Chemist-Community Collaborations Project Report

Characterizing Airborne Particulates in Hunting Park

Phase 1 | November 2010

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Public Interest Law Center of Philadelphia — Affiliated with the Lawyers Committee for Civil Rights Under Law — Since 1969

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OVERVIEW

Airborne particulate matter [1] (PM) has long been a concern for residents of Hunting Park, a North Philadelphia neighborhood designated as an environmental justice community. Hunting Park is home to a number of industrial facilities, often located in close proximity to residential areas and schools. In addition, residents of Hunting Park suffer at a greater rate than other Philadelphians from asthma, a respiratory condition that has been shown to be exacerbated by high PM concentrations. PM levels in Philadelphia are routinely monitored by Air Management Services (AMS), a division of the city's Department of Public Health; however, the nearest monitoring station in the AMS network is located well outside the Hunting Park neighborhood.

Hunting Park residents suspect that PM created by emissions from local industrial facilities and associated truck traffic may be harming their health, but lack the quantitative data needed to be informed about their exposures to PM. The Hunting Park Stakeholders group thus sought an independent assessment of the air quality in their community, intending to focus first on the concentration, and second on the composition of PM in the ambient air.

This report documents results from Phase 1 of a project geared to understand and characterize PM in a pilot study area of Hunting Park.[2] In Phase 1 of the air quality assessment, a network of continuous PM monitors developed by undergraduate engineering students from Drexel University was deployed for one week in seven locations throughout the Hunting Park study area, proximate to a known source of air emissions. Measured concentrations of particulates, 2.5 microns in diameter and smaller ($PM_{2.5}$), were then compared across sites within the study area, to federal regulatory standards for $PM_{2.5}$, and to $PM_{2.5}$ levels measured at other AMS monitoring sites throughout Philadelphia.

During the monitoring period, $PM_{2.5}$ levels in the Hunting Park study area did not exceed the National Ambient Air Quality Standards (NAAQS). Moreover, within the likely range of uncertainty, $PM_{2.5}$ levels were relatively consistent throughout the study area, with no significant differences between levels measured in the residential core of the community versus along the industrial strip at the eastern edge of the neighborhood. Measured levels also did not vary predictably according to time of day or day of the week. $PM_{2.5}$ levels measured in the study area were substantially lower than measurements by the AMS at their nearest monitoring site. However, it can not be determined at this time how much of this variation is due to differences in local environmental conditions and how much is due to differences in monitoring techniques. The tight clustering of $PM_{2.5}$ levels at sites around the city suggests that much of the difference may be due to the monitors used.

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[1] Airborne particulate matter consists of a wide class of materials of diverse chemical compositions and sizes that travel by air in the form of discrete solid particles and liquid droplets. Research Priorities for Airborne Particulate Matter: I. Immediate Priorities and a Long-Range Research Portfolio, Committee on Research Priorities for Airborne Particulate Matter, National Research Council, (1998).

[2] The researchers chose a study area bounded by Lawrence, Wingohocking, Front and Bristol streets, the boundaries of which were determined in consultation with local residents. Factors in determining the study area boundaries included the residents' desire to obtain readings from locations in close proximity to a known source of emissions, as well as the range limitations of the wireless technology used by the monitoring network employed in the study.

The findings thus appear not to account for the anecdotal concerns of high concentrations of dust and fumes generated by industrial facilities in the neighborhood; they also suggest that the high rates of asthma reported in the Hunting Park neighborhood are likely not attributable to $PM_{2.5}$ levels alone. However, uncertainty about the quality of the data produced by the monitoring method highlights the need for further investigation. Thus, the following actions are recommended:

(a) Validate the data from the sensor nodes developed by Drexel students more thoroughly against accepted methods used by AMS;
(b) Undertake monitoring with the sensor nodes simultaneously in Hunting Park and a “control community” relatively free of industrial and mobile sources of airborne particulates;
(c) Combine continuous air monitoring with simultaneous real-time health symptom reporting in order to investigate possible connections between $PM_{2.5}$ fluctuations and health;
(d) Undertake a similar investigation of PM_{10} and Total Suspended Particulate (TSP) levels in the study area; and
(e) Employ monitoring methods that sample particulate matter in order to determine size distribution and chemical composition of particulates in Hunting Park.

It is expected that some combination of these activities will be undertaken in Phase 2 of this study.

BACKGROUND – HUNTING PARK

Located within Upper North Philadelphia, the Hunting Park neighborhood occupies approximately 2.7 square miles, bounded roughly by West Wingohocking Street, Old York Road, the SEPTA regional rail tracks, and G Street (see Figure 1).[3] It comprises densely populated residential areas in close proximity to historic and continuing industrial uses. One of the largest of these industrial facilities is Richard S. Burns & Co. , a construction and demolition waste recycling facility and transfer station that processes up to 1500 tons of construction and demolition waste per day, largely by shredding.[4] Other industrial land uses in the Hunting Park neighborhood include specialty chemical manufacturing, auto body shops, car detailing and painting facilities, and a sprawling auto scrap yard. Hunting Park lacks adequate, safe green spaces[5] and is burdened with numerous vacant and abandoned lots which attract trash, vermin, and associated public health impacts.

Hunting Park residents report anecdotally that they experience poor air quality as a result of emissions from local industrial and solid waste processing facilities. Air Management Services (AMS), a division of the City of Philadelphia's Department of Public Health, operates a network of monitoring stations throughout the city; however, the station nearest to Hunting Park that measures ambient air quality, including PM, is at 1501 E. Lycoming Street, over two miles east of the most densely populated areas of Hunting Park.

DEMOGRAPHICS

The Pennsylvania Department of Environmental Protection (DEP) recognizes Hunting Park as an Environmental Justice Area due to its minority and poor population levels. According to U.S. Census data,[6] in 2000 the Hunting Park neighborhood, as defined above, had a population of 30,045. Approximately 63.5% were of Hispanic/Latino origin (compared to about 12.5% nationally), and 31.6% were African American (compared to about 12.3% nationally). Children under the age of 5 make up 9.9% of Hunting Park, nearly 50% higher than the national mark of 6.8%. Seniors age 65 and older make up about 5.8% of Hunting Park's population. Moreover, among the 14,780 people in Hunting Park who speak Spanish at home, 3,694 (25%) speak English "not well" or "not at all."

Hunting Park is an economically distressed area of Philadelphia, with a severely disadvantaged population. Statistics from the 2000 Census show that 46.8% of Hunting Park's population lived below the federal poverty line, as compared to 22.9% of all Philadelphians. Educational attainment is notably low in Hunting Park. Of adults over the age 25, only 30.4% of those in Hunting Park graduated from high

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[3] Hunting Park generally comprises U.S. Census Tracts PA 193 through PA 199. Also see Philadelphia City Planning Commission, *The Political and Community Service Boundaries of Philadelphia* at 47, 51 (available at http://www.philaplanning.org/data/boundaries.pdf).
[4] DiStefano, Joseph N. "PhillyDeals: Don't landfill that old house! Recycle it! " Philadelphia Daily News, Apr. 15, 2010. Also see Shaw Environmental, Inc. (for Richard S. Burns and Company, Inc.). "Transfer Station and Processing Facility Major Permit Modification - Cardone Expansion," Volume 2, Form P, Sections B.2.c. and B.7. April 2007, revised May 2009. (on file with authors, and available at Pennsylvania Department of Environmental Protection, Southeast Regional Office).
[5] A large city park that sits in the far northwest corner of the community has long been considered unsafe due to drugs and other illicit activities, but is now the focus of revitalization efforts.
[6] See www.census.gov.

school (compared to 71.2% of Philadelphians and 81.9% nationwide). Only 2.0% of residents hold a bachelor's degree.

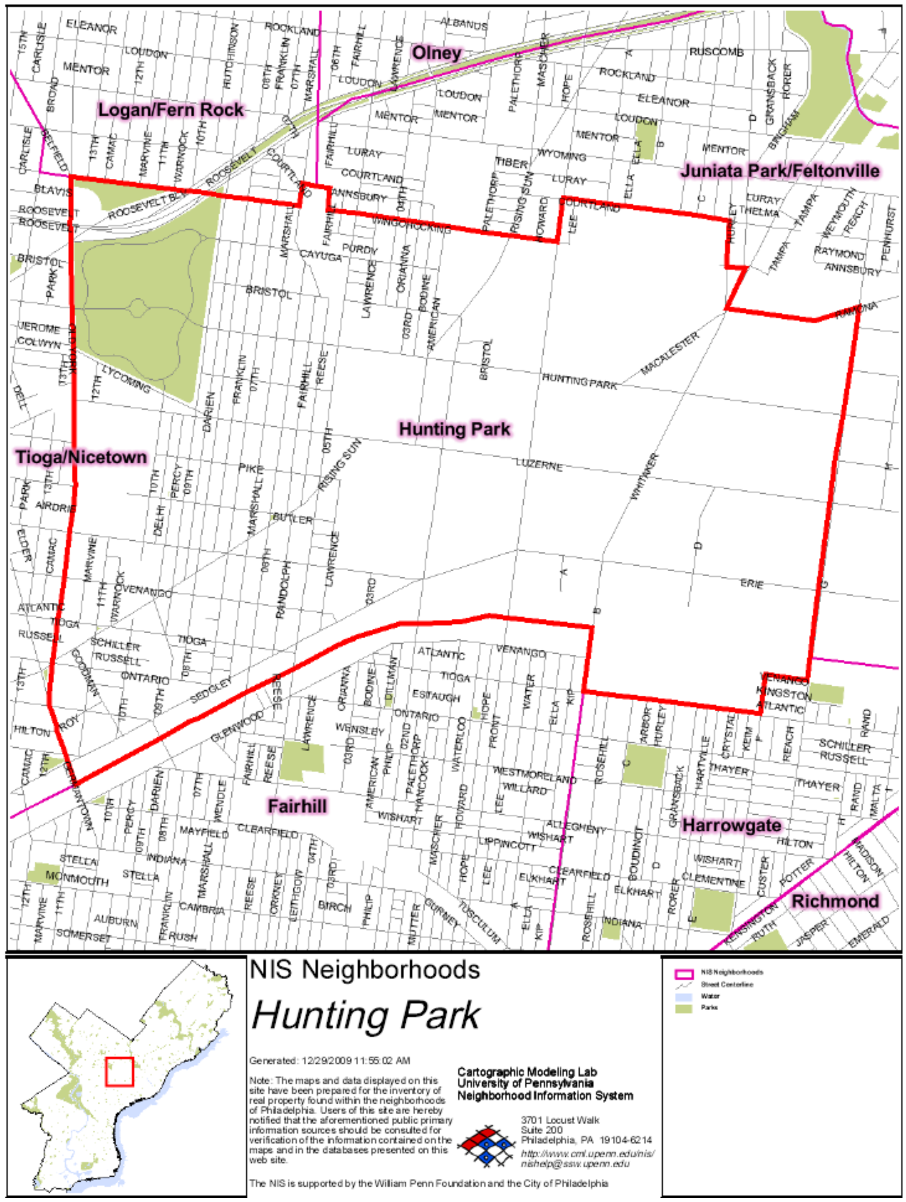

FIGURE 1: *HUNTING PARK NEIGHBORHOOD BOUNDARIES*[7]

[7] Cartographic Modeling Lab, University of Pennsylvania, December 29, 2009.

HEALTH ISSUES

Hunting Park residents have more health problems than residents of surrounding communities. Asthma, a respiratory ailment shown by numerous studies to be linked to environmental exposures, including ambient levels of particulate matter,[8] is especially prevalent. According to the Public Health Management Corporation's 2008 Community Health Database (CHDB),[9] asthma rates among children under age 18 in the ZIP code encompassing Hunting Park stood at 26%, compared to 22.8% for all of Philadelphia, and 18% in the Southeast Pennsylvania region. Among seniors age 60 and over, CHDB reported the 2008 asthma rate in Hunting Park at 18.3%, compared to 11.5% city-wide, and 11.2% regionally. Among all adults in 2008, Hunting Park's asthma rate was 22%, compared to 17.2% city-wide, and 14.1% in the region.

A higher percentage, or 53.4%, of adults in Hunting Park between ages 40 and 59 describe their health status as "fair" or "poor" versus 32.7% in Philadelphia and 19.5% in the region for the same age group. A similar trend is seen in the 60 and older age group: 48.8% in Hunting Park, 37% in Philadelphia, and 27.8% in the region. 11.4% of the children in Hunting Park are reported to be in "fair" or "poor" health, as compared to 9.6% of children across Philadelphia, and only 5.5% of children regionally. Of children residing in Hunting Park, 69.8% are at risk of obesity, which is far greater than the level of risk faced by other children in Philadelphia (46.9%) or in the region (34.7%). Adults in Hunting Park are more likely to be diabetic (20.1%) compared to adults in Philadelphia (13.0%) and the region (10.4%). Younger adults, aged 18-39, are more likely than their cohorts across Philadelphia and the region to have high blood pressure (24.2% to 14.1% to 10.9%, respectively), and high cholesterol (13.7% to 8.6% to 9.5%, respectively).

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[8] Marilena Kampa, Elias Castanas, Human health effects of air pollution, Environmental Pollution, Volume 151, Issue 2, Proceedings of the 4th International Workshop on Biomonitoring of Atmospheric Pollution (With Emphasis on Trace Elements), January 2008, Pages 362-367.

[9] Public Health Management Corporation's Community Health Data Base, 2008 Southeastern Pennsylvania Household Health Survey [*hereinafter* "CHDB, 2008"]. The CHDB data for Hunting Park cited in this section reflect data for the 19140 ZIP code, which includes Hunting Park and parts of other adjacent North Philadelphia neighborhoods; ZIP codes are the smallest geographic unit available in the CHDB database.

RESEARCH METHODS

In November 2009, a research collaboration was formed to characterize airborne particulates in Hunting Park. Organized as part of the Chemical Heritage Foundation's (CHF) Chemist-Community Collaborations (C_3) project,[10] the collaboration ultimately involved members of the Hunting Park Stakeholders group, staff and interns of the Public Interest Law Center of Philadelphia's Public Health and Environmental Justice Law Clinic, staff of the Clean Air Council, faculty and students from Drexel University's Department of Electrical and Computer Engineering, and staff and volunteers from CHF. Project goals and research questions were determined collaboratively; air monitoring sites were identified by residents active in the Hunting Park Stakeholders group in conversation with the Drexel University students responsible for developing the monitors and deploying them in the Hunting Park study area;[11] and data analysis was undertaken by CHF volunteer Robert Brzozowski. Jiazheng Li, Environmental Engineer, Air Management Service Laboratory, City of Philadelphia, provided technical support and information pertaining to air monitoring methods and data.

RESEARCH QUESTIONS AND OBJECTIVES

The primary objective of the Hunting Park collaboration was to obtain information about the levels and composition of particulate matter in the air in the neighborhood surrounding the Richard S. Burns facility as a means of assessing the degree to which particulate pollution might be presenting a hazard to human health in the community. Because of the absence of pre-existing information about PM in Hunting Park, characterizing airborne particulates was conceived from the beginning as a multi-phase process. In Phase 1, the collaboration aimed to produce a general survey of $PM_{2.5}$ levels that would help identify more specific areas for future investigation in the contemplated Phase 2 of the project.

In addition to measuring $PM_{2.5}$ levels in the community, Phase 1 sought information to help determine the relationship (if any) between $PM_{2.5}$ levels and emissions from the Burns facility. Such information included data from different sides of the facility, as well as data during periods when the facility was scheduled to be operating (e.g. during business hours) and periods when it was not (e.g. overnight or certain hours on weekend days). Beyond quantifying $PM_{2.5}$ levels, the collaboration sought to determine the public health significance by comparing measurements of $PM_{2.5}$ in Hunting Park to health-based regulatory standards, and to $PM_{2.5}$ levels measured in other Philadelphia neighborhoods.

This phase of investigation thus aimed to answer the following questions:

- What are the overall $PM_{2.5}$ levels in the area of Hunting Park surrounding the Burns facility?
- Do levels vary across the neighborhood? In particular, are they higher nearer to, or on one side of, the Burns facility?

[10] A project of CHF's Environmental History and Policy Program, C_3 addresses the need for better quantitative information about environmental conditions in Philadelphia-area communities by forming and facilitating research collaborations between chemist volunteers and community groups.

[11] The project team is grateful to Drexel University students Justin Arling, Kyle O'Connor, and Michael Mercieca, and their professors Kapil Dandekar and Tim Kurzweg, for making available their monitors at no cost to the community, as well as donating their time to the project.

- Do levels vary predictably with time of day or day of week?
- How do levels compare to the NAAQS for particulate matter?
- How do levels compare to levels measured at AMS monitoring stations in other parts of Philadelphia?

With the data and analysis produced in Phase 1, collaborators expected to define what sort of additional measurements would be valuable, where they should be taken, and what analytical procedures would be required to gather the desired data. In addition, the Hunting Park Stakeholders group identified the concentration of lead and the presence of asbestos fibers in airborne particulates as issues of particular interest to be pursued further in subsequent phases of monitoring.

EQUIPMENT – PARTICULATE SENSOR NETWORK

The initial investigation of $PM_{2.5}$ levels in Hunting Park employed a wireless air quality sensor network designed by seniors in Drexel University's Electrical and Computer Engineering major, working under the supervision of Professors Kapil Dandekar and Tim Kurzweg. The network consisted of several sensor nodes transmitting information via wireless technology to a base station computer (see Figure 2).

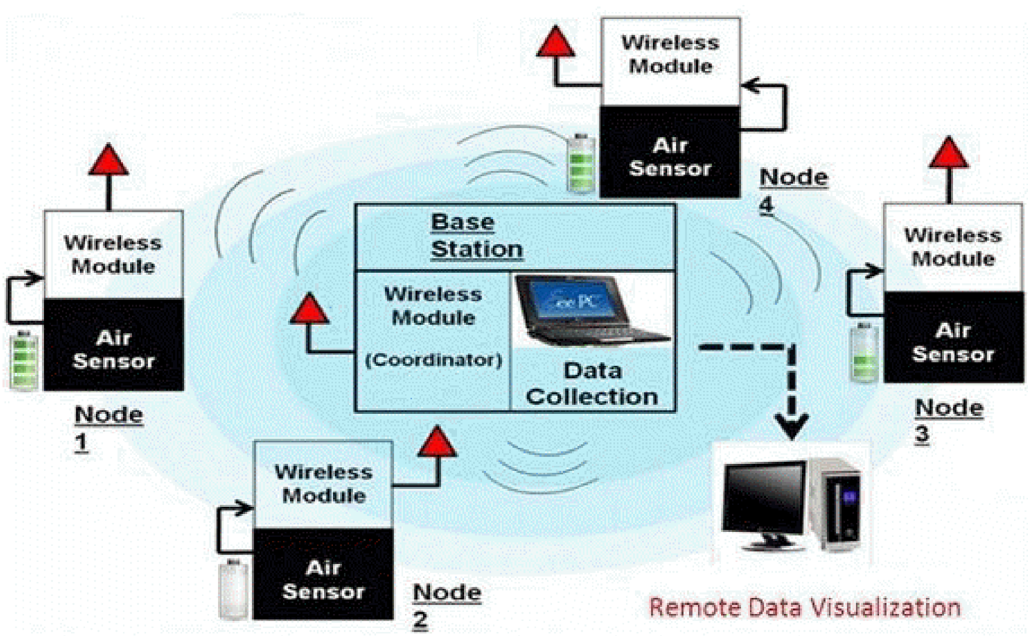

FIGURE 2: WIRELESS AIR QUALITY SENSOR NETWORK SYSTEM DIAGRAM

Roughly the size of a shoe box, each sensor node used a commercially available laser particle counter to determine the number of particles in a one-minute air sample taken every ten minutes. The nodes then transmitted their particle counts to the base station computer, which converted the particle counts into particle concentrations. The battery-powered nodes could operate around the clock for up to one week without maintenance, and data were made available on a website that could be viewed while the deployment was in progress, as well as after it was complete.[12]

In their method of determining $PM_{2.5}$ levels, the sensor nodes differ fundamentally from the monitors used by environmental regulatory agencies. The nodes use a laser to count particles then calculate concentrations using standard assumptions about particle diameter and density, while applying an experimentally derived correction factor to account for error caused by ambient weather conditions. In contrast, the Federal Reference Method (FRM) for measuring $PM_{2.5}$ collects particles on a filter paper and weighs them. The volume of air drawn through the filter paper is also controlled and divided into the weight of the particles to arrive at a concentration: the weight of the particles, in micrograms (µg), per cubic meter (m^3) of air. This method, known as a gravimetric method, is an inherently more reliable way of measuring PM levels, and state and city agencies like AMS use the FRM to determine compliance with NAAQS. FRM monitors are very expensive (on the order of tens of thousands of dollars) and do not produce data in real time. Rather, samples are collected over a given period, usually 24 hours, then weighed in a laboratory. The AMS also supplements the FRM monitor with a continuous method that uses a monitor with a MetOne BAM 1020 unit that continuously collects $PM_{2.5}$ samples and reports concentration readings on an hourly basis.

The sensor network was chosen over the FRM gravimetric methods or the continuous method for Phase 1 of the particulate characterization project because it provided an inexpensive means to conduct an initial survey of $PM_{2.5}$ levels. Because the technology was still under development, collaborators from Drexel University were willing to provide the monitors at no cost, donate the labor required to set up the sensor network, and ensure results were transmitted to a website. The sensor network system served the data collection goals of the collaboration well because it could be deployed in multiple locations throughout the community to establish geographic patterns in $PM_{2.5}$ levels. It could also generate multiple data points per hour, enabling observation of fluctuations in particulate levels over time. Although the sensor nodes were not calibrated to measure other particle sizes (e.g. PM_{10} or ultrafine particulates), they were still deemed appropriate because scientific researchers most often associate $PM_{2.5}$ levels with adverse health effects.[13]

However, significant questions about the data produced by the $PM_{2.5}$ sensor network limit the extent to which that data can be considered conclusive. The method is inherently less precise than gravimetric methods. Drexel University students validated their method against those used by the AMS by deploying a single sensor node at a monitoring station running both a $PM_{2.5}$ FRM gravimetric monitor and a continuous monitor that produces a reading of $PM_{2.5}$ levels concentrations every hour. From the

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[12] Epidemiological studies have shown evidence of a relatively consistent relationship between airborne particulate matter and adverse health effects, such as asthma and other respiratory tract diseases. Research Priorities for Airborne Particulate Matter: I. Immediate Priorities and a Long-Range Research Portfolio, Committee on Research Priorities for Airborne Particulate Matter, National Research Council, (1998).

[13] For more information, see Arling, Justin, Kyle O'Connor, and Michael Mercieca. "Engineering Projects in Community Service (EPICS): Air Quality Sensor Network for Philadelphia." Department of Electrical and Computer Engineering, Drexel University, May 7, 2010. Available from http://wireless.ece.drexel.edu/air_quality/project%20files/Final%20Report%20%282009-2010%29.pdf.

comparison with the latter, correction factors were derived, especially to account for effects of humidity on particle counts.[14] The empirical correction factors were based on data from only one sensor node, however. In addition, the several sensor nodes deployed in Hunting Park were never tested side by side, in order to determine whether the individual devices produced identical data under identical environmental conditions. As a result, it remains uncertain whether there is inherent variation among individual sensor nodes, and whether the correction factors apply equally well to all nodes.

***FIGURE 3:** MAP SHOWING DEPLOYMENT LOCATIONS FOR AIR MONITORING NODES*

[14] Arling, Justin, Kyle O'Connor, and Michael Mercieca. "Air Quality Sensor Network for Philadelphia: Data Validation." Department of Electrical and Computer Engineering, Drexel University, May 6, 2010. Available from http://wireless.ece.drexel.edu/air_quality/project%20files/Data%20Validation.pdf. See also Uva, Mark, Robert Falcone, Anthony McClellan, and Edward Ostapowicz. "Preliminary Screening System for Ambient Air Quality in Southeast Philadelphia." Department of Electrical and Computer Engineering, Drexel University, May 13, 2009. Available from http://wireless.ece.drexel.edu/air_quality/project%20files/Final%20Report%20%282008-2009%29.pdf.

DEPLOYMENT

Particulate monitors were deployed in seven locations within the Hunting Park study area: four (monitors 3, 6, 7, and 8) within the residential section of Hunting Park near the Richard S. Burns facility on May 4, 2010, and three (monitors 1, 2, and 4) along Rising Sun Avenue in an industrial area on the other side of the facility on May 5, 2010. Hung on fences with the permission of property owners (see Figure 4), monitors transmitted data through May 12 (with the exceptions of monitor 7, which transmitted data until 23:30 May 9; and monitor 4, which transmitted data until 12:22 May 10).

FIGURE 4: *SENSOR NODE HUNG ON FRONT PORCH OF HUNTING PARK HOME*

ANALYSIS OF DATA

Figure 5 presents data obtained from a single sensor node deployed in the Hunting Park study area. The vertical axis shows the $PM_{2.5}$ levels in micrograms per cubic meter (μg/m^3) and the horizontal axis shows time (the space between any two minor tick marks represents a six-hour interval). The plotted data have been corrected using empirical correction factors derived through side-by-side monitoring with a sensor node and an AMS continuous monitoring instrument in 2009 and 2010.

Successive data points tend to track smoothly over time with concentrations rising or falling over the span of hours. The plot provides credibility to monitoring data, for one expects $PM_{2.5}$ levels to change gradually over time. The plot also shows occasional shorter spikes in concentration involving two or three adjoining time points, representing periods of 20 to 30 minutes. These fluctuations could be attributable to momentary local conditions and/or brief glitches in the sensor node.

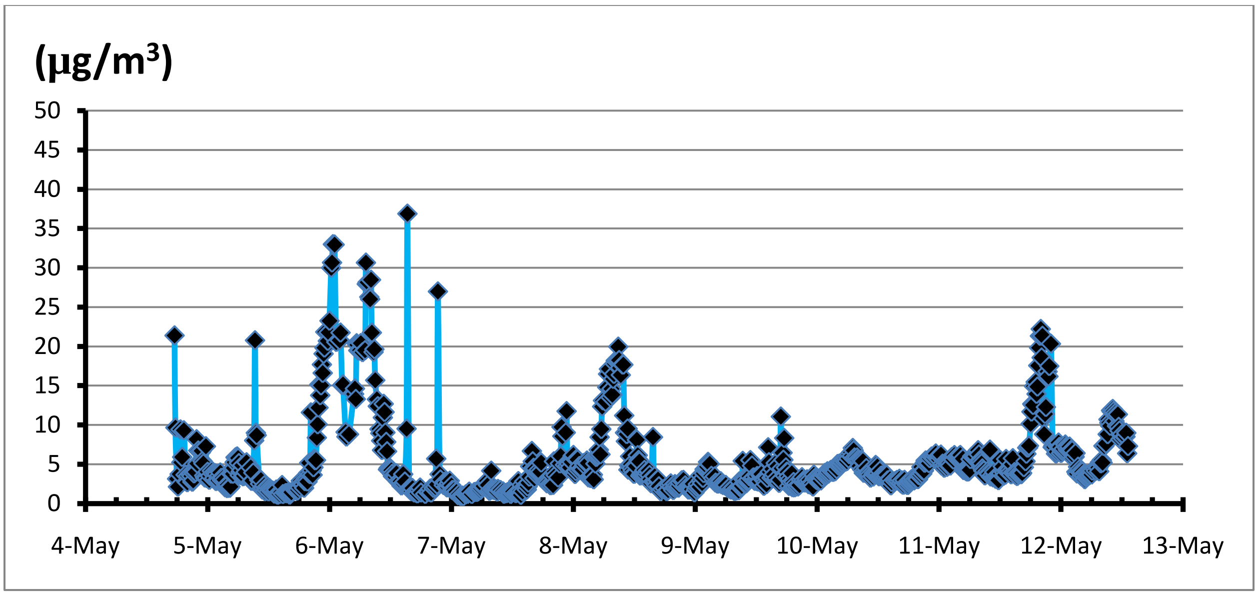


FIGURE 5 *– $PM_{2.5}$ LEVELS (μG/M^3) MEASURED BY ONE SENSOR NODE DURING STUDY PERIOD*

GEOGRAPHIC AND TEMPORAL VARIATION

Figure 6 plots corrected data from the four sensor nodes deployed in the residential neighborhood near the Burns facility (N3, N6, N7, and N8) to determine if $PM_{2.5}$ levels vary across the Hunting Park study area. Figure 6 shows that nodes tend to measure the same concentrations at the same time suggesting that there is no significant variation in $PM_{2.5}$ levels across the residential part of the neighborhood. N6 is a partial exception, with a number of fluctuations not shown in the other nodes. Although not certain, the fluctuations could be caused by a very local, intermittent source of particulates, such as cigarette smoke or traffic, or they could be attributable to a glitch in the monitor itself.

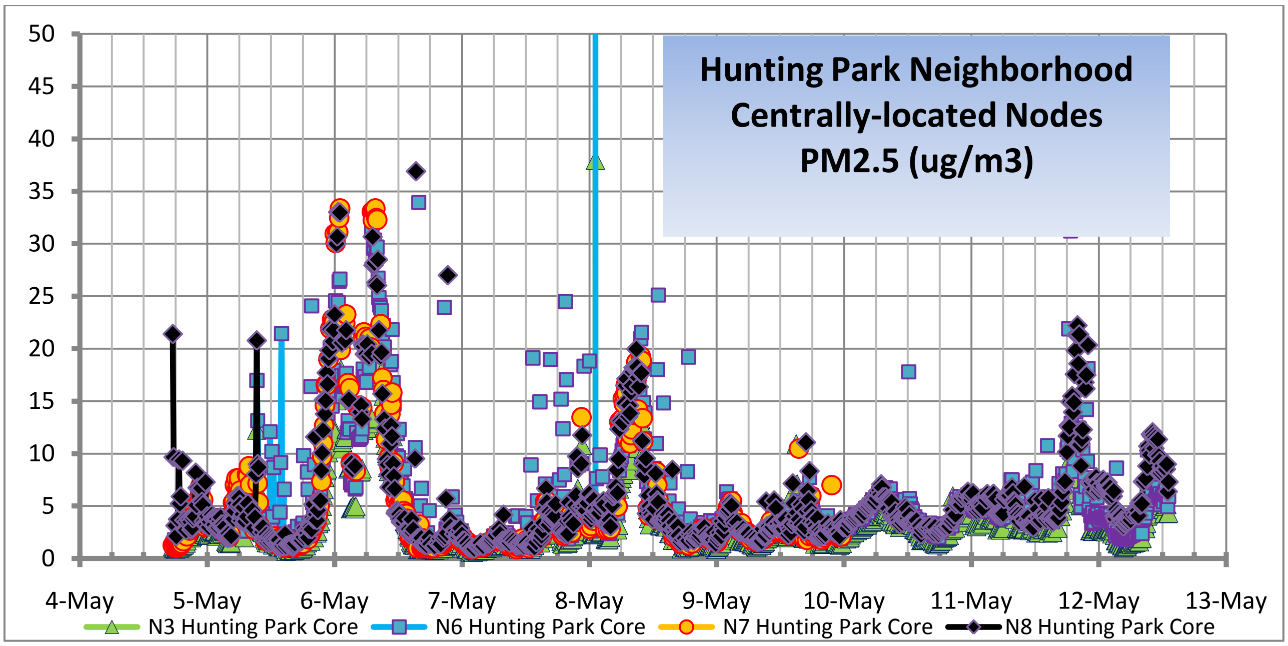


FIGURE 6 *– DATA FROM FOUR SENSOR NODES DEPLOYED IN THE RESIDUAL AREA*

In Figure 7, data from different nodes are compared by eliminating time as an explicit variable. Concentrations levels are plotted for every point in time from one arbitrarily selected reference node, N3, on the horizontal axis, against concentrations for corresponding points in time from the remaining three nodes in the residential area on the vertical axis. If the concentrations measured by the nodes were identical, the points would line up along a 45 degree line beginning at the origin. The larger the spread of points around the diagonal, the less well correlated the concentrations measured at the nodes are with one another.

Figure 7 also shows that $PM_{2.5}$ levels at N6, N7, and N8 trend slightly, though not substantially, higher than N3 levels. The source of this variability, however, is unknown because the four sensor nodes were not validated through side-by-side testing. Thus, it is impossible to say whether variations among nodes result from differences in air quality at each site, or due to variation among the sensor nodes.

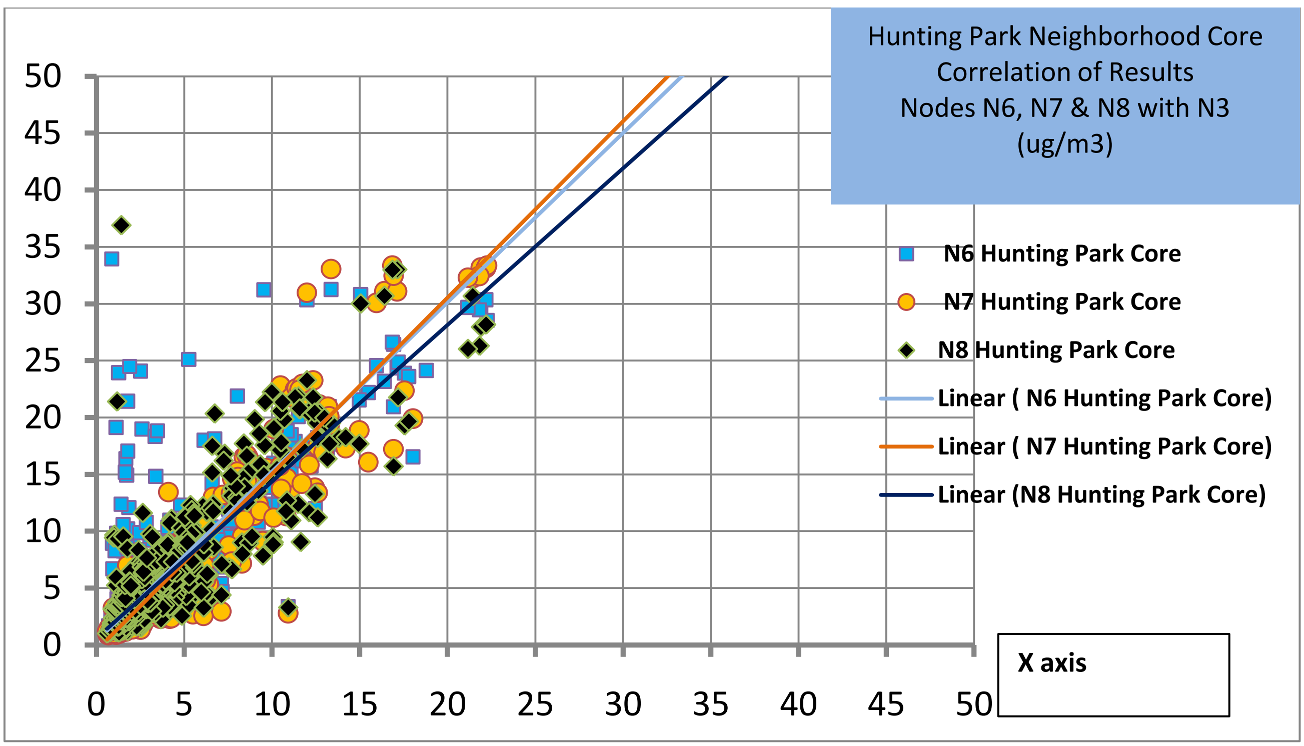


FIGURE 7 *– CORRELATION BETWEEN PARTICULATE LEVELS IN THE HUNTING PARK STUDY AREA*

Figure 8 shows corrected data from three sensor nodes (N1, N2, & N4) deployed on the eastern border of the neighborhood in the industrial strip along Rising Sun Avenue. As in Figure 6, levels at each point in time show strong general agreement

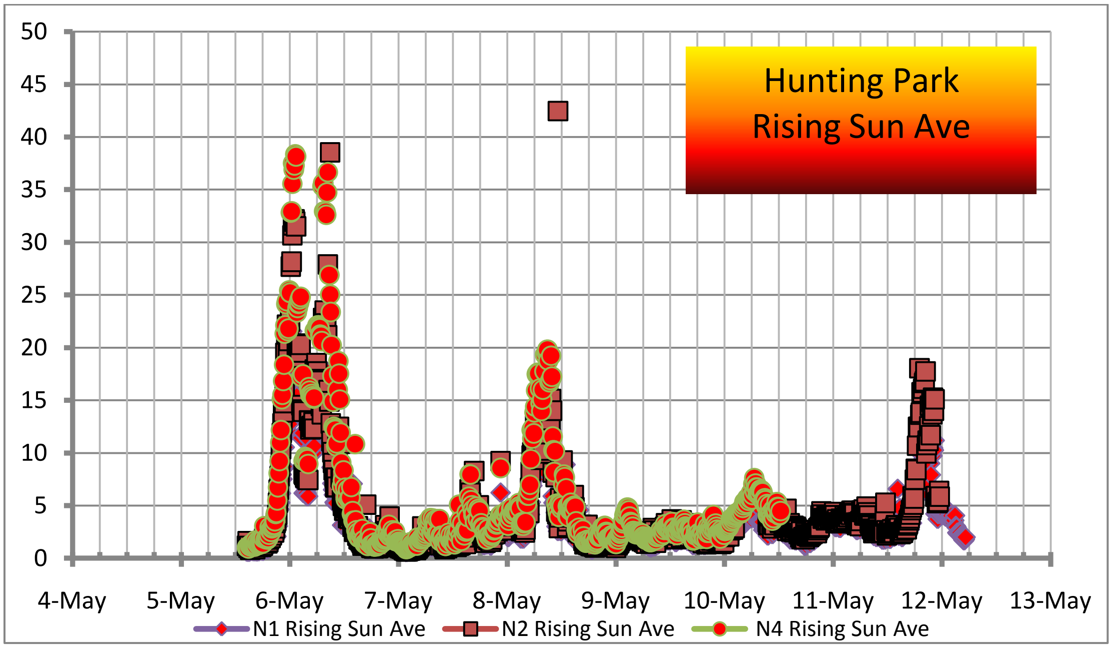


***FIGURE 8** – DATA FROM THREE SENSOR NODES DEPLOYED IN INDUSTRIAL AREA ALONG RISING SUN AVENUE*

In Figure 9, data from the three nodes along Rising Sun Avenue are correlated without time as an explicit factor and the result is similar to the residential area. There is relatively good correlation among data from the three locations, and it was observed that N2 and N4 show a slight positive bias compared to N1. Again, the variation could be caused by differences in air quality at the monitoring sites and/or differences inherent in the individual sensor nodes. Although sensor nodes N1 and N4 were deployed at sites closer together than N1 and N2, the variation between the first pair is greater than that between the second (the plot is further from a 45 degree angle). This observation suggests variations among the monitors, rather than variations in air quality, as the likeliest source of differences in measurements.

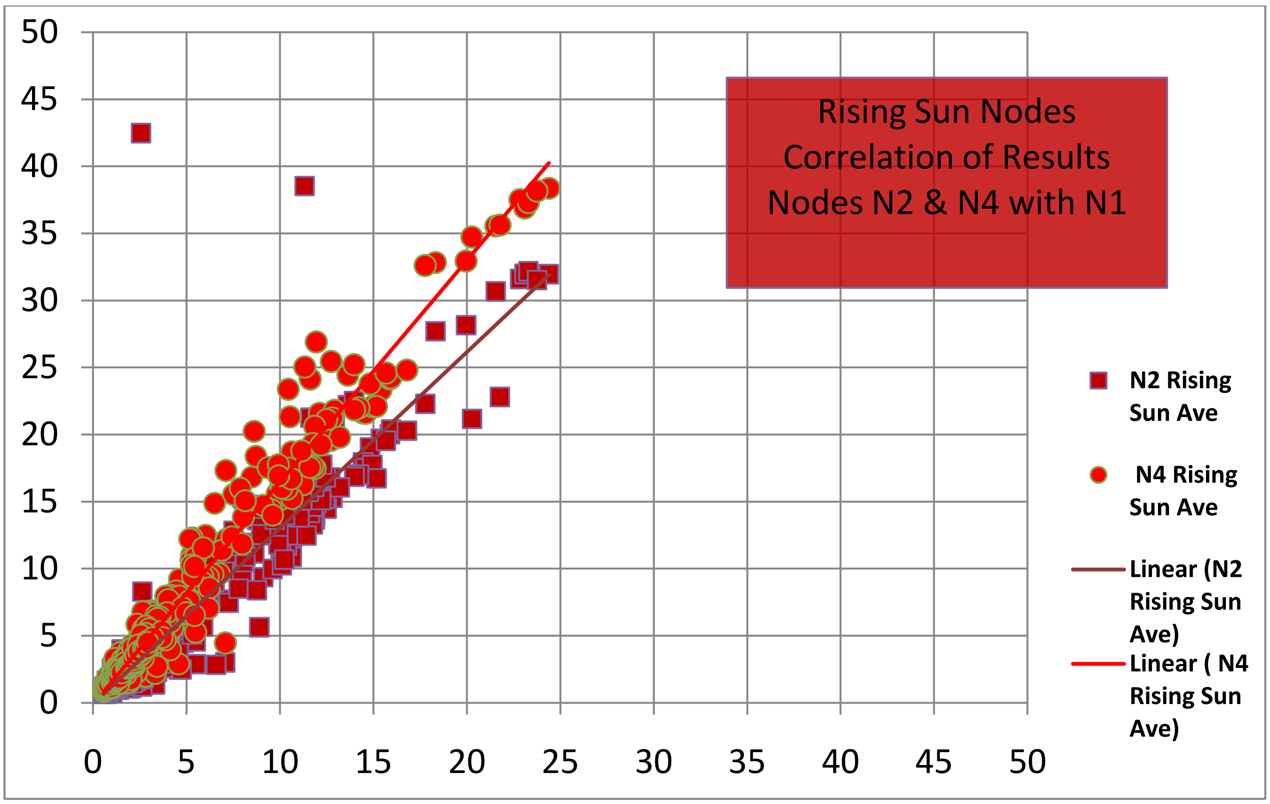


***FIGURE 9** – CORRELATION BETWEEN PARTICULATE LEVELS IN THE INDUSTRIAL STRIP ALONG RISING SUN AVENUE*

Figure 10 compares corrected data from four nodes in the residential core and three nodes along Rising Sun Avenue. As in Figures 6 and 8, levels at the seven monitoring sites show fairly close agreement over time, with the exception of intermittent spikes, especially at N6. Moreover, Figure 10 shows no discernable repeat pattern in $PM_{2.5}$ levels either between days (for example, between week days and weekend days) or within each day (for example, between daytime and night time periods).

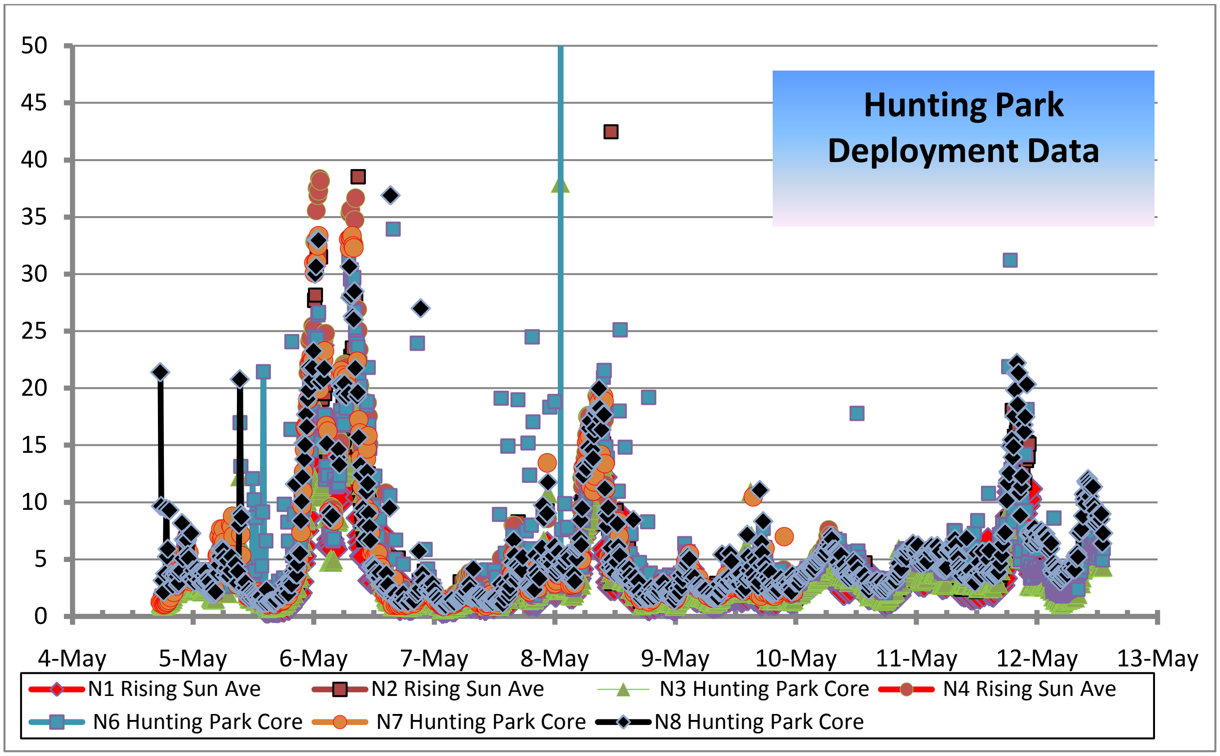


***FIGURE 10** – DATA FROM ALL SEVEN SENSOR NODES DEPLOYED IN HUNTING PARK*

COMPARISON TO REGULATORY STANDARDS

Under the federal Clean Air Act, the U.S. government sets limits – the NAAQS – on the concentrations of particulate matter (PM_{10} and $PM_{2.5}$) allowed in the ambient air. Intended to protect human health, the NAAQS for $PM_{2.5}$ provide a starting point for understanding what the levels of $PM_{2.5}$ measured in Hunting Park may mean for the health of residents. The NAAQS specify that the **annual average** level of $PM_{2.5}$ should not exceed **15 µg/m^3**, while the average concentration over any **24-hour** period should not exceed **35 µg/m^3**.[15] From the seven days of data collected in Hunting Park, only 24-hour averages can be derived. These are summarized in Table I, alongside 24-hour averages measured on the same days by the AMS at its Lycoming monitoring station (1501 E. Lycoming St.), using a continuous monitor and a gravimetric FRM monitor.

[15] US Environmental Protection Agency. "National Ambient Air Quality Standards." http://www.epa.gov/air/criteria.html (Accessed July 27, 2010).

Table I shows that $PM_{2.5}$ levels at the Hunting Park study area and the AMS's Lycoming monitoring station do not approach the 24-hour average NAAQS of 35 µg/m, the current safety threshold level for human health. However, regulatory limits on air pollution are uncertain and subject to updates and revision. Therefore, it can not be assumed that $PM_{2.5}$ levels in Hunting Park during Phase 1 have no health impact simply because they do not exceed the current standards.

24-Hour Average $PM_{2.5}$ Concentrations (µg/m^3) *NAAQS: 35 µg/m^3*			
	Hunting Park	**AMS Lycoming Lab**	
	Continuous (1)	Continuous	Gravimetric
May 5	9.7	13.6	10
May 6	2.4	5.6	12
May 7	5.7	8.9	5
May 8	2.5	5.8	9
May 9	3.7	3.4	x
May 10	5.4	5.2	4
May 11	4.7	10.0	6
Average	4.9	7.5	7.7

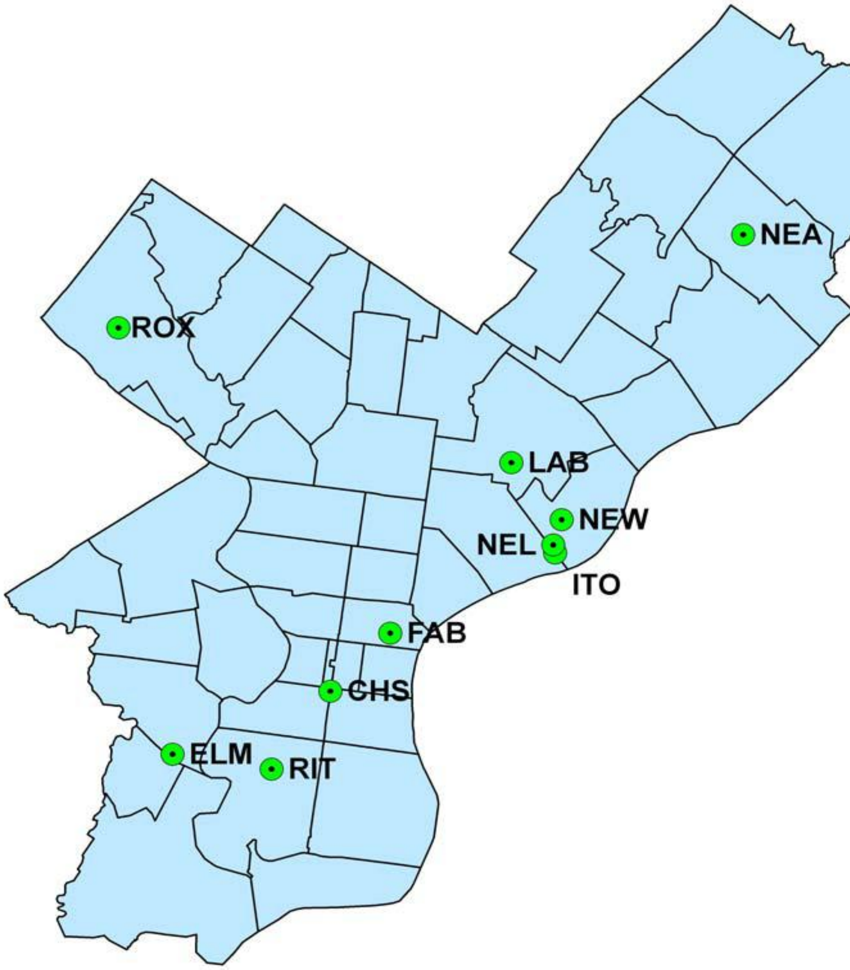
(1) Method developed by Drexel University

TABLE I: *SUMMARY OF 24-HOUR AVERAGE LEVELS OF $PM_{2.5}$ AT HUNTING PARK AND LYCOMING AMS SITES*

COMPARISON TO OTHER PHILADELPHIA LOCATIONS

Another way to understand what $PM_{2.5}$ levels in Hunting Park mean for residents is by asking how they compare to particulate concentrations in other places. AMS monitors $PM_{2.5}$ at a number of sites around the city,[16] shown in Figure 11. Comparing data from Hunting Park to data from these sites can potentially address two questions: how well monitoring data collected by the AMS represents air quality in Hunting Park, and how air quality in Hunting Park compares to other neighborhoods in Philadelphia.

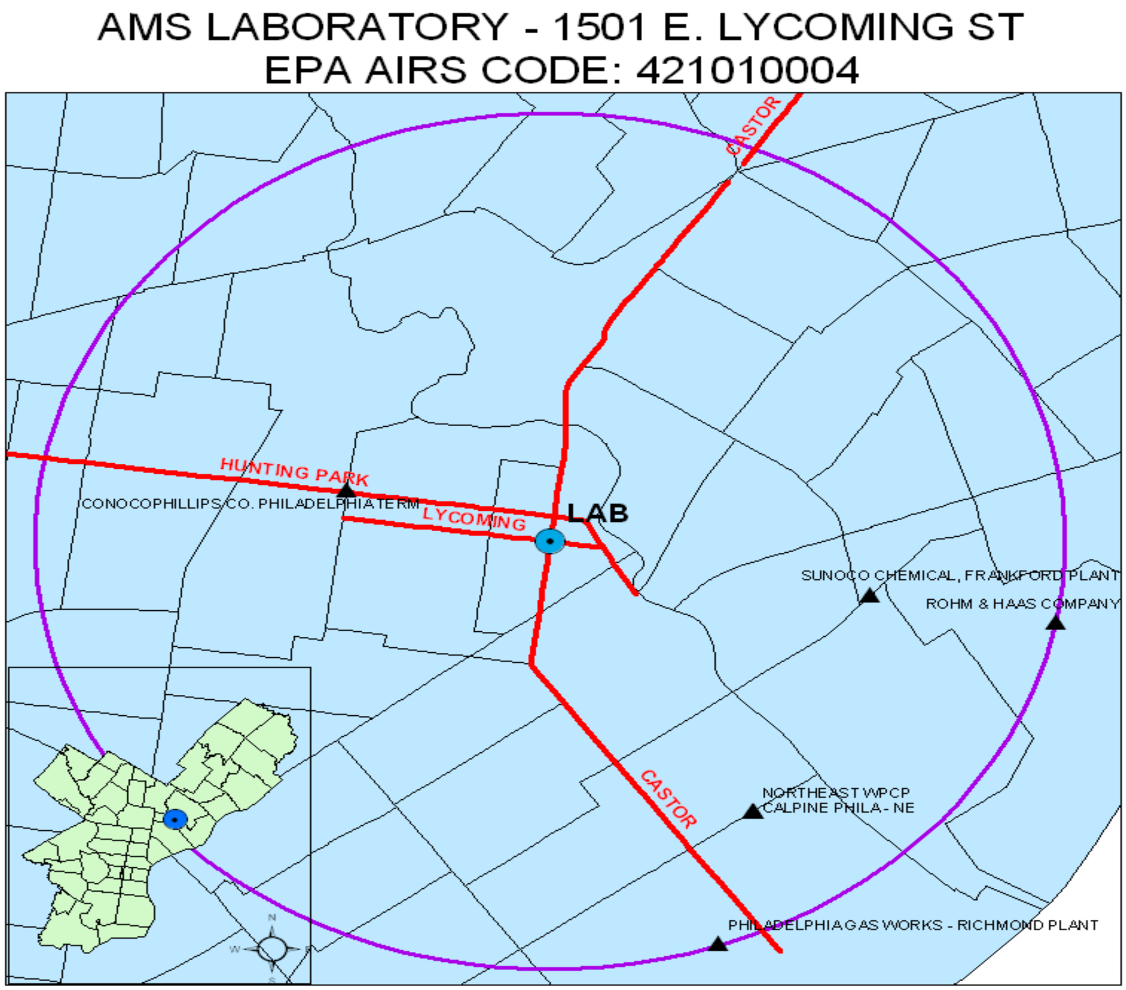
[16] Air Management Services. "2009-2010 Air Monitoring Network Plan." Department of Public Health, City of Philadelphia. July 1, 2009.



			Parameter																
AQS Site Code	AMS Site	Address	CO	SO2	Ozone	NO2	NO	Continuous PM10	PM2.5 Continuous	Speciated PM2.5 Analysis by EPA	PM2.5 FRM	PM10 SSI (quartz filter)	Metals Analysis by WV (TSP sampler with quartz filter)	TSP Metals analysis by AMS includes lead	PAMS VOC	Toxics (TO-14)/ Carbonyls	BaP analysis by Allegheny County, PA	MET	AMS Site
421010004	LAB	1501 E. Lycoming	X	X	X	X	X		X	X	X	X	X		X	X			LAB
421010014	ROX	Eva & Dearnley											X			X			ROX
421010024	NEA	Grant & Ashton			X				X		X							X	NEA
421010136	ELM	5917 Elmwood											X			X		X	ELM
421010047	CHS	500 S. Broad				X	X				X		X			X			CHS
421010048	NEW	3900 Richmond						X										X	NEW
421010649	NEL	3900 Richmond										X							NEL
421010449	ITO	Castor & Delaware										X		X			X		ITO
421010055	RIT	24th & Ritner		X						X	X		X			X			RIT
421010057	FAB	3rd & Spring Garden									X								FAB

***FIGURE 11** – LOCATIONS OF MONITORING SITES OPERATED BY AIR MANAGEMENT SERVICES*

Figure 12 shows the AMS monitoring site nearest to Hunting Park at 1501 East Lycoming Street. Roughly two miles east of the neighborhood, this site would be a likely source of data for policy makers or others trying to assess air quality in Hunting Park. However Hunting Park residents feel that the East Lycoming Site is not close enough to provide data that can accurately reflect air quality in their neighborhood.



PLID	NAME	STREET	2007 EMISSIONS (in tons)							
			CO	NO2	PB	PM10	PM25	PT	SO2	VOC
01533	CALPINE PHILA - NE	3900 RICHMOND STREET (NEWPCP)	0.61	0.42	0.00	0.00	0.00	0.00	0.41	0.10
05004	CONOCOPHILLIPS CO. PHILADELPHIA TERM	4210 G ST	0.00	0.00	0.00	0.00	0.00	0.00	0.00	19.58
09513	NORTHEAST WPCP	3899 RICHMOND ST	27.59	6.13	0.00	1.79	0.00	1.81	5.90	13.32
04922	PHILADELPHIA GAS WORKS - RICHMOND PLANT	3100 E VENANGO ST	0.89	3.80	0.00	0.10	0.00	0.10	0.01	0.17
01531	ROHM & HAAS COMPANY	5000 RICHMOND ST	1.16	6.87	0.00	0.42	0.40	0.53	0.13	10.17
01551	SUNOCO CHEMICAL, FRANKFORD PLANT	4700 BERMUDA STREET	34.22	248.46	0.01	70.67	51.73	72.36	197.20	179.36
		TOTAL	64.48	265.69	0.01	72.97	52.12	74.80	203.65	222.70

FIGURE 12 *– LOCATION OF THE AIR MANAGEMENT SERVICES LYCOMING LABORATORY IN RELATION TO HUNTING PARK*[17]

Figure 13 plots data from the continuous monitor at the AMS Lycoming site collected during the week that $PM_{2.5}$ sensor nodes were deployed in Hunting Park. A direct, quantitative comparison of the two

[17] The study area is located on the extreme left, to the north of Hunting Park Avenue (the longer of the nearly horizontal red lines), with much it falling just outside the arc of the circle.

sets of data is difficult to perform for several reasons, including the volume of data from different monitors not synchronized with each other and the fact that the AMS monitor took measurements every hour versus the every ten minute interval for each sensor node. A visual comparison between Figure 13 and Figure 10 (reproduced below in figure 13a) shows some general similarity between $PM_{2.5}$ levels and trends, but not an obvious, good correlation.

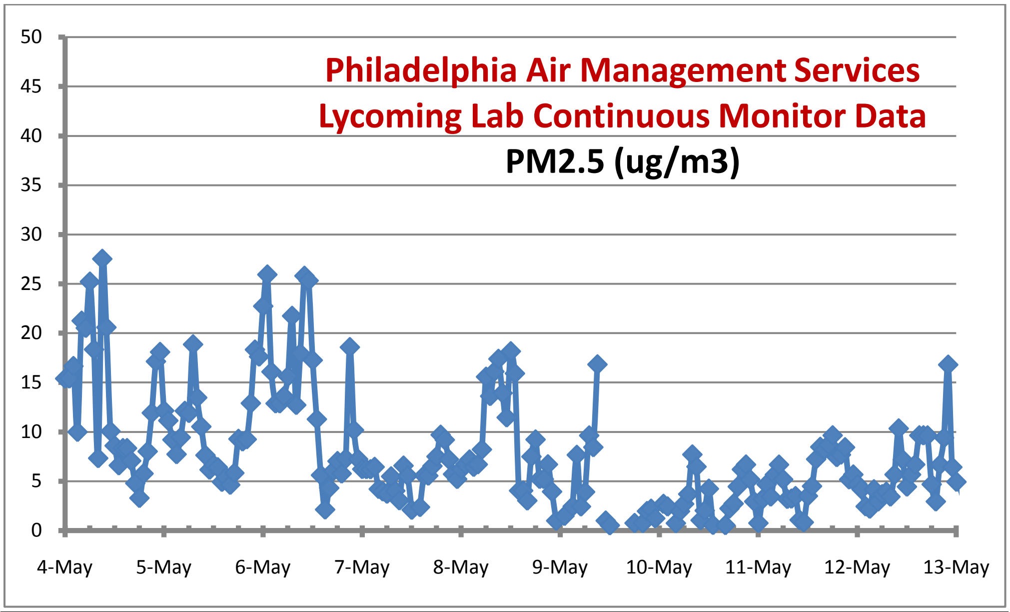


***FIGURE 13** – DATA FROM ALL SEVEN SENSOR NODES DEPLOYED IN HUNTING PARK*

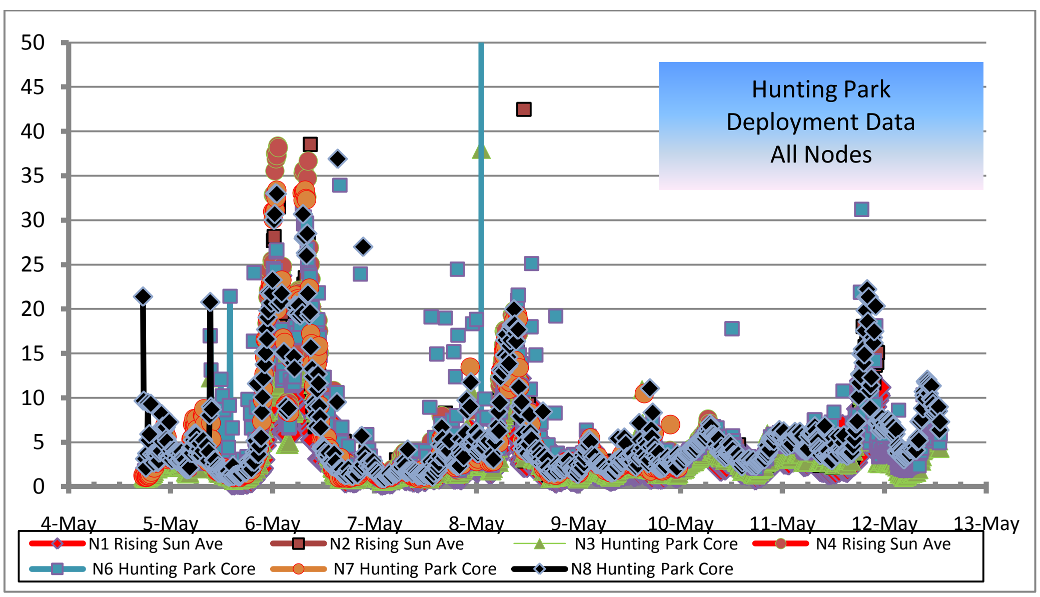


***FIGURE 13A** – DATA FROM ALL SEVEN SENSOR NODES DEPLOYED IN HUNTING PARK*

Figure 14 presents a quantitative comparison of Hunting Park, AMS continuous, and FRM gravimetric data aggregated into a 24-hour average for each sampling day (excluding May 4 and 12, when data did not span the full 24-hours). A smooth curve fitted through each set of data points makes a correlation between the data more evident, though the correlation is clearly still not exact.

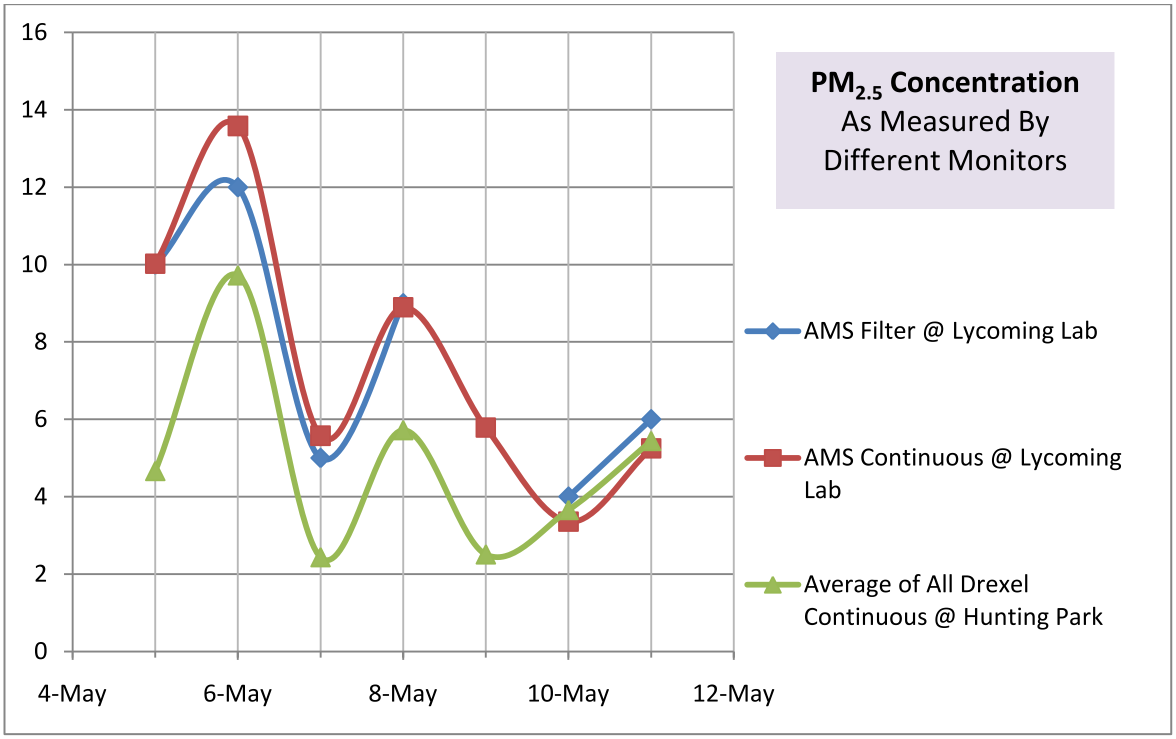


***FIGURE 14** – AGGREGATED 24-HOUR AVERAGES FROM HUNTING PARK VERSUS THE LYCOMING SITE*

In Figure 15, visual inspection suggests that measurements from the AMS's continuous monitor are very close to the FRM gravimetric monitor. The red line in the figure is very close to a 45 degree angle, suggesting that when the filter method measured 24-hour average concentration of, for example, 6 μg/m^3, the continuous monitoring data was likely to yield a 24-hour average concentration that was also very close to 6 μg/m^3.

Corrected data from the sensor nodes are much further from the FRM gravimetric data. The green line shows that averages from the sensor nodes tended to be lower than the FRM gravimetric monitor; when the latter measured 6 μg/m^3, the former generally measured 4 μg/m^3 or less.

While the plots can show how well absolute values for concentrations measured by two different monitoring methods agree with one another, two statistical measures describe how well the fluctuations in data from one method track the fluctuations in data from the other. The *correlation* *coefficient*, or r, measures how closely a set of data points falls along a straight line.[18] The points resulting from the comparison between the AMS continuous monitor data and the AMS filter (FRM) data have an r of 0.97, or a very high degree of correlation (for perfect correlation r = 1)—the red squares in Figure 15 all cluster near the red line. For the comparison between the sensor nodes and the FRM data, the data points scatter much more widely around the green line fitted through them, and the r is correspondingly lower, though still reasonably good: r = 0.81.

The *coefficient of variation*, or r^2, tells what proportion of fluctuation in one variable, in this case the AMS continuous data, can be accounted for by fluctuation in the other variable, in this case the AMS filter data.[19] An r^2 of 0.96, shown in Figure 15 for the comparison between two AMS data sets, indicates that 96 percent of fluctuations in $PM_{2.5}$ concentrations measured by the AMS continuous monitor can be accounted for by looking at how concentrations measured by the FRM varied. Again, data from the two AMS monitors are very consistent with one another. The comparison between the sensor node data and the AMS filter data has an r^2 value of 0.65, meaning that knowing how the filter data changes accounts for about two thirds of how concentrations measured in Hunting Park change. The other one-third of the fluctuations in the data cannot be accounted for with reference to the AMS's data.

The good correlation and high r and r^2 values between the two AMS monitors are to be expected: the two sets of measurements were taken at the same site, using sophisticated monitoring instruments deemed reliable by the EPA. It is also not unexpected that data from sensor nodes in the Hunting Park study area were consistently lower than that collected by the AMS using the FRM, in addition to the lower r and r^2 values, indicating that variations in measured concentrations at the two sites tracked less well. The Hunting Park data was collected two miles from the Lycoming site, using instruments with fundamental differences from the AMS equipment in how $PM_{2.5}$ concentrations are determined. What is not clear from the comparison, however, is how much of the difference is attributable to the differences in air quality at the monitoring locations, and how much is attributable to the monitoring technique.

Looking at $PM_{2.5}$ data from AMS sites across Philadelphia helps to answer this question by putting the Hunting Park data in a broader context.

[18] According to MathBits.com, "The quantity *r*, called the *linear correlation coefficient* measures the strength and direction of a linear relationship between two variables." See MathBits.com. "Correlation Coefficient." http://mathbits.com/mathbits/tisection/statistics2/correlation.htm (accessed July 5, 2010).

[19] According to MathBits.com, "The *coefficient of determination, r^2*, is useful because it gives the proportion of the variance (fluctuation) of one variable that is predictable from the other variable. It is a measure that allows us to determine how certain one can be in making predictions from a certain model/graph." See MathBits.com. "Correlation Coefficient." http://mathbits.com/mathbits/tisection/statistics2/correlation.htm (accessed July 5, 2010).

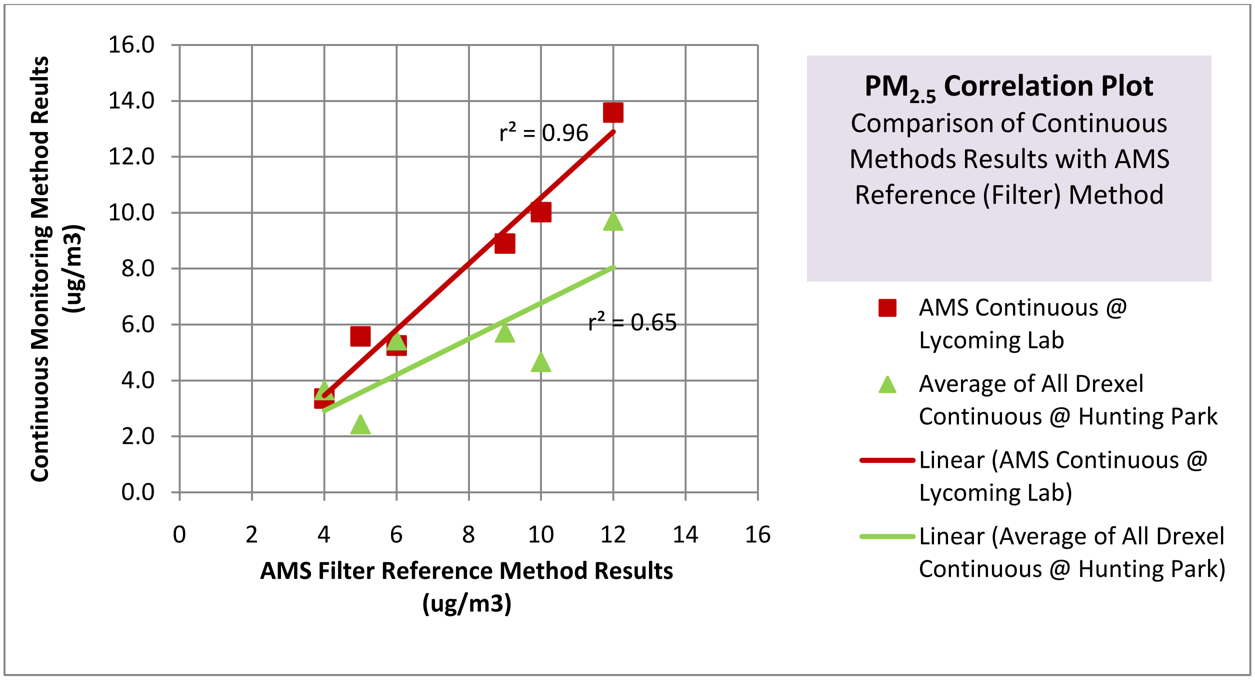


***FIGURE 15** – CORRELATION BETWEEN CONTINUOUS $PM_{2.5}$ DATA IN HUNTING PARK, LYCOMING, AND FRM DATA*

Figure 16 adds data from four additional AMS monitoring sites to the data plotted in Figure 14, showing how 24-hour average concentrations measured at the various sites compared to those measured by sensor nodes in Hunting Park. Note that while the shape of the curves is similar—the ups and downs of $PM_{2.5}$ levels in Hunting Park roughly track those at other places—the absolute levels measured in Hunting Park are consistently lower than those at other sites.

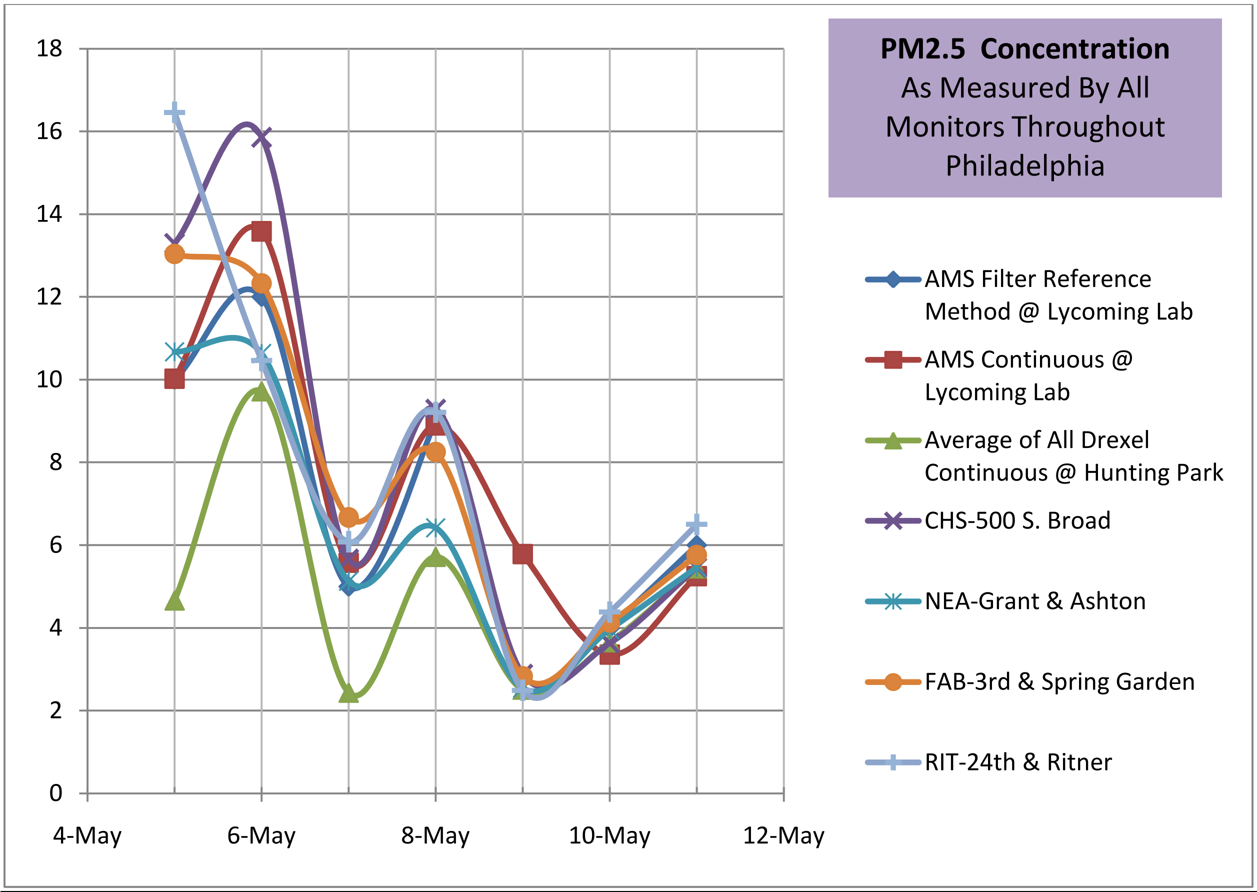


***FIGURE 16** – AGGREGATED 24-HOUR AVERAGES FROM HUNTING PARK VERSUS AIR MANAGEMENT SERVICES SITES*

Figure 17, like Figure 15, shows how each of these data sets correlates with FRM data from the AMS Lycoming site. What is notable about Figure 17 is that absolute values of $PM_{2.5}$ measured at the various Philadelphia sites are, in general, very close to those measured at the Lycoming site—all of the lines bunch together along that 45-degree angle in the center of the graph. As in Figure 16, only the Hunting Park measurements lie significantly below the values of the other readings. At the same time, the correlations among the Lycoming site and the other AMS monitors have r^2 values ranging from 0.60 to 0.97, suggesting that the discrepancy in fluctuations at Hunting Park versus those at the Lycoming site ($r^2 = 0.65$) are within the range that one would expect from monitors placed in different parts of the city. Thus, the monitors in Hunting Park were likely picking up actual changes in air quality. However, the difference among absolute $PM_{2.5}$ levels in Hunting Park and levels throughout the rest of the city suggests that lower $PM_{2.5}$ measurements in Hunting Park may well have more to do with the monitoring technique than local variations in actual $PM_{2.5}$ levels.

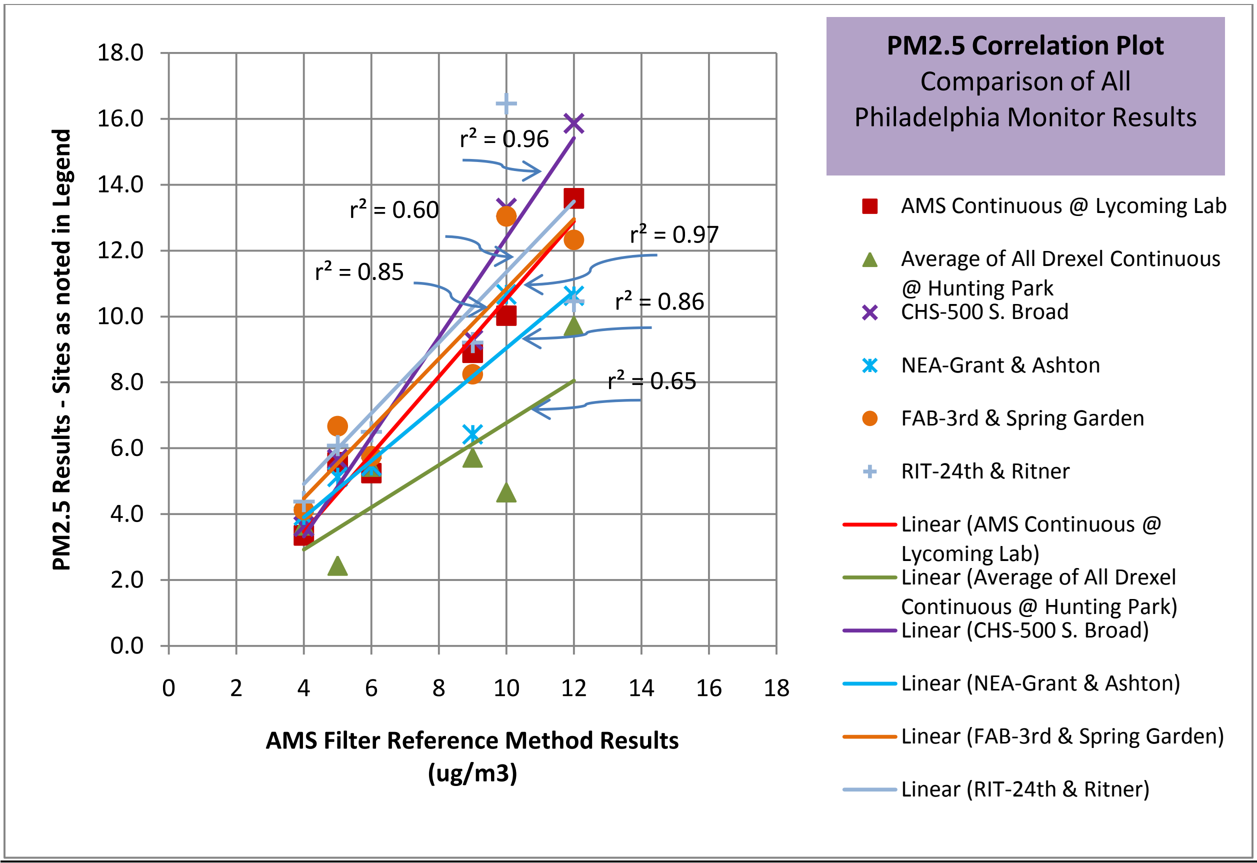


***FIGURE 17** – CORRELATION BETWEEN $PM_{2.5}$ LEVELS AT AIR MANAGEMENT SERVICES SITES*

CONCLUSIONS

Based on the data from the sensor network in the Hunting Park study area, four important conclusions follow:

- Data from the sensor nodes indicate that there are *no predictable geographic patterns* in the $PM_{2.5}$ levels as a function of monitor location within the Hunting Park study area. The $PM_{2.5}$ levels in the residential core and the industrial strip at the eastern end of the neighborhood appear to be roughly comparable. While some minor systematic variation between monitors was detected (cf. Figures 3 and 5), it appears this variation was due to discrepancies between monitors rather than variations in air quality.[20]

- Data suggest there are *no predictable temporal patterns* in the $PM_{2.5}$ levels either as a function of time of day or day of the week (e.g. weekday vs. weekend). As previously noted, $PM_{2.5}$ levels at the seven monitoring sites show fairly close agreement over time, with the exception of intermittent spikes that seem attributable to extraneous sources of particulates or errors in the monitors.

- Measured values for $PM_{2.5}$ levels in the Hunting Park study area during the study period *do not exceed* the National Ambient Air Quality Standards (NAAQS). The 24-hour average of $PM_{2.5}$ levels in Hunting Park fell into the range of 2.4 to 9.7 $\mu g/m^3$, which is below the EPA 24-hour standard of 35 $\mu g/m^3$. On certain days, however, there were spikes in $PM_{2.5}$ levels very close to the EPA limit. The ultimate impact of such spikes on public health is unknown (cf. Figures 6, 8, and 10).

- Measured values for $PM_{2.5}$ levels in Hunting Park are *lower than* values measured by the AMS at their nearest site, i.e. AMS's Lycoming Lab. Due to limitations in the validation of the monitors, it is impossible to determine how much of this difference is due to real variations in air quality between the two sites (i.e. the air in Hunting Park is cleaner) versus the Hunting Park monitors themselves (i.e. systematic under-reporting attributable to the sensor nodes' particle counting method and correction factors). In fact, given that the levels measured by the $PM_{2.5}$ sensor network in Hunting Park are consistently lower than the range of $PM_{2.5}$ levels measured at AMS sites in the rest of the city, there is good reason to suspect that the Hunting Park sensor network is under-reporting.

DIRECTIONS FOR FUTURE RESEARCH

During the study period, health related issues such as asthma attacks, demand for medical attention, and/or respiratory-induced illnesses were not monitored in the test area. Thus, without simultaneous health symptom reporting, the data gathered by the $PM_{2.5}$ sensor network do not generate conclusions

[20] This variation could be attributable to the fact that the monitors were not validated through side-by-side testing (cf. p. 15).

about how PM2.5 levels correlate with reports of high rates of asthma or the pollutants thought to be admitted by neighborhood industrial facilities. More research is required to better understand the uncertainty about the *quality of the data* produced, and the *scope of the existing data*. Therefore, in the second phase of research, it is recommended that the following additional steps be taken:

- Thoroughly validate the data from the sensor nodes developed by the Drexel University students against data using standard AMS methods in order to derive the appropriate correction factors. Rather than deriving the correction factors from data derived from 'one' sensor node placed at an AMS monitoring station, data should be derived from several sensor nodes placed at the station.

- Calibrate the sensor nodes with one another. Test the individual nodes side-by-side to ensure individual devices produce identical data under identical environmental conditions.

- Combine continuous air monitoring with *simultaneous health symptom reporting*, in order to investigate the possible correlations among fluctuations of $PM_{2.5}$ levels and public health incidences such as asthma flare-ups.

- Expand the scope of the analysis by using monitoring methods that can determine the *size distribution and chemical composition* of particulates in Hunting Park. This includes looking at the prevalence of other particles in the neighborhood, such as PM_{10}, and characterizing the particles for the presence of contaminants such as lead and asbestos. This could be accomplished by recalibrating the $PM_{2.5}$ sensor network to test for PM_{10} particles, or by deploying an inexpensive commercial monitor that collects particles on a filter for laboratory analysis.

ABOUT THE AUTHORS

ROBERT (BOB) BRZOZOWSKI holds a Ph.D. degree in Chemistry from Wesleyan University, an MBA from Pennsylvania State University, and B.Sc. degree in Chemical Engineering from the University of Connecticut. He has worked in technical positions of increasing responsibility as a process engineer, research scientist, laboratory manager, and manager of market development and analytical services. He is a member and past chairman of the Sampling and Laboratory Analysis Committee of the American Industrial Hygiene Association, which protects worker health and safety. Brzozowski is currently Project Director, NASA III Sustainability and Alternative Energy Education Grant, at Burlington County College in New Jersey.

GWEN OTTINGER received her Ph.D. in Energy and Resources from the University of California, Berkeley, and holds undergraduate degrees in Aerospace Engineering and Science, Technology, and Culture from Georgia Institute of Technology. Since completing her Ph.D., she has been working to bring technical expertise to environmental justice campaigns, first through service learning projects with her engineering students in the Department of Science, Technology, and Society at the University of Virginia, and more recently, in the Chemical Heritage Foundation's Chemist-Community Collaborations project, which she initiated as a research fellow in Environmental History and Policy in 2009. Ottinger's research focuses on the production and use of science by ordinary citizens in the environmental justice movement, and she is co-editor of *Technoscience and Environmental Justice: Expert Cultures in a Grassroots Movement* (forthcoming from MIT Press). Currently, Ottinger is Assistant Professor of Science and Technology Studies in the Interdisciplinary Arts and Sciences Program at the University of Washington-Bothell.

ADAM CUTLER is Director of the Public Health and Environmental Justice Law Clinic at the Public Interest Law Center of Philadelphia. The Clinic, formed in partnership with the Earle Mack School of Law at Drexel University, is staffed by students from the Earle Mack School of Law, where Cutler holds an adjunct faculty appointment. The mission of the Law Center's environmental practice and the Clinic is to provide legal and technical assistance to affected local communities to enforce their environmental rights and, through impact litigation and other methods of advocacy, to empower local activists to improve the public and economic health of their communities. Since the Clinic's founding in 2008, Cutler and the Clinic students have worked on behalf of numerous communities in the Philadelphia region and other areas of Pennsylvania, including the environmental justice communities of Hunting Park, Chester, and Philadelphia Chinatown. Cutler received his undergraduate degree in Economics, cum laude, from the Wharton School of the University of Pennsylvania and his law degree from the University of Pennsylvania Law School, where he served as an Executive Editor on the University of Pennsylvania Law Review.

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Prior to joining CHF, Doug worked with the Rohm and Haas Company for over 36 years in a wide range of areas including laboratory research, market research, marketing, communications, training, product management, and account management. In these positions, Doug worked in a broad range of chemical industries, including crop protection, pharmaceuticals, personal care, water treatment, biocides, coatings, industrial and institution, and oil and gas fields. Doug has an M.B.A. from Temple University and a B.A. in biology from Millersville University.

MATTHEW HILL is the the Environmental History and Policy Program's coordinator for the C_3 project at the Chemical Heritage Foundation. As the project coordinator, Hill pairs volunteer chemists and chemical engineers with environmental justice communities throughout the Delaware Valley, creating unique scientific partnerships that result in technically rigorous, locally informed, policy-relevant knowledge about the effects of environmental conditions on community health. Hill has an undergraduate degree in chemistry from the University of Colorado, and a Ph.D. in anthropology from the University of Chicago. He currently works as an applied anthropologist in the areas of organizational strategy and change, and has a research focus on urban and environmental issues. In addition to his consulting work, he teaches in the Urban Studies Program at the University of Pennsylvania.