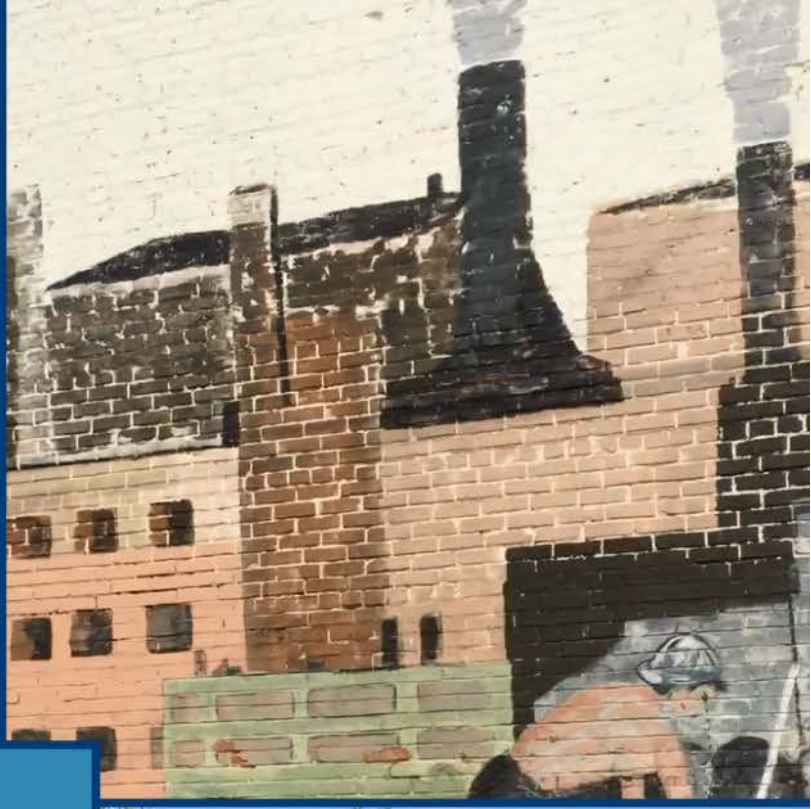

Citizen Air Quality Monitoring in Curtis Bay, Baltimore

June 2016

EIP ENVIRONMENTAL INTEGRITY PROJECT

ACKNOWLEDGEMENTS

This report was researched and written by Leah Kelly, Troy Sanders, Courtney Bernhardt, and Kira Burkhart of the Environmental Integrity Project.

THE ENVIRONMENTAL INTEGRITY PROJECT

The Environmental Integrity Project (EIP) (http://www.environmentalintegrity.org) is a nonpartisan, nonprofit organization established in March of 2002 by former EPA enforcement attorneys to advocate for effective enforcement of environmental laws. EIP has three goals: (1) to provide objective analyses of how the failure to enforce or implement environmental laws increases pollution and affects public health; (2) to hold federal and state agencies, as well as individual corporations, accountable for failing to enforce or comply with environmental laws; and (3) to help local communities obtain the protection of environmental laws.

EIP is grateful to the Chesapeake Center for Youth Development, the Filbert Street Community Garden, and the congregation at St. Paul's Evangelical Lutheran Church for allowing us to conduct monitoring on their properties in Baltimore City. We are also grateful to the Maryland Department of the Environment for discussing our early data and procedures with us and for allowing us to conduct co-locations with their monitor in Anne Arundel County.

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Executive Summary

From 2013 to 2015, the Environmental Integrity Project (EIP) conducted an air quality monitoring project in two Baltimore City neighborhoods, Curtis Bay and Brooklyn, to gather information about local levels of an air pollutant called fine particulate matter ($PM_{2.5}$). There are no government-operated air monitors in these communities, which are located adjacent to a heavily industrialized port area. Therefore, there is no data on air pollution concentrations in these neighborhoods.[a] Our goal was to test the hypothesis that pollution levels in Curtis Bay and Brooklyn are higher than in other parts of Baltimore City. We also wanted to develop a project template that was affordable enough to be replicated by communities with limited resources while producing high-quality data that would be recognized as valid by government agencies.

EIP encountered data irregularities in our project during 2013 and 2014. However, we obtained reliable datasets in 2015, monitoring at two separate locations in the Curtis Bay neighborhood: St. Paul's Lutheran Church and the Filbert Street Community Garden. We compared the pollution data from EIP's Curtis Bay monitors to two monitors operated by the Maryland Department of the Environment (MDE) elsewhere in the Baltimore area. For this comparison, we looked at MDE's closest monitor to Curtis Bay, located at its Glen Burnie site in Anne Arundel County, and MDE's highest-reading monitor that uses the same technical method as our monitors (for an "apples to apples" comparison, as the method can affect how high readings are). MDE's highest-reading monitor, using the same method as ours, is located at its Essex site in Baltimore County.

Findings

While EIP's datasets were not robust enough to establish a long-term trend, they do indicate support for our hypothesis. Measurements at both of our sites in Curtis Bay were consistently higher than the $PM_{2.5}$ levels recorded at MDE's sites. For example, the average readings at St. Paul's Church in January 2015 were 23.5 percent higher than the average readings at MDE's Glen Burnie monitoring site and 20.3 percent higher than at MDE's Essex site. There was less of a difference shown in August of 2015 when the average readings at EIP's monitor at St. Paul's Church were 10 percent higher than at MDE's Glen Burnie site.[b]

The fact that EIP's monitors in Curtis Bay recorded higher pollution levels than MDE's monitors located elsewhere could be attributable to monitor bias (EIP's or MDE's)

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[a] In 2012, EIP released a report titled *Air Quality Profile of Curtis Bay, Brooklyn, and Hawkins Point, Maryland*, in which we analyzed federal data on air pollution released from industrial sources in this area. Among other things, we found that plants there released toxic air emissions in very high amounts relative to the rest of the state and, in 2007 and 2008, released more air toxics than in any other zip code in the country. This report is available at: http://www.environmentalintegrity.org/news_reports/documents/FINALBAYBROOKREPORT_003.pdf.

[b] Due to irregularities in MDE's August 2015 data for its Essex monitor, we did not conduct a comparison to that monitor for that dataset.

as discussed in more detail below on pages v-vi. Or it could reflect different pollution levels at the sites. In addition, the $PM_{2.5}$ levels that we recorded at St. Paul's Church, which is located closest to the industrial area and between two roadways with heavy diesel truck traffic, were consistently higher than the levels that we measured at the Filbert Street Garden. This indicates support for another hypothesis that we developed during the project: that the highest $PM_{2.5}$ levels in Curtis Bay are present in the area between the two roads with heavy truck traffic, Curtis Avenue and Pennington Avenue.

As discussed in more detail in the Background section of this report, $PM_{2.5}$ is a pollutant that can cause adverse health effects, including increased risk of premature death due to lung cancer and heart and respiratory disease, even in concentrations below federal air quality standards. Studies have also documented significant increases in adverse birth outcomes, such as low birth weight, at relatively low levels of $PM_{2.5}$. The federal air quality standard for daily $PM_{2.5}$ is 35 micrograms per cubic meter ($\mu g/m^3$) and the annual standard (annual average of 24-hour readings) is 12 $\mu g/m^3$.[c] We did not record any levels above the daily standard, and we do not consider it appropriate to compare our data to the annual standard, which is supposed to reflect a full year's worth of readings.

Recommendations

- MDE should install a $PM_{2.5}$ monitor in the Curtis Bay community, in the area between Curtis Avenue and Pennington Avenue where EIP recorded the highest $PM_{2.5}$ levels during our sampling. Specifically, MDE should site its monitor in Curtis Bay Park, outside of the Curtis Bay Recreation Center, which is a location where young children, who are especially vulnerable to $PM_{2.5}$, play outdoors.

- State and local agencies, with the proper financial support, should conduct "hotspot" monitoring for $PM_{2.5}$ in communities of concern. The recent environmental justice monitoring project implemented by the Minnesota Pollution Control Agency (MPCA), discussed in more detail elsewhere in this report, provides a model for interested agencies.

- Access to a high-quality laboratory is essential to obtaining good data. Environmental agencies should assist citizen scientists by providing access to their laboratories for free or for a reduced price.

- Citizen scientists seeking to replicate our project should follow the procedures described in more detail in the body of this report and in the project guidance, titled *$PM_{2.5}$ Citizen Sampling Guide*,[d] that we are issuing with the report.

[c] Annual and 24-hour averages are then further averaged over a period of three years under EPA's standards.
[d] This guidance is available on EIP's website: http://www.environmentalintegrity.org/.

JANUARY 2015 DATA

TABLE A. COMPARISON OF $PM_{2.5}$ DATA AMONG EIP AND MDE SITES

Sample Date	$PM_{2.5}$ Concentration (µg/m³) by Site			
	EIP Curtis Bay Church	EIP Curtis Bay Garden	MDE Anne Arundel Co. Glen Burnie Site (closest to Curtis Bay)	MDE Baltimore Co. Essex Site (highest in network)
1/9/2015	7.9	6.4	5.6	6.0
1/12/2015	18.3	16.6	14.5	15.4
1/15/2015	23.1	21.1	21.3	21.0
1/18/2015	17.9	14.1	13.2	15.3
1/21/2015	22.2*	20.7*	22.0	18.6
1/24/2015	11.3	9.9	8.6	10.6
1/27/2015	8.6	8.0	7.1	6.2
Average	**15.6**	**13.8**	**13.2**	**13.3**

*Due to receipt temperature, filters could not be post weighed prior to sample expiration. However, results appear realistic and correlate with results from Glen Burnie and Essex, so we are including them in this analysis.

TABLE B. COMPARISON OF AVERAGE $PM_{2.5}$ CONCENTRATIONS AMONG SITES

Sites Compared (Average Concentrations)	Difference in µg/m³	Percent Difference[e]
Curtis Bay Church v. MDE Glen Burnie	2.4	23.5%
Curtis Bay Church v. MDE Essex	2.3	20.3%
Curtis Bay Church v. Curtis Bay Garden	1.8	14.1%
Curtis Bay Garden v. MDE Glen Burnie	0.6	8.1%
Curtis Bay Garden v. MDE Essex	0.5	5.8%

[e] Percent difference between sites is calculated based on the average of the percent difference for each pair of dates being compared.

AUGUST 2015 DATA

TABLE C. COMPARISON OF $PM_{2.5}$ DATA AMONG EIP AND MDE SITES

Sample Date	$PM_{2.5}$ Concentration (µg/m³) by Site			
	EIP Curtis Bay Church	EIP Curtis Bay Garden	MDE Anne Arundel Co. Glen Burnie Site (closest to Curtis Bay)	MDE Baltimore Co. Essex Site (highest in network)
8/7/15	8.5	7.5	7.2	6.2
8/10/15	7.6*	6.5	5.7	5.5
8/13/15	5.3	5.2	4.8	7
8/16/15	11.2	11.2	9.5	10.6
8/19/15	11.0	9.7	8.6	0
8/22/15	6.0	5.9	6.2	Not available
8/25/15	8.7	8.2	7.8	0
8/28/15	8.8	8.5	9.5	8.6
8/31/15	14.4	14.3	13.7	Not available
Average**	**9.2**	**8.8**	**8.4**	Not calculated due to missing data

* Data point invalid because power to monitor shut off mid-sampling.
** Averages do not include data from 8/10/15.

TABLE D. COMPARISON OF AVERAGE $PM_{2.5}$ CONCENTRATIONS AMONG SITES

Sites Compared (Average Concentrations)	Difference in µg/m³	Percent Difference[f]
Curtis Bay Church v. MDE Glen Burnie	0.8	10.0%
Curtis Bay Church v. Curtis Bay Garden	0.4	5.1%
Curtis Bay Garden v. MDE Glen Burnie	0.4	4.7%

[f] Percent difference between sites is calculated based on the average of the percent difference for each pair of dates being compared.

Methodology

A detailed description of the methodology that EIP used in our project, and how that methodology evolved over the course of the project, is available in the body of this report on pages 9-19 and in Appendix A. The most important aspects of our methodology are summarized below.

Instrument

The monitor that EIP used for our project was the BGI PQ200 with Very Sharp Cut Cyclone (VSCC). This monitor is classified by EPA as a Federal Reference Method monitor, meaning that it has passed rigorous performance tests and met strict design criteria required under federal regulations. The BGI PQ200 measures $PM_{2.5}$ by drawing air through the monitor for 24 hours and depositing fine particles onto a filter. The filter is then sent to a laboratory to be weighed. The resulting data represents a 24-hour concentration.

This "filter-based" method of monitoring is notably different from another monitoring method – "continuous monitoring" – that is also used by environmental agencies to measure $PM_{2.5}$. Continuous monitors (also sometimes called automated monitors) use different techniques, usually passing light rays through air to read particle concentrations, and they report data on an hourly basis. Continuous $PM_{2.5}$ monitors generally produce higher readings than filter-based models, even when gathering data in the same time and place.[g] For this reason, EIP did not compare our data (from a filter-based model) to data gathered by MDE's continuous monitors in the Baltimore area.

Measurement Certainty

The most important way in which EIP checked the quality of our data was by "co-locating" our monitors with a filter-based $PM_{2.5}$ monitor operated by MDE and comparing our data to MDE's. We conducted two separate co-locations at MDE's Glen Burnie site. After the first co-location in 2014 indicated problems with our data, we made several changes to our project. The data produced during the second co-location indicated that the problems had been resolved.

During the second co-location (in 2015), EIP's monitors recorded readings that were about 12.3% higher, on average, than MDE's monitors (average difference of 1.3 $\mu g/m^3$). This difference could be due to the "bias" (systemic distortion in one direction) of either EIP's monitors or MDE's. However, this difference is close to the bias range (+/-10%) deemed acceptable by EPA.[h] In addition, EIP's monitors showed a very high "correlation"

[g] For example, at MDE's Oldtown site in Baltimore City, a continuous $PM_{2.5}$ monitor is co-located with a filter-based $PM_{2.5}$ monitor. In 2014, the annual average concentration gathered by the filter-based monitor was 9.2 $\mu g/m^3$ while the 2014 average for the continuous monitor at the same site was 11.1 $\mu g/m^3$.

[h] EPA measures bias based on three years' worth of data, but we did not have the resources to gather this much data.

(the extent to which two variables have a linear relationship with each other) with MDE's monitor during the comparison, indicating high data quality.

Monitor bias is a problem that EPA has been investigating in official $PM_{2.5}$ networks throughout the country. Starting in 2007, filter-based monitors in official networks began showing increased negative bias, meaning that they began more frequently reporting lower levels of $PM_{2.5}$ than audit monitors during co-locations.[1] This demonstrates that there is measurement uncertainty even in official datasets and also raises questions about those datasets.

Site Selection

EIP selected monitoring sites based on four criteria: (1) human exposure, i.e. where people live, work, and play; (2) site security; (3) permission to locate a monitor on the property; and (4) proximity to the area with highest expected levels of $PM_{2.5}$. Our sites did not meet EPA siting criteria, however. EPA requires that a $PM_{2.5}$ monitor must be positioned at least a certain distance from trees and other obstructions. We were not able to find any safe and secure sites near our target area that met these requirements.

Laboratory Support

We made a series of changes to our project in late 2014 after our first co-location with state monitors indicated problems with our data. The most important change we made was switching to the laboratory at Research Triangle Institute (RTI), which provides analytical and data support to the EPA. RTI helped us to add a number of new safeguards to our filter-handling procedures. Our data improved dramatically after we began using RTI as our laboratory.

Cost

EIP rented monitors instead of purchasing one. Most Federal Reference Method monitors cost over $20,000, and rental allowed us to operate two monitors at the same time in different locations for data comparison purposes. For two monitors, our project cost was approximately $3,800 per month, including all equipment and laboratory costs. The cost would have been about $2,110 per month if we had rented only one monitor at a time.

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Background

What is $PM_{2.5}$?

Particulate matter (PM) is a type of air pollution that consists of airborne particles that come from different sources and can be made of up of a variety of components. Fine particulates, or $PM_{2.5,}$ are particles that are 2.5 micrometers ($1/30^{th}$ of a human hair) or less in diameter.[2] $PM_{2.5}$ is primarily caused by the combustion of materials in "mobile sources" like cars, trucks, and ships, and in facilities like power plants. These fine particles are emitted as soot (unburned carbon) or formed when other pollutants from the combustion process react in the atmosphere. Because these particles are so small, they can lodge deeply in the lungs, and, therefore, pose a much greater threat to human health than larger types of particulate matter. $PM_{2.5}$ has been associated with premature mortality from heart and respiratory disease and lung cancer, and can also aggravate existing respiratory conditions.[3]

EPA has set two federal health-based air quality standards for $PM_{2.5}$. These standards require states and local air quality agencies to limit the public's exposure to no more than 35 micrograms per cubic meter ($\mu g/m^3$) over 24 hours and to 12 $\mu g/m^3$ averaged over a year. Data captured by official networks must be averaged over a period of three years before it can be compared to either standard.[i]

$PM_{2.5}$ can cause adverse health effects even below these concentrations. Experts who study this issue agree that there is no evidence of a "threshold" below which $PM_{2.5}$ is safe.[4] Multiple epidemiological studies with prospective cohort designs[j] have attempted to calculate the mortality impact of $PM_{2.5}$. The two principle studies in the U.S., described in Table E, found that mortality, from all causes and from certain specific causes, increased as $PM_{2.5}$ in the air increased. As a way to present standardized risk estimates, each study estimated how much mortality would increase if $PM_{2.5}$ increased by 10 $\mu g/m^3$.

[i] The 24-hour standard is applied at the 98^{th} percentile. Thus, the 98^{th} percentile data point for each year (each point representing one 24-hour reading) is averaged over 3 years for each monitor.

[j] A prospective cohort study selects a group of people to study (a cohort), collects vital information about each individual in the cohort, and tracks the cohort over time in order to collect information about health outcomes (e.g., disease incidence or mortality) and risk factors (e.g., exposure to air pollution).

TABLE E. MAJOR STUDIES OF INCREASED MORTALITY DUE TO $PM_{2.5}$

Study name	Harvard Six Cities Study	American Cancer Society Study
Study description	This was the earliest of the studies and tracked over 8,000 people from six U.S. cities from 1974 to 1998.[5]	This study followed over one million adults between 1982 and 1998.[6]
Findings	An increase of 10 $\mu g/m^3$ in $PM_{2.5}$ was associated with increases of: • 16% in deaths from all causes; • 28% in deaths from cardiovascular disease; and • 27% in deaths from lung cancer.	An increase of 10 $\mu g/m^3$ in $PM_{2.5}$ was associated with increases of: • 4% in deaths from all causes; • 6% in deaths from cardiopulmonary disease; and • 8% in deaths from lung cancer.

Levels of $PM_{2.5}$ in the United States have been slowly declining over time, which means that more recent studies are based on lower exposure concentrations. Even at lower levels of exposure, however, there is strong evidence of a health risk. For example, the American Cancer Society Study, which tracked people between 1982 and 1998, originally used air quality data from 1979-1983. At that time, the average $PM_{2.5}$ concentration was 21.1 $\mu g/m^3$. The authors later reanalyzed the data using air quality data from 1999-2000. By then, the average $PM_{2.5}$ exposure concentration had declined to 14 $\mu g/m^3$. Using the more recent information, estimates of increased risk, on a per-microgram of $PM_{2.5}$ basis, were actually slightly higher.[k] Another recent study tracked a large number of older Americans[l] from 2000-2009.[7] The average exposure concentration in this study was 12.2 $\mu g/m^3$. Confirming earlier results, these authors found significant increases in all-cause and cardiovascular mortality.[m]

Exposure to $PM_{2.5}$ during pregnancy is also associated with adverse birth outcomes, including low birth weight and preterm birth.[8] Many studies have documented significant increases in adverse birth outcomes at low levels of $PM_{2.5}$. For example, Brauer et al. (2008) found that small increases in $PM_{2.5}$ in the Vancouver, British Columbia area were associated with both preterm birth and 'small for gestational age' birth weight.[n,9] A recently published study by researchers at Johns Hopkins University of women living in urban Boston found that small increases in relatively low levels of $PM_{2.5}$ were associated with increased risk of intrauterine inflammation (IUI). IUI is a risk factor for preterm birth, low birth weight, and poor respiratory outcomes in early childhood. Even after adjusting for factors like smoking,

[k] Using 1979-1983 air quality data, a 10 $\mu g/m^3$ change in $PM_{2.5}$ was associated with increases in all-cause, cardiopulmonary, and lung cancer mortality of 4%, 6%, and 8%, respectively. Using 1999-2000 air quality data, these risk increases were 6%, 8%, and 13%, respectively.

[l] This study included over 500,000 AARP members from six U.S. states and two metropolitan areas, age 50 to 71 at the beginning of the study.

[m] All-cause and cardiovascular mortality increased by 3% and 10%, respectively, per 10 $\mu g/m^3$ of $PM_{2.5}$. Respiratory mortality showed a non-significant increase of 5%.

[n] Specifically, a 1-$\mu g/m^3$ increase in $PM_{2.5}$ was associated with an adjusted Odds Ratio of 1.02 for small for gestational age birth weight and was also associated with a significant increase in birth at less than 35 weeks (adjusted Odds Ratio of 1.12). Modeled $PM_{2.5}$ concentrations for study subjects ranged from 0 to 11.3 $\mu g/m^3$.

obesity, and age, the researchers found that risk of IUI during the first trimester of a pregnancy increased about 40% when comparing exposure to daily $PM_{2.5}$ levels in the range of 4.16 - 8.99 $\mu g/m^3$ (the lowest quartile recorded in the study for that trimester) to levels in the range of 10.96 - 12.72 $\mu g/m^3$.[10]

How Is Ambient $PM_{2.5}$ Measured?

$PM_{2.5}$ in the "ambient" (outside) air can be measured in a variety of ways, and the type of sampling instrument and measurement method used will depend on the user's goals. Community groups and academics may select portable monitors, many of which are easy to handle and have the advantage of providing instantaneous data. However, to our knowledge, none of these models provide data of sufficient quality to be treated as accurate by regulators, and vendors that we spoke with would not make guarantees about accuracy or precision for these kinds of instruments at concentrations typical of those found in the U.S. Some guarantees may be made for instruments operating in environments with significantly higher $PM_{2.5}$ concentrations, however.

Official $PM_{2.5}$ measurements, captured by state or local air quality agencies, must be obtained according to a very detailed and complex set of regulatory requirements promulgated by the EPA. These measurements are used to determine whether a given geographic area meets the daily and annual federal air quality standards for $PM_{2.5}$. If monitoring shows that a standard is not met, then the area is designated as a "nonattainment area" for that standard, which imposes certain legal requirements relating to air pollution in that area. For example, pollution control standards are stricter for new "major" air pollution sources in nonattainment areas than for those in areas meeting federal standards, called attainment areas.

Federal Requirements

$PM_{2.5}$ monitors that produce data of sufficient quality for use in attainment designations must meet one of the following classifications: federal reference method (FRM or "Reference Method"), federal equivalent method (FEM or "Equivalent Method"), or Approved Regional Method.[o] A monitor that is designated as Reference Method has met the strictest and most detailed set of regulatory requirements. A monitor must meet detailed design criteria and pass a number of performance tests in order to be designated Reference Method for $PM_{2.5}$. To be designated Equivalent Method, a monitor must meet a set of similar, though less stringent, criteria and tests.[p] EPA maintains a list of instruments that have been designated as Reference or Equivalent Method for $PM_{2.5}$,[11] which is updated periodically.

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[o] The Approved Regional Method is a method that has been approved within a State or local air monitoring network for purposes of comparison to federal standards. 40 C.F.R. § 58.1. As far as we are aware, there are no $PM_{2.5}$ monitors currently designated as Approved Regional Method. Therefore, that method is not addressed in this report.

[p] In addition, there are three classes of Equivalent Method monitors for $PM_{2.5}$, and the requirements become progressively less stringent the higher the class number.

Monitors that have been designated Reference or Equivalent Method for $PM_{2.5}$ fall into two general categories: filter-based models (sometimes called "manual" models) and automated (sometimes called "continuous") models. The filter-based models measure $PM_{2.5}$ by pulling air into the monitor over a 24-hour period and depositing the fine particles onto a filter. The filters are then removed from the monitor and sent to a lab, where they are weighed to determine the concentration over the 24-hour sampling period. This produces a data point that represents a 24-hour concentration in $\mu g/m^3$. Automated monitors, on the other hand, gather data using different techniques, usually by passing light rays through air to read concentrations of particles, which are reported on an hourly basis. No filter or lab analysis is required and hourly data is aggregated to produce 24-hour averages for comparison to the daily federal air quality standard. As of December 2015, only filter-based models had been designated Reference Method, although automated models (and a few filter-based models) have been designated Equivalent Method.[12]

Once an instrument has been selected that meets Reference or Equivalent Method criteria, other requirements must also be satisfied in order for the resulting data to be considered up to federal standards. These other criteria include requirements for filter size and composition, filter handling, laboratory analytical process, sampling schedule, data completeness and interpretation, monitor siting, monitoring network design, and quality assurance checks. Due to the length and complexity of these requirements, this report will not discuss each one but will address certain criteria that became relevant for EIP's $PM_{2.5}$ project. However, the requirements can be found in EPA's regulations at 40 C.F.R. Parts 50, 53, and 58. Those identified below are the most specific for $PM_{2.5}$ monitoring networks and procedures.

TABLE F. KEY $PM_{2.5}$ MONITORING REGULATIONS

EPA Regulation	Procedures addressed
40 C.F.R. Part 50, Appendix L	Reference Method requirements – instrument design, filter handling, and filter weighing requirements ($PM_{2.5}$ only)
40 C.F.R. Part 50, Appendix N	Data handling conventions and comparison to the NAAQS ($PM_{2.5}$ only)
40 C.F.R. Part 53, Subparts E and F	Tests for designating monitors Reference or Equivalent method ($PM_{2.5}$ and $PM_{2.5\text{-}10}$ only)
40 C.F.R. Part 58, Appendix A	Quality assurance objectives and checks (multiple pollutants)
40 C.F.R Part 58, Appendix D	Network design criteria (multiple pollutants)
40 C.F.R. Part 58, Appendix E	Siting requirements for individual monitors (multiple pollutants)

Measurement Certainty

Anyone wishing to obtain high-quality $PM_{2.5}$ in a citizen monitoring project should be aware that there will always be some level of uncertainty about the accuracy of the data. There is uncertainty even in official monitoring networks used for attainment and nonattainment designations. EPA's Reference Method requirements exist for the purpose of reducing that uncertainty to a level that the agency has deemed acceptable.

EPA has identified two goals for reducing $PM_{2.5}$ measurement uncertainty to acceptable levels. First, total instrument bias should be within +/- 10%.[13] Bias is supposed to be a measure of systemic distortion in one direction. It is judged over a three-year period based on the way that a field monitor compares to a reference method "audit" monitor, which is treated as the correct monitor in the comparison, during a co-location. EPA's actual method for calculating bias is somewhat complex because confidence intervals are built into the equation.[14] However, in general, if sufficient data has been gathered and an audit monitor reads an average concentration of 15.0 $\mu g/m^3$, the field monitor will be within the acceptable bias range if it averages between 13.5 and 16.5 $\mu g/m^3$. The second data quality goal relates to precision, which is "a measure of agreement among repeated measurements of the same property under identical, or substantially similar, conditions. [It] is the random component of error."[15] Total precision, which is also measured based on data obtained during co-locations, should be 10% coefficient of variation.[16] The "coefficient of variation" involves a complicated formula, but it generally describes how multiple readings deviate from a mean.[17]

All monitors have some level of bias. In fact, EPA has recently been investigating the reasons for an increasing negative bias, starting in 2007, in Reference Method (filter-based) monitors used in official monitoring networks throughout the country.[18] In other words, filter-based field monitors in official networks are more often reporting lower levels of $PM_{2.5}$ than audit monitors during co-locations. The fact that a monitor has a demonstrated bias does not necessarily mean that it will produce data that is not of regulatory quality.

Baltimore's $PM_{2.5}$ Monitoring Network

$PM_{2.5}$ levels in Baltimore City are measured by a monitoring network designed and operated by MDE. The Baltimore area did not meet the federal air quality standard for annual $PM_{2.5}$ for a number of years. However, in December of 2014, the EPA finalized a determination that Baltimore does meet the annual standard, and it is, therefore, an "attainment area" for $PM_{2.5}$.

The "Baltimore attainment area" consists of six counties: Baltimore City, Baltimore County, Anne Arundel County, Carroll County, Howard County, and Harford County.[q] In 2015, in this area, MDE operated ten $PM_{2.5}$ monitors at eight different sites (two sites have two monitors co-located at the site). Of the ten monitors, three are automated,[r] and seven are filter-based. For simplicity and to assure an "apples to apples" comparison with EIP's filter-based monitoring, we will discuss only MDE's filter-based monitors in this report.

FIGURE 1. MAP SHOWING MDE FILTER-BASED $PM_{2.5}$ MONITORS AND EIP $PM_{2.5}$ MONITORS IN BALTIMORE ATTAINMENT AREA

MDE monitors are identified in yellow text. EIP monitors are identified in blue text. The Curtis Bay and Brooklyn neighborhoods, and adjacent industrial areas, are highlighted in red.

In 2015, MDE's seven filter-based $PM_{2.5}$ monitors were located at six different sites (two at the Padonia site) in the Baltimore attainment area. Three of these sites – Oldtown, BCFD Truck Company, and Northwest Police Station – were located in Baltimore City. Two sites, Essex and Padonia (which housed two filter-based monitors), were located in

[q] Queen Anne's County is identified as part of the Baltimore-Towson Metropolitan Statistical Area, but is not identified as part of the Baltimore attainment area. *See* MDE, Baltimore Nonattainment Area $PM_{2.5}$ Redesignation Request, May 28, 2013, at 2-3, *available at* http://www.mde.maryland.gov/programs/Air/AirQualityPlanning/Documents/SIPDocuments/1_RedesRequest.pdf

[r] One automated monitor is at the Edgewood Chemical Biological Center in Harford County, one is at a welcome center off of I-95 in Howard County, and one is co-located with a filter-based monitor at the Oldtown site in Baltimore City. The Oldtown site is discussed in this report only with respect to the filter-based monitor there.

Baltimore County. One site, Glen Burnie, was in Anne Arundel County. EIP's monitors were located in the Curtis Bay and Brooklyn neighborhoods in the southern part of Baltimore City (Figure 1). All of MDE's monitors were over four miles away from each of the sites at which EIP monitored in Curtis Bay and Brooklyn.

Five of MDE's monitors operated on a three-day schedule, meaning that they recorded a 24-hour sample once every three days, the minimum frequency required by EPA for monitors that are not co-located.[19] These are the Glen Burnie, Essex, Northwest Police Station, and BCFD Truck Company monitors, and one of the Padonia monitors. The second Padonia monitor, which operated for quality assurance purposes, sampled once every twelve days, and the Oldtown monitor sampled every day.[20]

During the relevant time period, the Baltimore area monitoring network met EPA's design criteria for regulatory monitoring networks. A metropolitan statistical area (MSA) with a population of over one million residents must have either two or three monitoring sites, depending on the how the highest $PM_{2.5}$ levels in the area compare to federal standards.[s] The Baltimore area, which is an MSA with over two million residents,[21] has maximum $PM_{2.5}$ levels that require a minimum of three monitors.[22]

Although some flexibility is provided to the agency designing the network, EPA's regulations make clear that most $PM_{2.5}$ monitors, especially in an urban area, are to provide data that is representative of area-wide exposures and not exposures in pollution "hotspots." $PM_{2.5}$ monitors in urban areas are generally supposed to be sited at "neighborhood scale."[23] "Neighborhood scale" monitors should "represent conditions throughout some reasonably homogenous urban sub-region with dimensions of a few kilometers" and are expected to "provide good information about trends and compliance with standards because [sites of this kind] often represent conditions in areas where people commonly live and work for periods comparable to those specified in" federal air quality standards.[24] Thus, the focus of EPA's $PM_{2.5}$ monitoring requirements is notably *not* on capturing pollution levels in smaller areas within an urban area that may have elevated $PM_{2.5}$ levels due to local source pollution.[t] In fact, EPA's regulations state that "micro" or "middle scale" sites, which are the sites scales that would reflect pollution "hotspots," are acceptable only if they "represent many such locations throughout a metropolitan area."[25] Instead, required monitoring stations "must be sited to represent area-wide air quality."[26]

Within the confines of these criteria regarding area-wide air quality, EPA has set a few additional requirements for monitoring network design. Of the monitors required in a certain area, at least one must be "sited at neighborhood or larger scale in an area of

[s] Specifically, two $PM_{2.5}$ monitors are required if the most recent 3-year design value is equal to or below 85% of any federal air quality standard for $PM_{2.5}$, and three $PM_{2.5}$ monitors are required if the most recent 3-year design value is above 85% of any federal air quality standard for $PM_{2.5}$. 40 C.F.R. Part 58, Appendix D, Section 4.7.1(a).

[t] EPA's regulations expressly limit how data collected in $PM_{2.5}$ hotspots may be compared to federal standards. For a monitor to be used to judge compliance with the annual $PM_{2.5}$ standard (12 $\mu g/m^3$), that monitor must be "representative of area-wide air quality." 40 C.F.R. § 58.30. Sites with high concentrations of $PM_{2.5}$ that are representative of a smaller area may be compared to the 24-hour standard but may be compared to the annual standard only if they collectively "identify a larger region of high ambient $PM_{2.5}$" levels. *Id.*

expected maximum concentration[,]" and one must be sited to capture "near-road" pollution levels in areas with one million or more people.[27] If a third monitor is required, then one monitor must also be "sited in an area with poor air quality."[28,u] MDE has designated the Oldtown site in Baltimore City as the site where $PM_{2.5}$ concentrations are likely to be the highest, while the I-95S site in Howard County (an automated monitor) fulfills the "near-road" requirement. It is not clear, from MDE's network plan, which monitor is in the area of poor air quality.[29]

MDE is required to operate at least two "continuous" (automated) monitors in the Baltimore area.[30] As discussed above, MDE has three automated monitors located in the Baltimore area.

Pollution Trends

FIGURE 2. 2010-2014 BALTIMORE $PM_{2.5}$ FILTER-BASED MONITOR TRENDS (ANNUAL AVERAGE)

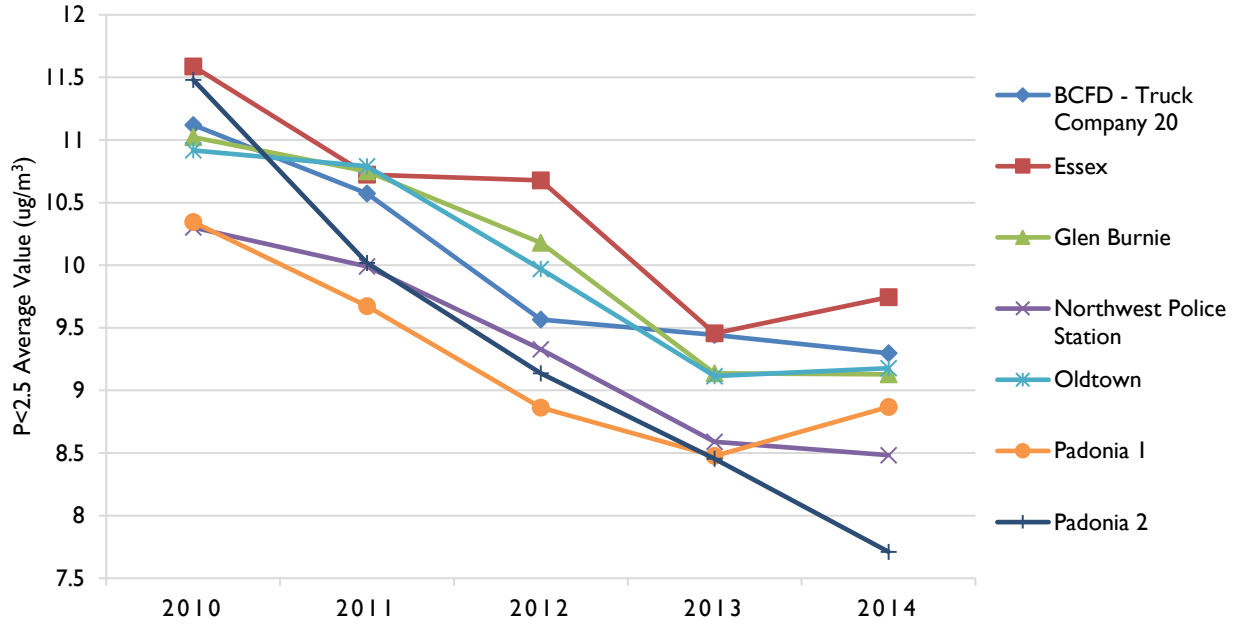


Figure 2 above shows monitor-specific annual averages, for filter-based monitors only, over the last five years for which annual data exist.[v] The Essex monitor, located in Baltimore County, has generally registered the highest annual average levels of $PM_{2.5}$ over the last five years.[w] Over the last two years, the next highest monitor has been the BCFD

[u] EPA's regulations do not explain how an area of poor air quality differs from an area of high pollution concentration.

[v] This chart was created using annual averages based upon quarterly averages. 2015 data is not included because concentrations fluctuate by seasons and all 4 quarters of 2015 data were not available as of this report's release date.

[w] The Essex monitor was also the highest during the first two quarters of 2015.

Truck Company 20 monitor, in Baltimore City, followed by the Oldtown monitor, also in Baltimore City, and the Glen Burnie monitor in Anne Arundel County. The Padonia monitors and the Northwest Police Station monitor, in Baltimore City, have been registering the lowest $PM_{2.5}$ levels since 2011. Pollution levels at all of the monitors were declining until 2014 when most started to plateau or, in the case of Essex, Oldtown, and Padonia 1, to increase slightly.

EIP's $PM_{2.5}$ Monitoring Project

Overview

EIP began sampling $PM_{2.5}$ in the South Baltimore communities of Curtis Bay and Brooklyn in the spring of 2013 and continued to sample periodically through August of 2015. The goals of our project were two-fold. First, we sought to test the hypothesis that $PM_{2.5}$ levels in the residential area of the Curtis Bay neighborhood, located close to port terminals and industrial areas, were higher than concentrations measured by state monitors located elsewhere in Baltimore. Second, we sought to develop a program that would allow ordinary citizens to obtain data that could be accepted as accurate by regulators and other decision makers.

Upon commencing the project, we identified a tension between accuracy and ease of implementation. We desired to create a project that could be replicated by residents of industrialized and port areas and other neighborhoods that may be disproportionately exposed to air pollution. We did not want to presume significant monetary resources or that citizens would have a great deal of time to spend implementing the project. Therefore, we sought to create a project that was relatively inexpensive and easy to carry out. However, we also considered it critical that such a project produce data of high quality that would not be dismissed by officials. If data gathered by citizens demonstrates the existence of a $PM_{2.5}$ "hotspot" in Maryland or elsewhere in the country, it is important that officials feel comfortable basing decisions to reduce pollution on that data.

However, we found that $PM_{2.5}$ monitoring that produces quality-assured data requires more time and resources than $PM_{2.5}$ monitoring that is easy to afford and implement. Higher quality data requires additional time, is technically challenging, and costs more. Each aspect of our project, starting with instrument selection through quality assurance procedures, was influenced by this dynamic.

As EIP's monitoring project progressed, we added procedures and spent more to improve data quality. The outcome, we believe, is a project that can be replicated by citizens that have never sampled air quality before and is within the budget of a community group that can obtain a moderate-sized grant or partner with a research institution that provides some funding and technical support. By the last year of our project, our sampling was producing data with a high degree of reliability.

Based on our experience, we have included several recommendations on pages 16-19 that could help to obtain more useful and accurate data and to assess data quality. Additional guidance is provided in our *$PM_{2.5}$ Citizen Sampling Guide*, which is available on our website.

Instrument Selection

EIP chose the BGI PQ200 model for our monitoring because it is designated by EPA as Federal Reference Method,[31] and is used as an audit monitor by EPA, meaning that it is used to assess the accuracy of other monitors.[32] It is also fairly portable - between 50 and 70 pounds depending on whether legs are attached – and, unlike other Reference Method models that we reviewed, it can be rented. We rented and operated two monitors at once within the Curtis Bay neighborhood in order to increase available data and to compare the data from each site. The rental costs, which included a calibrator for data quality checks, were approximately $3,800 a month. The alternative option, purchasing a monitor, would likely have been over $20,000 for a Reference Method model,[x] and would have yielded a more limited dataset because we could not have monitored in two places at once.

FIGURE 3. BGI PQ200

The BGI PQ200 collects $PM_{2.5}$ samples by drawing a constant flow of ambient air through a particle separator, isolating and depositing $PM_{2.5}$ onto a filter. The filter is weighed at a lab before and after sample collection to determine the net weight gain of $PM_{2.5}$. The monitor can be programmed to sample between certain times and we set it for a 24-hour period, from midnight to midnight, because compliance with the 35 µg/ml standard is measured over 24 hours. In accordance with Reference Method requirements**,** the monitor logs ambient temperature, filter temperature, barometric pressure and flow rate every 5 minutes during a sample period. If these parameters do not stay within certain ranges, the sample date is flagged by the monitor's computer system, and the user knows to consider that day's sample invalid.

In addition to these automated quality checks, we checked leaks and calibrated the monitor's flow, using a Delta TriCal calibrator, each time that we set up a new sample. We received initial training on how to operate the monitor and calibrator from Clean Air Rentals and training from BGI (now MesaLabs) on troubleshooting more advanced monitor problems.[y] Both vendors were extremely helpful and responsive to our technical questions over the course of the project. When operating at a site without electricity, we used a marine battery to power the monitor, and we recharged batteries weekly for free at AutoZone. The BGI PQ200 can also be powered using solar panels.

[x] The last time that we checked, the BGI PQ200 would cost just over $10,000 to purchase, but it was the only Reference or Equivalent Method model that we identified with a purchase cost under $20,000.
[y] Since we started this project, BGI has been purchased by the company MesaLabs, but BGI products are still available through MesaLabs.

Site Selection

One of our primary goals was to determine whether $PM_{2.5}$ levels in the Curtis Bay and Brooklyn neighborhoods are higher than $PM_{2.5}$ levels recorded by MDE's monitors elsewhere in the Baltimore area. Therefore, we selected our monitoring sites based on four criteria: (1) human exposure, i.e. where people live, work, and play; (2) site security; (3) permission to locate a monitor on the property; and (4) proximity to the area with highest expected levels of $PM_{2.5}$. Our hypothesis was that $PM_{2.5}$ levels would be highest in a small residential area in Curtis Bay located between Pennington Avenue and Curtis Avenue. These roadways are both subject to heavy diesel truck traffic, and this is also the closest residential area to the CSX coal terminal rail yard and the Fairfield industrial area and port terminals.

We identified this as a likely area of elevated $PM_{2.5}$ levels during our initial round of sampling in December 2012. At that time, we used a portable monitor, the SKC EPAM 5000,[z] to obtain continuous monitoring data for periods of up to an hour at different locations throughout Brooklyn, Curtis Bay, and Hawkins Point. Over the course of several days, we found that two locations had levels of particle pollution that were significantly higher than the other areas where we sampled. One area was Solley Park, located close to the Fort Smallwood complex, which houses two coal-fired power plants. We did not pursue additional monitoring here because this is not a residential area. The other area was Curtis Bay Park, immediately outside of the Curtis Bay Recreation Center. This is an area where children, who are especially sensitive to $PM_{2.5}$,[33] frequently play outside. It is also located in the middle of a residential neighborhood that is bounded by Curtis Avenue and Pennington Avenue,

FIGURE 4. MAP OF EIP MONITOR SITES AND TARGET AREA

EIP monitoring sites identified in yellow. Target area identified in red.

[z] While the SKC EPAM 5000 was not necessarily accurate at lower $PM_{2.5}$ concentrations, the vendor stated that it could be relied upon to provide relative concentrations and to identify areas where pollution levels are generally higher or lower than in other areas.

two streets with heavy truck traffic. For these reasons, we treated this as our target area for sampling.

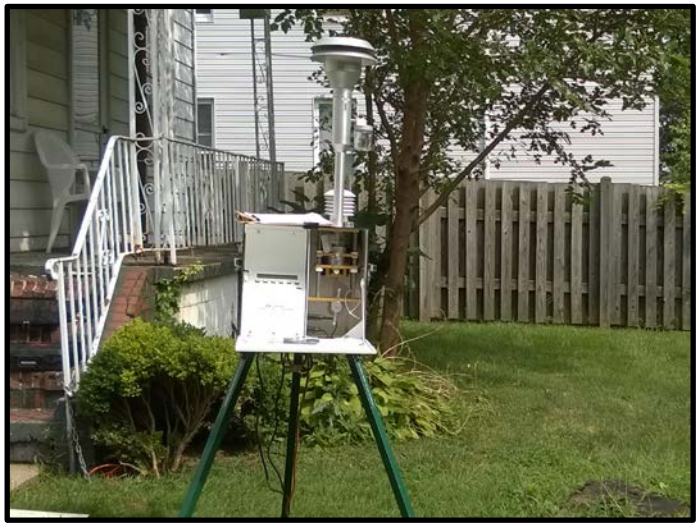
It took us several months to get permission to site a monitor in the target area. We began sampling in April 2013 at the Filbert Street Community Garden and the Chesapeake Center for Youth Development, located 0.2 and 1.1 miles respectively from of the target area. While sampling at these sites, we continued to reach out to residents and institutions in the target area, seeking permission to install a monitor. Residents expressed interest but ultimately declined due to concerns about security, monitor noise, and our need for frequent access to the instruments for data collection. In June 2013, we received permission to install a monitor in the target area on the property of St. Paul's Evangelical Lutheran Church.

TABLE G. DATES AND LOCATIONS OF MONITORING IN CURTIS BAY AND BROOKLYN

Year	Month	Monitoring Sites
2013	April – May	Filbert Street Community Garden Chesapeake Center for Youth Development
	July- October	St. Paul's Lutheran Church Filbert Street Community Garden Chesapeake Center for Youth Development
2014	June - July	St. Paul's Lutheran Church Filbert Street Community Garden
2015	January	St. Paul's Lutheran Church Filbert Street Community Garden
	August	St. Paul's Lutheran Church Filbert Street Community Garden

Photographs and information for each of our sites are provided below.

Site 1. St. Paul's Evangelical Lutheran Church



Site Information

- Neighborhood: Curtis Bay, Baltimore City
- GPS Coordinates: 39.22948, -76.58851
- 4.64 miles from closest state-run monitor (Glen Burnie monitor)
- Located in target area, between Pennington Avenue and Curtis Avenue.

Site 2. Filbert Street Community Garden

Site Information

- Neighborhood: Curtis Bay, Baltimore City
- GPS Coordinates: 39.22471, -76.59196
- 4.27 miles from closest state-run monitor (Glen Burnie monitor)
- Approximately 0.2 miles from target area.

Site 3. Chesapeake Center for Youth Development

Site Information

- Neighborhood: Brooklyn, Baltimore City
- GPS Coordinates: 39.237244, -76.606736 (rooftop); 39.237348, -76.606715 (courtyard).
- 4.2 miles from closest state-run monitor (Glen Burnie monitor)
- Approximately 1.1 miles from target area.

Our sites did not meet EPA's regulatory siting requirements for comparison to federal standards. EPA requires a $PM_{2.5}$ monitor to be located at least ten meters from the "drip line" of any tree and, if possible, the monitor should be twenty meters from the drip line. [34] In addition, the monitor must be a minimum of two meters from any wall, house, or other obstruction, and the distance between the monitor and the obstruction must be at least twice the height that the obstacle protrudes above the sampler. [35] We were not able to identify sites within or close to the target area that met these requirements where we felt that

the instruments would be secure. Placing the monitors next to objects, a tree at the garden and a porch at the church, allowed us to secure the instruments to those objects with heavy chains.

Site security is a factor that citizen scientists must take into account when selecting monitoring sites. This is especially true because Reference and Equivalent Method monitors are generally expensive to purchase, replace, or repair. Security problems can limit access to the best sites and can also compel removal or changes of monitoring equipment on very quick notice. For example, a break-in occurred in August 2013 at the Filbert Street Community Garden, while we were monitoring there. We had to quickly move the monitor to the Chesapeake Center for Youth Development for safe keeping.

Laboratory Support

While monitor selection is important, it is also critical to choose the right laboratory to analyze filter samples. The lab provides filters for use in the monitors, weighing the filters before sending them to the user. After sampling, the user returns filters to the lab, where they are reweighed to determine the final $PM_{2.5}$ concentration. Filters may need to be reweighed multiple times by the lab before and/or after use, depending on circumstances. They must also be kept in an environment conditioned to a certain temperature and humidity, and the lab must also maintain the accuracy of the weighing scale. EPA sets quality assurance requirements for labs, although, in our experience, it may be necessary for a lab to go above and beyond these requirements to produce reliable data.

In the last year of EIP's project, 2015, we used the laboratory at Research Triangle Institute International (RTI), headquartered in Research Triangle Park, North Carolina, to analyze our samples. For 35 years, RTI has contracted with the U.S. EPA to provide analytical and technical support to multiple EPA divisions, including the Office of Air Quality Planning and Standards. We strongly recommend that citizen scientists conducting filter-based $PM_{2.5}$ sampling use a laboratory, like RTI, that provides support to a federal or state agency in this kind of an analysis. As discussed in more detail below, when we began using RTI in 2015, the quality of our data improved markedly.

In 2013 and 2014, EIP used a laboratory that we selected based on apparent guarantees of accuracy and relatively low cost. This laboratory followed EPA regulatory requirements for $PM_{2.5}$ filter analysis. However, after discussing our 2013 and 2014 results with MDE and diagnosing sources of error by conducting a co-location at one of MDE's monitoring sites, we decided to switch to RTI.[aa] The specific concerns regarding the 2013

[aa] Before switching laboratories, we conducted a close comparison of the Standard Operating Procedures (SOPs) for 3 different labs: (1) the lab that EIP used in 2013-2014; (2) RTI; and (3) the state lab used by MDE and operated by the Maryland Department of Health and Mental Hygiene (DHMH). We found that, while all 3 labs followed EPA requirements, RTI and the DHMH lab went above and beyond these requirements in implementing quality checks. For example, RTI and DHMH measured filter stability before shipment to the user by reweighing a subset of filters multiple times, if necessary, to determine filter weight loss and assess when the filters reach a stable weight. Filters can lose weight on their own after manufacturing through "off-gassing" of volatiles in the filter. Conversely, the laboratory that we used in 2013 and 2014 did not have in its SOP requirements to weigh filters multiple times before shipment in order to determine filter stability, though it did meet EPA requirements for pre-shipment conditioning and initial filter weighing.

and 2014 data are discussed in more detail below in the section titled Assessing Data Quality. While RTI's analysis fee was more per sample, the improved data quality was well worth the expense.

Filter Handling Procedures

We also improved our filter handling procedures between our 2014 and 2015 sampling sessions. Because a goal was to make our project relatively easy for others to replicate, in 2013 and 2014, we avoided the most burdensome filter-handling procedures required by EPA, some of which we had been told were unnecessary by persons experienced in $PM_{2.5}$ sampling. However, RTI provided us with support that allowed us to add a number of procedures for how we handled filters and filter cassettes (devices that hold and stabilize the filter inside the monitor).

The differences between 2013 and 2014 filter handling and 2015 filter handling are set forth in a table at Appendix A. Of these, the most substantive were that we received filters already inserted into filter cassettes (avoiding the need to insert them in the field), kept the filters cool at all times after removing them from the monitor following sampling, and adhered to a strict schedule ensuring that no more than 30 days elapsed between initial weighing at the lab and sampling in the field or between field sampling and final weighing at the lab.

RTI assisted us enormously by providing us with kits that included already-assembled filters in filter cassettes, metal cassette covers, coolers, and ice packs to keep the filters cool while shipping. We strongly recommend that citizens undertaking a $PM_{2.5}$ sampling project work with a laboratory that will provide these materials, especially providing filters already assembled in filter cassettes, in order to streamline the process and improve data quality.

Project Cost

We provide an estimate of project costs in Table H to assist community groups and others that are interested in replicating this project. Shipping costs are excluded and will differ by location.

TABLE H. 30-DAY APPROXIMATE PROJECT COST* - 2 MONITORS

Types of expense	Cost (30-day period)	Notes
2 monitors rental	$2,500	$1,250 per monitor
Calibrator rental	$410	
Laboratory analysis (RTI)	$900	Assumes 20 samples. 10 per monitor. Collected once every 3 days. Includes coolers and ice packs.
Total:	**$3,810**	

* Excludes shipping and battery/solar panel costs, if necessary for power. Based on 2015 sampling. Prices may vary.

Because the monitors are expensive, approximately $10,000 to purchase each, we also recommend obtaining insurance to cover potential damage due to theft, vandalism, or mishandling during shipment.

Assessing Data Quality

For citizen scientists sampling $PM_{2.5}$, it helps to understand how to evaluate the quality of the data obtained. Several methods for doing this are presented below. However, the most important thing that citizens can do, if there is a cooperative state or local air quality agency, is to develop a dialogue with that agency's monitoring staff and to conduct a co-location with official monitors.

Co-location

In a co-location, two monitors are run simultaneously in the same location in order to compare the data from the two instruments. During the summer of 2014, EIP met with MDE's monitoring staff to discuss our project and our data. Following this discussion, MDE allowed us to co-locate our monitors at one of their sites in August of 2014 in order to compare data taken simultaneously and in the same place. The co-location was conducted at MDE's Glen Burnie site in Anne Arundel County, which was the closest site to our monitors in Curtis Bay. MDE operates a filter-based Federal Reference Method monitor at its Glen Burnie site. The data from that co-location is presented in Appendix B and shows that there was no correlation between our results and MDE's (correlation coefficient = 0.09).[bb]

After this co-location, we switched to RTI's laboratory and added the filter handling procedures discussed above. With those processes in place, we conducted a second co-location with MDE's Glen Burnie monitor in February 2015. EIP's results from the February co-location, shown in Table I below, were very highly correlated with MDE's

[bb] Correlation coefficients are interpreted as showing a strong correlation if they are close to -1 or 1 and a weak correlation if they are close to 0.

(correlation coefficient > 0.99). Levels rose and fell together. However, EIP's monitors consistently registered slightly higher concentrations than MDE's, with an average difference of 12.3%. EPA's data quality objectives for bias in $PM_{2.5}$ monitoring allow a bias of +/- 10% over a three year period. EIP's results were reasonably close to that range even though we were limited to comparing samples from a single month rather than three years. Data gathered by the EPA shows that the types of monitors used by EIP and MDE have both demonstrated a negative bias when operated in official networks (both read lower concentrations than a co-located audit monitor assumed to be correct), but EIP's model, the BGI PQ200 with Very Sharp Cut Cyclone (VSCC) has demonstrated less of a negative bias than MDE's model, [36] the R&P Sequential with VSCC. [cc]

TABLE I. 2015 CO-LOCATION WITH MDE

Sample Date	Site	24-hour Concentration (µg/m³)		Difference	Percent Difference
		EIP	MDE		
2/5/2015	Glen Burnie	6.7	5.7	1.0	17.5%
2/8/2015	Glen Burnie	29.0	28.4	0.6	2.1%
2/11/2015	Glen Burnie	13.3	11.5	1.8	15.7%
2/14/2015	Glen Burnie	10.7	9.4	1.3	13.8%
2/17/2015	Glen Burnie	17.1	14.9	2.2	14.6%
2/20/2015	Glen Burnie	11.9	10.5	1.4	13.3%
2/23/2015	Glen Burnie	9.5	8.7	0.8	9.2%
Average		**14.0**	**12.7**	**1.3**	**12.3%**[dd]

Correlation between Monitors

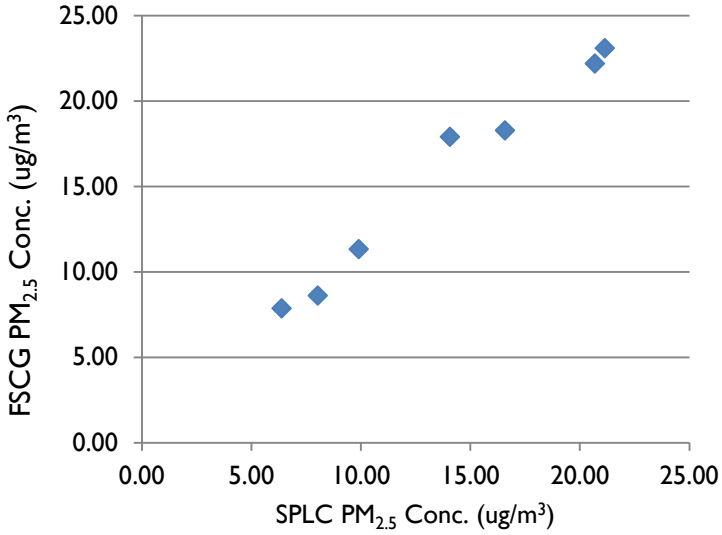
MDE also informed us, during our summer 2014 meeting, that $PM_{2.5}$ monitors located in the same area may measure different concentrations, but that the pollution levels

[cc] In an analysis of data from 2008-2010, EPA's consultants found that the BGI with VSCC model had an average bias of -2.0% while the R&P Sequential with VSCC model had an average bias of -5.9%. EPA Office of Air Quality Planning and Standards, "$PM_{2.5}$ Bias Continues to Puzzle," The QA Eye Newsletter, at 4, Issue 13, August 2012, *available at* http://www3.epa.gov/ttnamti1/files/ambient/qa/qanews13.pdf. A graph from a more recent study using 2011-13 data shows less of a difference between the two monitors, although both still demonstrated a negative bias and the BGI model was still less negative than the R&P model. Eberly, Shelley, et. al., Bias in Filter Based $PM_{2.5}$ methods, National Ambient Air Monitoring Conference, August 2014, *available at* https://www3.epa.gov/ttnamti1/files/2014conference/wedqaeberly.pdf

[dd] EIP calculated average percent difference for the co-location by averaging the percent difference between each individual data pair. This is part of EPA's equation for calculating bias, which is at 40 C.F.R. Part 58, Appendix A, Parts 4.1.3 and 4.3.1. EPA's equation uses percent difference plus a 95% confidence interval based on the number of data points involved in the calculation. Using EPA's method, the bias demonstrated by our monitor (treating MDE's monitor as the audit monitor) during the co-location would be 12.3% +/- 4.77. In other words, based on the limited dataset that we have, we could say that we are 95% confident that the bias between our monitors and MDE's would be between 7.5 and 17.08%. Having more samples would reduce the range of potential error.

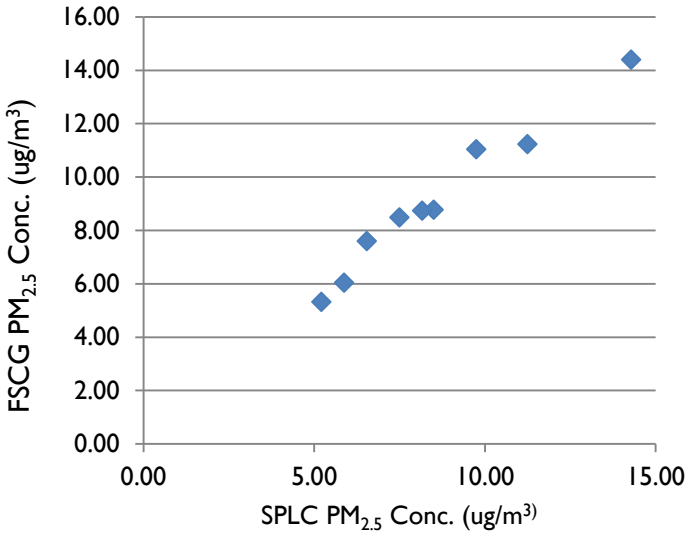
should be highly correlated (should rise and fall together). Prior to 2015, the $PM_{2.5}$ levels measured by EIP's two monitors located in Curtis Bay, which were very close in proximity, were not correlated. However, after we switched laboratories and filter-handling procedures, our data became much more highly correlated. This can be seen in scatter plots for our two Curtis Bay sampling sessions in 2015, one in January and one in August.

FIGURE 5. JANUARY 2015 MONITORING DATA COMPARISON



In January 2015, data from our monitors at St. Paul's Lutheran Church (SPLC) and Filbert Street Community Garden (FSCG) was highly correlated, with a correlation coefficient of 0.99 (Figure 5).

FIGURE 6. AUGUST 2015 CURTIS BAY PM2.5 READINGS



Similarly, in August 2015, data from our monitors at St. Paul's Lutheran Church (SPLC) and Filbert Street Community Garden (FSCG) was highly correlated, with a correlation coefficient greater than 0.98 (Figure 6).

Recognizing Data Quality

Citizens should look for certain indicators in $PM_{2.5}$ monitoring results when assessing data quality. In 2013 and 2014, a number of our readings came back below the laboratory's detection limit (<0.083 $\mu g/m^3$). While such "non-detects" are not anomalous in many kinds of datasets, they are anomalous for $PM_{2.5}$ data, as demonstrated by datasets produced by official monitoring networks.[ee] In fact, $PM_{2.5}$ concentrations below 2 $\mu g/m^3$ are rare in such datasets, and citizen scientists should consider it a red flag if they obtain multiple readings in this range, especially in an urban area. Very high readings without explanation should also be considered a red flag. We obtained two very high readings (66.44 $\mu g/m^3$ at the garden in August 2013 and 52.07 2 $\mu g/m^3$ at the church in October 2013) for which we could find no explanation, such as a local fire. Readings that are very far outside the range of other monitoring results, without explanation, also suggest that monitor functions, filter handling, or lab procedures may need improvement.

Curtis Bay $PM_{2.5}$ Data Discussion

EIP collected $PM_{2.5}$ data in the Curtis Bay neighborhood periodically from spring 2013 through August 2015. Our 2014 data is provided in Appendix B as an example of the data obtained before we switched to RTI and added the other procedures discussed above. However, we do not consider this data reliable or sufficient for comparison to data captured by MDE's monitors.

We are confident in the data we obtained in 2015 after switching to RTI, however. This data, collected at St. Paul's Lutheran Church and the Filbert Street Community Garden in January and August 2015, is presented in Tables J and L below. The 2015 datasets are not statistically robust enough to confirm or disprove our theory that $PM_{2.5}$ levels in Curtis Bay are higher than at MDE's other $PM_{2.5}$ monitoring sites in the Baltimore area. More monitoring would be required to make a definitive statement regarding this.

However, we did record higher average concentrations at both EIP Curtis Bay monitors than the average concentrations measured at MDE's Glen Burnie monitor, the closest state monitor to Curtis Bay by physical proximity, and MDE's Essex monitor, which has been registering the highest $PM_{2.5}$ levels in MDE's Baltimore network, out of the filter-

[ee] Summaries of official datasets are available on EPA's AirData website at http://www3.epa.gov/airdata/ad_rep_mon.html. Complete sets of official data can be downloaded from EPA's Air Quality System (AQS) website at http://aqsdr1.epa.gov/aqsweb/aqstmp/airdata/download_files.html.

based monitors.[ff] In addition, we consistently recorded higher concentrations of $PM_{2.5}$ at St. Paul's Church, located in our "target area" of the neighborhood, than at the Filbert Street Garden. Since both sites were operated by EIP, using the same model instrument and the same filter handling procedures, it is more likely that the data show an actual difference in $PM_{2.5}$ levels between the sites than a difference in sampling procedures and equipment. This data trend provides support for our hypothesis that $PM_{2.5}$ levels in the target area are higher than elsewhere in Curtis Bay.

The difference between EIP's Curtis Bay monitors and MDE's monitors located elsewhere may be due to differences in $PM_{2.5}$ levels at the sites or to bias in the monitoring instruments. As discussed above, EIP's monitors registered concentrations that were 12.3% higher on average than MDE's Glen Burnie monitor during a 2015 co-location. However, during our January sampling in Curtis Bay, the average concentration that we measured at St. Paul's Church was 23.5% higher than the average concentration recorded at MDE's Glen Burnie site and 20.3% higher than the average at MDE's Essex site. The average differences between all monitors during the August sampling, however, were 10% or lower.

TABLE J. CURTIS BAY SAMPLING DATA, JANUARY 2015 SESSION

Sample Date	$PM_{2.5}$ Concentration (µg/m³) by Site[gg]			
	EIP Curtis Bay Church	EIP Curtis Bay Garden	MDE Anne Arundel Co. Glen Burnie Site (closest to Curtis Bay)	MDE Baltimore Co. Essex Site (highest in network)
1/9/2015	7.9	6.4	5.6	6.0
1/12/2015	18.3	16.6	14.5	15.4
1/15/2015	23.1	21.1	21.3	21.0
1/18/2015	17.9	14.1	13.2	15.3
1/21/2015[hh]	22.2	20.7	22.0	18.6
1/24/2015	11.3	9.9	8.6	10.6
1/27/2015	8.6	8.0	7.1	6.2
Average	**15.6**	**13.8**	**13.2**	**13.3**

Our January 2015 monitoring session in Curtis Bay yielded 14 data points in total, 7 representing $PM_{2.5}$ levels at St. Paul's Church and 7 representing $PM_{2.5}$ levels at the Filbert Street Community Garden. We did not measure any levels that came close to the 24-hour

[ff] Three monitors within the Baltimore network had higher annual average concentrations in 2014 than the Essex monitor. However, all three were "automated" (not filter-based) Federal Equivalent Method monitors and it appears that this difference could be due to the type of instrument. For example, at the Oldtown site in Baltimore City, MDE has co-located an automated $PM_{2.5}$ monitor with a filter-based $PM_{2.5}$ monitor. The 2014 annual average for the automated model was 11.1 µg/m³, while the 2014 average for the filter-based monitor was 9.2 µg/m³.

[gg] EIP's data has been rounded to one decimal place for an "apples to apples" comparison with MDE's data, which is also reported to one decimal place, and to meet the requirements of 40 C.F.R. Part 50 Appendix N (3.0)(b).

[hh] Due to receipt temperature, filter could not be post weighed prior to sample expiration. However, results appear realistic and correlate with results from Glen Burnie and Essex, so we are presenting them here.

federal air quality standard of 35 µg/m^3. The dataset is also small and representative of only one season, making it inappropriate for comparison to the annual standard of 12 µg/m^3.[ii] The pollution levels measured at the church and the garden had an average difference of 1.8 µg/m^3 (14.1%) and were highly correlated, with a correlation coefficient of 0.99 (Figure 5). Levels measured at the church were consistently higher than levels measured at the garden.

TABLE K. COMPARISON OF AVERAGE $PM_{2.5}$ CONCENTRATIONS AMONG SITES, JANUARY 2015

Sites Compared (Average Concentrations)	Difference in µg/m^3	Percent Difference[jj]
Curtis Bay Church v. MDE Glen Burnie	2.4	23.5%
Curtis Bay Church v. MDE Essex	2.3	20.3%
Curtis Bay Church v. Curtis Bay Garden	1.8	14.1%
Curtis Bay Garden v. MDE Glen Burnie	0.6	8.1%
Curtis Bay Garden v. MDE Essex	0.5	5.8%

TABLE L. CURTIS BAY SAMPLING DATA, AUGUST 2015 SESSION

Sample Date	$PM_{2.5}$ Concentration (µg/m^3) by Site[kk]			
	EIP Curtis Bay Church	EIP Curtis Bay Garden	MDE Anne Arundel Co. Glen Burnie Site (closest to Curtis Bay)	MDE Baltimore Co. Essex Site (highest in network)
8/7/15	8.5	7.5	7.2	6.2
8/10/15	7.6*	6.5	5.7	5.5
8/13/15	5.3	5.2	4.8	7
8/16/15	11.2	11.2	9.5	10.6
8/19/15	11.0	9.7	8.6	0
8/22/15	6.0	5.9	6.2	Not available
8/25/15	8.7	8.2	7.8	0
8/28/15	8.8	8.5	9.5	8.6
8/31/15	14.4	14.3	13.7	Not available
Average**	**9.2**	**8.8**	**8.4**	Not calculated due to missing data

* Data point invalid because power to monitor shut off mid-sampling
** Averages do not include data from 8/10/15.

Our August 2015 monitoring session in Curtis Bay yielded 17 valid data points in total. The data point from 8/10/15 at St. Paul's Church was invalidated because power to the monitor was shut off after 13 hours, instead of gathering a 24-hour sample. Therefore,

[ii] This standard is also measured over a 3-year average.
[jj] To be consistent with our calculations of % difference during the co-location, here we calculated the % difference for each data pair and then averaged all of the differences for each site comparison.
[kk] EIP's data has been rounded to one decimal place for an "apples to apples" comparison with MDE's data, which is also reported to one decimal place, and to meet the requirements of 40 C.F.R. Part 50 Appendix N (3.0)(b).

we did not include data gathered on 8/10/15 at any monitor in our averages. It also appears that MDE's Essex monitor was experiencing technical problems during this time as two data points were unavailable and two registered as zeros (highly anomalous). Therefore, we did not compare averages obtained at the other sites to average concentrations registered at MDE's Essex site.

TABLE M. COMPARISON OF AVERAGE $PM_{2.5}$ CONCENTRATIONS AMONG SITES

Sites Compared (Average Concentrations)	Difference in $\mu g/m^3$	Percent Difference[ll]
Curtis Bay Church v. MDE Glen Burnie	0.8	10.0%
Curtis Bay Church v. Curtis Bay Garden	0.4	5.1%
Curtis Bay Garden v. MDE Glen Burnie	0.4	4.7%

Again, the August 2015 dataset is not appropriate for comparison to the annual federal air quality standard of 12 $\mu g/m^3$, and no levels approached the 24-hour standard of 35 $\mu g/m^3$. As with our January 2015 dataset, $PM_{2.5}$ concentrations measured at St. Paul's Church in August were consistently higher than those measured at the Filbert Street Garden (for all dates except for 8/16/15 when the 2 sites registered the same concentration). The average difference between the two sites was 0.4 $\mu g/m^3$ (5.1%), and the data from the two sites was highly correlated, with a correlation coefficient greater than 0.98 (Figure 6).

Recommendations

For Citizen Scientists

Citizen sampling of $PM_{2.5}$ is very challenging, especially when the goal is to obtain data that will be considered reliable by regulators and other officials. We found discussions with the state environmental agency's monitoring staff to be critical in helping us to improve our project. Another key lesson that we learned was to choose the right laboratory, ideally one that conducts $PM_{2.5}$ analysis for a state or federal agency, even if the analysis costs more than it would at other labs. In addition to the improved laboratory procedures, a good lab may be able to help citizens improve their own filter handling procedures, as RTI did for us, by providing equipment that streamlines the process.

As stated previously in this report, citizen scientists should tailor their projects to their specific goals and financial and staff resource limitations. For groups that wish to use monitoring as a community engagement tool or to obtain instantaneous or short-term data, it will likely make sense to choose a different approach than the one that we took. However, for groups that want to replicate our project, we recommend following the procedures that EIP used in 2015 as described in this report and in our *$PM_{2.5}$ Citizen Sampling Guide* (available on our website). We further recommend conducting regular evaluations of data quality using the methods described under the Assessing Data Quality section of this report and

[ll] Based on average of % difference for each data pair in each site comparison.

discussing the project and preliminary data with agency monitoring staff if possible. Lastly, a group seeking to replicate this project should allocate an average of 2 hours per week of staff time to responding to unforeseen problems, such as equipment troubleshooting, in addition to the time necessary to operate monitors and collect samples.

For Officials

Because of the complexity of $PM_{2.5}$ monitoring, environmental agencies can play a critical role in assisting citizens with a project like this. We strongly recommend that agencies make their laboratories available to citizens who are conducting filter-based $PM_{2.5}$ sampling for a free or for a reduced fee. For laboratories that already offer this service, we recommend providing citizens with equipment that will allow them to keep filters cool after sampling, to fully protect filters through the proper enclosures, and to avoid assembling filters and filter cassettes outside of the lab. It would also be helpful to provide citizens with chain-of-custody forms to help ensure that filters are used for sampling within 30 days of initial weighing and that filters are returned to the lab in time to be weighed 30 days after sampling.

Additionally, though we are very grateful for the input that MDE provided on this project and the opportunity that they allowed us for co-location, we think it is important that environmental agencies, with the right financial support, assume responsibility for at least some pollution "hotspot" monitoring. For a highly complex and potentially harmful pollutant like $PM_{2.5}$, agencies can do this far more efficiently and with less of a learning curve than citizens.

A model for such a program could be the community air monitoring program recently conducted by the Minnesota Pollution Control Agency (MPCA).[37] Over the course of two years, MPCA conducted monitoring for $PM_{2.5}$ and toxic air pollutants in seven different neighborhoods where a state monitor was not located. The Minnesota Legislature's directive to the agency was to prioritize "areas where low-income, indigenous American Indians, and communities of color are disproportionately impacted by pollution from highway traffic, air traffic and industrial sources."[38] Although a final report is not yet available from MPCA for the project, an interim report released in January 2015 states that elevated $PM_{2.5}$ levels were found at several of the community monitoring sites when compared with the state's fixed monitoring sites and that possible causes were being explored.[39] In addition, in 2015, funding was renewed for limited additional monitoring at two of the original seven sites, which monitoring will extend until the end of 2016.[40]

State legislatures and the U.S. EPA should make available funding for these kinds of hotspot monitoring projects, as $PM_{2.5}$ monitoring can be expensive. The Minnesota Legislature allocated over $500,000 for the environmental justice monitoring program in that state.[41] Other states and federal agencies should also consider providing funding to environmental agencies for these kinds of projects.

For Monitoring in Curtis Bay

State and local air quality agencies should be particularly willing to consider hotspot monitoring in states, like Maryland, where no hotspot monitoring has ever been done before by the agency and where existing data, such as emissions data, indicates an area of concern into which new pollution sources are being introduced.

This is the case in the Curtis Bay area, which has consistently had among the highest emissions in Maryland from industrial plants for a number of pollutants and which, until very recently, was the proposed site of the country's largest waste incinerator.[mm] EIP recommends that MDE work with the City of Baltimore to conduct $PM_{2.5}$ monitoring in Curtis Bay Park just outside of the Curtis Bay Recreation Center, which is city property. This park is sandwiched between two roadways that are subject to heavy diesel truck traffic, not far from a rail yard, and it is across the street from a vehicle yard maintained by the Maryland Transit Authority. It is one of two locations where EIP obtained the most elevated readings during our portable $PM_{2.5}$ sampling in December 2012. And it is also a place where children, who are especially vulnerable to $PM_{2.5}$ exposure, play and exercise outdoors, which further increases the health risks associated with $PM_{2.5.}$[42]

[mm] A company called Energy Answers received Clean Air Act approvals in 2010 to construct the nation's largest trash incinerator in Curtis Bay. In 2016, MDE found that those approvals had expired as a matter of law due to company's extensive lapse in construction of the facility.

APPENDIX A.
Comparison of Filter Handling Procedures, 2013-2014 v. 2015

	2013-2014 Sampling	2015 Sampling
Loading filters into monitors	Loaded and unloaded filters into cassettes at monitoring sites	Used cassettes pre-loaded with filters, provided by RTI.
Filter protection	Wore gloves when handling filters and cassettes (starting in 2014).	Wore clean latex gloves when handling filters and cassettes. Stored cassettes in metal protective covers at all times when not in use.
Filter storage and shipment	Shipped filters to lab in padded envelope, inside plastic containers provided by lab.	Stored cassettes in non-static bags and refrigerated in cooler or refrigerator after sampling.
Tracking samples	Kept chain of custody forms.	Kept chain of custody forms.
Schedule	All sampled filters were shipped back at the end of the monitoring period and did not adhere to 30 day sampling and gravimetric analysis cycle. Sampled every other day until 2014 co-location with MDE, after which we sampled every 3 days.	Filters used for sampling within 30 days of initial weighing at laboratory and shipped to laboratory in time for final weighing within 30 days of sample date. Sampled every 3 days to align with MDE's sampling schedule.
Filter cooling	Filters not cooled.	Filters kept cool at all times between removal from monitor and arriving at lab, either in refrigerator or in a cooler with frozen ice packs.
Trip, field, and lab blanks	Used field and trip blanks, but the lab did not retain a filter to use as a lab blank.	Used field and trip blanks; lab retained lab blanks.
Quality of results	Results were not correlated with each other or with results from MDE's Glen Burnie sampling location. Results included non-detects, values lower than 0.083 µg/m^3, and outliers.	Results highly correlated with MDE's Glen Burnie monitoring location and other EIP operated sites. Results contained no non-detects, values lower than 1 µg/m^3, or outliers.

APPENDIX B.
2014 Monitoring Data from Curtis Bay

EIP June - July 2014 Monitoring Data

Sample Date	$PM_{2.5}$ Concentration (µg/m3) by Site		
	EIP Curtis Bay Garden	EIP Curtis Bay Church	Considered Reliable?
6/17/2014	13.56	12.53	No
6/19/2014	12.73	9.33	No
6/21/2014	6.12		
6/24/2014	0.29	<0.083	No
6/26/2014	4.28	<0.083	No
6/28/2014	5.16	4.50	No
7/1/2014	10.53	<0.083	No
7/10/2014	9.15	10.91	No
7/12/2014	5.70	10.57	No
7/15/2014	6.10	6.16	No
7/17/2014	4.63	<0.083	No
7/19/2014	5.66	0.79	No
7/22/2014	0.29	1.04	No
7/24/2014	2.75	2.04	No
7/31/2014	12.78	14.37	No

Non-detects and anomalously low readings identified in pink.

During 2013 and 2014, EIP obtained datasets that we do not consider to be reliable. We are providing the table above as an example of the kind of data that should raise alarms for citizen scientists. The specific problems are:

- Multiple readings below the laboratory's detection limit (<0.083 µg/m^3).
- Multiple very low readings. Here, in addition to the non-detects, there were two readings near or below 1.0 µg/m^3.
- Data does not rise and fall together/is not correlated. The monitoring sites were located fairly close together and concentrations should have risen and fallen together.

APPENDIX C.
2014 EIP v. MDE Co-location Table

2014 Co-location with MDE

Sample Date	Site	24-hour Concentration ($\mu g/m^3$)		Difference - EIP & MDE
		EIP	MDE	
8/3/2014	Glen Burnie	<0.083	3.2	-
8/9/2014	Glen Burnie	<0.083	15.5	-
8/6/2014	Glen Burnie	21.70	13.2	8.50
8/15/2014	Glen Burnie	21.73	6.9	14.83
8/21/2014	Glen Burnie	16.15	10.8	5.35
9/2/2014	Glen Burnie	10.29	9.7	0.59
Average		**17.47**	**10.15**	**7.32**

In the summer of 2014, MDE allowed EIP to co-locate our monitors alongside MDE's monitor at the Glen Burnie site for the first time. The data from that co-location is presented above, and shows no correlation between our results and MDE's (correlation coefficient = 0.09).[nn]

[nn] Correlation coefficients are interpreted as showing strong correlation if they are close to -1 or 1, and weak correlation if they are close to 0.

References

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[14] 40 C.F.R. Part 58, App. A, Parts 4.1.3 and 4.3.1.
[15] U.S. EPA, Quality Assurance Handbook for Air Pollution Measurement Systems, Vol. II, Sec. 3.0, 2 of 6 (May 2013), available at: https://www3.epa.gov/ttnamti1/files/ambient/pm25/qa/QA-Handbook-Vol-II.pdf
[16] 40 C.F.R. Part 50, App. L, Section 5.0; 40 C.F.R. Part 58, App. A, Section 2.3.1.1.
[17] 40 C.F.R. Part 59, App. A, Section 4.2.1, 4.3.1
[18] U.S. EPA *supra* note 1.
[19] 40 C.F.R. § 58.12.
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[21] MDE 2016 Network Plan at 30.
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[24] 40 CFR Part 58, App. D, Section 4.7.1(c)(3).
[25] 40 CFR Part 58, App. D, Section 4.7.1(b).
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[27] 40 C.F.R. Part 58, App. D, Section 4.7.1(b)(1)-(2).
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