

**Chester Hazardous Air Pollutant Monitoring and Assessment Project
(HAP-MAP)
*Pilot Project report***

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0. Motivation and Background of Study

Fenceline communities frequently bear the brunt of environmental pollution. This is especially the case for communities in the shadow of fossil and petrochemical infrastructure. In many cases, these communities are also burdened with additional stressors (e.g. psychosocial), rendering them more vulnerable to the health consequences of pollutant exposures.

Existing regulatory programs to monitor air pollution exposure severely compromise the ability to assess health risks faced by fenceline communities. Recent national rules require 2-week samples to assess benzene concentration to be taken at the fenceline monitoring of refinery complexes. While this monitoring program provides limited insights into potential exposure for benzene, it lacks the spatial and temporal resolution needed to properly characterize exposures, it ignores other pollutants present in the mixture, and does little to relate pollutant exposures to their sources of origin; these other aspects are needed to quantify risks faced by fenceline communities.

To address the needs created by the shortcomings of regulatory monitoring programs, we brought together a team of experts in air pollution measurement, exposure and risk and designed a pilot study that leverages multiple measurement platforms to improve the characterization of neighborhood scale exposure and risk to a suite of hazardous air pollutants in fenceline communities near petrochemical infrastructure. Combining burgeoning low-cost sensor technology with state-of-the-art analytical instrumentation deployed on mobile and fixed site measurements, we characterized spatial concentration gradients in a highly industrialized urban corridor in the Northeastern US. Using the updated paradigm developed by the National Research Council of the NASEM, we used site measurement data to estimate pollutant exposure and quantify excess cancer risks and non-cancer hazards for the communities of interest. We integrate these data with measures of competing burdens faced by the community to provide additional context into neighborhood vulnerability beyond environmental pollution. Taken together, we aim to begin to bring the true consequences of petrochemical refining on community burden into focus.

1. Hazardous Air Pollutant Monitoring and Assessment Project (HAP-MAP) Overview

This study was designed to combine the strengths of different measurement platforms to better characterize the acute and chronic multipollutant neighborhood level risk to fenceline communities. Figure 1 shows how these measurement platforms provide information on the chemical complexity, spatial, and temporal resolution.

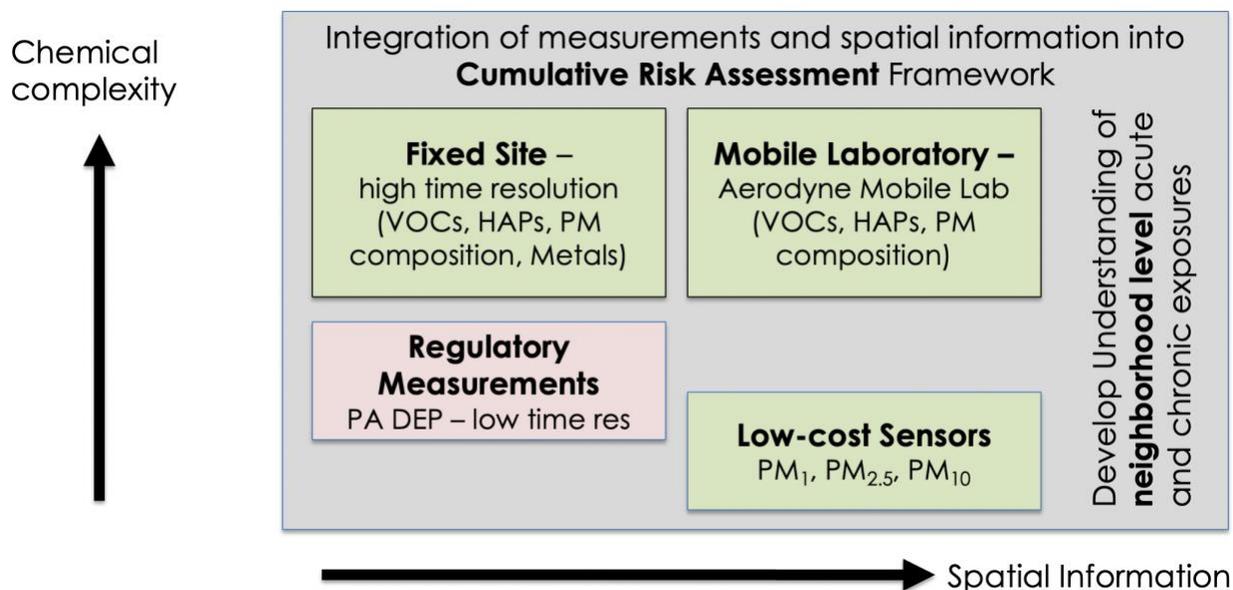


Figure 1. Schematic of the measurement framework utilized to enable the assessment of cumulative risk for fenceline communities. Chemical detail and complexity increases vertically and spatial information from measurements increases to the right. Color of box indicates temporal resolution with green providing measurement data at seconds to minute resolution and red for hour to 24-hour resolution.

While ubiquitous, **Regulatory measurements** do not provide sufficient spatial, temporal, or chemical measurements and are not designed to assess neighborhood level exposures, which is the focus of our work. They do provide long-term accurate standardized measurements for a relatively small number of chemicals, but protocols for detailed chemical measurements are infrequent; for example hazardous air pollutants and particle composition measurements are typically performed 1 in six days with a 24-hour collected sample. To improve our understanding of neighborhood level exposure we have completed three additional types of measurements for this project: Fixed site, Mobile laboratory, and Low-cost sensor monitoring, adding important resolution for our risk assessments. **Fixed site** monitoring with state-of-the-art instrumentation for measurements of hazardous air pollutants, and particulate chemical composition provides additional chemical detail beyond the regulatory measurements and does so continuously at high time resolution. The **Mobile laboratory** uses instrumentation similar to that at the fixed site to provide a high degree of temporal chemical detail and adds spatial information on pollutant concentrations and gradients for comparison between neighborhoods and measurements near known sources. Due to the mobile nature of the measurements, however, it cannot provide continuous datasets in each neighborhood of interest. **Low-cost sensor** technology is rapidly evolving and can be deployed in multiple locations across a study area and provide high time resolution, continuous data but with fewer pollutants available measured as low-cost options. Combining the strengths of each of the measurement platforms provides high time resolution data from multiple pollutants which can be integrated into a cumulative risk assessment framework for cancer and non-cancer health outcomes, and for acute and chronic exposures.

1.1. Hazardous Air Pollutant Monitoring and Assessment Project (HAP-MAP) Study area

The Chester HAP-MAP was initially planned to take place in St. James Parish, Louisiana. However, due to high prevalence of COVID preceding the planned sampling period, the target measurement area was changed to the industrial area between Philadelphia, PA and Wilmington,

DE. Central to this area are the cities of Chester, Trainer, and Marcus Hook Pennsylvania. The measurement area is home to a refinery, petrochemical industrial complex, smaller industry, the largest trash incinerator in the United States, a paper mill, and is bisected by Interstate-95. Across the Delaware River in New Jersey are additional petrochemical facilities, and a hazardous wastewater treatment facility. Figure 2 is a zoom of this interactive google map ([link](#)).

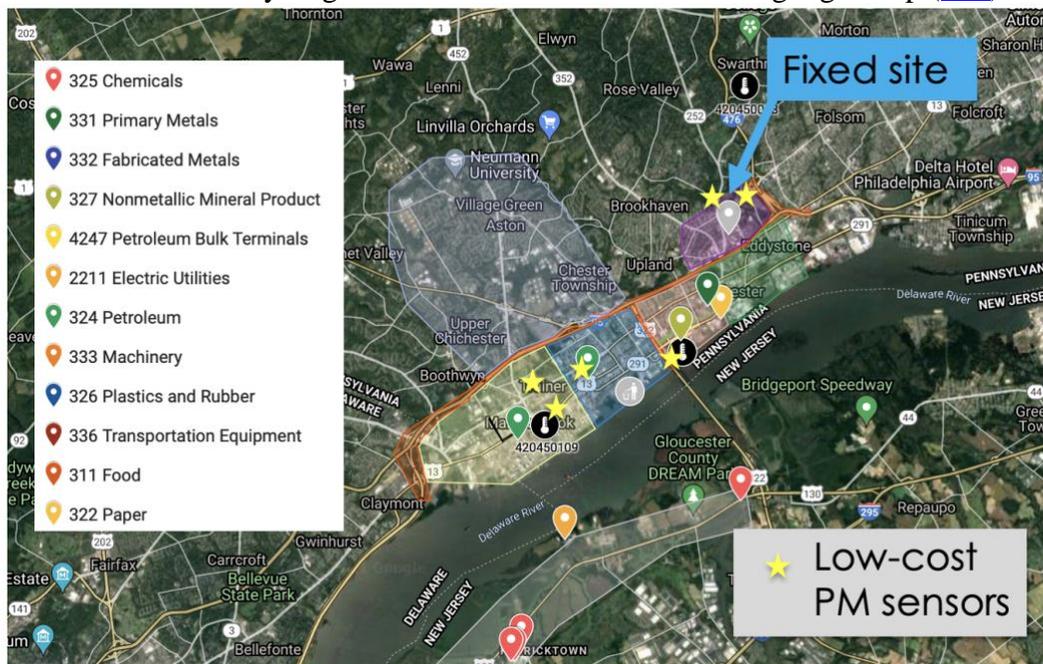


Figure 2. Study Area with facilities highlighted, location of the fixed site, and low-cost PM sensors deployed. Risk Screening Environmental Indicator (RSEI) classification given for each colored pin.

The locations of the regulatory measurement sites operated by the Pennsylvania Department of Environmental Protection (PA-DEP) are black circles with a thermometer icon. The fixed site (blue arrow) and low-cost sensor locations (yellow stars) are also displayed in Figure 2.

1.2. Vulnerability of the HAP-MAP Study Area

Key points:

1. The CDC Social Vulnerability Index for the study population is classified as “high”, indicating community difficulty in responding to external stressors (like environmental pollution).
2. The study population lives in a geographic region with more polluted sites and industrial facilities registered with the EPA that utilize “extremely hazardous” substances in their operations than the majority of the US population.
3. Environmental justice indices for air toxics in the area are based on NATA emissions inventories, which may be underestimated based on the measurement data.

The HAP-MAP study area is comprised of communities that face greater vulnerability to environmental exposures due to socioeconomic disadvantage, systemic racism, and co-exposures to multiple forms of pollution. To justify selection of our communities of focus, and to put estimated exposures and risks in context, we used tools developed by the Centers for Disease Control and Prevention (CDC) and the Environmental Protection Agency (EPA) to assess

vulnerability. These tools take advantage of census datasets of factors recognized to play a role in susceptibility to environmental pollution.

The CDC's Social Vulnerability Index (SVI) aims to characterize the ability of communities to respond to external stressors (e.g., extreme weather events, disease outbreaks, or anthropogenic pollution) in a way that minimizes harm to human health and the economy (CDC 2020a). It consists of 15 census-tract level indicators pertaining to four themes: socio-economic status, minority and foreign language status, household composition, and housing/transportation (CDC 2020a). The SVI for each census tract is assigned a value between 0 and 1, where 0 indicates the highest resilience and 1 represents the highest vulnerability (CDC 2020a). As shown in Figure 3, most communities included in the study are considered to have high or moderate-to-high vulnerability.

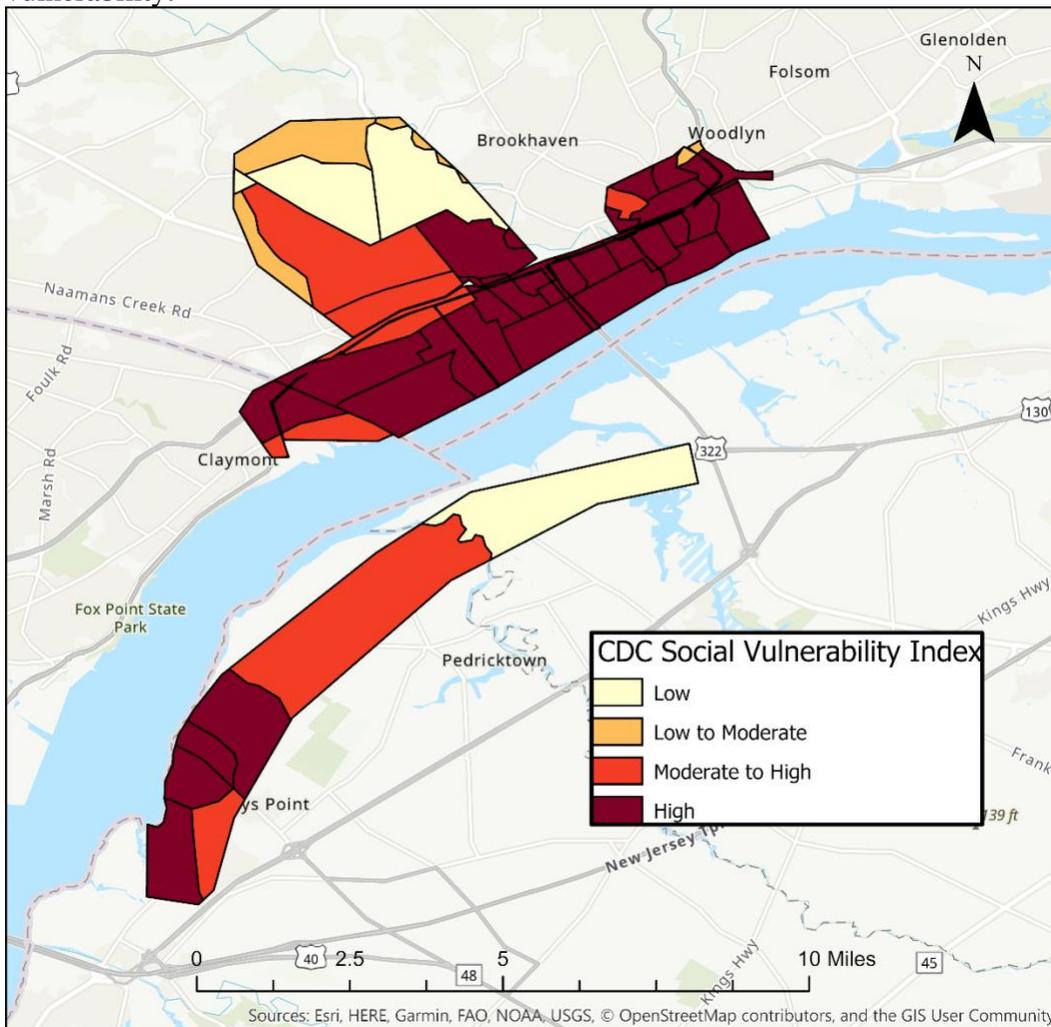


Figure 3. Center for Disease Control Social Vulnerability Index for the HAP-MAP Study Area (CDC 2020b). SVI categories are 0 – <0.25: low; 0.25-<0.50: low to moderate; 0.50 - <0.75: moderate to high; 0.75 - 1: high.

The EPA's Environmental Justice Screening and Mapping Tool (EJSCREEN) incorporates information on environmental stressors (e.g., traffic emissions, ozone) and demographic vulnerability (low-income and minority populations) to create a set of 11 environmental justice

(EJ) indices (EPA 2019). EJ indices are assigned at the census block group level and consider vulnerability compared to the general US population (EPA 2019). Figure 4 shows that several portions of the study area have EJ indices above the 95th percentile (i.e., higher values than at least 95% of census block groups in the U.S.) for traffic emissions, water discharges, proximity to industrial sites, and likelihood of lead paint risks.

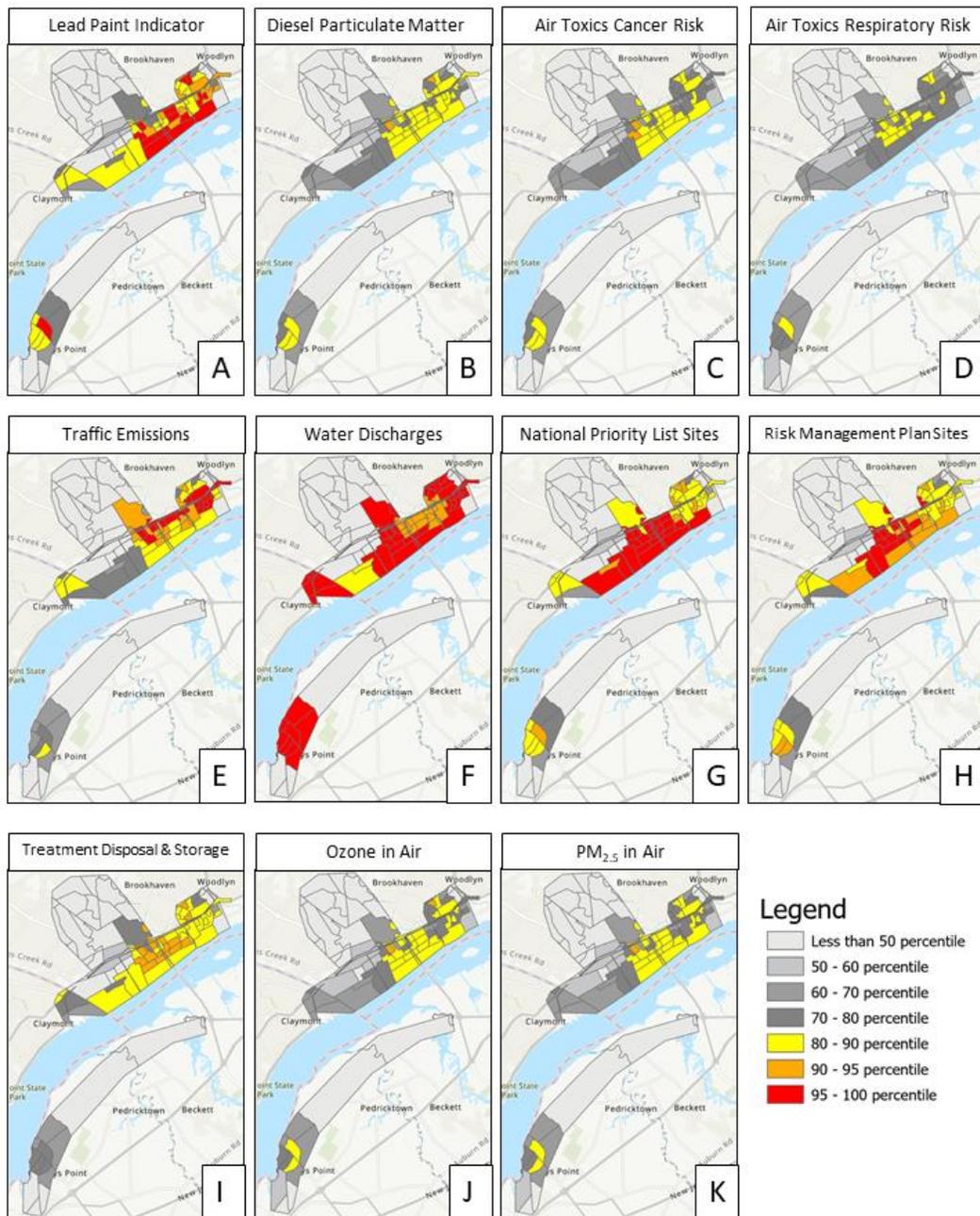


Figure 4. Environmental Justice Indices from EPA's EJScreen tool (EPA 2021). Panel G provides information on sites determined by EPA to be of national priority among locations in the U.S. with known or threatened releases of hazardous substances, pollutants, or contaminants. Panel H provides information on facilities that use extremely hazardous substances and are required by law to submit risk management plans to EPA.

High vulnerability can worsen the health consequences of a given chemical exposure through various means. People living in the HAP-MAP study area are exposed to elevated levels of numerous chemicals, which may add together or have synergistic (i.e., greater than additive) effects that increase the risk or severity of health problems. Chemical exposures may also be more harmful to residents with pre-existing health conditions. For example, people with diabetes (which impairs kidney function) who are exposed to cadmium are more likely to suffer from chronic kidney disease than those who do not have diabetes (Ginsberg et al. 2014). Similarly, many other physiological factors, such as poor nutritional status, and psychosocial factors like stress and racism can interact with chemical exposures to worsen health. For example, one study found that the effects of lead on blood pressure were stronger in people who were experiencing high levels of stress (Zota et al. 2013). These factors can affect both preparedness to respond to external stressors such as chemicals, and impair the ability to recover from them, thereby leading to health disparities (NEJAC 2004). It should be noted that the air toxics risks (see panels C and D of Figure 4) based on National Air Toxics Assessment (NATA) data show lower values for the study area than would be expected based on proximity to petrochemical industrial sites and our initial results. This finding warrants further investigation and suggests that current approaches to reporting and modeling air emissions may underestimate real-world risks.

2. Overview of HAP-MAP Measurements and measurement results

HAP-MAP measurement structure was designed to leverage a combination of measurement technologies and platforms to comprehensively characterize air pollutants throughout the study area with high time resolution for input into a cumulative risk assessment framework. To accomplish this, state-of-the-art analytical instrumentation was deployed at both a fixed site located at Widener University, and on a mobile laboratory operated by Aerodyne Research Inc. These measurements were complementary and provided key time-resolved concentration data of many hazardous air pollutants including benzene, toluene, ethylbenzene, and xylene (BTEX), formaldehyde, ethylene oxide, aerosol composition, and, at the fixed site, metals in the particulate matter. Intensive measurements for the fixed and mobile laboratory took place for 3 weeks between the 8th and 29th of September 2021. Mobile measurements focused on repeated driving patterns in the area between Widener University and the far western side of the Marcus Hook industrial complex. By repeating mobile measurements in the same pattern, we collected sufficient data to look at average concentrations spatially across the study area. While factors such as wind and weather can influence the concentration of a specific pollutant at any given instant in time, making many repeated measurements allows us to better assess the average pollutant concentrations that lead to chronic exposures for a given location. Ultimately, the goal is to determine the spatial variation in both acute and chronic exposures for a variety of pollutants and how those exposures differ for communities across the study area.

In parallel to the fixed and mobile platforms, 8 low-cost sensors for particulate matter (PM₁, PM_{2.5}, and PM₁₀) were deployed throughout the study region, with some measurements starting in August of 2021, and measurements will be ongoing for at least a year. Two sensors were co-located with Pennsylvania Department of Environmental Protection (PA DEP) monitoring sites. Two were located at Widener University; one was placed on the roof of the building the fixed site, and one at the location of the mobile lab parking area. Local community members hosted the final 2 low-cost sensors in the Marcus Hook and Trainer areas (Figure 2).

3. Measurement Results:

Analysis of the complete data set is ongoing. Here, we present air concentrations of formaldehyde and benzene. We chose to initially focus on these compounds as they are two higher risk hazardous air pollutants observed in the study area. The analysis presented for these pollutants is exemplary of the types of analyses we will extend to other hazardous air pollutants.

3.1. Fixed Site and Mobile Laboratory measurements

Key points:

1. Higher concentrations of benzene and formaldehyde were consistently observed near industrial facilities in the study area.
2. Consistent observations of high formaldehyde concentrations indicate the presence of an emission source that is not identified in the Toxic Release Inventory (TRI) for the area.
3. Airborne concentrations of both benzene and formaldehyde were higher than the concentrations estimated for the most recent (2014) National Air Toxics Assessment.

Measurements at the fixed site can be generally considered to be the polluted urban background (i.e. not tied to a particular local source) for the study area. Concentrations measured by the mobile lab that exceed the urban background are indicative of emissions from local sources.

3.1.1. Comparison of fixed and mobile measurements of formaldehyde

Figure 5 shows this general behavior with 5-minute averaged formaldehyde concentrations measured at the fixed site in black. In green, the mobile laboratory measurements of formaldehyde at 1-second time resolution is shown. Typically, the green and black traces have similar trends except for the high spikes in concentration observed by the mobile laboratory when it is driving and near local emission sources of formaldehyde. Notably the California EPA 8-hour Recommended Exposure Limit (REL) level of $9 \mu\text{g}/\text{m}^3$, approximately 7 ppb, is exceeded frequently in the mobile laboratory dataset. (Admin, 2015a) Due to the mobile nature of the measurements we did not stay in one place for 8 hours and therefore cannot conclude that the concentrations observed remained elevated over an 8-hour period of time.

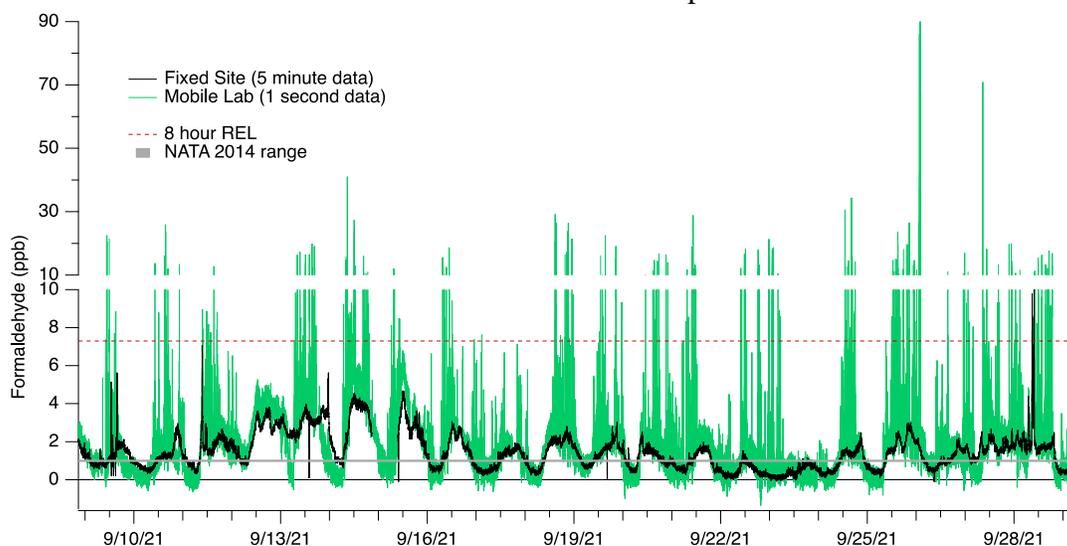


Figure 5. Formaldehyde measurements at fixed site and on mobile lab provide key information about increased fenceline exposures.

As mentioned in section 2.2, the National Air Toxics Assessment (NATA) uses self-reported emissions from industrial sources combined with modeling to calculate concentrations of air toxics to estimate community risk and is used in the EPA EJSCREEN tool. Formaldehyde is a key air toxic that goes into the assessment of risk. Therefore, we use the measurements of formaldehyde concentration from the fixed site to compare to the modelled values from the NATA for the study area. We compared our measured values with the latest (2014) NATA values at the fixed site and found that our mean measurement was about 40% higher than the mean value for the same area in the NATA (Figure 6). While these values are not directly comparable since they are from different years, and measurements only cover 1 month, they suggest that modeled concentrations and sources in this area should be examined in future assessments, and that regulatory exposure and risk estimates may not capture critical information needed to accurately characterize health burdens in fence-line communities.

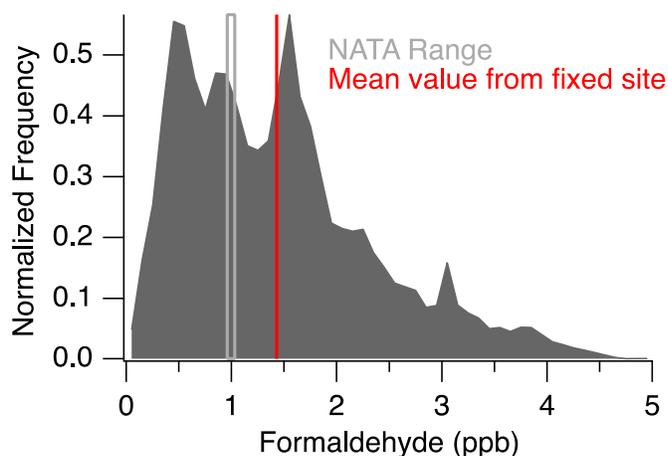


Figure 6. Distribution of formaldehyde measurements at the fixed site with the NATA range and mean value from fixed site shown for comparison.

3.1.2. Spatial measurements of benzene and formaldehyde across the study area

Measurements of formaldehyde from the mobile laboratory provide the opportunity to assess how concentrations of pollutants vary spatially within the larger study area.

To accomplish this, we divide the area into 50 m x 50 m grid cells and average all concentration data measured in each grid cell. This grid scale is large enough to be able to pool sufficient measurements together but small enough to observe any local variations that may exist due to emissions from industrial point sources or high-volume roadways, for example. Based on previously published work on pollutant mapping (Apte et al., 2017), 10 unique visits are required to resolve robust spatial averages. Thus, we report average concentrations only for grid cells that meet this minimum threshold of 10 unique visits (each visit is defined as being in the grid cell during a unique day-hour during September 2021 sampling) or more. Each grid cell is the average of all unique visit average values.

Below we show average pollutant maps for both benzene (Figure 7) and formaldehyde (Figure 8) in all locations where we have sufficient data, as described above. For benzene, the median grid cell concentration within the domain is 0.38 ppb, and the 25th and 75th percentiles are 0.32 ppb and 0.45 ppb, respectively. The median measured value during the HAP-MAP campaign is two times higher than the 2014 NATA modelled values for benzene in the study domain. The range of modelled 2014 NATA values (0.14-0.52 ppb) are lower in concentration compared to the range from the HAP-MAP study (0.16-2.99 ppb). However, despite the general similarity for benzene concentrations across the measurement area shown in Figure 7, there are a handful of locations within the domain where average benzene concentrations are considerably higher than the median value. Average benzene concentrations were highest on Church St. in the residential section of Marcus Hook, nearest to the Delaware River, with the highest grid cell average value of 2.99 ppb, roughly 8 times the median value. Another benzene hotspot shown on our map is a

roughly 0.5 km stretch of 10th Ave just west of the Marcus Hook neighborhood, where average benzene concentrations are greater than 1 ppb. In analyzing individual driving passes of the mobile lab along this stretch of 10th Ave, we find consistently elevated concentrations in the area which we describe as a ‘standing plume’. This standing plume exhibited high concentrations of a suite of hazardous air pollutants including benzene, but toluene, styrene, ethylbenzene, and xylene. 10th Ave cuts through the middle of the Sunoco operation west of Marcus Hook, and so is at the fence line in all directions. We detected this plume the majority of times we passed this stretch of road and found benzene concentrations elevated as high as 10 ppb in many instances. This work is ongoing, and a more complete analysis of plumes at the fence line of this and other industrial point sources in Chester. These plumes are critical to addressing issues such as cumulative risk and are likely important both in terms of long-term exposures, as we show here with these average concentrations, as well as shorter-term, acute exposures.

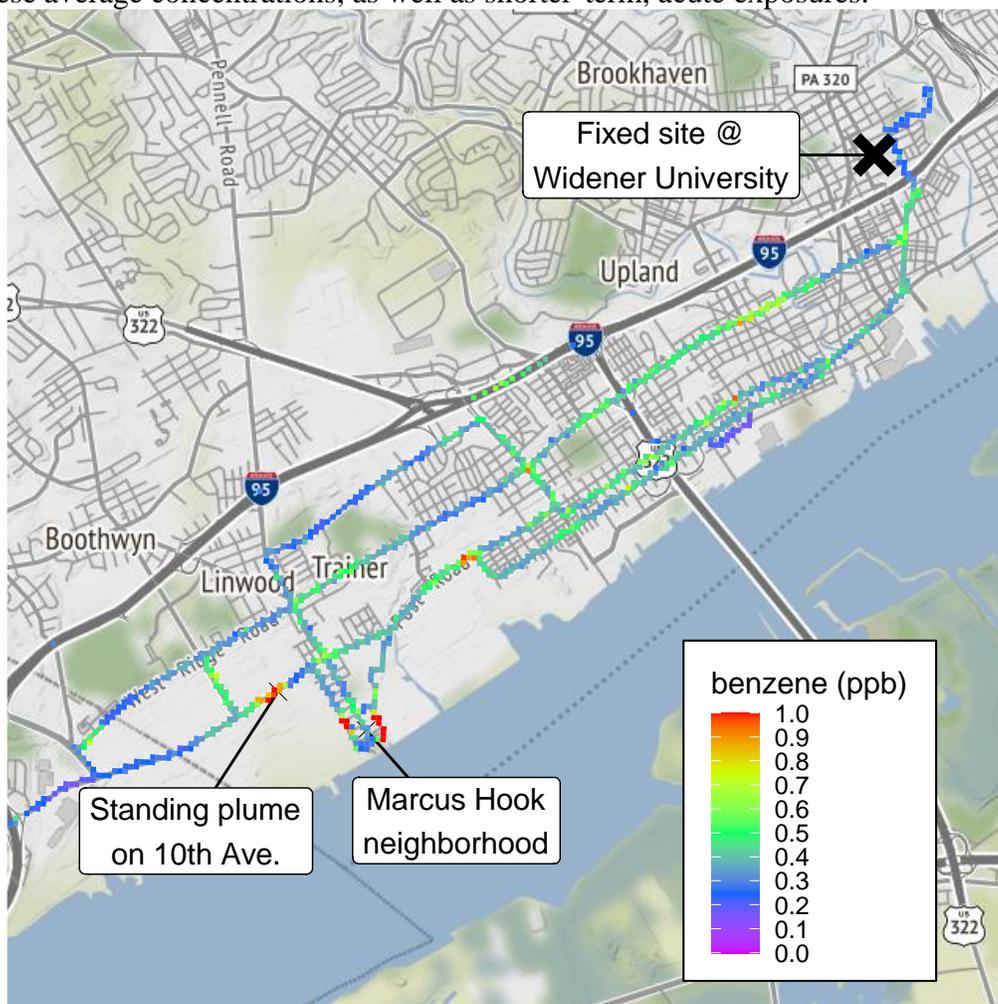


Figure 7. Averaged benzene concentrations in the study region from mobile lab measurements. Grid squares with concentrations larger than 1ppb are displayed as red but may have much higher average concentrations.

The formaldehyde map (Figure 8) shows different spatial patterns to that of benzene. Here, the median grid cell average concentration is 2.12 ppb (higher than the fixed site average of 1.43 ppb), with 25th and 75th percentile values of 1.76 ppb and 2.35 ppb, respectively. Similar to benzene there are several areas with persistently higher formaldehyde concentrations. The major

formaldehyde hotspot shown on the map is just east of the Commodore Barry Bridge, near the fenceline of multiple industrial facilities, but closest to the Evonik chemical plant. We have analyzed the “standing plume” at the fenceline of this site which contains both formaldehyde and toluene, and routinely extends into the residential area of Chester. Forthcoming analysis will fully detail the spatial extent of the plume, and what risk this plume (and others observed during the study) pose on shorter-term, acute timeframes. This map shows that long-term average formaldehyde exposures are higher at the fenceline of this facility compared to other parts of the sampling domain. 2014 NATA modelled concentrations of formaldehyde across the study area showed little variability in concentrations of formaldehyde in contrast to the mobile measurements. The hotspots observed in the area just east of the Commodore Barry suggest an emission source that is not identified in the Toxic Release Inventory (TRI) for the area including past inventories. The TRI is a self-reported database that forms the basis for other tools to assess pollutant exposure. Ultimately, these mobile measurements are key for improving risk estimates for local communities, improving the NATA, and identifying and characterizing documented and undocumented emission sources.

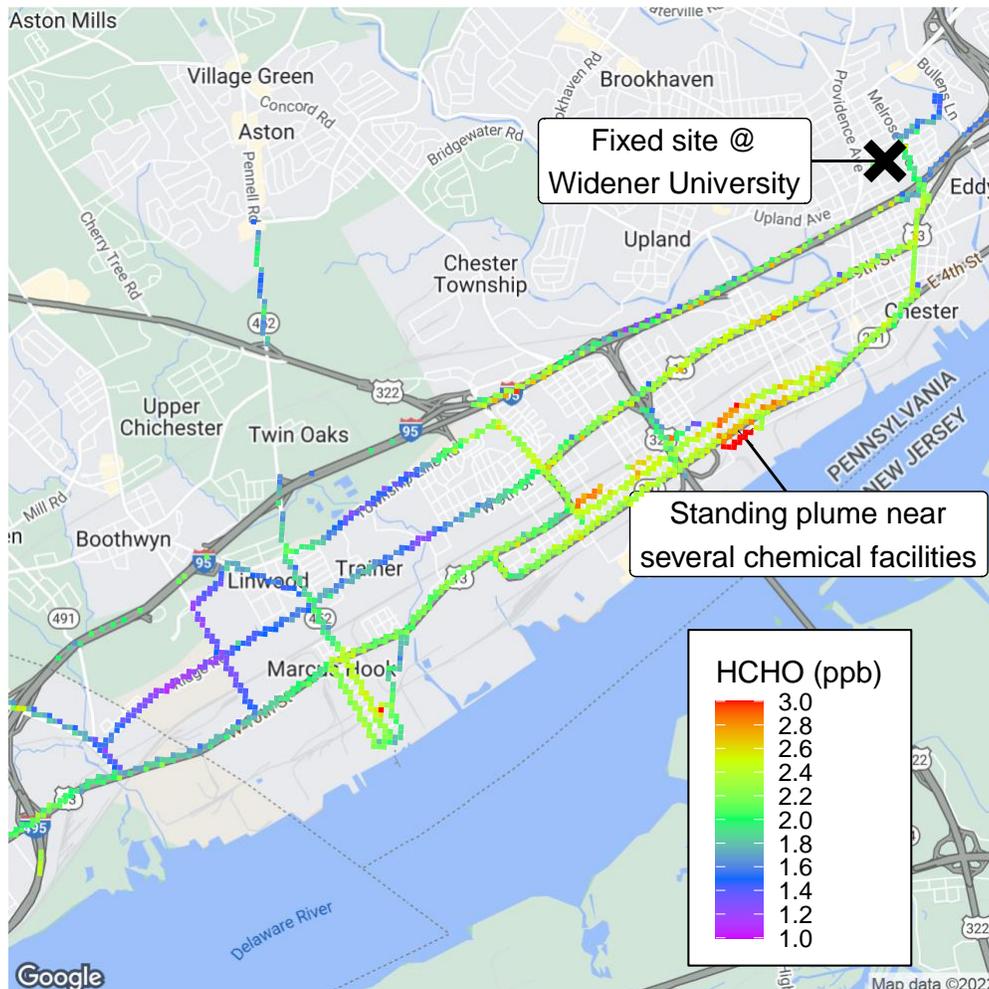


Figure 8. Averaged formaldehyde concentrations in the study region from mobile lab measurements

3.2. Low-Cost PM Sensors for continuous spatial information on PM_{10} , $PM_{2.5}$, PM_{10}

Key points:

1. Low-cost sensors provided spatial information on particulate matter concentrations with general agreement across the sites.
2. Single sensor increases in concentration can be attributed to emissions from local sources.
3. Deployment of sensors with community partners is an effective way for engagement with local residents and provide continuous data in areas of interest.

We have deployed six lower-cost MODULAIR-PM monitoring systems from Quant-AQ within the study area. Two are co-located with PA DEP sites, two at the Widener University urban background site, and two are at residences in study area. These low-cost sensors ran continuously during the campaign and provide additional high temporal resolution data for three size fractions of particulate matter ($PM_{1,2.5,10}$). Such sensors can be deployed at higher spatial resolution than is feasible with higher cost devices included at the urban background site and on the mobile platform. Continuous data provided by the sensors can facilitate a better understanding of the variability in chronic exposures and can capture short-duration plumes which lead to peak exposures.

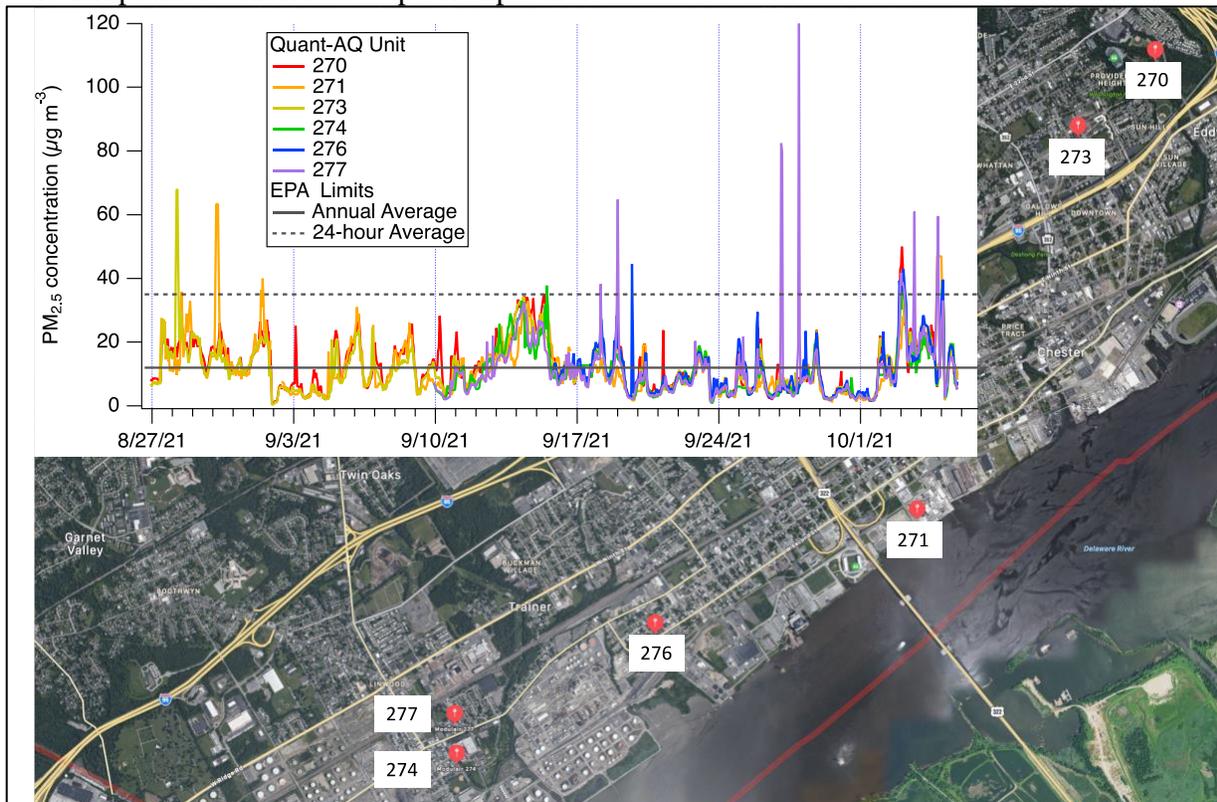


Figure 9. Comparison of $PM_{2.5}$ measurements from all low-cost sensors overlaid on map of sensor location in the study area.

The co-located sensors at the PA DEP sites show good agreement with reference grade instrumentation and will be used to improve calibrations for these sensors over the duration of the study. Our results also show that the sensors identify the same peaks observed by the fixed site and the mobile lab, when co-located. All six sensors pick up the same larger scale trends in PM levels, representing the regional concentrations driven in large part by meteorological

changes over time. However, some sites do measure shorter duration peaks likely indicative of contributions from sources impacting the local scale. Much of the time, the bulk (>60%) of the PM mass was comprised of the smallest fraction of particles (smaller than 1µm in diameter). This size may be suggestive of fresh emissions both from petrochemical facilities and from nearby traffic sources. There are events that are dominated by larger particles (particles with diameter greater than 1 micrometers), though events correspond to relatively low mass concentrations ($PM_{10} < 10 \mu g/m^3$)

3.3. Measurements of toxic metals in particulate matter

Key points:

1. Measurement results indicate the presence of vanadium in small particles when wind direction is from the refinery area.
2. Airborne lead concentrations were found to be approximately 60% higher than NATA modeled concentrations.
3. Toxic metals associated with petrochemical emissions, such as lead and arsenic, were also found mainly in the fine particle fraction which can penetrate deep into the lungs.

Refineries in the Chester area are major sources of several metals of health concern including lead, nickel, antimony, chromium, and molybdenum, according to TRI data. While some metals have essential roles in biology, all exert adverse health effects at some level, sometimes in trace amounts (Table 1).

Table 1: Health effects of inhalation exposure to examples of metals found in petrochemical emissions based on ATSDR toxicological profile data for each metal.

Lead	Neurotoxin, developmental effects in children
Nickel	Cancers of the respiratory tract, lung damage
Antimony	Pulmonary inflammation
Chromium	Cancers of the respiratory tract
Molybdenum	Respiratory irritation
Vanadium	Respiratory irritation
Arsenic	Lung cancer and irritation
Cadmium	Severe lung damage, renal effects

To investigate potential metals exposures in Chester area communities, we collected particulate matter in 10 different size fractions at the fixed site in Chester for subsequent metals analysis. Results indicate that the main elements associated with refineries, as well as arsenic, cadmium, selenium, and vanadium, were present in the fine particle fraction (<2.5 µm), suggesting potential petrochemical or traffic emissions (Figure 10, e.g., lead and vanadium). Total lead levels were measured at 1.68 ng/m³, compared to a NATA modelled concentration of 1.07 ng/m³, suggesting substantial underestimation in the NATA values. Metals in particulate matter smaller than 2.5 µm in diameter has also been implicated in a range of adverse health outcomes (e.g., cardiovascular effects, lung inflammation) due to its ability to penetrate deep into the lungs. Notable increases in vanadium concentrations for particles between 0.10-0.56 µm are observed on days with wind coming from the direction of the refineries (Figure 10).

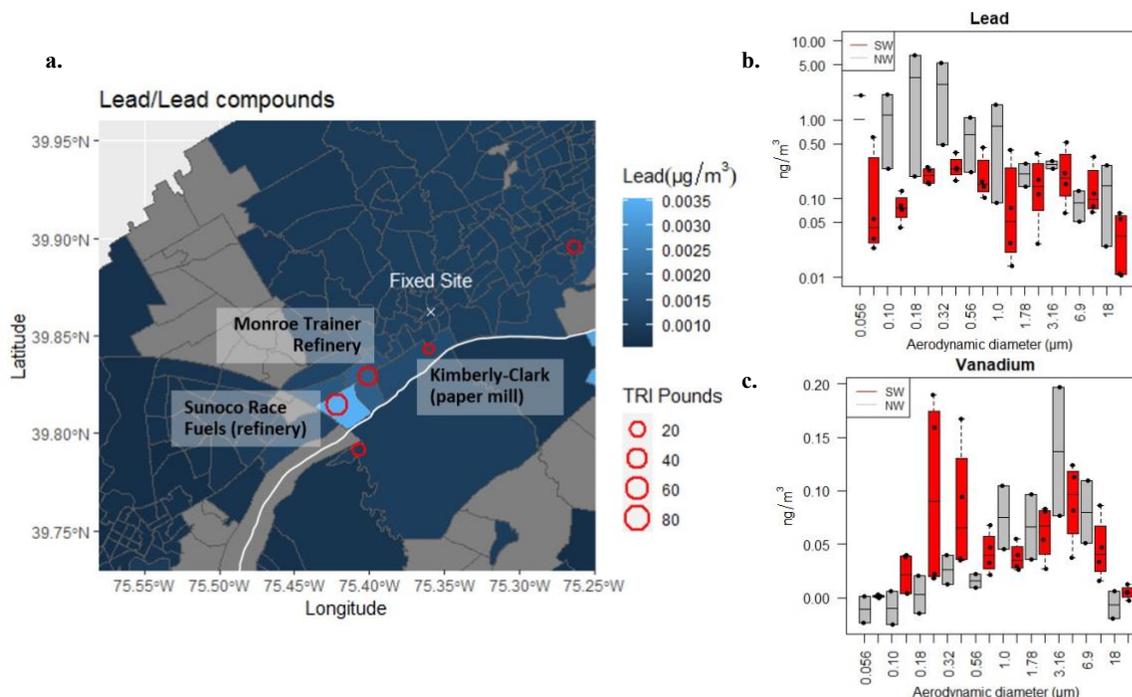


Figure 10. (a.): Spatial distribution of particulate matter lead levels based on previous measurements (NATA 2014) and lead emissions (TRI 2019) in Chester area. Metals levels in size-classified particulate matter for (b.) lead and (c.) vanadium grouped by wind.

3.4. Initial Risk Assessment results

Key points:

1. The pollutants measured in HAP-MAP are linked to a wide range of adverse health effects ranging acute respiratory irritation to increased cancer risk.
2. Our initial examination found exceedances of the California EPA's benzene chronic exposure limit and air concentrations of formaldehyde that were consistently higher than EPA's NATA predictions. Both chemicals are recognized human carcinogens.
3. Multi-pollutant plumes were repeatedly observed in the study region, highlighting the need to assess cumulative health risks to fenceline neighborhoods.

Air pollutants emitted by fossil and petrochemical industries can cause cancer and other adverse health effects. Despite this, monitoring of these pollutants in ambient air by EPA has been limited, thus barring full characterization of potential risks faced by communities near the fenceline of petrochemical facilities. Using state-of-the-art measurements of these pollutants from our monitoring efforts, we apply an established risk framework developed by the National Research Council and employed by EPA to begin to characterize cumulative health risks from exposure to multiple air pollutants and non-chemical stressors faced by fenceline communities (National Research Council, 2008)(US EPA, 2014).

We compiled EPA, OSHA, NIOSH, and California EPA toxicity values for health effects resulting from inhalation exposures for all measured pollutants. As a starting point, we selected formaldehyde and benzene for purposes of conducting an initial risk analysis; these chemicals were selected due to their clear linkage to petrochemical industry emissions. In order to make use of pollutant measurements in a risk framework, we needed to translate measurements into time-

weighted estimates of exposure. This was important to ensure that exposure estimates are compatible with the identified toxicity values, to facilitate characterization of risk.

Using spatial measurements from the mobile laboratory, we modeled chronic exposures to these hazardous air pollutants as mean hourly concentrations in a 50x50m grid (see Section 4.1 for more detail). Using this chronic exposure grid, we characterized likely non-cancer effects using a Hazard Quotient (HQ) approach; this entailed calculating ratios of chronic exposure estimates to the most protective of the identified toxicity values for each chemical (US EPA, 2015)(US EPA, 2005). We plotted these HQs over our study area to demonstrate the spatial variation in potential risk. In risk assessment, an HQ of 1 or greater indicates exposures are at or above the identified limit for health risk based on current toxicity values.

The California EPA provides the most protective toxicity value for benzene with a chronic reference exposure level (CalEPA chREL) of $27 \mu\text{g}/\text{m}^3$, which corresponds to approximately 0.94 ppb, associated with adverse effects on the hematologic system, nervous system, and development (CalEPA OEHHA, 2015a). Averaged grid cell concentrations from the mobile laboratory measurements indicate that 14 of 918 grid cell chronic exposure estimates exceeded this value (Figure 1). Some of these grid cells were in close proximity to the refining complex in Marcus Hook, others near gas stations. In addition to grid cells which exceeded an HQ of 1, 31 out of the 918 were above a hazard quotient of 0.75, and all were within an order of magnitude of an unacceptable HQ.

It is also critical to recognize that our current risk analysis only includes two of the measured chemicals. Our data clearly indicate that fenceline communities in Chester are exposed to mixtures containing an array of chemicals. In recognition of those simultaneous exposures, caution in interpretation is essential since the same health effects in exposed persons may be affected by inhalation of different chemicals. Even though exposure to an individual chemical may not trigger an unacceptable HQ on its own, concurrent exposures to other chemicals affecting the same part of the body or organ system may have an additive or synergistic adverse effect. Given this, when a broader set of chemical measurements have been translated into exposures and additional HQs have been estimated, we will calculate organ-specific hazard indices (HIs), which are a better measure of the cumulative burden of multiple chemicals on a single organ system. Examination of other species present with benzene and the cumulative risk of additional exposures is the subject of ongoing analysis.

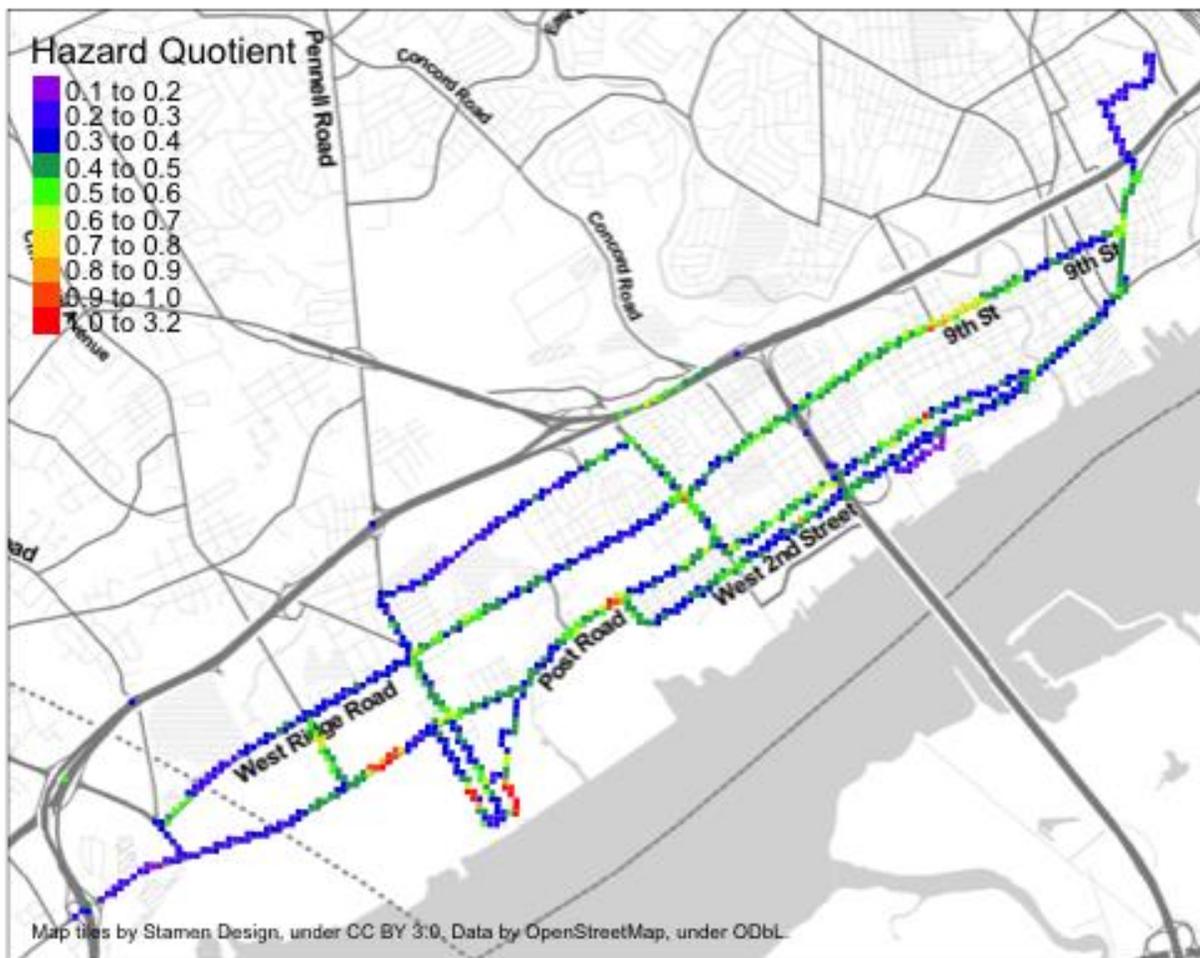


Figure 11. Map of benzene hazard quotients (HQs): ratios of benzene chronic exposure estimates for September 2021 to CalEPA chronic REL.

The most sensitive chronic agency toxicity value for formaldehyde is the CalEPA chREL, set at $9 \mu\text{g}/\text{m}^3$, approximately 7 ppb, associated with adverse effects on the respiratory system (CalEPA, 2015b). While none of 1236 grid cell chronic exposure estimates exceeded this chREL, 4 were at least half the chREL concentration, and measured values were substantially higher than the modelled 2014 values for the National Air Toxics Assessment for this area.

The mobile measurements provided high spatial and temporal multipollutant data rarely available to support inhalation exposure and risk assessment. We estimated individual benzene and formaldehyde chronic exposures for locations in our sampling area with at least 10 visits and identified several areas where benzene exceeded the CalEPA chREL, the concentration at or below which no adverse health effects would be anticipated in a human population, including sensitive subgroups (Figure 10). We plan to estimate chronic exposures and HQs using the most sensitive toxicity values for other compounds. In addition, we will use acute toxicity metrics to examine the health relevance of shorter-term exposures resulting from intermittent spikes in pollutant air concentrations.

4. Community groups and governmental agency engagement

Key points:

1. Two-way communication with community groups was key to planning and execution of the measurement project.
2. PA Department of Environmental Protection collaboration provided multiple sites for co-location of measurements, and background on the area.
3. The project has generated significant interest in the study area, and additional governmental agencies and community groups are interested in the results and continued work on air quality issues.

To maximize the impact of the science being done, active engagement with at-risk fenceline communities, and local, state, and federal officials is key. Two-way communication with stakeholders provides non-academic pathways to disseminate results and findings from this work. Despite the short timeframe for planning HAP-MAP we have successfully connected with key stakeholders.

4.1. Community groups

A longstanding relationship with the regional non-profit Clean Air Council provided initial contact with local environmental groups in the Chester/Trainer/Marcus Hook area. In particular, conversations with Chester Residents Concerned for Quality Living ([CRCQL](#)) and affiliated groups provided important background information for the study area. During the campaign, a “hotline” number was set up so residents could notify the Mobile Laboratory of any air quality issues in real-time. Following the intensive measurement campaign, Dr. DeCarlo has provided some initial results and updates from the study, with additional calls planned. Chester Environmental Partnership (CEP) invited Dr. DeCarlo to provide an overview of the study measurement plan to their group consisting of local residents, city and state government, and local industrial facility representatives. While both groups espouse similar goals, they do not work together due to historical issues between leaders of the respective groups. In addition to the groups that we have actively engaged in the intensive measurement portion of the study, several other local groups have expressed interest in finding ways to work with us on air quality and equity issues in the area. These include the Chester Housing Authority and in Delaware CHEC Inc. and Christiana Care a hospital network in the area.

4.2. Regulatory and governmental organizations

As part of the preparation for the measurement portion of the campaign, Drs DeCarlo and Burke had a series of discussions with officials from the Pennsylvania Department of Environmental Protection (PA-DEP). As a result of these discussions we were provided access to monitoring sites in the study region to co-locate 2 of the lower cost sensors. Initial results from the co-location of the sensors have been shared with PA-DEP and discussions are ongoing with the potential for additional instrument and sensor deployments. As a result of this work and discussions with PA-DEP Dr. DeCarlo is a co-investigator on a PA-DEP led proposal in review at EPA for enhanced community monitoring in the study area. Our collaboration with local community groups and the Clean Air Council, provided additional contacts in the area with the Delaware County General Counsel and the Region 3 Agency for Toxic Substances and Disease Registry. Both entities have expressed interest in learning about the results of the study as they become available. An overview of the main results will be presented in June 2022, with an in-person event being planned at Widener University in September 2022.

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