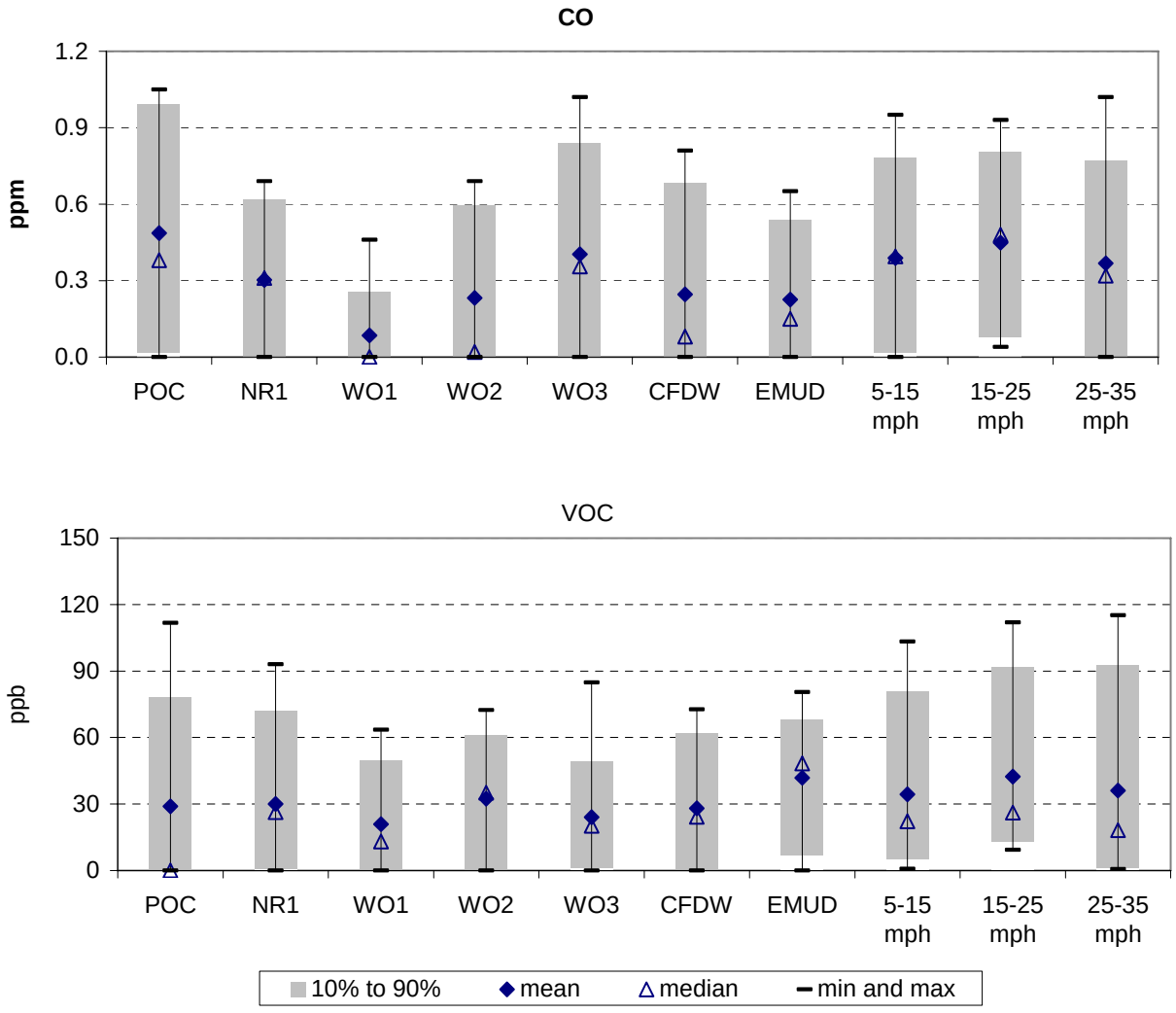

Figure 3-13b. Spatial surveys of CO and VOC during WOMS summer field study.

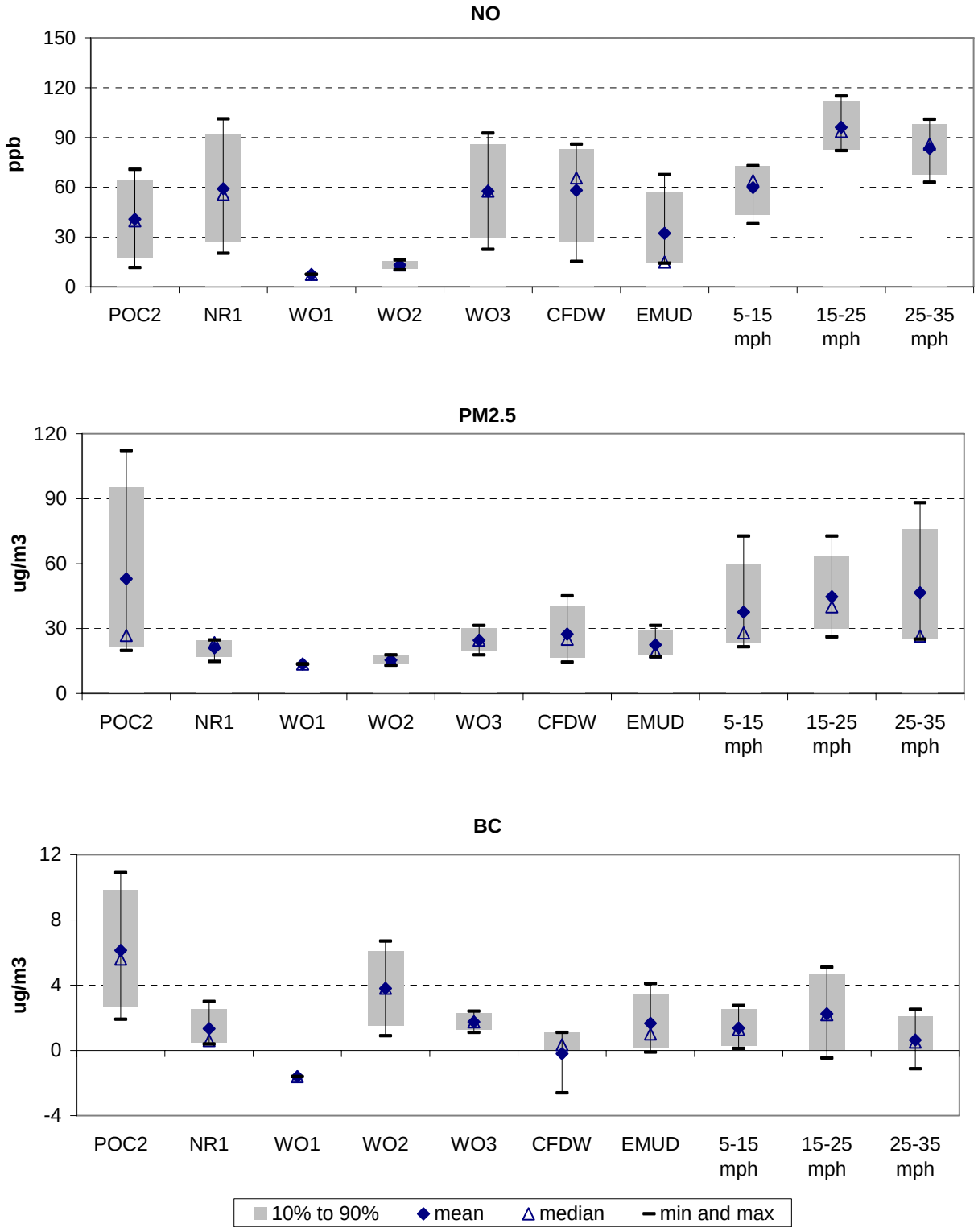

Figure 3-14a. Spatial surveys of NO, $PM_{2.5}$ and black carbon during WOMS winter field study.

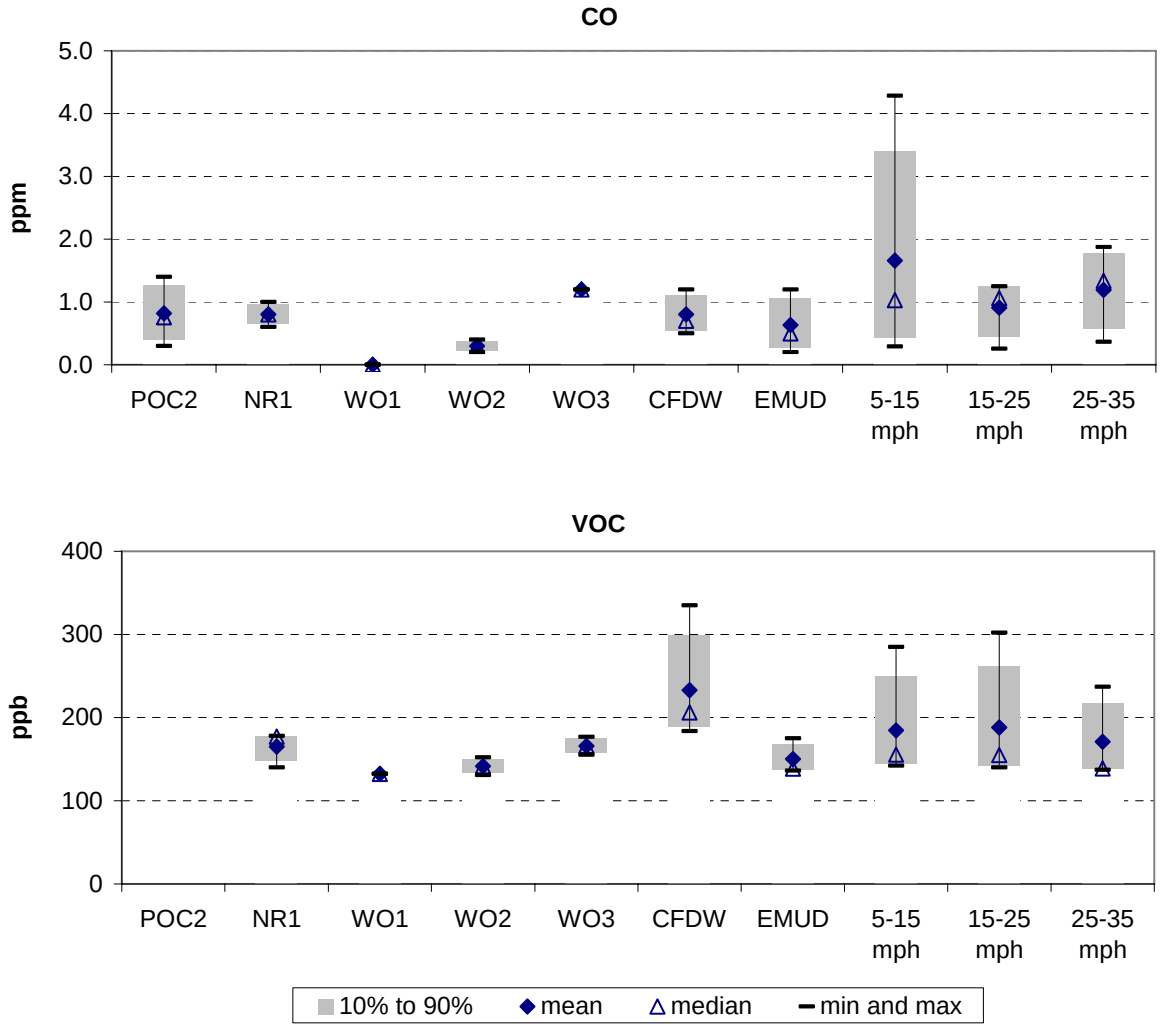

Figure 3-14b. Spatial surveys of CO and VOC during WOMS winter field study. There is less variability for WO1 and WO2 due to only a few data points for these locations.

3.3 Chemical Speciation for Source Attribution

DRI collected pairs of 24-hour Teflon and quartz filters with DRI medium volume (55 lpm) sequential filter sampler (SFS) on 14 consecutive days at three sites (EBMUD, Port of Oakland maintenance yard, and West Oakland site east of I-880). Tables 3-6 and 3-7 provide a summary of $PM_{2.5}$ mass, OC, EC and several organic compounds related to vehicle exhaust emissions for the summer and winter study, respectively. The relative concentrations of select organic compounds and sums of chemical types are shown by sampling location in Figure 3-15 for the summer study and in Figure 3-16 for the winter study. Each parameter is normalized by the average of all samples and error bars are the normalized standard error of the mean.

The ambient concentrations of PM components and selected organic compounds provide information regarding the likely sources of particulate carbonaceous particles in the region. As expected, the concentrations of the mobile source related organic compounds, hopanes and steranes, are highest at the site nearest of the 7th Street entrance to the Port at I-880 and at the central port site, especially during the winter study when the site was move closer to Maritime Street (POC2). Most samples had measureable concentrations of molecular marker normally associated with wood combustion (e.g., levoglucosan) and meat cooking (e.g. cholesterol, oleic acid).

Estimates of the CMB source contributions estimates to ambient total carbon are shown in Figure 3-17 and Figure 3-18 for the summer and winter periods, respectively. In some cases, particularly during the winter season, CMB significantly overestimated the amount of organic carbon (OC) present. This frequently occurs because OC is not used as a 'fitting species' due to the variability of its composition between the source and receptor. Since OC is an operationally defined parameter that may contain substantial amounts of lower molecular weight compounds which may be partitioned between gaseous and particle phases depending on sampling conditions, it is often the case that in samples collected close to combustion sources such as those that are used to define our source profiles the proportion of OC will be much higher relative to specific marker compounds than in ambient air samples. We believe this disparity to be greatest for biomass combustion sources such as wood burning or meat cooking, since these involve much lower temperatures than fossil fuel combustion. To correct for this problem, the apportionments of OC (and subsequently TC) were adjusted as follows:

$$OC_{corrected}^{wood\_burning} = OC_{apportioned}^{wood\_burning} - OC_{excess}^{total} x \left(\frac{OC_{apportioned}^{wood\_burning}}{OC_{apportioned}^{wood\_burning} + OC_{apportioned}^{meat\_cooking}} \right)$$

$$OC_{corrected}^{meat\_cooking} = OC_{apportioned}^{meat\_cooking} - OC_{excess}^{total} x \left(\frac{OC_{apportioned}^{meat\_cooking}}{OC_{apportioned}^{wood\_burning} + OC_{apportioned}^{meat\_cooking}} \right)$$

where $OC_{excess}^{total} = OC_{apportioned}^{total} - OC_{measured}^{total}$

Table 3-6. Partial summary of particulate organic speciation data [1] obtained during the summer WOMS.

site	day	PM2.5	EC	OC	TC	hop17	hop19	sum of H&S	naphth	chr_tr	anthra	sum of gas marker PAH	levg	olac	chol	docosa	octcos	noncos
EMUD	Sat	14.0	0.4	2.6	3.0	0.139	0.112	0.791	63.749	0.0094	0.0005	0.1490	125.652	0.187	0.1532	13.803	0.9992	1.5050
EMUD	Wed	6.6	0.3	1.6	1.9	0.078	0.070	0.410	57.298	0.0141	0.0012	0.0616	51.819	1.610	0.0000	3.112	0.6282	0.9195
EMUD	Thu	7.6	0.4	1.5	1.9	0.097	0.044	0.326	48.193	0.0023	0.0004	0.0321	20.661	0.000	0.2648	6.018	1.2653	1.2564
NR1	Fri	10.6	0.5	1.6	2.0	0.215	0.142	0.779	82.735	0.0293	0.0036	0.1689	44.149	0.484	0.0000	4.300	0.2881	0.8735
NR1	Sun	15.0	0.3	2.1	2.4	0.171	0.119	1.110	95.400	0.0121	0.0000	0.0851	65.207	0.000	0.0000	5.269	0.6437	1.0882
NR1	Wed	6.9	0.5	1.6	2.1	0.151	0.131	0.489	73.372	0.0285	0.0029	0.0716	62.831	9.239	0.2102	4.183	0.4624	1.1379
NR1	Thu	7.6	0.6	1.5	2.0	0.152	0.066	0.493	66.266	0.0203	0.0029	0.0450	31.725	2.272	0.0000	3.940	0.8180	0.9122
POC	Fri	27.8	0.4	2.0	2.4	0.164	0.084	0.591	82.182	0.0058	0.0000	0.0654	13.774	31.062	1.6634	8.591	0.8768	1.1620
POC	Sun	34.4	0.2	2.5	2.7	0.185	0.082	0.507	62.070	0.0047	0.0000	0.0421	51.559	4.579	0.0240	9.918	0.7027	1.3121
POC	Wed	7.1	0.3	1.4	1.7	0.079	0.064	0.232	55.179	0.0009	0.0000	0.0154	38.210	6.979	0.0000	5.520	0.5874	1.1899
POC	Thu	6.5	0.4	1.4	1.8	0.134	0.065	0.384	42.325	0.0089	0.0000	0.0172	16.611	0.000	0.0000	5.534	0.7447	0.5615
						13	15	61	13	161	71	226	57	203	147	59	81	83

site	day	PM2.5	EC	OC	TC	hop17	hop19	sum of H&S	naphth	chr_tr	anthra	sum of gas marker PAH	levg	olac	chol	docosa	octcos	noncos
EMUD	MEAN	9.4	0.3	1.9	2.2	0.105	0.075	0.51	56.414	0.009	0.001	0.081	66.04	0.60	0.14	7.64	0.96	1.23
NR1	MEAN	10.0	0.5	1.7	2.1	0.172	0.114	0.72	79.443	0.023	0.002	0.093	50.98	3.00	0.05	4.42	0.55	1.00
POC	MEAN	18.9	0.3	1.8	2.1	0.140	0.074	0.43	60.439	0.005	0.000	0.035	30.04	10.66	0.42	7.39	0.73	1.06
EMUD	stderr	2.00	0.02	0.30	0.31	0.016	0.017	0.12	3.908	0.003	0.000	0.030	26.96	0.44	0.07	2.76	0.16	0.15
NR1	stderr	1.84	0.06	0.14	0.09	0.015	0.017	0.15	6.298	0.004	0.001	0.027	7.96	2.14	0.05	0.29	0.11	0.06
POC	stderr	7.15	0.05	0.25	0.24	0.023	0.005	0.08	8.323	0.002	0.000	0.012	9.01	6.95	0.41	1.11	0.06	0.17
EMUD	norm. mean	0.73	0.91	1.06	1.04	0.753	0.858	0.92	0.862	0.712	0.667	1.164	1.35	0.13	0.68	1.18	1.29	1.12
NR1	norm. mean	0.78	1.22	0.93	0.98	1.236	1.303	1.30	1.214	1.869	2.333	1.333	1.04	0.63	0.26	0.68	0.74	0.92
POC	norm. mean	1.48	0.87	1.01	0.98	1.010	0.840	0.78	0.924	0.419	0.000	0.504	0.61	2.24	2.06	1.14	0.97	0.96
EMUD	norm. stderr	0.16	0.05	0.17	0.15	0.112	0.197	0.22	0.060	0.247	0.224	0.437	0.55	0.09	0.32	0.43	0.21	0.13
NR1	norm. stderr	0.14	0.15	0.08	0.04	0.108	0.193	0.27	0.096	0.333	0.793	0.385	0.16	0.45	0.26	0.04	0.15	0.06
POC	norm. stderr	0.56	0.12	0.14	0.11	0.165	0.062	0.14	0.127	0.137	0.000	0.170	0.18	1.46	2.02	0.17	0.08	0.15
	correl with TC					0.22	0.16	0.36	0.15	0.01	0.04	0.25	0.47	0.02	0.05	**0.70**	0.05	0.43
	correl with OC					0.13	0.09	0.30	0.09	0.07	0.15	0.16	0.45	0.00	0.02	**0.73**	0.06	0.47
	correl with EC					0.10	0.09	0.00	0.07	0.50	**0.58**	0.08	0.01	0.04	0.05	0.07	0.02	0.07

[1] Units are µg/m^3 for $PM_{2.5}$ mass, EC, OC and TC and ng/m^3 for organic compounds. Mnemonics are hop17 (17α(H),21ß(H)-29-Norhopane), hop19 (17α(H),21ß(H)-Hopane), H&S (sum of hopanes and steranes), naphth (naphthalene), chr_tr (chrysene-triphenylene), anthrax (anthracene), sum of gasoline exhaust marker PAH (sum of indeno[123-cd]pyrene, benzo(ghi)perylene and coronene), levg (levoglucosan), olac (oleic acid), chol (cholesterol), docosa (docosane), octocos (octacosane), noncos (nonacosane).

Table 3-7. Partial summary of particulate organic speciation data [1] obtained during the winter WOMS.

site	day	media_type	units	PM2.5	EC	OC	TC	EC/TC	hop17	hop19	sum of H&S	H&S/TC (ppt)	naphth	chr_tr	anthra	gas marker PAH	gmPAH/TC (ppt)	levg	olac	chol	docosa	octcos	noncos
EMUD	Sun	combined	ng/m3	18178	1160	3483	4643	0.25	0.1570	0.1600	1.2064	0.26	210.7	0.0411	0.4334	1.2956	0.28	319.7951	0.4861	0.2041	3.40	0.80	2.60
EMUD	Wed	combined	ng/m3	8551	704	1816	2520	0.28	0.2322	0.3137	1.6254	0.64	100.1	0.0000	0.2110	0.7613	0.30	46.6678	9.3073	0.7951	3.90	1.70	1.70
EMUD	Thu	combined	ng/m3	10695	1685	2732	4417	0.38	0.2360	0.1959	1.5386	0.35	263.4	0.0696	0.5805	2.3376	0.53	240.8271	22.4540	1.6460	6.60	1.50	2.30
EMUD	Fri	combined	ng/m3	22181	2806	3883	6690	0.42	0.3783	0.4059	2.6589	0.40	288.8	0.0663	0.7137	2.2716	0.34	301.9058	14.2866	1.4549	4.40	3.60	5.60
NR1	Wed	combined	ng/m3	9532	943	1800	2743	0.34	0.1976	0.2380	1.4612	0.53	140.3	0.0377	0.5146	0.8614	0.31	198.1818	9.1441	0.7490	6.30	4.80	5.30
NR1	Thu	combined	ng/m3	17014	1604	2029	3633	0.44	0.4307	0.4229	2.9194	0.80	347.7	0.0394	0.7160	2.2234	0.61	183.2804	26.3395	0.8457	4.30	1.50	2.10
NR1	Fri	combined	ng/m3	15400	2423	4045	6468	0.37	0.3438	0.3072	2.3184	0.36	292.7	0.0395	0.9212	1.5988	0.25	298.0412	1.4976	0.9246	6.00	2.90	4.90
POC2	Sun	combined	ng/m3	20357	1022	2176	3198	0.32	0.1504	0.2035	0.9670	0.30	129.0	0.0166	0.4960	0.5048	0.16	190.6902	1.5528	0.2820	3.80	0.80	1.50
POC2	Wed	combined	ng/m3	10787	1353	1817	3169	0.43	0.2090	0.1868	1.0161	0.32	91.3	0.0105	0.6028	0.3183	0.10	29.1732	0.0000	0.0942	5.50	0.60	0.90
POC2	Thu	combined	ng/m3	12464	2170	2544	4714	0.46	0.4734	0.4744	2.8907	0.61	238.5	0.0278	1.2323	0.8792	0.19	129.2343	3.6499	0.1495	7.30	3.50	2.80
POC2	Fri	combined	ng/m3	23879	3006	3852	6858	0.44	0.5114	0.4094	3.1490	0.46	243.0	0.0000	1.0751	0.9220	0.13	275.6105	0.0000	0.0531	7.70	2.40	5.20
									13	15	61		13.0	153	69	224		57	203	147	59	81	83

site	day	media_type	units	PM2.5	EC	OC	TC	EC/TC	hop17	hop19	sum of H&S	H&S/TC (ppt)	naphth	chr_tr	anthra	gas marker PAH	gmPAH/TC (ppt)	levg	olac	chol	docosa	octcos	noncos
EMUD	MEAN	combined	ng/m3	14901	1589	2979	4567	0.33	0.251	0.269	1.76	0.41	215.7	0.044	0.485	1.667	0.36	227.30	11.63	1.03	4.58	1.90	3.05
NR1	MEAN	combined	ng/m3	13982	1657	2625	4281	0.39	0.324	0.323	2.23	0.56	260.2	0.039	0.717	1.561	0.39	226.50	12.33	0.84	5.53	3.07	4.10
POC2	MEAN	combined	ng/m3	16872	1888	2597	4485	0.41	0.336	0.319	2.01	0.42	175.5	0.014	0.852	0.656	0.14	156.18	1.30	0.14	6.08	1.83	2.60
EMUD	stderr	combined	ng/m3	3185	453	455	853	0.04	0.046	0.056	0.31	0.08	41.827	0.016	0.108	0.384	0.06	62.54	4.60	0.33	0.71	0.60	0.87
NR1	stderr	combined	ng/m3	1969	371	618	973	0.02	0.059	0.047	0.37	0.11	53.729	0.001	0.102	0.341	0.10	31.20	6.36	0.04	0.54	0.83	0.87
POC2	stderr	combined	ng/m3	3132	444	444	869	0.03	0.091	0.073	0.59	0.07	38.486	0.006	0.179	0.146	0.02	51.89	0.86	0.05	0.90	0.69	0.95
EMUD	norm. mean			0.98	0.93	1.09	1.03	0.88	0.826	0.886	0.88	0.88	0.994	1.371	0.708	1.287	1.210	1.12	1.38	1.53	0.85	0.84	0.94
NR1	norm. mean			0.92	0.97	0.96	0.96	1.03	1.067	1.064	1.12	1.21	1.198	1.204	1.048	1.206	1.306	1.11	1.46	1.25	1.03	1.35	1.26
POC2	norm. mean			1.11	1.10	0.95	1.01	1.09	1.107	1.050	1.00	0.91	0.808	0.425	1.244	0.507	0.484	0.77	0.15	0.22	1.13	0.81	0.80
EMUD	norm. stderr			0.21	0.26	0.17	0.19	0.11	0.152	0.185	0.16	0.18	0.193	0.498	0.157	0.297	0.190	0.31	0.55	0.49	0.13	0.26	0.27
NR1	norm. stderr			0.13	0.22	0.23	0.22	0.07	0.194	0.154	0.18	0.24	0.247	0.016	0.149	0.263	0.324	0.15	0.76	0.07	0.10	0.37	0.27
POC2	norm. stderr			0.21	0.26	0.16	0.20	0.08	0.301	0.239	0.29	0.15	0.177	0.180	0.261	0.113	0.061	0.26	0.10	0.07	0.17	0.30	0.29
		correl with TC							0.39	0.19	0.41	0.07	0.43	0.08	0.43	0.18	0.01	**0.52**	0.02	0.02	0.13	0.08	0.46
		correl with OC							0.16	0.05	0.20	0.17	0.34	0.10	0.21	0.17	0.01	**0.68**	0.05	0.02	0.03	0.03	0.41
		correl with EC							**0.64**	0.40	**0.61**	0.00	0.44	0.04	**0.64**	0.15	0.01	0.27	0.00	0.01	0.28	0.13	0.40

[1] Units are µg/m^3 for $PM_{2.5}$ mass, EC, OC and TC and ng/m^3 for organic compounds. Mnemonics are hop17 (17α(H),21ß(H)-29-Norhopane), hop19 (17α(H),21ß(H)-Hopane), H&S (sum of hopanes and steranes), naphth (naphthalene), chr_tr (chrysene-triphenylene), anthrax (anthracene), sum of gasoline exhaust marker PAH (sum of indeno[123-cd]pyrene, benzo(ghi)perylene and coronene), levg (levoglucosan), olac (oleic acid), chol (cholesterol), docosa (docosane), octocos (octacosane), noncos (nonacosane).

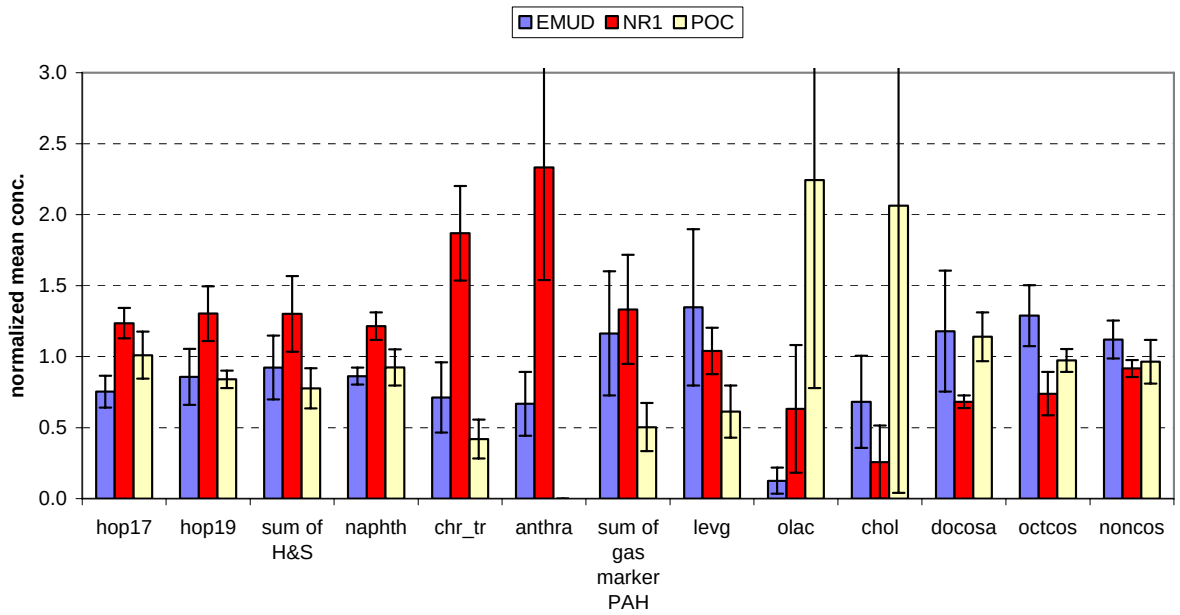

Figure 3-15. Relative concentrations of select organic compounds and sums of chemical types by sampling location during summer WOMS. Each parameter is normalized by the average of all samples and error bars are the normalized standard error of the mean.

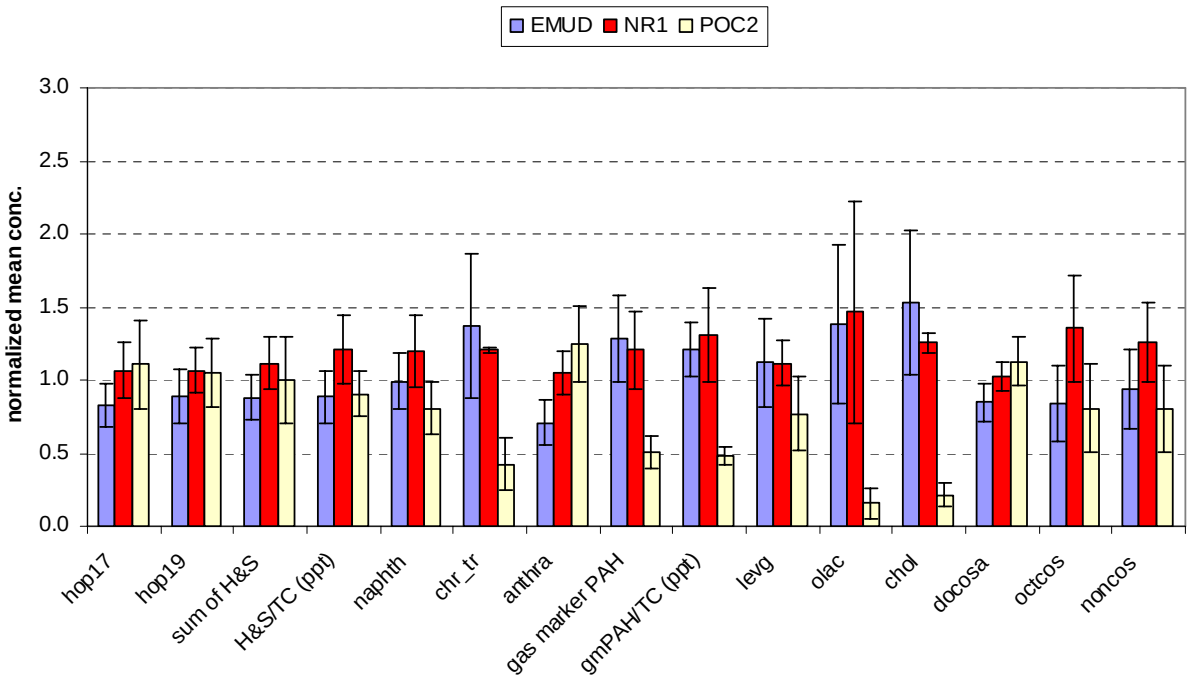

Figure 3-16. Relative concentrations of select organic compounds and sums of chemical types by sampling location during winter WOMS. Each parameter is normalized by the average of all samples and error bars are the normalized standard error of the mean.

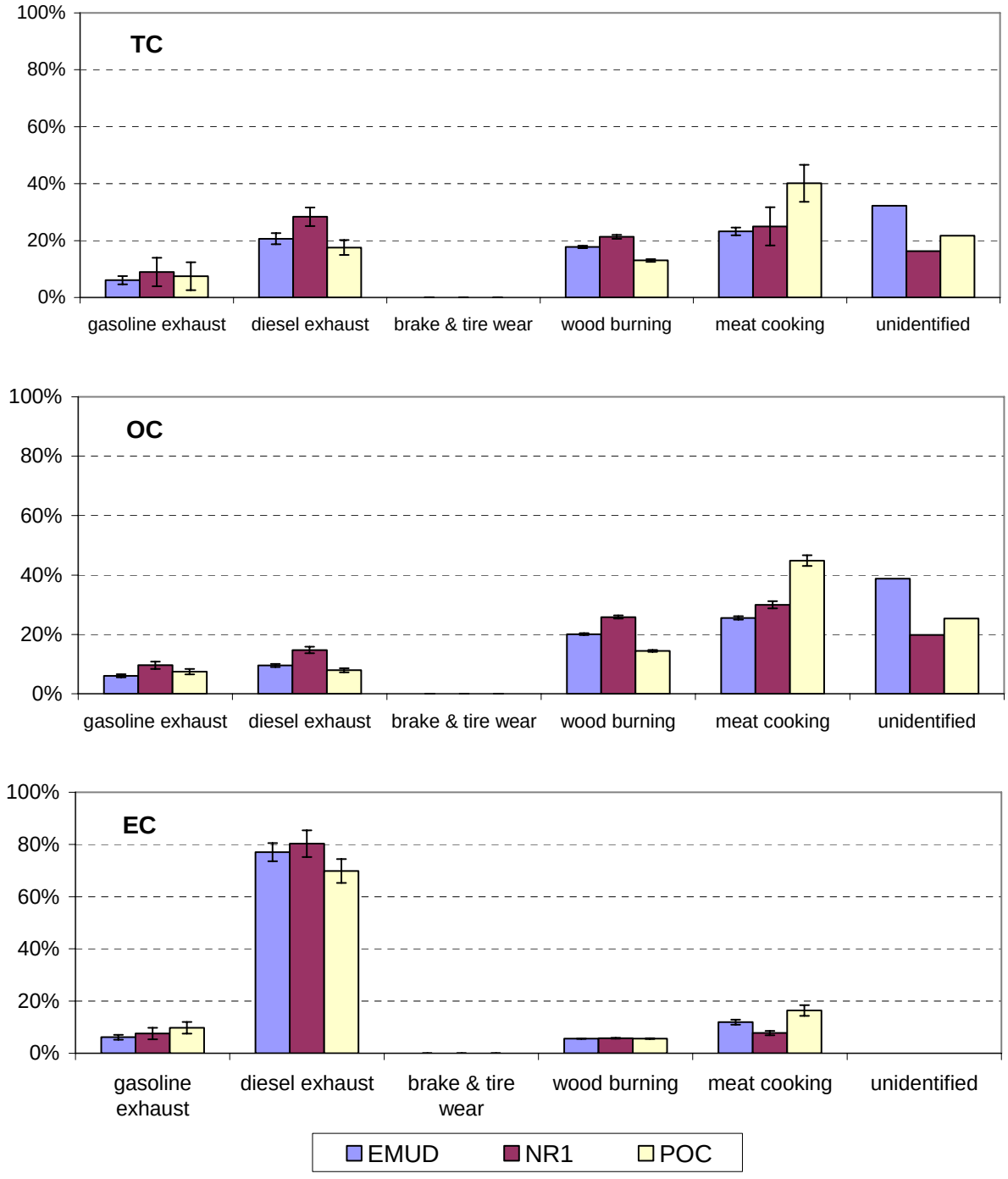

Figure 3-17. Estimates of source contributions to ambient total carbon by Chemical Mass Balance during summer WOMS.

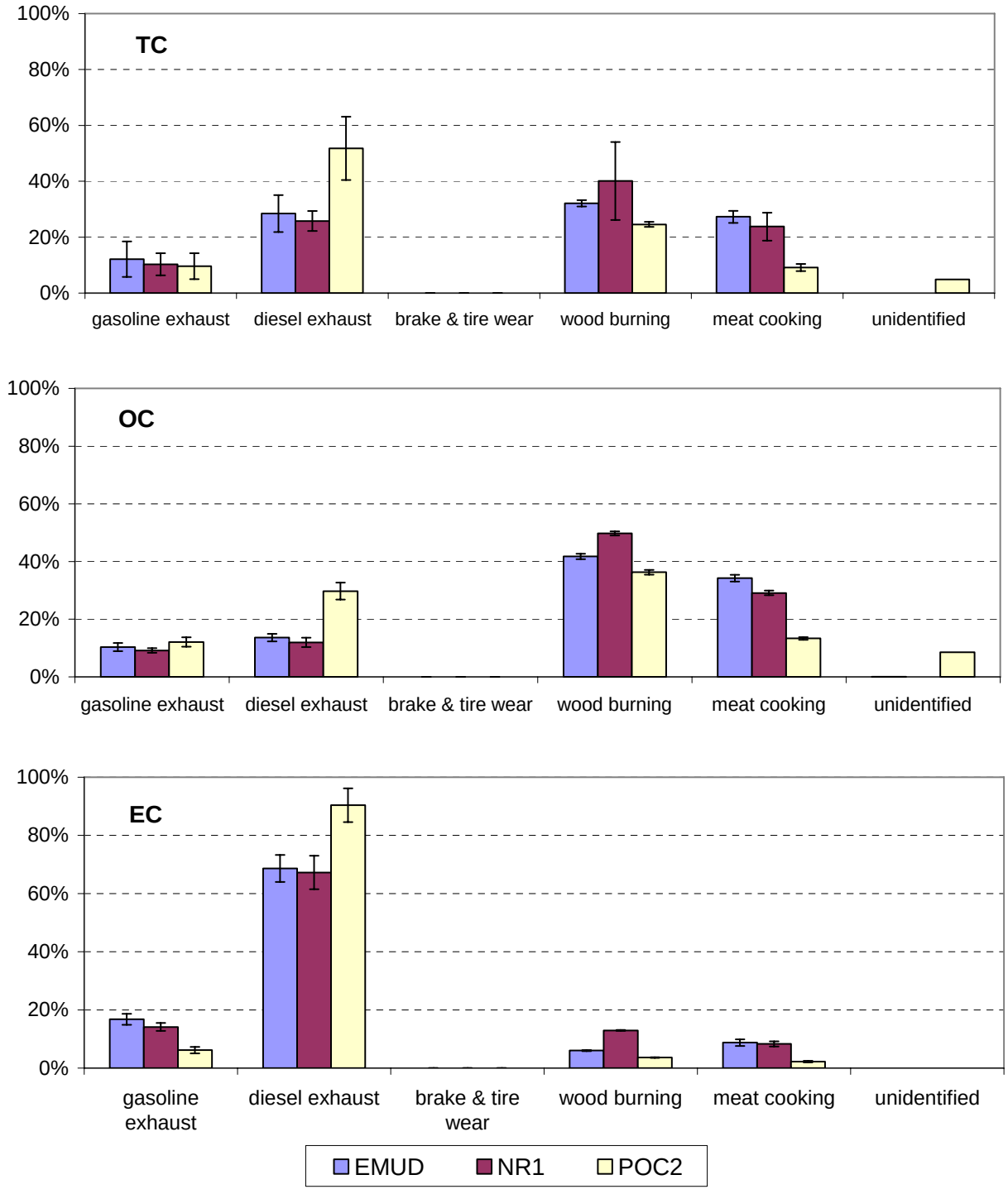

Figure 3-18. Estimates of source contributions to ambient total carbon by Chemical Mass Balance during winter WOMS.

This reduced the total apportionments to 100% or less of the measured concentrations in all cases. Where the total apportioned OC was already less than the measured concentration, no adjustments were made. While this adjustment is only an approximation we believe it should improve the overall accuracy of the apportionments for these two source types.

Diesel exhaust accounted for 70-90% of the ambient EC and gasoline vehicle exhaust, wood combustion and meat cooking accounted for the remaining EC with the larger of the three source contributions being gasoline exhaust. The highest average absolute (1.7 $\mu g/m^3$) and fractional contribution (90%) of diesel exhaust to EC was measured at the POC2 sampling site during the winter period when the sampling location was in closer proximity diesel traffic along Maritime Street. During the winter period, the average absolute (1.1 $\mu g/m^3$) and fractional contributions (~70%) of diesel exhaust to EC at NR1 and EMUD were similar. Though the absolute contributions (0.2-0.3 $\mu g/m^3$) of diesel exhaust were much lower during the summer than winter period, the fractional contributions at NR1 and EMUD (~80%) were just as high during summer.

During the winter period, vehicle exhaust accounted for about half of the ambient concentrations of TC with a factor of three higher contributions of diesel (35%) relative to gasoline (11%) exhaust. Wood combustion (32%) and meat cooking (20%) accounted for the remainder. Only 2% of the TC, on average, was unidentified indicating insignificant contributions of SOA during the winter period.

During the summer period, vehicle exhaust accounted for about a third of the ambient concentration of TC with the same factor of three higher contribution of diesel (22%) relative to gasoline (8%) exhaust. Wood combustion (17%), meat cooking (29%) and unidentified sources (23%) accounted for the remainder. The greater proportion of unidentified TC during summer is attributed to contributions of SOA due to greater photochemical activity compared to winter.

3.4 Comparisons of WOMS Data to BAAQMD Monitoring Data and HRA Modeling Results

We previously compared the seasonal averages of BTEX, aldehydes, $PM_{2.5}$ mass, OC, EC and estimates of DPM at the WOMS sampling sites with comparable averages for the three air toxic monitoring network (ATMN) sites and Chemical Speciation Network (CSN) site shown in Figure 3-19. These comparisons are summarized in Table 3-8 using averages of the WOMS sampling sites located within West Oakland to represent the community average. BTEX concentrations in West Oakland are similar to those measured at the three ATMN sites. Aldehyde levels are higher in Fremont and San Jose than in West Oakland reflecting greater contributions of atmospheric formation of aldehydes from photooxidation of hydrocarbons in downwind area of the Bay Area. The fractions of DPM to TC and $PM_{2.5}$ were higher in West Oakland than San Jose. However, the mass concentrations of DPM were similar in both areas and other sources account for a greater proportion of ambient TC and $PM_{2.5}$ in San Jose.

A potential uncertainty in these comparisons is whether four weeks of WOMS data are representative of the seasonal averages and the combined WOMS summer and winter study are valid annual averages. Figure 3-20 shows the average BTEX concentrations by month at the three ATMN sites in the San Francisco Bay Area. Figure 3-21 shows analogous data for 1,3 butadiene and carbonyl compounds. Primary pollutant concentrations are typically much higher

during the late fall to early winter (November to January) due to meteorological conditions that are more conducive to higher ambient pollutant concentration. Concentrations of primary pollutants are consistently lower from mid-spring to late summer. The WOMS summer period in August and winter period (two weeks in December and two weeks in January) were selected to represent these two contrasting periods during the year. The comparisons in Table 3-9 of the annual averages air toxic monitoring network data for benzene, toluene, ethylbenzene, xylene, formaldehyde and acetaldehyde with the WOMS equivalent 2-month averages comprised of August and the means of December and January show that the two averages are generally within 10 percent and any differences due to averaging periods are comparable to uncertainty of the measurements.

The two data sets also differ in the years in which the data were collected. ATMN and CSN data from 2005 to 2007 were used in the average pollutant concentrations versus 2009-2010 for WOMS. The trend plots in Figures 3-22 and 3-23 show that the annual average pollutant concentrations have been essentially flat from 2005 to 2008 and that comparisons of the averages over these years with WOMS data are reasonable valid.

Lastly, we examined whether the concentrations and spatial variations in the DPM estimated from the WOMS saturation monitoring data are consistent with modeled results from the recent health risk assessment conducted by the California Air Resources Board and the District. Figure 3-24 shows the estimated potential cancer risk in West Oakland from diesel PM emissions (CARB, 2008). The spatial variations in modeled concentrations of DPM in $\mu g/m^3$ can be estimated by multiplying the isopleth values of excess cancer by the unit cancer risk factor. For example, the highest isopleth value of 1500 x 10^{-6} excess cancer divided by the unit cancer risk factor of 3.19 x 10^{-4} $(\mu g/m^3)^{-1}$ is equivalent to 4.7 $\mu g/m^3$. The methodology used to estimate the potential cancer risks was consistent with the Tier-1 analysis presented in the Office of Environmental Health Hazard Assessment's Air Toxics Hot Spots Program Guidance Manual for Preparation of Health Risk Assessments (OEHHA, 2003) using an assumed 80^{th} percentile breathing rate to estimate dosage.

Table 3-10 compares the concentrations of DPM (µg/m3) estimated from the WOMS saturation monitoring data with modeled results from the CARB/BAAQMD health risk assessment. The model estimates of DPM were consistently higher that the concentrations of DPM at the WOMS community sampling sites estimated from EC measurements by about a factor of 2.3.

One of the main findings of the West Oakland Truck Survey (BAAQMD, 2009) was that, compared to the HRA, there were significantly fewer medium-heavy duty and heavy, heavy-duty trucks on surface streets in West Oakland overall but a higher percentage of the trucks on the surface streets were found to be servicing the Port of Oakland. Using the activity data collected in the Truck Survey to adjust the HRA risk estimates reduces the total potential cancer risk from DPM by about 25%.

Between 2005, the base year of the HRA, and the 2009-2010 WOMS significant reductions in DPM emissions were estimated. The HRA projected about a 20% to 50% reduction in DPM emissions from all sources in West Oakland between 2005 and 2010 (ARB, 2008). The larger reduction amount was contingent upon planned regulations on ship main engines and on-

road private fleets of diesel trucks, both of which were adopted in 2008. There have been delays in implementation in some of the Statewide DPM regulations. However, there has also been focused enforcement of diesel regulations in West Oakland and focused grant activity to support early compliance and reduce DPM in advance of regulation schedules. Both BAAQMD and ARB are currently working on refined estimates of DPM emission reductions that have occurred since the HRA; but the range of reductions projected in the HRA provides a reasonable bounding estimate.

Using the correction provided by the Truck Survey and the HRA projection to estimate the reductions from regulations and grants, the average estimated West Oakland DPM concentrations would range between about 1.2 and 1.8 $\mu g/m^3$ in 2010, compared to 1.4 $\mu g/m^3$ estimated from WOMS measurements.

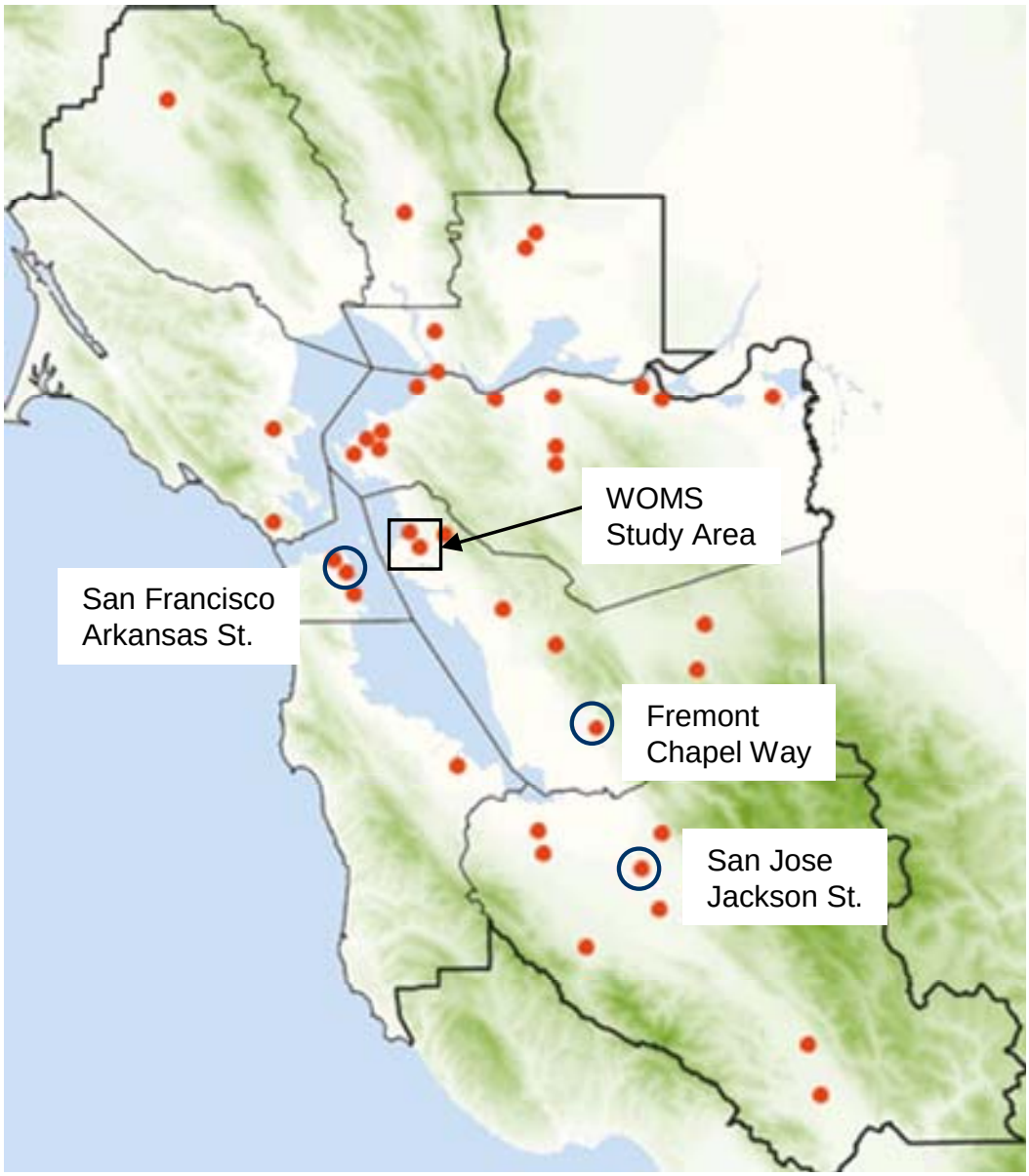

Figure 3-19. Map showing locations of BAAQMD criteria pollutant monitoring sites (red dots), air toxic monitoring sites (blue circles) and Chemical Speciation Network site (San Jose only) relative to the WOMS study area (black rectangle).

Table 3-8. Comparisons of the WOMS seasonal community mean concentrations of BTEX, aldehydes, and PM with comparable data from the District air toxic monitoring network sites and PM speciation monitoring site.

	WOMS Community Mean	ATMN San Francisco	ATMN/STN San Jose	ATMN Fremont
Summer				
Benzene	0.16 ± 0.03	0.13	0.18	0.20
Toluene	0.19 ± 0.05	0.46	0.56	0.61
Ethylbenzene	0.08 ± 0.02	0.10	0.10	0.11
Xylenes	0.37 ± 0.08	0.30	0.40	0.45
Formaldehyde	1.33 ± 0.16	1.10	2.47	1.78
Acetaldehyde	0.52 ± 0.12	0.38	0.64	0.68
Acrolein	0.01 ± 0.01	0.42	0.67	0.56
PM2.5 mass	7.43 ± 0.37		9.97	
OC	1.47 ± 0.07		3.90	
EC	0.42 ± 0.03		0.51	
DPC	0.70 ± 0.05		0.80	
DPM	0.82 ± 0.05		0.93	
DPC/TC	36.8%		17.2%	
DPM/PM2.5	11.1%		9.3%	
Winter				
Benzene	0.30 ± 0.02	0.51	0.87	0.47
Toluene	0.51 ± 0.04	1.42	2.22	1.04
Ethylbenzene	0.15 ± 0.01	0.20	0.31	0.19
Xylenes	0.60 ± 0.07	1.17	1.79	1.00
Formaldehyde	1.24 ± 0.06	1.54	2.32	1.60
Acetaldehyde	0.44 ± 0.02	0.70	0.97	0.63
Acrolein	0.03 ± 0.00	0.36	0.52	0.56
PM2.5 mass	14.52 ± 0.73		17.26	
OC	1.92 ± 0.10		7.21	
EC	1.22 ± 0.06		1.60	
DPC	1.74 ± 0.09		2.24	
DPM	1.98 ± 0.10		2.54	
DPC/TC	55.9%		25.5%	
DPM/PM2.5	13.7%		14.7%	

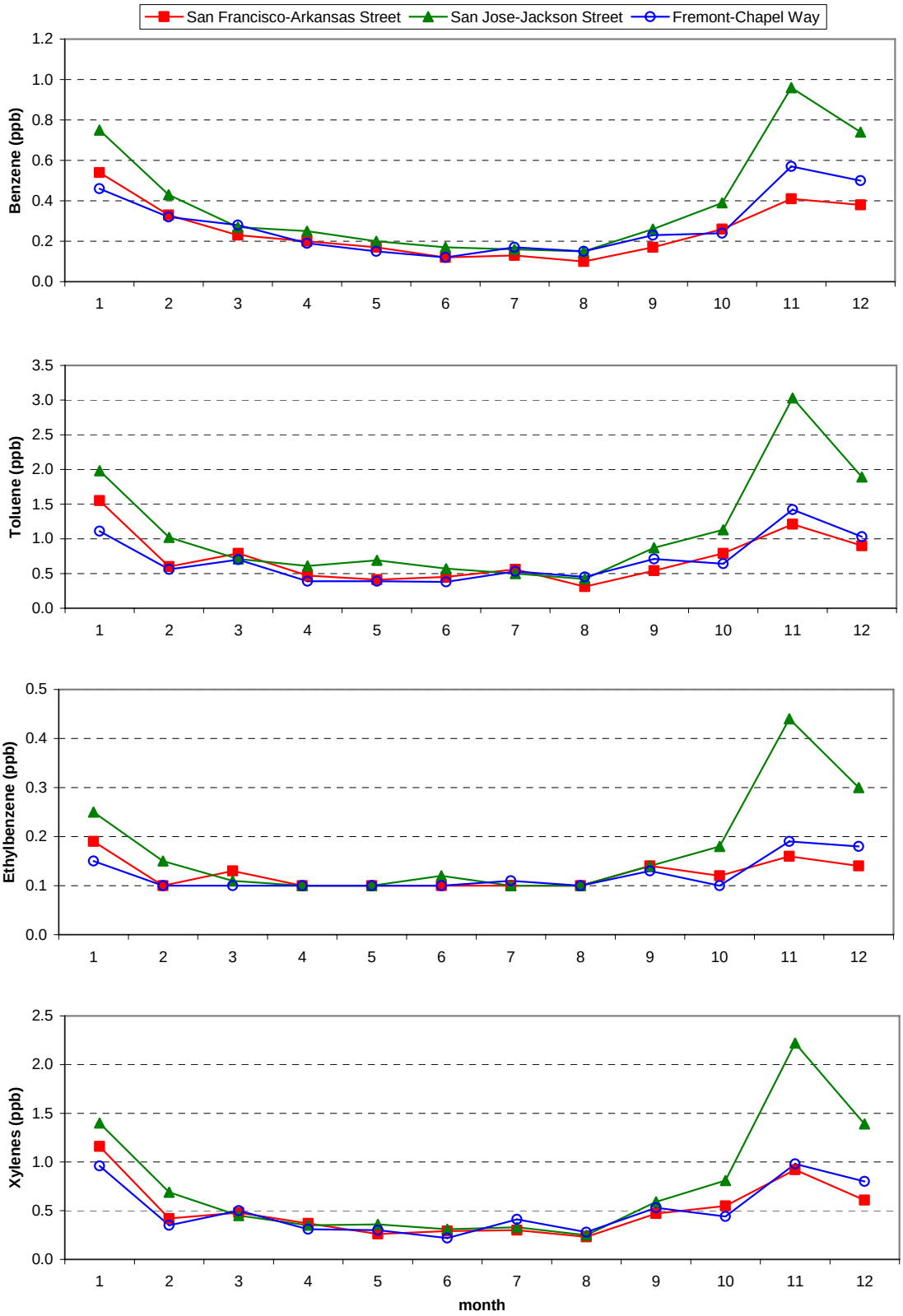

Figure 3-20. Monthly average BTEX concentrations at 3 sites in the SF Bay area, Jan 2005 to Dec 2007.

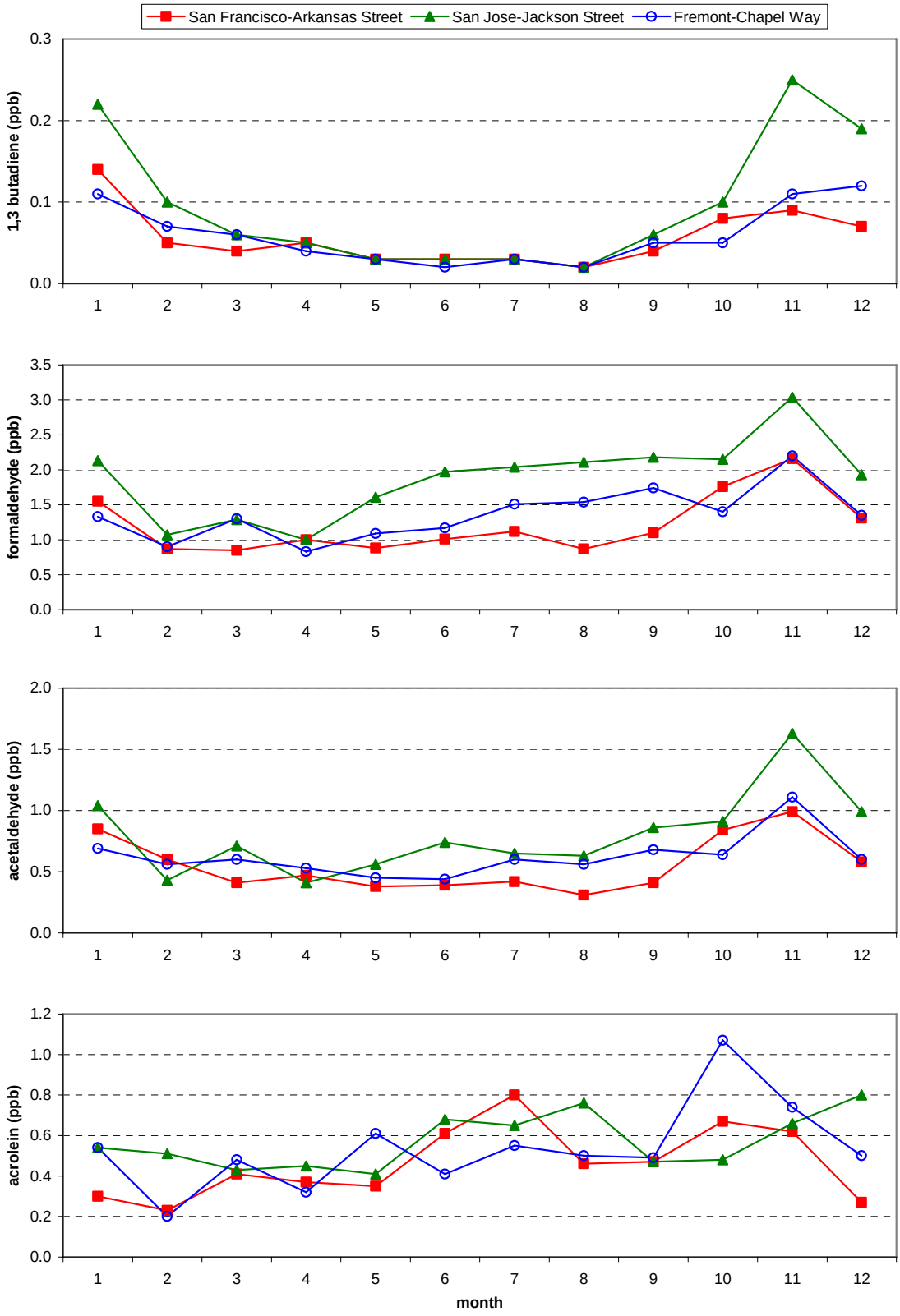

Figure 3-21. Monthly average 1,3 butadiene and carbonyl concentrations at 3 sites in the SF Bay area, Jan 2005 to Dec 2007.

Table 3-9. Comparisons of annual averages air toxic monitoring network data for benzene, toluene, ethylbenzene, xylene, formaldehyde and acetaldehyde with WOMS equivalent 2-month averages comprised of August and the means of December and January.

Site	Average Period	benzene	toluene	ethylbenzene	xylenes	formaldehyde	acetaldehyde
Fremont	2 months *	0.33	0.82	0.15	0.72	1.69	0.65
	Annual	0.32	0.87	0.14	0.69	1.78	0.66
	2mo/Annual	**1.04**	**0.94**	**1.07**	**1.05**	**0.95**	**0.99**
San Francisco	2 months *	0.32	0.94	0.15	0.74	1.32	0.54
	Annual	0.30	0.89	0.14	0.67	1.41	0.56
	2mo/Annual	**1.08**	**1.06**	**1.08**	**1.10**	**0.93**	**0.95**
San Jose	2 months *	0.52	1.39	0.20	1.10	2.39	0.81
	Annual	0.45	1.26	0.19	0.98	2.16	0.78
	2mo/Annual	**1.17**	**1.10**	**1.07**	**1.12**	**1.11**	**1.04**

* 2 month averages include equal weighting of August and the combined average of December and January.

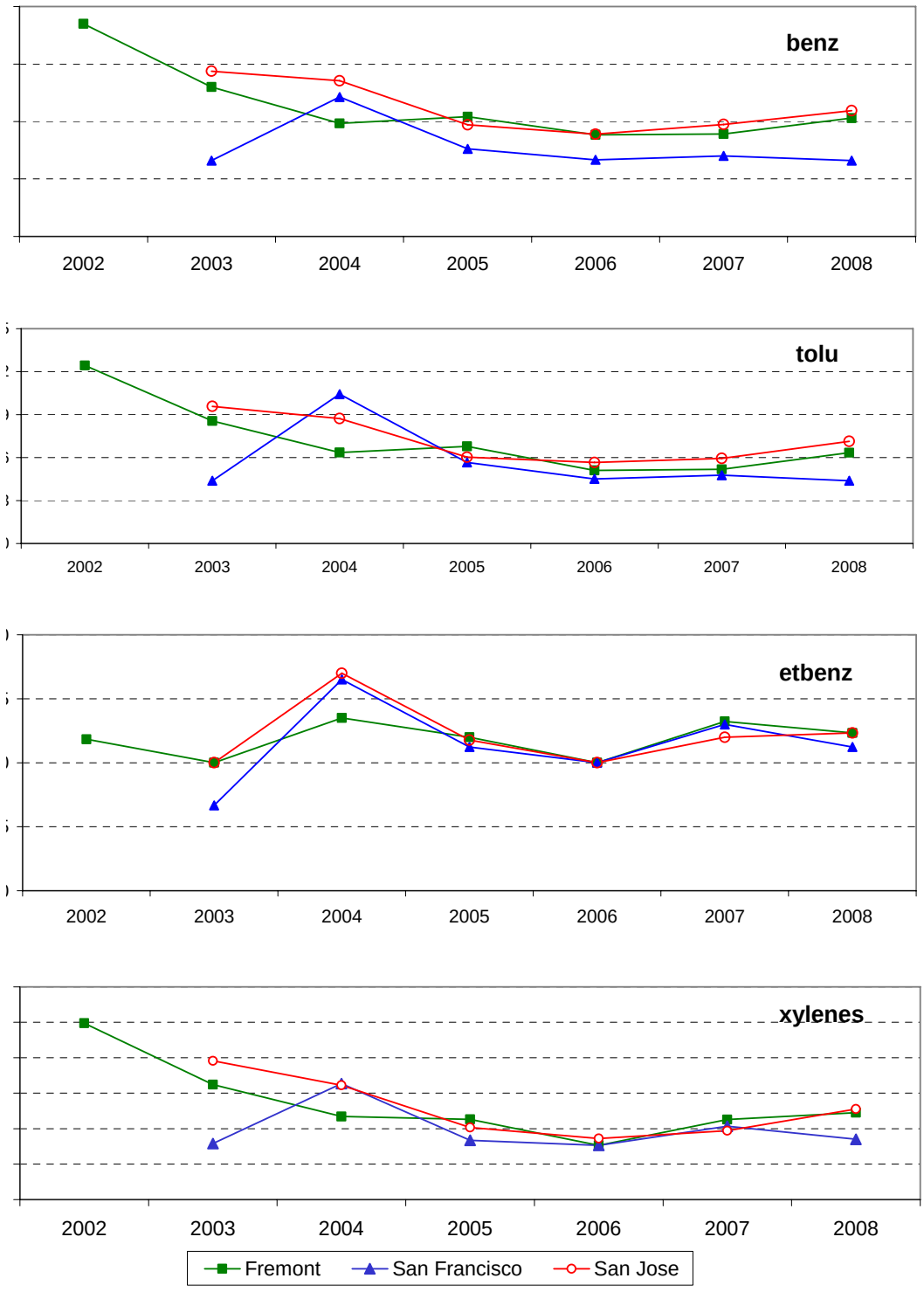

Figure 3-22. Trends in summer average BTEX at 3 sites in the SF Bay area from 2002 to 2008.

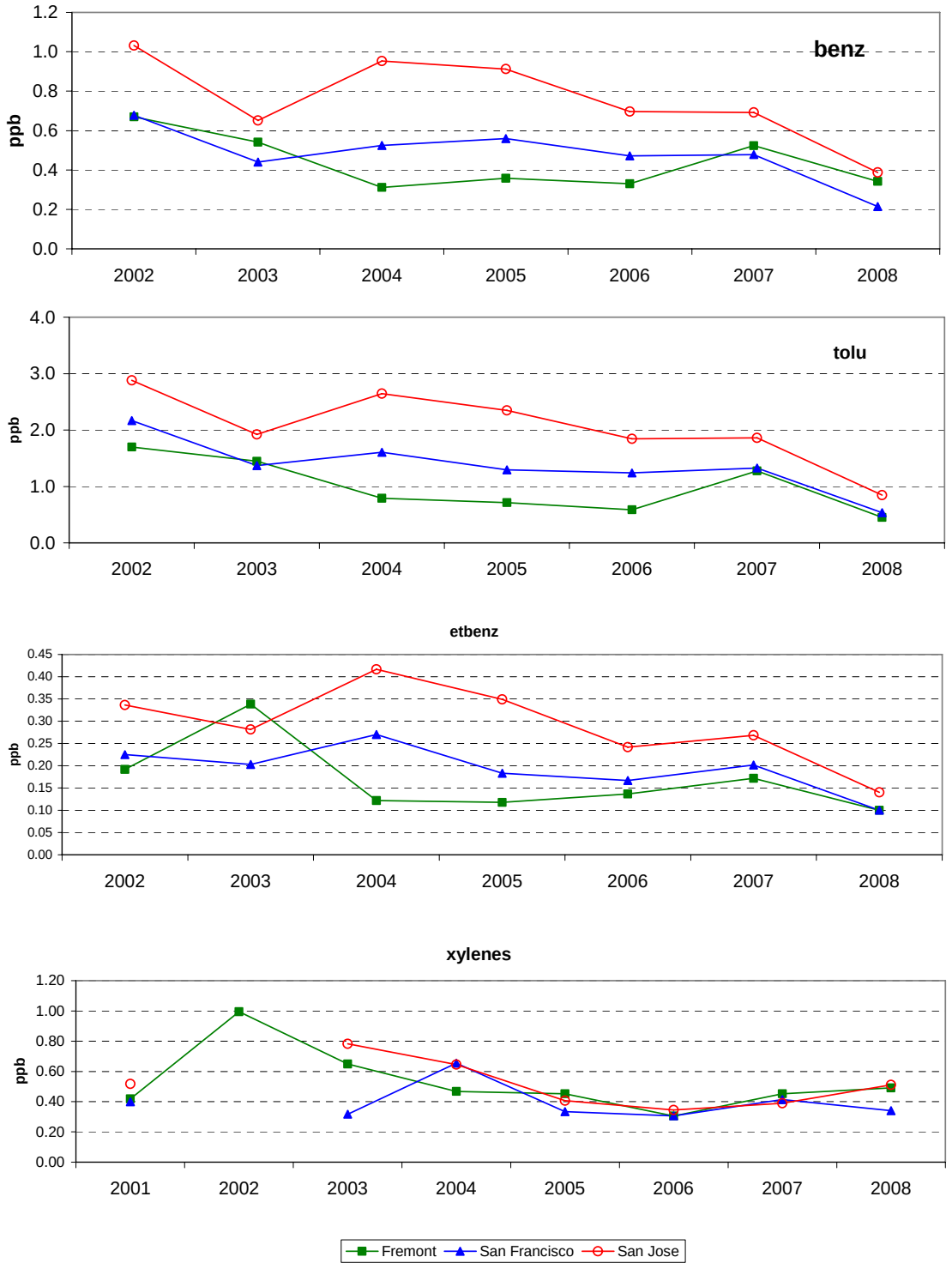

Figure 3-23. Trends in winter average BTEX at 3 sites in the SF Bay area from 2002 to 2008.

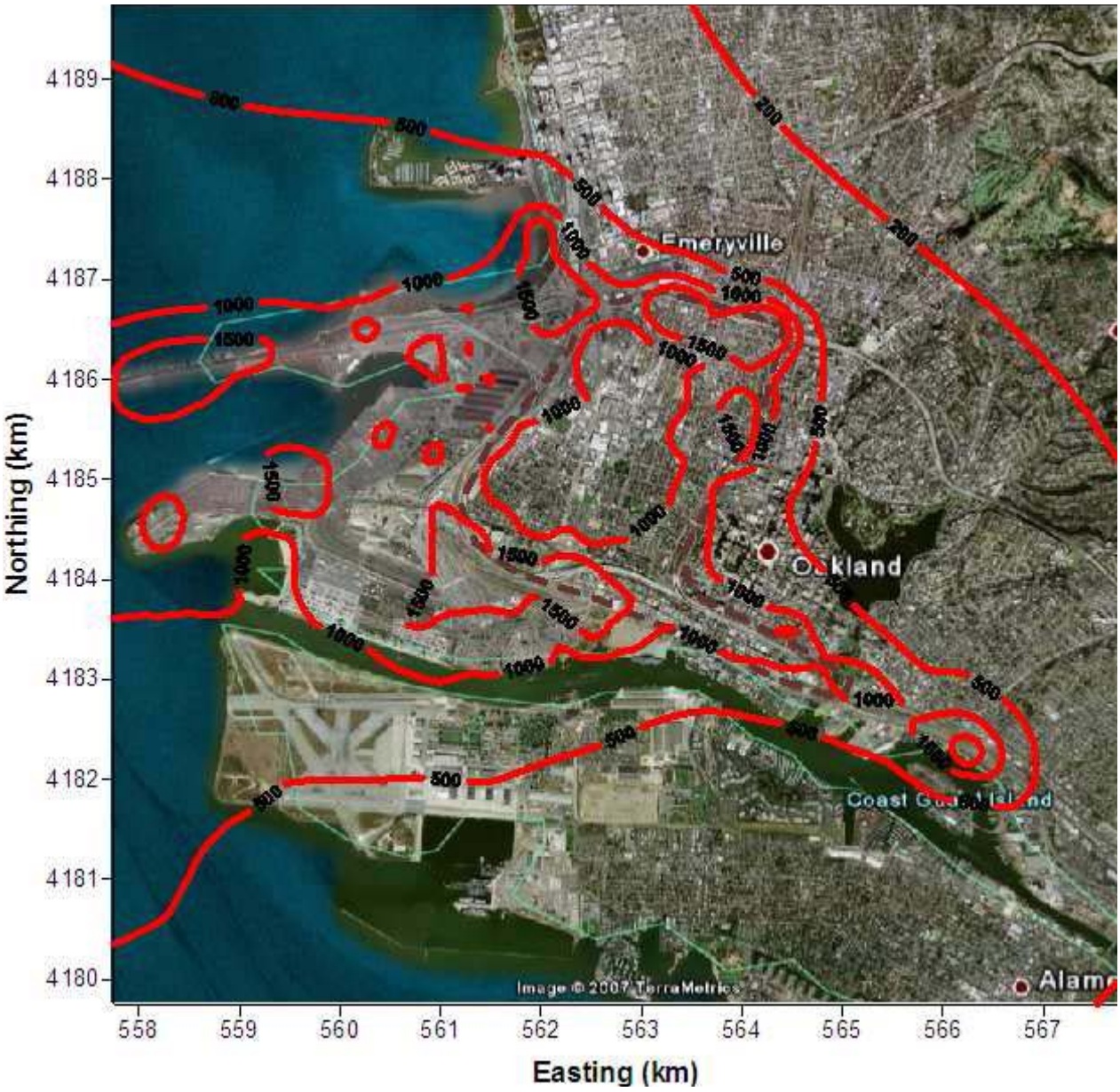

Figure 3-24. Estimated West Oakland Community Potential Cancer Risk from All Diesel PM Emissions Sources. The risk levels are based on the 80th Percentile Breathing Rate. Total Modeled Emissions = 845 T/Y in 2005. Modeling Domain = 10 km x 10 km. Resolution = 250 m x 250 m. Source: CARB, 2008.

Table 3-10. Comparisons of DPM ($\mu g/m^3$) estimated from the WOMS saturation monitoring data with modeled results from the CARB/BAAQMD health risk assessment.

	WOMS Summer	WOMS Winter	WOMS Average Sum & Win	Annual Average HRA Estimates	Adjusted HRA Estimates	HRA/ WOMS	Adj HRA/ WOMS
POU	0.44 ± 0.11	1.77 ± 0.30	1.1	< 1.6	0.6 - 0.9	1.4	0.7
POC	0.64 ± 0.12	2.66 ± 0.31	1.7	4.7	1.8 - 2.8	2.9	1.4
NR1	0.92 ± 0.10	2.03 ± 0.15	1.5	3.1	1.2 - 1.9	2.1	1.0
WO1	0.81 ± 0.16	2.05 ± 0.68	1.4	3.1	1.2 - 1.9	2.2	1.1
WO3	0.89 ± 0.11	2.06 ± 0.27	1.5	3.1	1.2 - 1.9	2.1	1.0
WO2	0.84 ± 0.10	1.85 ± 0.25	1.3	3.1	1.2 - 1.9	2.3	1.1
EMUD		1.93 ± 0.69	1.9	3.1	1.2 - 1.9	1.6	0.8
CFDW	0.66 ± 0.12	1.98 ± 0.33	1.3	3.1	1.2 - 1.9	2.4	1.2
Community Mean	**0.82 ± 0.01**	**1.98 ± 0.10**	**1.4**	**3.1**	**1.2 - 1.9**	**2.2**	**1.1**
STN San Jose	0.93	2.54	1.7				

Notes for Table 3-10. The adjusted annual average HRA estimates reflect changes in distributions and volumes of truck traffic and mitigation measures that have been implementation at the time of WOMS and 2005, which is year of the emission estimates upon which the HRA modeling is based. The combined decrease in DPM emissions is estimated by the BAAQMD to be in the range of 40 to 60%. As described in Section 2.5, DPM values were estimated from the correlations of elemental or black carbon with total carbon measured at locations near diesel traffic. This methods assumes that diesel exhaust is the main source of EC or BC in urban areas, which has been supported by past source apportionment studies. Therefore, DPM estimates from this method are upper limits of the true DPM concentrations to the extent that other combustion sources (e.g., gasoline vehicles, wood burning and meat cooking) contribute to the ambient EC or BC concentrations.

4. FINDINGS AND CONCLUSIONS

WOMS was conducted to characterize the magnitude and spatial variations in concentrations of toxic air contaminants within the Port of Oakland and the adjacent community of West Oakland and was designed to address the four questions.

Question #1. *Do gradients in pollutant concentrations exist within the West Oakland that can be related to the community's proximity to emissions from the Port of Oakland and related heavy-duty vehicle traffic?*

The mobile monitoring data showed spatial patterns of higher pollutant concentrations that were generally consistent with proximity to vehicle traffic. Concentrations of directly emitted pollutants were highest on heavily traveled roads with consistently lower concentrations away from the roadway. Pollutants that have higher emission rates from diesel trucks (NO, BC) tended to exhibited sharper gradients than pollutants that are largely associated with gasoline vehicle (CO and VOC, including BTEX). While automobiles are ubiquitous and distributed throughout the city, most diesel truck traffic tends to be concentrated along well-established truck routes. The observed spatial patterns were consistent with these differences. BC and NO concentrations were higher on the main truck routes within the Port, on the frontage road along the east edge of I-880, and on several of the major arterial streets in West Oakland (e.g., 7th Street, Grand Ave. and Mandela Pkwy). Pollutant concentrations were about a factor of 2 to 5 lower for most pollutants within the residential areas of West Oakland that are at least a city block off the main arterial streets. The higher pollutant concentrations were also measured near the entrance to the port near I-880 at 7th Street, Grand Avenue and Adeline Street. $PM_{2.5}$ and CO concentrations were more uniform spatially than BC and NO. With the exception of the higher values at WO3, BTEX mixing ratios were relatively uniform spatially. The higher levels at WO3 may be related to local emissions near this sampling location and from nearby freeway traffic.

The mobile monitoring results were generally consistent with the spatial variations observed with the 7-day passive and mini-volume aerosol samples. The passive samples on the east edge of I-880 (G5) had average NO values about five times higher than at the residential community sites during summer and about 2.5 times higher during winter. Atmospheric mixing is generally stronger during summer due to greater surface heating resulting in larger gradient in pollutant concentrations with proximity to major sources of emissions. Other sampling sites near I-880 also had higher NO and NO_2 values than residential sites, but much lower than at G5. The observed gradient in NOx levels is generally consistent with past studies that have shown that traffic-related pollutants disperse rapidly downwind of the roadway (Zhu et al., 2002). NOx levels were uniformly low at the neighborhood-scale sites. The spatial variations of EC (also DPC and DPM) were qualitatively similar to NO during the summer study with concentrations increasing with greater proximity to traffic. Average EC concentrations were about two times higher during the summer period at sampling locations near I-880 (NR1, WO1, WO2 and WO3) compared to locations further downwind of I-880 (EMUD and CFDW). The EC and NO values at the central port site (POC) were comparable during the summer period to levels at EMUD and CFDW.

Both OC and $PM_{2.5}$ exhibited less spatial variations than EC due to contributions of secondary pollutants from the atmospheric transformations of directly emitted (primary)

pollutants. Secondary organic aerosols (SOA) are typically larger components of particulate organic matter during summer and secondary nitrate and sulfate particles are major components of $PM_{2.5}$. Secondary pollutants have more uniform spatial distributions over a larger area than directly emitted pollutants. NO_2 levels similarly showed a smaller range of values than NO and lower NO_2/NOx ratios at roadway and near-road sites. NO_2 levels were uniformly lower during the winter study than in summer due to slower conversion of NO to NO_2. Concentrations were lower during the afternoon compared to morning and during weekdays compared to Sunday.

During summer, the mean concentration of DPM at the four community sampling sites near I-880 (NR1, WO1, WO2 and WO3) was 0.9 $\mu g/m^3$ compared to 0.4 at POU, 0.6 at POC and 0.7 at the downwind community site (CFDW). During winter, the mean concentration of DPM at the four sites near I-880 was 2.0 $\mu g/m^3$ compared to 1.8 at POU, 2.7 at POC2 and 2.0 at CFDW and EMUD. The DPC/TC and DPM/$PM_{2.5}$ ratios at the West Oakland community sampling sites were 30-40% and 10-12%, respectively during summer and 50-60% and 17-19 %, respectively during winter. These ratios are reasonably consistent with the source contribution estimates obtained from the Chemical Mass Balance (CMB) receptor modeling analysis considering the uncertainties of the methods. The estimated DPM concentrations for the WOMS community sampling sites were also comparable to similar estimates derived from the San Jose PM speciation monitoring data.

Diesel exhaust accounted for 70-90% of the ambient EC based on the CMB analysis. Vehicle exhaust accounted for about half of the ambient concentrations of TC during the winter period with a factor of three higher contributions of diesel (35%) relative to gasoline (11%) exhaust. Wood combustion (32%) and meat cooking (20%) accounted for the remainder. Only 2% of the TC, on average, was unidentified indicating insignificant contributions of SOA during the winter period. During the summer period, vehicle exhaust accounted for about a third of the ambient concentration of TC with the same factor of three higher contribution of diesel (22%) relative to gasoline (8%) exhaust. Wood combustion (17%), meat cooking (29%) and unidentified sources (23%) accounted for the remainder. The greater proportion of unidentified TC during summer is attributed to contributions of SOA due to greater photochemical activity compared to winter.

Question # 2. *Is the existing air quality monitoring in the area adequate to characterize the spatial variations in cumulative exposure within the community?*

The BAAQMD EBMUD monitoring station adequately represents pollutant concentrations within West Oakland except within 200-300 m of major roadways. On-road concentrations of DPM along I-880 and other truck routes within the Port of Oakland may be over a factor of five higher than the community average and BTEX and CO may be factors of 2-3 higher. The higher concentrations on-road decrease sharply away from the roadway.

Question #3. *Are seasonal mean pollutant concentrations higher in West Oakland than elsewhere in the urban areas of the San Francisco Bay Area?*

The seasonal mean concentrations of BTEX measured at the BAAQMD monitoring station at the EBMUD are generally comparable are similar to those measured at the three air toxics monitoring network sites in the Bay Area (San Francisco, Fremont and San Jose). Aldehyde levels are higher in Fremont and San Jose than in West Oakland reflecting greater

contributions of atmospheric formation of aldehydes from photooxidation of hydrocarbons in downwind area of the Bay Area. The mass concentrations of DPM in West Oakland were similar to San Jose. However fractions of DPM to TC and $PM_{2.5}$ were higher in West Oakland than San Jose because other sources account for a greater proportion of ambient TC and $PM_{2.5}$ in San Jose.

As described in Section 2.5, DPM values were estimated from the correlations of elemental or black carbon with total carbon measured at locations near diesel traffic. This methods assumes that diesel exhaust is the main source of EC or BC in urban areas, which has been supported by past source apportionment studies. However, DPM estimates from this method are upper limits of the true DPM concentrations to the extent that other combustion sources (e.g., gasoline vehicles, wood burning and meat cooking) contribute to the ambient EC or BC concentrations.

Another potential uncertainty in these comparisons is whether four weeks of WOMS data are representative of the seasonal averages and whether the combined WOMS summer and winter study are valid annual averages. The two-month and annual averages agree to within 10 percent and any differences due to averaging periods are comparable to uncertainty of the measurements. The annual average pollutant concentrations have been essentially flat from 2005 to 2008 and that comparisons of the averages over these years with WOMS data are reasonable valid.

Question #4. *Are the concentrations and spatial variations in the DPM estimated from the WOMS saturation monitoring consistent with the modeled results from the ARB and BAAQMD health risk assessment?*

We examined whether the concentrations and spatial variations in the DPM estimated from the WOMS saturation monitoring data are consistent with modeled results from the recent health risk assessment conducted by the California Air Resources Board and the District (CARB, 2008). The spatial variations in modeled concentrations of DPM in $\mu g/m^3$ were estimated by dividing the modeled potential cancer risk isopleths values by 318. The model estimates of DPM were consistently higher that the estimated concentrations of DPM at the WOMS community sampling sites by about a factor of 2.3. However, significant reductions in DPM emissions were estimated by the ARB and BAAQMD for the period between 2005, the base year of the HRA, and the 2009-2010 WOMS. We adjusted the annual average HRA estimates to reflect changes in distributions and volumes of truck traffic provided by the Truck Survey conducted by the BAAQMD and projected impact of mitigation measures that have been implementation since 2005. The combined decrease in DPM emissions is estimated by the BAAQMD to be in the range of 40 to 60%. Using these corrections the average estimated West Oakland DPM concentrations would range between about 1.2 and 1.9 $\mu g/m^3$ in 2010, compared to 1.4 $\mu g/m^3$ estimated from WOMS measurements.

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