Investigation of the Impact of Burning Upon Ambient $PM_{2.5}$ Levels in Owosso During November 2011

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Background

During 2011, the Michigan Departments of Environmental Quality (DEQ) and Community Health (DCH) began work with their counterparts in Minnesota, Wisconsin and Indiana and at the Lake Michigan Air Directors Consortium (LADCO) to develop an air monitoring system that could help quantify the impact that wood smoke has upon communities in the region. Central to this wood smoke monitoring system is a meter that measures the concentration of particulate matter smaller than 2.5 micrometers in diameter ($PM_{2.5}$ or fine particulate matter). The DEQ received a beta (test) version of the wood smoke monitoring system in mid-October and tested it in Owosso, Michigan during November 2011.

This document summarizes the technical findings of the deployment of this monitor in Owosso. A less technical companion document will be created for communicating the findings of this investigation to the general public.

Introduction

In Owosso, city ordinance Chapter 13-4 addresses open fires and defines the incineration of waste materials and recreational fires. The incineration of waste material, defined as paper and paper products excluding diapers; clean, clear, unpainted, unfinished untreated wood and wood products excluding particle board and similar products; and yard waste, is allowed between 7:00 am and 7:00 pm on Tuesdays and Thursdays outside of one- or two-family dwellings. In addition, recreational fires outside of one- or two-family dwellings are permitted between noon and 10:00 pm Sunday through Thursday and between noon and midnight Friday and Saturday. Materials acceptable for use in recreational fires include clean, clear, unpainted, unfinished and untreated wood and wood products excluding particle board and similar products; split firewood; tree limbs and charcoal[1]. Despite set back requirements and other smoke, spark and odor restrictions, the DEQ and the DCH have repeatedly received complaints from citizens in Owosso having health concerns from these burning practices.

Being immediately downwind of a burning event may be a nuisance. It can also be a health problem, particularly for people with lung or heart conditions. The type of air pollution emitted from uncontrolled burning is dependent upon what is being burned. For example, the burning of domestic waste can emit dioxins and furans[2] while polycyclic aromatic hydrocarbons are typical of wood combustion. While these pollutants can and are emitted as gases, much of the air pollution from open burning is in particulate form, including $PM_{2.5}$ which can lodge deep within the lungs.

Smoke is an obvious component of open burning and $PM_{2.5}$ concentrations in visible plumes can be 35 $\mu g/m^3$ or higher[3]. However, given that plumes are not always visible, public perception about how local burning practices are affecting overall air quality in Owosso varies. While it is has been suggested that burning activities are increasing the $PM_{2.5}$ ambient air concentrations throughout the city, it has not been possible to investigate the issue quantitatively without ambient air data.

[1] Section 13-4, Chapter 13: Fire Prevention and Protection, City of Owosso.
[2] Gullet, et al, 2010.
[3] Trent Wickman, US Forest Service, personal communication, March 2012.

The purpose of deploying the wood smoke monitoring system in Owosso was to provide such data. The system was specifically placed in a location that was not immediately proximal or downwind of visually identifiable $PM_{2.5}$ sources (e.g., outdoor wood boilers, burn pits, burn barrels) excluding indoor burning units (e.g. fire places and indoor wood stoves). The purpose of this investigation was not intended to quantify the impact of any single specific $PM_{2.5}$ source, but rather a characterization of the concentrations of $PM_{2.5}$ in overall ambient outdoor air. The monitoring took place in Owosso during the month of November when leaf burning would typically be at a maximum.

Instrumentation

The wood smoke monitoring system contains a Thermo Electron Personal DataRAM (Data logging Real-time Aerosol Monitor), that measures $PM_{2.5}$ based upon the amount of light that particulate scatters from a calibrated light source. The Personal DataRAM (PDR) provides accurate continuous readings of $PM_{2.5}$ as low as 1 microgram per cubic ($\mu g/m^3$).[4] It is housed in a weatherproof Pelican with an internal heater and an external sampling probe so it can be deployed outside. See Figure 1.

Figure 1: PDR (top left) and associated hardware in its field enclosure:

To determine how $PM_{2.5}$ concentrations vary in Owosso, the PDR was paired with a Thermo Electron DataRAM4 owned by the DEQ. 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.

[4] Instruction Manual P/N (100181-00), Thermo Electron Corporation, Franklin, Massachusetts.

Figure 2: DataRAM4 (bottom) and associated hardware in its enclosure.

Quality Assurance

To ensure that the PDR and DataRAM4 were operating correctly, the DEQ compared the DataRAM4 along side a Rupprecht & Patashnick Tapered Element Oscillating Microbalance (TEOM) located at the DEQ's Lansing air monitoring station for several days. Then a comparison was made between the PDR and the DataRAM4, also at the DEQ's Lansing air monitoring station. Based upon the results presented in Figures 3 and 4, the PDR and DataRAM4 closely replicated the TEOM and one another. Such replication allowed for accurate site by site comparisons in Owosso once the PDR and DataRAM4 were deployed.

Figure 3: Comparison of the DataRAM4 and the DEQ TEOM co-located at the DEQ's Lansing station (1-hour averages, µg/m^3 by hour)

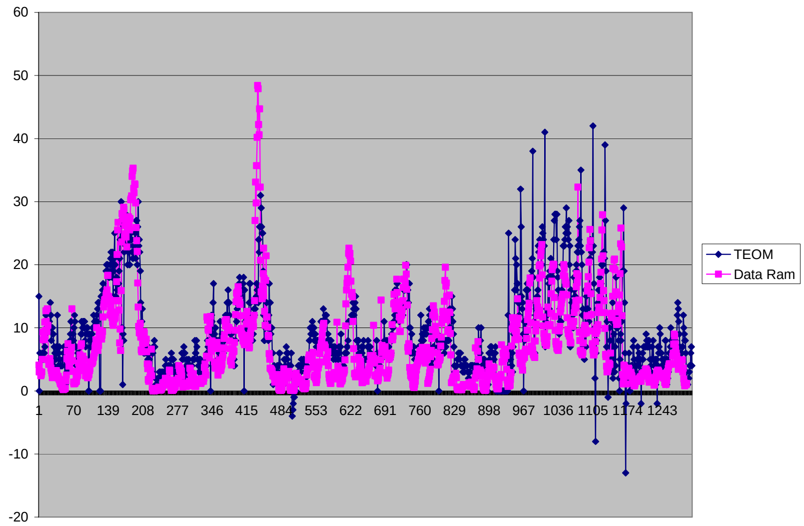
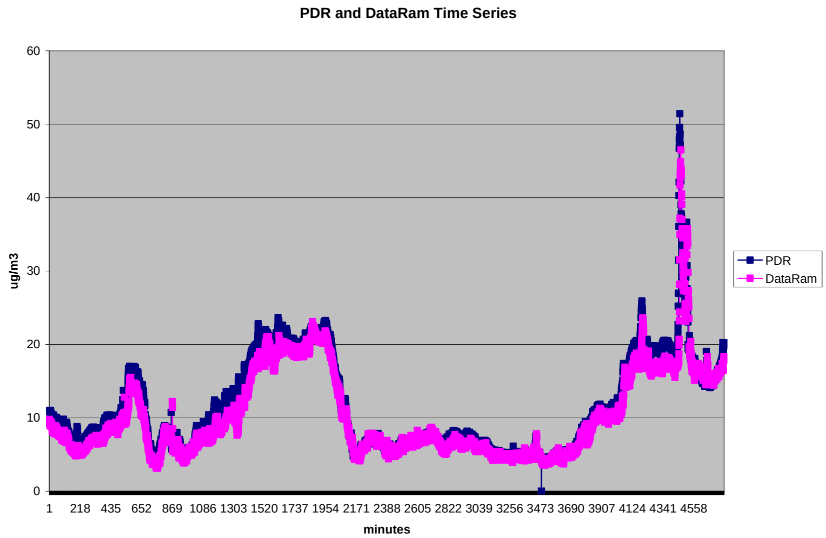


Figure 4: Comparison of the PDR and DataRAM4 co-located at the DEQ's Lansing station (1-minute averages)



Deployment and Operation in Owosso

On November 3, 2011, staff from DEQ and DCH met with representatives of the Shiawassee County Health Department and the City of Owosso to identify two locations in the city that would represent ambient air in Owosso impacted by burning emissions but not directly downwind of a $PM_{2.5}$ source. One area with open-burning related air emissions, based on residents' complaints, was identified to exist west of the intersection of M-21 and M-52, in the vicinity of St. Paul's School (orange oval in Figure 5). To estimate the contribution of the emissions from this source area upon areas downwind, the PDR was placed near the Amos Gould House on West Oliver and Washington Streets, close to the city center. To provide an estimate of the amount of $PM_{2.5}$ generally upwind of the open-burning emission source area, the DataRAM4 was placed at a home located on Irene Street. The residence on Irene Street was also selected because the DEQ, DCH and the City typically do not log complaints regarding burning in this area. However, during deployment, it was noted that many homes in the Irene Street neighborhood had chimneys typically associated with fireplaces or indoor woodstoves.

As ambient $PM_{2.5}$ levels are higher in a smoke plume than outside of it, and 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.

Figure 5: Area identified by residents as having open-burning emissions (large orange oval) and air monitoring locations

The PDR and DataRAM4 ran for three time periods: November 3-14, November 14-28 and November 28-30. See Figures 6 through 8. Unfortunately, a power outage caused the DataRAM4 to shut down on November 25. Therefore, for the period of November 25-30, there are no data for the Irene Street monitoring location.

Figure 6: One-minute $PM_{2.5}$ levels (µg/m^3) in Owosso during November 3-14.

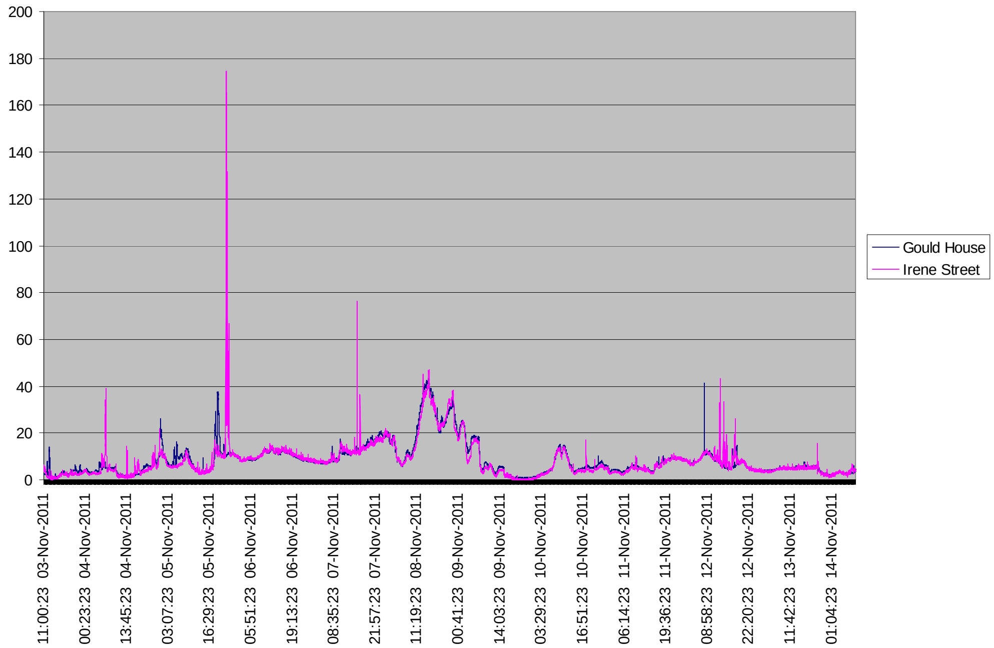


Figure 7: One-minute $PM_{2.5}$ levels (µg/m^3) in Owosso during November 14-28.

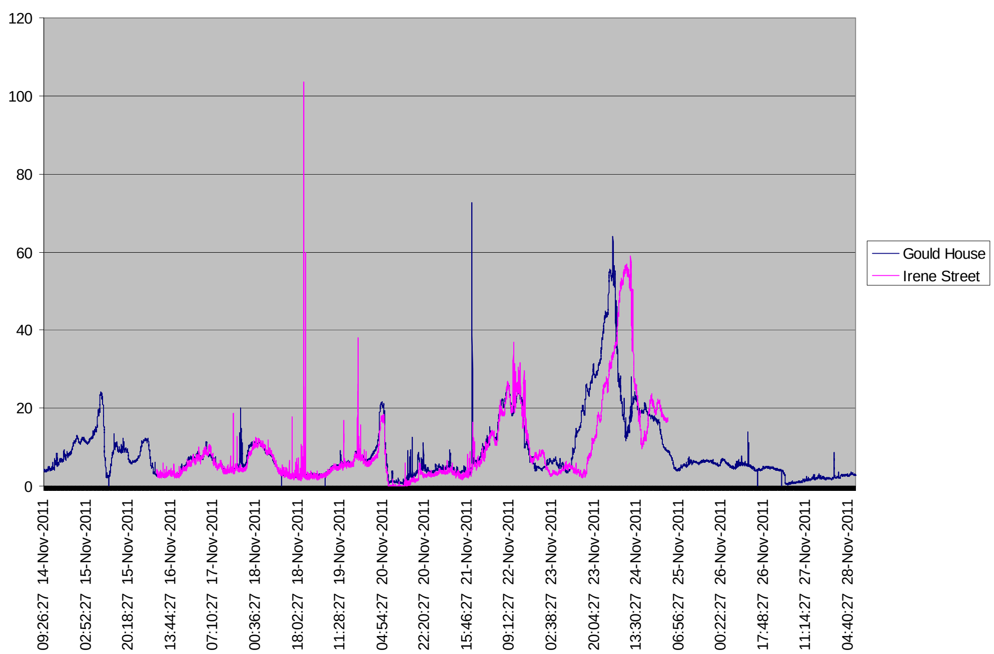
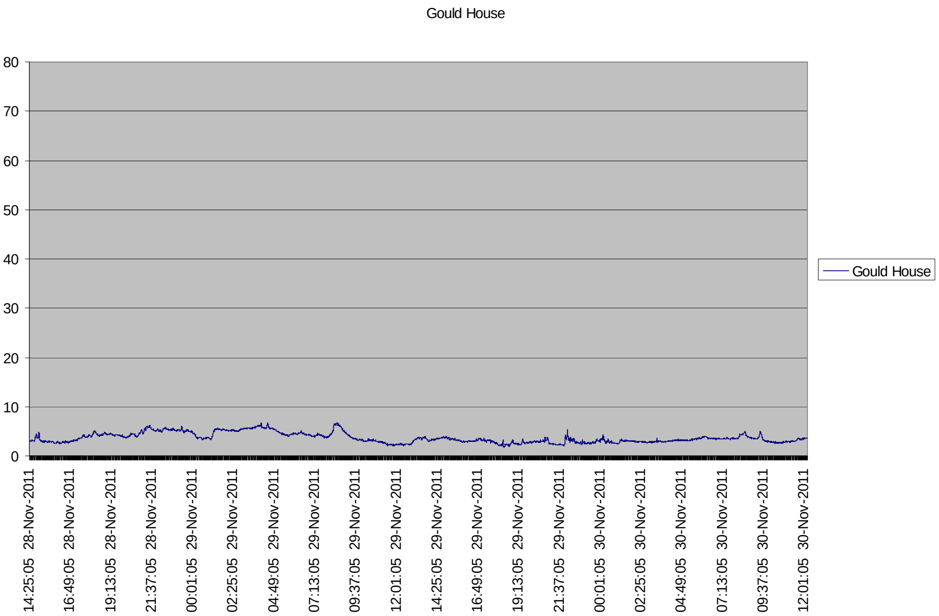


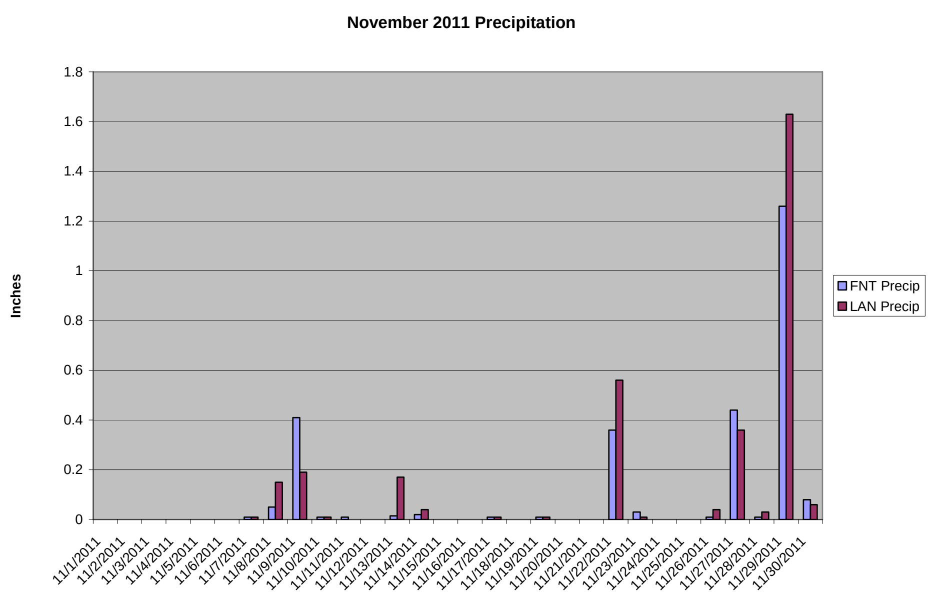
Figure 8: One-minute $PM_{2.5}$ levels ($\mu g/m^3$) in Owosso during November 28-30



Discussion of Results

As can be seen from Figure 9, November 2011 had several days with precipitation. Data collected at Capital Region International Airport in Lansing and Bishop Airport in Flint indicate that there was some form of precipitation on 16 days during the month. This relatively high frequency of precipitation likely kept the fallen leaves wet, making leaf burning difficult and therefore perhaps less prevalent than in years past.

Figure 9: November 2011 precipitation (with "trace" considered to be equivalent to 0.01 inches)



Still, periods of elevated $PM_{2.5}$ concentrations were measured. There was a prolonged period where both monitoring locations had concentrations of between 20-60 µg/m^3 on November 22-24 (Thanksgiving) and periods with concentrations between 20-40 µg/m^3 on November 8 and then again on November 15. In addition, there were four very short-term spikes above 60 µg/m^3 that occurred on Saturday, November 5; Monday, November 7; Friday, November 18 and Monday, November 21. Unlike what was observed for the more prolonged periods on November 8, 15 and 22-24, these short-term spikes occurred at only one of the two monitoring locations.

To determine what was causing the elevated concentrations on November 8, 15, 22, 23 and 24, 1-hour data from this period was plotted from the DEQ's continuous $PM_{2.5}$ monitoring stations closest to Owosso: Flint, Bay City and Lansing. As can be seen from Figures 10 through 12, the TEOMs at the three air monitoring stations also recorded elevated $PM_{2.5}$ levels during these periods. This suggests that the elevated concentrations observed at both the Gould House and Irene Street monitors were regional in nature and therefore not directly attributable to leaf or other burning specific to Owosso.

Figure 10: One-hour $PM_{2.5}$ concentrations (µg/m^3) from the DEQ TEOMs located in Flint, Bay City and Lansing for November 8.

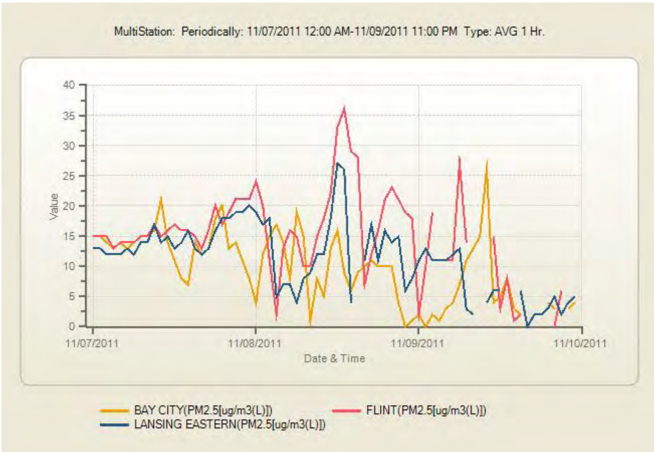


Figure 11: One-hour $PM_{2.5}$ concentrations (µg/m^3) from the DEQ TEOMs located in Flint, Bay City and Lansing for November 15.

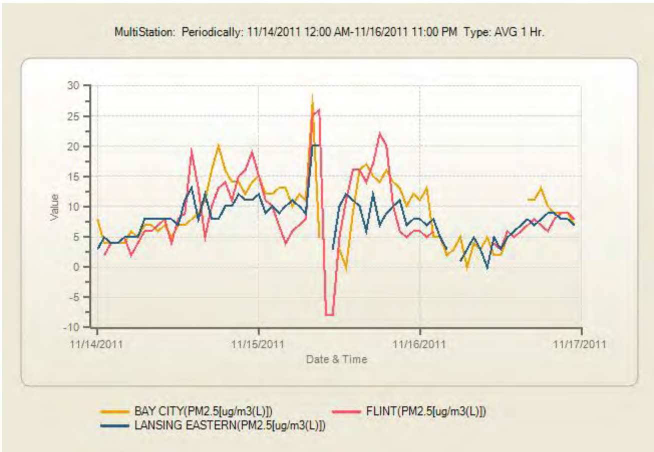
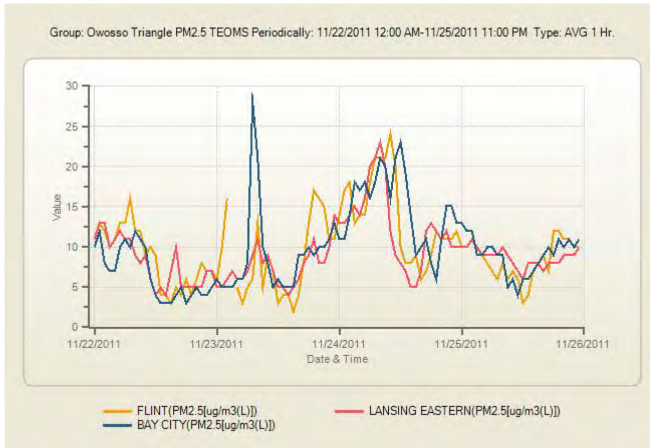


Figure 12: One-hour $PM_{2.5}$ concentrations (µg/m^3) from the DEQ TEOMs located in Flint, Bay City and Lansing for November 22-24.



Figures 13 through 16 expand Figures 6 and 7 to give more detail on the short-term peaks found at the Irene Street monitor on November 5, 7 and 18 and at the Gould House monitor on November 21.

Figure 13: One-minute $PM_{2.5}$ levels (µg/m^3) in Owosso during November 5.

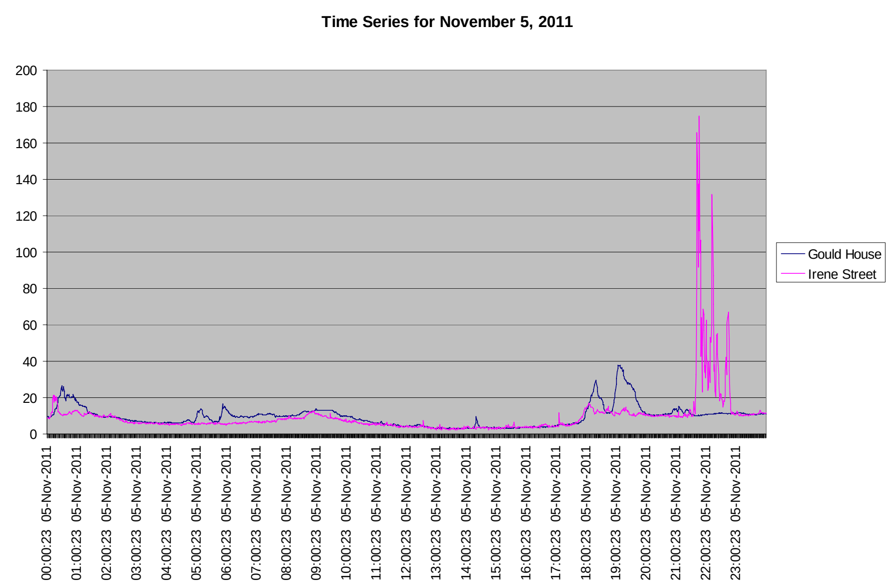


Figure 14: One-minute $PM_{2.5}$ levels ($\mu g/m^3$) in Owosso during November 7.

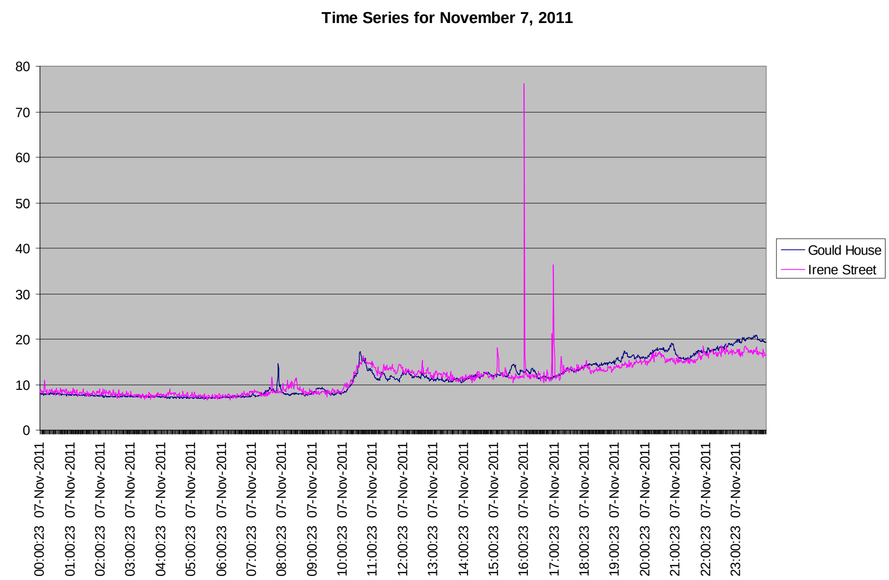


Figure 15: One-minute $PM_{2.5}$ levels ($\mu g/m^3$) in Owosso during November 18.

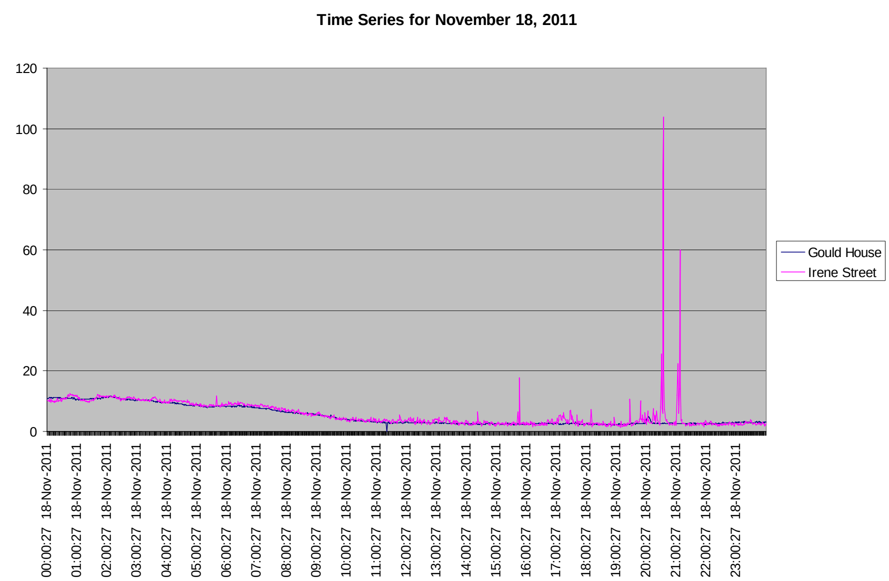
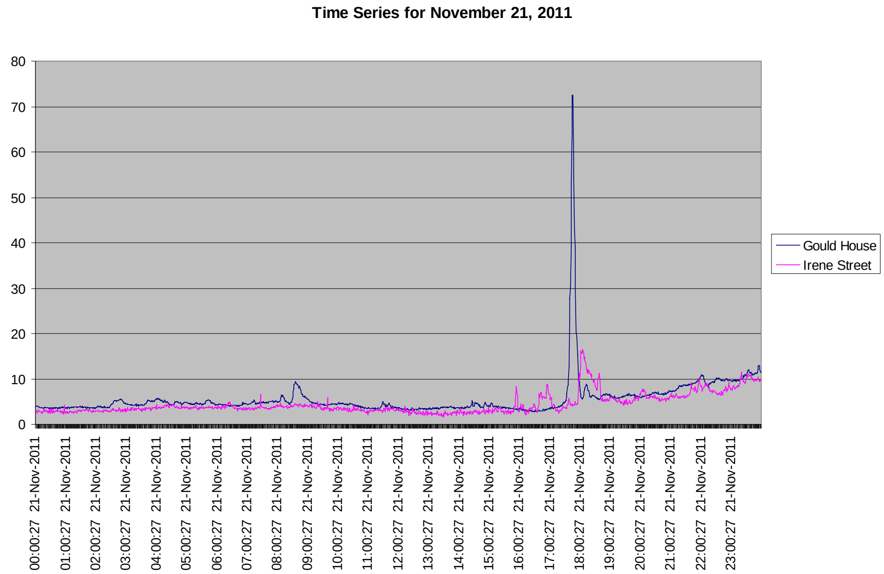


Figure 16: One-minute $PM_{2.5}$ levels ($\mu g/m^3$) in Owosso during November 21.



All four short-term peak episodes occurred between 4 pm and 11 pm and with the exception of November 5, lasted only for a matter of minutes. The episode on November 5 lasted for approximately one hour. Table 1 presents background meteorological information for these days. Table 2 is a compilation of the corresponding 1-hour $PM_{2.5}$ levels on these days.

Table 1: Background meteorological data for days having peak 1-minute levels greater than 60 $\mu g/m^3$.

Date	Hour	Day of Week	Hourly FNT wind, T (dir-mph, ^oC)	Hourly LAN wind, T (dir-mph, ^oC)	Precip-itation (inches)
11-5-2011	2300	Saturday	E-01, 2	SE-05, 4	0.00
11-7-2011	1700	Monday	SW-03,14	WSW-02, 13	0.00
11-18-2011	2100	Friday	S-09, 6	S-10, 6	0.01
11-21-2011	1800	Monday	N-05, 3	NE-05, 4	0.00

Table 2: One-hour $PM_{2.5}$ concentrations on those days having 1-minute levels greater than 60 $\mu g/m^3$.

	11/5/2011		11/7/2011		11/18/2011		11/21/2011	
Hour	Gould	Irene	Gould	Irene	Gould	Irene	Gould	Irene
0	17.5	12.6	7.9	8.5	11.0	10.9	3.7	2.9
1	12.2	10.5	7.7	8.2	10.9	10.9	3.7	2.9
2	8.3	7.8	7.4	8.0	10.9	11.1	4.4	3.0
3	6.4	5.8	7.4	7.6	10.1	10.3	4.6	3.4
4	6.6	5.5	7.2	7.8	9.0	9.8	4.9	3.8
5	10.1	5.7	7.1	7.4	8.3	8.6	4.7	3.6
6	9.8	6.2	7.3	7.7	8.2	9.0	4.3	3.7
7	10.3	7.2	8.6	8.3	7.2	7.9	4.8	3.7
8	11.4	9.7	7.9	9.2	6.0	6.2	6.3	4.1
9	12.0	9.0	8.4	8.3	4.7	4.8	4.5	3.7
10	7.8	6.0	12.3	12.8	3.5	3.7	4.2	3.2
11	5.1	4.7	11.6	13.4	2.9	3.5	3.8	3.2
12	4.2	3.8	11.9	12.7	2.9	3.4	3.3	2.7
13	3.1	2.9	11.0	11.7	2.7	3.2	3.6	2.4
14	3.8	3.3	11.9	11.8	2.5	2.7	4.0	2.7
15	3.3	3.7	12.6	12.2	2.5	2.9	3.7	3.3
16	3.8	4.2	12.1	13.9	2.6	2.7	3.1	4.6
17	6.1	6.8	13.0	13.2	2.6	3.7	15.1	4.4
18	18.1	12.8	14.5	13.4	2.4	2.6	6.5	9.6
19	24.7	11.4	16.0	14.5	2.5	3.1	6.2	5.3
20	10.9	10.0	17.5	15.8	2.9	7.6	6.6	6.0
21	11.5	35.2	16.5	15.6	2.6	4.9	8.6	6.9
22	11.2	34.5	18.2	17.1	2.7	2.4	9.7	7.6
23	11.0	10.9	19.9	17.2	3.0	2.6	10.7	9.5
24hr ave	9.6	9.6	11.5	11.5	5.2	5.8	5.6	4.4

Table 2 shows that the highest 1-hour averages were recorded at the Irene Street monitor on November 5th. Since the Gould House did not witness elevated levels during this period and given east-southeast winds during the entire day (Figures 17 and 18), it is possible that smoke from leaf or brush burning in the targeted emission source area near the M-21/M-52 intersection may have been the cause. However, it is highly unlikely that such burning would have started and ended so late in the day. Instead, it is likely that the $PM_{2.5}$ originated from a more localized source. As discussed previously, there are several nearby residences that have chimneys associated with wood burning devices.

Figure 17: Wind frequency distribution from the DEQ's Lansing air monitoring station for November 5, 2011.

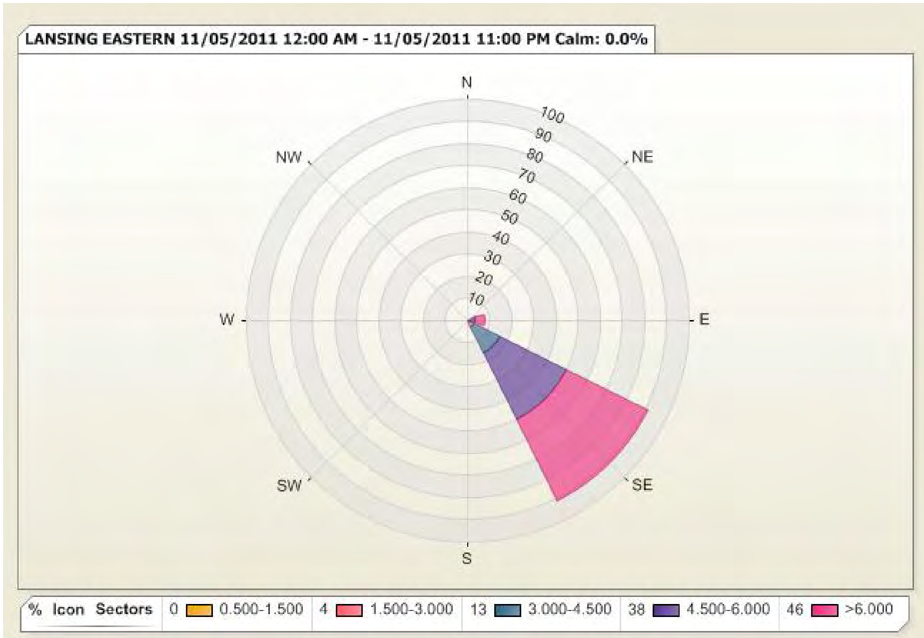
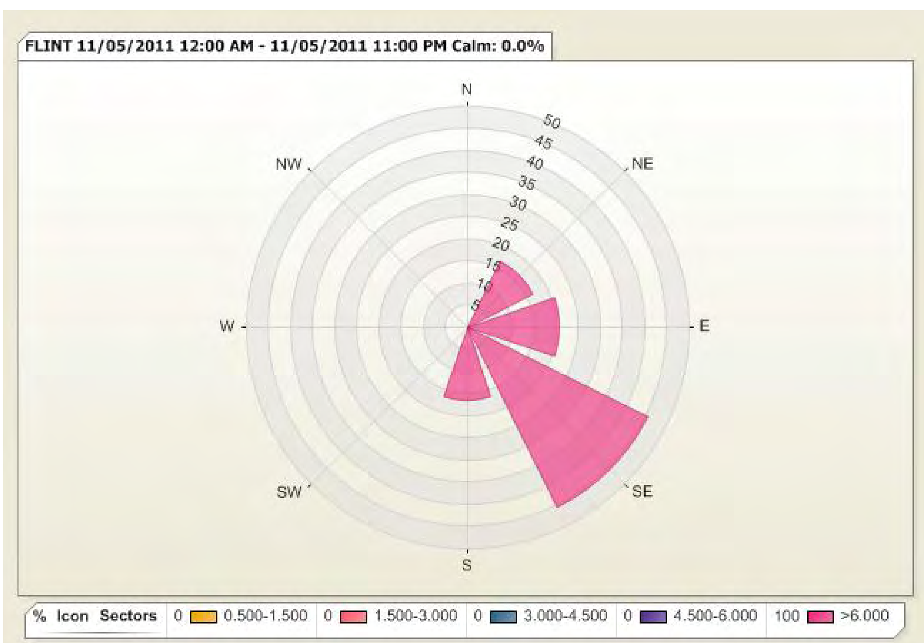


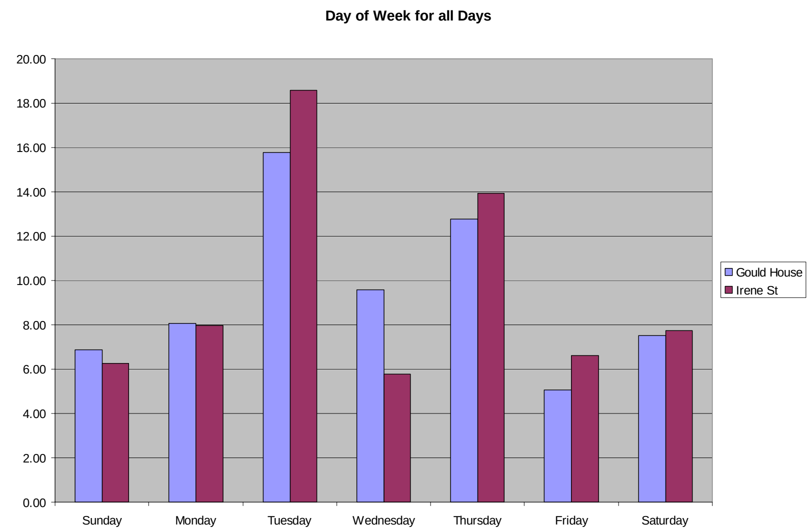
Figure 18: Wind frequency distribution from the DEQ's Flint air monitoring station for November 5, 2011.



Day of Week Analysis

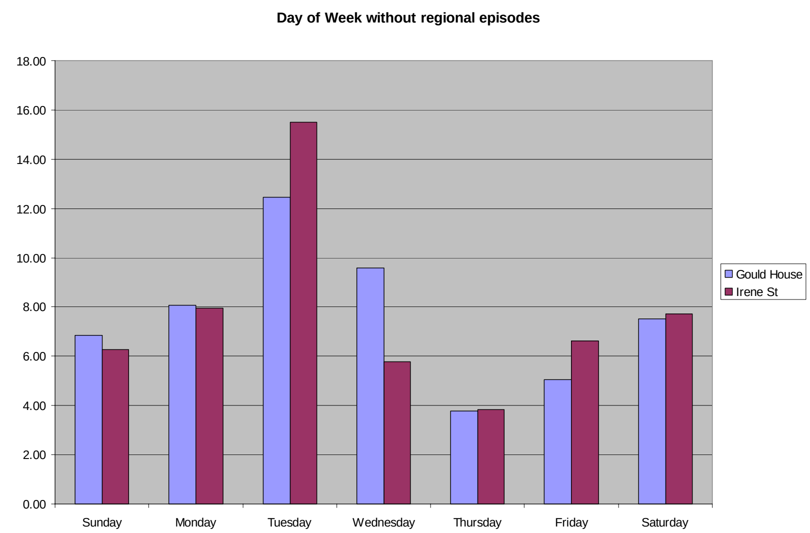
To determine if those days in Owosso when burning was allowed had higher $PM_{2.5}$, average $PM_{2.5}$ concentrations by day of week is presented in Figure 19.

Figure 19: Average $PM_{2.5}$ concentrations (µg/m^3) by day of week.



While Figure 19 shows the highest levels occurred on Tuesdays and Thursdays, regional transport played a significant role on November 8 (Tuesday), 15 (Tuesday) and 22-24 (Tuesday-Thursday). Figure 20 shows the average concentrations by day of week with November 8, 15 and 22-24 removed from the data set. While $PM_{2.5}$ concentrations remain the highest on Tuesdays, caution must be exercised in drawing correlations with burning as the Tuesday bin in Figure 20 is based on only one data point: November 29. As can be seen from Figure 9, there was significant rainfall on that day.

Figure 20: Average $PM_{2.5}$ concentrations (µg/m^3) by day of week with regionally impacted days removed.



Analysis 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). In fact, 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 (Table A.3). Specifically, published studies report that a 10 µg/m^3 increase in $PM_{2.5}$ over a 24-hour period correlates to significant increases in these negative health outcomes (see Appendix 2). The DCH finds that the epidemiologic literature supports the conclusion that vulnerable populations may be at risk for negative health outcomes from air concentrations between 12-36 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 National Ambient Air Quality Standards (NAAQS). NAAQS require three years of data collection using sampling methods designed to characterize $PM_{2.5}$ over large geographic regions such as the entire area of Southeast Michigan. 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 for air sampling and duration of sampling are not appropriate for public health investigations, the NAAQS do include criterion for limiting $PM_{2.5}$ exposure to an annual average below 15 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 15 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 EPA recognizes that 24-hour peak exposures are a risk to vulnerable populations. The EPA 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 Appendix 2).

The DCH suggests using NAAQS $PM_{2.5}$ air concentration criteria as a reference for evaluating the Owosso $PM_{2.5}$ air concentrations in a public health context. The 24-hour averages for Owosso $PM_{2.5}$ data, along with the Lansing, Bay City, and Flint data, are less than 15 µg/m^3 (Table 4). In addition, the 98^{th} percentiles of all of these datasets are less than 35 µg/m^3. Based on this comparison, the November average $PM_{2.5}$ air concentrations appear to be of minimal risk to human health. As noted previously, November weather patterns may have resulted in a dataset that may be unique to this month and not represent other months of the year.

Comparing the Owosso (population of 15,194) $PM_{2.5}$ air concentrations to Bay City (population of 34,932), Lansing (population of 114, 297), and Flint (population of 102,434), the Owosso dataset does have the highest 98^{th} percentiles and maximums for both the 1-hour and 24-hour averages (Table 4). These high-end concentrations in the Owosso dataset skewed the Owosso means high and increased the standard deviations. Owosso mean concentrations are 2-3 µg/m^3 higher than their associated Owosso median concentrations. Owosso standard deviations are, on average, 1.6 to 2 times greater than the standard deviations from the other city datasets. These differences may indicate that localized sources are contributing to Owosso $PM_{2.5}$ air concentrations and resulting in unusually high transient $PM_{2.5}$ air concentrations. Additionally, Owosso's population is 2.2-7.5 times smaller than the comparison cities of Bay City, Lansing, and Flint. 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, thus it may be considered unusual for Owosso to have similar $PM_{2.5}$ levels as these larger cities. As can be seen from Figure 21, the two sites in Owosso have fewer days in the good range and more days in the moderate AQI range than Flint, Bay City or Lansing.

Figure 21: The number of days per AQI rating during the study period (November 2011) at the Owosso sites and other nearby cities.

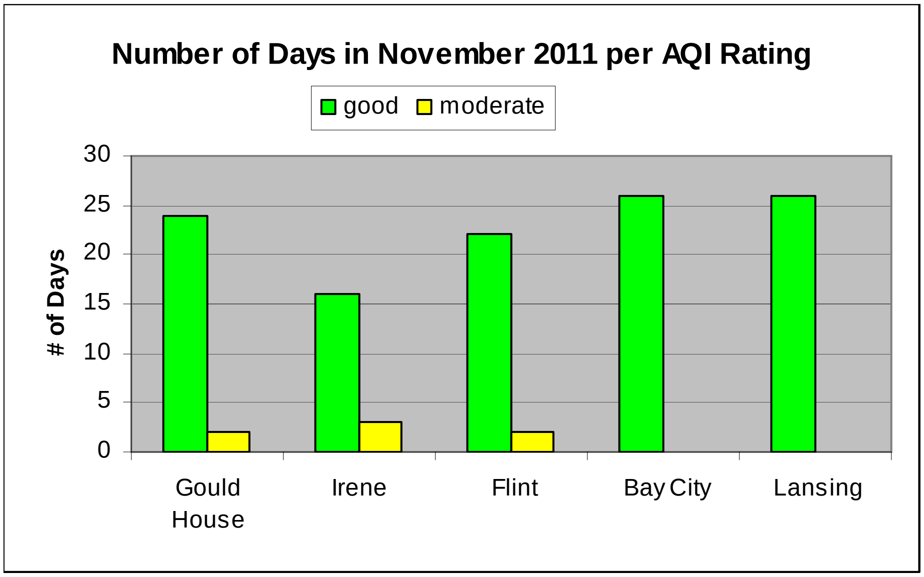


Table 4. Descriptive statistics for the ambient $PM_{2.5}$ ($\mu g/m^3$) concentrations from four Michigan cities.

	Mean	SD	Median	75th	90th	98th	Max
	$\mu g/m^3$	*$\mu g/m^3$*	*$\mu g/m^3$*	*$\mu g/m^3$*	*$\mu g/m^3$*	*$\mu g/m^3$*	*$\mu g/m^3$*
1-hour Averages							
Bay City	9	4.7	8	12	15	21	32
Lansing	8	4.1	8	11	13	19	27
Flint	9	5.7	8	12	16	23.2	37
Owosso Gould	8	7.4	5.7	10	17	31	54
Owosso Irene	8	8	5	10	18	35	55
24-hour Averages							
Bay City	9	3.1	8.5	10	14	15	15
Lansing	8	2.9	8	9.8	13	14.4	15
Flint	9	3.4	8.5	11.3	14.3	16.9	18
Owosso Gould	8	5.6	6.1	10	14.8	24	25
Owosso Irene	9	6.8	6.6	10.5	16.8	27.3	30

Conclusion

Ambient air monitoring of $PM_{2.5}$ was conducted in November, 2011 at two locations as a limited investigation of the impact of domestic wood, leaf, and trash burning in the Owosso community. The monitors were intentionally not placed to capture in-plume impacts. The high frequency of November rainfall and the influence of regionally transported $PM_{2.5}$ made it difficult to draw conclusions about the overall impact that the burning of waste, wood or leaves has upon air quality. While there were periods lasting up to an hour where $PM_{2.5}$ concentrations spiked at 60 $\mu g/m^{3,}$, it was not possible under this study design to identify the origin of the $PM_{2.5.}$ However, since these spikes typically occurred at only one of the two monitoring sites, it appears that the source or sources are local in nature and not city-wide, thus possibly implicating combustion sources. The measured $PM_{2.5}$ levels did not pose a significant public health hazard. However, the data did suggest that local sources do have an impact upon air quality, producing short-term peak levels and resulting in longer term $PM_{2.5}$ levels similar to those more commonly found in larger cities. Peak $PM_{2.5}$ levels closer to local combustion sources than the monitoring sites could not be estimated, but would be expected to be higher than those measured.

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Appendix 1: MDCH Brochure on Outdoor Smoke - See next two pages

Burning Issues

Burn barrels, leaf piles and most outdoor wood boilers are low to the ground. This means the smoke they make also stays low to the ground and in our breathing zone.

A chimney on your home is constructed so that the smoke goes higher into the air and reduces the amount of smoke you and your neighbors breathe.

What's blowing in the wind?

Burning paper releases toxic chemicals, including dioxin, that have been linked to cancer.

Burning treated and/or painted wood releases toxic chemicals and metals, such as arsenic.

Burning plastic releases toxic chemicals and heavy metals, such as mercury and lead.

What can you do?

Instead of burning your trash and leaves, **Reduce, Reuse, Recycle.**

- Buy in bulk.
- Start composting.
- Find a free drop-off recycling center near you.
- Learn more: www.michigan.gov/dnrerecycling

Outdoor Wood Boilers

- Purchase an EPA-qualified model - they burn 90% cleaner than non-qualified models.
- Be sure to follow local ordinances when installing your boiler.
- Follow the manufacturer's operating instructions and always burn dry, seasoned wood.

- Learn more: www.epa.gov/burnwise

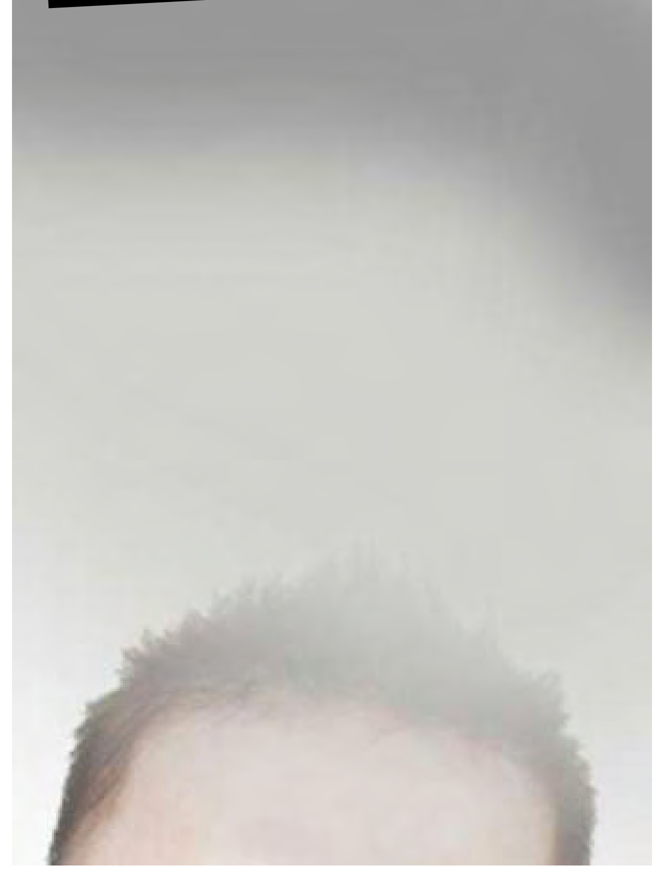
For More Information...

Health risks of breathing smoke:
MDCH Division of Environmental Health
1-800-648-6942
www.michigan.gov/mdch-toxic

Rules and regulations:
Department of Environmental Quality
1-800-662-9278
www.michigan.gov/openburning

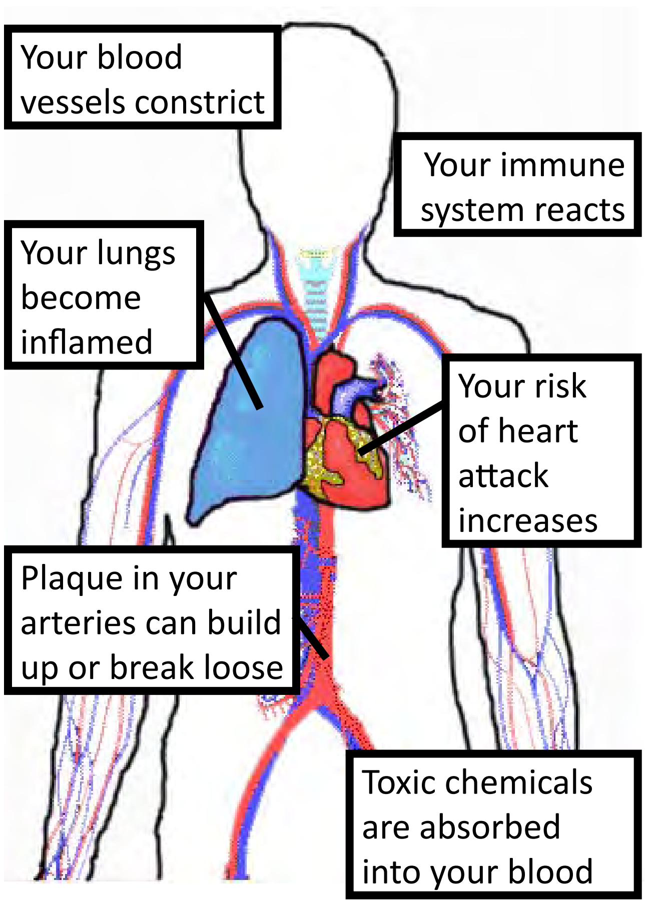
UP IN SMOKE

It's time to clear the air between neighbors about the dangers of smoke.



Smoke from a burning leaf pile, burn barrel or outdoor wood boiler is not just a nuisance, it's also bad for your health.

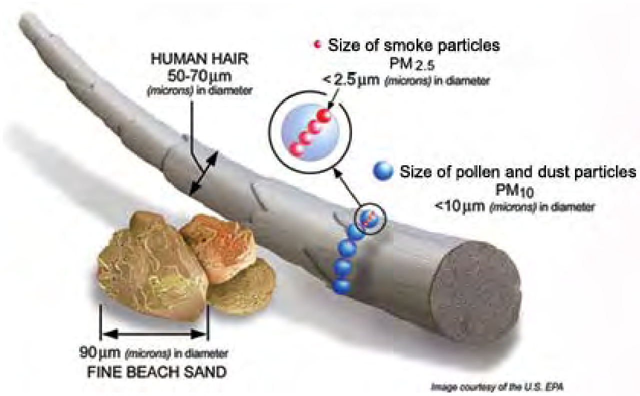
When exposed to smoke...



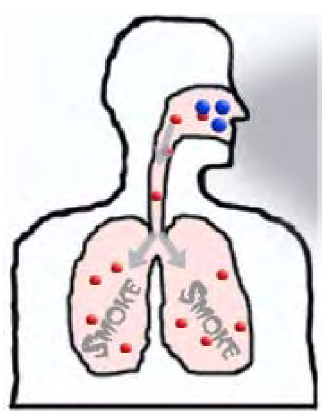
What is Smoke?

Even if you're not standing directly in the smoke from a fire, you can be at risk.

Smoke is made up of a lot of very tiny particles and gases. Smoke particles are so small they can be breathed deep into the lungs and quickly absorbed into the blood.



Unlike pollen and other larger particles that are stopped by our bodies before they go too deep into the lungs, smoke particles are small enough to slip through our bodies' defense systems.



This makes smoke very dangerous to those who have serious health problems, like asthma and emphysema, or are at risk of a heart attack.

Who is at greatest risk from smoke?

- ☑ People with breathing problems, including asthma, emphysema, bronchitis, pneumonia or allergies
- ☑ People with arteriosclerosis (plaque build-up in arteries)
- ☑ Older adults
- ☑ Pregnant or nursing women

Being exposed over and over to the chemicals found in smoke can also cause developmental problems in children and increase the chances of getting cancer.

Even healthy children and adults are affected by small particles and chemicals in smoke.

Smoke makes it hard for everyone to breathe.

Appendix 2: Potential Health Effects Associated with Short-term Exposure to Fine Particulate Matter from Wood Smoke

I. Overview

Fine particulate matter is also referred to as $PM_{2.5}$, meaning, particles that are 2.5 microns or less in diameter. PM_{10} are "coarse particles" less than 10 microns in diameter. Thus, $PM_{2.5}$ is a subset of particles within PM_{10}.

This appendix summarizes some of the more relevant information characterizing the short-term human health hazards and the dose-response information for fine particulate matter ($PM_{2.5}$) from wood smoke. For the purposes of this discussion, "short-term" is regarded as 24 hours or less. This information is compiled here to help interpret the public health significance of short-term measured $PM_{2.5}$ levels associated with outdoor smoke from the residential burning of wood and leaves ("wood smoke"). These activities typically result in transient, peak wood smoke levels in the nearby ambient air where neighbors may be exposed. These intermittent, peak exposures may persist for minutes or hours, and they may be recurring. Such emissions have, at times, resulted in public complaints focused on aesthetics, health symptoms, or health concerns. This appendix is intended to be a useful resource for local and state public health officials, as well as concerned citizens, to help interpret the potential public health significance of wood smoke $PM_{2.5}$ levels.

Wood smoke is a mixture of thousands of chemicals in the form of gases and small particles. The wood smoke particles are typically between 0.1 and 0.3 microns (µm) in diameter, and rarely exceed 1 µm in diameter. The chemical composition of the smoke will depend on intensity of the fire, the type of material being burned (wood, leaves, trash), the moisture of the material, and other factors. Smoldering fires emit smoke that is primarily a mixture of organic chemicals that range between 0.05 and 0.6 µm (Bolling et al. 2009). Many of the chemicals in wood smoke have well-documented adverse human health effects, including such commonly regulated pollutants as fine particles, carbon monoxide, and nitrogen oxides, respiratory irritants, and polycyclic aromatic hydrocarbons (PAHs) (CARB, 2008).

Among the currently regulated pollutants in wood smoke, fine particles ($PM_{2.5}$) serve as the best exposure metric in most circumstances and, in addition, tend to be among the most elevated in relation to existing air quality standards (Naeher et al. 2007). Air quality investigations related to wood smoke commonly focus on $PM_{2.5}$ measurements as it is more representative of the particle sizes released during the burning process. Further, $PM_{2.5}$ measurements are associated with significant public health hazards, and $PM_{2.5}$ has a National Ambient Air Quality Standard (NAAQS). Although it is recognized that $PM_{2.5}$ is a complex mixture of components that may be expected to vary, the EPA (2006) concluded that it was appropriate to evaluate and regulate fine particles as a group. This was based largely on epidemiologic evidence of health effects using various indicators of fine particles in a large number of areas that had significant contributions of differing components or sources of fine particles. While most epidemiologic studies continue to be indexed by $PM_{2.5}$, some epidemiologic studies also have continued to implicate various components within the mix of fine particles that have been more commonly studied (e.g., sulfates, nitrates, carbon, organic compounds, and metals) as being associated with adverse effects. The available information continues to suggest that many different chemical components of fine particles and a variety of different types of source categories are all associated with, and probably contribute to, effects associated with $PM_{2.5}$. There is some evidence that the chemical composition of $PM_{2.5}$ may influence the particle-elicited health effects of exposure (Bolling et al., 2009). However, at this time there is insufficient evidence to link the health effects of $PM_{2.5}$ to any particular PM constituents or sources (EPA, 2009). Consequently, the current evidence continues to support the view that fine particles should be addressed as a group for purposes of public health protection (EPA, 2006).

The focus of this Appendix is on the potential health effects of relatively short-term or “peak” exposures that can occur intermittently with various scenarios involving burning wood or leaves (vegetation). The evidence indicates that short-term $PM_{2.5}$ exposure is associated with cardiovascular effects, respiratory effects, and mortality (EPA, 2009). People with heart or lung disease, the elderly, and children are at highest risk from exposure to $PM_{2.5}$ (MDEQ, 2011). Of course, the occurrence of adverse effects from $PM_{2.5}$ exposure depends on the concentration and duration of the exposure and the sensitivity of individuals.

Although EPA (2006, 2009) has not found a “threshold” concentration of $PM_{2.5}$ below which no effects occur, there are useful “benchmarks” of exposure levels that are associated with various levels of effects. The EPA’s Clean Air Scientific Advisory Committee (CASAC) recommended that EPA estimate the public health impacts of $PM_{2.5}$ by assuming that a threshold may exist at 10 $\mu g/m^3$ (EPA, 2006). A review of the Michigan $PM_{2.5}$ ambient air monitoring data indicates that the “background” annual average level at various areas monitored in the state is the range of approximately 6-13 $\mu g/m^3$, while the 98th percentile 24-hour levels are in the range of approximately 17 to 36 $\mu g/m^3$ (MDEQ, 2011). This is particularly relevant to the interpretation of the significance of elevated short-term $PM_{2.5}$ levels, as many epidemiologic studies characterize the magnitude of excess risk estimates associated with 10 ug/m^3 increases in $PM_{2.5}$ (EPA, 2009; see Table A.3 below).

There is a fair amount of information on the potential health effects of $PM_{2.5}$, particularly for urban air and for time periods of 24 hours or longer. There is relatively less information available on health effects from exposure to very short-term (i.e., less than 24 hours) peak concentrations, and there is relatively less information that is specific to $PM_{2.5}$ from wood smoke. In contrast to the large amount of information relating urban PM to human health impacts, there are relatively few studies directly evaluating the community health impacts of air pollution resulting from the burning of biomass (Naeher et al., 2007). Literature reviews have identified studies that associate wood smoke exposure with elevated risk of cardiovascular and respiratory illnesses such as bronchitis, bronchiolitis, and pneumonia (EPA, 2009; Naeher et al. 2007; Bolling et al., 2009; Delfino et al., 2009). Wood smoke appears to be at least as dangerous for causing respiratory diseases as other major categories of combustion-derived particles in the same size range (Naeher et al. 2007).

When $PM_{2.5}$ monitoring data are not available, simple observations of +/- visible smoke can help to generally characterize what the levels may be. As shown in Tables A.4 and A.5, western states have associated different degrees of visibility impacts with approximate $PM_{2.5}$ levels, under relatively arid conditions when large areas are influenced by wildfires. The USFS (2012; personal communication) has advised that visible levels of $PM_{2.5}$ indicate that the level is at least 35 ug/m^3. LADCO (2011; personal communication) has suggested that the burning of a single cigarette (10,000 ug of $PM_{2.5}$ emissions) can create an indoor smoke haze that many people are familiar with; that level may be approximately 200 to 300 ug/m3 (e.g., a 12’ by 12’ room with 9’ ceilings would be about 48 m^3, resulting in a concentration of 208 ug/m^3).

The following three sections summarize the relevant information on: the EPA National Ambient Air Quality Standard and Air Quality Index (AQI) for $PM_{2.5}$ (24-hour), health hazards and dose-response information for short-term exposures to $PM_{2.5,}$ and public safety information related to forest fire smoke exposure in western states of the U.S.

II. EPA National Ambient Air Quality Standard and Air Quality Index (AQI) for $PM_{2.5}$ (24-hour)

Under the Clean Air Act, the EPA has established “primary” National Ambient Air Quality Standards (NAAQS) that are requisite to protect the public health, with an adequate margin of safety. A primary standard is set at, “the maximum permissible ambient air level…which will protect the health of any [sensitive] group of the population,” and that for this purpose “reference should be made to a representative sample of persons comprising the sensitive group rather than to a single person in such a group” (EPA, 2009). The NAAQS have various averaging times to address health impacts. Short averaging times reflect the potential for acute (immediate) effects, whereas long-term averaging times are designed to protect against chronic effects. The current primary NAAQS for fine particulate matter ($PM_{2.5}$) are presented in Table A-1 below.

Table A-1. Primary (Health-Related) NAAQS for $PM_{2.5}$ (MDEQ, 2011)

Pollutant	Level	Averaging Time	Criteria for Compliance
$PM_{2.5}$	15.0 ug/m^3	Annual arithmetic mean	The $PM_{2.5}$ annual standard is met when the annual arithmetic mean concentration is less than or equal to 15 ug/m^3. The 24-hour standard is met when the 98th percentile 24-hour concentration in a year, averaged over 3 years, is less than or equal to 35 ug/m^3.
	35 ug/m^3	98th percentile 24-hour average over 3 years	

The Air Quality Index (AQI) is EPA’s color-coded tool for communicating air quality to the public (http://www.deqmiair.org/). AQI values range from 0 to 500. The higher the AQI value, the greater the level of air pollution and the greater the health concern. States use the AQI to issue voluntary daily air quality forecasts and to evaluate air quality status and trends, as a public service to their residents.

Table A.2. The EPA's Air Quality Index (AQI)

AQI Color and Category	$PM_{2.5}$ 24-hour (ug/m3)	Cautionary Statements	Health Effects Statement
GREEN Good	0.0 – 15.4	None	None
YELLOW Moderate	15.5 – 35.4	Unusually sensitive people should consider reducing prolonged or heavy exertion.	Respiratory symptoms possible in unusually sensitive individuals, possible aggravation of heart and lung disease in people with cardiopulmonary disease and older adults.
ORANGE Unhealthy for Sensitive Groups	35.5 – 65.4	People with heart or lung disease, older adults, and children should reduce prolonged or heavy exertion.	Increasing likelihood of respiratory symptoms in sensitive individuals, aggravation of heart or lung disease and premature mortality in people with cardiovascular disease and older adults.
RED Unhealthy	65.5 – 150.4	People with heart or lung disease, older adults, and children should avoid prolonged or heavy exertion. Everyone else should limit prolonged exertion.	Increase aggravation of heart or lung disease and premature mortality in people with cardiopulmonary disease and older adults; increased respiratory effects in general population.
PURPLE Very Unhealthy	150.5 – 250.4	People with heart or lung disease, older adults, and children should avoid all physical activity outdoors. Everyone else should avoid prolonged or heavy exertion.	Significant aggravation of heart or lung disease and premature mortality in people with cardiopulmonary disease and older adults; significant increased respiratory effects in general population.
MAROON Hazardous	250.5 – 500.4	Everyone else should avoid any outdoor exertion; people with heart or lung disease, older adults, and children should remain indoors.	Serious aggravation of heart or lung disease and premature mortality in people with cardiopulmonary disease and older adults; serious risk of respiratory effects in general population.

III. Health Hazards and Dose-response Information for Short-term Exposures to $PM_{2.5}$

Table A.3. Summary of studies of human exposures to $PM_{2.5}$ and correlated health effects.

Reported Study Findings	$PM_{2.5}$ Concentration Summary	Citation
1.28% (95% CI: 0.78-1.78%) increase in number of hospital admissions for heart failure per increase of 10 µg/m^3 of ambient $PM_{2.5}$ on the same day.	mean (24-hr): 13.4 µg/m^3	Dominici et al. 2006
0.91% (95% CI: 0.18-1.64%) increase in number of hospital admissions for COPD per increase of 10 µg/m^3 of ambient $PM_{2.5}$ on the same day.	mean (24-hr): 13.4 µg/m^3	Dominici et al. 2006
0.81% (95% CI: 0.30-1.32%) increase in number of hospital admissions for cerebrovascular disease per increase of 10 µg/m^3 of ambient $PM_{2.5}$ on the same day.	mean (24-hr): 13.4 µg/m^3	Dominici et al. 2006
0.44% (95% CI: 0.02-0.86%) increase in number of hospital admissions for ischemic heart disease per increase of 10 µg/m^3 of ambient $PM_{2.5}$ two days prior.	mean (24-hr): 13.4 µg/m^3	Dominici et al. 2006
0.92% (95% CI: 0.41-1.43%) increase in number of hospital admissions for respiratory tract infection per increase of 10 µg/m^3 of ambient $PM_{2.5}$ two days prior.	mean (24-hr): 13.4 µg/m^3	Dominici et al. 2006
Abnormal electrocardiograms (ECG) correlates with increased ambient $PM_{2.5}$ 24 hours prior to examination of patient.	range (24-hr): 2.3–45.1 µg/m^3	Gold et al. 2000
Decrease in vascular reactivity (i.e., abnormal function of change in blood vessel diameter which may result in greater risk of heart attack or stroke) with increased ambient $PM_{2.5}$ based on 6 day moving averages.	mean (24-hr): 11.5 µg/m^3 standard deviation: ± 6.4 µg/m^3 range: 1.1 – 40 µg/m^3	O'Neil et al. 2005
Odds Ratio (OR) of 1.48 (95% CI: 1.09-2.02) for onset of myocardial infarction per increase of 25 µg/m^3 $PM_{2.5}$ two hours prior.	mean (1-hr): 12.1 µg/m^3 standard deviation: ± 8.9 µg/m^3 5th & 95th: 4.6 & 24.3 µg/m^3	Peters et al. 2001
Odds Ratio (OR) of 1.62 (95% CI: 1.13-2.34) for onset of myocardial infarction per increase of 25 µg/m^3 $PM_{2.5}$ 24 hours prior.	mean (24-hr): 12.1 µg/m^3 standard deviation: ± 6.8 µg/m^3 5th & 95th: 4.6 & 24.3 µg/m^3	Peters et al. 2001
Increased exhaled nitric oxide, which is used as an indication of respiratory inflammation, with 1 hour prior increase in $PM_{2.5}$.	mean (1-hr): 19.5 µg/m^3 maximum: 106 µg/m^3 25th & 75th percentiles: 7.6 & 25.5 µg/m^3	Adamkiewicz et al. 2004
Increased exhaled nitric oxide, which is used as an indication of respiratory inflammation, with 24 hour prior increase in $PM_{2.5}$.	mean (24-hr): 19.7 µg/m^3 25th & 75th percentiles: 9.7 & 27.4 µg/m^3	Adamkiewicz et al. 2004

Increased exhaled nitric oxide by children with persistent asthma correlated with 2-day prior average increase in $PM_{2.5}$ exposure.	mean (24-hr): 32.8 $\mu g/m^3$, 36.2 $\mu g/m^3$ standard deviation: 21.8 $\mu g/m^3$, 25.5 $\mu g/m^3$ range: 7.2 – 197 $\mu g/m^3$	Delfino et al. 2006
Increased exhaled nitric oxide by children with asthma marginally associated with recent increase in $PM_{2.5}$ exposure.	mean (24-hr): 6.4 $\mu g/m^3$ range: 1.3 – 22.6 $\mu g/m^3$	Koenig et al. 2005
Decreased forced expiratory volume in 1 second (FEV_1) in children (9-18 years) with asthma associated with 1-hour maximum $PM_{2.5}$ and 8-hour maximum $PM_{2.5}$ concentrations over 24-hour periods.	mean (24-hr): 31.2 $\mu g/m^3$ standard deviation: 21.8 $\mu g/m^3$ 1-hour maximum: 90.1 standard deviation: 79.8 $\mu g/m^3$ 8-hour maximum: 46.2 standard deviation: 33.4 $\mu g/m^3$	Delfino et al. 2008
Based on $PM_{2.5}$ concentrations from 1999-2000, long-term exposures to $PM_{2.5}$ associated with increased relative risk (RR) for mortality. For every 10 $\mu g/m^3$ increase in $PM_{2.5,}$ RR for all-cause mortality was 1.06 (1.02-1.10), cardiopulmonary mortality was 1.08 (1.02-1.14), and lung cancer was 1.13 (1.04 – 1.22).	mean (1999-2000): 14.0 $\mu g/m^3$ standard deviation: 3.0 $\mu g/m^3$	Pope et al. 2002
Increased risk of acute ischemic heart disease events was associated with same day increases in ambient $PM_{2.5}$ concentrations.	means (24-hour measures collected from 1993-2004): 10.8, 11.3, 10.1 $\mu g/m^3$ standard deviation: 10.6, 11.9, 9.8 $\mu g/m^3$ maximum: 108, 94, 82 $\mu g/m^3$	Pope et al. 2006
Long-term exposure to elevated $PM_{2.5}$ was correlated with reduced lung development of children (10-18 years) measured as change in forced expiratory volume in 1 second (FEV_1) over time.	range of means (8-year) for 12 different locations: 5 - 30 $\mu g/m^3$	Gauderman et al. 2004.
In three California counties, daily respiratory mortality significantly increased by 2.1-7.6% per 10 $\mu g/m^3$ increase in $PM_{2.5}$ on the same day or previous day.	mean (24-hr), minimum-maximum: Contra Costa Co.: 14 $\mu g/m^3$, 1-77 $\mu g/m^3$ Los Angeles Co.: 21 $\mu g/m^3$, 4-85 $\mu g/m^3$ Orange Co.: 21 $\mu g/m^3$, 4-114 $\mu g/m^3$	Ostro et al. 2006
In U.S. population over 65 years old, long-term exposure to a 10 $\mu g/m^3$ increase in $PM_{2.5}$ is associated with a 6.8% (95%CI: 4.9-8.7%) increase in mortality in the eastern US and a 13.2% (95%CI: 4.9-8.7%) increase in mortality in the central US.	Median (25th -75th percentiles): central US: 10.7 $\mu g/m^3$ (9.8-12.2 $\mu g/m^3$) eastern US: 14.0 $\mu g/m^3$ (12.3-15.3 $\mu g/m^3$)	Zeger et al. 2008

In addition to the studies summarized in Table A.3, it may be noted that Brown et al. (2007) reviewed the literature on health effects of $PM_{2.5}$ exposure as it pertains to emissions from outdoor wood boilers. They concluded that increases in $PM_{2.5}$ exposure (at levels of 12 to 30 ug/m^3) for 2 to 4 hours can induce cardiopulmonary effects in humans. They estimated that 6-hour average $PM_{2.5}$ levels associated with “at risk,” “moderate risk” and “high risk” for respiratory or cardiac effects were 19, 25, and 53 ug/m^3, respectively. These estimates and characterizations appear to be more restrictive than the NAAQS and AQI breakpoints presented above.

IV. Public safety information related to forest fire smoke exposure in western states of the U.S.

The CARB (2008) report, "Wildfire Smoke: A Guide for Public Health Officials," was developed by representatives from several public health and environmental agencies to provide emergency response guidance to local public health officials to communicate wildfire smoke health risks and precautions to the public. This guide is particularly useful for the assessment of wood smoke (from wood or leaf-burning) because it is focused on $PM_{2.5}$ from vegetation fires, and because it offers specific guidance regarding short-term exposures. The guide also notes that, in the absence of PM monitoring data, visibility impairment can be another way to estimate particle levels (Table A.4). However, the visibility categories that they provide only apply in dry air conditions; for a given PM level, visibility decreases substantially at relative humidity above 65%, therefore, this method should not be used under conditions of high humidity (CARB, 2008). Also, visibility impairment may be useful when wood smoke is having an effect over a large geographic scale, such as during wildfires, and may not be useful for relatively localized vegetation burning situations.

Although CARB (2008; Table A.4) provides health benchmarks for short-term (1- to 3-hour and 8-hour) $PM_{2.5}$ exposures, they caution that: "There are no directly relevant epidemiological or controlled human exposure studies that offer guidance in the selection of particulate matter levels with averaging times less than 24 hours, in part because studies of short-term effects of particles generally have not been conducted and in part because the toxicity of smoke is related to gaseous as well as particulate components. However, these short-term levels (1- to 3-hr and 8-hr averages) were derived from the $PM_{2.5}$ AQI levels, which are based on a strong body of epidemiological evidence associating 24-hour $PM_{2.5}$ exposures with respiratory and cardiovascular morbidity and mortality."

Montana (2012) has also developed a set of visibility and health hazard guidance, including short-term exposures (Table A.5). Compared to the CARB (2008) guidance (Table A.4), the Montana breakpoints are significantly more conservative (i.e., lower).

The utility of these CARB and Montana values for interpreting short-term wood smoke $PM_{2.5}$ data is supported by the fact that they were developed by reputable environmental and public health agencies, and that they are based on wood smoke (rather than general urban $PM_{2.5}$) and short-term impacts down to 1 hour. One limitation of their use is that the benchmarks for ≤ 8 hours are not clearly tied to key studies and they are partially based on default modeling conversion factors. A second limitation is that these $PM_{2.5}$ values are used to recommend actions that the public should take to protect themselves during an emergency response scenario caused by wildfires, which are not an everyday or frequently repeated event. In contrast, leaf burning, multiple campfires in campgrounds or outdoor wood boiler scenarios can be recurring smoke sources. The recommended actions for wildfire events may best be applied to infrequent burning events, such as the burning of leaves once or twice per year.

Table A.4. Wildfire Smoke Recommended Actions for Public Health Officials (CARB, 2008) [1]

AQI Category	$PM_{2.5}$ or PM_{10} levels (ug/m^3, 1- to 3-hr avg.)	$PM_{2.5}$ or PM_{10} levels (ug/m^3, 8-hr avg.)	$PM_{2.5}$ or PM_{10} levels (ug/m^3, 24-hr avg.)	Visibility – Arid Conditions (miles) [2]	Recommended Actions
Good	0 – 38	0 – 22	0 – 15	≥ 11	If smoke event forecast, implement communication plan
Moderate	39-88	23-50	16-35	6-10	Issue public service announcements advising public about health effects and symptoms and ways to reduce exposure. Distribute information about exposure avoidance.
Unhealthy for sensitive groups	89-138	51-79	36-65	3-5	If smoke event projected to be prolonged, evaluate and notify possible sites for cleaner air shelters. If smoke event projected to be prolonged, prepare evacuation plans.
Unhealthy	139-351	80-200	66-150	1.5-2.75	Consider "smoke day" for schools (i.e., no school that day), possibly based on school environment and travel considerations. Consider canceling public events, based on public health and travel considerations.
Very unhealthy	352-526	201-300	151-250	1-1.25	Consider closing some or all schools (however, newer schools with a central air cleaning filter may be more protective than older, leakier homes. See "closures", below). Cancel outdoor events (e.g., concerts and competitive sports).
Hazardous	> 526	> 300	> 250	< 1	Close schools. Cancel outdoor events (e.g., concerts and competitive sports). Consider closing workplaces not essential to public health. If PM level projected to continue to remain high for a prolonged time, consider evacuation of sensitive populations.

[1] These 1- and 8-hour $PM_{2.5}$ levels are estimated using the 24-hour breakpoints of the $PM_{2.5}$ Air Quality Index by dividing the 24-hour concentrations by the following ratios: 8-hr ratio is 0.7; 1-hr ratio is 0.4.
[2] The visibility categories apply in dry air conditions; for a given PM level, visibility decreases substantially at relative humidity above 65%. Therefore, this method should not be used under conditions of high humidity (CARB, 2008).

Table A.5. Montana Wildfire Smoke Guidance for $PM_{2.5}$ Measurements (Using a BAM Instrument).

Breakpoints and Associated Visibility for Particulate Concentrations

Health Effect Categories	Visibility (miles)[3]	24-Hour BAM (ug/m^3)[1]	8-Hour BAM (ug/m^3)[2]	1-Hour BAM (ug/m^3)[3]
Hazardous	< 1.3	>135.4	> 193.4	> 338.5
Very Unhealthy	2.1 - 1.3	80.5 - 135.4	115.0 - 193.4	201.1 - 338.5
Unhealthy	5.0 - 2.2	35.5 - 80.4	50.7 - 114.9	88.6 - 201.0
Unhealthy for Sensitive Groups	8.7 - 5.1	20.5 - 35.4	29.2- 50.6	51.1 - 88.5
Moderate	13.3 - 8.8	13.5 - 20.4	19.2 - 29.1	33.6 - 51.0
Good	> 13.4 +	0.0 - 13.4	0.0 - 19.1	0.0 - 33.5

1. Washington State Department of Ecology, Washington Air Quality Advisory (2007), at https://fortress.wa.gov/ecy/enviwa.
2. Applied U.S. EPA SCREEN adjustment factor for 8-hour, 0.7, multiplied to the 24-hour PM-2.5 Pollutant Standards Index.
3. John Coefield, Cyra Cain, Montana Department of Environmental Quality empirical study (July 2000) presented at Fire, Smoke and Health Workshop, Seattle, WA, June 5 - 6, 2001.

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