Investigation of Wood Smoke in Grand Haven, Michigan May-September 2012

Michigan Department of Environmental Quality
Air Quality Division

Michigan Department of Community Health
Division of Environmental Health

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Background

During 2011, the Michigan Departments of Environmental Quality (MDEQ) and Community Health (MDCH), along with their counterparts in Minnesota, Wisconsin, Indiana, and the Lake Michigan Air Directors Consortium (LADCO), began work to develop an air monitoring system that could help quantify the impact that wood smoke has upon communities in the region. Central to this system was an instrument that measures the concentration of atmospheric particulate matter smaller than 2.5 micrometers in diameter ($PM_{2.5}$ or fine particulate matter), one of the primary constituents of wood smoke. The MDEQ received a test version of the wood smoke monitoring system in October 2011 and deployed it in Owosso, Michigan during November 2011. A report summarizing that investigation can be found in Appendix A.

During the summer of 2012, the MDEQ followed up the Owosso study by investigating $PM_{2.5}$ concentrations from wood smoke emanating from a campground in Grand Haven, Michigan. The purpose of this document is to summarize the technical findings of the MDEQ's Grand Haven study.

Introduction

Residents of the Sunset Hills neighborhood along Lake Michigan in Grand Haven Township have complained of the campfire smoke from the nearby Christian Reformed Conference Grounds (CRCG). The CRCG campground has approximately 100 campsites with fire pits that are typically utilized from Memorial Day (May) through Labor Day (September). At the request of the MDEQ Director, the Air Quality Division (AQD) conducted a short-term study in the Sunset Hills neighborhood during the summer of 2012 to measure fine particulate matter from the campfires. The AQD also has long-term monitoring stations to the south in Holland, to the east in Grand Rapids, and to the north in Muskegon. All three long-term monitoring sites measure wind speed, wind direction, fine particulate matter, and other pollutants.

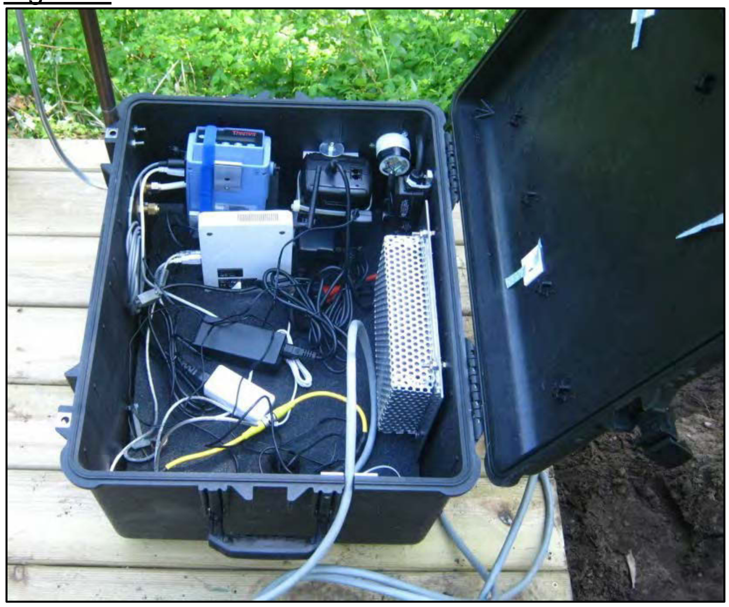
The primary goal of the investigation was to conduct continuous measurements of fine particulate matter at two locations in the Sunset Hills neighborhood of Grand Haven Township. The MDEQ purchased the portable Thermo Data logging Real-time Aerosol Monitor 4 (DataRAM4) several years ago to conduct short-term monitoring. In an interest to obtain fine particulate measurements from wood smoke, LADCO purchased several Thermo Electron Personal DataRAM (PDR) units, Pelican cases, and other equipment for mobile smoke monitoring kits. In partnership with the Northeast States Coordinated Air Use Management (NESCAUM), the kits were assembled by NESCAUM staff and sent to the MDEQ, the University of Wisconsin, and other states for special studies. The MDEQ received the wood smoke kit from NESCAUM in mid-October 2011. The Thermo DataRAM4 and Thermo PDR units are portable particulate sample devices that are ideal for a community-scale project to study the issue of wood smoke and other burning sources.

Instrumentation

The wood smoke monitoring system contained a PDR, which provided accurate, continuous readings of $PM_{2.5}$ as low as 1 microgram per cubic meter ($\mu g/m^3$). It was housed in a weatherproof Pelican case with an internal heater and an external sampling probe so it could be deployed outside (see Figure 1).

In addition, a Gill WindObserver II ultrasonic anemometer recorded continuous meteorological data at the same location as the PDR. The wind speed and wind direction data was collected by an internal PC unit that logged the data and was then downloaded for analysis through a remote desktop procedure.

Figure 1: PDR in Pelican case.



To determine how $PM_{2.5}$ concentrations vary in Grand Haven, the PDR was paired with the Thermo Electron DataRAM4 owned by the MDEQ. Although somewhat larger and less portable, the DataRAM4 operates in the same manner as the PDR. Like the PDR, the DataRAM4 is housed in a heated enclosure with an external sample head and an internal particulate sizing device to measure $PM_{2.5}$ (see Figure 2).

Figure 2: DataRAM4 in heated enclosure.

Initial Quality Assurance Activities

To ensure that the PDR and DataRAM4 were operating correctly, the MDEQ compared both monitors, time averaged over one hour, alongside a Rupprecht & Patashnick Tapered Element Oscillating Microbalance (TEOM) located at the MDEQ's Lansing air monitoring station for several days. Then a comparison was made between the PDR and the DataRAM4 using minute data, also at the MDEQ's Lansing air monitoring station. Based upon the results presented in Figures 3 and 4, the PDR and DataRAM4 closely replicated one another. Both instruments also tracked the TEOM, but were 1-3 $\mu g/m^3$ lower than the TEOM on average. However, the DataRAM4 showed a higher frequency of peaks above 35 $\mu g/m^3$ (the level of the 24-hour $PM_{2.5}$ National Ambient Air Quality Standard [NAAQS]) than what was recorded by the TEOM. The MDEQ has seen that high relative humidity or precipitation can sometimes interfere with the proper operation of the DataRAM4. Given that the spikes on May 1 and May 8 peaked during periods of high relative humidity, this could be a possible explanation (Table 1). However, the MDEQ felt that the replication between monitors was still adequate to allow for site-by-site comparisons in Grand Haven.

The PDR was calibrated prior to the study by NESCAUM to ensure accurate results. Due to the time needed for this calibration, the PDR was not co-located at the Lansing monitor location for as long as the DataRAM4.

Figure 3: Comparison of the DataRAM4, PDR and the TEOM co-located at the MDEQ's Lansing station (1-hour averages).

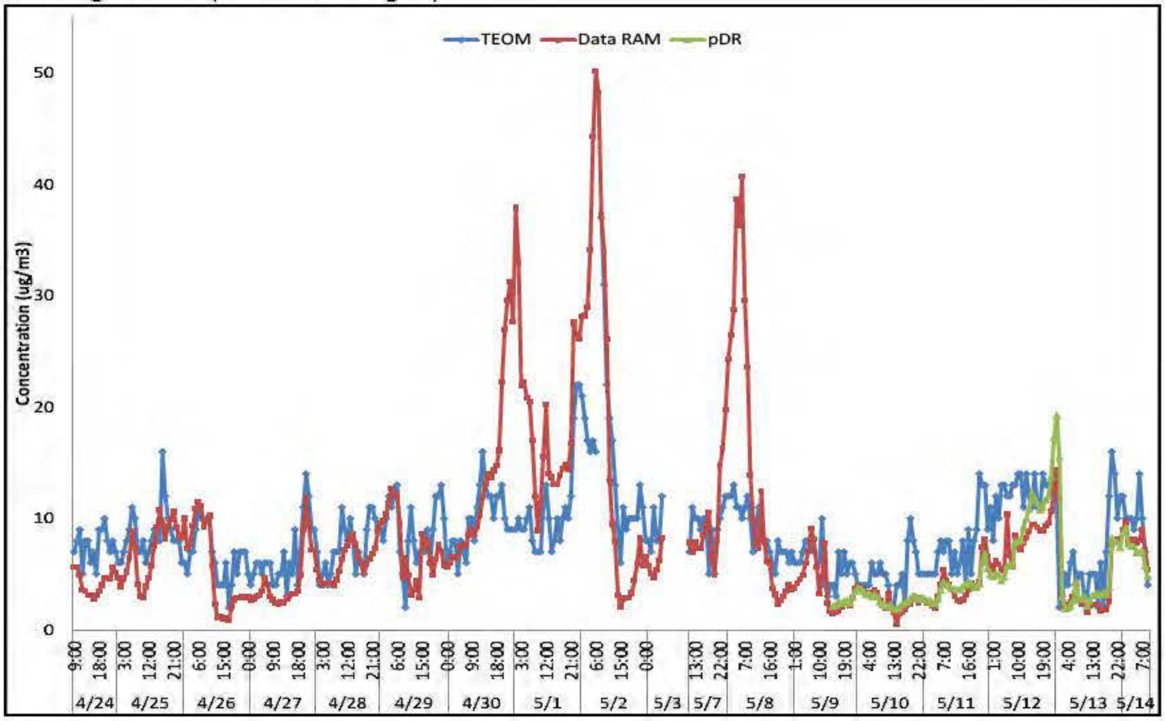
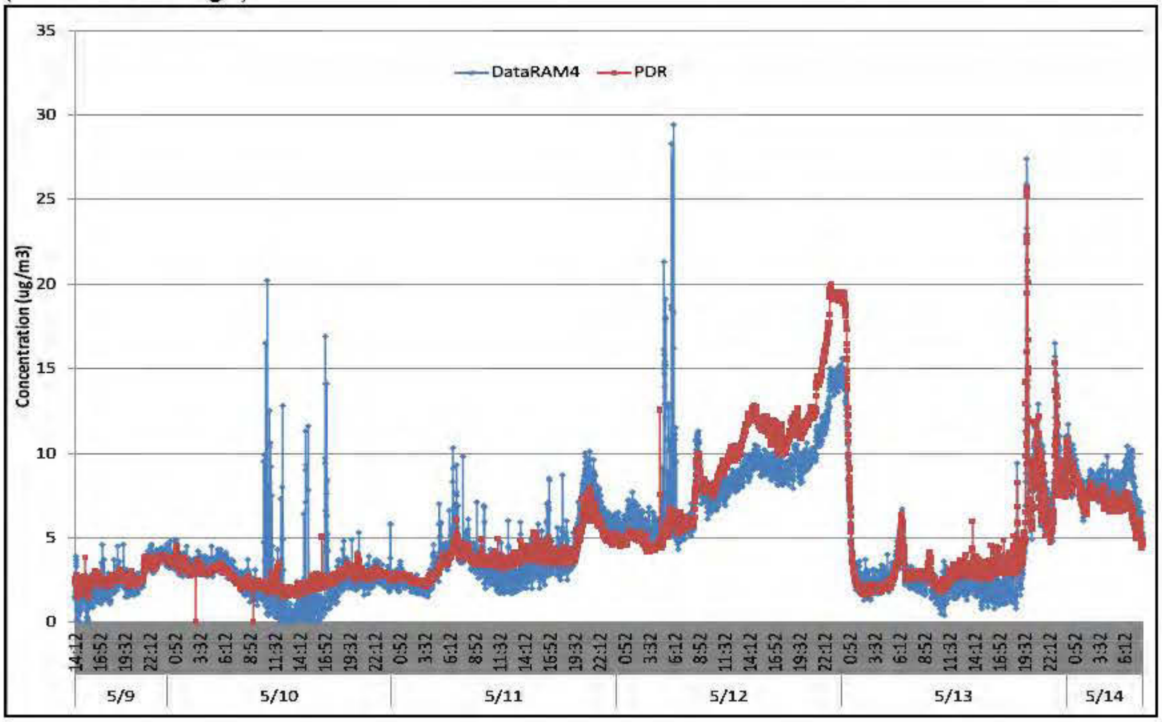


Table 1: Relative humidity and weather for hours in Lansing with only the DataRAM registering $PM_{2.5}$ levels above 35 µg/m^3. (National Weather Service [NWS] data from Lansing)

Date	Time	Relative Humidity	Weather
5/1	12:00 AM	96%	Overcast
5/8	6:00 AM	97%	Partly Cloudy

Figure 4: Comparison of the PDR and DataRAM4 co-located at the MDEQ's Lansing station (1-minute average).



The ultrasonic anemometer was also run alongside the standard anemometer at the Lansing site. The difference in the wind speeds between monitors was generally less than one mile per hour and the average wind direction differences were less than 5 degrees. Figures 5 and 6 show these data. The wind directions diverge more at lower wind speeds due to the limitations of the instruments' threshold accuracies.

Figure 5: Comparison of the ultrasonic anemometer and the Lansing station anemometer average hourly wind speeds.

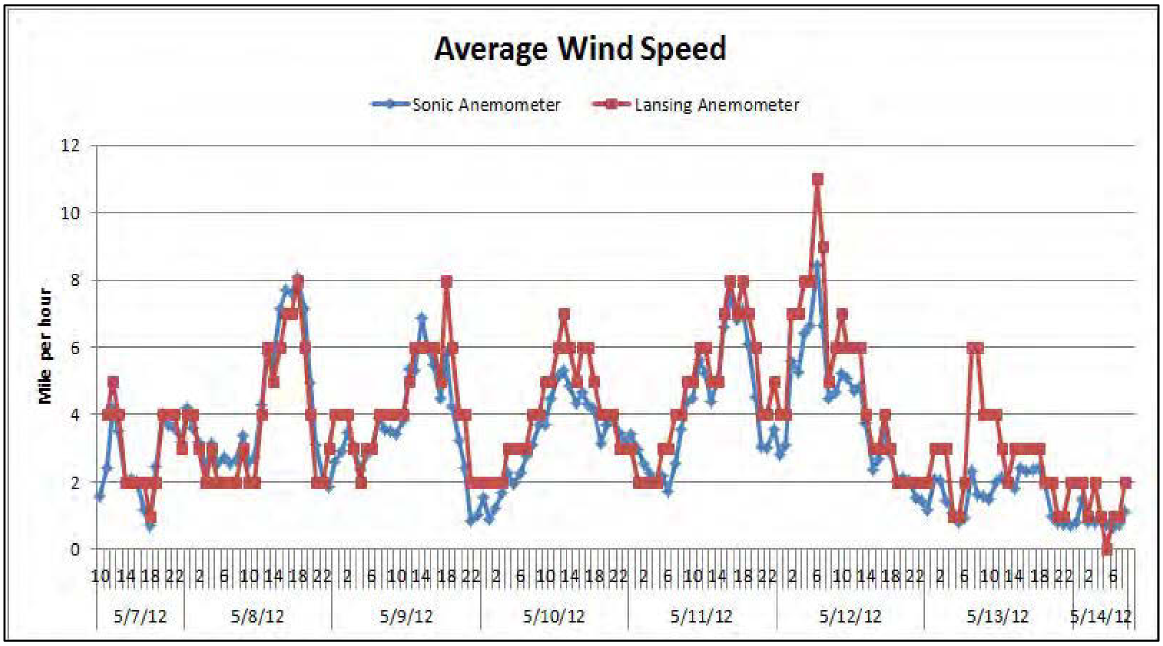
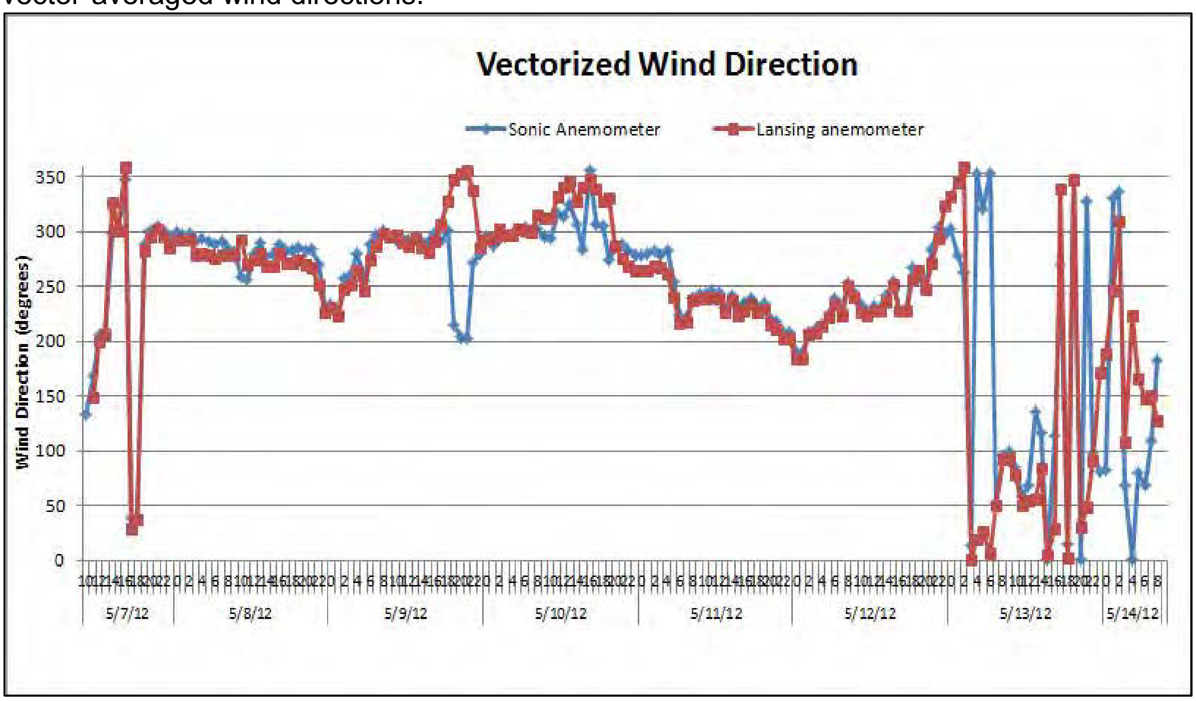
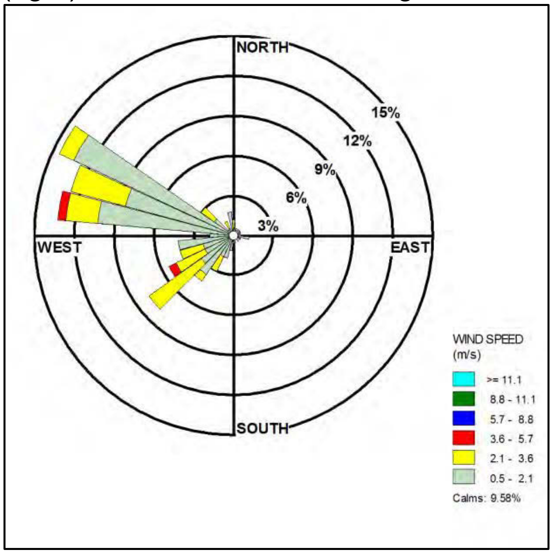


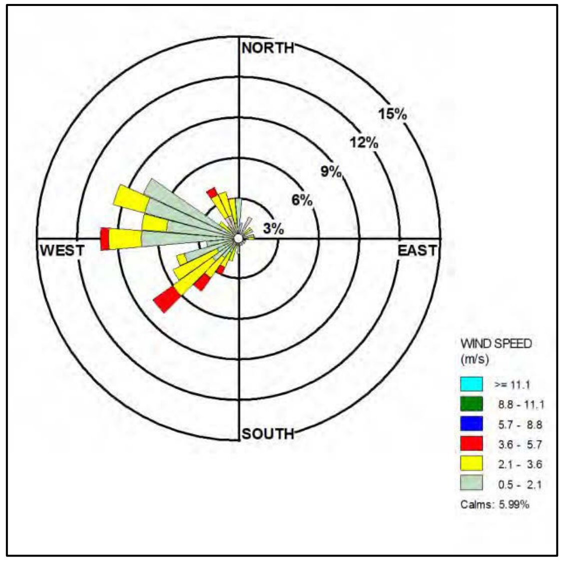
Figure 6: Comparison of the sonic anemometer and the Lansing station anemometer hourly vector-averaged wind directions.



Windroses comparing the sonic anemometer and the Lansing anemometer show similar wind pattern for when they were co-located at the Lansing monitoring station (see Figure 7).

Figure 7: Windroses for the ultrasonic anemometer (left) and Lansing anemometer (right) co-located at the Lansing site.





Deployment and Operation in Grand Haven

On April 16, MDEQ staff met with homeowners in the Sunset Hills neighborhood in Grand Haven to identify locations to site the monitors. Across the private road from the Diekema residence, there is an area that slopes down to the campground. The residents stated that they had observed smoke from the campfires traveling up this slope and into the neighborhood, especially under low wind speed conditions. The residents felt that this location was likely the most impacted area in the neighborhood. The PDR was deployed at this location, called the Diekema house for the purposes of this study, for the duration of the study. The ultrasonic anemometer was also located at this site for wind speed and direction (see Figure 8).

Figure 8: The location of the PDR at the Diekema house showing the sonic anemometer looking southeast (left) and looking down the slope to the east-northeast.

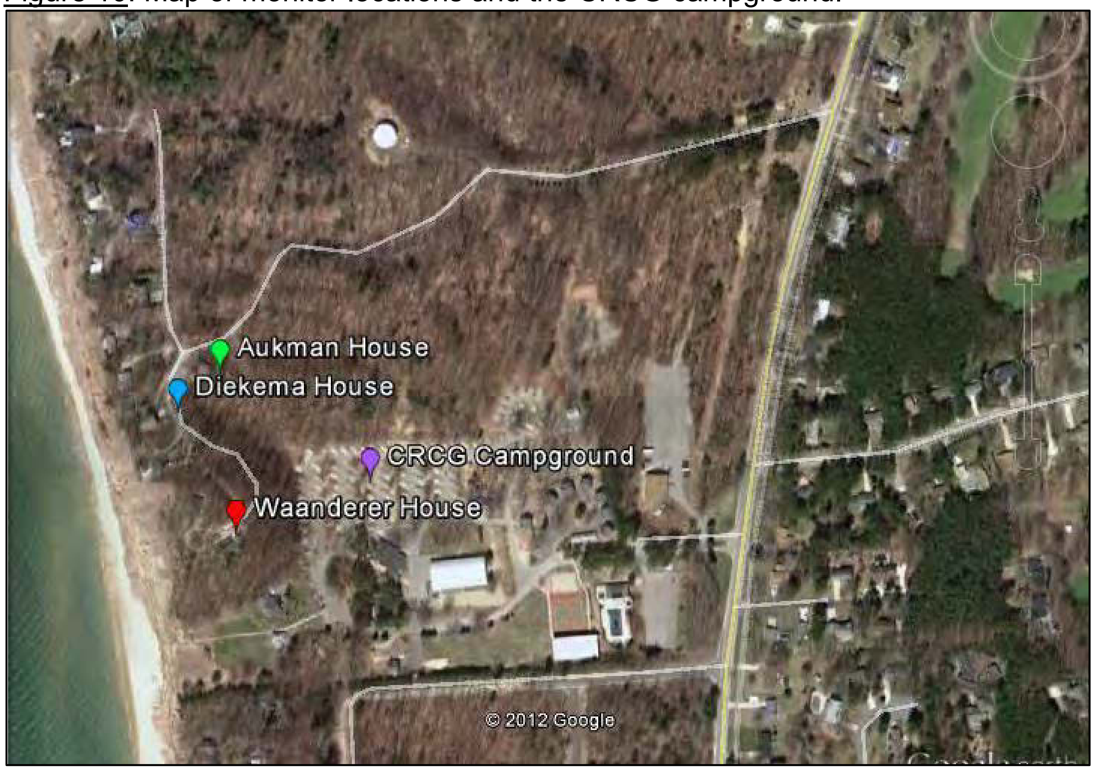
The second location, the Waanderer house, was to the south of the maximum impact area and on top of a hill. This site was chosen to ascertain the variability of wood smoke levels in the neighborhood. The DataRAM4 was placed at this site (see Figure 9).

The PDR and DataRAM4 were installed on May 16, 2012. This start date was chosen to establish a baseline for $PM_{2.5}$ before the camping season began. The Sunset Hills residents reported that they usually experience some smoke around Memorial Day (May 28, 2012), but the camping season is not fully underway until mid-June.

In mid-July, it was determined that the data being collected at the Waanderer house on top of the hill was not unique from the data at the Diekema house. The Sunset Hills residents communicated that the Aukman log house across the road from the Diekema residence experienced frequent and strong odors from campfire smoke. The owner of the log house was interested in having the sampler on his property, so on July 30, the DataRAM4 sampler was moved to this residence, located just north of the campground's particulate sampler (see Figure 9), and placed on the eastern edge of the deck. The sampler collected data at this location until the end of the study. The location of samplers and the campground can be seen in the map below (Figure 10).

Figure 9: Location of the DataRAM4 at the Waanderer house (left) looking south and the Aukman house (right) looking southeast.

Figure 10: Map of monitor locations and the CRCG campground.

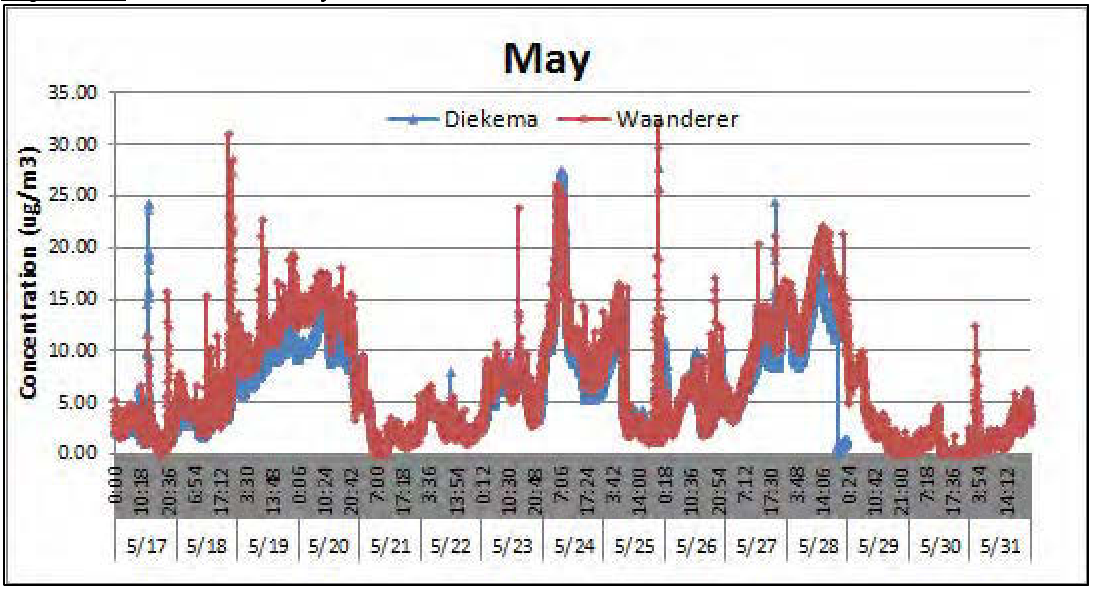


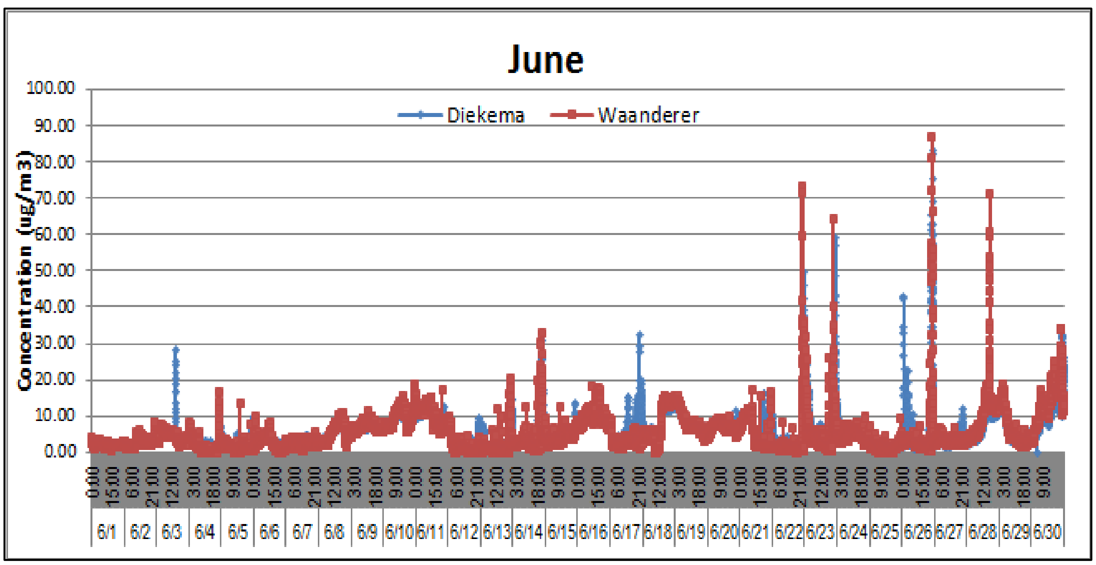
Because plumes can shift directions quickly with variations in wind, both the PDR and DataRAM4 were configured to record 1-minute average concentrations, 24 hours per day. Staff visited the site to transfer data files from both samplers and the sonic anemometer to a laptop computer every two weeks. The filter was changed on the PDR and both samplers were zeroed (i.e., recalibrated) once a month. The instruments were operated from May 17 to September 9, and were removed on September 10, 2012.

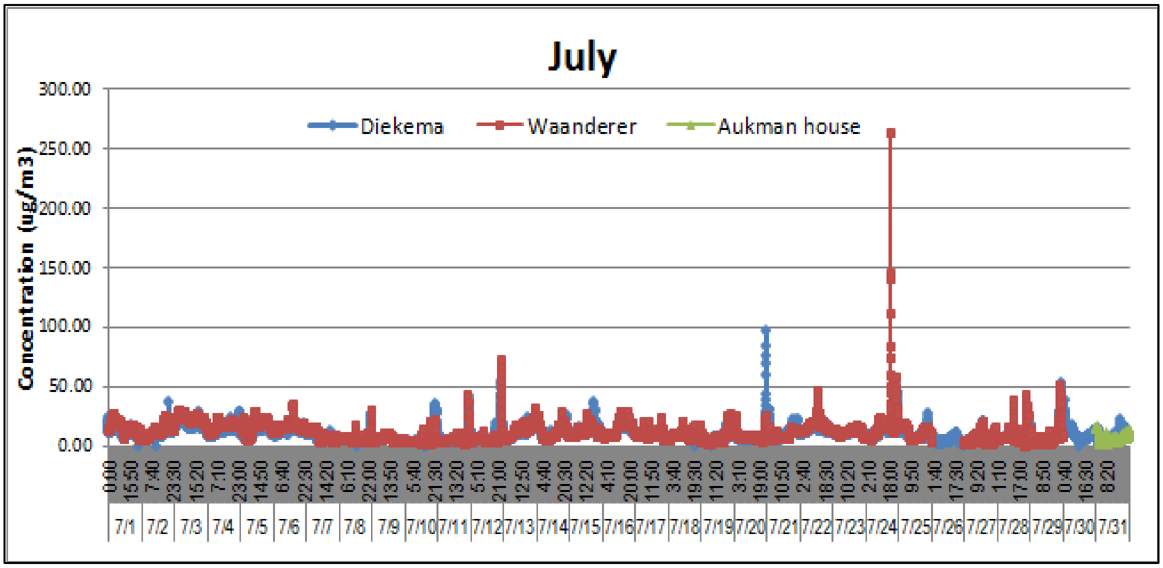
Results

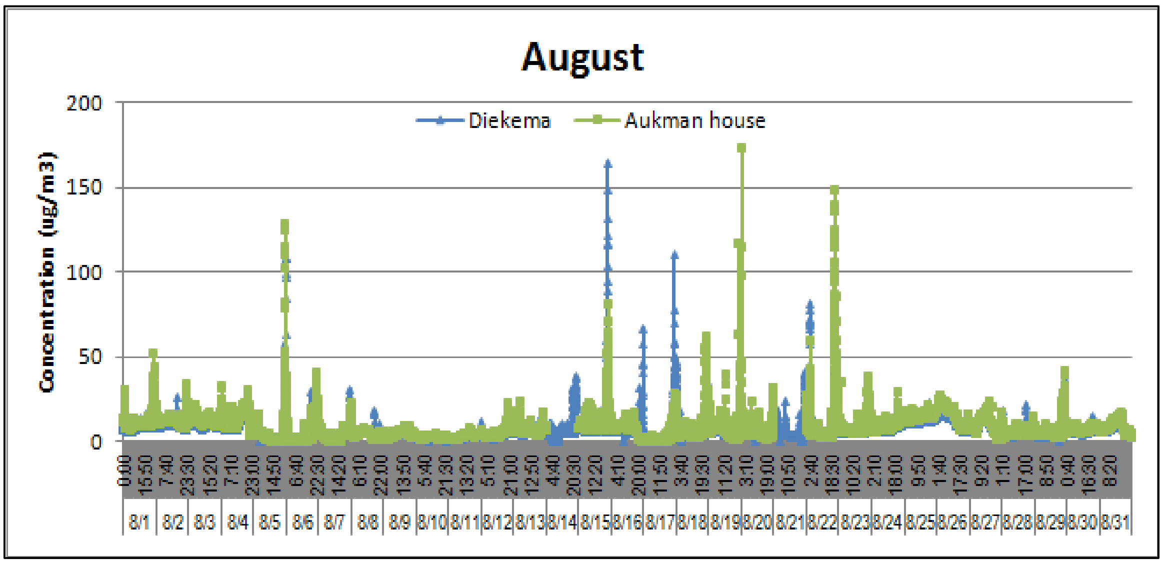
While there is not a well-defined health criteria associated with 1-minute $PM_{2.5}$ concentrations, 1-minute data was collected at each monitor over the summer. As stated in the previous section, the purpose of this data was to identify transient plumes. Figure 11 shows the variability of the 1-minute data per month for each site. Note that the concentrations on the y-axis are different for each monthly graph.

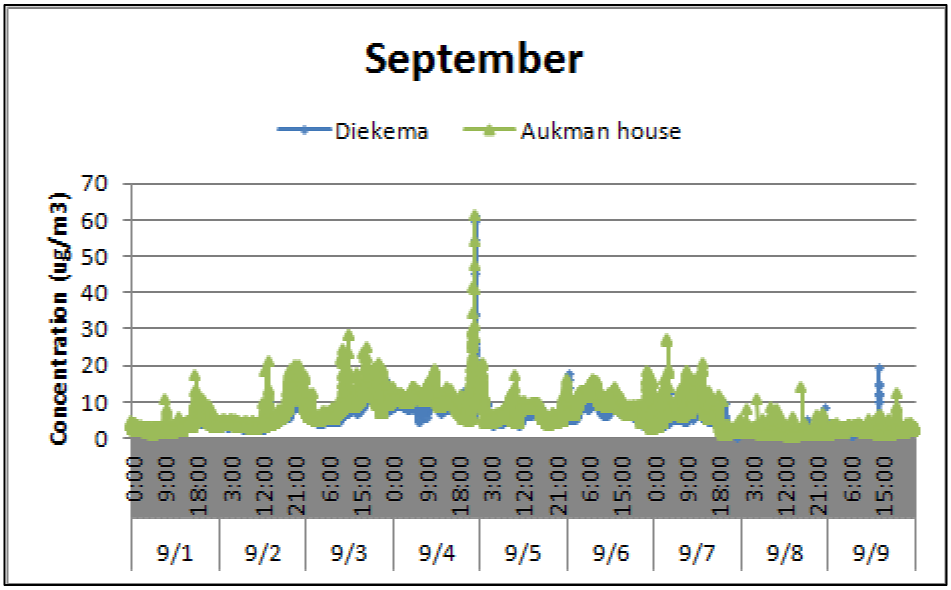
Figure 11: Minute data by month at the Sunset Hills sites.






July
Concentration (ug/m3)
Diekema
Waanderer
Aukman house
300.00
250.00
200.00
150.00
100.00
50.00
0.00


August
Concentration (ug/m3)
Diekema
Aukman house
200
150
100
50
0



DataRAM4 Spiking

Unfortunately, the DataRAM performed poorly at times during the course of the study. However, rather than totally ignore the data collected by the DataRAM, a systematic effort was made to separate DataRAM concentration spikes resulting from glitches in monitor operation or interferences from those spikes caused by wood smoke.

As can be seen from Figure 11, there were periods where the $PM_{2.5}$ concentrations recorded by the DataRAM4 were both higher than 35 µg/m^3 and significantly higher than what was observed by the nearby PDR. From Table 2, below, it appears that interferences due to high relative humidity (defined here and documented from the Lansing co-location as 90 percent or greater) were not an issue with the possible exception of hours during July 26, August 14, and August 21. To remove any possible bias introduced because of spiking during high relative humidity events, the data from the DataRAM4 for these three days were removed from the statistical calculations.

The DataRAM4 also had some issues with larger particle sizes getting trapped and causing the concentrations to be excessive. On several occasions, the particle diameter for the DataRAM4 would report 4.127 microns for several minutes. Since we are concerned with particle diameters less than 2.5 microns, the corresponding concentrations were removed from the statistical calculations.

Spiking from Localized Non-smoke Sources

In addition, short-term spiking (defined as lasting less than 10 minutes and having a change in concentration from the previous minute greater than 15 µg/m^3) was sometimes observed between 3:00 AM and 8:00 PM by both the PDR and the DataRAM4. Because of the 3:00 AM to 8:00 PM timeframe, it is clear that these short-term spikes were likely caused by factors other than smoke (e.g., car exhaust or re-entrained road dust). As it would be difficult to definitely identify the sources causing the spikes, these spikes were also removed from the statistical calculations.

Data Completeness

Following standard United States Environmental Protection Agency (USEPA) quality assurance procedures developed to ensure that data is not used when monitors are not operating correctly, data collected within a given day or hour (as defined by block) was needed to be 75 percent complete to be included in the analysis. Therefore, some hours of data were eliminated due to issues mentioned above, as well as when data was downloaded (i.e., the instrument needed to be stopped for data to be downloaded). Also, the day when the DataRAM4 was transferred to the new site at the Aukman house was eliminated due to lack of completeness as well as allowing the instrument to equilibrate.

Finally, three days of data were lost on the PDR from May 29 through May 31 due to instrument error.

Table 2: Relative humidity and weather for hours in Grand Haven with only the DataRAM4 registering $PM_{2.5}$ levels above 35 µg/m^3. (NWS data from Benton Harbor).

Date	Time	Relative Humidity	Weather	Action Day?
6/28	5:00 PM	57%	Clear	Y
7/24	6:00 PM	43%	Clear	N
7/26	11:00 PM	96%	Partly Cloudy	N
7/28	12:00 PM	46%	Clear	N
7/28	9:00 PM	78%	Clear	N
8/01	10:00 PM	84%	Clear	N
8/14	10:00 AM	94%	Fog	N
8/19	11:00 AM	70%	Partly Cloudy	N
8/20	12:00 PM	63%	Partly Cloudy	N
8/21	7:00 AM	96%	Clear	N
8/22	11:00 PM	38%	Clear	N
8/23	6:00 PM	41%	Clear	N

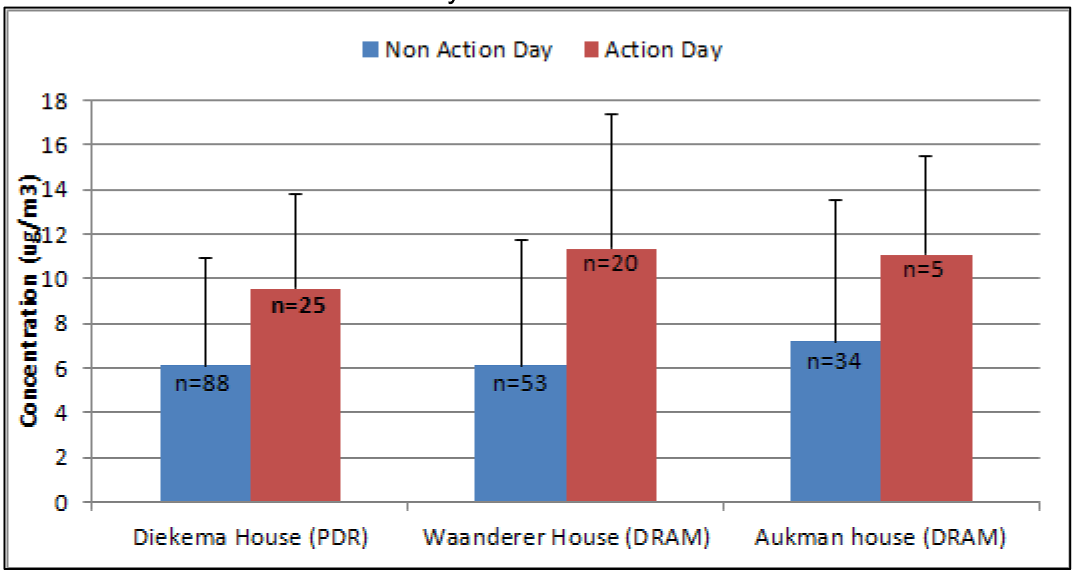
Air Quality Action Day Comparisons

Meteorologists at the MDEQ provide forecasts on a daily to weekly basis to predict regional air pollutant levels. When air quality is predicted to be unhealthful, an air quality action day is issued to alert sensitive individuals who may wish to lessen their exposure.

During this study, 25 air quality action days occurred in West Michigan. The Grand Haven Township Open Burning Ordinance expressly prohibits open burning on air quality action days. Therefore, air quality action days provide a set of days without campfires that can be compared to the rest of the days. Action days in the summer are most often in response to high ozone values. However, conditions that are favorable for forming ozone are often favorable for forming $PM_{2.5}$. Data was analyzed based on hour, day of the week, wind direction, and wind speed averages. In these analyses, the air quality action days were analyzed separately, since no burning or campfires occurred on those days.

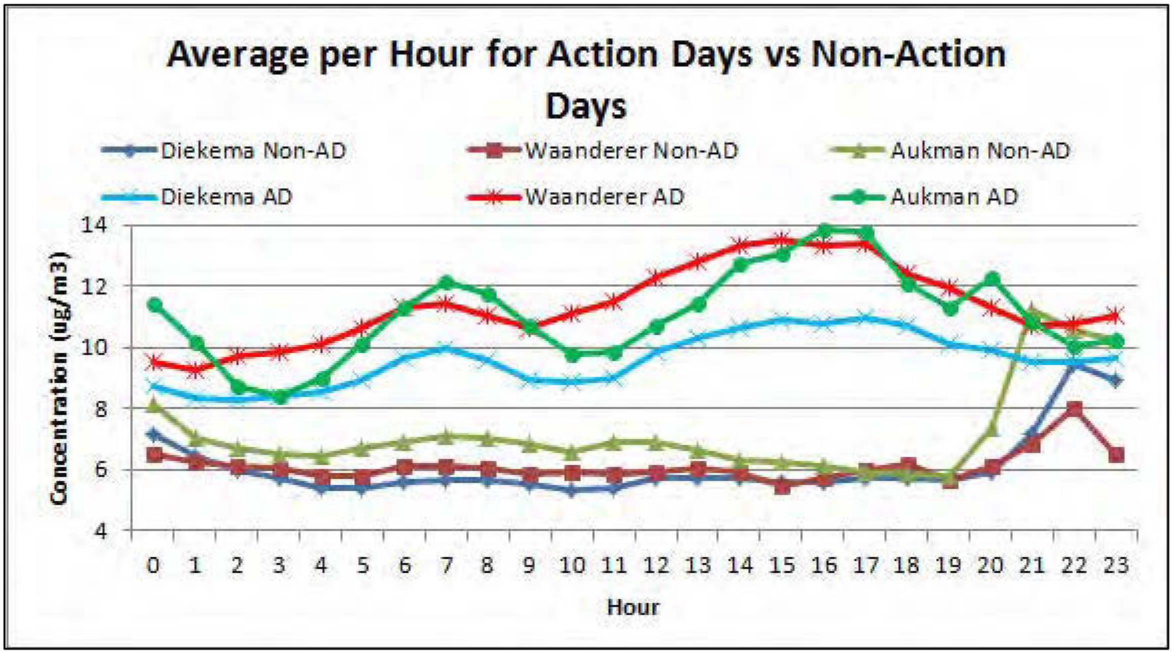
Air quality action days over the summer had higher $PM_{2.5}$ concentrations than non-action days (see Figure 12), suggesting that regional transport plays a significant role in the overall air quality in the Sunset Hills neighborhood.

Figure 12: Average concentration for air quality action days and non-action days at the three Grand Haven sites. The error bars indicate variance of the mean, the number on the bar indicates the number of days for that bar.



Looking at the data for hour of day, distinctive differences were seen between $PM_{2.5}$ concentrations for action day versus non-action days. The action days had high concentrations during the morning and afternoon hours and concentrations drop at night, which is typically seen with regional ozone concentrations. On non-action days, a very different pattern was observed. The values remained relatively the same until they began to rise starting at 8:00 PM, peaking around 10:00 PM and gradually dropping back down (see Figure 13). This pattern is consistent with nighttime campfires. The monitor at the Diekema house recorded hourly averages lower than the other monitors during air quality action days. However, all three monitors were more similar on non-action days.

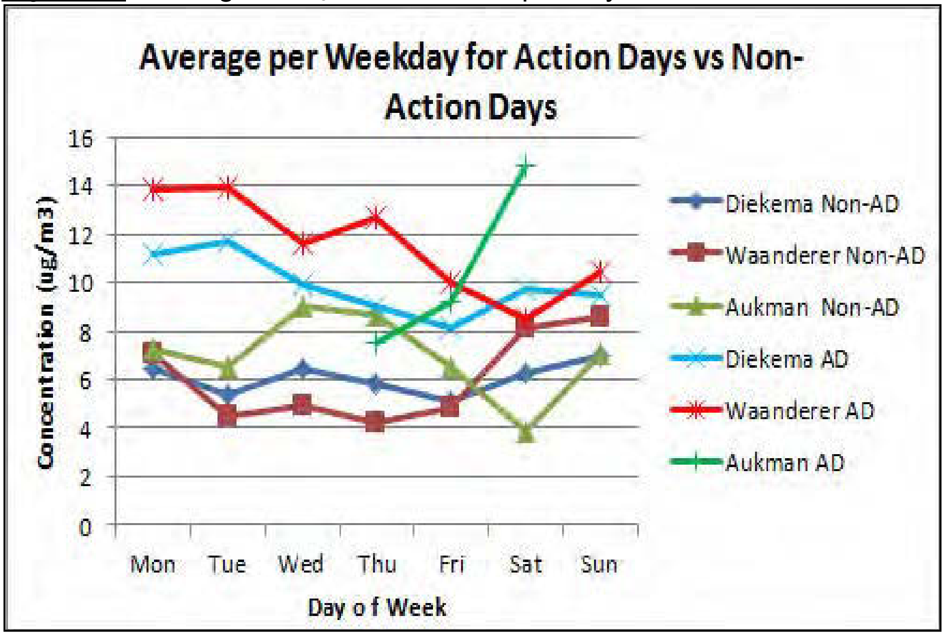
Figure 13: Average per hour for action days and non-action days at the Sunset Hills monitors.



The day of week averages showed slightly higher concentrations for action days than non-action days; however, no other consistent patterns were observed. The Waanderer house was monitored during the first half of the summer and the Aukman house was monitored for the remainder of the summer. These show very different patterns in $PM_{2.5}$ concentrations. Camping patterns may change throughout the summer, which would confound any weekday or weekend patterns (see Figure 14).

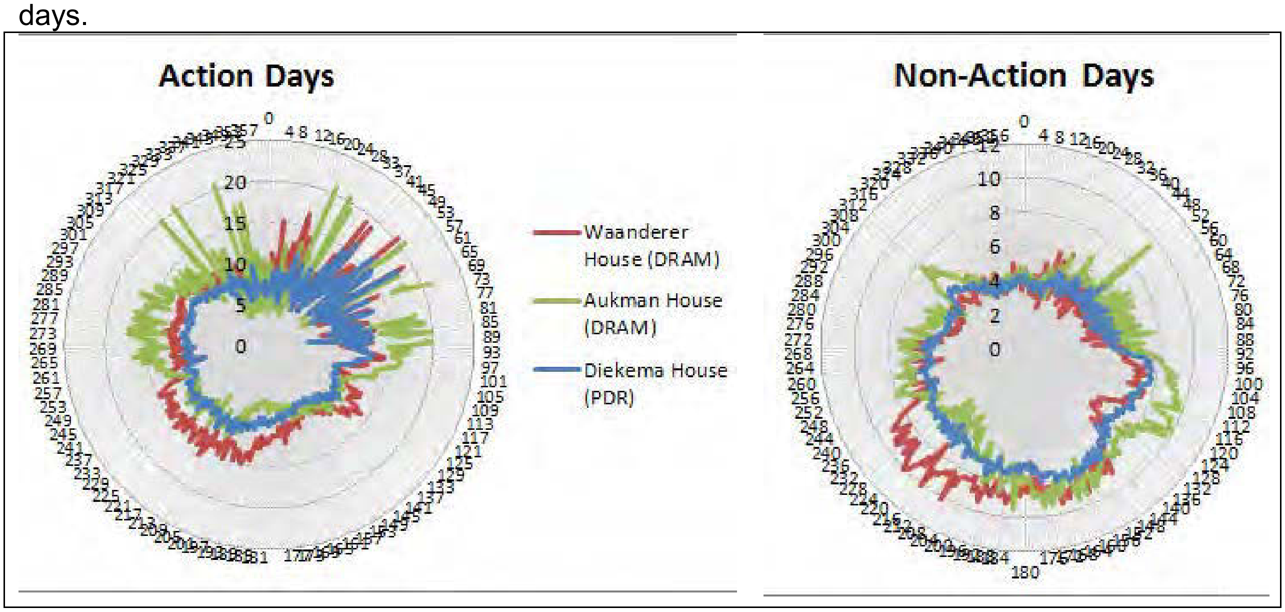
For the action days, 20 of the 25 occurred when the monitor was located at the Waanderer house. The action days compared to the non-action days show an opposite pattern at the Waanderer house, with the highest action day concentrations occurring during the week, whereas non-action days had higher $PM_{2.5}$ concentrations on the weekend. The Aukman house monitor had too few actions days for a robust comparison.

Figure 14: Average $PM_{2.5}$ concentration per day of week for action and non-action days.



The average $PM_{2.5}$ concentration per wind direction for action days and non-action days are shown in Figure 15. On action days, $PM_{2.5}$ concentrations were higher overall and higher concentrations occurred when winds were coming from the north and northeast. On non-action days, higher concentrations occurred when winds were coming from the south. The campground was located east of the Waanderer house and southeast of the other houses.

Figure 15: Average $PM_{2.5}$ concentration (µg/m^3) by wind direction on action days and non-action days.

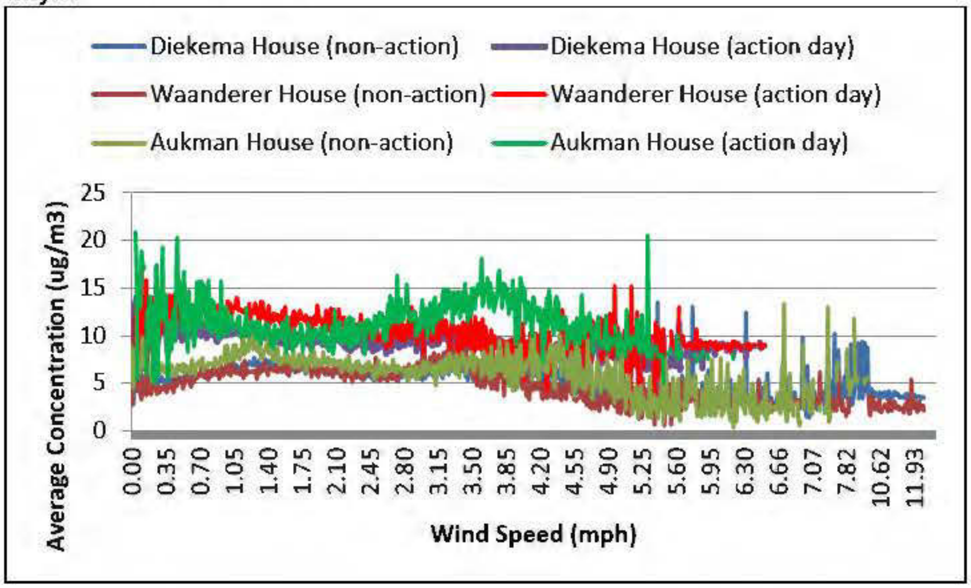


As was suggested by Figures 12 and 13, Figure 15 shows that, in general, $PM_{2.5}$ concentrations were higher during action days than during non-action days. However, the $PM_{2.5}$ that occurred in the Sunset Hills neighborhood on non-action days originates from the direction of CRCG for the

Diekema and Aukman houses. The Waanderer house had higher $PM_{2.5}$ concentrations from the south and west, but not from the east, as would be expected from the campground.

$PM_{2.5}$ concentrations appeared slightly higher at slower wind speeds less than 4 mph for non-action days. On action days, wind speeds were rarely higher than 6 mph. The Diekema and Waanderer houses had slight decreases in concentrations as the wind speed increased, whereas readings at the Aukman house were more variable, likely due to the few number of action days in that data set (see Figure 16).

Figure 16: Average $PM_{2.5}$ concentration by wind speed on action days and non-action days.

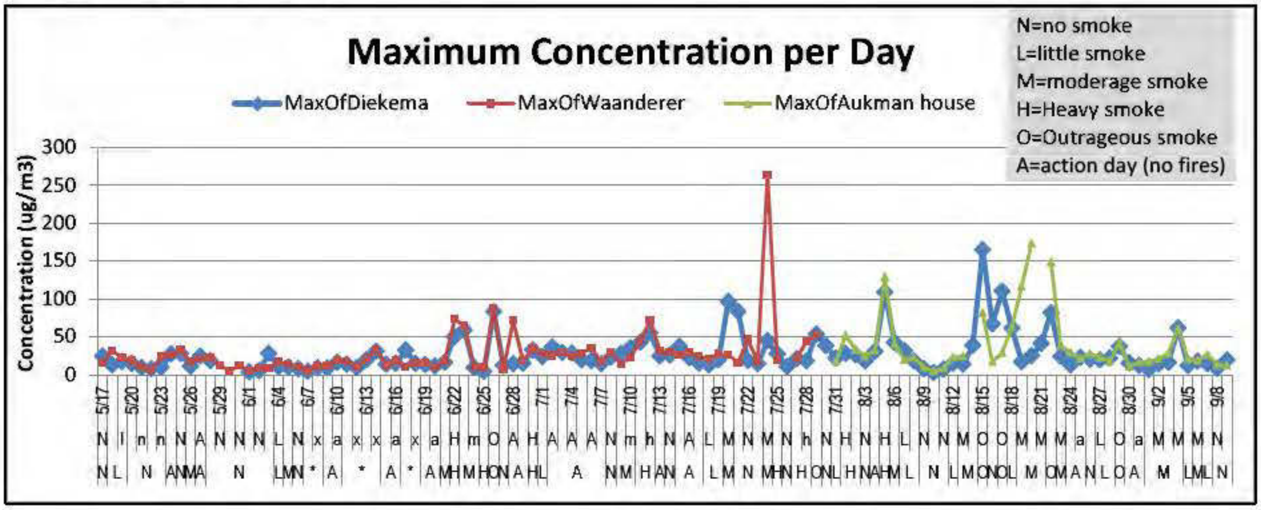


Based on the location of the campsite and the comparison with non-burning action days, smoke appeared to affect the $PM_{2.5}$ concentration trends. However, the averages were not higher than during action days for most cases.

Comparison to Residents Observations

A resident in the neighborhood recorded his observations of the perceived smoke levels during most days. Based on his observations, the maximum minute concentration at each site was determined per day (see Figure 17).

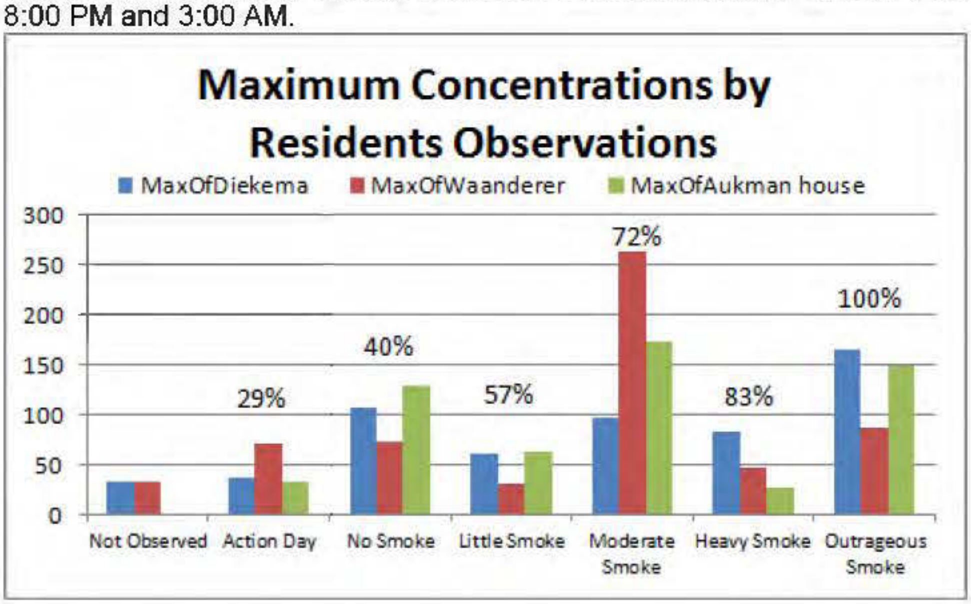
Figure 17: Maximum concentration of the minute averages per day. Resident's observation level is indicated below the dates.



The highest point on Figure 17 occurred at 5:08 PM on July 24 and only at the Waanderer house. In this case, there was a 15-minute time period of high values that quickly returned to normal after that period. While the resident recorded smoke as being moderate on this day, the wind direction was from the northwest, which suggests that the campground was not the source.

Figure 18 shows the maximum concentration per level of the resident's smoke log observations for each site at Sunset Hills. The percentages above each smoke level indicate the percentage of time the daily maximum for that smoke level occurred from 8:00 PM to 3:00 AM, the time when most camp fires would be occurring.

Figure 18: Maximum concentration plotted against resident's smoke log observations, with the percent of time that the maximum concentration was observed between 8:00 PM and 3:00 AM.



The days where smoke was observed to be the heaviest occurred mostly at night when campfires would be most prevalent.

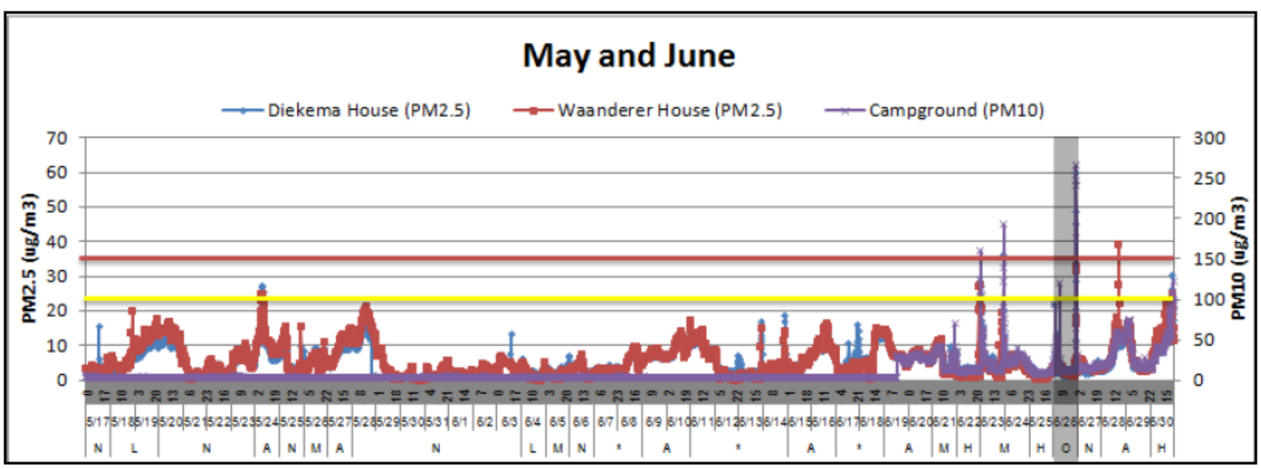
Comparisons to the CRCG Campsite Monitor

CRCG voluntarily developed an extensive Campfire Best Management Practices policy to minimize smoke. According to the this policy, campers are directed to burn only smaller pieces of dry hardwoods, use some type of kindling, and combine fires with neighbors if possible. Burning garbage is prohibited. Three sites are equipped with a propane-fueled fire pit.

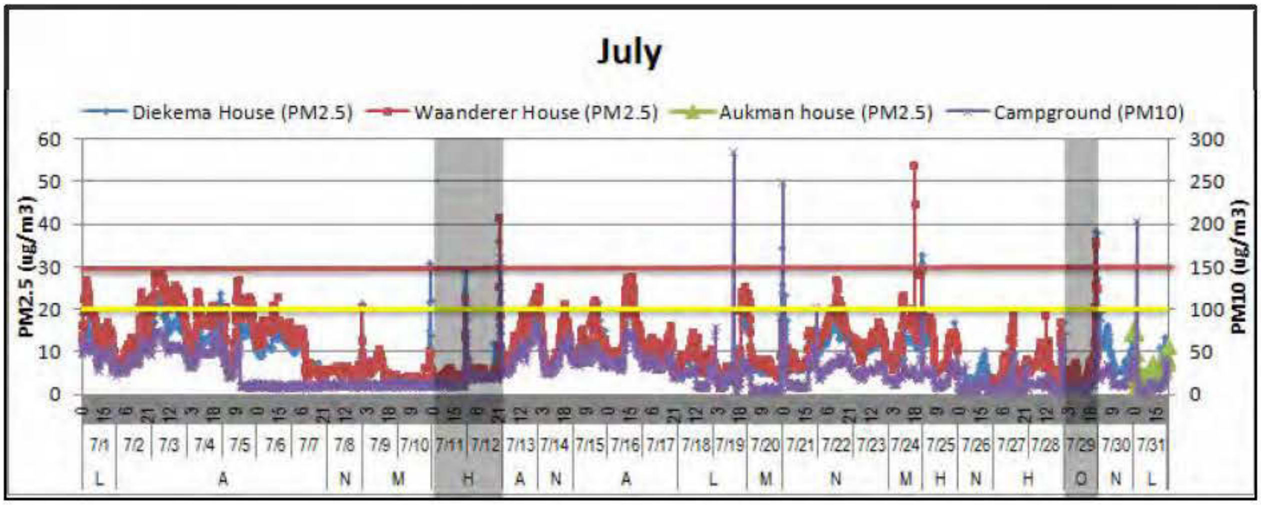
As part of their smoke management policy, the CRCG also installed a PM_{10} monitor that is maintained and calibrated annually. Data from the monitor is averaged daily every 15 minutes from 3:00 PM to 3:00 AM. Real time data is monitored by staff and used to determine appropriate campfire actions. Fires are not allowed on action days or when the campsite monitor is reading above 150 µg/m^3. According to the CRCG Director, if any fires are burning when the monitor reaches 150 µg/m^3, these fires are extinguished by placing the logs in a bucket of water rather than dowsing the fire with water to reduce smoke. When the air quality index (AQI) is moderate and the PM_{10} campsite monitor reads above 100 µg/m^3, fires are put out at 11:00 PM. If conditions are favorable, campfires are permitted until 1:00 AM.

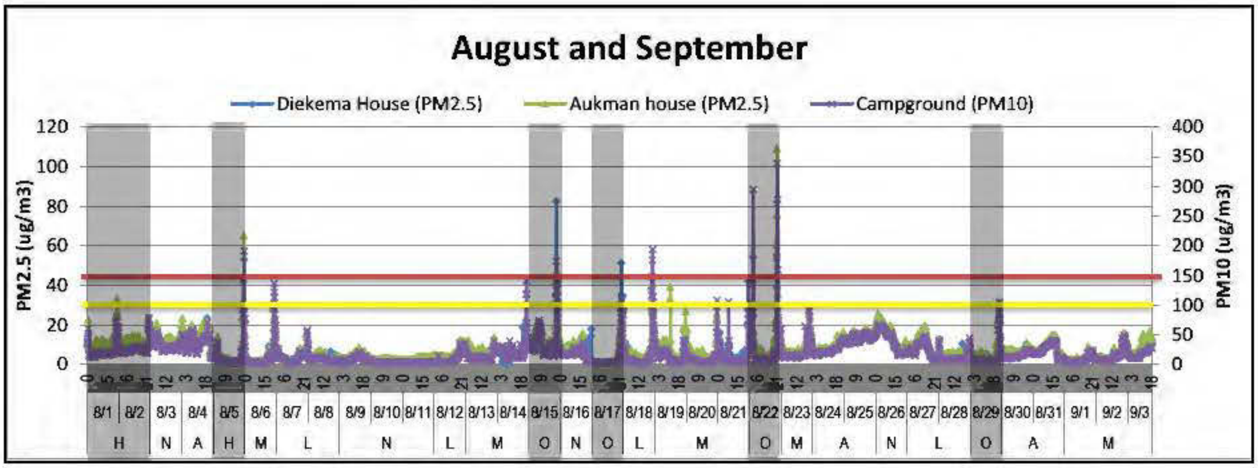
Figure 19 shows the 15-minute averaged data for the MDEQ-operated Sunset Hills sites and the CRCG monitor. The resident's perceived level of smoke is also indicated for each day. The campground monitor closely tracked the MDEQ-operated Sunset Hills monitors on most days. The red line indicates a level of 150 µg/m^3. This is the level on the PM_{10} monitor at which fires were extinguished. The yellow line indicates the level at which fires would be extinguished at 11:00 PM. The gray boxes indicate days when the Sunset Hills residents called the Fire Department to have campfires extinguished. The campgrounds monitor often reached 150 µg/m^3 on days when the Fire Department was called. However, there are a few days; for example in the beginning of August; when the Fire Department was called, but the PM_{10} and $PM_{2.5}$ maximum levels were in the 20 µg/m^3 range. Humidity impacts visibility and may have had an influence on these days.

Figure 19: 15-minute averages of the Sunset Hills monitors to the CRCG monitor data. The red line indicates that fires must be extinguished when the CRCG monitor reaches that level. The yellow lines indicate that fires would be put out at 11:00 PM. The gray shading indicates days when the Sunset Hills residents called the Fire Department.



N=no smoke
A=action day (no fires)
L=little smoke
M=moderate smoke
H=heavy smoke
O=outrageous smoke
*=no observation

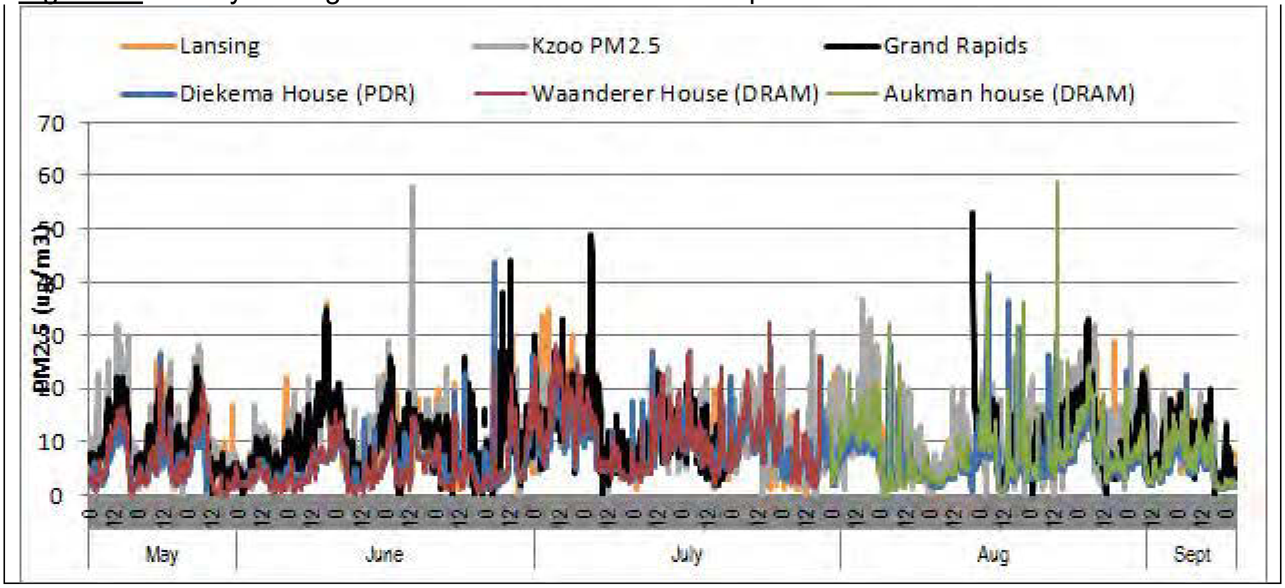




Comparison to the Air Quality at Other Sites in Michigan

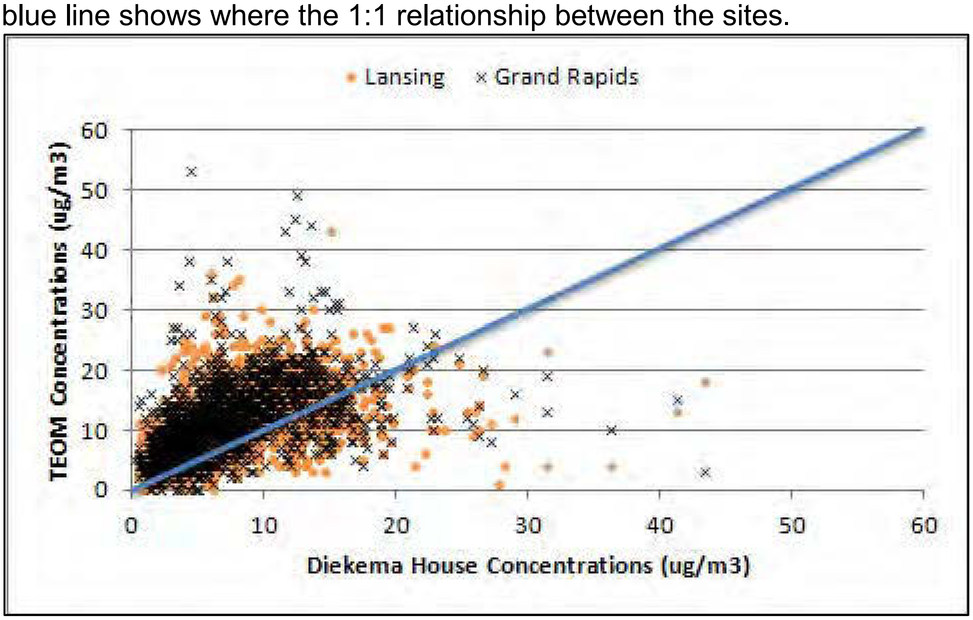
The data collected in Grand Haven was compared to other sites in Michigan. Only hourly data was available using TEOM data. The closest monitor with TEOM data was the Grand Rapids-Monroe Street monitor. Unfortunately the Grand Rapids monitor was down for nearly one month over the summer, so the Lansing and Kalamazoo TEOM data were also used. The Grand Rapids, Lansing, and Kalamazoo monitors appeared to have higher hourly values than the Sunset Hills monitors, especially in the beginning and end of the summer (see Figure 20).

Figure 20: Hourly averages of the Sunset Hills sites compared with TEOM sites.



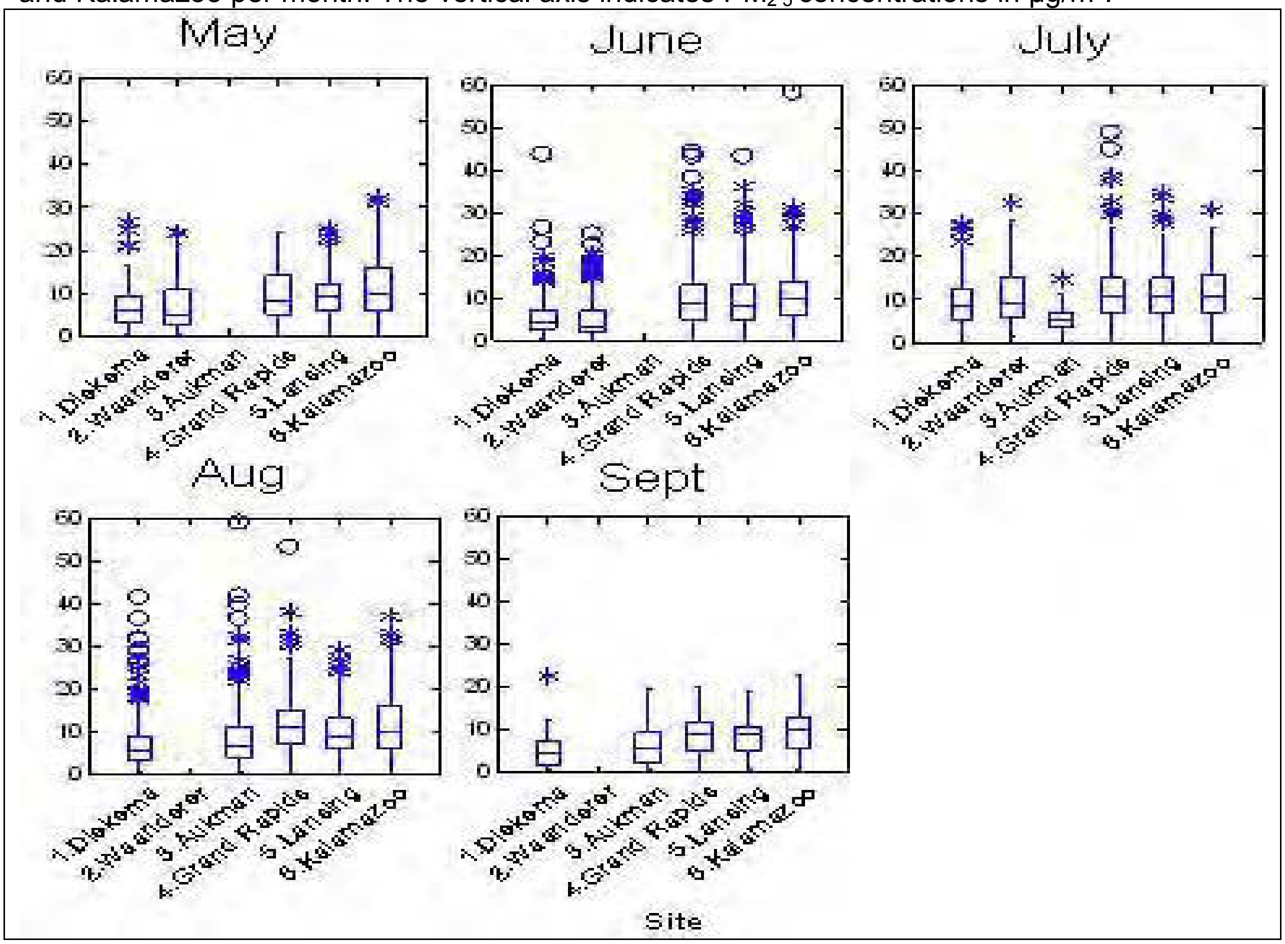
Even though the Grand Rapids, Lansing, and Kalamazoo sites had higher values for much of the summer, there were occasional 1-hour spikes throughout the summer that were higher than the Grand Rapids and Lansing TEOM sites. Figure 21 shows a scatter plot of the hourly Grand Rapids and Lansing data to the hourly averages for the Diekema house. The diagonal line indicates the 1:1 line, meaning points on that line had the same concentration at the Sunset Hills and TEOM sites. The points above the line indicate when concentrations were higher at the TEOM sites than the Sunset Hills sites. Points below the line indicate concentrations where the Sunset Hills sites were higher than the TEOM sites.

Figure 21: Lansing and Grand Rapids $PM_{2.5}$ compared to Diekema house $PM_{2.5}$. The blue line shows where the 1:1 relationship between the sites.



Box plots comparing the three Grand Haven sites with Grand Rapids, Lansing, and Kalamazoo by month are shown in Figure 22. The line in the box indicates the median value for each site based on hourly values. The box indicates the 25th and 75th quartile range, or where 50 percent of the data concentrations fall. The whiskers show 1.5 times the interquartile range (the height of the box. The stars (*) indicate outliers and the circles indicate extreme outliers. Although the medians for the Grand Haven sites are often lower than the other three sites, the range of values is similar for all sites, even though Grand Haven has a smaller population than the other cities.

Figure 22: Box plots of the three Grand Haven sites compared to the Grand Rapids, Lansing, and Kalamazoo per month. The vertical axis indicates $PM_{2.5}$ concentrations in µg/m^3.



Meteorological Influences

The Sunset Hills meteorological data was very unique compared to nearby sites. The ultrasonic anemometer was in an area with many trees, which blocked the wind, resulting in lower average wind speeds (Figure 23). In addition, from the plots of 12:00 AM to 6:00 AM and 11:00 AM to 6:00 PM in Figure 24, it appears that the winds in the Sunset Hills neighborhood and at the CRCG are heavily influenced by breeze from Lake Michigan during the daylight hours and by the reciprocal land breeze during the night.

Figure 23: Windroses for the Sunset Hills ultrasonic anemometer and for other MDEQ air monitoring sites near Grand Haven.

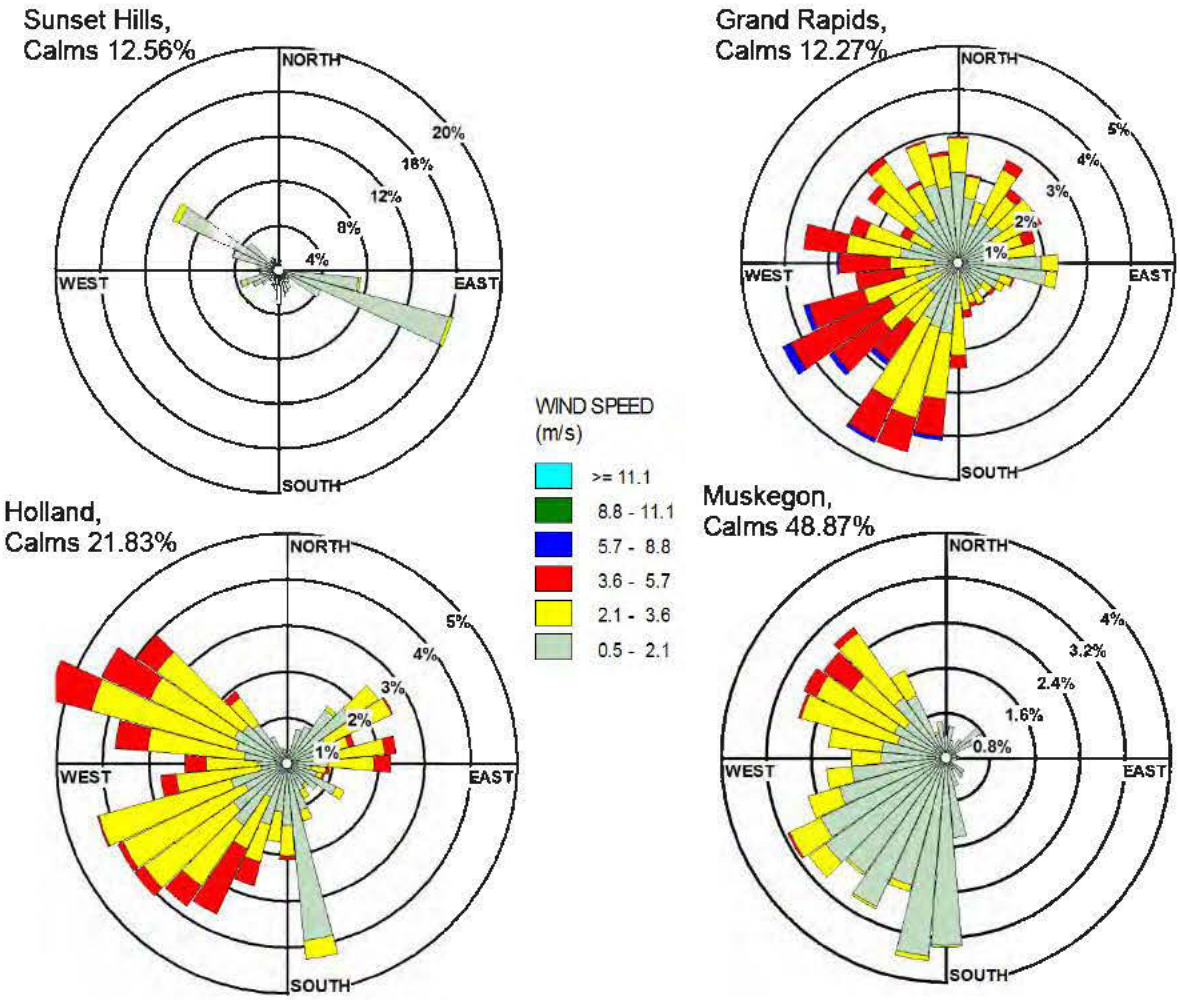


Figure 24: Windroses for the Sunset Hill Site from 12 AM to 6 PM (left) and from 11 AM to 6 PM (right)

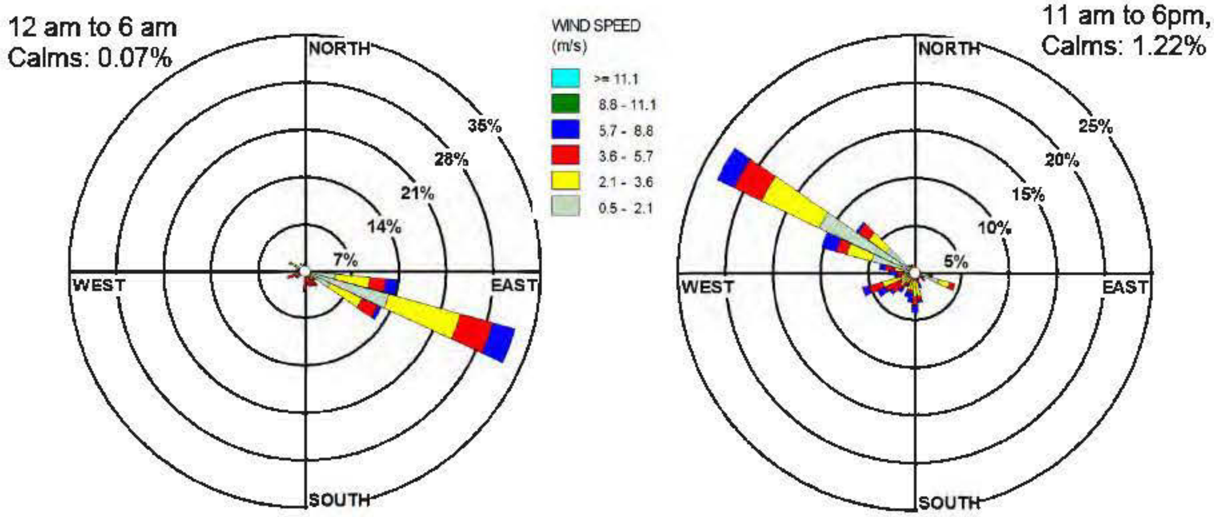
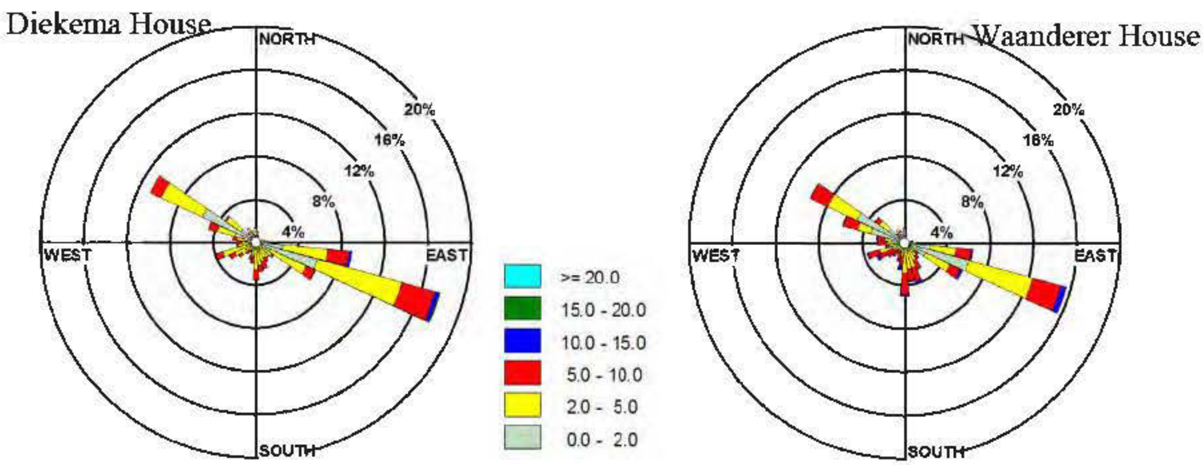
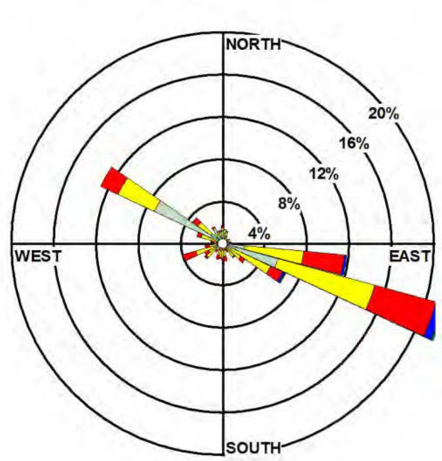


Figure 25 show the pollution roses for the Sunset Hills sites. The Diekema house had the highest concentrations (dark blue) coming from the ESE. The Waanderer house had the highest concentrations coming from ESE to the WSW. The Aukman house had the highest concentrations coming from the ESE similar to the Diekema house.

Figure 25: Pollution roses showing the concentration frequency per wind direction at the Sunset Hills monitors.

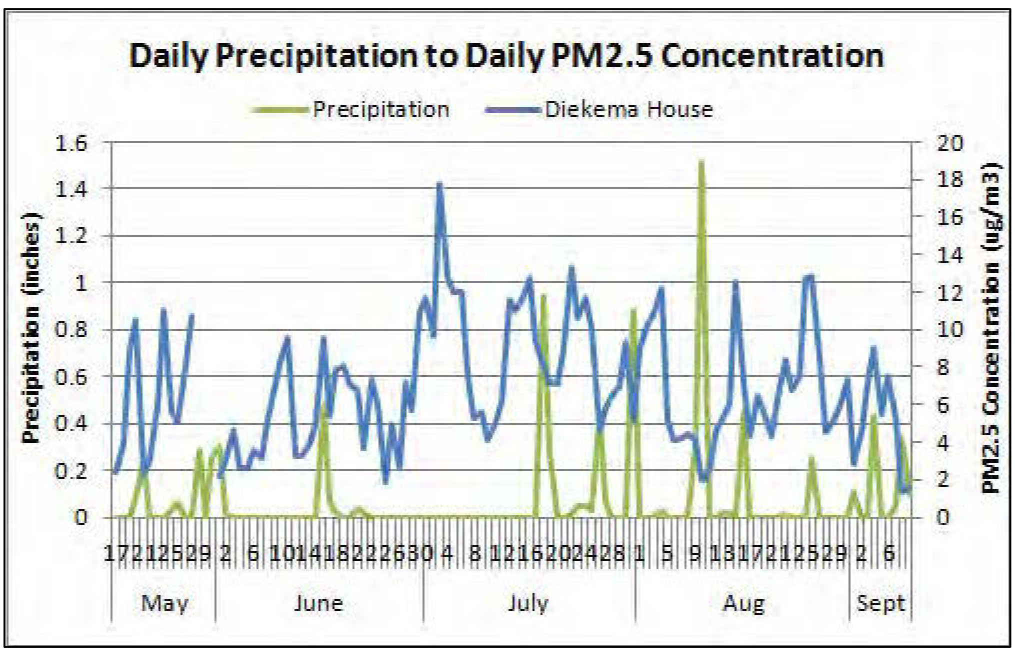


Aukman House



The daily precipitation values from Holland, Michigan are shown in Figure 26. The $PM_{2.5}$ concentrations generally decreased on days when rain occurred. Rain tends to decrease the $PM_{2.5}$ pollutants by washing them out of the air. It may also be due to fewer emissions from campfires and other sources during rain events.

Figure 26: Daily precipitation values from Holland, Michigan compared to the $PM_{2.5}$ concentrations at the Diekema house monitor.



Comparison to the USEPA's $PM_{2.5}$ Standards

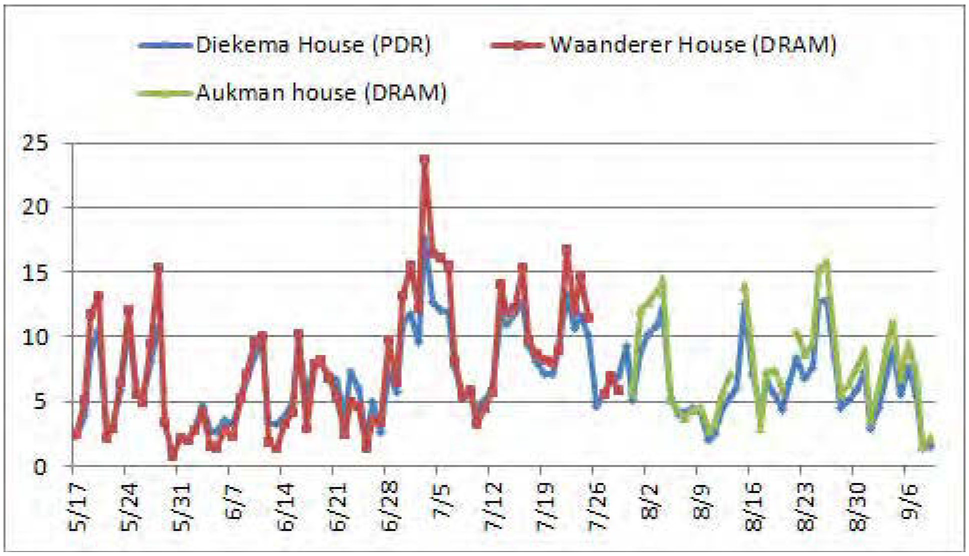
The USEPA has established health-based standards for $PM_{2.5}$. The annual and 24-hour standards and their level and form are shown in Table 3. Both standards require three years of data for attainment designations to occur. However, for comparison purposes, the level of the 24-hour and annual NAAQS (35 μg/m^3 and 12 μg/m^3, respectively) will be used in this analysis without regard to the form of the NAAQS (i.e., the 98th percentile averaged over three years).

Table 3: Averaging time, level and form of the $PM_{2.5}$ standard.

Pollutant	Average Time	Level	Form
Particulate Matter ($PM_{2.5}$)	Annual	12.0 $\mu g/m^3$	Annual mean, average over 3 years
	24-hour	35 $\mu g/m^3$	98^{th} percentile, averaged over 3 years

Figure 27 shows the 24-hour averages of the Sunset Hills monitoring data. No 24-hour averages were recorded above a level of 35 $\mu g/m^3$. The highest daily average of 23.7 $\mu g/m^3$ was observed on July 3, an action day, so no fires were allowed at the campground.

Figure 27: 24-hour averages of the three sites in Sunset Hills.



Tables 4 and 5 show the averages, standard deviation, and the 75^{th}, 90^{th} and 98^{th} percentiles for the three Sunset Hills sites as well as hourly TEOM data from three of AQD's nearby air monitoring stations. The data are divided into action days, when no campfires were permitted at CRCG, and non-action days when campfires were generally permitted. Also, statistics are shown based on the resident's observation logs for heavy smoke day and outrageous smoke days. Table 4 shows the 1-hour statistics and Table 5 shows the 24-hour statistics.

Table 4: 1-hour statistics for action days, non-action days, heavy smoke and outrageous smoke days.

	N	Median	Mean	SD	75th	90th	98th	Max
		μg/m³	μg/m³	μg/m³	μg/m³	μg/m³	μg/m³	μg/m³
1-hour Averages Action Days (no campfires)								
Diekema House	600	8.9	9.6	4.1	12.3	15.3	19.1	26.6
Waanderer House	480	10.1	11.4	5.9	15.1	19.9	26.4	28.5
Aukman House	120	9.8	11.1	4.3	14.6	17.2	20.4	20.7
Grand Rapids	567	14	15.0	6.1	18	21	32.16	49
Kalamazoo	591	15	15.4	5.3	19	22	27	31
Lansing	588	14	14.9	5.2	18	22	26	36
1-hour Averages Non-Action Days								
Diekema House	2,103	4.9	6.1	4.4	8.1	11.9	16.5	43.5
Waanderer House	1,294	4.4	6.1	5.2	8.4	14.0	20.0	32.6
Aukman House	864	5.9	7.2	5.6	9.9	13.5	21.4	58.8
Grand Rapids	1,583	8	8.9	5.1	12	16	20.8	53
Kalamazoo	2,119	9	9.7	5.8	13	17	24	58
Lansing	2,163	8	8.6	4.6	11	15	20	43
1-hour Averages Heavy Smoke Day (Resident's Log)								
Diekema House	262	5.5	6.8	4.6	9.2	12.8	17.8	28.3
Waanderer House	192	4.7	6.4	5.1	9.0	14.8	19.3	20.3
Aukman House	72	10.7	10.0	6.0	13.0	15.0	23.8	32.3
Grand Rapids	117	8	8.4	4.1	11	14	17.3	21
Kalamazoo	253	8	8.8	5.3	12	16.2	22	24
Lansing	263	7	7.9	4.3	10	14	19	23
1-hour Averages Outrageous Smoke Day (Resident's Log)								
Diekema House	143	4.2	7.0	7.9	8.4	16.1	34.6	43.5
Waanderer House	48	3.1	4.7	5.4	4.5	7.9	25.6	26.2
Aukman House	96	5.5	8.4	9.1	9.9	18.6	40.7	58.8
Grand Rapids	119	8	8.3	4.6	11.8	15	18	26
Kalamazoo	132	8	8.9	6.0	13	17	22.7	31
Lansing	144	8	8.4	4.7	11	13	16	43

Table 5: 24-hour statistics for action days, non-action days, heavy smoke and outrageous smoke days.

	N	Median	Mean	SD	75th	90th	98th	Max
		μg/m³	μg/m³	μg/m³	μg/m³	μg/m³	μg/m³	μg/m³
24-hour Averages Action Days (no campfires)								
Diekema House	25	9.4	9.6	3.0	12.0	12.7	17.7	17.7
Waanderer House	20	10.0	11.4	4.5	14.8	16.2	23.7	23.7
Aukman House	5	9.4	11.1	3.5	14.6	15.2	15.2	15.2
Grand Rapids	24	14	16.0	5.4	19	23.1	32	32
Kalamazoo	25	16	15.7	2.9	18	19	21	21
Lansing	25	16	16.1	5.7	19	20	36	36
24-hour Averages Non-Action Days								
Diekema House	88	5.5	6.1	2.9	7.9	10.7	12.8	13.3
Waanderer House	54	5.0	6.1	4.2	8.3	13.2	16.0	16.7
Aukman House	36	6.9	7.2	3.5	9.4	12.7	15.4	15.8
Grand Rapids	66	8	8.8	3.6	11	14	17.4	19
Kalamazoo	91	9	9.6	3.9	11	15	20.0	22
Lansing	90	8	8.6	3.4	10	13.5	17.7	20
24-hour Averages Heavy Smoke Day (Resident's Log)								
Diekema House	11	6.1	6.8	2.9	9.8	10.6	11.0	11.0
Waanderer House	8	5.6	6.4	4.1	9.2	12.7	13.2	13.2
Aukman House	3	12.1	10.0	4.2	12.6	12.7	12.7	12.7
Grand Rapids	5	8	8.4	2.3	9.8	12	12	12
Kalamazoo	11	7	8.6	3.7	11.5	14.2	16	16
Lansing	11	7	7.8	3.1	9.8	12.2	14	14
24-hour Averages Outrageous Smoke Day (Resident's Log)								
Diekema House	6	6.1	7.0	3.1	8.3	12.1	12.6	12.6
Waanderer House	2	4.7	4.7	1.6	5.8	5.8	5.8	5.8
Aukman House	4	8.3	8.4	4.8	12.1	14.0	14.0	14.0
Grand Rapids	5	7	8.2	3.4	10.8	13	13	13
Kalamazoo	6	9	8.7	2.7	11	11.9	12	12
Lansing	6	8.5	8.5	2.7	10	11.8	12	12

Discussion of Potential Health Impacts

Breathing elevated levels of fine particulate matter can be an acute health risk for people with pre-existing respiratory or cardiovascular conditions and can be a chronic health risk for the general population (Adamkiewicz et al. 2003, Delfino et al. 2008, Dominici et al. 2006, Gauderman et al. 2004, Gold et al. 2000, Koenig et al. 2005, O'Neill et al. 2005, Ostro et al. 2006, Peters et al. 2001, Pope et al. 2002, Pope et al. 2006, Zeger et al. 2008). Epidemiologic studies have found that sensitive populations exposed for as little as one hour of elevated $PM_{2.5}$ can result in increased emergency room visits for cardiovascular and respiratory effects (Owosso Report, Appendix 2, Table A.3). Specifically, published studies report that a 10 μg/m³ increase in $PM_{2.5}$ over a 24-hour period correlates to significant increases in these negative health outcomes (see Owosso Report Appendix 2). The MDCH finds that the epidemiologic literature supports the conclusion that vulnerable populations may be at risk for negative health outcomes from air concentrations between 12 and 36 µg/m^3 of $PM_{2.5}$ that occur in a 24-hour period, recognizing that longer or repeated exposures pose greater risk.

Residential air quality concerns cannot practically be investigated using the NAAQS. NAAQS require three years of data collection using sampling methods designed to characterize $PM_{2.5}$ over large geographic regions and timeframes such as the entire area of southwest Michigan over one year. The NAAQS are not designed to assess variation in $PM_{2.5}$ within a given day (e.g., hourly variation) and thus would not account for maximum short-term exposures. Although the NAAQS methods for air sampling and duration of sampling are not appropriate for public health investigations, the NAAQS include criterion for limiting $PM_{2.5}$ exposure to an annual average below 12 µg/m^3 with no more than two percent of the daily measurements exceeding 35 µg/m^3. This criterion attempts to keep average $PM_{2.5}$ exposure to less than 12 µg/m^3, while explicitly limiting the number of 24-hour peak exposures (i.e., exceeding 35 µg/m^3). By creating this system, the USEPA recognizes that 24-hour peak exposures are a risk to vulnerable populations. The USEPA has also developed an Air Quality Index (AQI) to advise the public when short-term levels of $PM_{2.5}$ and other pollutants in their outdoor air are high enough to pose a health hazard (see Owosso Report Appendix 2).

For these reasons, MDCH used the $PM_{2.5}$ NAAQS as a first-cut screening criteria for putting the Grand Haven $PM_{2.5}$ air concentrations in a public health context. The 24-hour averages for Grand Haven $PM_{2.5}$ data are less than 12 µg/m^3 (Table 5). In addition, the 98^{th} percentiles of the 24-hour summaries are less than 35 µg/m^3. Based on this comparison, the summer 24-hour average $PM_{2.5}$ air concentrations appear to be of minimal risk to human health. Actions days, when burning was not allowed, had the highest $PM_{2.5}$ concentrations, suggesting regional sources of $PM_{2.5}$ are a significant contributor to air pollution.

Comparing the Grand Haven (population 10,511) $PM_{2.5}$ air concentrations to Grand Rapids (population 189,815), Lansing (population of 114,297), and Kalamazoo (population 74,743), the Grand Haven dataset is generally similar to or less than the larger cities on both the 1-hour and 24-hour averages (Table 4). Grand Haven's 98^{th} percentile values for the 1-hour averages dataset on *Outrageous Smoke Days* appear to be higher than the three comparison cities; however, the mean and median concentrations are similar. Elevated transient $PM_{2.5}$ air concentrations can be an indication of a local source.

Health-based comparison values have not been established by the USEPA for $PM_{2.5}$ measurements representing less than a 24-hour exposure. The states of Montana and California have public health guidance numbers for as low as a 1-hour $PM_{2.5}$ exposure to address concerns related to residential smoke exposures during wildfires. Initial public actions in those states begin at 33.6 and 39 µg/m^3, respectively, and involve informing the public to take precautions to limit exposure.

There are a relatively small number of $PM_{2.5}$ studies of people where 1-hour exposure was measured; however, those studies show associations to cardiovascular and respiratory effects. Adamkiewicz et al. (2004) reported increases in exhaled nitric oxide (NO) in older adults (N=29 adults), an indication of respiratory inflammation associated with $PM_{2.5}$ exposure (mean: 19.5 µg/m^3) 1-hour prior to the NO measurement. Similar findings were reported for children with asthma, where an increase of 10 µg/m^3 $PM_{2.5}$ (range: 5-26 µg/m^3) was associated with a 7 ppb increase in exhaled NO (Mar et al. 2005). In both studies, the correlation was greatest with the most immediate $PM_{2.5}$ exposure measurements and declined with greater amounts of time between exposure and NO measurements.

Two-hour $PM_{2.5}$ exposures with an increase of 25 µg/m^3 have been statistically significantly correlated with the onset of myocardial infarction (Peters et al. 2001). A similar study in Indianapolis found that an increase in cardiac arrests was correlated with increasing $PM_{2.5}$ ambient air concentration that ranged from 5.6 to 30.5 µg/m^3, and people between 60 and 75 years old were at the greatest risk.

Given the limited number of human studies and the lack of well-accepted health-based comparison values, a determination on the health risks posed by 1-minute to 1-hour $PM_{2.5}$ levels measured in this study cannot be determined. It is worth noting that Grand Haven's population is 7 to 17 times smaller than the comparison cities of Grand Rapids, Kalamazoo, and Lansing. Typically, cities with larger populations tend to have more $PM_{2.5}$ sources (i.e., diesel exhaust, fireplaces, industry, etc.) and higher $PM_{2.5}$ ambient air concentrations. Therefore, it may be considered unusual for Grand Haven to have similar $PM_{2.5}$ levels as the larger cities.

Conclusion

$PM_{2.5}$ monitoring conducted by the MDEQ shows that smoke from the CRCG reaches and impacts the Sunset Hills neighborhood. This impact is greatest during the late evening hours, especially during the weekend. However, the $PM_{2.5}$ concentrations on days when smoke from the CRCG impacts the Sunset Hills neighborhood are still generally lower than what the neighborhood experiences from regional air pollution sources on air quality action days. As such, the air quality in the Sunset Hills neighborhood, on average, is similar to what is observed by the MDEQ's permanent air monitoring stations located in Grand Rapids, Kalamazoo, and Lansing.

The $PM_{2.5}$ levels measured by the MDEQ did not reach levels that exceeded the level of the 24-hour NAAQS.

Shorter-term 1-hour impacts are difficult to assess given the lack of definitive health criterion to compare against; however, the 1-hour dataset were similar to measurements made in Grand Rapids, with the exception of the 98th percentile on *outrageous smoke days.* It appears transient plumes of smoke enter the Sunset Hills neighborhood, and the health risk from those transient plumes cannot be evaluated with current criteria or published literature. Extremely vulnerable individuals may be at significant risk from exposure to transient plumes of $PM_{2.5}$; however, such individuals would also be at risk from other sources that can create transient $PM_{2.5}$ exposures.

The CRCG does not allow campfires on air quality action days. In addition, the CRCG has a smoke management policy wherein campfires are required to be curtailed when its PM_{10} monitor records concentrations above 150 µg/m^3 or above 100 µg/m^3 on days when the regional AQI is moderate or higher. Correlating smoke concentrations, as measured by the MDEQ's $PM_{2.5}$ monitors and the CRCG's PM_{10} monitor with an observational smoke log maintained by the Sunset Hills residents, shows that the days with the highest perceived smoke don't always have the highest particulate concentrations. Still, if the CRCG were to lower the criteria for curtailing fires to somewhere between 100 to 125 µg/m^3, the smoke impact on the Sunset Hills neighborhood could potentially be lessened.

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