NCHRP Project 25-55

NCHRP Research Report 1058
Assessing Air Pollution Dispersion Models for Emissions Regulation

Appendix B
Report on the Berkeley Freeway Tracer Experiment

Source: Left and right images: ICF. Center: Caltrans traffic camera on I-80 at Ashby Ave, Berkeley, CA, 3/24/2022.

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Author Acknowledgments

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Contents

1 Introduction

The objective of National Cooperative Highway Research Program (NCHRP) 25-55 is to provide decision makers, particularly state departments of transportation (DOTs), with technical support identifying the appropriate air quality dispersion models for regulatory applications related to conducting project-level air quality analyses under the National Environmental Policy Act (NEPA) and to meet transportation conformity rule requirements. The goal is to develop a technical report that:

1. Specifies procedures to test air quality dispersion models using real-world air quality data (which must include data from tracer studies) for regulatory applications in the transportation sector for criteria pollutants typically assessed in project level analysis;
2. Conducts a custom tracer experiment to meet the requirements of item 1 and applies available data to conduct detailed evaluation of the selected models against air quality field data;
3. Presents comparative analyses (including technical and methodological evaluations) to provide insights into why a particular model is the best performing model for those specific transportation applications; and

As part of Phase II of the study, tracer gas dispersion experiments we conducted Task 6 of this project, the focus of which is a set of Tracer Experiments. However, the details of this task have changed substantially from what was developed in the Interim Report,[1] according to Proposed Work for Phase II memorandum[2] and Response to Panel Comments[3] documents.

According to the Panel's final direction, ICF partnered with the University of California, Berkeley (UCB) and Lawrence Berkeley National Laboratory (LBNL), referred to here as the Berkeley team, to conduct a tracer study from a mobile release platform that simulate vehicle emissions along Interstate 80 in Berkeley, CA, a 10-lane freeway with traffic volume of 280,400 AADT (2017) and 4.8% truck fraction (13,460 AADT) located near the eastern shoreline of the San Francisco Bay using multiple different tracers. The site is also co-located with a near-road SLAMS air quality monitoring site (Aquatic Park) that records continuous measurements of: NO, NO_2, CO, $PM_{2.5}$ and black carbon (BC) 8 meters from the road edge. Tracer experiments were performed over three days over a two-month period with measurements collected downwind at multiple locations during each experiment.[4]

Tracer gases were released from mobile platforms to simulate the release of emissions from mobile sources, and gas concentrations were measured along the concentration gradient downwind of the roadway. Meteorological variables and traffic-related air pollutant concentrations were also measured upwind and downwind of the roadway tracer release. The data collected from these experiments will be used to evaluate the performance of near roadway air quality dispersion models by comparing the predicted and measured tracer concentrations knowing the exact tracer emission rate.

To supplement the data collected during the tracer experiment, this study also included:

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[1] NCHRP 25-55, Assessment of Regulatory Air Pollution Dispersion Models to Quantify the Impacts of Transportation Sector Emissions, Phase 1: Interim Report – Research Plan and Design, ICF, ZAMURS AND ASSOCIATES, and CSU, April 2019.

[2] Technical memorandum to NCHRP 25-55, Advisory Panel, from Edward Carr, Seth Hartley, Mike Brady, John Zamurs, October 31st, 2019.

[3] Technical Memorandum to William Rogers, NCHRP 25-55, Senior Program Officer, from Edward Carr, Seth Hartley, Mike Brady, John Zamurs, December 12, 2019.

[4] Three preliminary experiment days were also conducted over five months in advance of the three experiment days.

1. An upwind monitor to the study, collecting upwind air pollutant concentrations at the same time as the tracer experiment along with the downwind Aquatic Park SLAMS site for determining the emission contribution from I-80 traffic,
2. One full day traffic study (vehicle classification and volumes) to the study, enhancing the regular Caltrans PEMS data, and
3. A third tracer release vehicle to improve continuity in tracer release.

Along with the tracer and near-road air quality and meteorology measurements, this provides the information needed for input to the air dispersion model evaluation subsequently completed.

The tracer experiment was performed in May and June, 2021. It involved a total of 10 separate experiments.

The main goal of the tracer experiment was to measure the tracer release from a mobile platform that simulates the release of emissions from vehicles and accurately measures the concentrations at both the maximum location and the concentration gradient downwind of the roadway. The measured concentrations are integrated to time intervals simulated by regulatory dispersion models. Necessary, concurrent measurements of meteorological and traffic variables were also collected, along with traffic-based air pollution measurements. The data collected from this experiment will be used to evaluate the performance of near roadway air quality dispersion models by isolating the dispersion processes from the emission component in a subsequent task (Task 7). By comparing the predicted and measured tracer concentrations independent of emissions models, the performance of the dispersion model can be evaluated.

Other goals of this tracer experiment are to target facility types that DOTs expect will stress the regulatory air quality models, especially those showing potential for air quality concern. The goal is also, to the extent feasible, to address known challenges for regulatory models, including both low and variable wind speed conditions for both low traffic speed with congestion and heavy traffic volume with near posted traffic speeds.

This report is written primarily by subcontractors from the university of California at Berkeley, Lawrence Berkeley National Laboratory, and Wiltec (a traffic data collection firm), with support from ICF. It documents the work conducted under Task 6 for the tracer-based field experiment (the “Berkeley Freeway Experiment”). To the best of our knowledge we have disclosed all relevant, available information on the experiment and its conclusions. We are not aware of any issues of concern with the data presented here that might limit its usage in model validation studies, such as that conducted under Task 7 of this project.

2 Experimental Methods

Experimental Approach

A series of pilot tests and ten experiments were conducted over four days between February and June 2021 on Interstate 80 (I-80) near Aquatic Park in Berkeley, California, as summarized in Table 1 and shown in Figure 1 and Figure 2. Perfluorocarbon tracer (PFT) gas was released from mobile platforms traveling along I-80 in a loop for one hour, with tracer release automated using a GPS-integrated controller within the bounds of projected cross streets of Hearst Avenue and 66th Avenue and vehicle turnarounds at the Gilman Street and Powell Street exits. During each experiment, three pickup trucks served as the mobile platforms and simultaneously traveled on the prescribed driving route. Each truck released one of three unique PFTs over the 60-min period, so the source contribution of each mobile platform can be distinguished in the total PFT signal. Air samples were collected in multi-layer foil sampling bags using custom-built samplers at various downwind distances at two locations along the north-south stretch of I-80, such that two experiments were completed with each release period. Sample bags were returned to the lab after each experiment and analyzed by gas chromatography (GC) to determine measured PFT concentrations downwind of the tracer release. At the location upwind of the roadway, traffic-related air pollutant concentrations and wind direction and speed were measured using an instrumented research van. Downwind concentrations of the same pollutants were concurrently measured by the Bay Area Air Quality Management District (BAAQMD) at their Berkeley Aquatic Park near-road monitoring station, located in the North Experimental Area on the east side of I-80. Downwind wind speed was measured in the South Experimental Area.

Table 1. Summary of tracer gas dispersion experiments conducted on the section of I-80 that borders Berkeley's Aquatic Park.

Date	Expt #	Release #	Expt Area	Release Start	Release End	# Samplers	Sample Resolution (min)
2021- Feb-12	Pilot*	1	North	10:30	11:30	10	5, 10, and 60
2021-May-03	1	2	North	8:00	9:00	3	60
	2		South			12**	7.5
2021-Jun-06	3	3	North	8:00	9:00	3	60
	4		South			6	10
	5	4	North	10:40	11:40	3	60
	6		South			6	10
2021-Jun-24	7	5	North	8:00	9:00	3	60
	8		South			6	10
	9	6	North	10:40	11:40	3	60
	10		South			6	10

*A single tracer was released by one truck during this pilot test, with samplers only set up at the North Experiment Area. Multiple samplers were collocated to test different configurations, including sampling frequency, integration time, and inlet height.

**For this first day's experiment at the South end, we used two rows of 6 samplers each, placed on either side of W. Bolivar Road, with paired samplers set at equal downwind distances and approximately 6 meters apart, to provide duplication and confirm our sampling approach. For this experiment, samplers were placed at target distances of 10, 20, 30, 50, 100, and 150 m downwind of the freeway. Once confirmed, all subsequent experiments placed samplers in the South Experiment Area only on the south side of W. Bolivar Road. We also slightly modified the target downwind distances to 1, 9, 18, 30, 50, and 100 m.[5]

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[5] These are the "stated" receptor distances recorded by UCB. The values used in Task 7 are measured from the sources and differ somewhat. This will be explained in subsequent reports.

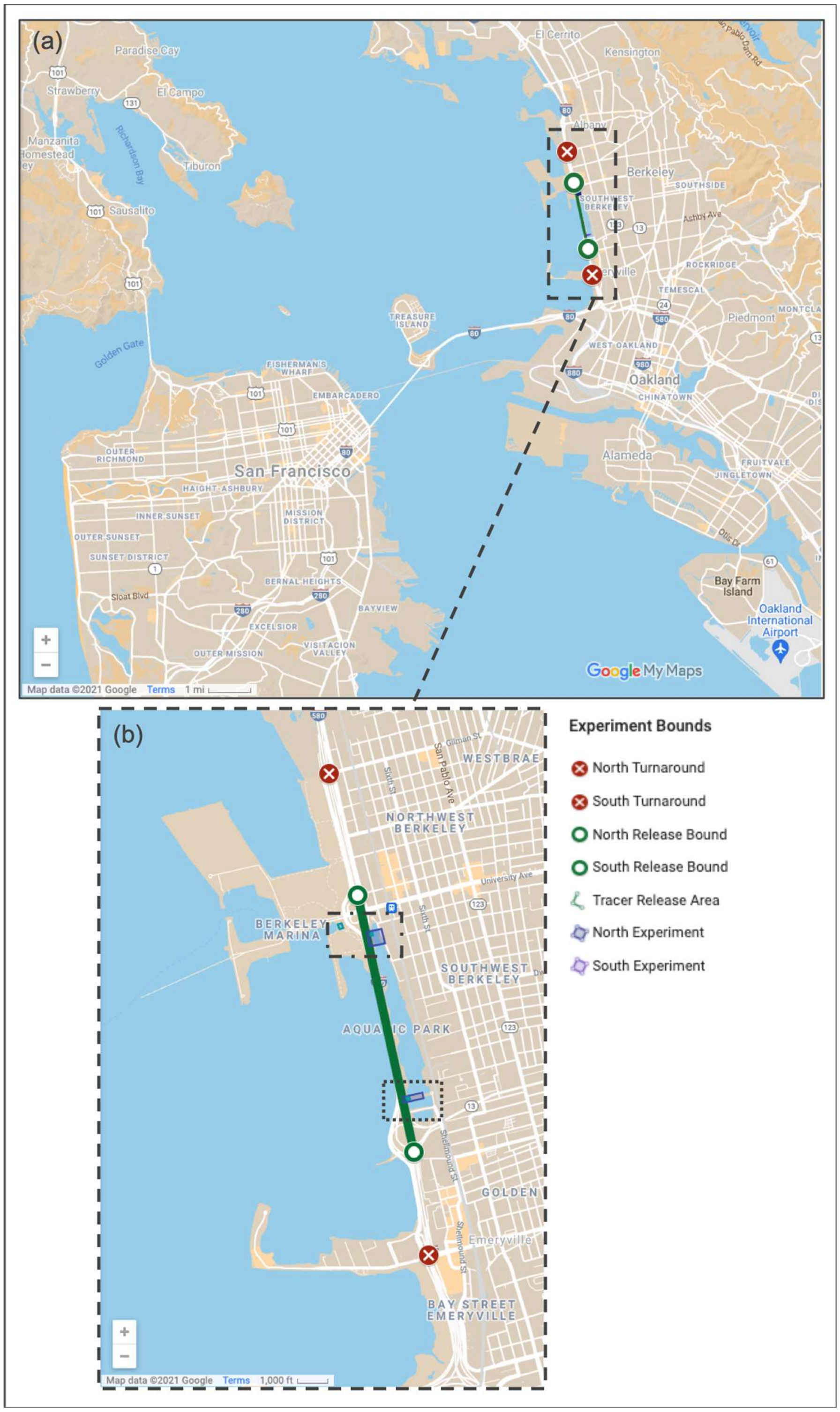

Figure 1. The study area along I-80 in Berkeley, CA, with greater detail for the boxed area indicated in (a) shown in subpanel (b). The mobile platform turnaround points are marked by the red circles with a white X and the tracer release zone is shown by the green line bounded by the open green circles. The two experimental areas noted by the two boxes in (b) and shown in greater detail below in Figure 2. Maps are from Google and oriented vertically north-south, with scale noted in the lower left text box of each subplot.

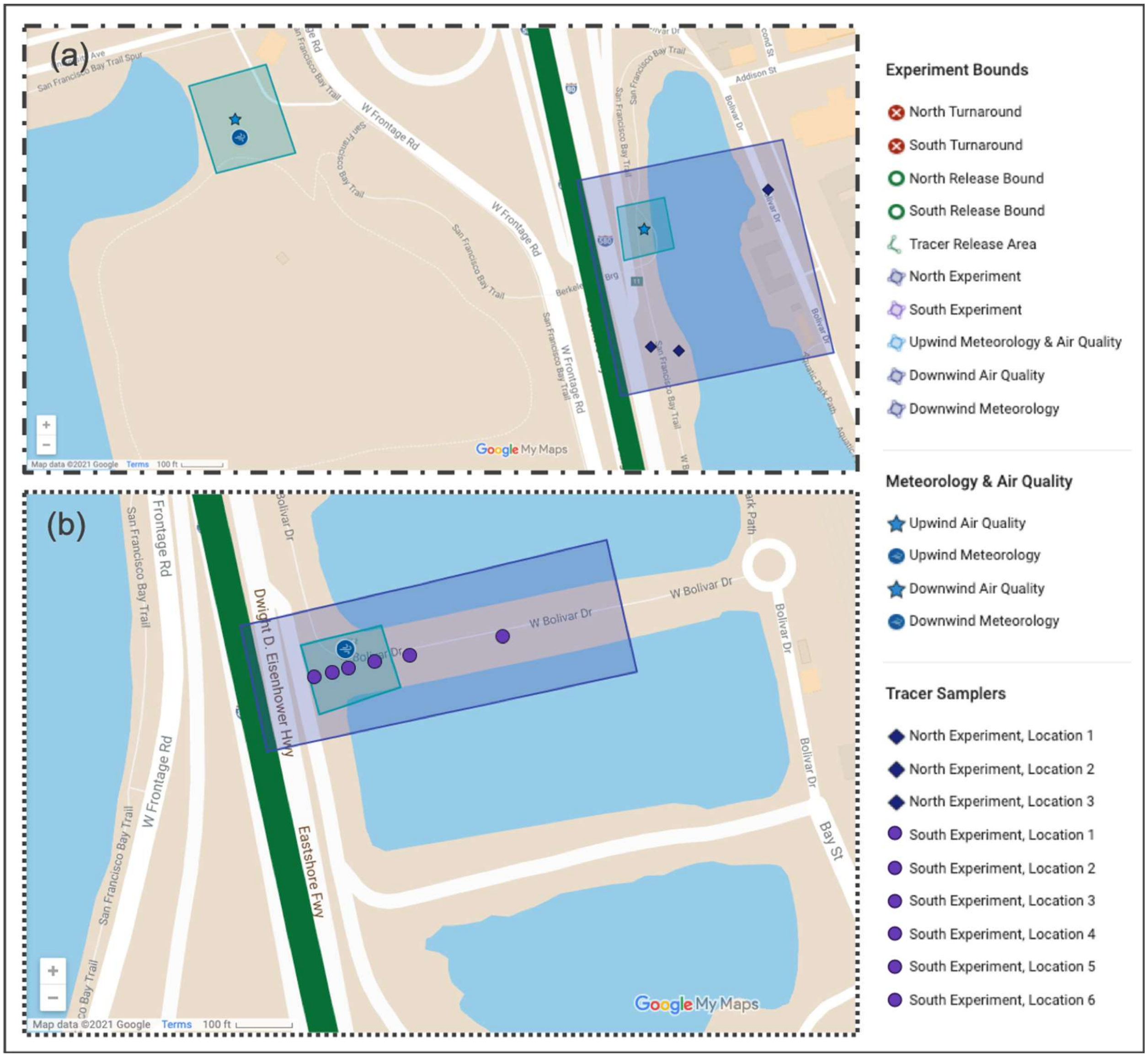

Figure 2. The two experimental areas indicated by the boxed areas above in Figure 1b. (a) The North Experiment Area, where 60-min integrated samples were collected at three sites (navy diamonds) within the dark purple box to the right of I-80. Downwind air quality (blue star) was measured at the BAAQMD monitoring station shown within that dark purple box. Upwind meteorological (blue circle) and air quality (blue star) sampling was also conducted, as shown in the light blue box to the left of I-80. (b) The South Experiment Area, where 10-min integrated samples were collected at six sites (purple circles) and downwind meteorology (blue circle) was measured within the lighter purple box. As noted above in Table 1 and described in detail in the main text, the sampler placement was slightly different in Experiment 2, compared to the subsequent experiments that are depicted here. Maps are from Google and oriented vertically north-south, with scale noted in the lower left text box of each subplot.

Tracer Release

ICF used a model to estimate the minimum tracer release rate that would be necessary to attain a far-field downwind PFT concentration greater than the GC limit of quantification (about 25 ppt). This modeling assumed tracer gas release along a 2456 m stretch of I-80 between Hearst Avenue and 66th Avenue, truck turnarounds at Powell and Gilman, 55 mph free flow driving on the freeway, about 200 s of active PFT release ("on") per loop in both directions, about 220 s of no PFT release ("off") per loop during turnarounds, and 8.57 loops per one-hour sampling period. Under favorable wind (280°, 0.9 m s^{-1}) and slightly unstable atmospheric conditions, a release rate of 130 g h^{-1} for each tracer during each 1-hour experiment was determined as sufficient to provide downwind concentrations >25 ppt up to about 100 m downwind of the freeway. This release rate corresponds to an instantaneous release rate of 0.076 g s^{-1} when the tracer is being actively released between the bounds of Hearst Avenue and 66th Avenue. Based on these modeled results, a custom tracer release system was designed with a conservative target release rate of 200 g h^{-1} for each tracer (0.117 g s^{-1}).

Three PFTs were used in these experiments: perfluoro-1,2-dimethylcyclobutane (PDCB), perfluoromethylcyclopentane (PMCP), and perfluoromethylcyclohexane (PMCH). All tracers were purchased from Synquest Labs (Alachua, FL), with reported physical properties summarized in Table 2. Before each experiment, 200 L tracer "source" bags (Cali-5-Bond, Calibrated Instruments; McHenry, MD) were prepared in the laboratory (Figure 3).

Table 2. Perfluorocarbon tracers (PFTs) used in this study and their chemical properties.

PFT, i	CAS Registry #	Purity by Mass, X_i	Molecular Weight, MW_i (g mol^{-1})	Density, ρ_i (g mL^{-1})	Vapor Pressure, P_i^o(atm)
Perfluoro-1,2-dimethylcyclobutane (PDCB)	2994-71-0	0.99	300	1.62	1.13
Perfluoromethylcyclopentane (PMCP)	1805-22-7	0.95	300	1.70	0.70
Perfluoromethylcyclohexane (PMCH)	355-02-2	0.94	350	1.79	0.15

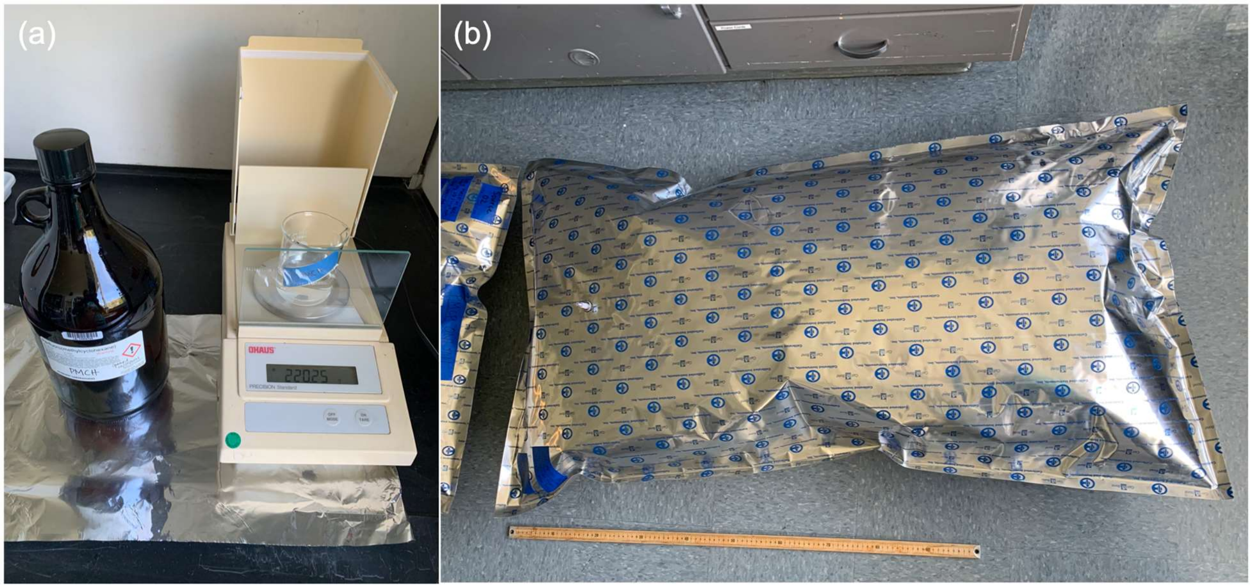

Figure 3. Laboratory preparation of tracer source bags, including (a) weighing the tracer material to be injected into the bag and (b) the final bag size after being filled with ultrahigh purity N_2 and the liquid tracer had evaporated.

Liquid tracer mass ($m_{i,liq}$) was weighed and injected by syringe into the source bag containing a measured volume of ultrahigh purity nitrogen (N_2) gas (V_{N_2}), which was transferred to the bag from a compressed cylinder using a mass flow controller. The resulting mole fraction of tracer (Y_i) in each source bag is:

$$Y_i = \left(\frac{n_i}{n_{i,liq} + n_{N_2}}\right)$$

where the moles of tracer (n_i), moles liquid tracer including impurities ($n_{i,liq}$), and moles of N_2 (n_{N_2}) are given by:

$$n_i = \frac{X_i(m_{i,liq})}{MW_i}$$

$$n_{i,liq} = \frac{m_{i,liq}}{MW_i}$$

$$n_{N_2} = V_{N_2}\left(\frac{P}{RT}\right)$$

where Xi is the purity of the liquid tracer by mass, all impurities in the liquid tracer are assumed to have the same molecular weight (MWi) as the PFT itself, T and P are the standard temperature (298 K) and pressure (1 atm) settings of the mass flow controller, and R is the ideal gas constant (0.08206 L atm K-1 mol-1). The volume of N2 added was sufficient to ensure that all of the PFT liquid evaporated inside the bag. This condition is met when the resulting partial pressure of each PFT (Pi) is less than its vapor pressure (Pi°), assuming the total pressure of the PFT + N2 gas mixture is ambient and equal to 1 atm (P):

$$P_i = PY_i < P_i^{\circ}$$

The concentration of tracer in the source bag (C_i, g L^{-1}) is given by the following equation, and concentrations in each source bag are reported below in Table 5:

$$C_i = Y_i \left(\frac{P}{RT}\right) MW_i$$

The target of releasing 200 g of each PFT over a 60-min experimental period was buffered by 5–10% to prevent the source bag from completely emptying during the experiment, with the constraint that the combined volume of N_2 and PFT added was limited to <180 L so that the source bag was not pressurized. Separate source bags with 420 g of PDCB and PMCP were prepared and used for two experimental releases on the same day. The maximum amount of added PMCH—the least volatile of the three tracers—was about 200 g, so each prepared source bag was used only for one experimental release. Source bags were prepared at least 24 hours in advance of the release experiment.

On the morning of each experiment, the source bags were placed into large cardboard boxes secured in the bed of each of the three pickup trucks. The source bags were connected to a tracer gas release system in each truck. The PFT + N_2 mixture was drawn out of the source bag and pushed to the tailpipe through 1/4" outer diameter Teflon tubing using a vacuum pump. An inline flow meter (Bios Defender Series, Mesa Labs; Lakewood, CO) was used to record the release flow rate. A U-shaped piece of 3/8" outer diameter copper tubing at the end of the Teflon tubing was inserted into the truck's tailpipe, as shown in Figure 4. With this design, the tracer gas was mixed with and emitted at the temperature and location of the truck's exhaust.

On-board GPS monitored vehicle speed and location, and the release system used this information to control when and the rate at which the tracer was released. The Raspberry Pi controller automatically turned the release on and off when the truck reached the bounds of the release zone shown in Figure 1. A laptop recorded the GPS output and the actual flow rate measured by the Bios, and the laptop clocks were assumed to be roughly synced in local time across the three tracer release vehicles. From each release system's recorded pump flow rate ($Q_i(t)$, L s^{-1}) and the calculated source bag concentration (C_i), the instantaneous release rate ($\dot{m}_i(t)$, g s^{-1}) and total mass released (m_i, g) for each experiment were determined with the below equations (Table 5):

$$\dot{m}_i(t) = C_i Q_i(t)$$

$$m_i = \sum \dot{m}_i(t)\Delta t$$

Figure 4. Tracer release system installed on one of the vehicles that served as a mobile platform during the experiment. (a) The source bag was secured within a large cardboard box in the bed of the pickup truck. (b) The PFT + N_2 mixture was pumped out of the source bag through 1/4" Teflon tubing, through the automated system that was housed in the bin on the passenger seat, including the pump, flow meter, and Raspberry Pi controller. The GPS was secured on the vehicle's dash and the laptop that logged pump flow rate and GPS data was placed on the floor. (c) The PFT gas flowed through a second stretch of 1/4" Teflon tubing along the side of the truck bed and down to the tailpipe, where 3/8" copper tubing was installed. (d) This copper tubing was bent into a U-shape into the truck's tailpipe so that tracer gas was co-emitted with the truck's exhaust at temperature.

Tracer Sampling

At the North Experimental Area, 60-min integrated samples were collected at distances of 1, 20, and 100 m downwind of I-80 (Figure 5). These distances are measured from the jersey barrier/fence that separates I-80 from the sampling area. Sampler inlet heights were measured from ground level in the Aquatic Park sampling area, while I-80 and the tracer release are both at a slightly higher elevation about 2 m above the sampling area ground level. To avoid any potential wake effects next to the elevated freeway's jersey barrier, the inlet of the sampler 1 m downwind was extended on a pole with 1/8” tubing about 3 m above the ground.[6] The sampler at the 20 m distance was placed on top of a picnic table at a height of about 120 cm and the sampler at the 100 m distance was placed on the roof of a parked car at a height of about 185 cm (recorded with a tape measure). All were sited away from trees or other obstructions to airflow.

Figure 5. In the North Experimental Area, samplers were placed at downwind target distances of (a) 1, (b) 20, and (c) 100 m. All inlet heights were >1 m above ground and were placed away from potential obstacles that would bias sampled air flow.

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[6] Note that the original documentation reported this as 3.4 m while the sampler inlet height in the accompanying dataset was recorded as 3 m. Task 7 modeling for these receptors is done using the 3 m height measurement above ground level (or 5.6 above MSL). Accordingly, the rounded value of 3 m is presented here.

As shown in Figure 6, each sampler was housed in an aluminum box with a side inlet, through which a battery-powered pump operating at a flow rate about 0.12 L min^{-1} continuously pulled ambient air into a 10 L multi-layer foil bag (Cali-5-Bond, Calibrated Instruments; McHenry, MD). The sampling was manually started at the beginning of each release period by plugging the pump into the battery. At the end of the 60-min release period, each sampler's battery was unplugged from the pump. No background or decay samples were taken for these sets of 60-min integrated samples, but preliminary pilot testing showed background concentrations of 0 ppt for all three tracers at these locations.

Figure 6. Custom-built samplers used in the North Experimental Area, which continuously filled a 10 L multi-layer foil bag over the 60-min release period. As indicated in (a), the battery-powered pump was connected to an inlet bored through the side of the aluminum box, and continuously pulled ambient air into the bag to collect a 60-min integrated sample (b).

At the South Experimental Area, downwind air samples were collected by custom-built samplers that semi-continuously pulled ambient air into either 0.5 or 5 L multi-layer foil sample bags (Cali-5-Bond, Calibrated Instruments; McHenry, MD) that were filled sequentially at set integration intervals. For most experiments, these samplers were placed at downwind distances of 1, 9, 18, 30, 50, and 100 m, in a row along the south edge of W. Bolivar Road. The only exception to this setup is Experiment 2, where two rows of samplers were placed approximately 6 m apart on both sides of the road at target downwind distances of 10, 20, 30, 50, 100, and 150 m. Like with the North Experimental Area, these distances were measured from the jersey barrier/fence that separated I-80 from the sampling area and final downwind distances will be determined by ICF using a reference point on I-80. The inlet of the sampler closest to the highway (1 m downwind) was similarly extended on a pole to a height of about 3 m above the sampling area ground level, as shown in Figure 7. The inlets of the other five samplers were elevated off the ground at a height around 0.7 m, using folding chairs as supports. As noted above, these sampler inlet heights were measured from ground level in the Aquatic Park sampling area, while the tracer release along I-80 occurred about 2 m above the sampling area ground level.

Figure 7. In the South Experimental Area, samplers were placed at downwind target distances of 1, 9, 18, 30, 50, and 100 m. The inlet height at the 1 m distance (a) was extended to a height about 3 m above the sampling area ground level, while the inlets of all other samplers were elevated to about 0.7 m on the backs of folding chairs (b, c). Note the passing mobile tracer release platform in (d) relative to the elevated inlet for the nearest highway sampler also shown in (a).

Each sampler could fill up to 14 sample bags, with sampling frequency and integration period determined by bag volume (Figure 8). A pump continuously pulled air through the main trunk line of each sampler at a flow rate of about 0.8 L min^{-1}. A series of solenoid valves controlled the flow to the 14 branches off this trunk line that each led to a sample bag, while an on-board Raspberry Pi equipped with a real-time clock controlled the sequence and duration that each sample bag was filled.

For most experiments, 10-min integrated samples were collected, as noted in Table 1. Typically, the sampling cycle captured ten sequential 10-min integrated samples that spanned a total of 100 min: one background, six release, one transition, and two decay samples. A semi-continuous duty cycle was used for pumping air into the bags. Background samples were pumped into 0.5 L bags on a 5% duty cycle of 20 sec over the 10-min period, meaning that the solenoid was open and air was pulled into the bag for 1 sec every 20 sec. This duty cycle frequency was increased for the subsequent samples so that any "peak events" by the mobile tracer release platform passing by the stationary sampling site would not be missed—for the 5 L sample bags, the solenoid valves followed a 50% duty cycle that was 1.4 seconds in duration. This meant that about 4 L samples were collected during the release, transition, and decay periods by opening the corresponding solenoid valve and pumping ambient air into the bag for 0.7 sec and then closing the valve for 0.7 sec, repeated over the 10-min integration period. Between experiments, the samplers were flushed to prevent any carryover contamination. This flushing cycle pulled ambient air through the 14 open sample lines without bags attached for 1 min each.

Figure 8. Custom-built samplers used in the South Experimental Area, which semi-continuously filled a series of 0.5 and 10 L multi-layer foil bags to capture 10-min integrated samples during the background, release, transition, and decay period of each experiment. As indicated in (a), the battery-powered system used a programmed Raspberry Pi to control the order, duration, and sampling frequency of up to 14 integrated samples. As also shown in Figure 7, the sampler and attached bags were covered with a drop cloth on the ground (b), as the filled bags (c) could not fit inside the standard aluminum sampler boxes.

The pilot test and Experiment 2 were the exceptions to the above sampling schedule. For Experiment 2, 14 samples that were each 7.5-min in duration were collected over a 105-min period: two background, eight release, one transition, and three decay samples. The background sample followed the same duty cycle as above, whereas the subsequent bags were filled with a 70% duty cycle of 1 sec (0.7 sec open, 0.3 sec closed).

During the pilot test, these multiport samplers were instead placed at the three sampling locations (1, 20, and 100 m downwind) in the North Experimental Area. At each location, there was a set of paired samplers that together collected a total of 22 5-min integrated samples into 0.5 L bags over 110 min—four background and the first seven release samples were sequentially collected by the first sampler, and then the second sampler picked up the last five release, two transition, and four decay samples. These 5-min integrated samples were collected using a different kind of duty cycle than used in the subsequent experiments, in which ten 2-sec "sips" were taken in even intervals over each 5-min sampling period. Two of these paired 5-min samplers operating on the same sampling schedule were used at the site closest to the highway (1 m downwind) to evaluate the potential impact of inlet height on measured concentrations, with one inlet extended to about

2.75 m above ground and the other extended higher to about 3.8 m. At the 20 m site, an additional two samplers with longer sample integration periods were used to evaluate whether "peaks" of passing tracer release were missed with this duty cycle on longer time scales. One sampler collected eleven 10-min integrated samples using ten 2-sec sips taken in even intervals over each 10-min sampling period, which corresponded to the two 5-min samples taken by the collocated higher-resolution sampler. Additionally, a 60-min integrated sample was concurrently collected during the release period by the continuous sampler system shown in Figure 5. Based on the results of this pilot, the semi-continuous duty cycle described above was developed and employed for subsequent experiments.

After each day of experiments, all sample bags were returned to the laboratory and analyzed by gas chromatography and electron capture detection (GC ECD). Samples were directly injected into a gas chromatograph (GC Series 6890N, Agilent Technologies; Santa Clara, CA) equipped with a 50-meter long porous layer open tabular column, 530 µm internal diameter with 15.0 µm film thickness (19095P-M25PT, Agilent Technologies; Santa Clara, CA). The initial oven temperature of 120 °C was ramped to 195 °C in 11 minutes with a flow rate of 4 mL min^{-1} of ultrahigh purity helium. The resolved analytes were detected using a micro-electron capture detector (µ-ECD, Agilent Technologies; Santa Clara, CA) operated at 200 °C with a constant column flow plus N_2 makeup gas flow of 50 mL min^{-1}. Tracer compounds are identified by retention time: 6.774 min for PMCP, 6.967 min for PDCB, and 8.443 min for PMCH. A multipoint calibration series was prepared by serial dilution of pure standards in ultra-zero air, and primary certified gas cylinders were custom prepared from the high purity liquid tracer. The resulting calibration curves range from 0.025–2000 ppb. Calibration checks with a 0.5 ppb standard throughout the experimental and analysis period indicate a 5–6% error in reported PFT concentrations.

Meteorology & Air Quality Measurements

During the experiments, background air pollutant concentrations were measured upwind of the highway with an instrumented research van and compared to the downwind concentrations measured at the BAAQMD trailer. Table 3 lists the instrumentation used by the Berkeley team and the BAAQMD to measure traffic-related air pollutants: black carbon (BC), nitric oxide (NO), nitrogen dioxide (NO_2), nitrogen oxides ($NO_x = NO + NO_2$), carbon monoxide (CO), and fine particulate matter ($PM_{2.5}$).

For most pollutants, the analyzers used by the Berkeley team at the upwind site in the research van were comparable to the federal equivalent method (FEM) instruments employed by the BAAQMD at the downwind near-roadway monitoring station. Measurements of BC were based on the principle of filter-based absorption spectroscopy (i.e., aethalometer) in both cases and concentrations of NO, NO_2, and NO_x were all determined by chemiluminescence. The upwind and downwind measurements of CO were both based on optical spectroscopy. The exception is $PM_{2.5}$, for which the Berkeley team used an optical particle counter (OPC) to measure $PM_{2.5}$ mass concentration upwind. The OPC estimates $PM_{2.5}$ mass concentration from a measurement of particle number concentration based on light scattering, assuming spherical particles of unit density. Since the optical properties of particulate matter are aerosol-dependent, the OPC gives an uncalibrated measure of $PM_{2.5}$ compared to the FEM concentrations reported by the BAM. For this reason, the Berkeley team deployed a second OPC at the downwind BAAQMD site to measure relative differences in upwind and downwind $PM_{2.5}$ concentrations.

Table 3. Analyzers used to measure traffic-related air pollutants upwind and downwind of the tracer release experiments. For most pollutants, the upwind measurements were made with the Berkeley instrumentation and the downwind concentrations were measured by the BAAQMD. The exception is $PM_{2.5}$, in which the Berkeley team collocated one of their instruments at the BAAQMD site to directly compare to the upwind measurement, since the operating principles of Berkeley's and BAAQMD's analyzers were not equivalent.

Pollutant	Berkeley Analyzers & Operating Principles	BAAQMD Analyzers & Operating Principles
NO, NO_2, NO_x	EcoPhysics CLD64, chemiluminescence (Ann Arbor, MI)	TECO 42i, chemiluminescence (Waltham, MA)
CO	LGR 915-0039, cavity ringdown absorption spectroscopy (San Jose, CA)	TECO 48i, non-dispersive infrared absorption spectroscopy (Waltham, MA)
$PM_{2.5}$	Particles Plus 8306, light scattering (Stoughton, MA)	Met One BAM 1020, beta attenuation (Grants Pass, OR)
BC	Magee Scientific AE33, aethalometers (Berkeley, CA)	Teledyne API 633, aethalometer (San Diego, CA)

The Berkeley team performed daily calibrations of the upwind gas analyzers using compressed gas cylinders with certified concentrations. The zero responses of the upwind BC analyzer and both OPCs were verified daily by sampling filtered air, and we assume the BAAQMD's analyzers are similarly regularly validated. Non-zero BC or $PM_{2.5}$ concentration calibration standards do not exist.

As shown in Figure 2 and Figure 9, the research van was stationed to the west of I-80 and the North Experimental Area, with sampling inlet at a height of about 2.75 m and positioned in the upwind direction, towards the San Francisco Bay. A blower pulled ambient air through that inlet into a manifold inside the van, from which the gas and particle analyzers sampled. A 2D sonic weather sensor with internal compass (AIO 2 Sonic, Met One; Grants Pass, OR) was stationed next to the research van at a height of about 1.7 m and measured minute by minute wind direction and speed.[7]

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[7] Note that the dataset for the May experiment reports this value at 4 m. All modeling for Task 7 uses the 1.7 m height recorded here applied to all experiments.

Figure 9. Concentrations of key air pollutants and wind speed/direction were measured upwind and downwind of the tracer release experiments. (a) At the upwind site, measurements were made with a 2D sonic weather sensor and an instrumented research van with a sample inlet on the roof oriented towards the San Francisco Bay. (b) Concentrations of NO, NO_2, NO_x, CO, $PM_{2.5}$, and BC were measured with analyzers housed in the van, and instrument response was verified daily with gas calibration standards and particle filters. (c) Downwind concentrations of the same pollutant species were measured at the BAAQMD's Berkeley Aquatic Park monitoring station in the North Experimental Area, including a $PM_{2.5}$ analyzer that the Berkeley team temporarily installed on the station's perimeter fence. (d) Downwind measurements of wind speed were made with a 3D sonic anemometer in the South Experimental Area.

Secondly wind speed was measured downwind at the South Experimental Area with a 3D sonic anemometer (81000 Ultrasonic Anemometer, RM Young; Traverse City, MI) oriented in the north-south direction at a height of about 1.8 m.[8] The downwind OPC was installed at a height of about 1.8 m on the perimeter fence of the

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[8] Subsequent analysis of the 3-D sonic anemometer showed it to be influenced by the road traffic. Thus the Task 7 modeling uses only the 2-D sonic for on-site, ambient wind measurements.

BAAQMD monitoring station, several feet away from the particle sampling inlets located on the trailer roof. All instrument clocks were synced to local time. Upwind air pollutant concentrations were measured at a time resolution of 1 Hz and then averaged to hourly values. BAAQMD data is reported on an hourly basis and was downloaded from the California Air Resources Board (CARB) Air Quality and Meteorological Information System (https://arb.ca.gov/aqmis2/aqdselect.php?tab=hourly).

In addition to making the upwind and downwind measurements during each experiment, the instrumented research van was collocated next to the BAAQMD trailer on a day in July 2021 that was typical of the experimental periods (Figure 10). All instruments were operated in the research van as they were during the upwind measurements of the tracer release experiments, and the second OPC was installed on the BAAQMD fence. Based on the results of this collocation, the data collected by the Berkeley team was linearly adjusted to better equate to the hourly downwind BAAQMD regulatory data using the parameters reported in Table 4. The two OPCs showed slight differences in reported concentrations during this collocation, so the upwind OPC data was similarly linearly adjusted to better match the downwind OPC installed on the BAAQMD fence. The collocation data also suggests that NO is quickly oxidized to NO_2. This means that NO and NO_2 should not be considered as conserved species and, for the upwind/downwind comparison, NO_x is the only conserved species of the three.

Figure 10. The instrumented research van collocated with the BAAQMD monitoring station to compare the upwind and downwind measurements.

Table 4. Collocation-derived linear parameters used to adjust the upwind pollutant concentration data.

Linear Correlation Parameter	BAAQMD = m(Berkeley) + b					Downwind OPC = m(Upwind OPC) + b
	BC	CO	NO_x	NO	NO_2	
slope, m	0.63	1.21	0.07	0.87	0.59	1.27
intercept, b	0.03	0.00	0.00	0.00	0.00	-0.07
R^2	0.73	0.99	0.76	0.82	0.74	0.95

3 Summary of Tracer and Air Quality Results

Table 5 summarizes the calculated source bag concentration (C_i, g L^{-1}), average instantaneous release rate ($\dot{m}_{i,avg}$, g s^{-1}), and total mass released (g) for each PFT and experiment.[9] Figure 11 shows an example of the typical concentration decay curves that were measured in each experimental area. Figure 12 plots a typical time series of total PFT concentrations measured in the 10-min integrated samples collected at each downwind distance in the South Experimental Area.

On average, 116 g PDCB, 113 g PMCP, and 96 g of PMCH were emitted per release period, respectively at a rate of 0.08, 0.09, and 0.07 g s^{-1}. These release rates resulted in a total PFT (sum of measured PDCB, PMCP, and PMCH) downwind concentration gradient that was greater than the GC limit of quantification across the sampling field in all experiments. Moreover, the time-resolved total PFT concentration field was relatively steady in each experiment, indicating that the three mobile release platforms together created a reasonably constant line source.

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[9] Note that the values used in the Task 7 modeling were recalculated to coincide with the 1-hour experimental period rather than the values presented here which reflect the total amount of gas released out of the source bag. This is discussed further in the Task 7 report.

Table 5. For each tracer, the calculated PFT source bag concentrations (C_i, g L^{-1}), average instantaneous release rates ($\dot{m}_{i,avg}$, g s^{-1}), and total mass released (m_i, g) during each experiment. Note that Experiments 1–10 were sequentially paired with the same release. For example, Release 1 covers both Experiment 1 in the North and Experiment 2 in the South Experimental Area.

Expt #	Release #	PDCB			PMCP			PMCH		
		C_i (g L^{-1})	$\dot{m}_{i,avg}$ (g s^{-1})	m_i (g)	C_i (g L^{-1})	$\dot{m}_{i,avg}$ (g s^{-1})	m_i (g)	C_i (g L^{-1})	$\dot{m}_{i,avg}$ (g s^{-1})	m_i (g)
Pilot	1	N/A			2.48	0.10	103.1	N/A		
1	2	1.69	0.06	101.3	1.64	0.04	62.6	1.29	0.06	82.7
2										
3	3[10]	2.71	0.08	123.5	2.52	0.10	130.1	1.33	0.07	107.7
4										
5	4	2.71	0.05	76.4	2.52	0.06	80.5	1.33	0.07	101.7
6										
7	5	3.02	0.10	143.0	2.90	0.11	145.6	1.31	0.08	96.2
8										
9	6	3.02	0.11	133.2	2.90	0.12	153.0	1.30	0.07	90.7
10										
Average		2.63	0.08	115.5	2.49	0.09	112.5	1.31	0.07	95.8

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[10] On June 6, 2021, no data was recorded for the PDCB release logger after the first 30 min of the release. For modeling this in Task 7, for the 8-9 am release we assumed same release rate as the first 30 min. We then used the ratio of 10:40 - 11:40 vs. 8-9 am release for PMCP to estimate the release rate for PDCB for experiment 4 (10:40-11:40 am). This is discussed further in the Task 7 report.

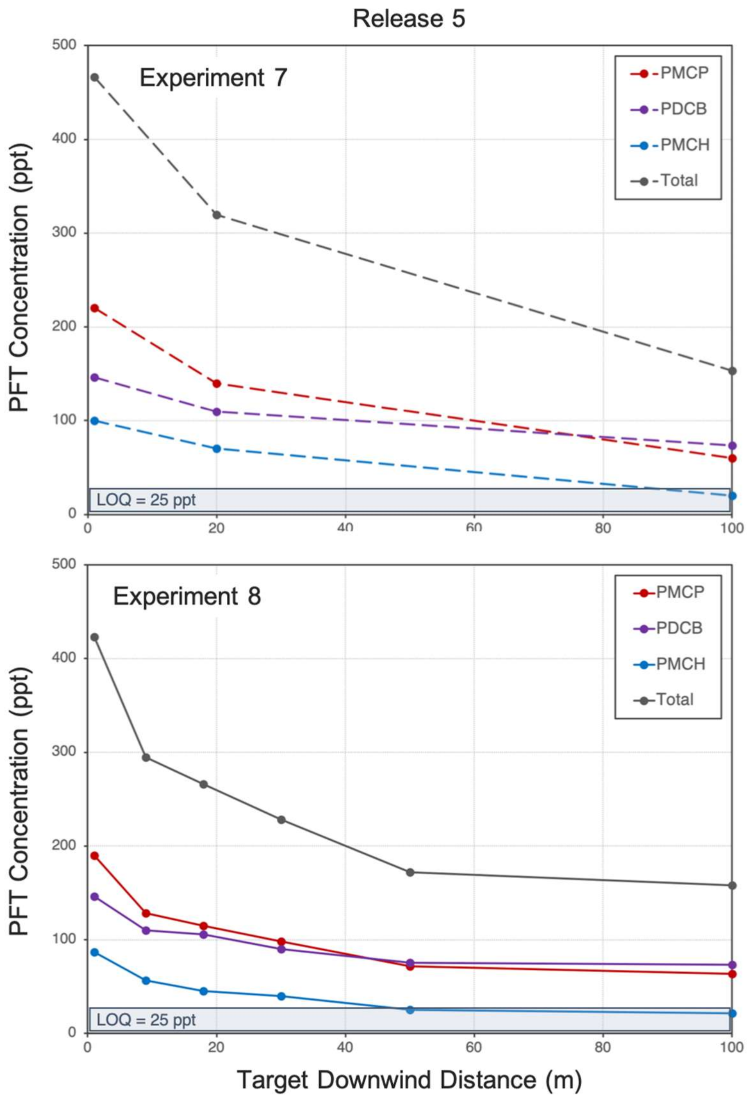

Figure 11. An example from Release 5 of the typical hourly-average concentration gradient measured at the North (top plot, Experiment 7) and South (bottom plot, Experiment 8) Experimental Areas. Each plotted point is the 60-min average concentration at the specified target downwind distance during the release period. For the time-resolved sampling in the South Experimental Area, the background, transition, and decay samples are not included in this 60-min average. The analytical limit of quantification (LOQ) about 25 ppt is identified by the shaded grey-blue box. Each tracer is shown separately, with PMCP in red, PDCB in purple, and PMCH in blue. The total PFT concentration is the sum of the individual tracers and is plotted in grey.

Table 6 reports the minimum, maximum, and average hourly concentrations of the pollutants measured upwind and downwind of the I-80 over nine hours of the tracer release experiments: 08:00–09:00 on 2021-May-03, 08:00–12:00 on 2021-Jun-06, and 08:00–12:00 on 2021-Jun-24. The range of measured concentration differences (downwind minus upwind) are also reported. Average wind speed was 1.8 m s^{-1} at both the upwind and downwind locations, and average upwind direction was 221.9°.

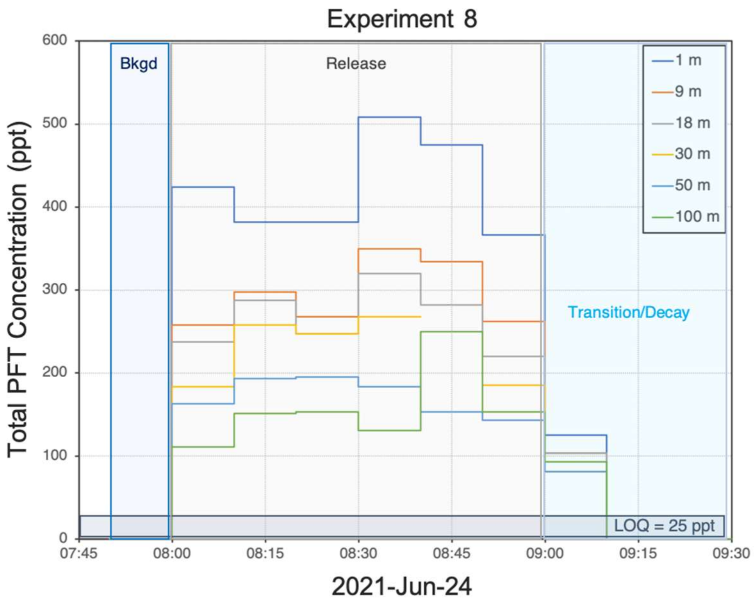

Figure 12. An example of the time-resolved total PFT concentrations measured over the course of an experiment at each target downwind distance in the South Experimental Area (Release 5, Experiment 8). Each 10-min integrated sample is shown as a horizontal plateau in the time series, with the step function indicating the next 10-min integrated sample. The background, release, transition, and decay periods of the experiment are indicated by the shaded boxes, as is the analytical limit of quantification (LOQ). Note that there was an error in the sample taken from 08:40–08:50 at the 30 m distance, which appears as an empty data point in this figure.

Table 6. Hourly average concentrations and upwind/downwind differences of traffic-related air pollutants measured during the tracer release experiments at the upwind location in the instrumented research van and downwind at the BAAQMD monitoring station. The upwind data has been adjusted using the linear correlation parameters reported in Table 4.

Location		$PM_{2.5}$, BAM[11] (µg m^{-3})	$PM_{2.5}$, OPC (µg m^{-3})	BC (µg m^{-3})	CO (ppm)	NO_x (ppm)	NO (ppm)	NO_2 (ppm)
Upwind Van	min	N/A	0.6	0.03	0.103	0.000	0.000	0.005
	avg		26.3	0.16	0.156	0.001	0.001	0.007
	max		58.3	0.86	0.364	0.003	0.004	0.025
Downwind BAAQMD	min	4.0	2.4	0.37	0.350	0.009	0.005	0.004
	avg	13.4	28.0	0.79	0.449	0.021	0.013	0.008
	max	27.0	53.3	1.91	0.561	0.050	0.031	0.019
Difference (Downwind–Upwind)	min	N/A	-5.0	0.33	0.187	0.008	0.004	-0.006
	avg		1.7	0.62	0.294	0.020	0.012	0.001
	max		5.9	1.05	0.454	0.047	0.027	0.005

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[11] The BAM data is reported purely for information purposes and to emphasize that the two OPCs must be used to determine upwind/downwind differences. It is otherwise not used. The OPC vs OPC regression was used to adjust the upwind OPC to better agree with the downwind OPC, as reported in Table 4.

4 Additional Tracer and Air Quality Experimental Results

Collocation Results

Hourly concentrations measured by the Berkeley team in the instrumented research van were compared to those values reported by the BAAQMD, based on seven hours of collocated sampling on 2021-Jul-07 (10:00–17:00). Table 7 reports the averages of these hourly concentrations (± standard deviations), which cover similar concentration ranges as were observed during the tracer release experiments (Table 6).

Table 7. Average (± standard deviation) hourly concentrations measured at the BAAQMD monitoring trailer and collocated Berkeley research van. The Berkeley research van data are presented here as measured and have not been adjusted by the linear correlation parameters that were derived during this test.

Location	$PM_{2.5}$, BAM (μg m^{-3})	$PM_{2.5}$, OPC (μg m^{-3})	BC (μg m^{-3})	CO (ppm)	NO_x (ppm)	NO (ppm)	NO_2 (ppm)
BAAQMD Trailer	12.7 ± 2.1	15.9 ± 4.6	0.56 ± 0.12	0.316 ± 0.013	0.027 ± 0.005	0.016 ± 0.003	0.010 ± 0.002
Berkeley Research Van	N/A	12.6 ± 3.4	0.82 ± 0.10	0.269 ± 0.019	0.035 ± 0.003	0.018 ± 0.002	0.016 ± 0.001

Figure 13 and Figure 14 show scatterplots of the hourly pollutant concentrations measured in the Berkeley research van vs at the BAAQMD monitoring trailer, including the linear correlations that were used to adjust the upwind data (Table 4). These linear trends include a fixed point at the origin, as the calibration checks verified the zero response of the research van analyzers and the same is assumed for the BAAQMD instruments. Additionally, the diurnal trends in pollutant concentrations measured by the BAAQMD over the full 24 hours off the collocation experiment day are included. These time series show that the hours of collocation (10:00–17:00) capture the peak and mid-range concentrations over the course of the day but miss the lower nighttime concentrations that could strengthen the correlation trends. Note that some of the BAAQMD CO and NO_x data is missing from CARB AQMIS.

The collocation data also suggests that NO is quickly oxidized to NO_2, presumably by ozone. As noted above, this means that NO and NO_2 should not be considered as conserved species, and for the upwind/downwind comparison, NO_x is the only conserved species of the three. As previously mentioned, only the adjusted OPC data that is reported below should be used to evaluate the upwind/downwind difference in $PM_{2.5}$, as the uncalibrated upwind measurement is difficult to compare to the absolute concentrations reported by the BAAQMD's BAM.

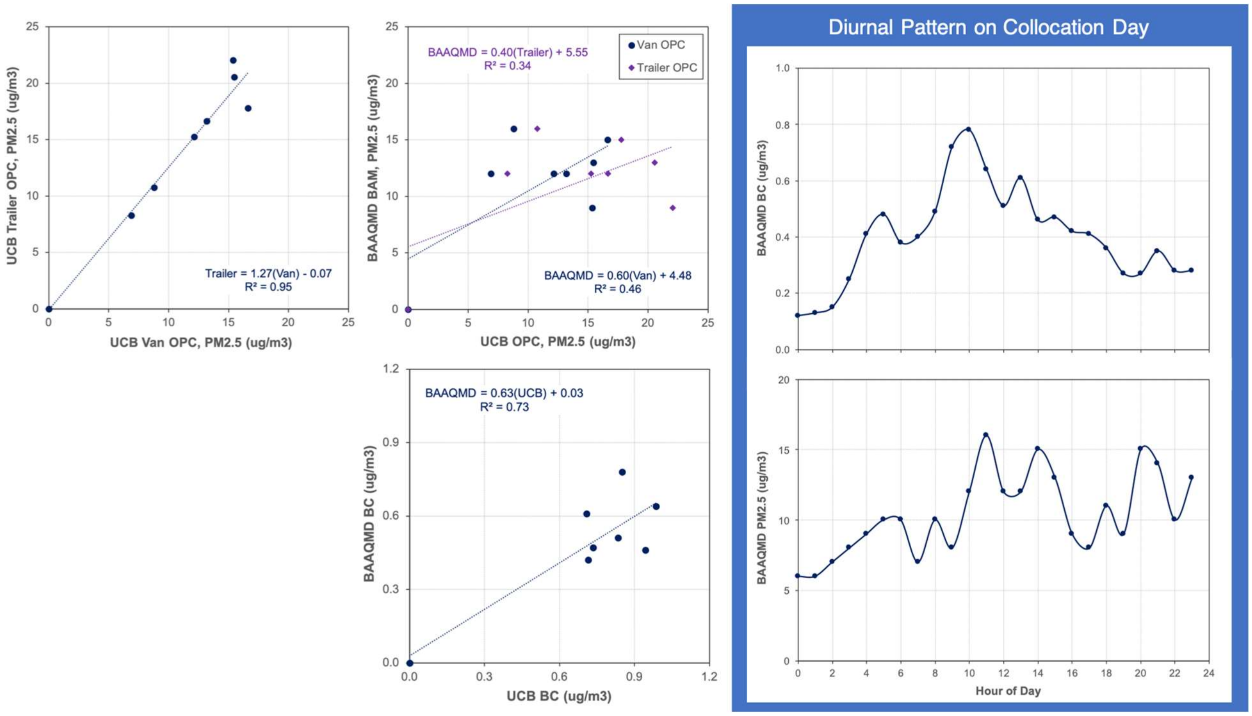

Figure 13. Scatterplots of collocated Berkeley research van and BAAQMD trailer hourly concentrations of $PM_{2.5}$ and BC, including linear trends that were used to adjust the upwind data during post-processing. Note that UCB here refers to instruments operated by the Berkeley research team, BAAQMD refers to the regulatory data downloaded from the CARB AQMIS, van refers to the OPC that was used in the upwind research van, and trailer is shorthand for the OPC that was installed on the fence of the BAAQMD monitoring station. The righthand panel shows 24-hour times series of BAAQMD data from the collocation day.

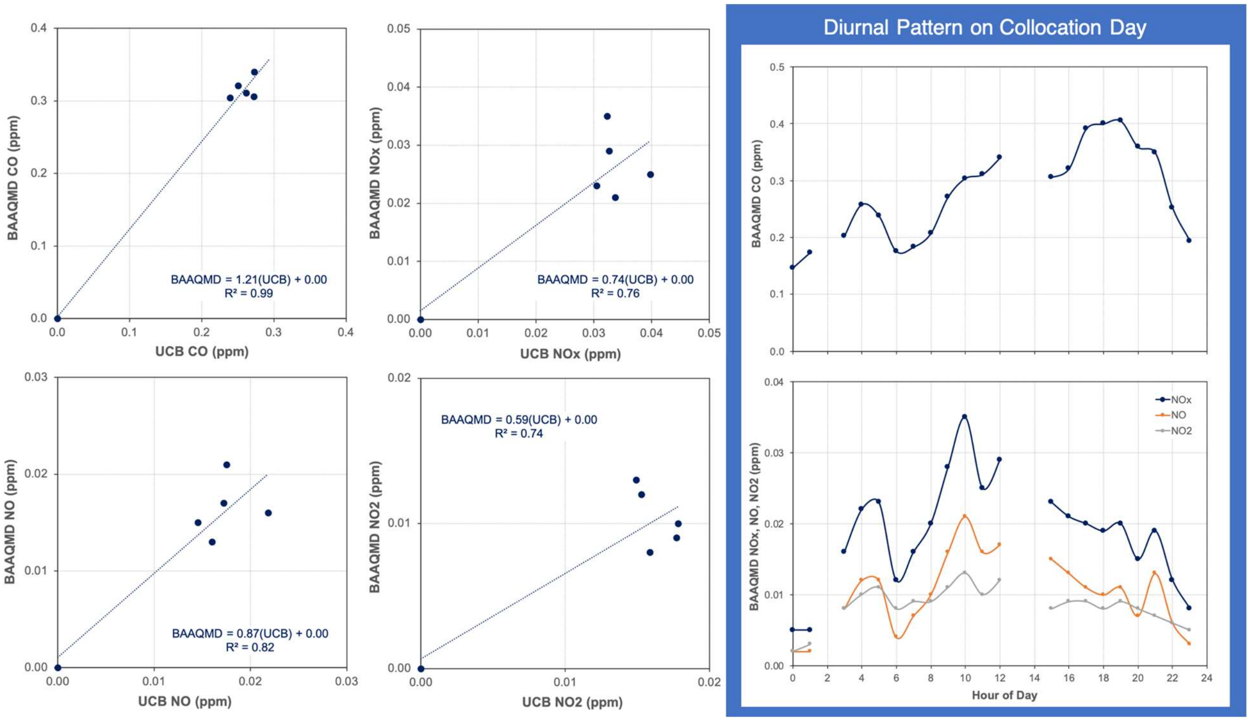

Figure 14. Scatterplots of collocated Berkeley research van and BAAQMD trailer hourly concentrations of CO, NO, NO_2, and NO_x, including linear trends that were used to adjust the upwind data during post-processing. Note that UCB here refers to instruments operated by the Berkeley research team, BAAQMD refers to the regulatory data downloaded from the CARB AQMIS, van refers to the OPC that was used in the upwind research van, and trailer is shorthand for the OPC that was installed on the fence of the BAAQMD monitoring station. The righthand panel shows 24-hour times series of BAAQMD data from the collocation day.

Pilot Test Results

The pilot test showed that there were minor differences between the high and low inlets at the 1 m sampling location that was closest to the tracer release, guiding the roughly 3 m height used in subsequent experiments (Figure 15). However, the sipping schedule employed with the 5- and 10-min integrated samples showed apparent bias by "peak" events as the tracer release vehicle passed by. For this reason, the new semi-continuous duty cycle was developed and deployed with the larger volume sample bags in the full-scale experiments.

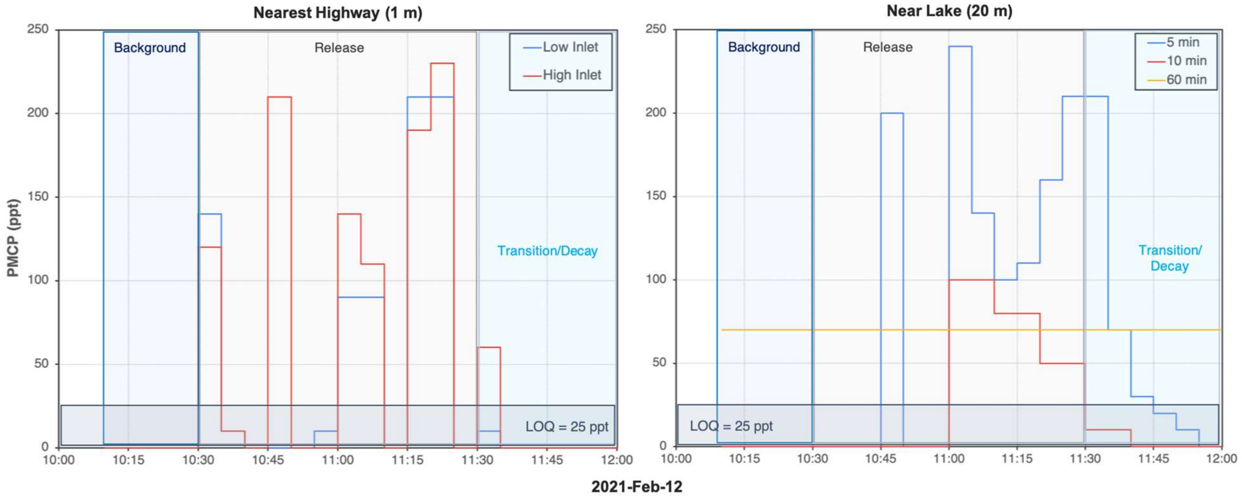

Figure 15. Time series of collocated samplers with different sampling configurations from Release 1 in the pilot test at the North Experimental Area: (left) the two inlet heights for the 5-min integrated samples collected at the nearest highway (1 m) site; (right) 5-min (blue) and 10-min (red) integrated samples taken on the sipping schedule show different peak trends and result in a different 60-min average concentration during the release period compared to the continuous sampler (yellow) at the near lake (20 m) site. The background, release, transition/decay periods are indicated in the text box.

Tracer Experiment Results

Table 8 reports the hourly average concentration measured at each downwind distance during the 60-min release period of each experiment.[12] For the pilot test, the values from the 5-min sampler at each of the three locations and the sampler with the high inlet at the 1 m location in the North Experimental Area are listed in this table. For Experiment 2, only the concentrations measured along Row 1 on the south side of Bolivar Rd are reported, like in all subsequent experiments. Figure 16 through Figure 18 plot the 60-min release period concentration gradients measured at each downwind distance for all experiments and show the trend for all three tracers and the total sum of all three PFTs. Figure 19 plots time-resolved total PFT concentrations measured at each target downwind distance for all experiments conducted in the South Experimental Area.

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[12] Note that these hourly concentrations do not consider the transition/decay periods.

Table 8. Hourly average concentration during the 60-min release period of each experiment.

Date	Experiment #	Distance (m)	Average Release Concentration (ppt)			
			PDCB	PMCP	PMCH	Total
2021-02-12	Pilot*	1	N/A	84	N/A	84
		20		97		97
		100		28		28
2021-05-03	1	1	122	110	80	312
		20	61	30	20	111
		100	85	70	40	195
	2**	10	93	61	46	200
		20	93	61	48	202
		30	82	50	34	166
		50	66	34	23	123
		100	46	28	15	89
		150	32	16	5	53
2021-06-06	3	1	171	220	110	501
		20	110	130	50	290
		100	61	50	20	131
	4	1	169	195	85	449
		9	118	120	52	290
		18	110	102	38	250
		30	85	73	32	190
		50	75	50	25	150
		100	51	60	18	129
	5	1	110	100	70	280
		20	73	60	40	173
		100	49	30	10	89
	6	1	116	120	98	334
		9	77	67	55	199
		18	71	53	47	171
		30	65	48	32	145
		50	59	37	27	123
		100	63	37	18	118
2021-06-24	7	1	146	220	100	466
		20	110	140	70	320
		100	73	60	20	153
	8	1	146	190	87	423
		9	110	128	57	295
		18	106	115	45	266

Date	Experiment #	Distance (m)	Average Release Concentration (ppt)			
			PDCB	PMCP	PMCH	Total
		30	90	98	40	228
		50	75	72	25	172
		100	73	63	22	158
	9	1	134	150	80	364
		20	98	90	50	238
		100	73	40	20	133
	10	1	148	137	83	368
		9	118	92	55	265
		18	100	80	45	225
		30	92	75	38	205
		50	89	63	32	184
		100	67	52	22	141

* Pilot results are from the 5-min samplers and the sampler with the high inlet at the 1 m location.

** Values from the samplers along Row 1 on the south side of Bolivar Rd, like all subsequent experiments in the South Experimental Area, are reported for Experiment 2.

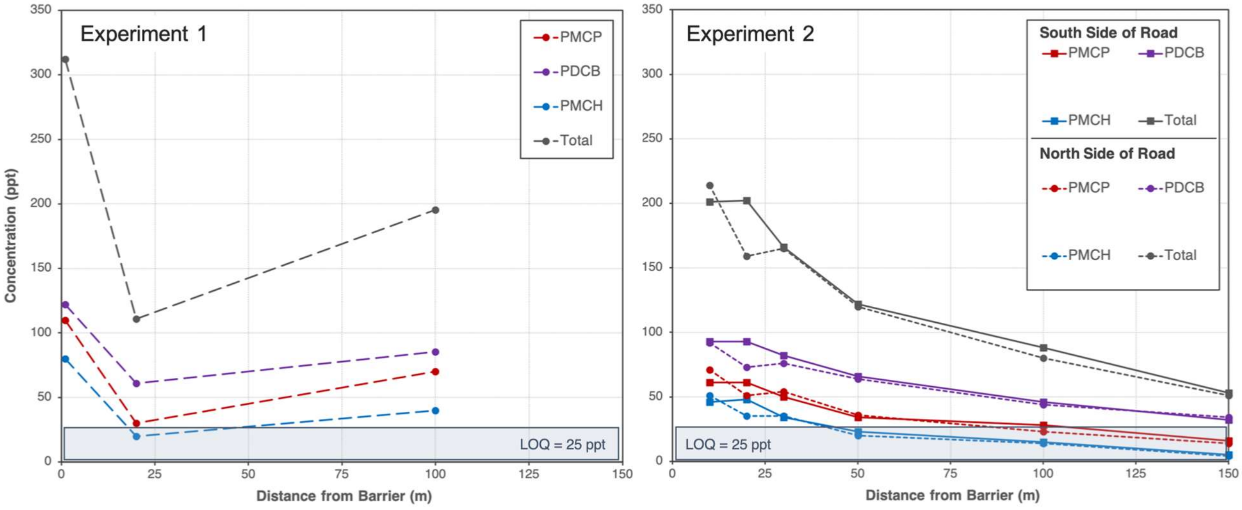

Figure 16. Hourly-average concentration gradients measured during Experiments 1–2 on 2021-May-03 (Release 2). Each plotted point is the 60-min average concentration at the specified target downwind distance during the release period. For the time-resolved sampling in the South Experimental Area, the background, transition, and decay samples are not included in this 60-min average. The analytical limit of quantification (LOQ = 25 ppt) is identified by the shaded grey-blue box. Each tracer is shown separately, with PMCP in red, PDCB in purple, and PMCH in blue. The total PFT concentration is the sum of the individual tracers and is plotted in grey.

The dual rows of samplers along either side of W. Bolivar Road in Experiment 2 agree well with each other. There were pump errors with the samplers in Experiment 1, and the concentrations reported for the 100 m distance may be biased high.

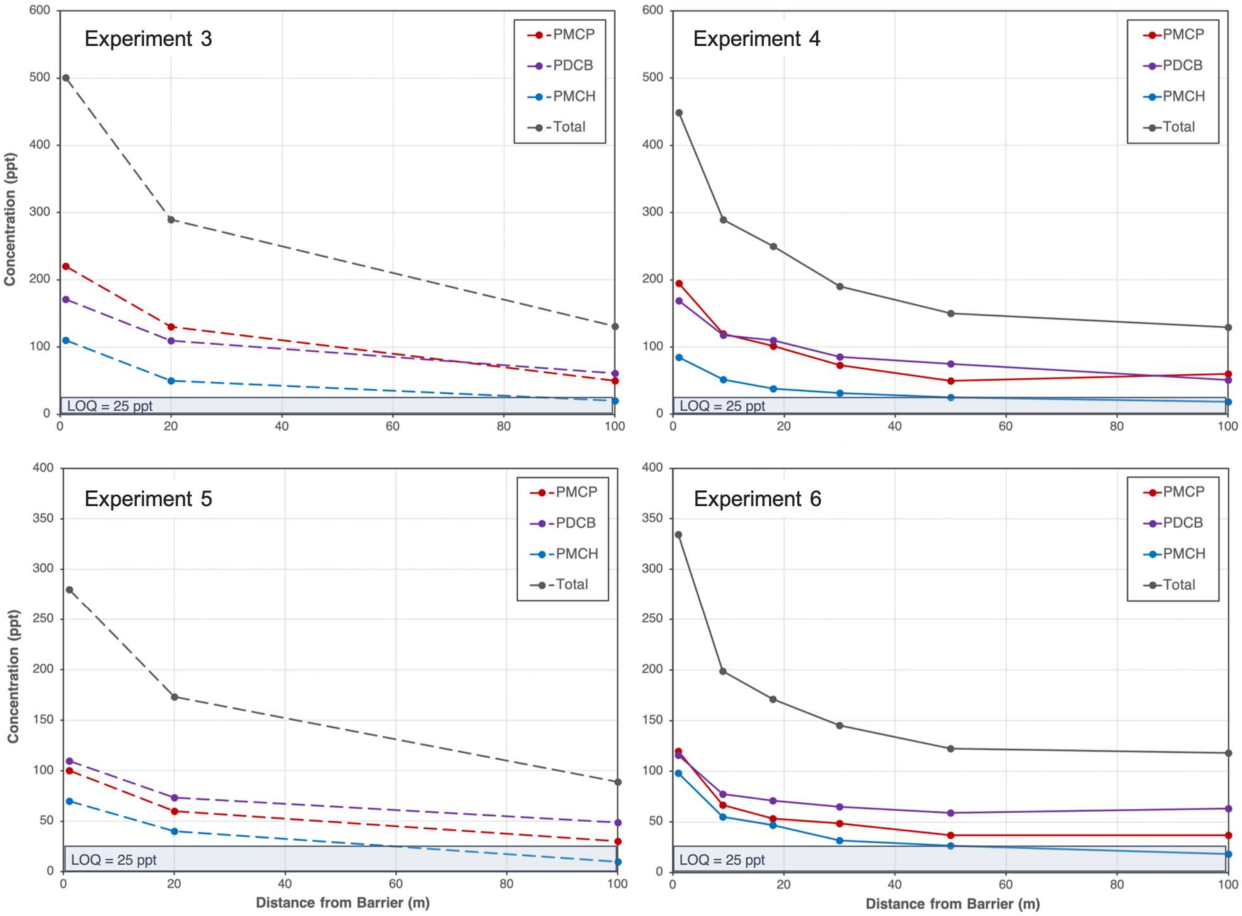

Figure 17. Hourly-average concentration gradients measured during Experiments 3–6 on 2021-Jun-06 (Releases 3 and 4). Each plotted point is the 60-min average concentration at the specified target downwind distance during the release period. For the time-resolved sampling in the South Experimental Area, the background, transition, and decay samples are not included in this 60-min average. The analytical limit of quantification (LOQ = 25 ppt) is identified by the shaded grey-blue box. Each tracer is shown separately, with PMCP in red, PDCB in purple, and PMCH in blue. The total PFT concentration is the sum of the individual tracers and is plotted in grey.

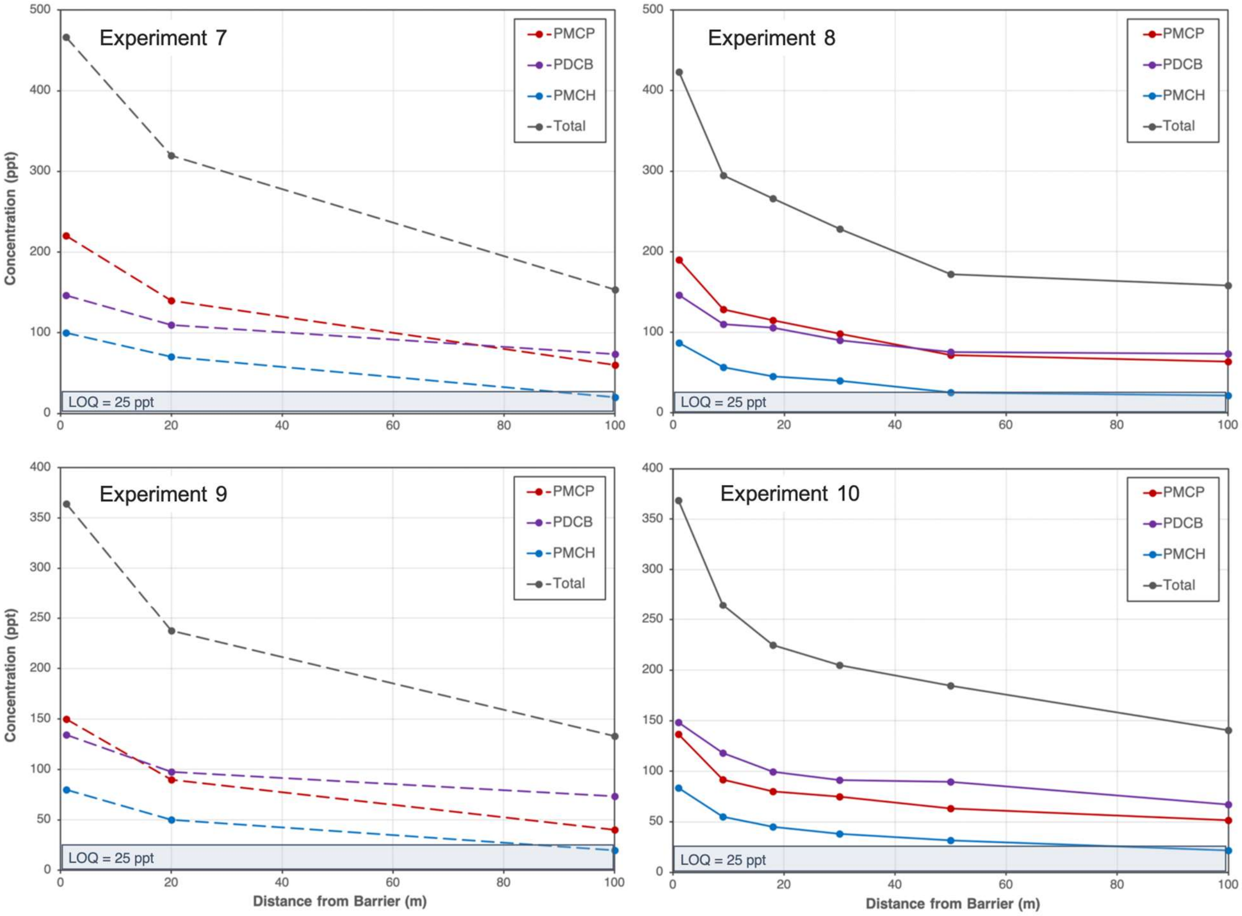

Figure 18. Hourly-average concentration gradients measured during Experiments 7–10 on 2021-Jun-24 (Releases 5 and 6). Each plotted point is the 60-min average concentration at the specified target downwind distance during the release period. For the time-resolved sampling in the South Experimental Area, the background, transition, and decay samples are not included in this 60-min average. The analytical limit of quantification (LOQ = 25 ppt) is identified by the shaded grey-blue box. Each tracer is shown separately, with PMCP in red, PDCB in purple, and PMCH in blue. The total PFT concentration is the sum of the individual tracers and is plotted in grey.

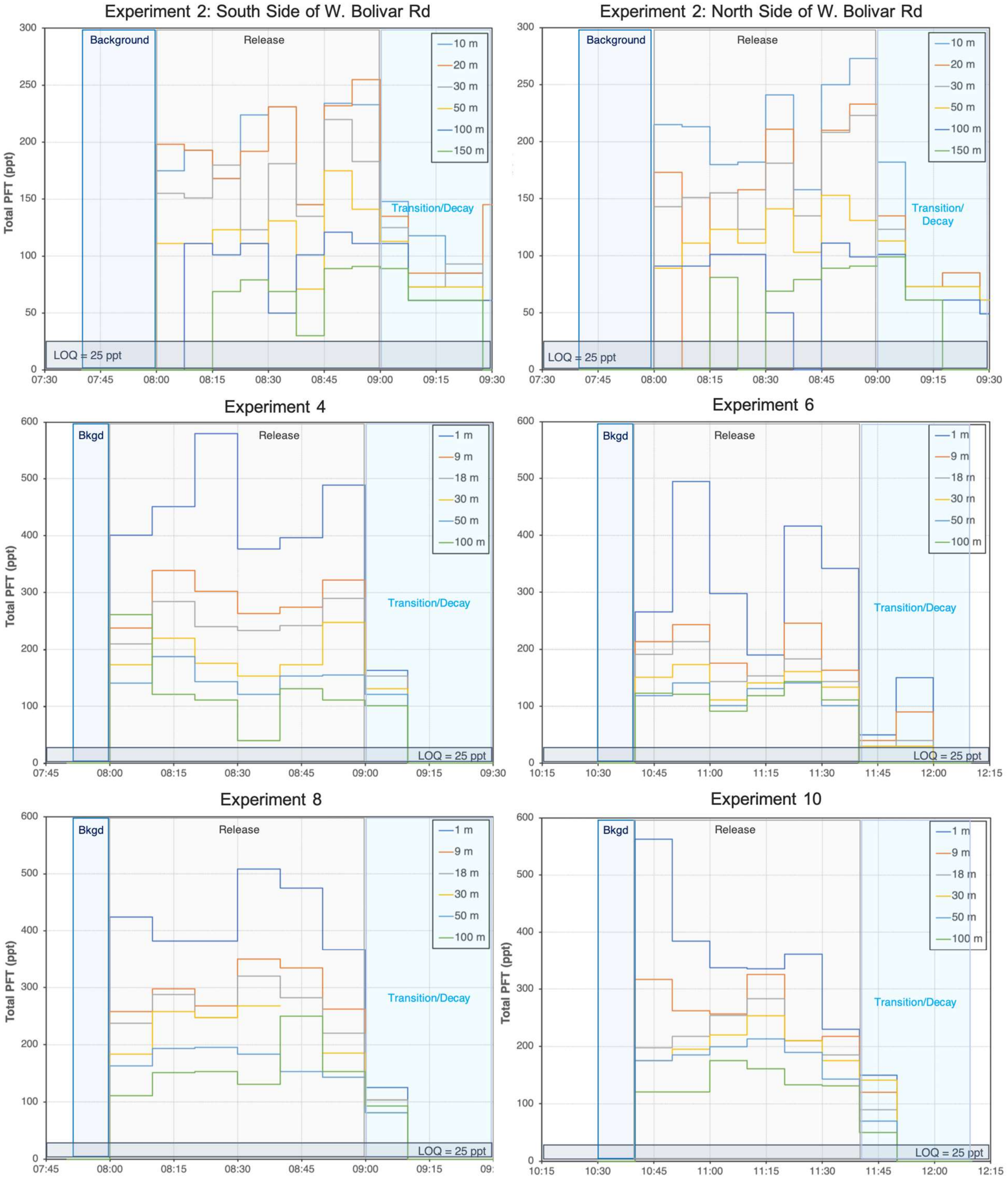

Figure 19. Time-resolved total PFT concentrations measured at each target downwind distance for all experiments conducted in the South Experimental Area. Each 7.5-min (Experiment 2) or 10-min (all subsequent experiments) integrated sample is shown as a horizontal plateau in the time series, with the step function indicating the next integrated sample. The background, release, transition, and decay periods of the experiment are indicated by the shaded boxes, as is the analytical limit of quantification (LOQ).

Air Quality & Meteorology

The scalar average hourly wind speed measured at the upwind and downwind sites are reported in Table 9. Hourly average air pollutant concentrations measured upwind in the Berkeley research van and downwind at the BAAQMD monitoring station over the course of each tracer release experiment are reported in Table 10, in addition to the corresponding difference between measured downwind and upwind concentrations. The upwind data has been adjusted using the linear correlation parameters reported in Table 4.

Table 9. Scalar average hourly wind speed measured at the upwind and downwind sites. Recall that the downwind anemometer was oriented in the north-south direction while the upwind anemometer featured an internal compass.

Date	Hour of Day	Upwind Speed ($m\ s^{-1}$)	Downwind Speed ($m\ s^{-1}$)
3-May	8	0.95	1.47
6-Jun	8	1.96	1.97
	9	1.97	1.54
	10	2.15	1.72
	11	2.96	2.03
24-Jun	8	1.29	1.97
	9	1.46	1.54
	10	1.59	1.72
	11	2.30	2.03

Table 10. Hourly concentrations measured downwind at the BAAQMD monitoring station and upwind in the Berkeley research van and their differences, from over the course of all tracer release experiments. The upwind data has been adjusted using the linear correlation parameters derived during the collocation test.

Location	Day	Hour	PM$_{2.5}$, BAM (µg m^{-3})	PM$_{2.5}$, OPC (µg m^{-3})	BC (µg m^{-3})	CO (ppm)	NO$_x$ (ppm)	NO (ppm)	NO$_2$ (ppm)
Downwind BAAQMD	3-May	8	19.0	53.3	1.91	0.551	0.050	0.031	0.019
	6-Jun	8	19.0	52.9	0.76	0.350	0.015	0.007	0.008
		9	21.0	45.5	0.96	0.383	0.014	0.007	0.007
		10	27.0	41.7	0.85	0.384	0.012	0.006	0.006
		11	15.0	48.0	0.66	0.353	0.009	0.005	0.004
	24-Jun	8	5.0	2.9	0.68	0.468	0.028	0.018	0.010
		9	4.0	2.4	0.51	0.484	0.025	0.016	0.009
		10	6.0	2.5	0.39	0.561	0.020	0.013	0.007
		11	5.0	2.7	0.37	0.509	0.017	0.011	0.006
Upwind Research Van	3-May	8	N/A	58.3	0.860	0.364	0.003	0.004	0.025
	6-Jun	8		49.2	0.125	0.148	0.001	0.001	0.005
		9		39.5	0.121	0.152	0.001	0.001	0.006
		10		39.3	0.116	0.158	0.001	0.001	0.006
		11		46.6	0.115	0.154	0.001	0.001	0.005
	24-Jun	8		1.09	0.027	0.104	0.001	0.001	0.005
		9		0.64	0.033	0.103	0.000	0.000	0.005
		10		1.02	0.043	0.107	0.000	0.000	0.005
		11		1.08	0.036	0.111	0.000	0.000	0.005
Difference (Downwind – Upwind)	3-May	8	N/A	-5.0	1.05	0.187	0.047	0.027	-0.006
	6-Jun	8		3.7	0.64	0.202	0.014	0.006	0.003
		9		5.9	0.84	0.231	0.013	0.006	0.001
		10		2.3	0.73	0.226	0.011	0.005	0.000
		11		1.4	0.55	0.199	0.008	0.004	-0.001
	24-Jun	8		1.8	0.65	0.364	0.027	0.017	0.005
		9		1.8	0.48	0.381	0.025	0.016	0.004
		10		1.5	0.35	0.454	0.020	0.013	0.002
		11		1.6	0.33	0.398	0.017	0.011	0.001

5 Traffic Data

Traffic data was also collected on each experimental day. Although traffic data information is not needed for the tracer study it is important for the pollutant evaluation in Task 7.

Tracer Vehicle Data

For the tracer study, the tracer vehicles were instrumented with sensors to collect GPS data for each tracer vehicle with time series data for each truck's location (latitude and longitude), speed and local time. This data shows both the tracer vehicles' locations and freeway travel speeds and is also indicative of the overall traffic speed.

PeMS

Traffic volume (vehicles per hour) were collected from Caltrans' online PeMS.[13],[14] PeMS allows users to query measured and derived freeway traffic data (both current and archived). PeMS can output vehicle miles traveled (VMT), vehicle hours traveled (VHT), flow, occupancy, speed, truck flow, truck proportion (percent), Q (VMT/VHT), truck VMT, truck VHT, and other metrics on an hourly or 5-minute interval by freeway, direction (i.e., I-80-E), and lane from individual sensors. It also reports VMT, VHT, Q (speed), truck VMT, truck VHT, and other metrics for an aggregate road segment, which may be user-defined based on political boundaries, postmiles, and other metrics.

We collected:

- Total vehicle flow
- Total vehicle speed
- Truck flow
- Truck proportion (percent)
- Truck VMT
- Truck VHT

in 5-minute increments over the full day of each experiment for the aggregate traffic across all lanes. We used VMT and VHT to determine traffic speed, and the corresponding truck metrics to determine truck speed. We collected this from Sensor 401198, the North Aquatic Park Sensor on I-80 east bound and 401242, the North Aquatic Park west bound sites. We also collected traffic at nearby sites for comparison, including at the North of University (aka Virginia St) locations (stations 400060 and 400612) and those at the Pinole Weigh in Motion (WIM) site. The North of University sensors are just north of the measurement locations, but within the driving loop, and were observed to be more reliable than the Aquatic Park sensors eastbound. The Pinole WIM are used for reference only.

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[13] https://merritt.cdlib.org/d/ark:%2F13030%2Fm5154j4b/2/producer%2FPRR-2009-25.pdf

[14] https://pems.dot.ca.gov/

WIM

Caltrans also collects WIM data, with one set of detectors along I-80 approximately 9 road miles eastbound (north) of the proposed monitoring site in the city of Pinole. These are shown as sites 57 and 58 in Figure 9. WIM provides 24-hour traffic data including axle weights and gross weight, axle spacing, vehicle classification, speed, and vehicle overall length.

The WIM data is north of the I-80/I-580 split outside of the study area. It was examined for similarity of traffic information for this study area. WIM data was collected for the experiment period and used to validate the PeMS data. This data is not used in modeling.

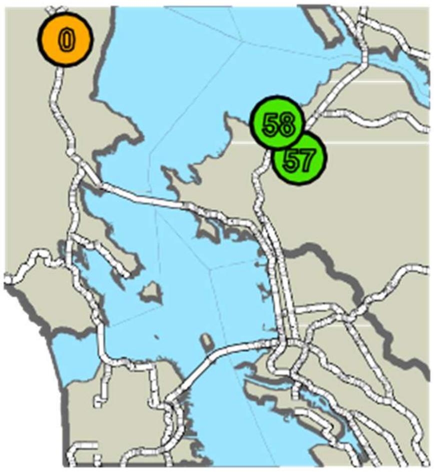

Figure 20. Caltrans District 4 Weigh in Motion Data Sites near the Proposed Study Area.

Caltrans Traffic Cameras

To support improved estimates of fleet mix we recorded streams from the existing Caltrans traffic cameras in the area. Caltrans maintains permanently stationed cameras along the study segment. There are three live video cameras (I-80: Ashby, I-80: Emeryville, and I-80: Gilman) surrounding the project study area from Ashby Avenue to Gilman Street (Figure 21). The I-80: Ashby camera,[15] located along this segment, focuses on the westbound lanes. The I-80: Emeryville camera,[16] just south of this segment, focuses on the eastbound lanes. It captures eastbound traffic after the Ashby exit but does not capture traffic joining I-80 from Ashby. The I-80: Gilman camera, [17] located just south of Gilman Street, captures both directions of mainline traffic, but does not capture traffic joining or exiting I-80 from Gilman (Figure 22).

These live camera feeds are not archived by Caltrans. They were recorded during the experiments. However, due to software issues in recording the streams, the full period from each camera may not have been captured as software stopped and was restarted during the periods. These are available for review but are not used in the Task 7 modeling.

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[15] http://cwwp2.dot.ca.gov/vm/loc/d4/tv121i80ashby.htm
[16] http://cwwp2.dot.ca.gov/vm/loc/d4/tv516i80westofashbyavenue.htm
[17] http://cwwp2.dot.ca.gov/vm/loc/d4/tv515i80gilmanstreet.htm

Figure 21. Caltrans Live Traffic Cameras in the Area, Emery (bottom), Ashby (middle), Gilman (top).[18]

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[18] http://cwwp2.dot.ca.gov/vm/iframemap.htm

Figure 22. Caltrans Live Traffic Cameras in the Area, Emery (left), Ashby (right), Gilman (bottom).

Wiltec Field Traffic Survey

The June 6, 2021 experiment day also included a subcontracted traffic survey. Wiltec conducted manual observation surveys of vehicular traffic flow in both directions of the I-80 freeway near the Aquatic Park Berkeley. Video traffic monitors were installed to collect video footage for a 24-hour period corresponding to the June 6 (Sunday) experiment.

Video files were downloaded and reviewed by trained staff from which the traffic data was extracted. The data captured was 24-hour vehicle counts of the total freeway in both directions with results broken down in 15-minute increments according to the standard FHWA vehicle classification format. Processed results are available, along with video from the recording cameras. The surveys ran from midnight Saturday to midnight Sunday.

The recording cameras were located to allow views of vehicle axles and for safety of the installation location with regards to passing vehicles and the safety of the video equipment. During advance field reconnaissance Wiltec determined that they could not install any of the equipment on the pedestrian overpass because it would have hung over the freeway below. Wiltec installed the equipment on other poles located on the ramp leading up to the overpass. Figure 23 shows the view from this location.

Figure 23. Wiltec traffic counting view on I-80 east-bound (looking south).

To capture the west-bound direction the ramp on the other side led away from the overpass and so we could not install the equipment there. Additionally, there is a rather large homeless encampment in that area that could have threatened the installed equipment. So, based on surveys along the adjacent frontage road, Wiltec eventually settled on a light pole down near the Ashby off-ramp. There is no on or off-ramp between these two locations, so the traffic volumes were the same as those at the pedestrian overpass. For the purposes of the axle classification counts, this location was fine. Figure 24 shows the view from this location.

Figure 24. Wiltec traffic counting view on I-80 west-bound (looking north).

Table 11 and Table 12 summarize the hourly data from all lanes observed during the experiment.

Table 11. Vehicle axle classification count results, west-bound summary, Sunday June 6, 2021, I-80 at Berkeley aquatic park

	TOTAL OF ALL LANES													
CLASS =>	1	2	3	4	5	6	7	8	9	10	11	12	13	TOTALS
HOUR TOTALS	MOTOR CYCLES	CARS AND VANS (+ TRAILERS)	PICKUPS AND TRUCKS (+ TRAILERS)	ALL BUSES	2-AXLE SINGLE UNIT TRUCKS	3-AXLE SINGLE UNIT TRUCKS	4-AXLE SINGLE UNIT TRUCKS	3 & 4-AXLE TRACTOR / SINGLE TRAILER COMBOS	5-AXLE TRACTOR / SINGLE TRAILER COMBOS	6 & 7-AXLE TRACTOR / SINGLE TRAILER COMBOS	5-AXLE TRACTOR / MULTI TRAILER COMBOS	6-AXLE TRACTOR / MULTI TRAILER COMBOS	ALL 7+AXLE HEAVY TRUCKS	
000-100	12	2037	52	7	9	5	5	0	27	2	12	1	1	2,170
100-200	4	1273	22	13	11	1	3	0	36	3	18	1	0	1,385
200-300	2	1097	24	1	9	5	1	0	44	7	29	0	0	1,219
300-400	5	988	20	2	8	11	5	2	35	4	13	0	2	1,095
400-500	8	1255	36	12	16	4	4	1	31	8	11	2	1	1,389
500-600	9	1802	127	8	21	14	5	1	45	2	7	1	1	2,043
600-700	9	2356	122	14	9	7	1	1	41	0	13	1	4	2,578
700-800	11	2417	172	5	21	9	4	0	37	0	8	1	2	2,687
800-900	10	3406	216	2	45	12	3	1	50	2	3	1	0	3,751
900-1000	34	4641	303	2	55	10	0	1	47	3	11	1	0	5,108
1000-1100	44	5562	387	13	41	8	0	0	40	3	3	1	0	6,102
1100-1200	39	5964	294	10	30	4	0	0	32	2	6	2	2	6,385
1200-1300	15	6030	484	5	34	5	2	0	45	0	5	0	0	6,625
1300-1400	21	6184	496	9	43	5	0	0	47	0	6	0	0	6,811
1400-1500	23	6200	505	3	42	4	0	0	44	0	8	1	0	6,830
1500-1600	30	5932	461	11	45	0	1	0	35	1	6	0	0	6,522
1600-1700	29	5888	427	15	37	7	0	0	52	0	6	0	0	6,461
1700-1800	9	5869	433	9	34	2	0	0	41	0	6	0	0	6,403
1800-1900	31	5695	440	20	36	6	2	0	39	0	6	0	0	6,275
1900-2000	15	5989	432	9	42	2	1	0	66	0	12	0	0	6,568
2000-2100	10	5312	303	14	28	5	2	0	53	0	9	0	0	5,736

	TOTAL OF ALL LANES													
CLASS =>	1	2	3	4	5	6	7	8	9	10	11	12	13	TOTALS
HOUR TOTALS	MOTOR CYCLES	CARS AND VANS (+ TRAILERS)	PICKUPS AND TRUCKS (+ TRAILERS)	ALL BUSES	2-AXLE SINGLE UNIT TRUCKS	3-AXLE SINGLE UNIT TRUCKS	4-AXLE SINGLE UNIT TRUCKS	3 & 4-AXLE TRACTOR / SINGLE TRAILER COMBOS	5-AXLE TRACTOR / SINGLE TRAILER COMBOS	6 & 7-AXLE TRACTOR / SINGLE TRAILER COMBOS	5-AXLE TRACTOR / MULTI TRAILER COMBOS	6-AXLE TRACTOR / MULTI TRAILER COMBOS	ALL 7+AXLE HEAVY TRUCKS	
2100-2200	4	5164	163	5	24	5	0	0	74	0	10	0	0	5,449
2200-2300	3	3778	113	7	29	4	0	0	72	0	9	0	0	4,015
2300-000	2	2605	60	3	38	5	0	0	51	0	11	0	0	2,775
Total	**379**	**97444**	**6092**	**199**	**707**	**140**	**39**	**7**	**1084**	**37**	**228**	**13**	**13**	**106,382**

Table 12. Vehicle axle classification count results, east-bound summary, Sunday June 6, 2021, I-80 at Berkeley aquatic park

	TOTAL OF ALL LANES													
CLASS =>	1	2	3	4	5	6	7	8	9	10	11	12	13	TOTALS
HOUR TOTALS	MOTOR CYCLES	CARS AND VANS (+ TRAILERS)	PICKUPS AND TRUCKS (+ TRAILERS)	ALL BUSES	2-AXLE SINGLE UNIT TRUCKS	3-AXLE SINGLE UNIT TRUCKS	4-AXLE SINGLE UNIT TRUCKS	3 & 4-AXLE TRACTOR / SINGLE TRAILER COMBOS	5-AXLE TRACTOR / SINGLE TRAILER COMBOS	6 & 7-AXLE TRACTOR / SINGLE TRAILER COMBOS	5-AXLE TRACTOR / MULTI TRAILER COMBOS	6-AXLE TRACTOR / MULTI TRAILER COMBOS	ALL 7+AXLE HEAVY TRUCKS	
000-100	8	3445	43	13	0	0	0	1	24	4	6	0	0	3,544
100-200	2	2019	20	7	0	0	0	0	39	4	5	0	0	2,096
200-300	2	1415	19	8	1	0	0	0	42	1	7	0	0	1,495
300-400	3	1046	19	7	2	0	0	0	35	7	4	0	0	1,123
400-500	3	948	12	9	1	0	0	0	44	12	8	0	0	1,037
500-600	1	1203	53	3	0	0	0	2	32	16	1	1	0	1,312
600-700	8	1877	107	6	1	1	0	2	32	0	4	0	0	2,038
700-800	11	3037	195	4	1	3	0	1	54	0	4	1	0	3,311
800-900	13	4425	241	15	1	2	0	0	39	0	1	1	0	4,738
900-1000	23	5819	243	5	1	3	0	0	40	1	2	0	0	6,137
1000-1100	23	7500	277	3	1	1	0	0	38	0	2	0	0	7,845
1100-1200	17	7858	237	9	1	1	0	0	50	0	1	0	0	8,174
1200-1300	40	7910	269	9	1	0	0	0	36	1	1	0	0	8,267
1300-1400	34	7749	266	5	0	1	1	1	38	1	2	0	0	8,098
1400-1500	31	6885	299	0	0	4	0	0	34	1	1	0	0	7,255
1500-1600	22	6184	402	5	0	0	0	0	31	1	4	0	0	6,649
1600-1700	22	7481	398	6	0	0	2	0	37	4	7	0	0	7,957
1700-1800	30	7580	369	5	0	0	1	0	34	0	4	0	0	8,023
1800-1900	26	6662	290	4	0	0	0	3	53	0	9	0	0	7,047
1900-2000	17	6040	218	13	0	0	0	3	46	0	3	0	0	6,340
2000-2100	10	5331	151	4	0	0	0	0	65	0	9	0	0	5,570

	TOTAL OF ALL LANES													
CLASS =>	1	2	3	4	5	6	7	8	9	10	11	12	13	TOTALS
HOUR TOTALS	MOTOR CYCLES	CARS AND VANS (+ TRAILERS)	PICKUPS AND TRUCKS (+ TRAILERS)	ALL BUSES	2-AXLE SINGLE UNIT TRUCKS	3-AXLE SINGLE UNIT TRUCKS	4-AXLE SINGLE UNIT TRUCKS	3 & 4-AXLE TRACTOR / SINGLE TRAILER COMBOS	5-AXLE TRACTOR / SINGLE TRAILER COMBOS	6 & 7-AXLE TRACTOR / SINGLE TRAILER COMBOS	5-AXLE TRACTOR / MULTI TRAILER COMBOS	6-AXLE TRACTOR / MULTI TRAILER COMBOS	ALL 7+AXLE HEAVY TRUCKS	
2100-2200	4	5081	40	2	0	0	0	0	35	2	2	0	0	5,166
2200-2300	9	4408	23	2	0	0	0	1	53	1	2	0	0	4,499
2300-000	3	2989	31	0	0	0	0	0	68	2	1	0	0	3,094
Total	**362**	**114892**	**4222**	**144**	**11**	**16**	**4**	**14**	**999**	**58**	**90**	**3**	**0**	**120,815**

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