Influence of Roadway Emissions on Near-Road $PM_{2.5}$: Monitoring Data Analysis and Implications for Determining Transportation Projects of Local Air Quality Concern (POAQC)




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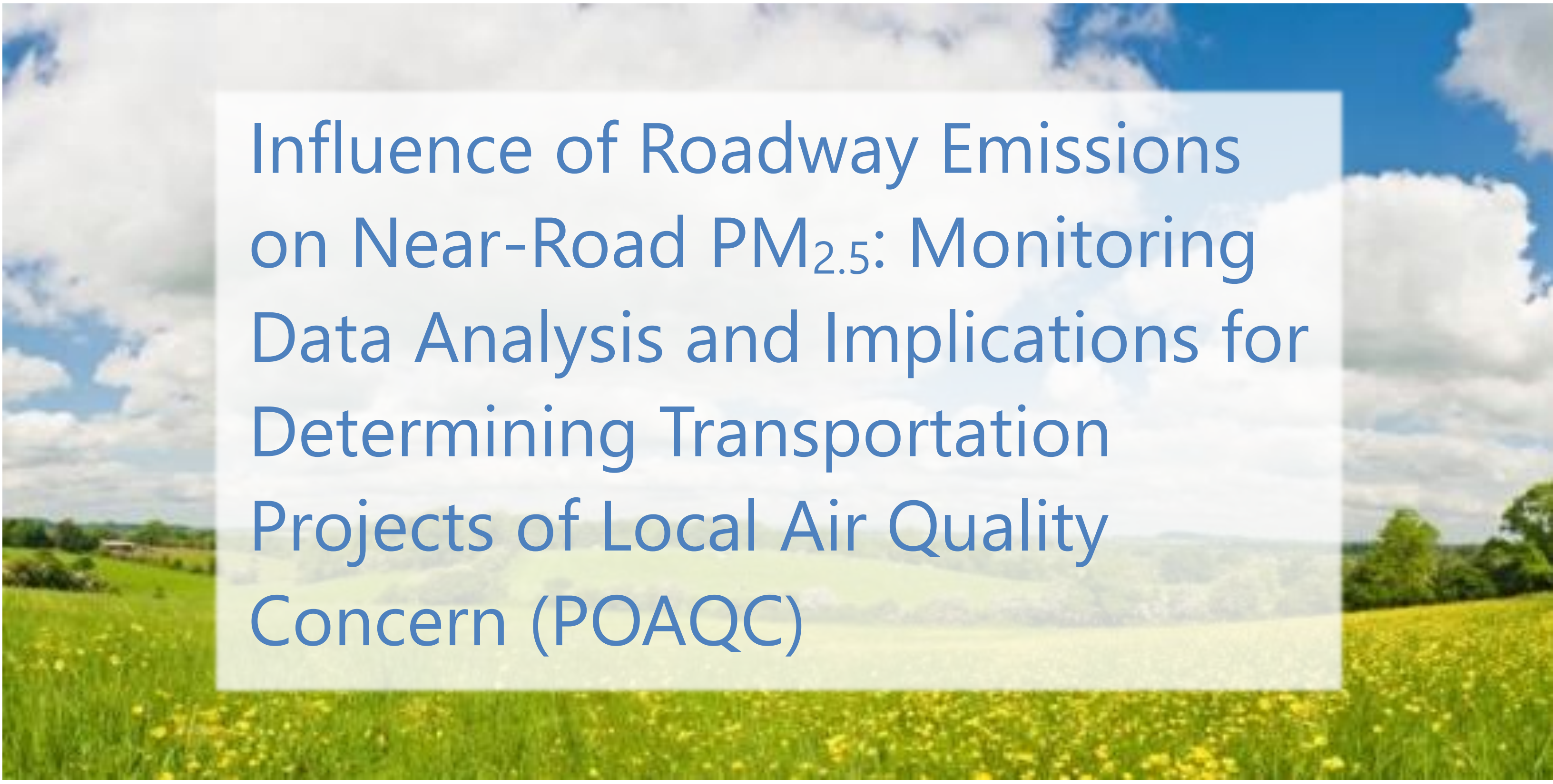

Influence of Roadway Emissions on Near-Road $PM_{2.5}$: Monitoring Data Analysis and Implications for Determining Transportation Projects of Local Air Quality Concern (POAQC)

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Abstract

This work was completed as part of the Near-Road Air Quality Research Pooled Fund TPF-5(284), under the U.S. Federal Highway Administration Transportation Pooled Fund Program. The lead agency for TPF-5(284) is the Washington State Department of Transportation. Other participants that funded this work include FHWA and the Arizona, California, Colorado, Ohio, Texas, and Virginia Departments of Transportation. Sonoma Technology, Inc., provides TPF-5(284) participants with technical, planning, facilitation, and website support.

Background. Transportation projects in particulate matter (PM) nonattainment and maintenance areas are required to undergo a quantitative transportation conformity hot-spot analysis if they are identified as projects of local air quality concern (POAQC) due to their potential to cause PM hot spots. The objective of this study was to use measurements from U.S. near-road air quality monitors to examine the impacts of major roadways on near-road pollution, and determine what project characteristics could reasonably exclude a hypothetical project from consideration as a POAQC.

Methods. We examined the concentrations of particulate matter 2.5 micrometers in aerodynamic diameter or smaller ($PM_{2.5}$) measured in 2017 from forty-eight near-road monitoring sites. From these data, we calculated the near-road $PM_{2.5}$ increment, i.e., the difference between the near-road and background $PM_{2.5}$ concentrations, which represents the contribution of roadway emissions to $PM_{2.5}$. We used two methods to represent daily average $PM_{2.5}$ background concentrations at the near-road monitor. First, we employed data from a single monitor closest to the near-road site. Second, we used measurements from $PM_{2.5}$ monitors within 40 km of each near-road site and combined them using an inverse distance weighting (IDW) method. We evaluated near-road sites on a case-by-case basis and addressed confounding factors affecting increment calculations related to (1) $PM_{2.5}$ measurement method, (2) the local environment of the near-road monitor, (3) whether the type of land use at the near-road and background monitors was similar, and (4) whether there was a predominant land/sea breeze.

Results. The range of 2017 annual average $PM_{2.5}$ increments found after removing sites with confounding factors was between 0.13 ± 0.16 µg/m^3 and 2.04 ± 0.16 µg/m^3 (where the uncertainty of $\pm$ 0.16 represents the 95% confidence interval on the mean), representing the upper bound of the impact of roadway emissions. The range of $PM_{2.5}$ increments from monitors located 10 or more meters from the roadway was between zero and 1.44 ± 0.17 µg/m^3. Regression models and a general additive model showed a statistically significant relationship between distance to the road, percent of time the monitor was upwind, and fleet-equivalent annual average daily traffic (FE-AADT) with the $PM_{2.5}$ increment. Using the EPA Motor Vehicle Emissions Simulator (MOVES) to forecast national average vehicle exhaust emissions, and thereby near-road contribution to $PM_{2.5}$, we project that the upper bound of near-road $PM_{2.5}$ increments for the types of highways assessed here will decrease from 2.04 ± 0.16 µg/m^3 in 2017 to 1.39 ± 0.16 µg/m^3 in 2040, based on a roadway with 8% heavy-duty vehicles and constant AADT and travel speeds. These results, and the methodology provided in this study, provide a way to estimate an upper bound of $PM_{2.5}$ impacts for transportation highway projects as represented in the dataset we evaluated and can help inform transportation conformity interagency consultation regarding POAQC designations.

1. Introduction and Objectives

The objectives of this study were to: (1) assess the $PM_{2.5}$ annual average increment representing the impact of roadway emissions on near-road $PM_{2.5}$ at near-road monitoring sites in 2017, (2) quantify the relationship between the increments and site-specific factors such as traffic volumes and the monitor's distance to the roadway, (3) use modeled exhaust emissions to forecast how the traffic-related $PM_{2.5}$ will change between 2017 and 2040, and (4) draw insights from these results that are relevant to the conformity requirements for transportation project $PM_{2.5}$ hot-spot analysis, including the relationship between site characteristics and increment values, and implications for which transportation projects can be reasonably excluded from consideration as a project of local air quality concern (POAQC).

Motor vehicle emissions contribute to particulate matter in the United States, through the direct emission of $PM_{2.5}$ and the emission of precursor gases that form $PM_{2.5}$ through gas-to-particle conversion (McCarthy et al., 2006; Abu-Allaban et al., 2007; Brown et al., 2012; Jimenez et al., 2009; May et al., 2014; Saha et al., 2018a; Stroud et al., 2014; Massoli et al., 2012; Kittelson et al., 2006). For roadways with significant traffic, a concern is the potential for elevated localized $PM_{2.5}$ levels, i.e., hot spots (Yanosky et al., 2018; U.S. Environmental Protection Agency, 2015a). A number of factors impact the traffic contribution to $PM_{2.5}$, including the traffic mix and volume, the age of vehicles, vehicle speed, meteorological conditions, local topography, and the built environment, including roadway geometry and the presence of barriers or sound walls (Zhu et al., 2002; Baldauf et al., 2008; 2016; Yanosky et al., 2018). Diesel emissions from heavy-duty diesel vehicles (HDDVs) are an important component of total roadway $PM_{2.5}$ emissions (Gertler, 2005; California Air Resources Board, 2015). In addition to exhaust emissions, traffic-related $PM_{2.5}$ emissions also include brake wear, tire wear, and re-suspended road dust (Gertler et al., 2000; Clayton et al., 2003). Beginning in 2014, EPA mandated the deployment of air quality monitors alongside selected major roadways in the United States; these have been used to examine the impact of traffic-related pollution (Watkins, 2016; Seagram et al., 2019; DeWinter et al., 2018). Measurements at the near-road sites focus on $PM_{2.5}$, carbon monoxide (CO) and nitrogen dioxide (NO_2), and typically do not include PM_{10} measurements.

Prior studies examined incremental $PM_{2.5}$ impacts from the near-road monitors in 2015 and 2016 as well as more detailed case studies of individual monitors (Seagram et al., 2019; DeWinter et al., 2018; Brown et al., 2019). This study builds on that work by examining annual average $PM_{2.5}$ increments in 2017 and taking the next step of accounting for confounding factors in calculating the increment.

Clean Air Act (CAA) section 176(c) (42 U.S.C. 7506[c]) mandates that transportation projects that are federally funded will not cause or worsen air quality violations or delay attainment of the National Ambient Air Quality Standards (NAAQS) and therefore must conform to the purpose of the State Implementation Plan (SIP) for air quality (i.e., "transportation conformity"). Clean Air Act transportation conformity requirements are promulgated by the U.S. Environmental Protection Agency (EPA) to ensure that federally funded transportation projects do not impede the SIP for attaining and maintaining the NAAQS. In 2006, EPA issued a final rule entitled "$PM_{2.5}$ and PM_{10} Hot-Spot Analysis in Project-Level Transportation Determinations for the New

$PM_{2.5}$ and Existing PM_{10} National Ambient Air Quality Standards" (PM hot-spot rule).[1] In 2015, EPA issued updated guidance for quantitative PM hot-spot analyses: "Transportation Conformity Guidance for Quantitative Hot-spot Analysis in $PM_{2.5}$ and PM_{10} Nonattainment and Maintenance Areas" (U.S. Environmental Protection Agency, 2015a). To meet the conformity requirements, transportation projects are required to undergo quantitative hot-spot analysis if they are identified, through interagency consultation, as a POAQC.

The transportation conformity regulation (40 CFR 93.123[b]) defines conditions to determine if a project is a POAQC; these conditions include significant levels of diesel vehicle traffic, or being identified in a PM SIP as a POAQC. The preamble to the 2006 final rule gives the example of, "A project on a new highway or expressway… with annual average daily traffic (AADT) greater than 125,000 where 8% or more of such AADT is diesel truck traffic." In practice, the final decision of whether a project is a POAQC is discussed and decided through interagency consultation. If a project is determined to be a POAQC, the subsequent $PM_{2.5}$ hot-spot analysis must follow a detailed procedure accounting for base-year and future-year traffic activity of the proposed project, and modeling associated emissions and air quality. Contributions of $PM_{2.5}$ that are modeled to result from the project are summed with the estimated background concentration, and compared to the NAAQS. The required transportation conformity analyses can vary depending on the area—for example, modeling road dust is not required for every project analysis. Given the complexity of quantitative $PM_{2.5}$ hot-spot analyses, information that clarifies which projects are unlikely to be a POAQC is valuable. The work presented here improves understanding of incremental $PM_{2.5}$ impacts of major U.S. roadways, and can directly inform interagency consultation regarding POAQC determinations.

2. Methods

This study examined the contribution of roadway emissions to annual average $PM_{2.5}$ concentrations at U.S. near-road monitors in 2017. To complete $PM_{2.5}$ increment analyses, we refined the data used to remove various confounding factors that might skew understanding of roadway impacts. First, we examined $PM_{2.5}$ measurements from all 49 near-road sites where measurements met EPA data completeness thresholds during 2017. Since our objective was to assess near-road $PM_{2.5}$ increments, we needed to then pair near-road site data with data from an ambient monitor. Of the 49 near-road sites, 48 sites had at least one ambient site within 40 km where $PM_{2.5}$ measurements met data completeness thresholds. For the 48 sites, total near-road $PM_{2.5}$ concentrations were compared to the NAAQS to establish a national-scale understanding of near-road $PM_{2.5}$. Next, to improve accuracy for increment assessments, we narrowed our sample to cover only those site pairings where the near-road and the ambient site measured $PM_{2.5}$ using identical monitoring instruments. This produced a sample of 40 near-road sites for which we estimated $PM_{2.5}$ increments. Among the 40 near-road sites, nine sites were estimated to have negative $PM_{2.5}$ increments, indicating that confounding factors skewed increment assessment at those sites (i.e., roadway emissions by definition add some incremental concentration to background; a negative increment implies incorrect representation of background concentrations at the near-road site). We therefore further narrowed our analysis sample to the 31 sites for which we estimated a positive near-road $PM_{2.5}$ increment. We refer to this sample as our "initial

[1] 40 CFR 93.123(b)(1).

case" in findings presented later. Each of the 40 near-road sites were then evaluated for potential confounding factors including characteristics of the near-road environment such as site elevation or the presence of nearby barriers, commonality of land use between near-road and background monitors, and potential sea breeze effects that could skew findings. Removing sites with a noted confounding factor resulted in a sample of 20 near-road sites we refer to as the "focused case" which is also a subset of the initial case. In summary, we progressively narrowed our data sample to remove confounding factors and improve increment evaluation:

1. 49 sites: our starting sample of all sites reporting complete near-road $PM_{2.5}$ data in 2017
2. 48 sites: all of the near-road sites with an ambient monitor available for background
3. 40 sites: near-road sites paired with ambient sites using identical monitoring instruments
4. 31 sites: our "initial case" near-road site sample after removing negative increment sites
5. 20 sites: our "focused case" sample after addressing remaining confounding factors

The statistical relationships between the annual average $PM_{2.5}$ increment and traffic volumes, distance of the monitor to the roadway, and meteorological variables were assessed using pairwise correlation of determination (R^2), regression models, and a general additive model (GAM) from sets (4) and (5) of the near-road sites listed above. Last, we used the near-road increments calculated with 2017 data and emissions forecasts to estimate the traffic impact on $PM_{2.5}$ from 2018 to 2040. We used estimates of the fraction of traffic-related $PM_{2.5}$ emissions originating from exhaust, and forecast changes in exhaust emissions from the EPA Motor Vehicle Emissions Simulator (MOVES) and the Emission FACtors (EMFAC) models, to forecast the future traffic impact. We then evaluated the implication of these results on the POAQC designation of proposed highway projects.

2.1 Data Sources

This study used a range of data sources to evaluate near-road pollution. $PM_{2.5}$ concentrations, collocated meteorological data, and near-road site information came directly from EPA's Air Quality System (AQS) and EPA-provided metadata. When representative meteorological data for a near-road site were not available, nearby meteorological data from the MesoWest database were used. Land use data were adapted from the National Land Cover Database (NLCD), developed by the United States Geological Survey (USGS) and Gridded Population of the World, developed by NASA's Socioeconomic Data and Applications. This section details the sources of data used in this study, completeness thresholds, initial data processing steps, and methods used to calculate variables.

2.1.1 Air Quality Data and Near-Road Site Characteristics

The list of near-road monitoring sites is publicly available through the EPA.[2] Sites in this study are identified by their EPA AQS site ID codes. Some cities have multiple near-road sites (e.g.,

[2] https://www3.epa.gov/ttnamti1/nearroad.html.

Denver-0027 and Denver-0028), and some sites have collocated measurements of $PM_{2.5}$, identified by their parameter occurrence code (POC) (e.g., Milwaukee-0056-1 and Milwaukee-0056-3). EPA also provides the geographic coordinates of the monitor and the distance of the near-road monitor from the road, defined as the distance to the edge of the roadway. Although the EPA near-road site metadata do not include a detailed breakdown of vehicle classifications, the metadata do contain AADT and fleet-equivalent AADT (FE-AADT) information for the target road from the year of site installation. EPA developed the FE-AADT calculation to represent an emissions-weighted traffic volume, taking into account both AADT and fleet mix (U.S. Environmental Protection Agency, 2012). FE-AADT is calculated as:

$$(AADT - HD_c) + (HD_m \times HD_c),$$

where HD_c is the volume of heavy-duty vehicles on the target roadway, and HD_m is a scaling factor that represents the ratio of heavy-duty to light-duty emissions of oxides of nitrogen (NO_x). The number of HDDVs was estimated from FE-AADT and AADT, using the EPA recommended national default scaling value of $HD_m = 10$.

Daily and hourly $PM_{2.5}$ measurements from all ambient monitors within 40 km of a near-road site were acquired from EPA's AQS. The network of ambient monitors was designed to monitor regional compliance with federal and state health standards, so ambient monitors are not typically sited in areas known to be near major emission sources. AQS measurements have been quality-controlled by the submitting agency. Data with specific qualifier flags to indicate quality assurance errors or exceptional events were excluded from this analysis. Only near-road and ambient measurement sets with over 75% completeness in at least 3 out of 4 quarters (Jan-Mar, Apr-Jun, Jul-Sep, Oct-Dec) were used in this study. Of the 49 near-road sites with 2017 $PM_{2.5}$ data, one site, Austin-1068, could not be paired with ambient monitoring data meeting completeness thresholds. The remaining 48 sites were used in the study.

Near-road sites with sufficient data completeness are presented in **Table 1**, along with site characteristics and the total number of nearby available ambient monitors. The land use indicators of population density, land surface imperviousness, and urban percentage signify that the near-road sites are from a range of environments, including highly urban, suburban, and semi-rural areas. Near-road monitors are stationed within 50 meters of major roadways, and the monitor's distance to road and target roadway AADT and FE-AADT values are presented later in Tables 2 and 3. Some near-road sites had numerous ambient monitors within a 40 km distance, most sites had multiple ambient monitors within that distance, and four sites had only one ambient monitor present within that distance. Some ambient monitors were within 40 km of multiple near-road sites.

Table 1. Near-road sites (48) measuring $PM_{2.5}$ that met completeness requirements in 2017 with at least one available nearby ambient monitor. Population density, percent of land surface that was impervious, and urban percentage were calculated within a 5 km radius domain of the near-road monitor.

Site Name	State	AQS ID	Population density[3] people/km^2	Impervious[4] %	Urban[Error! Bookmark not defined.] %	Ambient sites within 40 km	Distance to meteorology site – zero for collocated (km)
Atlanta-0056	GA	13-121-0056	2947	47	82	3	0
Berkeley-0013	CA	06-001-0013	3492	33	54	7	18
Birmingham-2059	AL	01-073-2059	1245	44	86	4	0
Boston-0044	MA	25-025-0044	8352	50	67	5	2
Charlotte-0045	NC	37-119-0045	1731	39	81	2	0
Cheektowaga-0023	NY	36-029-0023	2435	43	84	2	6
Cincinnati-0048	OH	39-061-0048	2263	35	65	10	4
Cleveland-0073	OH	39-035-0073	993	29	71	1	16
Columbus-0038	OH	39-049-0038	1661	28	67	3	0
Denver-0027	CO	08-031-0027	4336	53	95	6	0
Denver-0028	CO	08-031-0028	2236	54	93	6	0
Detroit-0093	MI	26-163-0093	2493	46	89	9	0
Fort Lauderdale-0035	FL	12-011-0035	3044	46	89	4	6
Fort Lee-0010	NJ	34-003-0010	14601	39	67	8	8
Fort Worth-1053	TX	48-439-1053	2241	37	77	2	0
Hartford-0025	CT	09-003-0025	3331	43	75	3	0
Houston-1052	TX	48-201-1052	2789	59	96	1	0
Indianapolis-0087	IN	18-097-0087	2221	51	93	5	3
Kansas City-0042	MO	29-095-0042	1378	30	74	4	0
Lakeville-0480	MN	27-037-0480	1226	21	48	6	0
Las Vegas-1501	NV	32-003-1501	3546	69	98	6	0

[3] Data source: Gridded Population of the World, developed by NASA's Socioeconomic Data and Applications Center
[4] Data source: National Land Cover Database developed by USGS

Site Name	State	AQS ID	Population density[3] people/km^2	Impervious[4] %	Urban^Error! Bookmark not defined.^ %	Ambient sites within 40 km	Distance to meteorology site – zero for collocated (km)
Laurel-0006	MD	24-027-0006	1331	23	53	8	0
Livonia-0095	MI	26-163-0095	1536	37	81	9	0
Long Beach-4008	CA	06-037-4008	4404	67	97	7	0
Louisville-0075	KY	21-111-0075	1753	47	81	5	6
Memphis-0100	TN	47-157-0100	1298	26	62	3	2
Milwaukee-0056	WI	55-079-0056	1414	37	75	4	0
Minneapolis-0962	MN	27-053-0962	5166	56	90	8	0
Nashville-0040	TN	47-037-0040	1315	39	74	1	5
New Orleans-0021	LA	22-071-0021	2117	42	83	2	20
Oakland-0012	CA	06-001-0012	5490	57	83	8	9
Ontario-0027	CA	06-071-0027	2089	37	71	5	0
Philadelphia-0075	PA	42-101-0075	2868	33	63	5	11
Portland-0005	OR	41-067-0005	1893	35	71	2	0
Providence-0030	RI	44-007-0030	4933	63	87	6	2
Queens-0125	NY	36-081-0125	15552	65	92	8	0.5
Raleigh-0021	NC	37-183-0021	384	21	44	2	22
Richmond-0025	VA	51-760-0025	2098	34	71	4	14
Rochester-0015	NY	36-055-0015	2695	29	64	1	10
Sacramento-0015	CA	06-067-0015	2804	45	78	4	0
San Antonio-1069	TX	48-029-1069	2024	39	78	2	0
San Jose-0006	CA	06-085-0006	6165	60	96	4	4
Seattle-0030	WA	53-033-0030	4310	44	64	3	0
St. Louis-0094	MO	29-510-0094	3238	53	96	7	0
Tacoma-0024	WA	53-053-0024	2937	53	91	4	0
Tempe-4019	AZ	04-013-4019	2192	50	86	9	0
Washington DC-0051	DC	11-001-0051	4460	41	79	6	0
Wilkinsburg-1376	PA	42-003-1376	2135	37	72	9	8

2.1.2 Meteorological Data

Of the 48 near-road sites, 27 sites had collocated hourly meteorological measurements of wind speed and wind direction available for over 75% of the year. For 14 sites, there was a nearby AQS monitor within 30 km with available hourly meteorological measurements of wind speed and wind direction, with over 75% completeness. The remaining seven sites had nearby meteorological data available from other sources. Hourly wind speed and direction from the MesoWest database was used for Berkeley-0013, Fort Lauderdale-0035, Nashville-0040, New Orleans-0021, Oakland-0012, Richmond-0025 and Rochester-0015. The same meteorology station was used for Berkeley-0013 and Oakland-0012. The distances between near-road sites and nearby meteorology stations are presented in Table 1.

For the 48 sites, the hourly wind direction data were used to characterize when the near-road monitor was upwind or downwind of the road, or when winds were parallel with the road. First, the angle from the near-road monitor to the center of the nearby road was deduced from the coordinates using ArcMap. Then, the wind direction was classified as upwind, downwind, or parallel, using 120 degree bins for each category. The percentage of time for each day in each wind category was calculated by summing the number of hours in each category and dividing by 24. Daily average wind speed and direction were calculated by taking vector averages of the hourly wind speeds and using the resulting magnitude as daily average wind speed. Annual average values were calculated from these variables.

2.1.3 Land Use

In order to examine land use characteristics of the domains around the near-road sites, publicly accessible resources were used. NASA's Socioeconomic Data and Applications Center provides a data product, Gridded Population of the World (GPW) at spatial resolution of 30 arc seconds (approximately 1 km). Population Density version 4.10 for the year 2015 was used, assuming negligible changes between 2015 and 2017. The GPW record of numbers of persons per square kilometer represents residents and is consistent with national census records (Doxsey-Whitfield et al., 2015). The federal Multi-Resolution Land Characteristics (MRLC) consortium provides access to the NLCD developed by the USGS. The gridded data products of imperviousness and land cover from the most recently available NLCD (2011 at the time of this work), at 30-meter resolution, were used. Imperviousness is defined between 0 and 100%, with 100% representing impervious concrete, and 0% representing natural environments such as soil. The land use product contains 96 different categories. These categories were classified into three bins: urban, 50% urban, and non-urban.

Gridded land use datasets were then processed alongside spatial AQS metadata of site location using the ArcGIS program, ArcMap. Domains were created with a radius of 1, 5, and 10 km, centered around the near-road monitors and nearby ambient monitors. Average population density, imperviousness, and urban percentage derived from land cover were calculated for these domains, with missing data (typically representing rivers or other natural features) being classified as a value of zero for all three land use variables. This was carried out for near-road sites and nearby ambient sites. The result is that each site was assigned a value for each of the three land use bins, at each of the three radius zones, for both near-road and ambient sites. Based on these criteria, and on a visual examination identifying the densest urban regions, the commonality of land use between near-road and nearby ambient site was determined.

2.2 Increment Calculation

For sites with hourly data, a daily average $PM_{2.5}$ was calculated, using a 75% completeness threshold for each day. The daily $PM_{2.5}$ ambient measurements within 40 km of each near-road site were used to estimate the background $PM_{2.5}$ concentrations. Background $PM_{2.5}$ was estimated at near-road sites using ambient monitors within a 40 km radius in two ways: an IDW average of multiple monitors, and using the nearest ambient monitor to represent background concentrations. For the IDW method, ambient sites are given a relative weighting factor that is proportional to the inverse length of the distance from the near-road monitor squared, so that sites closer to the near-road monitor play a stronger role in representing the background. This method follows EPA guidance[5] and is consistent with the previous method employed by Seagram et al. (2019). Daily $PM_{2.5}$ increments representing the contribution from traffic were calculated as the difference between the near-road value and the background value from both the IDW and nearest monitor methods. Daily $PM_{2.5}$ increments were then averaged to calculate the annual average $PM_{2.5}$ increment. The ± uncertainty for each annual average increment is calculated as the 95% confidence interval on the mean, defined as 1.96 × standard deviation (increment)/(N-1)^0.5, where N represents the valid number of days of data.

2.3 Data Analysis Methods: Confounding Factors

We evaluated whether confounding factors could impact the calculated increment at each near-road site. We evaluated four confounding factors: the commonality of instrument method at near-road and ambient sites, characteristics of the near-road site environment, commonality of land use between near-road and nearby ambient sites, and the sea breeze effect.

Monitoring instruments that meet specific quality control and operational standards are designated by the EPA as Federal Reference or Equivalent Methods (FRM or FEM) provided they are calibrated and operated according to standardized procedures (U.S. Environmental Protection Agency, 2016). While these instruments have met rigorous standards, there still remain differences in instrumental precision and performance, which can depend on the chemical composition of the PM sampled, the instrument method, and environmental conditions. A national 3-year assessment from 2014-2016 found biases unique to each instrument were less than 10% for FRMs, and up to 22% for some FEM instruments (U.S. Environmental Protection Agency, 2015b). For this project, a case study of the Milwaukee-0056 site was used to illustrate the impact of choosing differing or identical instrument methods at the near-road and ambient sites (see discussion in Section 3.2). Based on EPA's work and the Milwaukee case study, increments were calculated using only identical instrument methods between sites; e.g., if the near-road site had an FRM instrument only data from the same FRM instrument at the nearby sites were used to calculate the increment.

[5] See Section 8 in epa.gov/state-and-local-transportation/project-level-conformity-and-hot-spot-analyses#pmguidance.

The immediate environment of the near-road sites was examined to see if local topography or other environmental characteristics were a confounding factor in measuring near-road $PM_{2.5}$ for any sites. The immediate area of the near-road sites was examined using Google Earth and Google Maps Street View. Google Earth was used to quantify the elevation difference between the near-road monitor and the centroid of the target road. Street View was used to determine the presence or absence of any barriers such as sound walls, trees, or bushes between the monitor and the roadway or near the monitor. Many sites had complex local topography and/or a complex built environment, including nearby interchanges, depressed roadways, or nearby walls that could influence the $PM_{2.5}$ measurements.

The availability of ambient monitors that can provide an accurate representation of the background $PM_{2.5}$ was examined using land use data. $PM_{2.5}$ can vary significantly within a metropolitan domain; for example, variations of annual average $PM_{2.5}$ of about 25-30% were observed in Jefferson County in the years 2000-2009 (Superczynski and Christopher, 2011). Jefferson County includes the Birmingham-2059 near-road site and is roughly equivalent to our 40 km radius zone. The study of Jefferson County found significantly higher $PM_{2.5}$ near the urban center of Birmingham, driven by emissions from manufacturing, industry, and power generation (Superczynski and Christopher, 2011). We used population density, imperviousness, and derived urban intensity to evaluate site pairs of near-road and ambient sites to determine whether ambient monitors were representative of the background $PM_{2.5}$ at the near-road site. We binned near-road and ambient sites into one of four land uses: rural, suburban, urban or dense urban. If no ambient monitor in the same land use bin was within 20 km of the near-road site, we identified land use as a confounding factor. For this study, a case study of the near-road site, Cleveland-0073, was carried out to demonstrate how commonality of land use can impact the increment (see discussion in Section 3.4.2).

Another confounding factor that could skew representation of background $PM_{2.5}$ is the sea breeze effect. The sea breeze effect is the impact of meteorology on the environment of coastal domains and other areas near large bodies of water. Coastal communities often experience a diurnal pattern of winds flowing toward the land during the day and toward the ocean during the night, driven by the pressure gradient resulting from different rates of heating on land and on water. This diurnal wind circulation, and the absence of significant emissions from the water, leads to lower air pollutant concentrations alongside coastal regions. The sea breeze effect can lead to a positive or negative bias in calculating the increment. A case study of the near-road site, Berkeley-0013, was carried out to demonstrate how the sea breeze effect can impact the increment (see discussion in Section 3.4.3).

3. Results

3.1 $PM_{2.5}$ NAAQS Comparison for 48 Near-Road Sites

The distributions of daily average near-road $PM_{2.5}$ from the 48 near-road sites in 2017 are presented in **Figure 1**. The $PM_{2.5}$ NAAQS (annual and 98th percentile daily average) are also shown. Note that Figure 1 compares measured concentrations to the NAAQS for research purposes only; the analysis represents only one year of data and does not represent a calculation to determine attainment status. There are significant differences across the near-road monitoring sites, representing the range of $PM_{2.5}$ seen across the different metropolitan areas and the impact of local sources. Sites with multiple instruments (POCs) are plotted separately; different distributions are due to the differences in instrument method and in the sampling intervals. Two sites, Long Beach-4008 (POC 1 and POC 3), and Ontario-0027, exceeded the annual average $PM_{2.5}$ NAAQS value of 12 μg/m^3. Five sites exceeded the daily 98th percentile $PM_{2.5}$ value of 35 μg/m^3: Long Beach-4008 (POC 1 and POC 3), Ontario-0027, Oakland-0012, San Jose-0006, and Seattle-0030.

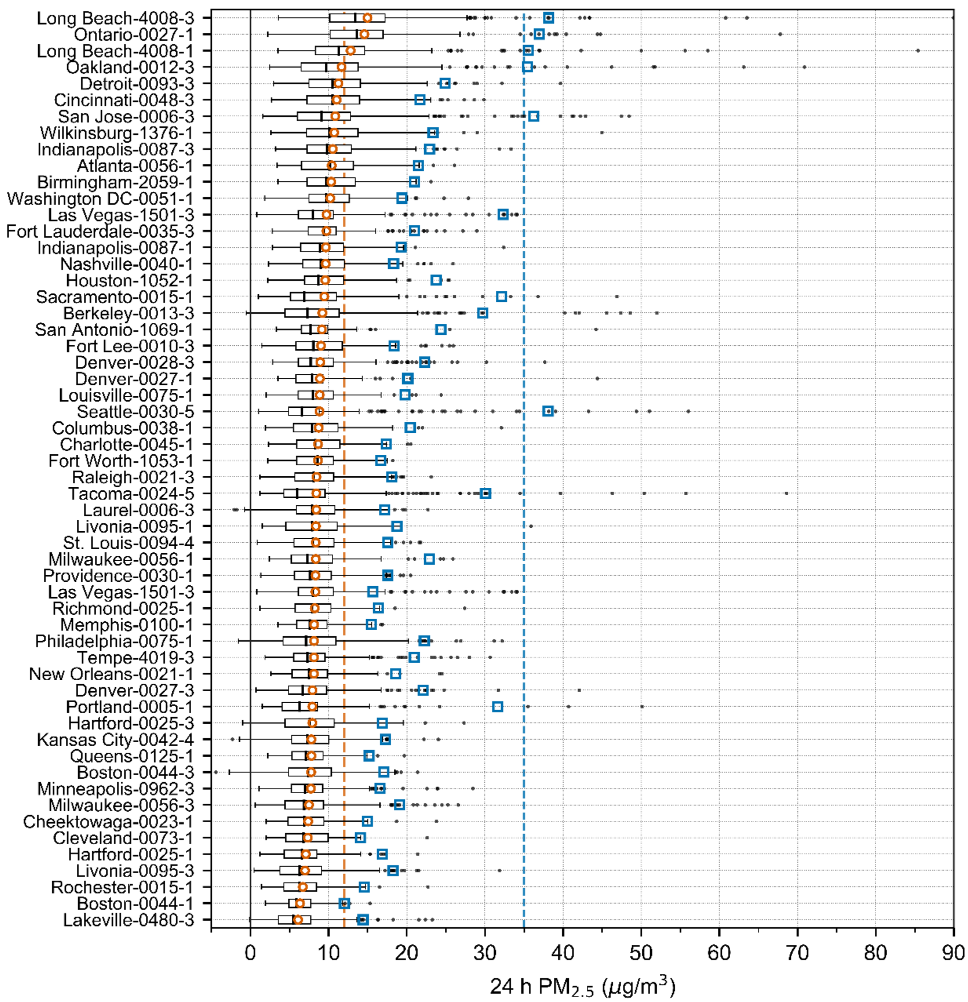

Figure 1. Distribution of daily average $PM_{2.5}$ at 48 near-road monitoring sites in 2017, sorted by annual mean. The annual mean (orange circles) and 98th percentile of 24 hr $PM_{2.5}$ concentrations (blue squares) are shown. The orange dashed lined denotes the annual NAAQS threshold (12 μg/m^3), and the blue dashed line denotes the daily average NAAQS threshold (35 μg/m^3).

3.2 Determining the Impact of Instrument Method

The available instrumentation at Milwaukee-0056 (55-079-0056) and a nearby ambient site (55-079-0058) made these sites useful for a case study to evaluate how different instrument methods could impact estimation of the increment. The sites were separated by a distance of 282 meters, meaning the background air at the two sites was likely quite similar. Both sites had two sets of instrumentation available, the FRM gravimetric R & P Model 2025 PM-2.5 Sequential Air Sampler w/VSCC (AQS method code 145) and the FEM Met One BAM-1020 Mass Monitor w/VSCC (AQS method code 170). This means that for this site pair, four ways of calculating the increment are possible. The distributions of the four sets of measurements and the increments for 2017 are shown in **Figure 2**. Only times when measurements from all four instruments were available were used for this case study. Depending on what instruments are chosen for the analysis, significant differences are seen in the resulting increment. For the case of a near-road BAM (FEM) and a nearby FRM, the resulting average increment was -0.19 µg/m^3, a non-physical result that was due to the differences in measurement technique. The reverse selection choice, a near-road FRM and a nearby BAM results in a positive bias, with an artificially high average increment value of 1.08 µg/m^3. Using identical instrument methods to calculate the increment results in the best representation of the increment, and the resulting distributions are similar (an average increment of 0.39 µg/m^3 when using FRMs at both sites and 0.49 µg/m^3 when using BAMs at both sites).

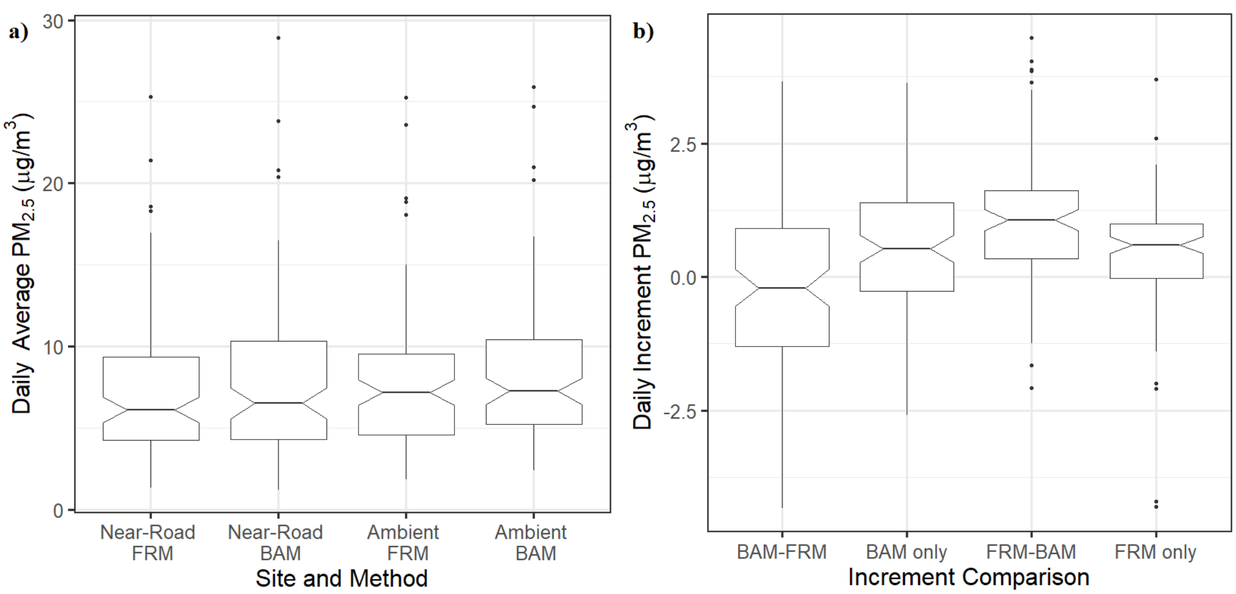

Figure 2. Case study of FRM and BAM (FEM) (a) daily average $PM_{2.5}$ distributions at Milwaukee-0056 and a nearby ambient monitoring site, and (b) four increment distributions derived from near-road and ambient measurements.

This case study demonstrates that instrument method type is a potentially confounding factor in calculating the increment, and that using identical instrument methods removes this confounding factor. The case study findings are consistent with EPA assessments of instrumental bias (U.S. Environmental Protection Agency, 2015b). Therefore, for the remainder of the study, only identical instrument methods were used in calculating the increment. When multiple sets of near-road instruments were available, the FRM instrument was chosen, due to the higher precision of FRM instruments relative to most FEM instruments. Of the 48 near-road sites, 8 sites did not have an ambient site within 40 km that used the same instrument method: Fort Lauderdale-0035, Raleigh-0021, Nashville-0040, Seattle-0030, Tacoma-0024, Detroit-0093, Las Vegas-1501 and Fort Lee-0010. These sites were excluded from the remainder of the analysis.

3.3 $PM_{2.5}$ Increments at Near-Road Sites

The range of annual average $PM_{2.5}$ increment values calculated using the IDW method and the nearest monitor method to represent background concentrations is shown in **Figure 3**. Only the 40 sites with identical instrument comparisons are shown. Among all 40 sites, nine sites had a negative increment, 16 sites had an increment from 0 μg/m^3 to 0.54 μg/m^3, 11 sites had increments from 0.72 μg/m^3 to 1.44 μg/m^3, and four sites had increments from 1.73 μg/m^3 to 2.12 μg/m^3. A negative increment implies that the $PM_{2.5}$ value from the background estimate was higher than the value from the near-road site.

The distribution of IDW and nearest monitor increments are very similar. Denver-0027, Long Beach-4008, Providence-0030, and Cincinnati-0048 are the four sites with the highest increments; their monitors were sited less than 10 meters from their respective roadways (8.7, 9, 5 and 8 meters, respectively). This is consistent with literature indicating a modest $PM_{2.5}$ concentration gradient from the roadway (Karner et al., 2010; Baldauf et al., 2008; Saha et al., 2018b). In contrast, the other 36 sites had a wide range of distances to road, with most monitors sited more than 10 meters from the roadway (with the exception of three sites). Thus, while not all sites in close proximity to the roadway had a high increment, all sites 10 meters or more from the roadway had an increment value less than or equal to 1.44 μg/m^3. In other words, all sites with increments > 1.44 μg/m^3 were within 10 meters from the road. In addition to distance from the road, other variables including traffic volume, fleet mix, and meteorology contributed to the variability of the increments seen in Figure 3.

Thirty-one sites had a positive increment. The 31 sites had increment values that ranged from near zero (0.06 μg/m^3 at St. Louis-0094) to 2.12 μg/m^3 at Cincinnati-0048. The upper bound of increments from the IDW or the nearest monitor method of estimating the background is identical. While some differences exist between the nearest monitor and IDW methods of calculating the increment, they are less than 0.5 μg/m^3 for 87% of sites, and less than 0.2 μg/m^3 for 69% of sites. They were equal to zero for three sites because only one monitor with an identical instrument method was available at those sites. This consistent comparison between the IDW and nearest monitor increments gives us greater confidence that the range of $PM_{2.5}$ caused by traffic at the near-road sites is between 0 and 2.12 μg/m^3. The uncertainty on each annual average increment and the instrument method type, FEM or FRM, is shown in Figure 3. Increments greater than 1.5 μg/m^3 were found from both FEM instrument sites (Cincinnati-0048 and Providence-0030), and FRM instrument sites (Long Beach-4008 and Denver-0027).

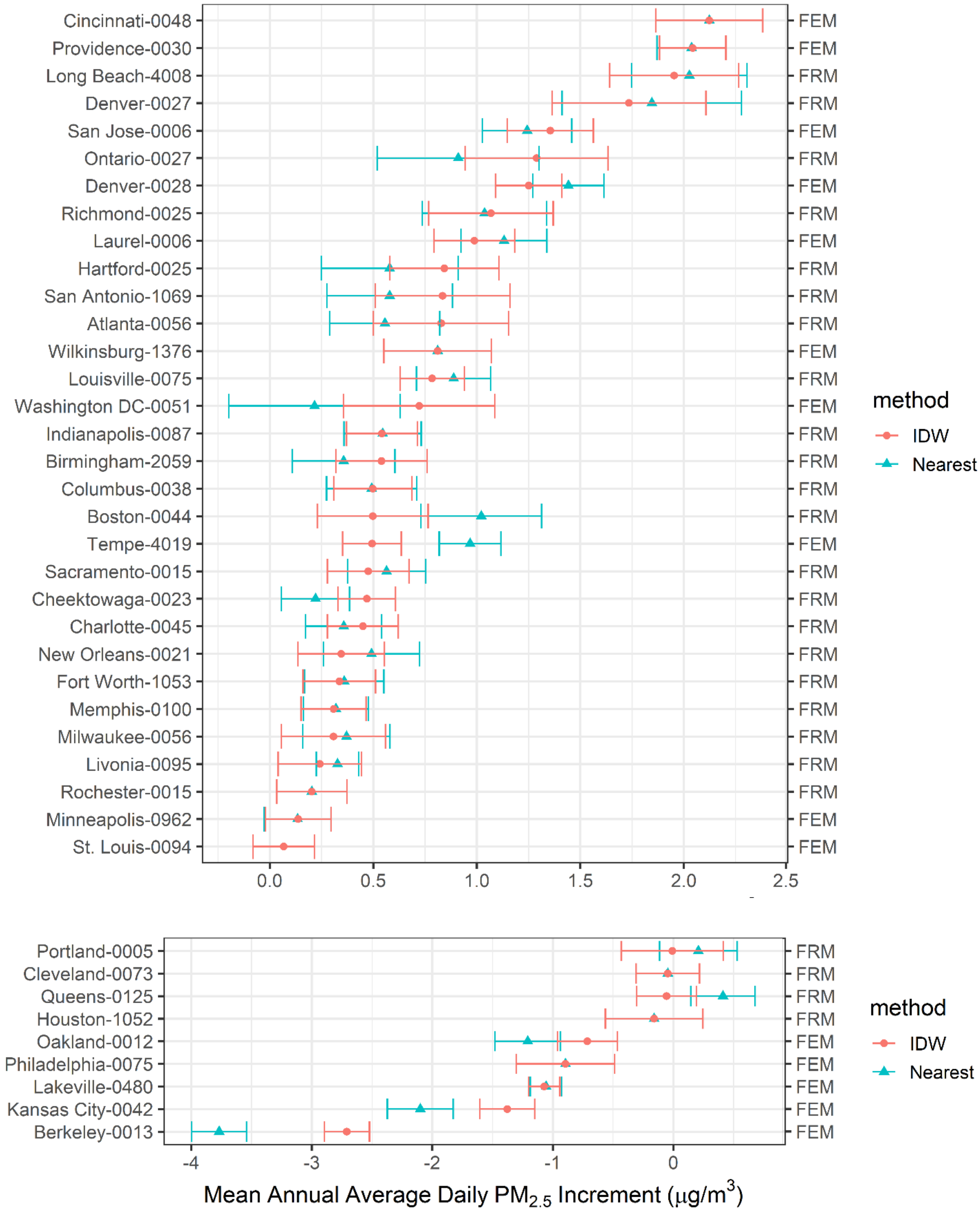

Figure 3. Distributions of annual average $PM_{2.5}$ increments using identical instrument methods from 40 near-road sites, computed using inverse distance squared weighting (IDW) and nearest monitor (Nearest). The 31 near-road sites with positive increments are shown at the top, and the nine near-road sites with negative increments are shown at the bottom. The instrument measurement type (FRM vs FEM) is shown for each site. Uncertainty bars show the 95% confidence interval on the mean.

3.4 Confounding Factors in Addition to Instrument Method

3.4.1 Near-Road Site Environment

Four sites were identified as having near-road site environmental factors that could confound the resulting increments: Livonia-0095, Tacoma-0024, Nashville-0040, and Ontario-0027. The base of the Livonia-0095 monitor was on a hillside 30 feet higher than the target road centroid; the hillside included bushes and other natural obstacles, which could lead to an underestimation of the $PM_{2.5}$ increment. The base of the Tacoma-0024 monitor was on a hillside 12 feet above the target road centroid, with bushes and other natural obstacles present between the monitor and the roadway. A similar situation was seen in the case of Nashville-0040, with a 9-foot height differential between the monitor base and the road. A sound wall near Ontario-0027 ended 10 meters before reaching the monitor, which could cause PM to accumulate near the sound wall and spill over into the monitor sampling region—an effect that could lead to an over-bias of the $PM_{2.5}$ increment.

3.4.2 Land Use

Land use data representing population density, imperviousness, and urban intensity were used to identify cases where data from nearby ambient monitors were inappropriate to represent the background $PM_{2.5}$ at the near-road site. Cleveland-0073 helps to illustrate how varying land use between near-road and ambient monitors confound increment estimation. Cleveland-0073 and the one available ambient site (39-035-0034, 14.4 km to the northwest) are shown with NLCD land use data in **Figure 4**. Cleveland-0073 has a negative increment resulting from this site pair. The ambient site is close to the urban center of Cleveland, and also near the coast of Lake Erie. The near-road site is quite removed (~20 km) from the urban center at the boundary of suburban and rural land use outside the city. In this case, it is likely that the differences in background $PM_{2.5}$ between the ambient site and the near-road site confound the calculation of the near-road increment. The higher $PM_{2.5}$ expected in the city center of Cleveland explains the negative increment observed in this case. This means the ambient site is not representative of the background, and it may not be possible to realistically isolate the traffic impact from this site pair.

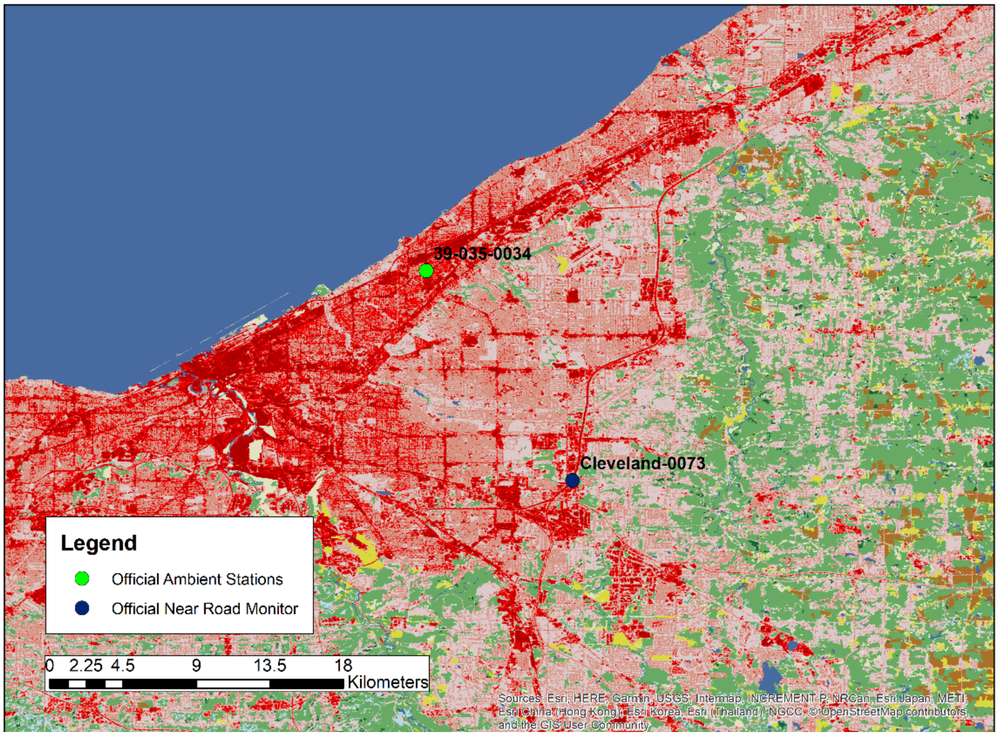

Figure 4. Land use in the domain of Cleveland-0073 and the nearby ambient site (AQS ID 39-035-034). Land use data from the NLCD shows dense urban areas in red, suburban areas in pink, natural areas in green, and agricultural areas in yellow.

In a number of site pairs, the two sites are not in the same land use category, which could lead to an under-bias or over-bias of the increment. Seven of the nine near-road sites with negative increments, including Cleveland-0073, were determined to lack nearby ambient stations adequate to represent background $PM_{2.5}$. Cleveland-0073, Kansas City-0042, Lakeville-0480, Philadelphia-0075, Queens-0125 and Portland-0005 had similar land use differences, in that the nearest ambient monitor was in a significantly more urbanized region of the city, often the city center, whereas the near-road monitor was in a less developed region, and in some cases in a suburban/rural region. The land use was comparable between the near-road site of Houston-1052 and the nearby ambient site; however, the nearby site was in an area more heavily populated by industrial and manufacturing facilities compared to the near-road site, potentially skewing background concentrations.

3.4.3 Sea Breeze Effect

The sea breeze effect and commonality of land use are similar confounding factors in that they both result from inadequate data from nearby ambient sites to represent the background $PM_{2.5}$. **Figure 5** shows the case of Berkeley-0013, where the sea breeze effect was a confounding factor in estimating the $PM_{2.5}$ increment. While both Berkeley-0013 and its nearby ambient monitors were in dense urbanized regions, the Berkeley near-road site was adjacent to San Francisco Bay. Data showing predominant wind speeds from the west and southwest confirmed the sea breeze wind circulation. Given the predominant wind patterns and the monitor's close proximity to the San Francisco Bay, the background $PM_{2.5}$ at the Berkeley near-road site was likely to be much lower than that at the ambient sites. This results in the negative increment observed when using the site pairings shown in Figure 5, or any of the pair-wise increments computed with the seven sites within 40 km of Berkeley-0013. The sea breeze effect leads to a lower $PM_{2.5}$ background near Berkeley-0013, making any site pairs unrealistic for isolating the traffic impact. Oakland-0012 was impacted by a sea breeze effect as well, resulting in a negative increment.

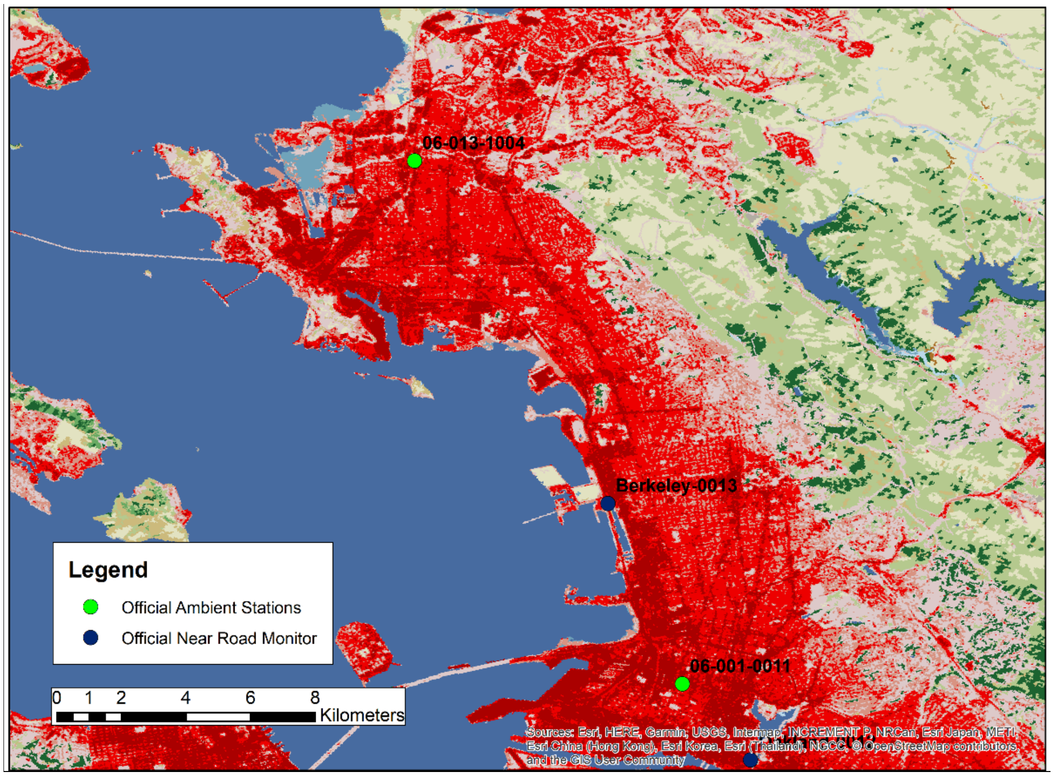

Figure 5. Land use in the domain of Berkeley-0013 and the nearby ambient sites (AQS IDs 06-001-0011 and 06-013-1004). Land use from the NLCD shows dense urban areas in red, suburban areas in pink, natural areas in green, agricultural areas in yellow, and water in blue.

3.4.4. Near-Road Site Characteristics and Confounding Factor Evaluations

Table 2 lists the 20 sites included in the focused case after removing confounding factors. Increments from the IDW and nearest monitor methods are presented only where identical method comparisons were available. The meteorological parameters of average wind speed, and upwind vs. downwind conditions for the near-road sites are shown. The number of trucks was estimated from EPA's FE-AADT values assuming a scaling factor of 10 for HDDVs. **Table 3** shows similar data for the other 28 sites from our 48 site near-road dataset and the evaluation for each of the confounding factor categories.

Table 2. Near-road site characteristics and 2017 increments from IDW and nearest monitor methods, for the focused case of 20 near-road sites where all sites with a noted confounding factor have been removed. Number of trucks was estimated from FE-AADT and AADT values assuming the default scaling factor of 10.

Site Name	AQS ID	Annual Average $PM_{2.5}$ (2017)	IDW $PM_{2.5}$ Increment	Nearest Neighbor $PM_{2.5}$ Increment	Average Wind Speed (m/s)	Percent Downwind	Percent Upwind	Percent Parallel	Distance to Road (meters)	FE-AADT	AADT	Number of Trucks	Method Type	N of background stations (IDW)
Birmingham -2059	01-073-2059	10.33	0.54	0.36	0.2	36	38	27	23	215,527	141,190	8,260	FRM	4
Charlotte-0045	37-119-0045	8.65	0.45	0.36	1.0	13	41	45	30	260,830	153,000	11,981	FRM	2
Cheektowaga-0023	36-029-0023	7.39	0.47	0.22	2.5	47	33	20	20	220,543	131,019	9,947	FRM	2
Columbus-0038	39-049-0038	8.72	0.5	0.49	1.0	37	35	28	32	286,050	142,361	15,965	FRM	3
Denver-0027	08-031-0027	7.93	1.73	1.84	1.0	24	25	52	9	263,118	249,000	1,569	FRM	6
Denver-0028	08-031-0028	8.92	1.25	1.44	1.1	33	25	42	6	210,835	192,000	2,093	FEM	3
Indianapolis -0087	18-097-0087	10.55	0.54	0.55	1.9	28	36	36	25	362,110	189,760	19,150	FRM	5
Laurel-0006	24-027-0006	8.49	0.99	1.13	1.0	25	31	44	16	452,309	186,750	29,507	FEM	4
Long Beach-4008	06-037-4008	14.9	1.95	2.03	1.1	52	23	25	9	619,008	192,000	47,445	FRM	2
Louisville-0075	21-111-0075	8.86	0.78	0.89	1.9	30	32	38	32	247,600	163,000	9,400	FRM	2
Memphis-0100	47-157-0100	8.14	0.31	0.32	2.1	23	44	33	24	292,968	140,850	16,902	FRM	2
Milwaukee-0056	55-079-0056	7.52	0.31	0.37	2.3	47	18	35	14	133,000	133,000	0	FRM	3
Minneapolis -0962	27-053-0962	7.72	0.14	0.13	1.7	30	34	36	33	387,250	277,000	12,250	FEM	6
New Orleans-0021	22-071-0021	8.07	0.35	0.49	3.2	41	33	25	29	129,229	68,015	6,802	FRM	2
Providence-0030	44-007-0030	8.31	2.04	2.04	2.2	44	17	39	5	416,790	186,300	25,610	FEM	5
Rochester-0015	36-055-0015	6.69	0.2	0.2	3.5	40	19	41	20	144,717	110,990	3,747	FRM	1

Site Name	AQS ID	Annual Average $PM_{2.5}$ (2017)	IDW $PM_{2.5}$ Increment	Nearest Neighbor $PM_{2.5}$ Increment	Average Wind Speed (m/s)	Percent Downwind	Percent Upwind	Percent Parallel	Distance to Road (meters)	FE-AADT	AADT	Number of Trucks	Method Type	N of background stations (IDW)
Sacramento-0015	06-067-0015	9.46	0.48	0.56	1.5	29	27	44	20	475,000	186,000	32,111	FRM	3
San Jose-0006	06-085-0006	10.81	1.36	1.24	2.2	33	13	53	32	294,140	191,000	11,460	FEM	4
Tempe-4019	04-013-4019	8.14	0.49	0.97	0.7	45	40	15	12	624,315	320,138	33,797	FEM	7
Washington DC-0051	11-001-0051	10.23	0.72	0.22	1.6	27	47	26	15	172,747	115,480	6,363	FEM	3

Table 3. Near-road site characteristics and 2017 increments from IDW and nearest monitor methods, for the 28 near-road sites with a noted confounding factor. Validity of the confounding factors; identical instrument method, near-road environmental site factors and common land use and no sea breeze are presented for each site. These 28 sites, along with the 20 sites presented in Table 2 make up the full set of 48 sites that could be paired with ambient data.

Site Name	AQS ID	Annual Average $PM_{2.5}$	IDW $PM_{2.5}$ Increment	Nearest Monitor $PM_{2.5}$ Increment	Identical Method	Near-Road Site Factors	Common Land Use and No Sea Breeze	Average Wind Speed (m/s)	Percent Downwind	Percent Upwind	Percent Parallel	Distance to Road (meters)	FE-AADT	AADT	Number of Trucks	Method Type	N of background stations (IDW)
Atlanta-0056	13-121-0056	10.39	0.83	0.56	valid	valid	invalid	0.5	18.65	35.13	46.22	2	406,256	284,920	13,482	FRM	4
Berkeley-0013	06-001-0013	9.24	-2.71	-3.77	valid	valid	invalid	3.0	59.62	22.11	18.27	25	379,246	265,000	12,694	FEM	7
Boston-0044	25-025-0044	8.02	0.5	1.02	valid	valid	invalid	1.4	56.5	23.12	20.37	10	251,761	198,239	5,947	FRM	5
Cincinnati-0048	39-061-0048	11	2.12	2.12	valid	valid	invalid	1.5	17.91	41.85	40.24	8	386,380	163,000	24,820	FEM	1
Cleveland-0073	39-035-0073	7.33	-0.05	-0.05	valid	valid	invalid	2.6	33.8	21.62	44.57	20	287,580	153,660	14,880	FRM	1
Fort Worth-1053	48-439-1053	8.67	0.34	0.36	valid	valid	invalid	2.0	49.23	27.46	23.31	15	242,856	184,680	6,464	FRM	2
Hartford-0025	09-003-0025	7.96	0.84	0.58	valid	valid	invalid	1.5	37.07	41.13	21.8	17.7	231,855	159,900	7,995	FRM	3
Houston-1052	48-201-1052	9.61	-0.16	-0.16	valid	valid	invalid	1.7	46.75	29.36	23.88	15	334,915	202,120	14,755	FRM	1

Site Name	AQS ID	Annual Average $PM_{2.5}$	IDW $PM_{2.5}$ Increment	Nearest Monitor $PM_{2.5}$ Increment	Identical Method	Near-Road Site Factors	Common Land Use and No Sea Breeze	Average Wind Speed (m/s)	Percent Downwind	Percent Upwind	Percent Parallel	Distance to Road (meters)	FE-AADT	AADT	Number of Trucks	Method Type	N of background stations (IDW)
Kansas City-0042	29-095-0042	7.87	-1.38	-2.1	valid	valid	invalid	1.4	42.52	26.9	30.57	20	347,582	114,495	25,899	FEM	3
Lakeville-0480	27-037-0480	6.15	-1.07	-1.06	valid	valid	invalid	2.0	24.77	39.8	35.43	30	193,200	87,000	11,800	FEM	3
Livonia-0095	26-163-0095	8.37	0.24	0.33	valid	invalid	invalid	2.7	24	52	24	49	279,700	172,600	11,900	FRM	9
Oakland-0012	06-001-0012	11.71	-0.71	-1.21	valid	valid	invalid	3.0	53	22	26	20	424,008	216,000	23,112	FEM	8
Ontario-0027	06-071-0027	14.57	1.29	0.91	valid	invalid	invalid	0.8	43	20	37	9	625,736	215,000	45,637	FRM	2
Philadelphia-0075	42-101-0075	8.51	-0.89	-0.89	valid	valid	invalid	0.7	35	39	26	12	257,460	124,610	14,761	FEM	1
Portland-0005	41-067-0005	7.91	-0.01	0.21	valid	valid	invalid	1.1	19	40	41	27	289,052	156,000	14,784	FRM	2
Queens-0125	36-081-0125	7.78	-0.06	0.41	valid	valid	invalid	2.5	46	27	27	28	322,030	166,339	17,299	FRM	8
Richmond-0025	51-760-0025	8.25	1.07	1.04	valid	valid	invalid	2.1	29	29	42	21	259,720	151,000	12,080	FRM	3
San Antonio-1069	48-029-1069	8.9	0.84	0.58	valid	valid	invalid	2.3	12	51	37	20	405,295	201,840	22,606	FRM	2
St. Louis-0094	29-510-0094	8.35	0.07	-0.72	valid	valid	invalid	1.9	42	29	29	25	360,077	159,326	22,306	FEM	3
Wilkinsburg-1376	42-003-1376	10.7	0.81	0.81	valid	valid	invalid	1.7	45	19	37	18	148,248	87,534	6,746	FEM	1
Detroit-0093	26-163-0093	11.3	NA	NA	invalid	valid	valid	1.7	28	24	49	8.5	188,200	140,500	5,300	NA	NA
Fort Lauderdale-0035	12-011-0035	9.81	NA	NA	invalid	valid	invalid	3.9	63	18	19	30	622,161	306,000	35,129	NA	NA
Fort Lee-0010	34-003-0010	9.03	NA	NA	invalid	valid	invalid	1.3	1	52	47	20	612,212	311,234	33,442	NA	NA
Las Vegas-1501	32-003-1501	9.11	NA	NA	invalid	valid	valid	1.4	30	38	32	15	353,825	260,000	10,425	NA	NA
Nashville-0040	47-037-0040	9.62	NA	NA	invalid	invalid	invalid	2.3	44	31	26	30	338,879	144,204	21,631	NA	NA
Raleigh-0021	37-183-0021	8.56	NA	NA	invalid	valid	invalid	1.2	41	31	28	20	203,280	141,000	6,920	NA	NA

Site Name	AQS ID	Annual Average $PM_{2.5}$	IDW $PM_{2.5}$ Increment	Nearest Monitor $PM_{2.5}$ Increment	Identical Method	Near-Road Site Factors	Common Land Use and No Sea Breeze	Average Wind Speed (m/s)	Percent Downwind	Percent Upwind	Percent Parallel	Distance to Road (meters)	FE-AADT	AADT	Number of Trucks	Method Type	N of background stations (IDW)
Seattle-0030	53-033-0030	8.88	NA	NA	invalid	valid	valid	1.3	33	34	33	8	471,630	237,000	26,070	NA	NA
Tacoma-0024	53-053-0024	8.47	NA	NA	invalid	invalid	valid	1.8	27	16	57	30	413,920	208,000	22,880	NA	NA

3.5 $PM_{2.5}$ Increments at 20 Sites – Focused Case

Next we examine a focused case of increments from 20 near-road sites. For this focused case, all sites with one or more of the previously discussed confounding factors have been removed. Increments from 20 sites are presented in **Figure 6**, a subset of the results presented in Figure 3. This focused case of 20 sites has a similar range and distribution of annual average $PM_{2.5}$ increment values as the initial case of 31 sites presented earlier; however once confounding factors are addressed, there are no sites with negative increments. The upper bound of $PM_{2.5}$ increments, 2.04 µg/m^3, is similar to the upper bound (2.12 µg/m^3) presented in Section 3.3 where we examined all 40 sites with identical instrumentation. Only three sites have an increment greater than 1.44 µg/m^3, and all of these have monitors sited less than 10 meters from the roadway.

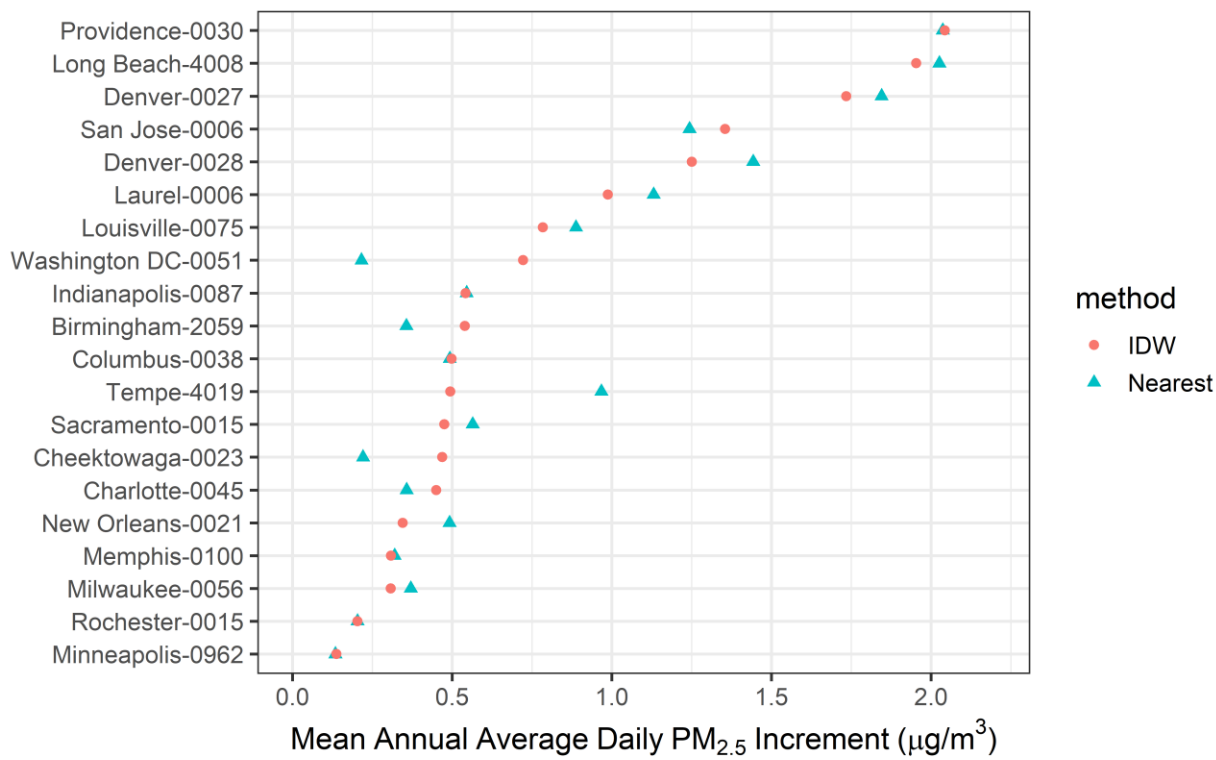

Figure 6. Distributions of annual average $PM_{2.5}$ increments computed using IDW and nearest monitor calculation (Nearest). A focused case of 20 sites is shown, controlling for confounding factors.

3.6 Comparison to Meteorology, Traffic, and Site Characteristic Variables

The initial case of 31 increments and the focused case of 20 increments, all using identical instrument comparisons, were used to assess the relationship of near-road increments to variables representing meteorology, traffic, and site characteristics. The initial case of 31 sites was included due to its higher sample size. The coefficient of determination (R^2 value) is presented for four cases: the sets of 31 sites and 20 sites, both with IDW and nearest monitor calculations of the increment (**Table 4**). Increments were compared with annual average wind speed; percent of time the near-road site was downwind, parallel, or upwind of the adjacent roadway; distance to road; FE-AADT; AADT; and estimated number of HDDVs. A positive correlation with the increment was seen for FE-AADT, AADT and the percent of time the near-road site was parallel or downwind of the road. A negative correlation was seen between the increment and percent of time upwind of the road, distance to road, and wind speed. For the focused case of 20 sites, and the IDW method, the largest correlation was for distance to road ($R^2 = 0.34$), followed by percent upwind ($R^2 = 0.25$) and FE-AADT ($R^2 = 0.12$). Weaker correlations were observed for number of HDDVs, percent of time parallel to the road, AADT and average wind speed. Almost no correlation was seen for percent of time downwind of the road. Correlations were similar between the set of 20 sites and the set of 31 sites, with some higher correlations seen in the 20 site case. FE-AADT and number of HDDVs show a higher correlation to the increment than AADT, likely indicating the importance of HDDVs in contributing to $PM_{2.5}$ emissions for these roadways. Increments calculated through the IDW method and the nearest monitor method showed very similar statistical relationships to the meteorology and traffic variables. These pairwise correlations are limited because they only consider one comparison at a time independently.

Table 4. Coefficient of determination (R^2 value) for IDW and nearest monitor increments. The comparisons are shown with the initial case of 31 sites with identical instrument methods and the focused case of 20 sites limiting confounding factors. Variables are rank-ordered by IDW Method, 20 site comparison R^2 values.

Variable	IDW Method (31 Sites)	Nearest Monitor (31 Sites)	IDW Method (20 Sites)	Nearest Monitor (20 Sites)
Distance to Road	0.30	0.26	**0.34**	0.37
Percent Upwind	0.08	0.10	**0.25**	0.28
FE-AADT	0.13	0.11	**0.12**	0.22
Number of HDDVs	0.13	0.09	**0.10**	0.16
Percent Parallel	0.14	0.09	**0.09**	0.08
AADT	0.03	0.06	**0.07**	0.17
Average Wind Speed	0.08	0.07	**0.06**	0.07
Percent Downwind	0.01	0.00	**0.03**	0.04

Regressions for the IDW-calculated increment and three other variables, distance to road, percent of time the monitor was upwind, and FE-AADT, are shown in **Figure 7**, for both the 31-site and the 20-site cases. A linear regression ($y = a \cdot x + b$) was used for FE-AADT and an inverse relationship ($y = a/x + b$) was used for distance to road and percent of time the monitor was upwind. The coefficients and p values of these regressions are shown in **Table 5**. The p values show that these modeled relationships are statistically significant. The modeled increment falls from approximately 2 $\mu g/m^3$ at 5 meters from the roadway to approximately 0.5 $\mu g/m^3$ at 30 meters from the roadway for the 20 site case (99.9% confidence that the relationship exists). The increment falls from 1.5 $\mu g/m^3$ when the receptor is upwind of the road 15% of the time, to 0.75 $\mu g/m^3$ when the receptor is upwind of the road 30% of the time for the 20 site case (97%

confidence). The linear regression for FE-AADT predicts a relationship of 0.14 $\mu g/m^3$ higher $PM_{2.5}$ values for every 100,000 increase in FE-AADT.

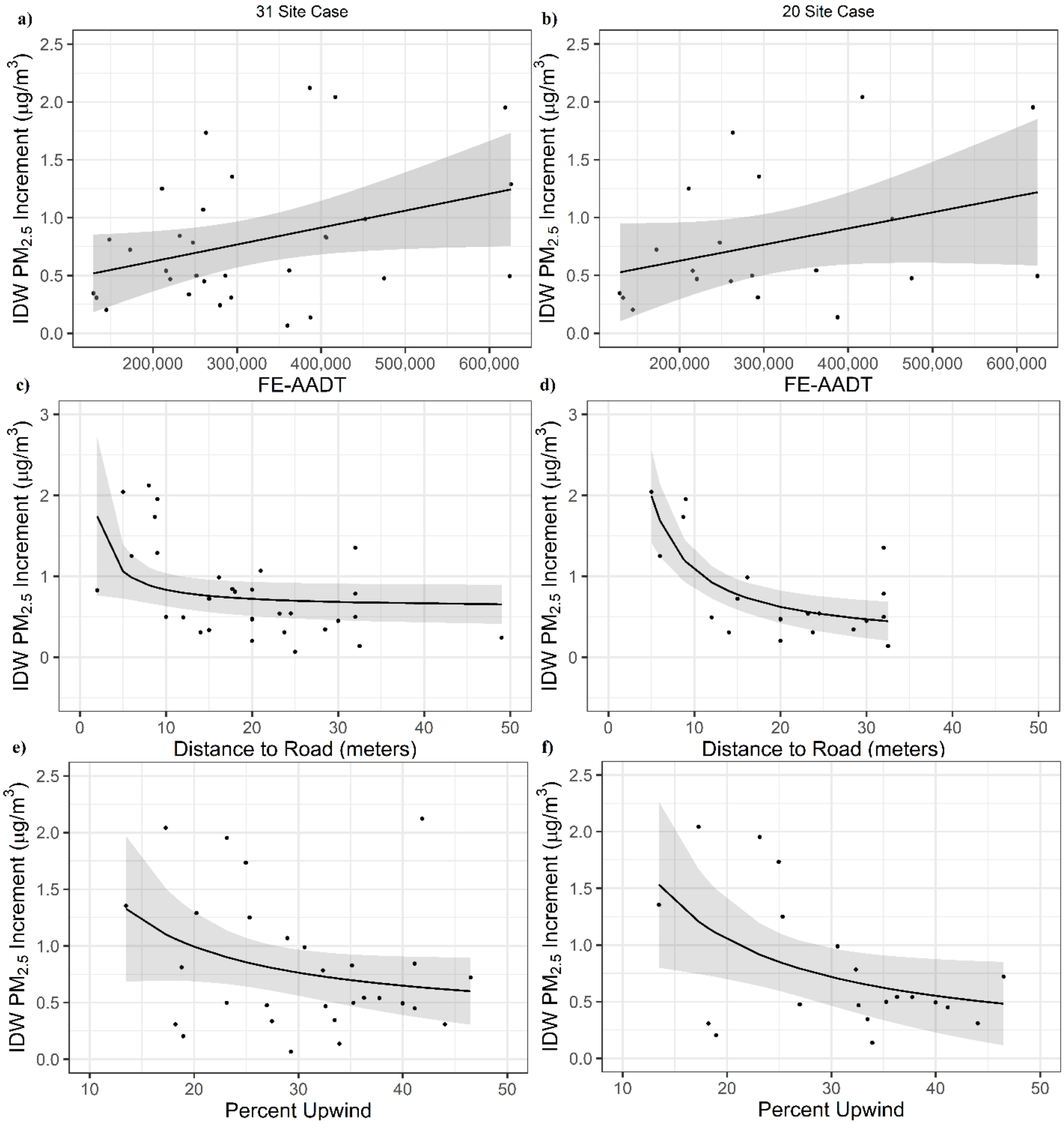

Figure 7. The relationship between the IDW $PM_{2.5}$ increment in comparison to FE-AADT (a and b), distance to road (c and d), and percent of time upwind (e and f). The initial case of 31 near-road sites is shown at left (a, c and e), and the focused case of 20 sites limiting confounding factors is shown at right (b, d and f). Regressions are shown in black, with the range of the standard error of the regression line shown in dark grey.

Table 5. The intercepts, slopes, p values and R^2 values for the regressions presented for six cases in Figure 7. For FE-AADT, a linear regression is used, of the form y = a • x + b. For distance to road and percent upwind, an inverse relationship is used, of the form y = a /x + b.

Regression Model	Distance to Road vs IDW Increment (20 Sites)	Distance to Road vs IDW Increment (31 Sites)	Percent Upwind vs IDW Increment (20 Sites)	Percent Upwind vs IDW Increment (31 Sites)	FE-AADT vs IDW Increment (20 Sites)	FE-AADT vs IDW Increment (31 Sites)
a	9.15	2.27	19.93	13.80	$1.40 \cdot 10^{-6}$	$1.46 \cdot 10^{-6}$
b	0.17	0.61	0.05	0.30	0.35	0.33
p value	0.000185[a]	0.0517[a]	0.034[a]	0.082	0.127	0.0483[a]
R^2	0.34	0.30	0.25	0.08	0.12	0.13

[a] Statistically significant relationship at 95% or higher confidence.

In order to represent multiple explanatory variables at once, a GAM was used to predict the near-road IDW increment using distance to road, percent of time a site was upwind, and FE-AADT (the top three factors from Table 4). The model was run to optimize the restricted maximum likelihood estimation (REML), and each of the three predictor variables was given three degrees of freedom. The model was constructed for both the 31-site case and focused 20-site case. As before, the most important explanatory variables were distance to road, then percent upwind, and FE-AADT. For the 31 site case, the model had an adjusted R^2 value of 0.36, a modest improvement from the original R^2 value of 0.3 between the IDW increment and distance to road (shown in Table 5). For the focused case of 20 sites, distance to road had a p value equal to 0.00032, percent upwind had a p value equal to 0.15 and FE-AADT had a p value equal to 0.22. The model had an overall adjusted R^2 value of 0.63, predicting the majority of the variability in the IDW increment. Overall, the regression models shown in Figure 7, the correlations shown in Table 5, and the GAM model show a statistically significant correlation between distance to road, percent upwind, and the increment, and a modest correlation between FE-AADT and the increment.

4. Implications for POAQC Screening

Under transportation conformity, interagency consultation partners weigh proposed transportation projects on a case-by-case basis and assess whether a project is a POAQC requiring quantitative $PM_{2.5}$ hot-spot assessment. $PM_{2.5}$ conditions are dynamic in metropolitan areas—the vehicle fleet becomes cleaner each year as older, higher-polluting vehicles are replaced by vehicles meeting more stringent emissions standards, and regional air quality conditions are generally improving over time. EPA, for example, documents a 41% decrease in $PM_{2.5}$ concentrations nationally from 2000 to 2017.[6] Section 93.123(b)(1)(i) requires $PM_{2.5}$ hot-spot analyses to be completed for, "New highway projects that have a significant number of diesel vehicles, and expanded projects that have a significant increase in the number of diesel vehicles." In the context of changing fleet emissions and regional air quality, interagency consultation partners must dynamically assess factors that lead to a POAQC determination,

[6] https://www.epa.gov/air-trends/particulate-matter-pm25-trends

including what constitutes a significant increase in diesel vehicles. This discussion illustrates how quantitative data from this study can be used to inform POAQC determinations.

The upper bound of the 2017 $PM_{2.5}$ increment was 2.04 ± 0.16 μg/m^3 for the focused case of 20 near-road sites, where all sites noted with possible confounding factors have been removed. The upper bound of the increment for near-road sites with monitors sited 10 meters or more from the roadway was 1.44 ± 0.17 μg/m^3. The implications for designating proposed roadway projects as POAQC are shown next, followed by the forecasts of the upper bound of traffic-related $PM_{2.5}$ for the coming decades using projected changes in emissions.

4.1 The Current Influence of Traffic Emissions on Annual Average $PM_{2.5}$

The near-road sites represent a wide range of highway environments, with significant variability in traffic volume, fleet mix, meteorology, and other environmental conditions shown in Table 1 and Table 2. For the set of 20 near-road sites presented in Table 2, the monitor distance to the road ranged from 5 to 33 meters from the roadway. In Table 2, average wind speed ranges from 0.24 m/s to 3.11 m/s and the percent of hours upwind ranged from 13.5% to 46.5%. AADT ranged from ~68,000 to ~320,000; FE-AADT ranged from ~129,000 to ~624,000. The estimated number of HDDVs ranged from 0 to 47,445. Long Beach-4008, the site with the highest estimated number of HDDVs, had an increment of 1.95 ± 0.31, which is near the upper bound of 2.04 ± 0.16. About half of the sites (11 out of 20) had more than 10,000 HDDVs. The roadway geometry within 1 km of these sites showed wide variety, with numerous sites stationed at curved roadways and within 500 meters of a major interchange. The immediate environment of the near-road sites was also diverse, including dividers, complex lane structures, and other structures of the built environment present at many sites.

Annual average $PM_{2.5}$ increments are very similar whether calculated using the nearest monitor or IDW method, and have the same upper bound. Increments show a very similar upper bound when examining FEM or FRM based increments. Increment values for each site have a low statistical uncertainty, with increments higher than 1 μg/m^3 having an uncertainty less than 25% (Figure 3). Considering all of these reasons, the increments represent traffic-related $PM_{2.5}$ over a wide range of highway project conditions. These findings provide the following insights which should prove useful during interagency consultation over POAQC determinations. These insights are applicable to transportation project situations covered by the data set evaluated here (see Table 2).

- Proposed highway projects for sites where the current (e.g., 2017) ambient air quality (i.e., background concentration) has an annual average $PM_{2.5}$ level of at least 2.04 ± 0.16 μg/m^3 below the NAAQS value (currently set at 12 μg/m^3) should not expect to see air quality impacts that result in an average annual $PM_{2.5}$ concentration above the NAAQS.

- Proposed highway projects where the only receptors of concern are beyond 10 meters of the roadway and where the current annual average $PM_{2.5}$ level is at least 1.44 ± 0.17 μg/m^3 below the NAAQS value should not expect to see air quality impacts that result in an average annual $PM_{2.5}$ above the NAAQS.

Given the statistical relationships demonstrated in Tables 4 and 5, it is clear that distance to road, the percent of time the near-road site is upwind of the road, and FE-AADT are key factors influencing the increment. Figure 7 presents these relationships. The interagency consultation process can weigh how specific project conditions relate to the variables shown in Figure 7 and can consider these relationships in the context of POAQC determination. For example, based on the 20 site case, the $PM_{2.5}$ increment is estimated to fall ~50% between 10 meters and 30 meters from the roadway (Figure 7d).

4.2 Projecting the Impact of Emission Changes Over Time

The results from the near-road monitoring sites showing the range of traffic-related $PM_{2.5}$ impacts can be synthesized with our understanding of the projected change of vehicle emissions in the coming decades. First, we examine the relative contribution of exhaust and non-exhaust emissions to traffic-related $PM_{2.5}$. Second, we forecast how the exhaust emissions of $PM_{2.5}$ will change over time with fleet turnover. Third, we use these findings to forecast how the increments identified in Section 3 will change in the coming decades.

4.2.1 The Contribution of Exhaust Emissions to Traffic-Related $PM_{2.5}$

Traffic-related $PM_{2.5}$ emissions come from three sources: exhaust, re-suspended road dust, and brake and tire wear. **Table 6** shows results from three analyses about the relative contributions of $PM_{2.5}$ emissions from these sources. In a companion research effort to this one, also supported by the Near-Road Air Quality Transportation Pooled Fund, Craig et al., used the MOVES model to estimate site-specific emissions for two cases (Craig et al., 2019). For the case of Providence-0030, a target roadway with 186,300 AADT and 13.7% HDDV, the exhaust was found to contribute to 49% of traffic $PM_{2.5}$ emissions in 2015 and 2016. For the case of Indianapolis-0087, a target roadway with 189,760 AADT and 10.1% HDDV, the exhaust was found to contribute to 40% of traffic $PM_{2.5}$ emissions in 2016. A study by Jeong et al. (2019) examined the traffic emissions of a roadway in Toronto in 2016 with 400,000 AADT, using the chemical composition of $PM_{2.5}$ and source apportionment. They found that exhaust contributed to 65% of traffic-related $PM_{2.5}$ emissions, with a strong dependence on HDDV fraction (approximately 6-13% of the fleet mix). For comparison, a review article examining studies from roadways around the world found that exhaust emissions contributed to the majority of overall traffic $PM_{2.5}$ emissions in most of the published studies reviewed (Pant and Harrison, 2013).

Table 6. Ratios of $PM_{2.5}$ traffic emissions by process from modeled studies of Providence-0030 and Indianapolis-0087, and a measurement campaign in Toronto.

Process	Craig et al. (2019) Modeled $PM_{2.5}$ Emissions (%): Providence	Craig et al. (2019) Modeled $PM_{2.5}$ Emissions (%): Indianapolis	Jeong et al. (2019) Measured $PM_{2.5}$ Emissions (%): Toronto
Running Exhaust	49	40	65
Road Dust	44	53	13
Brake and Tire Wear	7	7	22
Total	100	100	100

4.2.2 Projections of Exhaust Emissions from 2017 to 2040

The projected exhaust emissions for U.S. vehicles for the calendar years 2017 to 2040 are shown in **Table 7**. Emissions in grams per mile per average vehicle are shown for HDDVs, light-duty vehicles (LDVs), and an average vehicle in a vehicle fleet composed of 8% HDDVs and 92% LDVs. The 8% HDDV case is a weighted average using 8% HDDV emission rate and 92% LDV emission rate. National average emission estimates are presented using the MOVES 2014 model developed by the EPA, and for San Francisco using the EMFAC 2017 model, developed by the California Air Resources Board (CARB). The percent change of the emissions reductions relative to the year 2017 are shown in **Table 8**, using data from Table 7. A decrease of exhaust emissions is shown in all cases for both vehicle types, due to fleet turnover. For example, the exhaust emissions of a roadway with 8% HDDV in San Francisco are projected to decrease by 88% by 2040 using EMFAC, assuming constant AADT and a constant HDDV fraction of 8%. The specific change in exhaust emissions for a given roadway will depend on changes in the regional vehicle fleet and traffic activity over time.

Table 7. Projected exhaust-only $PM_{2.5}$ emissions of vehicles for the calendar years 2017-2040. Emissions are shown in grams per mile per average vehicle, for HDDV, LDV, and a fleet mix with 8% HDDV and 92% LDV. Emissions are shown for a national average using MOVES, and for San Francisco (SF) using EMFAC.

Year	MOVES HDDV	MOVES LDV	MOVE HDDV 8%	EMFAC SF HDDV	EMFAC SF LDV	EMFAC SF HDDV 8%
2017	0.22042	0.00807	0.02506	0.12152	0.00216	0.01171
2018	0.19095	0.00749	0.02216	0.09684	0.00218	0.00976
2019	0.16631	0.00698	0.01973	0.07686	0.00220	0.00818
2020	0.14486	0.00656	0.01762	0.05888	0.00217	0.00670
2025	0.07571	0.00497	0.01063	0.00902	0.00172	0.00231
2030	0.04051	0.00397	0.00690	0.00857	0.00130	0.00188
2035	0.02778	0.00341	0.00536	0.00830	0.00100	0.00158
2040	0.02579	0.00315	0.00497	0.00814	0.00084	0.00143

Table 8. Projected change of exhaust-only $PM_{2.5}$ emissions of vehicles for the 2018-2040 calendar years, relative to the baseline year of 2017. The percent of 2017 emissions from Table 6 is shown for heavy-duty vehicles (HDDV), light-duty vehicles (LDV), and a fleet mix with 8% HDDV and 92% LDV. Emissions are shown for a national average modeled using MOVES, and for San Francisco (SF) using EMFAC.

Year	MOVES HDDV	MOVES LDV	MOVE HDDV 8%	EMFAC SF HDDV	EMFAC SF LDV	EMFAC SF HDDV 8%
2017	100	100	100	100	100	100
2018	87	93	88	80	101	83
2019	75	87	79	63	102	70
2020	66	81	70	48	100	57
2025	34	62	42	7	80	20
2030	18	49	28	7	60	16
2035	13	42	21	7	46	14
2040	12	39	20	7	39	12

4.2.3 *Projected Traffic Contribution to $PM_{2.5}$*

The upper bound of traffic-related $PM_{2.5}$ represented by the increment for near-road sites in 2017 can be combined with the projected change in exhaust emissions (Table 8), and an assumed fraction of traffic-related $PM_{2.5}$ due to exhaust, to forecast the upper bound of traffic-related $PM_{2.5}$ in the coming decades. In 2017, the upper bound of the observed annual average $PM_{2.5}$ traffic impact was 2.04 ± 0.16 μg/m^3, with an upper bound of 1.44 ± 0.17 μg/m^3, for sites with monitors 10 meters or more from the roadway. Using an example conservative case, based on the modeled Indianapolis-0087 study, we can take the fraction of 40% to illustrate a lower end estimate of the contribution of exhaust emissions to total traffic-related emissions. The change in the $PM_{2.5}$ traffic impact for a given project can then be calculated using the equation:

$$PM_{2.5} \text{ increment (future year) } \mu g/m^3 = 1.224 + 0.816 \bullet [\text{Percent change from 2017 to future year}]$$

Where 1.224 $\mu g/m^3$ is the 60% of traffic-driven $PM_{2.5}$ that is attributed to non-exhaust factors and 0.816 $\mu g/m^3$ is the 40% of traffic-driven $PM_{2.5}$ that is attributed to exhaust, which is forecast to decrease. Likewise, for distances 10 meters or more from the roadway, we have the equation:

$$PM_{2.5} \text{ increment, 10 meters or greater from roadway (future year) } \mu g/m^3 = 0.864 + 0.576 \cdot [\text{Percent change from 2017 to future year}]$$

The projected change of the $PM_{2.5}$ increment is illustrated in the following examples. These examples are based on the formulas above, use the MOVES national average emissions estimate, and assume a project with constant vehicle speeds and HDDV fraction of 8% for all years. The exhaust emissions are projected to be 42% of 2017 emissions by 2025 and 20% of 2017 emissions by 2040. Using the equations above, the $PM_{2.5}$ impact of a highway would fall from 2.04 ± 0.16 $\mu g/m^3$ in 2017 to 1.57 ± 0.16 $\mu g/m^3$ by 2025, and to 1.39 ± 0.16 $\mu g/m^3$ by 2040, if AADT, fleet mix, and vehicle speeds remain constant. Following the same method, for the domain greater than or equal to 10 meters from the roadway, the $PM_{2.5}$ impact of a highway would fall from 1.44 ± 0.17 $\mu g/m^3$ in 2017 to 1.11 ± 0.17 $\mu g/m^3$ by 2025 and 0.98 ± 0.17 $\mu g/m^3$ by 2040. Using the EMFAC modeled emissions of San Francisco, a roadway with constant AADT, and 8% HDDV fleet mix could expect to have its $PM_{2.5}$ impact fall from 2.04 ± 0.16 $\mu g/m^3$ in 2017 to 1.32 ± 0.16 $\mu g/m^3$ by 2040. This procedure only accounts for changing exhaust emissions caused by fleet turnover, and does not account for the full range of factors in forecasting incremental $PM_{2.5}$ impacts that may be considered during interagency consultation.

As discussed earlier, POAQC determinations are considered during interagency consultation on a case-by-case basis for proposed projects. Under the transportation conformity requirements, Section 93.123(b)(1)(i), consultation partners evaluate whether projects involve a significant number or increase in diesel vehicles. The analysis procedures presented here can dynamically link proposed projects to anticipated incremental air quality impacts over time, thus helping to define on a case-by-case basis whether projects involve significant changes in diesel vehicles and merit being identified a POAQC. The assessment process can reflect site-specific characteristics such as projected changes of fleet-average exhaust emissions, HDDV fraction, AADT, the distance between the roadway edge and sensitive receptor locations, and the persistence of prevailing wind direction.

4.3 Application of Findings

The 2006 final rule states that if a project has a significant number of diesel vehicles, it is determined to be a POAQC; the preamble to the rule gives the example of a highway with an AADT greater than 125,000 and a diesel truck traffic of 8% or more. Our study presents results based on 2017 data, and a procedure to represent fleet turnover in the coming decades. The results presented here can inform interagency consultation on whether proposed highway projects have a significant number of diesel vehicles and are POAQC for conformity purposes. Suggested analysis steps include:

1. Compare proposed project characteristics to roadway characteristics evaluated in this study. If the proposed project's characteristics are covered by the data used in this study (see Section 4.1), proceed to the remaining steps.

2. Establish the current project site's background $PM_{2.5}$ concentration, and determine whether a "buffer" exists. For example, if the annual average $PM_{2.5}$ background concentration is 9 $\mu g/m^3$, and the NAAQS is 12 $\mu g/m^3$, the buffer is:
   12 $\mu g/m^3$ - 9 $\mu g/m^3$ = 3 $\mu g/m^3$.

3. If estimates are available of how background $PM_{2.5}$ is forecast to change for the conformity analysis years, calculate the adjusted buffer for those years.

4. Determine what receptors are of interest for the project and their distance to the roadway.

5. Identify the current maximum increment applicable to the project based on closest receptor: the current maximum increment is 2.04 ± 0.16 $\mu g/m^3$ within 10 meters of the roadway, 1.44 ± 0.17 $\mu g/m^3$ beyond 10 meters.

6. Forecast how the increment will change for the conformity analysis years, considering the projected fleet mix in future years (see Section 4.2).

7. If the increment is less than the buffer for the analysis years, and if no other unique project characteristics are expected to increase the $PM_{2.5}$ increment, it can be reasonably determined that the number of diesel vehicles is not significant and the project is not a POAQC.

8. If the increment is greater than the buffer, examine the forecasted project characteristics for FE-AADT, percent upwind, and receptor distance from roadway. Based on the statistically significant relationships shown in Figure 7, assess whether the maximum expected increment should be adjusted downward. Determine if any other known project characteristics warrant additional increment adjustments. Redo previous analysis step.

5. Conclusion

Measurements from 48 near-road highway monitoring sites were used to examine the annual average $PM_{2.5}$ impact of traffic in 2017. These sites have diverse meteorological, roadway, and traffic conditions. The impact of roadway emissions was represented by the $PM_{2.5}$ increment, which is the difference between near-road and background estimates of $PM_{2.5}$. The background estimates were calculated using an IDW method and a nearest monitor method. Based on published EPA findings of instrument performance, we investigated the influence of differences in instrument method on the increment calculation, using the Milwaukee-0056 near-road site as a case study. Consistent with EPA's findings, we found the potential for variation in outcomes across instrument methods. Because of this confounding factor, only identical instrument methods were used to calculate the increment. Three other confounding factors were assessed: characteristics of the near-road monitoring environment, the commonality of land use between the near-road site and the ambient site, and the sea breeze effect. These factors were assessed for the 48 sites on a case-by-case basis.

A set of 31 site cases with identical instrument methods and negative increment sites removed resulted in increments ranging from near zero to 2.12 ± 0.26 µg/m^3. A focused set of 20 sites was chosen, where all sites with noted confounding factor(s) were removed; this set had a similar range of increment values ranging from near zero to 2.04 ± 0.16 µg/m^3. The increments for sites located 10 meters or more from the roadway were between zero and 1.44 ± 0.17 µg/m^3. For increments based on the 20 site case, relationships between the increment and meteorological, traffic, and site variables were assessed. The observed relationships match common sense expectations and were statistically significant for some variables, most importantly for distance to road, percent of time a near-road monitor was upwind of the road, and FE-AADT. Increments calculated from the IDW method and the nearest monitor method had an identical upper bound (2.04 ± 0.16 µg/m^3) and similar correlations with meteorological, traffic and site variables. Regressions showed a statistically significant relationship between $PM_{2.5}$ and distance from the roadway, with $PM_{2.5}$ decreasing 50% between 10 and 30 meters from the roadway. The data evaluated represent a diversity of environments and conditions, for roadways up to approximately 624,000 FE-AADT.

The increment results were combined with estimates of the exhaust fraction contribution to $PM_{2.5}$, and the projected change of exhaust emissions between 2017 and 2040. Holding traffic volume, travel speeds, and fleet mix constant, traffic-related $PM_{2.5}$ is projected to decrease in the coming decades because of reduced g/mi exhaust emissions from newer vehicles and fleet turnover. Using MOVES national average emissions, and a conservative example assumption that only 40% of the 2017 increment was due to exhaust, the upper bound of traffic-related $PM_{2.5}$ is projected to fall from 2.04 ± 0.16 µg/m^3 in 2017 to 1.39 ± 0.16 µg/m^3 in 2040, assuming constant traffic conditions. The forecasting methodology can be used by project analysts seeking to understand the future-year $PM_{2.5}$ impact of a possible roadway project, using site-specific factors.

This work builds on and refines work presented previously. Previous studies estimated $PM_{2.5}$ increments greater than 2.04 µg/m^3 at a few near-road monitors in each of 2015 and 2016 (DeWinter et al., 2018; Seagram et al., 2019). At each site in which increments were previously reported as being greater than 2.04 ug/m^3, confounding factors were present that are now addressed in the work presented here. These confounding factors include, for example, different monitoring instruments at the background and near-road sites, and characteristics of the environment surrounding the near-road monitoring site. In addition, as shown in (Seagram et al., 2019)(Figure 5), there is emerging evidence that near-road $PM_{2.5}$ concentrations are generally trending downward, a finding consistent with expectations related to downward-trending fleet-averaged g/mi $PM_{2.5}$ exhaust emission rates. For these reasons, 2017 data are used here to identify 2.04 µg/m^3 as the upper bound of traffic related $PM_{2.5}$ increments, in comparison to findings from previous analyses and earlier calendar years.

A key factor for transportation conformity is to weigh whether background concentrations plus an expected project increment will be below the NAAQS. This study examined annual average comparisons of the $PM_{2.5}$ increment and traffic variables, and our analysis presents the upper bound of traffic-related annual average near-road $PM_{2.5}$ increments, derived from 2017 concentration data and a diverse set of near-road sites. The results can inform interagency consultation regarding potential project impacts and help interagency consultation participants determine whether a project meets the definition of a POAQC under the transportation conformity requirements. Future work is needed to assess the relative contribution of exhaust and non-exhaust $PM_{2.5}$ emissions, and to refine understanding of non-exhaust emission changes over time and changing travel activity.

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