An Environmental Exposure Assessment of Particulate Matter and Volatile Organic Compounds Using On-Sight Monitoring and Modeling to Predict Exposures

Southwest Pennsylvania Environmental Health Project

Erin Straw

University of Pittsburgh

Graduate School of Public Health

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Abstract

With the recent growth of the unconventional oil and gas industry, nearby residents have become increasingly concerned with potential hazardous exposures and environmental pollutions related to these developments. Southwest Pennsylvania Environmental Health Project (EHP) conducted a 5-month air monitoring exposure assessment in Butler County, Pennsylvania. The communities of interest were located near two major unconventional oil and gas development (UOGD) sites: MarkWest's Bluestone Natural Gas Processing Facility and Trillith Compressor Station. EHP monitored Particulate Matter ($PM_{2.5}$) and Volatile Organic Compounds (VOCs) in order to identify and evaluate potential human exposures related to UOGD activity.

After site analysis, EHP identified up to a 178% increase in the number of wells and permits present when expanding the site buffers from 1.5 to 2.0 miles. An average of 3.1 $PM_{2.5}$peaks per day were recorded for the seven monitoring sites. The accumulated particle concentration of $PM_{2.5}$reached as high as 107,842 ug/m3/day. An overall index score was calculated using the collected data to allow for overall comparison between monitoring sites. The highest index score was 8.68 and the lowest was 3.44 (worst and best air quality, respectively). After VOC analysis, EHP found that up to 32 different chemicals were detected at one time during a selecting monitoring period. EHP also developed an Air Model to predict $PM_{2.5}$ exposures. The Air Model predicted an average of 1.5 $PM_{2.5}$exposures per day. The tools and information present in this assessment can be used to characterize geographical areas with potential for high exposure concentrations and frequencies and interpreting overall air pollution in a region of interest. This information is also useful for physicians in order to further examine adverse health effects and the relation to potential exposures.

Introduction

A 5-month air monitoring study by the Southwestern Pennsylvania Environmental Health Project (EHP) was conducted in Butler County, Pennsylvania focused on residences near MarkWest's Bluestone Natural Gas Processing Facility and Trillith Compressor Station. The project recorded real-time and intermittent air quality measurements, and developed an air model to predict specific air pollution plumes. The purpose of this project is to utilize these resources in order to identify and evaluate the potential for human exposures facing residents neighboring the UOGD sites.

The air pollutants monitored include fine particulate matter ($PM_{2.5}$) and volatile organic compounds (VOCs). The most recent emissions data available from the Pennsylvania Department of Environmental Protection (PA DEP) reported emissions from both sources accumulating 56 tons of $PM_{2.5}$ and 1,584 tons of VOCs in 2014.

Air monitors were placed inside and outside of seven monitoring sites located on participating residents' properties. Monitoring was conducted from December-January 2016, March-April 2016 and again from August-September 2016 UOGD facilities within 2 miles of the monitoring sites were included as potential sources of emissions.

The information and tools presented in this assessment can characterize geographical areas with high exposure concentrations and frequencies, which can then be utilized by physicians and other health care providers to further examine adverse health effects potentially related to the exposures of unconventional oil and gas development.

Key Findings: Upon completion of the project, EHP conducted an analysis of the $PM_{2.5}$ recordings and VOC sample collections. By expanding the study spatially from 1.5 to 2.0 miles, there was up to a 178% increase in the number of wells and permits in the surrounding areas and as little as a 28% increase. An average of 3.1 $PM_{2.5}$ peaks per day* for the seven monitoring sites was calculated, indicating potentially harmful exposure events. There was an average of 2,068.80 relative exposure units between the seven monitoring sites. $PM_{2.5}$ accumulated particle concentration was identified to be as high as 107,842 ug/m3/day. Peaks per day, relative exposure and accumulated particle concentration were three components used in mathematically developing an overall air quality index score for each monitoring site. Other components used in developing the index score can be found in Table 5. The Index Score is a number ranging from 0-10 that indicates the overall quality of the air for that monitoring site. A smaller index score indicates better air quality and a higher index score indicates a poorer air quality. The highest index score (i.e. worst quality air) was 8.68. The lowest index score (i.e. best quality air) was 3.44 at R6. In addition to $PM_{2.5}$, summa canisters detected up to 32 different chemicals present in the air at designated monitoring sites.

*Peaks of $PM_{2.5}$ are calculated using a metrics developed by the Environmental Health Project. This metrics classifies exposures (i.e. peaks) as any 15-minute period where $PM_{2.5}$ concentrations are two standard deviations above the data's mean.

Target Analytes: $PM_{2.5}$ and VOCs

Since 2014, the Environmental Health Project has monitored real-time, episodic $PM_{2.5}$ exposures as they relate to nearby oil and natural gas development at residences in Pennsylvania, New York, Ohio and West Virginia. EHP focuses on the short-term, high concentration exposures and the synergistic relationship between $PM_{2.5}$ and VOC's, specifically as they pertain to human health*.

According to the EPA ($PM_{2.5}$) consists of solid or liquid particles present in the air that are smaller than 2.5 micrometers in diameter and is often the result of emissions from various sources. Due to its small size, $PM_{2.5}$ is able to penetrate deep into the lungs upon inhalation, leading to potentially adverse health effects. Susceptible individuals include those suffering from heart and lung diseases, children and the elderly. $PM_{2.5}$ can affect both the lungs and the heart and may lead to premature death in individuals with heart and lung disease. $PM_{2.5}$ has also been linked to heart attacks, irregular heartbeats and respiratory aggravation (EPA). National Ambient Air Quality Standards (NAAQS) set the acceptable level for ambient $PM_{2.5}$ as 35ug/m3 for 24 hours.

Volatile organic compounds, VOCs, are compounds that easily become vapors or gasses. Common VOCs include benzene, toluene, acetone, ethyl alcohol, perchloroethene, trichloroethene and formaldehyde (New York State Department of Health). VOCs are present in many household items such as aerosol sprays, cleaning products and pesticides as well as sources of construction and industry processes. Vapors and gasses have the potential to be inhaled and may lead to headaches, nausea and irritation of the eyes, nose, throat and skin. Liver, kidney and nervous system damage may also occur. Health effects may vary depending on the specific VOCs present (EPA). EHP previously identified health effects of VOCs associated with UOGD. Health effects associated with short term exposures of specific VOCs include: headache and dizziness (Benzene), headaches, sleepiness and confusion (Tolulene), eye, nose, throat and skin irritation (Xylenes), and nose and eye irritation, impaired short term memory and asthma attacks (Formaldehyde). Long term exposures to specific VOCs may lead to chronic health effects including aplastic anemia and leukemia (Benzene), possible permanent neurological problems (Tolulene and Xylenes), and asthma, eczema, nose and throat cancer (Formaldehyde) (EHP). Some VOCs, such as benzene, are known human carcinogens (ATSDR).

*Not only can $PM_{2.5}$ penetrate deep into the lungs, but it may also carry compounds, such as VOCs, into the lungs with it (https://www.airqualitynow.eu/pollution_ health_effects.php).

Locating Nearby UOGD Sources:

When evaluating human exposure and potential health effects related to UOGD emissions, it's imperative to determine the spatial density of UOGD activity, and the temporal component of exposure per source (i.e. when the exposures began, how much exposure occurs per year and with each new source, the additional contaminant load). Using PA DEP reported data and FracTracker.com, EHP identified UOGD sites, including well pads, compressor stations and processing facilities located within 1.5 and 2.0 miles from each air monitoring site. Image 2 displays the overall community of interest with both Bluestone processing plant and Trillith compressor station. The numbers on the well and permit symbols indicate the number present at that location.

Other Contributing Exposure Sources: Pipelines and Roadways

Pipelines are also a main component of unconventional oil and gas development and are therefore a source for potential exposures. Pipelines carry the gas from one location to another. Although pipelines were not a focus in this report, they still may lead to potential exposures and therefore were identified in Butler County using the National Pipeline Mapping System and are depicted in Image 4 below. Since vehicle emissions are also a source of $PM_{2.5}$, state roads were identified as an additional source of exposure and are displayed in Image 1. Interstate 79 is a major roadway that runs North to South through Butler County. $PM_{2.5}$ levels are found to be higher closer to roads than areas further away (UK Department for Environment and Rural Affairs). Bluestone processing plant, Trillith compressor station and all seven air monitoring sites are located to the east of I-79 and therefore are mostly downwind of potential emissions.

Image 1: UOGD Pipelines Present in Butler County, Pennsylvania

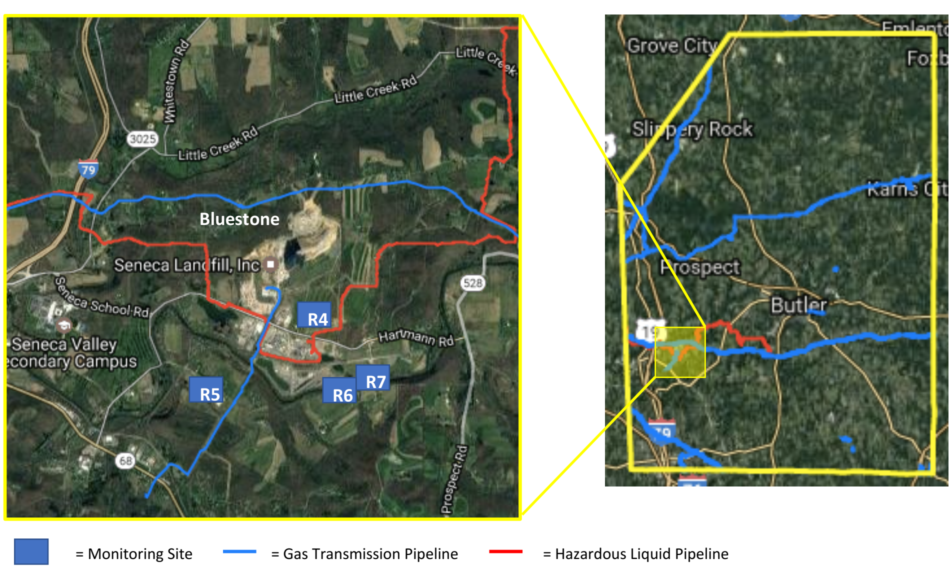
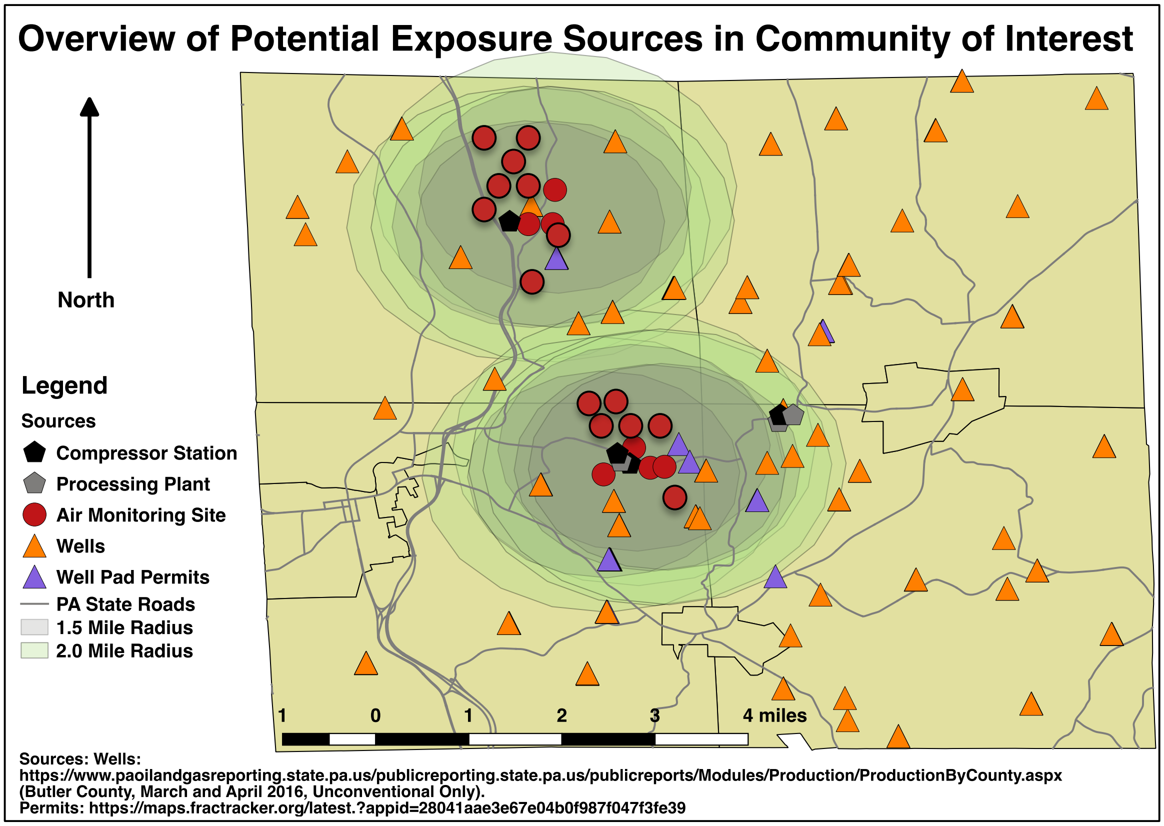


Image 2: Generated Map of Monitoring Sites and Emission Sources



<u>Increasing Exposure as the Study Site Expands Spatially</u>:

A radius was created around each monitoring site in order to identify the number of wells and well permits within 1.5 miles and 2.0 miles of the residences. A previous EHP report, titled "EHP Air Exposure Model" (http://www.environmentalhealthproject.org/files/EHP air exposure model_ hows the weather short version.pdf) identified that sites within two miles of UOGD are likely to be affected by activity regardless of the weather and therefore two miles was chosen as the radial distance for source identification. Processing plant exposures have been found to reach distances greater than two miles, but the exact limit is unknown. Two additional processing plants and one compressor station are also located near the Bluestone processing facility, falling within the two-mile radius of R4, R6 and R7. Well pad permits were included on the generated site map as potential source of exposure in the area. This means that some well pads identified under permit only status on FracTracker may be functioning despite permit only status. If the permit sites are not yet functioning, they will soon be built and contribute to air pollution and resulting exposures in the near future and therefore were included to help community members identify potential exposure in their area. The results are identified in Tables 1 and 2.

Methods

Using Speck Air Quality monitors developed by Carnegie Mellon University, EHP monitored $PM_{2.5}$ levels inside and outside of residences located in close proximity to either of the Trillith or Bluestone sites. The monitors record real-time, minute-by-minute data, which allows EHP to identify when $PM_{2.5}$ levels change and identify possible patterns and correlations over time. For the purpose of EHP's analysis, a $PM_{2.5}$ "peak" is defined as a $PM_{2.5}$ level recorded by the Speck Air Quality Monitor that is more than two times the mean $PM_{2.5}$ level.

Real-time $PM_{2.5}$ data was collected throughout the winter months of December 2015 and January 2016, the spring months of March and April, the summer months of July and August and lastly in the fall during the month of September 2016. The $PM_{2.5}$ samples were collected indoors and outdoors of seven residences; four located near the Bluestone processing facility and three near Trillith compressor station. Only outdoor data was used in analysis for the purpose of this project due to confounding variables for the indoor data.

EHP used 6-liter summa canisters with 24-hour intake flow regulators to collect 12 samples of VOCs. VOC samples were collected simultaneously at two air monitoring sites near the Bluestone Processing facility and one home-site near the Trillith Compressor Station on March 9th, May 19th, July 20th, and Sept 12th 2016. The VOC samples were collected at R4 (0.11 miles from the bluestone site), R6 (0.22 miles from the Bluestone site) and R2 (0.15 miles from the Trillith site) and analyzed using the EPA T0-15 Analysis Method. The T0-15 analysis method identifies what VOCs listed as hazardous air pollutants in the 1990 Title III Clean Air Act Amendments (EPA) are present in the ambient air collected by the summa canister (https://www3.epa.gov/ttnamti1/files/ambient/airtox/to-15r.pdf).

Table 3 below shows the distance and direction of each home from either the Trillith Compressor Station or Bluestone Processing facility.

EHP developed an Air Model that can be used to predict exposures related to UOGD. The model incorporates meteorological data (i.e. wind speed and direction, cloud coverage) with distance and angle the monitoring site is from the pollution source. Depending on these factors and the source type (i.e. well pad, compressor station or processing plant), the model will produce and output of predicted exposures which can be used for future evaluation as well as comparison to recorded data.

Weather and Meteorological Effects on Exposures:

Hourly weather information from the Butler County Airport was downloaded from https://www.ncda.noaa.gov/qclcd/QCLCD to identify the predominant wind directions for the months of air monitoring. Weather statistics were calculated using Minitab Express and are summarized in Table 4.

Results

Table 1: Wells and Permits Between 2007-2016 Within 1.5 and 2.0 Miles of Monitoring Sites

Monitoring Site	# Wells w/in 1.5 Miles	#Permits w/in 1.5 Miles	Total # w/in 1.5 Miles	# Wells w/in 2.0 Miles	# Permits w/in 2.0 Miles	Total # w/in 2.0 Miles	% Increase in number of wells / permits
R1	8	3	**11**	22	3	**25**	127.27%
R2	6	3	**9**	22	3	**25**	177.78%
R3	13	3	**16**	22	3	**25**	56.25%
R4	15	2	**17**	23	9	**32**	88.24%
R5	15	7	**22**	19	9	**28**	27.70%
R6	16	9	**25**	21	14	**35**	40.00%
R7	17	9	**26**	25	9	**34**	30.77%

Table 2: Amount of Compressor Stations and Processing Plants Between 2007-2016 Within 1.5 and 2.0 Miles of Monitoring Sites

Monitoring Site	# CS w/in 1.5 Miles	# PP w/in 1.5 Miles	Total # w/in 1.5 Miles	# CS w/in 2.0 Miles	# PP w/in 2.0 Miles	Total # w/in 2.0 Miles	% Increase
R1	1	0	**1**	1	0	**1**	0.00%
R2	1	0	**1**	1	0	**1**	0.00%
R3	1	0	**1**	1	0	**1**	0.00%
R4	2	1	**3**	3	3	**6**	100.00%
R5	2	1	**3**	2	1	**3**	0.00%
R6	2	1	**3**	3	3	**6**	100.00%
R7	3	2	**5**	3	3	**6**	20.00%

***CS = Compressor Stations, PP = Processing Plants**

EHP found that by expanding the study spatially from 1.5 to 2.0 miles, there was up to a 178% increase in the number of wells and permits in the surrounding areas and as little as a 28% increase. R2 experienced the greatest percent increase of wells and permits from 9 total within 1.5 miles, but 25 within two miles. R5 demonstrated the smallest percent increase, however their total wells and permits within 1.5 miles was much higher to begin with (22) compared to R2's (9). On average, all of the monitoring sites experience a 78.29% increase when expanding their exposure sources from 1.5 to 2.0 miles. Due to the high concentration of unconventional oil and gas development activity occurring in the area, a 100% increase in exposure to processing plants and compressor stations also occurred for some monitoring sites (R4 and R6). R1, R2, R3 and R5 did not experience any increase in compressor station or processing plant exposure when expanding from 1.5 to 2.0 miles radially. Refer to Tables 1 and 2 above for details on each monitoring sites' exposure sources.

Table 3: **Community Site Summary for Monitoring Sites and Sources of Exposure**

Monitoring Site	Source of Exposure	Distance from Source to Monitoring Site	Direction from Source to Monitoring Site	Dates Monitored
R1	Trillith	0.37 mi (0.59 km)	E, NE (64.71°)	3/16-4/16
R2	Trillith	0.15 mi (0.24 km)	E (80.66°)	8/16-9/16
R3	Trillith	0.31 mi (0.5 km)	E (80.5°)	3/16-4/16
R4	Bluestone	0.11 mi (0.18 km)	E, NE (63.99°)	3/16-4/16, 7/16-8/16
R5	Bluestone	0.34 mi (0.55 km)	SW (226.43°)	12/15-1/16
R6	Bluestone	0.22 mi (0.36 km)	S, SE (145.25°)	3/16-4/16
R7	Bluestone	0.23 mi (0.38 km)	SE (134.89°)	3/16-4/16

Note: 1 mile = 0.6 km

In a previous report titled "EHP Air Exposure Model" http://www.environmentalhealthproject.org/files/EHP%20air%20exposure%20model_%20hows%20the%20weather%20short%20version.pdf, EHP demonstrated that residents within 400 yards (0.227 miles) of UODG activity, are likely to have their air affected regardless of the weather conditions. R2, R4, R6 and R6 are within 400 yards of either Bluestone or Trillith and therefore may be affected by emissions despite weather or wind direction. R1, R3 and R5 fall outside of 400 yards and therefore the weather may play a significant part in their emissions exposures.

Since some monitoring sites fall outside of this range, weather conditions, especially wind direction, were taken into consideration for analysis.

Table 4: Wind Direction Summary Statistics.

Month	N	Mean	Standard Deviation	Minimum (Degrees)	Maximum (Degrees)
March	2232	165.612	108.220	10	350
April	1802	189.476	104.588	10	350
July	1551	200.577	83.942	10	350
August	930	174.371	77.392	10	350
September	1323	147.910	89.944	10	350

Note: Degree = direction on a wind compass.

For the months monitored, weather analysis indicated that July and August had a predominant wind direction coming from the South, Southwest, and West directions. March, April and September did not have a predominant wind direction; however, the highest frequency winds blew from the South, Southwest and West. The majority of monitoring sites, with the exception of R5, were downwind of either Trillith Compressor Station or Bluestone Processing Site during the study monitoring periods. A downwind location means that any emissions from the sources will travel towards the monitoring sites, potentially increasing the residents' risk of exposure from these emission sources.

$PM_{2.5}$ Data Analysis:

Working with collected $PM_{2.5}$concentration values from Speck air quality monitors, EHP analyzed each data set from the respective monitoring site (R1-R7).

Key exposure metrics pulled from EHP's data analysis include:

1)Peak Frequency: how many times a peak larger than two times the mean occurred
2)Peaks per Day Score: calculated score based off number of peaks recorded per day,

3)Exposure per Peak: relative units indicating amount of potential exposure occurring for each peak

4) Accumulated particle exposure: summary of factors contributing to exposure and

5) An Index Score: overall indication of exposure and air quality.

The index score is a weighted value, based on the speck monitor results on a 1-10 scale. A higher Index Score indicates higher exposures and poorer air quality. Speck air monitoring ($PM_{2.5}$) results are displayed in Table 5.

The summa canisters collected a minimum of 2 and a maximum of 32 volatile organic compounds. These readings were divided into total chemicals recorded, and Tentatively Identified Chemicals (TICs). The full list of chemicals and TICs can be found in Appendix III. Chemicals detected at all monitoring sites included: Methane, Propene, Ethanol, Acetone, Dichlorodifluoromethane (CFC 12), Trichlorofluoromethane, Ethyl acetate, n-Hexane and Toluene. Tentatively Identified Chemicals detected at all monitoring sites included: Propane, Isobutane, n-Butane, n-Pentane, Trimethylsilanol, Hexanemethylcyclotrisiloxane, Unknown siloxane, and two other unknown compounds.

Table 5: Summary of $PM_{2.5}$ Index Values

Monitoring Site	Dates Monitored	Peak Frequency	Peaks /day	Peak Duration (min)	Time btwn Peaks (hr)	Exposure /Peak (relative units)	Total Exposure (relative units)	Accum. Part. Conc. (ug/m3/day)	Count 35th (ppl)	Conc. 35th (ug/m3)	Index Score
R1	3/16/16-4/16/16	97	3	32.3	7.9	29	2539	107842	592	24.1	8.68
R2	8/1/16-9/1/16	93	2.9	22.3	8.2	15	1372	6521	427	17.3	5.98
R3	3/16//16-4/16/16	94	2.9	29.7	8.0	32	3030	41823	202	8.2	7.45
R4	3/16/16-4/16/16	113	3.5	33.4	6.3	37	4166	11287	146	5.9	7.82
R4	8/1/16-9/1/16	109	3.4	22.8	7.1	19	2121	5061	244	9.9	5.76
R5	12/1/15-1/1/16	91	2.8	29.5	8.3	25	2289	11057	224	9.1	6.84
R6	3/16/16-4/16/16	83	2.6	19.7	8.9	17	1363	3527	346	14.0	3.44
R7	3/16/16-4/16/16	103	3.2	21.9	7.3	21	2184	6480	182	7.4	5.73

Note: The scalar conversion factor from counts to mass (concentration) that represents the mean density and unit conversion from approximately 2um particles per liter (ppl) to ug/m3. This conversion is under the assumption that approximately 25, 2um particles per liter are sensed by the Speck Monitors for every microgram per cubic meter of air.

Table 6: Summary of VOC Collections

Monitoring Site	Minimum Total Chemicals	Maximum Total Chemicals	Minimum Tentatively Identified Chemicals	Maximum Tentatively Identified Chemicals
R2	2	12	6	12
R4	4	32	8	15
R6	4	11	7	15

Table 7: Estimated Air Model Exposures

Monitoring Site	Dates Modeled	# Predicted Exposures	Predicted Average Frequency (exposure/day)	Predicted Average Duration (hr.min)
R1	3/1/16-4/30/60	134	2.2	4.2
R2	7/1/16-9/28/16	68	0.8	7.5
R3	3/1/16-4/30/16	128	2.1	4.5
R4	3/1/16-4/30/16	86	1.4	6.1
R4	7/1/16-9/28/16	66	0.7	8.3
R5	3/1/16-4/30/16	103	1.7	5.7
R6	7/1/16-9/28/16	66	1.6	7.9
R6	3/1/16-4/30/16	96	1.6	4.8
R7	3/1/16-4/30/16	98	1.6	4.6

Discussion

Images 3 and 4 provide satellite images of air monitoring sites near Trillith compressor station and Bluestone processing plant for better visualization of the discussion section. The arrow indicates primary wind direction during monitoring. Yellow pins indicate the 7 air monitoring sites where EHP collected real-time continuous readings of $PM_{2.5}$ as well as periodic samples of VOCs from designated locations (R2, R4, R6).

R2 and R4 were located closest, and downwind of compressor stations. R4 obtained the highest impact $PM_{2.5}$ results for outdoor peak frequency, peaks per day score, exposure per peak and total exposure.

Image 3: Air Monitoring Sites Near Trillith Compressor Station

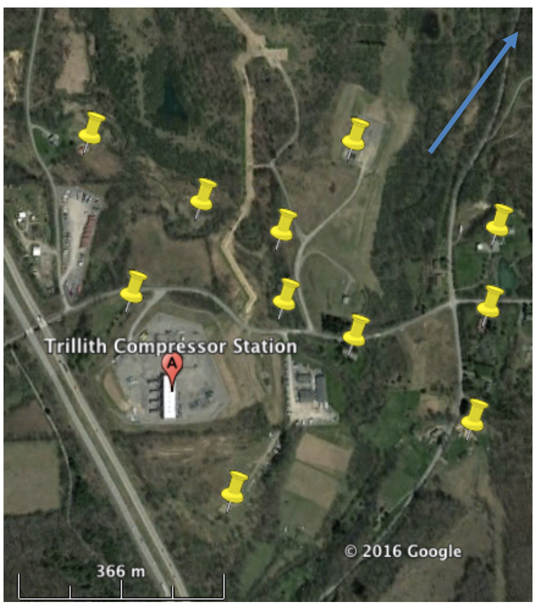
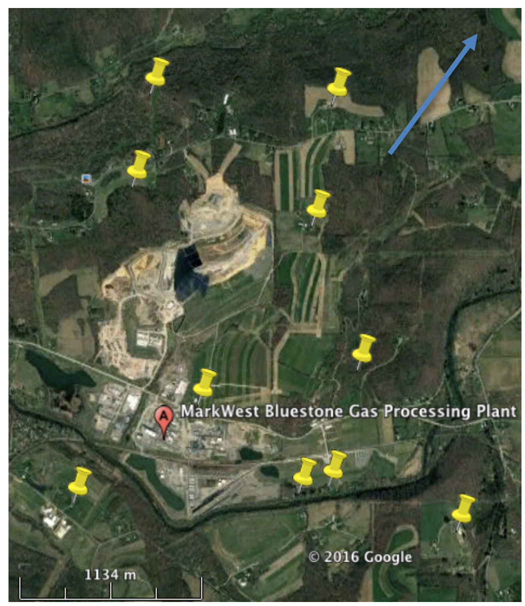


Image 4: Air Monitoring Sites Near Bluestone Processing Plant



Monitoring sites R6 and R7 contain the most wells and permits within 1.5 miles, yet R6 maintains some of the best outdoor air quality in terms of Index score, peak frequency, peak per day score and total exposure (Accumulated particle exposure). Refer to table 5 for more information. This may be the result of R6 not being directly downwind of the emission stacks, as it is more to the east of the Bluestone processing plant.

The $PM_{2.5}$ monitors recorded an average of 3.1 peaks per day for the seven monitoring sites. As mentioned, since Bluestone and Trillith are located close to each other, EHP considers all homes in this study as a community. In terms of community exposure to fine particulate matter, 3.1 exposures per day, per home is inconsistent with the NAAQS data. NAAQS averages values for 24-hours which disregards the peak exposures which can be harmful to health. Recurring peak exposures can exacerbate health impacts.

Only R4 was monitored on two separate occasions: March – April 2016 and August – September 2016. R4's Speck results for the two recording periods yielded fairly similar results for each finding, except for Accumulated Particle Concentration, which was much higher in spring months (41,823 ug/m3/day) compared to the summer months (11,287 ug/m3/day). This indicates the importance of repetitive monitoring, to better identify variations in the data collected. Despite this large difference in particle accumulation, the overall index score for R4 remained the same.

It is also important to note that Trillith compressor station sits approximately 100 feet higher than monitoring sites R1, R2 and R3, which are located on relatively level topography. Taking this into consideration, emissions from the compressor station may be traveling over R2 via wind and accumulating more on R1 and R3. Accumulated particle concentration (ug/m3/day) increased dramatically in these three monitoring sites, as distance increased from the compressor station. R2 (6,521 ug/m3/day) is closest to the station, followed by R3 (41,823 ug/m3/day). R3 (107,842 ug/m3/day) is the furthest away from the station. R1, R2 and R3 are directly downwind of Trillith compressor station, which may explain the trend in particle accumulation.

In terms of VOC detection, at R4, a summa canister detected 32 different chemicals and 15 Tentatively Identified Compounds (TICs) on September 12-13, from 7pm to 12pm. This suggests that major activity occurred around site R4, which is closest to the Bluestone Processing Plant.

Rates of pollution differ depending on the type of UOGD activity. For instance, EHP previously found that processing plants and actively fracked sites emit more pollution that do functioning wells (EHP Air Exposure Model). Unfortunately, there is a lack of available recent emission data for processing plants and compressor stations, which is a limitation when trying to assess current emissions in the nearby community. The most recent PA DEP data available is from 2014 and can be found here: http://www.dep.pa.gov/business/air/baq/businesstopics/emission/pages/marcellus-inventory.aspx . Also, the data that is available is self reported from the UOGD companies, which may lead to inaccuracies in the reported data. Another limitation is the variation in monitoring dates. This requires the weather information used for the air model to be averaged over a longer time period, reducing the precision of the prevailing wind directions. Throughout the months of monitoring, the specific stages of process of the unconventional oil and gas development that were underway at Bluestone and Trillith were not known. This means that the processes cannot be specifically correlated with the recorded air exposures.

Wells, well permits, compressor stations and processing plants were all identified as potential sources of air pollution exposures, but other variables may exist, such as pipelines and roadways. PA Interstate-79 runs adjacent to the community of interest. Trillith is approximately 550 feet to the east of I-79, making it, as well as R1, R2 and R3 predominately downwind of any traffic exposures. Exposures from I-79 and other roadways are accounted for in the baseline collection of the homes in comparison to the compressor stations and processing plants.

The predicted frequency of exposures acquired from the Air Model were consistent with the recorded data. The air model predicted an average of 1.5 exposures per day whereas the Speck monitors detected an average of 3 exposures per day. Although the model did not estimate every exposure captured, this is expected as the air model runs on the assumption that emissions occur from a single source, 24 hours per day, 7 days a week, on flat topography. Due to the amount of UOGD within the study area and the valley-like topography, EHP expected a higher rate of exposure than the air model would produce. The Industrial Source Complex Model (a popular steady-state Gaussian plume model which can be used to assess pollutant concentrations from a wide variety of sources associated with an industrial complex) may be used for a more accurate prediction of exposures, however due to the density of exposure sources in the community EHP's Air Model was used instead. A major difference between the predicted air model exposures and the recorded data is the duration of exposures. The air model predicted exposures lasting several hours, whereas the recorded data indicated the exposures lasted only minutes instead. This difference may be due to the fact that the air model incorporates wind speed, which means that light or no wind (which occurred often) would result in higher duration times for exposures.

Conclusions and Recommendations

EHP monitored and modeled periodic, transient and repeated exposures which can occur at very high concentrations. The Speck Air Quality Monitors and Summa Canisters picked up elevated levels of $PM_{2.5}$ and potentially hazardous chemicals, respectively. An average of 3.1 peaks per day of $PM_{2.5}$ were recorded with accumulated particle concentrations reaching as high as 107,842 ug/m3/day. The Air Model predicted 1.5 peaks per day of $PM_{2.5}$, which is consistent with the real-time data. By increasing the radius surrounding monitoring sites from 1.5 to 2.0 miles increased the number of total wells and well permits by 128%. Resident should take precautions to protect themselves against air pollution. Precautions include the use of air filters and purifiers and keeping doors and windows closed.

For future reports, it may be beneficial to monitor all sites of interest over the same time period. This will allow for more precise weather information, as well as an elimination of confounding variables that may be present between different seasons. It may also be beneficial to have residents at the monitoring site keep a journal of any activity that may generate exposures. For example, if a plume from a compressor station occurs, the resident can record the date, time and extent of the plume in order to identify if this had any effect on the resulting air monitoring data.

Individuals concerned about health effects potentially related to unconventional oil and gas development in their area should consult their physician and describe any symptoms. The Air Model used in this assessment is useful in predicting hazardous exposures and is a powerful screening tool for potential health effects.

Resources

Agency for Toxic Substances and Disease Registry (ATSDR): Benzene

https://www.atsdr.cdc.gov/substances/toxsubstance.asp?toxid=14

Department for Environment, Food and Rural Affairs: Sources and Effects of PM2.5

https://laqm.defra.gov.uk/public-health/pm25.html

EHP Air Exposure Model

http://www.environmentalhealthproject.org/files/EHP%20air%20exposure%20model_%20hows%20the%20weather%20short%20version.pdf

EHP: Potential Health Effects Due to Inhalation

http://www.environmentalhealthproject.org/healthcare-providers/medical-toolbox

Indoor Air Quality Index: Volatile Organic Compounds

http://www.iaqindex.com/faqlist/10-iaqfaqvoc.html

National Pipeline Mapping System

https://pvnpms.phmsa.dot.gov/PublicViewer/

New York State Department of Health: Volatile Organic Compounds in Commonly Used Products

https://www.health.ny.gov/environmental/indoors/voc.htm

PA Department of Environmental Protection: Air Emissions Data From Natural Gas Operations

http://www.dep.pa.gov/business/air/baq/businesstopics/emission/pages/marcellus-inventory.aspx

U.S. EPA: National Ambient Air Quality Standards

https://www.epa.gov/criteria-air-pollutants/naaqs-table

U.S. EPA: Particulate Matter

https://www.epa.gov/pm-pollution/particulate-matter-pm-basics

https://www.epa.gov/pm-pollution/health-and-environmental-effects-particulate-matter-pm

U.S. EPA: Particle Pollution and Your Health

https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P1001EX6.txt

U.S. EPA: T0-15 Collection Method

https://www3.epa.gov/ttnamti1/files/ambient/airtox/to-15r.pdf

U.S. Environmental Protection Agency: Volatile Organic Compounds Impact on Indoor Air Quality

https://www.epa.gov/indoor-air-quality-iaq/volatile-organic-compounds-impact-indoor-air-quality

Appendix I: Unconventional Wells in Community of Interest, from March and April 2016 Production Report (PADEP)

Name	SPUD Date	March Gas Quantity (Mcf)	April Gas Quantity (Mcf)	Total Gas Quantity (Mcf)	Well Municipality
PHYLLIS A WYLIE 1	7/11/07	0	400	400	FORWARD
OLIVE M MARBURGER LIVING TRUST 2	2/2/09	6882	13424	20306	FORWARD
EDWARD R GAW JR 1	12/23/08	224	32	256	FORWARD
OLIVE M MARBURGER LIVING TRUST 1	1/12/09	2274	1755	4029	FORWARD
MARBURGER FARM DAIRY INC UNIT 2H	9/3/11	5473	13950	19423	FORWARD
MARBURGER FARM DAIRY INC UNIT 1H	8/28/11	14850	9697	24547	FORWARD
MERTEN UNIT 1H	12/23/11	32976	30564	63540	FORWARD
MERTEN UNIT 2H	3/15/12	29372	25713	55085	FORWARD
HIXON UNIT 1H	11/23/13	26012	28292	54304	FORWARD
HIXON UNIT 2H	11/23/13	36898	35992	72890	FORWARD
MARBURGER FARM DAIRY B UNIT 1H	4/24/12	31297	32858	64155	FORWARD
MARBURGER FARM DAIRY B UNIT 2H	4/27/12	27165	27977	55142	FORWARD
HIXON UNIT 4H	8/6/12	42047	33091	75138	FORWARD
GILL UNIT 1H	10/16/12	64063	62550	126613	FORWARD
GILL UNIT 2H	10/19/12	45481	40674	86155	FORWARD

GILL UNIT 3H	10/21/12	42559	35527	78086	FORWARD
HIXON UNIT 5H	10/5/12	67469	54800	122269	FORWARD
RUTLEDGE UNIT 1H	1/19/13	57033	47073	104106	FORWARD
RUTLEDGE UNIT 2H	1/19/13	44939	38039	82978	FORWARD
RUTLEDGE UNIT 3H	1/19/13	37344	32558	69902	FORWARD
RUTLEDGE UNIT 4H	1/19/13	52656	42257	94913	FORWARD
HIXON UNIT 6HB	2/8/14	21689	18213	39902	FORWARD
VICNOR GAW UNIT 4H	11/23/15	1235.42	4871	6106.42	FORWARD
LONCHENA P 1	10/13/08	15280.05	1551.87	16831.92	FORWARD
KNAUFF P 1	10/22/08	1824.69	17019.99	18844.68	FORWARD
HUDSON J 2	10/21/08	16953.41	1750.32	18703.73	FORWARD
R KNAUF UNIT 1H	1/5/10	16726.58	16316.77	33043.35	FORWARD
R KNAUF UNIT 2H	1/5/10	16840.08	16286.13	33126.21	FORWARD
MAGILL UNIT 1H	1/9/10	23765.62	16066.22	39831.84	FORWARD
MAGILL UNIT 2H	2/4/10	22250.36	22799.09	45049.45	FORWARD
MCELHINNY UNIT 4H	2/10/11	23280.45	20821.01	44101.46	FORWARD
MCELHINNY UNIT 1H	2/10/11	25065.49	22317.37	47382.86	FORWARD
BEHM UNIT 1H	2/28/11	30462.12	24003.98	54466.1	FORWARD
BEHM UNIT 2H	3/16/11	33312.07	29157.47	62469.54	FORWARD
BEHM UNIT 3H	3/2/11	64654.99	31922.94	96577.93	FORWARD
LAMPERSKI UNIT 1H	11/5/12	68820.93	60129.99	128950.92	FORWARD
RAPE UNIT 2H	9/5/12	66682.38	65124.82	131807.2	FORWARD
LAMPERSKI UNIT 2H	10/17/12	59551.92	62822.83	122374.75	FORWARD
SCHILLING SOUTH UNIT 1H	12/3/13	58359.33	55492.07	113851.4	FORWARD
SCHILLING SOUTH UNIT 2H	12/4/13	62051.02	55212.13	117263.15	FORWARD
STEVEN LESNEY ET UX 1	1/5/07	734	729	1463	CONNOQUENESSING

PATTON UNIT 1H	11/23/11	41843	32324	74167	CONNOQUENESSING
PATTON B UNIT 7H	10/4/13	42609	26917	69526	CONNOQUENESSING
GUIHER UNIT 4H	5/14/14	55523	47653	103176	CONNOQUENESSING
GUIHER UNIT 7HB	5/14/14	38701	37576	76277	CONNOQUENESSING
LUTHERLYN UNIT 5H	5/14/14	54373	32858	87231	CONNOQUENESSING
LUTHERLYN UNIT 6H	5/14/14	57528	35948	93476	CONNOQUENESSING
KYNE UNIT 1H	9/15/14	61943	54917	116860	CONNOQUENESSING
KYNE UNIT 2H	9/15/14	58345	34267	92612	CONNOQUENESSING
KYNE UNIT 3H	9/15/14	59758	35005	94763	CONNOQUENESSING
REEDY D 2	2/20/08	1189.05	1048.14	2237.19	CONNOQUENESSING
SHANNON UNIT 1H	4/13/10	22682.03	21989.71	44671.74	CONNOQUENESSING
SHANNON UNIT 2H	4/22/10	8726.89	8400.15	17127.04	CONNOQUENESSING
VOLL UNIT 1H	7/5/10	13409.17	13028.09	26437.26	CONNOQUENESSING
VOLL UNIT 2H	8/1/10	18271.3	17461.11	35732.41	CONNOQUENESSING
GILLILAND UNIT 1H	10/28/10	22537.97	21515.55	44053.52	CONNOQUENESSING
GILLILAND UNIT 2H	10/29/10	412.21	970.5	1382.71	CONNOQUENESSING
GILLILAND UNIT 3H	11/1/10	12109.25	17844.08	29953.33	CONNOQUENESSING
GILLILAND UNIT 4H	11/2/10	8842.61	0	8842.61	CONNOQUENESSING
GILLILAND UNIT 5H	1/22/11	21835.91	22348.78	44184.69	CONNOQUENESSING
VOLL UNIT 3H	3/14/11	21799.4	20924.64	42724.04	CONNOQUENESSING
VOLL UNIT 4H	3/15/11	30026.43	28725.05	58751.48	CONNOQUENESSING
GILLILAND UNIT 11HB	2/7/11	17249.37	17060.03	34309.4	CONNOQUENESSING
CARSON UNIT 1H	6/1/11	35509.92	33916.66	69426.58	CONNOQUENESSING
CARSON UNIT 3H	6/2/11	29851.05	28588.8	58439.85	CONNOQUENESSING
BRICKER UNIT 1H	8/24/11	60366.41	56802.68	117169.09	CONNOQUENESSING
SHIPLEY UNIT 3H	2/14/14	82070.07	77997.88	160067.95	CONNOQUENESSING
SHIPLEY UNIT 5H	2/14/14	70720.34	66628.48	137348.82	CONNOQUENESSING
SHIPLEY UNIT 7H	2/15/14	77548.1	70161.11	147709.21	CONNOQUENESSING

BURR UNIT 2H	7/6/14	71372.31	65199.16	136571.47	CONNOQUENESSING
BURR UNIT 1H	7/5/14	116056.48	110108.62	226165.1	CONNOQUENESSING
MICHAEL UNIT 3HB	7/30/14	59626.32	51548.01	111174.33	CONNOQUENESSING
MICHAEL UNIT 5H	7/31/14	66367.44	60700.09	127067.53	CONNOQUENESSING
MICHAEL UNIT 9HB	8/2/14	61065.6	52106.56	113172.16	CONNOQUENESSING
MICHAEL UNIT 11H	8/3/14	60905.5	55221.79	116127.29	CONNOQUENESSING
MICHAEL UNIT 1H	7/29/14	60726.08	55794.62	116520.7	CONNOQUENESSING
BLOOM UNIT 6H	10/1/14	104418.4	91937.07	196355.47	CONNOQUENESSING
GROSICK UNIT 1H	9/1/10	23543.05	22108.62	45651.67	LANCASTER
GROSICK UNIT 2H	9/16/10	17321.72	16421.78	33743.5	LANCASTER
GROSICK UNIT 3H	9/22/10	9876.58	10031.47	19908.05	LANCASTER
GROSICK UNIT 4H	9/30/10	10118.2	9676.94	19795.14	LANCASTER
GROSICK UNIT 5H	10/6/10	15505.97	13917.93	29423.9	LANCASTER
GROSICK UNIT 6H	10/16/10	16310.81	16114.6	32425.41	LANCASTER
GROSICK UNIT 7H	10/24/10	10348.49	10157.64	20506.13	LANCASTER
WACK UNIT 9H	5/7/12	23695.57	22478.67	46174.24	LANCASTER
GRAHAM UNIT 1H	5/2/11	11004.18	11139.18	22143.36	LANCASTER
GRAHAM UNIT 2H	5/2/11	23018.28	23788.67	46806.95	LANCASTER
GRAHAM UNIT 3H	5/3/11	17787.87	15207.88	32995.75	LANCASTER
PLESNIAK UNIT 3H	12/8/11	27254	26081.92	53335.92	LANCASTER
PLESNIAK UNIT 9H	12/9/11	31126.56	29841.86	60968.42	LANCASTER
GRUBBS UNIT 2H	1/4/12	14095.29	13701.92	27797.21	LANCASTER
PALLACK UNIT 1H	10/8/11	23856.41	23101.86	46958.27	LANCASTER
PALLACK UNIT 3H	10/26/11	26474.66	25461.7	51936.36	LANCASTER
BURGH UNIT 2HD	7/25/12	11450.06	11754.02	23204.08	LANCASTER
WARNER UNIT 1H	12/17/12	36834.2	34998.09	71832.29	LANCASTER
WARNER UNIT 2H	12/18/12	38127.31	35915.66	74042.97	LANCASTER
L&L PROPERTIES UNIT 1H	5/17/13	57338.11	54086.53	111424.64	LANCASTER

L&L PROPERTIES UNIT 2H	5/20/13	58994.76	55004.47	113999.23	LANCASTER
DORSCH UNIT 2H	5/31/14	44178.06	40419.75	84597.81	LANCASTER
DORSCH UNIT 4H	6/1/14	44592.47	43256.56	87849.03	LANCASTER
HAMILTON UNIT 1HB	8/10/14	55424.74	51161.78	106586.52	LANCASTER
HAMILTON UNIT 2HB	8/10/14	39896.98	36754.65	76651.63	LANCASTER
BINTRIM UNIT 1H	9/8/14	51610.6	48420.12	100030.72	LANCASTER
BINTRIM UNIT 3H	9/9/14	51107.98	48384.49	99492.47	LANCASTER
BICEHOUSE UNIT 3H	9/11/14	32809.12	31307.79	64116.91	LANCASTER
R DOUBLE UNIT 1H	2/8/10	17596.03	16984.43	34580.46	JACKSON
R DOUBLE UNIT 2H	2/20/10	13413.64	12311.23	25724.87	JACKSON
DRUSHEL UNIT 5H	8/12/10	16747.61	15433.76	32181.37	JACKSON
DRUSHEL UNIT 3H	7/30/10	28671.13	26812.1	55483.23	JACKSON
DRUSHEL UNIT 4H	8/6/10	18273.88	17566.68	35840.56	JACKSON
DRUSHEL UNIT 2H	7/23/10	17021.01	16321.29	33342.3	JACKSON
TALARICO UNIT 11H	11/24/10	10192.21	11738.41	21930.62	JACKSON
TALARICO UNIT 10H	2/7/11	19110.74	17430.27	36541.01	JACKSON
TALARICO UNIT 9H	11/23/10	29143.23	28207.83	57351.06	JACKSON
MEYER UNIT 2H	2/3/12	66178.3	54476.57	120654.87	JACKSON
JRGL UNIT 3H	4/10/12	42963.18	40639.45	83602.63	JACKSON
BREAKNECK BEAGLE CLUB UNIT 1H	6/18/12	35615.47	33442.8	69058.27	JACKSON
BREAKNECK BEAGLE CLUB UNIT 2H	6/18/12	33952.11	31976.13	65928.24	JACKSON
BREAKNECK BEAGLE CLUB UNIT 3H	6/18/12	47547.66	43845.68	91393.34	JACKSON
BREAKNECK BEAGLE CLUB UNIT 4H	6/18/12	43841.7	40450.92	84292.62	JACKSON
DRUSHEL UNIT 6HD	10/22/12	50631.38	47812.38	98443.76	JACKSON
BAME UNIT 1H	2/14/13	46943.45	44532.67	91476.12	JACKSON

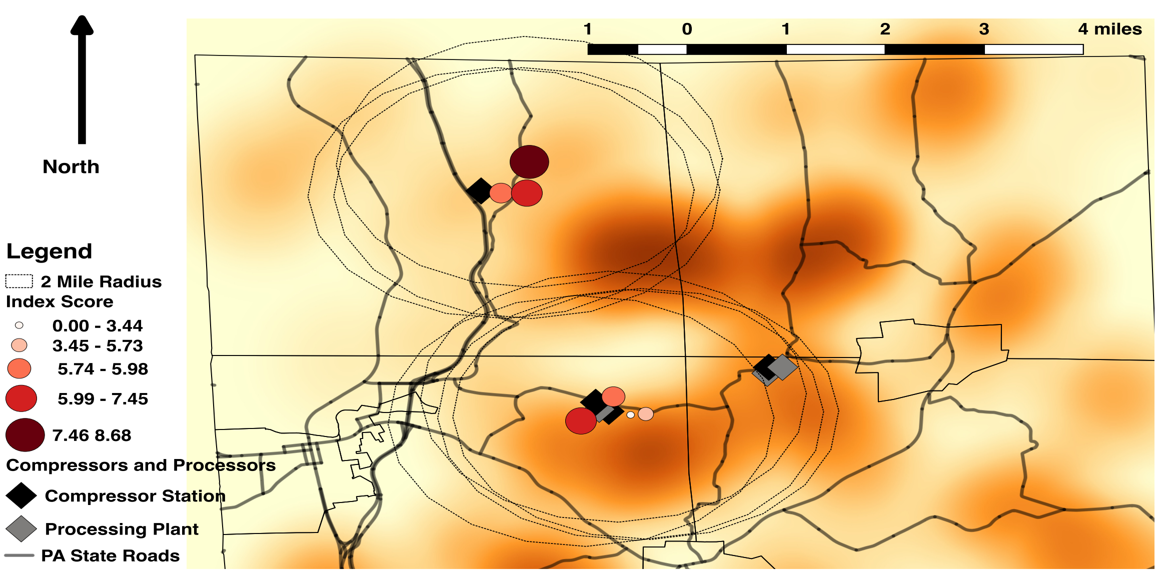
BAME UNIT 2H	2/7/13	44374.05	41761.9	86135.95	JACKSON
BAME UNIT 3H	2/8/13	41290.39	37957.28	79247.67	JACKSON
BAILLIE TRUST UNIT 1H	4/11/13	69160.52	64459.54	133620.06	JACKSON
BAILLIE TRUST UNIT 2H	4/12/13	39742.86	37602.54	77345.4	JACKSON
BAILLIE TRUST UNIT 4H	4/15/13	42317.45	39993.59	82311.04	JACKSON
BALLIE TRUST UNIT 3H	4/13/13	61470.15	58398.71	119868.86	JACKSON
BAILLIE TRUST UNIT 5HB	6/7/13	49040.97	46433.41	95474.38	JACKSON
BAILLIE TRUST UNIT 6HB	6/6/13	60807.79	57091.16	117898.95	JACKSON
BELL PROPERTIES UNIT 2H	4/21/14	36867.38	36348.12	73215.5	JACKSON
BELL PROPERTIES UNIT 4H	4/21/14	41586.23	37722.94	79309.17	JACKSON
BELL PROPERTIES UNIT 6H	4/22/14	46394.39	46255	92649.39	JACKSON
BELL PROPERTIES UNIT 10H	4/23/14	38164.72	34365.76	72530.48	JACKSON
BELL PROPERTIES UNIT 8H	4/22/14	38795.6	36052.8	74848.4	JACKSON

The following heat maps represent the production rate of the natural gas well pads within the study area. As the heat spots darken, the production rates of the well pads increase. EHP was interested in examining the correlation of production rates to the $PM_{2.5}$ analysis.

All maps were generated using QGIS. Image 1 depicts a map of both sites, which EHP classified as a community of interest. The monitoring sites and the Bluestone Processing Facility were geocoded using known coordinates and addresses. Geographic coordinates for Trillith Compressor station were obtained from GoogleEarth and coordinates for well permits were obtained from FracTracker (https://maps.fracktracker.org). Active wells were obtained from PA DEP oil and gas reporting website. Unconventional wells in Butler County were selected to obtain the production rates from March and April 2016, when most of the Speck Monitoring was conducted. (https://www.paoilandgasreporting.state.pa.us/publicreports/Modules/Production/Prod).

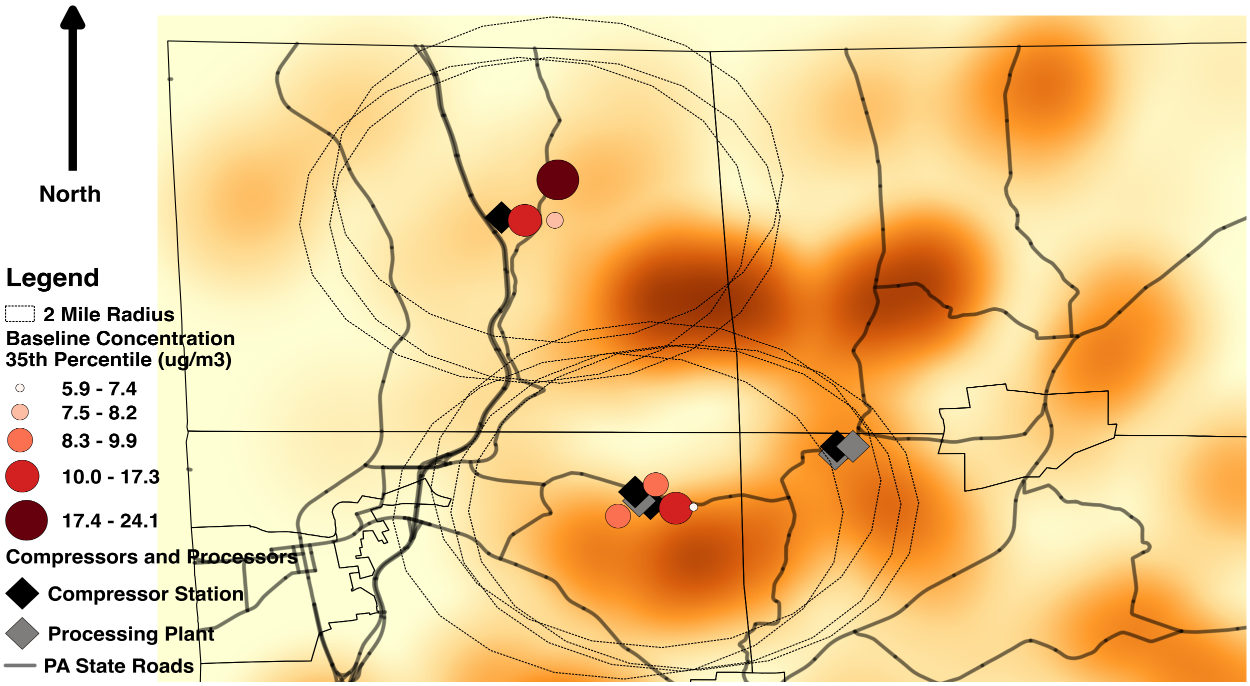
Appendix II: Heat Maps of Key Speck Monitor Findings

Outdoor PM2.5 Index Score for Monitoring Sites



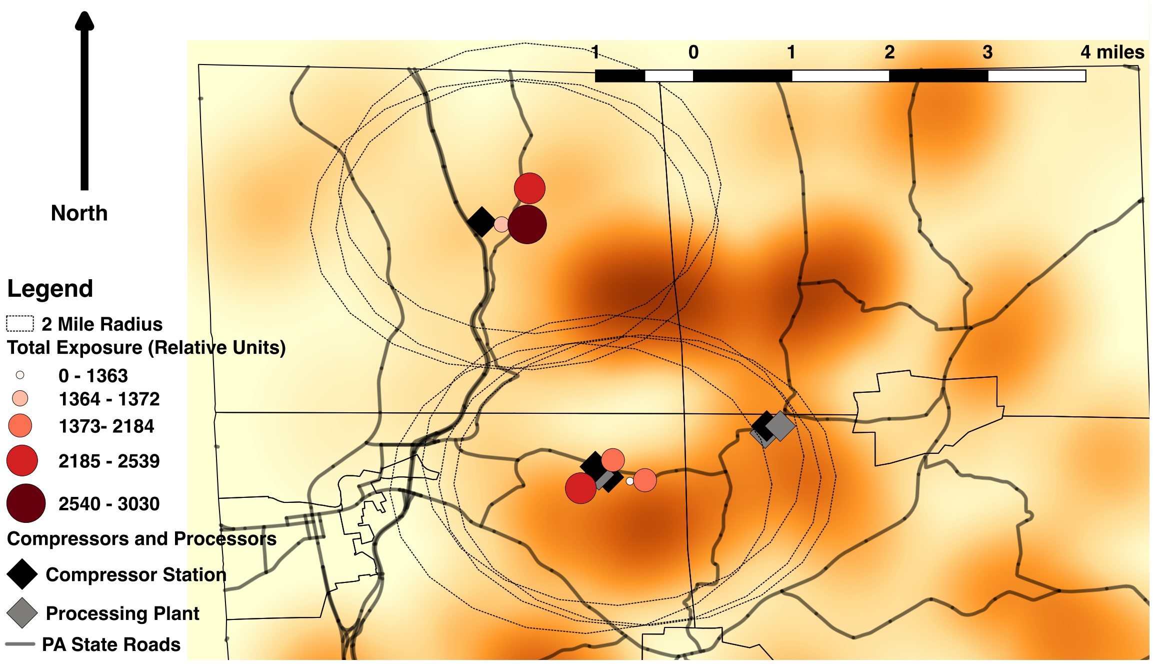
Sources: Wells: https://www.paoilandgasreporting.state.pa.us/publicreports/Modules/Production/ProductionByCounty.aspx
(Butler County, March and April 2016, Unconventional Only)
Roads: https://www.pasda.psu.edu/uci/DataSummary.aspx?data=54

PM2.5 Baseline Concentration (ug/m3) at Monitoring Sites



Sources: Wells: https://www.paoilandgasreporting.state.pa.us/publicreports/Modules/Production/ProductionByCounty.aspx (Butler County, March and April 2016, Unconventional Only)
Roads: https://www.pasda.psu.edu/uci/DataSummary.aspx?dataset=54

Total PM2.5 Exposure (in Relative Units) of Monitoring Sites



Sources: Wells: https://www.paoilandgasreporting.state.pa.us/publicreports/Modules/Production/ProductionByCounty.aspx(Butler County, March and April 2016, Unconventional Only)
Roads: https://www.pasda.psu.edu/uci/DataSummary.aspx?dataset=54

Appendix III: VOCs and TICs detected in Monitoring

VOCs	TICs
Propene	Propane
Dichlorodifluoromethane (CFC 12)	Sulfur Dioxide
Ethanol	Acetaldehyde
Acetonitrile	Acetic Acid
Acrolein	Isobutane
Acetone	Methyl Alcohol
Trichlorofluoromethane	2-Methylpropene
2-Propanol (Isopropyl Alcohol)	n-Butane
Methylene Chloride	n-Pentane
Vinyl Acetate	Cyclopentane
2-Butanone (MEK)	n-Hexanal
Ethyl Acetate	Isoprene
n-Hexane	Dimethylsilanediol
Tetrahydrofuran (THF)	Biphenyl
1,2-Dichloroethane	Diphenyl Ether
Benzene	1-Butanol
Cyclohexane	tert-Butanol
1,2-Dichloropropane	2-Butoxyethanol
Methyl Methacrylate	Trimethylsilanol
4-Methy-2-pentanone	n-Butanal
n-Heptane	1-Butanol
Toluene	n-Hexane
2-Hexanone	Hexamethylcyclotrisiloxane
n-Butyl Acetate	Octamethylcyclotetrasiloxane
n-Octane	2-Ethyl-1-hexanol
Tetrachloroethene	C11H24 Alkane: Straight Chain

VOCs Contd.	TICs Contd.
Ethylbenzene	Oxime-,methyoxy-phenyl
m,p-Xylenes	2-Ethylhexylacetate
Styrene	Unknown hydrocarbon
o-Xylene	Unknown Siloxane
n-Nonane	Unknown
alpha-Pinene	
1,2,4-Trimethylbenzene	
d-Limonene	
Napthalene	