Health Consultation

OUTDOOR WOOD BOILER INVESTIGATION

PLEASANT LAKE, JACKSON COUNTY, MICHIGAN

Prepared by the
Michigan Department of Community Health

OCTOBER 13, 2009

Prepared under a Cooperative Agreement with the
U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Agency for Toxic Substances and Disease Registry
Division of Health Assessment and Consultation
Atlanta, Georgia 30333

Health Consultation: A Note of Explanation

A health consultation is a verbal or written response from ATSDR or ATSDR’s Cooperative Agreement Partners to a specific request for information about health risks related to a specific site, a chemical release, or the presence of hazardous material. In order to prevent or mitigate exposures, a consultation may lead to specific actions, such as restricting use of or replacing water supplies; intensifying environmental sampling; restricting site access; or removing the contaminated material.

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Acronyms and Abbreviations

ASTM	American Society for Testing and Materials
ATSDR	Agency for Toxic Substances and Disease Registry
CAPEB	Cooperative Agreement Program Evaluation Branch
DEQ	Michigan Department of Environmental Quality
DHAC	Division of Health Assessment and Consultation
EPA	Environmental Protection Agency
FEF	forced expiratory flow
$FEF_{25\%-75\%}$	forced expiratory flow during middle 50% of FVC test
FEV_1	forced expiratory volume in one second
$FEV_{1\%}$	percentage of FVC expired in one second (ratio FEV_1 : FVC)
FRM	federal reference method
FVC	forced vital capacity
m^3	meters cubed
MDCH	Michigan Department of Community Health
MIOSHA	Michigan Occupational Safety and Health Administration
NESCAUM	Northeast States for Coordinated Air Use Management
OWB	outdoor wood boiler
PEF	peak expiratory flow
PM	particulate matter
PM_{10}	particulate matter with a 10 µm diameter or smaller
$PM_{2.5}$	particulate matter with a 2.5 µm diameter or smaller
SD	standard deviation of a sample
US	United States
µg	micrograms
µm	micrometers

Summary

INTRODUCTION

At the request of the Jackson County Health Department, Michigan Department of Community Health (MDCH) in collaboration with Michigan Department of Environmental Quality (DEQ) conducted an environmental public health investigation regarding excessive smoke and odors being generated by an outdoor wood boiler (OWB) within a residential development. MDCH was concerned about vulnerable population such as children, people with impaired breathing conditions like asthma, and people with heart disease.

CONCLUSIONS

Conclusion 1

MDCH concludes that inhaling elevated concentrations $PM_{2.5}$ found in wood smoke on a short-term or long-term basis in a residential neighborhood can harm people's health. MDCH concludes that the continued operation of the specific OWB in question is an *urgent public health hazard* based on the findings described in this health consultation.

Basis for conclusion

MDCH's determination is based on the combined information gathered from site investigations, peer-reviewed literature, publicly available documents, and personal health information provided by the complainant. During the investigation, the OWB in question was found to emit substantial amounts of smoke during operation that contained a known hazardous substance ($PM_{2.5}$) at levels that may harm people's health, especially sensitive individuals. The investigation confirmed the complainant's descriptions and video documentation.

Next Steps

MDCH will continue to work with the local health department and through the public health code to address this hazard.

Conclusion 2

MDCH further finds that the operation of other significant smoke emitting sources that contributes to ground level smoke and associated hazardous substances to the ambient air are a *public health hazard* to vulnerable populations.

Basis for conclusion

MDCH's determination is based on observations of other significant smoke emitting sources and finding from the OWB site investigation.

Next Steps

MDCH will continue to work with the local health department and through the public health code to address this hazard.

FOR MORE INFORMATION

If you have concerns about your health, you should contact your health care provider. Please call MDCH Division of Environmental Health at 1-800-648-6942 regarding this health consultation.

Public Health Issues and Purpose

Public Health Concern: Hydronic heaters, also known as outdoor wood boilers (OWBs), have been demonstrated to produce elevated amounts of fine particulate matter (e.g. $PM_{2.5}$). $PM_{2.5}$ refers to particles smaller than 2.5 micrometers in diameter (Figure A-1) that penetrate deeply into human lungs with the smallest size fractions entering the blood stream. Short-term exposures of vulnerable populations to elevated $PM_{2.5}$ concentrations have been reported in published literature to result in negative health effects including premature death.

Purpose: Evaluation of public health implications of smoke and odors generated from the use of an OWB in a residential development.

Background

On November 5, 2006, DEQ received its first complaint from the neighbor experiencing the smoke and odors. On November 6, 2006, a DEQ Air Quality Division engineer conducted an on-site inspection and observed the OWB. The DEQ Engineer concluded that the OWB was placed in a location that did not allow proper dispersion of smoke and odors. The placement of the OWB results in smoke and odors dispersing at ground level with wind movement. The complainant's (i.e., neighbor) property and home begins approximately 180 and 220 feet directly to the east and downwind of the OWB (Figure A-2).

Over the subsequent couple years, the complainant requested action from local township officials including local public health citing Act 368, part 333.2433 of the Michigan public health code. The complainant repeatedly presented concerns to the DEQ including citing the following regulation as the DEQ's authority for action:

R 336.1901 Air contaminant or water vapor, when prohibited

Rule 901. Not withstanding the provisions of any other department rule, a person shall not cause or permit the emission of an air contaminant or water vapor in quantities that cause, alone or in reaction with other air contaminants, either of the following:
(a) Injurious effects to human health or safety, animal life, plant life of significant economic value, or property.
(b) Unreasonable interference with the comfortable enjoyment of life and property.

The DEQ (letter: January 20, 2007 from the Air Quality Division Chief) and local county health department (letter: October 19, 2007 RE: Legal opinion regarding outdoor wood boiler (OWB) complaint) responded to the complainant in writing regarding their decision about the complainant's request. The DEQ Air Quality Division stated in its response letter to the complainant:

> Excerpts from paragraph 2: "First we have no doubt that your neighbor's OWB is having a negative impact on your home and family." "We agree that something needs to be done to abate the air pollution that OWBs are causing in many states, including Michigan. We also agree that the Department of Environmental Quality's (DEQ's) "OWB and Air Quality Fact Sheet" discourages the installation and use of OWBs and provides several recommendations that would mitigate some the adverse impacts of OWBs if the recommendations were followed. Finally we agree that Rule 901 prohibits the emission of smoke and odors that cause an unreasonable interference with the comfortable enjoyment of life and property."
>
> Paragraph 3: "However, we respectively disagree that Rule 901 is the appropriate regulatory mechanism to regulate the tens of thousand of residential OWBs that have been installed in Michigan over the past few years. We believe that the best way to regulate OWBs in for the United Stated Environmental Protection Agency (EPA) to develop emission standards and a certification program for the manufacturers and distributors of OWBs similar to the program that EPA developed for indoor residential wood burners. We have joined many other states in encouraging the EPA to start developing such a program. Unfortunately, we have not been successful and it does not look like EPA will be developing any regulatory program for OWBs in the near future. Therefore, we have started to work on developing State of Michigan emission design standards and a certification program for the manufactures and distributors of new OWBs. We believe this is the most effective and expeditious way for Michigan to abate the air pollution from OWBs that you and thousands of other Michigan citizens are experiencing."
>
> Paragraph 5: "We urge you to continue to follow up with your local township government and pursue relief under your local nuisance ordinance, since there is nothing else that we can do in the immediate future to address the impact that your neighbor's OWB is causing. You may also want to consult an attorney to discuss any legal actions that may be available to you"

The local county health department letter to the complainant stated:

> "…county health department does not have the authority and duty to regulate OWB's under the public health code. Further, the local county health department's opinion states that "…in the absence of a local ordinance, the agency with such authority and duty is the Michigan Department of Environmental Quality (MDEQ)".

These documented communications are representative of the interactions between the complainant, state and local governments in an attempt to resolve the situation.

Other northeast states have public health concerns about the use of OWB's. The Northeast States for Coordinated Air Use Management (NESCAUM) has investigated air pollution concerns regarding OWBs. They estimate that 29,568 OWBs have been sold in Michigan from 1990-2005 and that annual sales are increasing each year (NESCAUM 2006). NESCAUM describes OWBs as located outside and able to continuously burn wood to heat water that is plumbed into a house that provides radiant heat and/or hot water (Figure A-3).

NESCAUM (2006) focuses on the most commonly sold OWBs that lack secondary combustion capability (i.e., first generation OWBs). First generation OWBs have design and operating features that result in excessive smoke, nuisance conditions, and $PM_{2.5}$ emissions. The OWB firebox is large and holds enough wood to provide heat for long periods (e.g., 24 hours) before needing to be refilled. Because the firebox has a large door, burning non-recommended fuels (i.e. green, wet, or non-split wood; yard waste; household refuse) can easily occur. During operation, first generation OWBs continuously burn wood. The wood burns under oxygen-deprived conditions (i.e., smoldering) until the building requires heat, at which time air is allowed into the firebox initiating an intense flame to heat the water. The OWB cycles from smoldering to intense fire conditions during operation. Smoldering conditions causes chemicals to be released as gases that cool and form PM that condenses on internal surfaces and is released to the air. During the intense fire conditions, the PM on internal surfaces can be released to the air. The heat from the fire is captured by the water, resulting in smoke that lacks heat (i.e., cold smoke). Cold smoke does not rise, but instead tends to fall back toward the ground. The combined effect of cold smoke and the typical short smoke stack height of the OWB is inadequate dispersion of smoke and associated fine PM. This results in ground level smoke and fine PM in the breathing zone.

States have begun to implement rules about OWB operation. For example, Maine established regulations (July 4, 2008, Chapter 150 Control of Emissions from Outdoor Wood Boilers) to set a minimum distance of separation between an OWB owner and neighbors to protect human health. The regulations also consider the effects of unique topography and meteorological conditions that could require a greater distance than the minimum. Maine states that an OWB without emission controls must be installed at least 250 feet from the nearest property lines or at least 270 feet from the nearest dwelling that is not on the same property as the outdoor wood boiler. In addition Maine states "No person shall operate any outdoor wood boiler…if an abutting residence is located less than 500 feet from the outdoor wood boiler, unless the outdoor wood boiler has an attached stack extending two feet higher than the peak of the roof of the structure being served by the outdoor wood boiler." Maine provides a fact sheet that further says "If terrain conditions could complicate air flow patterns on a parcel of land (e.g. in a valley, hilly or tall trees nearby), it may be necessary to install the OWB even farther away than the minimum setback distances to avoid costly changes that could be required later if a nuisance condition occurs when the boiler is operated."

The OWB (model: Woodmaster 4400) discussed in this health consultation does not have secondary emission controls and operates as described by NESCAUM (2006) with smoldering and intense flame cycles. As determined by DEQ, the placement of this particular OWB was approximately 180 feet from the complainant's property in a low-lying area of land, resulting in the top of the smoke stack being no higher than the middle of the surrounding houses (Figure A-4).

This health consultation evaluates the public health risks of the OWB.

Discussion

Environmental Contamination

DEQ and MDCH staff jointly conducted site visits to evaluate the smoke and odor complaints related to the operation of an OWB. The site visits consisted of three activities. The first activity was to observe and record qualitative descriptions of the smoke opacity and presence of odors on the complainant's property and surrounding area when the OWB was in operation. The DEQ Air Quality Division engineer made qualitative observations according to the DEQ smoke and odor investigation method (Modification of ASTM E544 Standard Practices for Referencing Suprathreshold Odor Intensity). During the smoke and odor observations, MDCH used a real-time optical aerosol monitor for $PM_{2.5}$ (TSI Side Pack model: AM510) to measure $PM_{2.5}$ concentrations. For the final activity, MDCH used a continuous data recording optical aerosol monitor (TSI Dust Track model: 8520, SN: 85200673) to track $PM_{2.5}$ air concentration patterns over 12.8 hours.

MDCH and DEQ confirmed the location and operation of the OWB (model: Woodmaster 4400). Additionally, MDCH and DEQ observed at least one open-burning source (burn barrel) in use during a site visit. Both sources were observed to emit white smoke that moved with the wind direction off the property of the OWB owner. MDCH and DEQ experienced odors downwind of the OWB while in operation (i.e., emission of white smoke). MDCH staff identified an increase in $PM_{2.5}$ ambient air concentration during the observed odor events around the complainant's home. MDHC observed that the increases in $PM_{2.5}$ ambient air concentrations corresponded with staff observed mild odors (Figure 1) (Appendix C).

Over 12.8 hours, MDCH identified a spiked pattern of $PM_{2.5}$ concentrations in the complainant's ambient air consistent with the operation of an OWB (Johnson 2006) (Figure 2). MDCH observed minimal variation in $PM_{2.5}$ ambient air concentrations at the referent location (Appendix D). The average $PM_{2.5}$ concentration over the 12.8 hours was 31 ± 13 µg/m^3 with a maximum 1-minute average of 151 µg/m^3 and a maximum 1-hour average of 40 µg/m^3. At a referent site located in a residential development without an OWB, MDCH determined an average $PM_{2.5}$ ambient air concentration was 1 ± 1 µg/m^3 with a maximum 1-minute average of 11 µg/m^3 and a maximum 1-hour average of 1 µg/m^3 (Appendix D). MDCH determined that ambient air concentrations were significantly higher at the complainant's property compared to the referent site.

MDCH concludes that the spiked pattern of $PM_{2.5}$ concentrations in the complainant's ambient air are caused by the operation of the OWB in question.

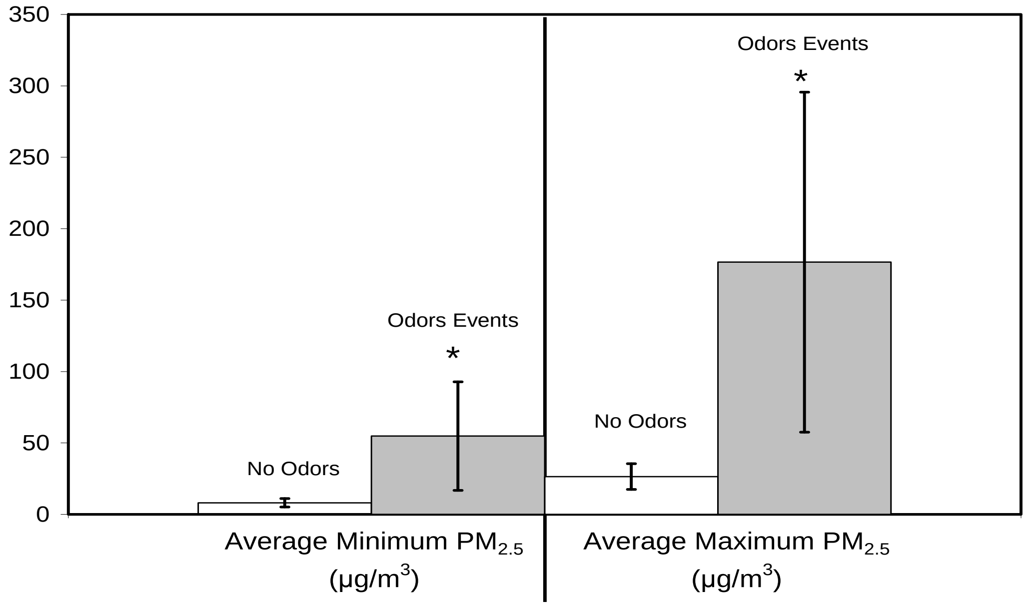

Figure 1. Bar graph comparing average minimum and maximum $PM_{2.5}$ concentrations during odor and non-odor events (details in Appendix C).

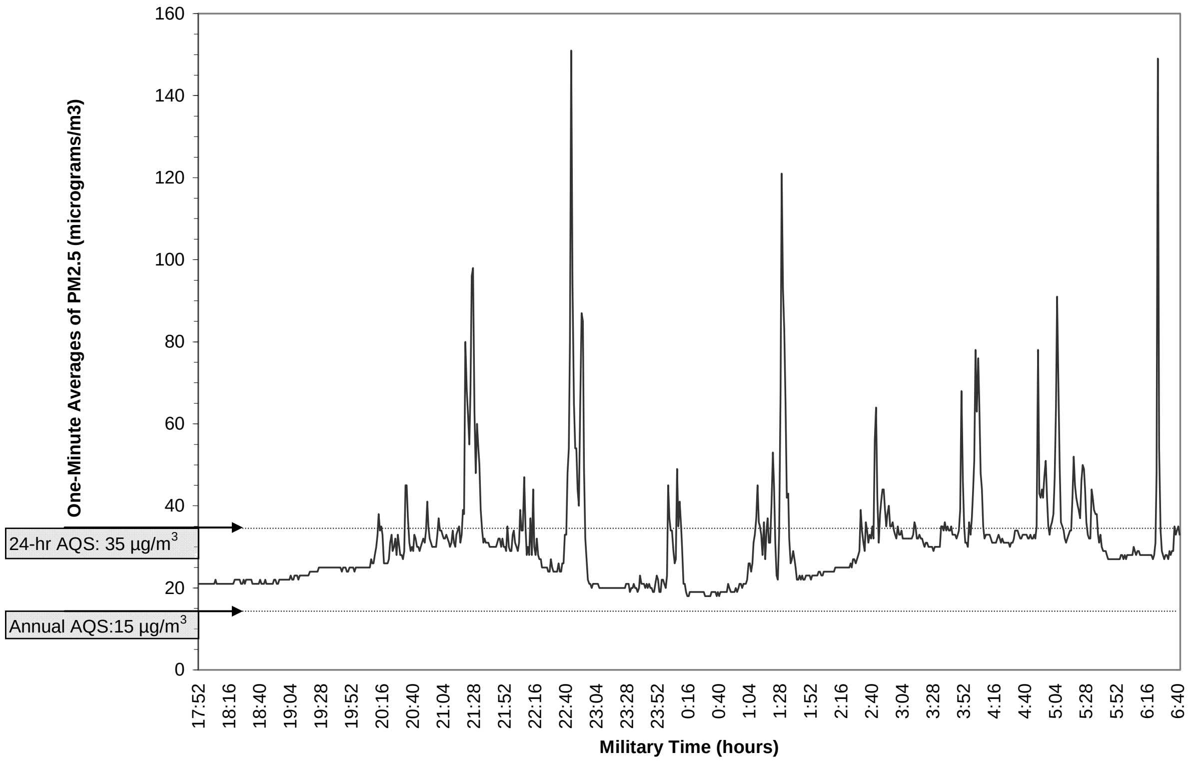

Figure 2. Line graph of one-minute $PM_{2.5}$ averages collected during the evening of March 25th and 26th at the complainant's property (details in Appendix D).

Exposure Pathways Analysis

An exposure pathway contains five parts: (1) a source of a potentially hazardous substance, (2) transport of the hazardous substance through an environmental material (i.e., soil, air, water, food), (3) a point of exposure, (4) a route of entry into a person, and (5) a receptor person or population. An exposure pathway is considered *complete* if evidence exists that all five of these elements are, have been, or will be present. More simply stated, an exposure pathway is considered complete when people are highly likely to be exposed to the hazardous substance. A pathway is considered a *potential* exposure pathway if at least one of the elements is missing but could be found at some point. An *incomplete* pathway is when at least one element is missing and will never be present.

MDCH concludes a completed exposure pathway exists while the OWB is in operation based on site visit observations, pattern of $PM_{2.5}$ ambient air concentrations from the complainant's property and the complainant's video documentation of the wood smoke (Table 1). A completed exposure pathway also existed for burn barrel use.

Table 1. Exposure pathway analysis.

Source(s)	Chemical	Transport	Exposure			Time Frame	Status
			Point	Route	Population		
Outdoor Wood Boiler without emission controls or other sources (e.g. burn barrels)	$PM_{2.5}$	Air	Air	Inhalation	Local Residents	Past	Complete
						Present	Potential
						Future	Potential

Researchers have determined that wood smoke and its PM impact air quality in residential areas (Allen et al. 2008, Barn et al 2008, Hellén et al. 2008, Anuszewski et al. 1998). Further, wood smoke and PM infiltrate into homes in both summer and winter (Barn et al 2008, Anuszewski et al. 1998). OWBs can generate large quantities of wood smoke including large quantities of $PM_{2.5}$ (Johnson 2006). Wood smoke will contain partial combustion products (i.e. organic chemicals and trace elements) (US EPA 1993). These partial combustion products cool as they are exhausted to the outside and form PM that includes these chemicals (US EPA 1993). Northeast States for Coordinated Air Use Management (NESCAUM) conducted a study that reported "average fine particulate emissions from one OWB are equivalent to the emissions from 22 EPA certified wood stoves, 205 oil furnaces, or as many as 8,000 natural gas furnaces (NESCAUM 2006)." Hellén et al. (2008) found that residential wood combustion can cause very high, short-lived PM air concentration and sustained elevations in atmospheric chemical concentrations such as benzene (e.g. 70% of benzene in the air was from wood burning). Johnson (2006) established that OWBs cause frequent, repeated, and highly-elevated concentration spikes of PM, specifically $PM_{2.5}$. Because OWBs are used for heating homes, as well as other heating purposes, OWB operate 24 hours per day, seven days per week, for seven to twelve months per year in the northern Midwest. People living near these units can experience both short-term (acute) and long-term (chronic) exposures to wood smoke.

Toxicological Evaluation

Wood smoke is a combination of gas and PM. PM is reported as a range of diameter sizes measured in micrometers (µm). PM less than 10 µm (PM_{10}) and PM less than 2.5 µm ($PM_{2.5}$) are common size ranges found in wood smoke (Park and Lee 2003, Hellén et al. 2008, Johnson 2006, NESCAUM 2006, Gullett et al. 2004). The size range of particles included within PM_{10} measurements also captures $PM_{2.5}$. The smaller the PM the further into the lungs the particles can reach. Thus $PM_{2.5}$ is the size range that can go furthest into the lungs with the smallest of these particles (less than 0.1 µm) having been shown to pass through the lungs into a person's blood stream (Nemmers et al. 2002).

The gas and particles of wood smoke contain detectable amounts of numerous types of organic chemicals (polycyclic aromatic hydrocarbons (PAHs), phenols, aldehydes, alkenes, alkanes, and aromatics) (US EPA 1993, Gullett et al. 2004). This includes several chemicals that can increase a person's risk of cancer including benzo(a)pyrene, chrysene, dibenzo(a,h)anthracene, indeno(1,2,3 cd)pyrene, benzo(k)fluoranthene, benzo(a)anthracene, benzo(b)fluoranthene, benzene, and formaldehyde (Brown et al. 2007, Hellén et al. 2008, NESCAUM 2008). Additionally, trace elements can be released during the combustion of wood or other material (US EPA 1993). Amount and types of chemicals in any particular wood smoke will depend on the characteristics of the materials being burned, system used to conduct the combustion, and how the system is operated (Hellén et al. 2008, US EPA 1996, NESCAUM 2008).

Researchers have described plausible pathways in which PM causes disease. These pathways are triggered by the physical presence of the PM, the chemicals contained in the PM, or the combination of both. The pathways begin with an innate immune response involving oxidative stress and an inflammatory response. The inflammation response causes a release of proteins that effect blood vessel function and results in tightening around the blood vessels. For people with existing partial blood vessel blockages (i.e., plaque build up), the inflammation response is thought to cause plaques to break off and move freely in the blood stream (i.e., embolism) and/or constrict the blood vessels resulting in increased blood pressure and possible complete blockage of blood vessels. Damage to the inner-lining of blood vessels may also occur resulting in vascular or cardiovascular disease (O'Neill et al. 2005, Brook 2007, Rajagopalan et al. 2005, Pope et al. 2004).

The inflammation response may also affect the part of the nervous system that controls heart function. Research suggests changes in nervous system function from PM exposure can trigger heart attacks. The physical presence of PM may interact with nerve endings causing a nerve reflex resulting in altered function of the part of the nervous system that controls the heart. This nerve reflex may best explain why very short PM exposures (1 hour) correlate with increased hospitalization for heart disease and increased numbers of moralities due to heart disease. It is also plausible that the smallest particles enter the blood stream and directly interfere with heart function (Nemmar et al. 2002, Brook 2007).

Elevated exposures to wood smoke and its PM are associated with acute and chronic changes in the physiology of people and associated with negative health outcomes (Zelikoff et al. 2002, Naeher et al. 2007). These negative health outcomes include increased risk of hospitalization and/or mortality from heart disease, respiratory disease, and disease of the blood vessels. MDCH provides a more extensive review of published studies in Appendix E. As a brief overview, published studies report increased exposures to PM can increase the risk of deaths per day by 0.7 and 8 percent per 10 µg/m^3 increase in PM measured as $PM_{2.5}$ or PM_{10}. These risks primarily apply to sensitive populations that include people with partially blocked arteries (i.e., atherosclerosis), heart disease, respiratory disease (e.g. asthma, chronic obstructive pulmonary disease), older adults, or people smoking cigarettes. Short-term exposures to PM (1 hour – 2 days) can trigger negative clinical outcomes (i.e., heart attack or death). Long-term exposures to PM are correlated with risk of cardiovascular and respiratory effects up to and including mortality. Long-term exposure may increase the risk of developing heart or respiratory disease.

The US EPA recognizes $PM_{2.5}$ as a hazardous air pollutant and has established National Ambient Air Quality Standards (NAAQS) (15 µg/m^3 annual average, 35 µg/m^3 24-hr 98th percentile) to reduce $PM_{2.5}$ concentrations in ambient air (see Appendix D). MDCH finds that the $PM_{2.5}$ ambient air concentrations recorded on the complainant's property were on average 31 times higher than the referent location (Appendix D).

No government ambient air $PM_{2.5}$ standard exists for the purpose of public health evaluation in a residential development. However, Brown et al. (2007) proposed such standards in a recent publication in relation to an evaluation of OWB wood smoke and stated the following:

"In summary, cancer appears to be the sensitive endpoint with a 7-months-a-year, lifetime exposure of 6 μg/m^3: it yields over1 in 100,000 risk of cancer" Brown et al. (2007) goes on to state, *"an exposure level of 18μg/m^3 (over 6 hr) puts people at risk of health problems like asthma. Other risks highlighted in Table 5* [in Brown et al.] *include: exposures to concentration of 24 μg/m^3 is a moderate risk for hospitalization due to asthma or COPD, whereas exposure levels of 30 μg/m^3 places people at high risk for serious health problems and hospitalization from asthma, COPD and cardiovascular disease for the most susceptible."*

MDCH can not eliminate the possibility that concentrations reported to correlate with decreased respiratory function, measures of cardiac function, increased hospital admissions due to respiratory or cardiac effects, or increases in daily mortality will occur on the complainant's property during the heating season if the OWB continues to be operated (Appendix D). Additionally, MDCH cannot assume that the measured $PM_{2.5}$ concentrations represent a reasonable maximum exposure, so higher concentrations than those recorded may occur.

Health Outcome Data

The complainant neighbors with documented medical sensitivity to wood smoke have been under medical evaluation for respiratory and/or cardiovascular conditions. The neighbors are non-smokers and reported regular exercise prior to current health conditions. Medical results from the male complainant's pulmonologist and cardiologist state findings of chronic lung disease and coronary artery disease with severe calcification. The spouse's pulmonologist diagnosed a severe cough likely due to chronic bronchitis and sinusitis brought on by smoke exposure, and possible asthmatic bronchitis secondary to smoke inhalation. During a particularly severe smoke event caused by a smoke source from the property in question, one of the smoke-sensitive neighbors was taken to the hospital due to a severe restriction in breathing. The spirometry report stated a finding of "very severe obstruction". The medical spirometry report stated that the patient's lung function, as measured by FVC, FEV1, FEF25-75, and PEF, were 9-66 percent (%) of normal lung function for a person of that age, height, ethnicity, and gender.

On December 19, 2008, Robert D. Albertson, M.D., F.C.C.P, cardiopulmonary specialist, advised in writing that these individuals "avoid all smoke exposure", based on their health conditions. The statement further elaborated the severity by stressing that the patient's lung condition is "absolutely exacerbated by exposure to smoke" and "ongoing exposure could cause permanent and progressive damage to [the patient's] lungs, which could cause [the patient's] significant disability". On December 22, 2008, Mark A Rasak, D.O., F.A.C.O.I., F.A.C.C., F.S.C.A.I., wrote that "Continued exposure from this source could of course cause progression of the disease, serious health complications and eventually contribute to his demise. As a cardiologist, I would strongly advise the patient to be removed from this dangerous source and or other source of smoke caused by burning."

Children's Health Considerations

Children may be at greater risk than adults from exposure to hazardous substances. Children engage in activities such as playing outdoors that could increase the amount of hazardous substances they take into their bodies. They are shorter than most adults, and therefore breathe dust, soil, and gases found closer to the ground. Their lower body weight and higher intake can result in more exposure (US EPA 2008). Children are growing and can sustain permanent damage if toxic exposures are high enough during critical growth stages. The implication is that children, more so than adults, can experience substantially greater exposures to toxicants in air.

Infants and children have a higher resting metabolic rate and oxygen consumption rate per unit of body weight than adults, which results in the volume of air passing through the lungs of a resting infant being up to twice that of a resting adult on a body weight basis (U.S. EPA 2008). Therefore, children will take in more air contaminants than adults on a body weight basis. Several studies find respiratory effects of ambient air concentration of $PM_{2.5}$ on children with asthma (Naeher et al. 2007, Koenig et al. 2005, Delfino et al. 2004, Koenig et al. 2003, Delfino et al. 2008). Ulirsch et al. (2007) found children under the age of 17 years old at greater risk of hospitalization due to respiratory disease with increased PM_{10} exposure. Ostro et al. (2009) reports a 4.1 percent greater risk of child hospitalization for respiratory effects associated with a 14.6 $\mu g/m^3$ increase in $PM_{2.5}$.

Although children do not currently live on the complainant's property, the OWB is located within a residential development where MDCH staff observed children and toys. MDCH did take into consideration the need to be health protective of children, particularly those with asthma, when making the public health determination in this consultation.

Conclusions

MDCH concludes that inhaling elevated concentrations $PM_{2.5}$ found in wood smoke on a short-term or long-term basis in a residential neighborhood can harm people's health. MDCH concludes that the continued operation of the specific OWB in question is an *urgent public health hazard* based on the findings described in this health consultation. In brief, this determination is based on the combined information gathered from site investigations, peer-reviewed literature, publicly available documents, and personal health information provided by the complainant. During the investigation, the OWB in question was found to emit substantial amounts of smoke during operation that contained a known hazardous substance ($PM_{2.5}$) at levels that may harm people's health, especially sensitive individuals. The investigation confirmed the complainant's descriptions and video documentation.

MDCH further finds that the operation of other significant smoke emitting sources that contributes to ground level smoke and associated hazardous substances to the ambient air are a *public health hazard* to vulnerable populations.

Recommendations

1. Immediately following the investigation, MDCH issued a memorandum describing the findings of this investigation that supported MDEQ and the Jackson County Health Department in taking appropriate actions to eliminate the major sources of smoke and associated hazardous substances.
2. MDCH remains available to assist MDEQ and the Jackson County Health Department on this issue as requested.

Public Health Action Plan

1. Based on the memorandum of findings described above, the Jackson County Health Department sought and received a temporary legal action that stopped the use of the OWB in question. Through a court trial, a final remedy was reached on May 20, 2009.
2. MDCH will remain available as needed for future consultation at this site.

If any citizen has additional information or health concerns regarding this health consultation, please contact MDCH's Division of Environmental Health at 1-800-648-6942.

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Preparers of Report

Michigan Department of Community Health
Division of Environmental Health

Kory Groetsch
Toxicology and Response Section

ATSDR Region 5 Office

Mark Johnson
Office of Regional Operations

ATSDR Division of Health Assessment and Consultation

Trent LeCoultre, Technical Project Officer
Cooperative Agreement Program Evaluation Branch

Certification

This Health Consultation was prepared by the Michigan Department of Community Health under a cooperative agreement with the Agency for Toxic Substances and Disease Registry (ATSDR). It is in accordance with approved methodology and procedures. Editorial review was completed by the cooperative agreement partner.

Technical Project Officer, Cooperative Agreement Program Evaluation Branch (CAPEB), Division of Health Assessment and Consultation (DHAC), ATSDR

The Division of Health Assessment and Consultation, ATSDR, has reviewed this public health consultation and concurs with the findings.

Team Leader, CAPEB, DHAC, ATSDR

Appendix A. Referenced Figures.

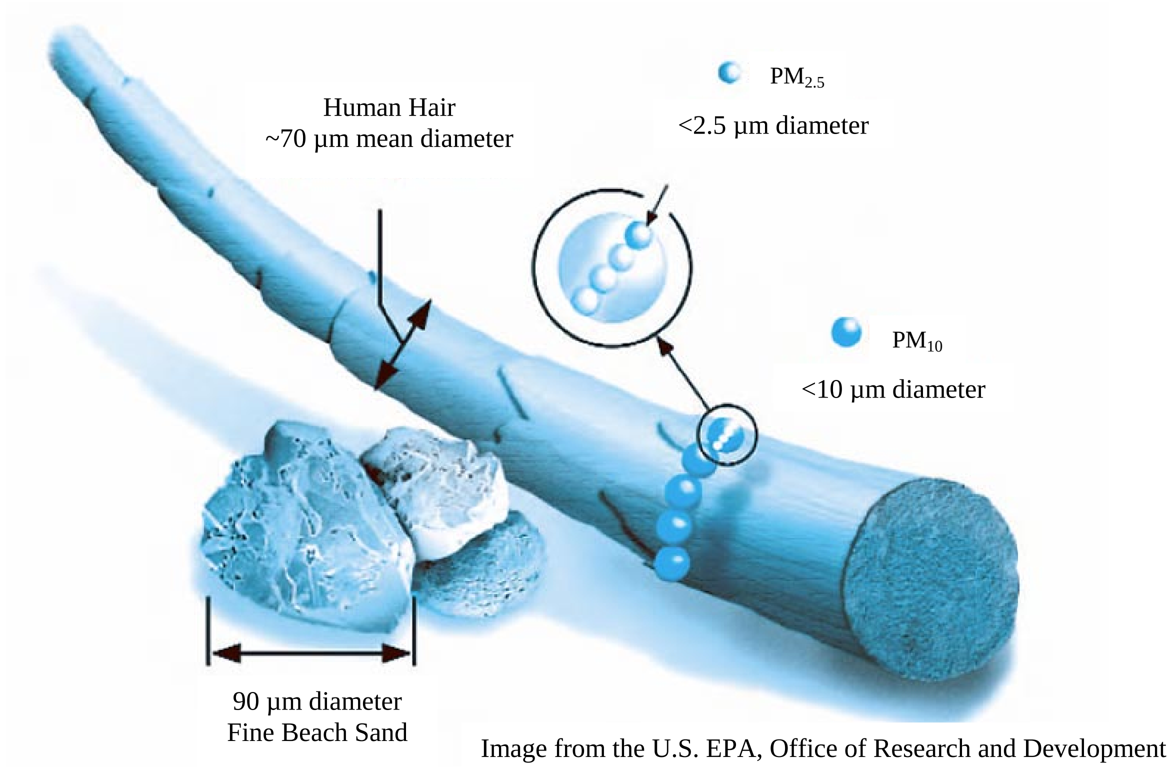


Figure A-1. Image of the relative size of particulate matter

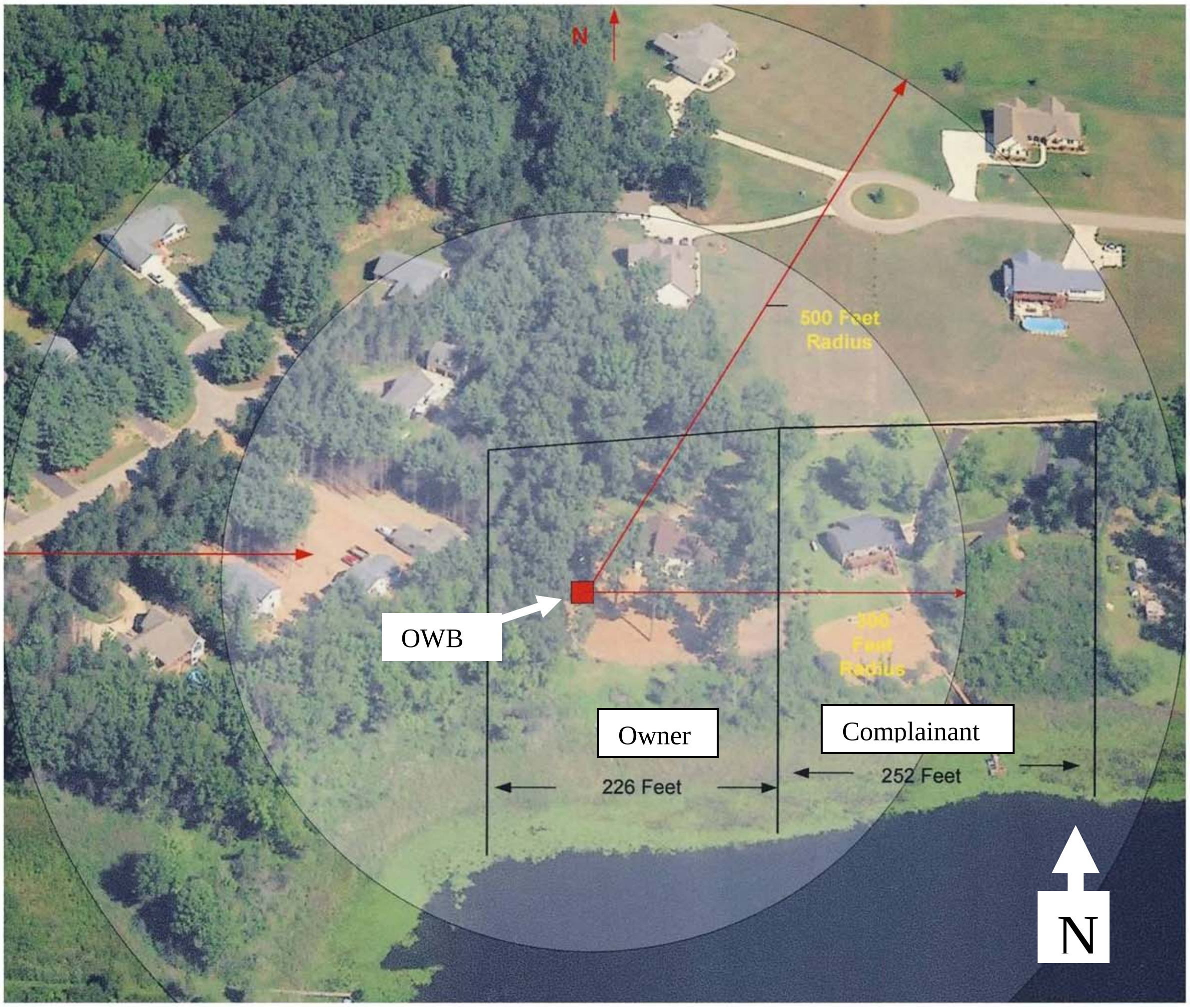
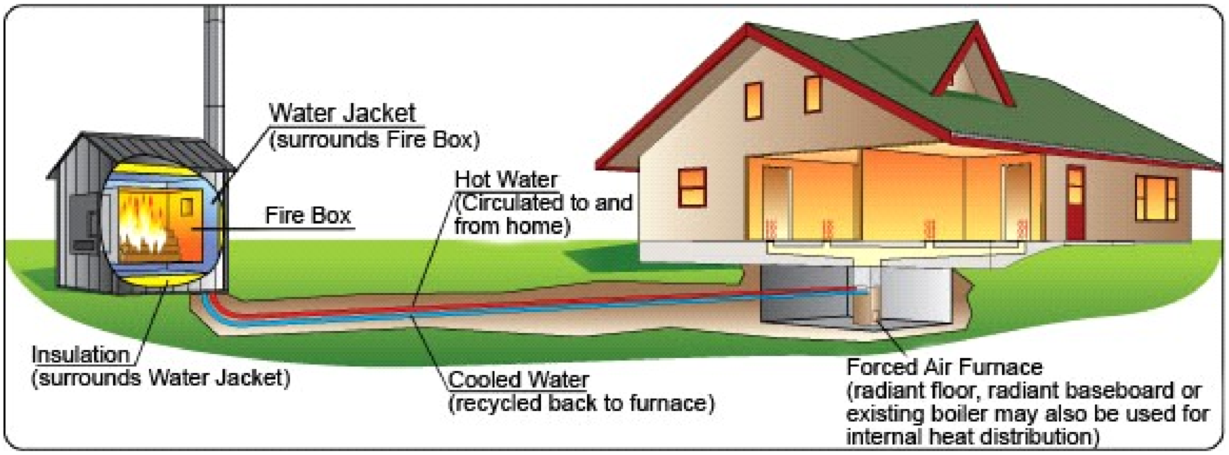


Figure A-2. Aerial photo of owner and complainant properties.



Source: Hearth, Patio and Barbeque Association (from US EPA website and New Hampshire Environmental Health Services)

Figure A-3. Illustration of the installation of an outdoor wood boiler and a suggested height of stack.

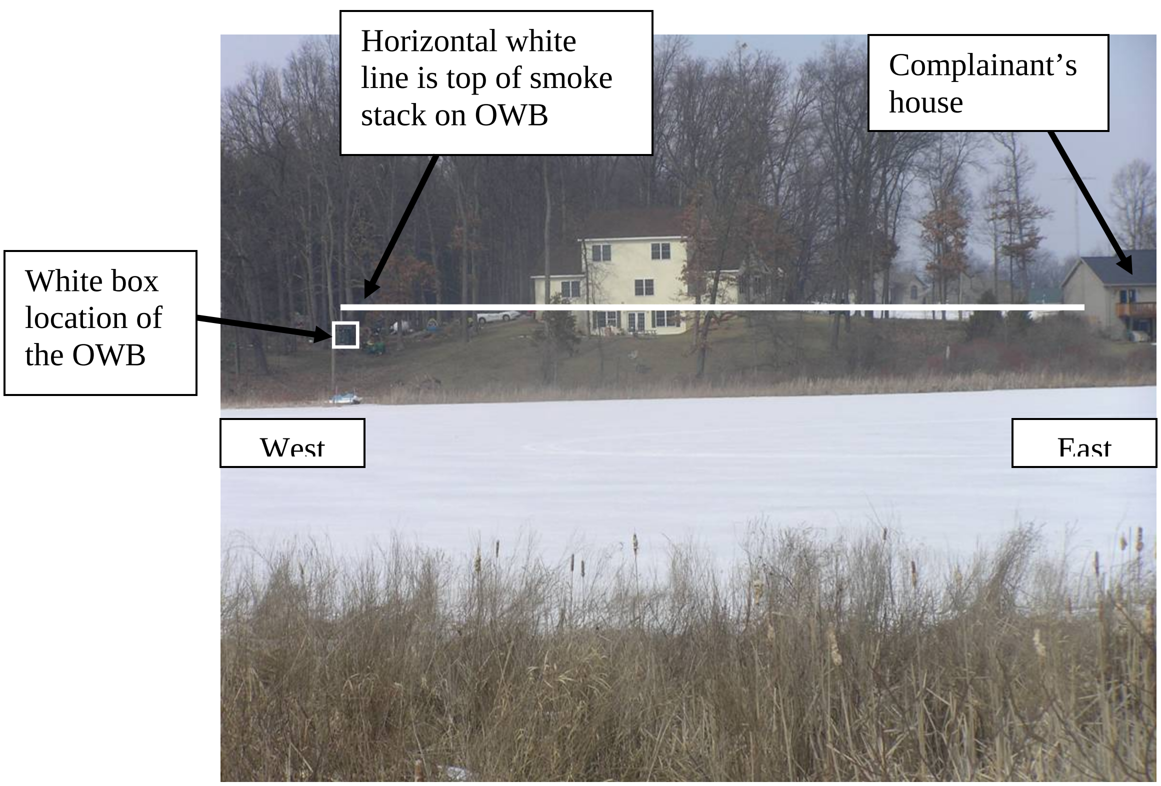


Figure A-4. Photo of location of OWB relative to complainant's house.

Appendix B. Instrument Description for $PM_{2.5}$ Measurement.

Measurement Conditions
Cordwood burning as a source of home heating has been documented to result in fluctuating concentrations of PM in the ambient air of residential developments (Hellén et al. 2008). OWBs, a type of cordwood burning unit, has been demonstrated to cause elevated concentrations of PM within several hundred feed of an operating unit (Johnson 2006, DEQ 2004).

Light Scattering PM Meters
Light scattering PM meters (i.e., nephelometers) use a beam of light (light source) to measure particles in air. Particles deflect the light and a light detector, typically placed at a 90^o angle to the light source, measures the deflected light that is then converted to a measure of particle density. Nephelometers can measure PM changes in air in increments as small as one second. Nephelometers are commonly used to measure PM when tracking fluctuating concentration and estimating personal exposure. Michigan's Occupational Safety and Health Administration (MIOSHA) uses nephelometers (TSI SidePak model: AM510) for this purpose at work sites. Numerous publications have demonstrated the use of nephelometers to measure PM (Howard-Reed et al. 2000, Johnson 2006, Sullivan et al. 2005, Liu et al. 2002, Rea et al. 2001, Delfino et al. 2004, Delfino et al. 2006, Delfino et al. 2008, Koenig et al. 2003, Koenig et al. 2005) for the purpose of estimating personal exposure.

TSI PM Nephelometers Used in Health Consultation
MIOSHA uses the TSI, Inc. light scattering PM instrument SidePak (model: AM510). TSI, Inc. also makes the DustTrak (mode: 8520) that operates on the same technology as the SidePak, however, has a computer that allows recording of individuals measures in one-minute intervals. Several published reports document the use of these instruments in PM investigations (Levy at al. 2001, Chung et al. 2001, Jenkins et al. 2004, MacIntosh et al 2002, Branis and Hovorka, Carbone 2009, CDC 2004, Vardavas et al. 2008, Jiang and Bell 2008, Semple et al. 2007).

The TSI SidePak AM510 (MIOSHA equipment number LESS 01438) is a hand-held (106 mm × 92 mm × 70 mm) nephelometer that uses a wavelength of 670 nm that detects particles down to approximately 0.1 μm. The SidePak AM510 was obtained from and maintained by MIOSHA. The SidePak was operated according to manufacture specifications. The air inlet had a silicon coated impactor that selected for particles smaller than 2.5 μm. Thus, the SidePak AM510 used in this study measured particles between 0.1-2.5 μm. The unit is calibrated by the manufacture with a test dust (ISO 12103-1, A1) that provides a wide size range of respirable ambient air particles. The air flow rate was set by the manufacture at 1.7 l/min and was checked several times during its use with the D*rycal DC-lite* flow meter. The meter was zeroed prior to each use with the zero-filter. Measured concentrations were set to report 1-second or 5-second averages.

The TSI DustTrak model 8520 (serial number: 85200673) was calibrated in January 2008 and was obtained from and maintained by Argus-Hazco, Inc (46400 Continental Dr., Chesterfield, MI 48047). The unit is calibrated by the manufacture with a test dust (ISO 12103-1, A1). The DustTrak was operated according to manufacture specifications. The DustTrak was zeroed at the beginning of each sampling day with a zero-filter. The flow-rate was confirmed to be 1.7 l/min

D*rycal DC-lite* flow meter. The air inlet had a silicon coated impactor that selected for particles smaller than 2.5 μm. The range of concentrations that could be detected was set for 0 – 1000 μm/m^3. The DustTrak recorded 1-minute average $PM_{2.5}$ concentrations in "Log" mode allowing data to be recorded for numerous hours.

Precision and Accuracy

Precision is the repeatability of measurements. Instrument that have good precision generate measurements that are nearly the same when measuring a homogenous sample. Good precision is the not the same as good accuracy. Accuracy is a measure of how close a datum is to the true concentration. With $PM_{2.5}$ measurements, it is not possible to know the true concentration in ambient air. The true concentration can only be estimated by a measurement method. All measurement methods have bias. Bias is the difference between the true concentration and the estimated concentration. The larger the difference between the two concentrations the greater the bias is. Gravimetric methods are most commonly used to establish the true $PM_{2.5}$ concentration to which all other measurement devices are compared. Gravimetric methods collect the mass of $PM_{2.5}$ and weigh that mass. Gravimetric methods can underestimate the true concentration of PM by 10-40% due to the loss of volatile chemicals, effects of low humidity, or factors related to collection (i.e., rate of air flow to the filter) (Misra et al. 2001, Sarnat et al. 2003, Chow et al. 2008). Although some bias exists, the US EPA has designated certain gravimetric methods as Federal Reference Methods (FRMs).

Good precision and accuracy are desired in any method, but only precision is necessary for making statistical comparisons between two different conditions or locations. The objective of this health consultation was to make such comparisons in ambient air PM concentrations between differing conditions or locations.

In general, nephelometers have been shown to have good precision in comparison to gravimetric methods. Studies have shown highly predictive and linear (coefficient of determination (r^2) range 0.65 to 0.99) relationships to gravimetric methods (Branis and Hovorka, Lui et al. 2002, Quintana et al. 2000, Fisher and Koshland 2007, Lanki et al. 2002, Sioutas et al. 2000, Wu et al. 2005, Waggoner and Weiss 1980). Specifically, the DustTrak has been tested against a US EPA FRM and has been found to be highly predictive and linear with an r^2 equal to 0.86 (MacIntosh et al 2002). Jenkins et al. (2004) tested the DustTrak model 8520 against a gravimetric method using wood smoke and also found a highly predictive and linear relationship (r^2= 0.997). Branis and Hovorka tested the DustTrak model 8520 on ambient air over winter, summer, and autumn and reported r^2 range of 0.83-0.98. Levy et al. (2001) and Hill et al. (2005) compared the DustTrak to a gravimetric methods and reported r^2=0.70 and 0.96, respectively.

The accuracy of nephelometers relative to gravimetric methods can be biased due to a variety of parameters that describe the aerosol's composition, density, range of particle diameters, and refractive index. Further, nephelometic measures can be significantly affected by high relative humidity (greater than 80-85% relative humidity) (Thomas and Gebhart 1994, Sioutas et al. 2000, Liu et al. 2002, Chakrabarti et al. 2004, Quintana et al. 2000). In combination, these factors result in nephelometers overestimating PM concentrations compared to gravimetric methods. Publications of DustTrak accuracy find it overestimates PM on average by approximately 2-3 times (Levy at al. 2001, Chung et al. 2001, Jenkins et al. 2004, MacIntosh et al 2002, Branis and Hovorka). Jenkins et al. (2004) conducted laboratory measures with wood smoke and reported that the average ratio between the DustTrak and a gravimetric method was 2.6 ± 0.5. This matched the findings of MacIntosh et al. (2002) when comparing the DustTrak to a FRM gravimetric method in which a proportional bias of 2.6 was reported.

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Appendix C. Description of site visits during sensory observations and results of minimum maximum $PM_{2.5}$ measurements.

Prior to MDCH involvement, the DEQ conducted an investigation that identified the brand, model, and placement of the OWB (model: Woodmaster 4400) at the residence in question. The general design and operation of the Woodmaster 4400 OWB was described at the manufactures website (http://www.woodmaster.com/index.php). On three separate dates, MDCH and DEQ conducted site visits on the complainant's property. These site visits were conducted to observe the OWB during operation and determine the plausibility of the complainant's concerns regarding the emission and movement of smoke and odors from the OWB to the complainant's property. The site visits were conducted between 3:00-9:00 pm when the average ambient temperature was 25-50 ^{o}F and wind speeds were typically light but varied (0-21 mph) (Table C-1 to C-3). Wind direction averaged from westerly to north westerly winds. The relative percent humidity ranged from 31-70 percent during the site visits. The dates on which these site visits were conducted did not represent the coldest days of the year, thus demand for heat production from the OWB would be less frequent resulting in fewer burn cycles and fewer opportunities to observed smoke and odor emissions.

Sensory observations from the site visit include visible white smoke on the property of the OWB owner. Visible white smoke dissipated prior to reaching the complainant's property. The OWB appeared to operate as described by Johnson (2006) with periods of copious smoke release followed by minimal visible smoke release that presumably coincided with the heat demands of the house. MDCH and DEQ staff observed mild odors that the DEQ engineer described as indications of wood burning. DEQ provided a qualitative ranking from 0 to 5 indicating the strength of the odors observed. Zero represents no odors were detected with the following descriptions for 1-5:

1. Just barely detectable.
2. Distinct and definite odor.
3. Distinct and definite objectionable odor.
4. Intense odor to cause a person to avoid it.
5. Odor so strong as to be overpowering and intolerable.

The observed mild odors were assigned qualitative rankings of 1 or 2 by the DEQ engineer. Because these site visit observations coincided with visible smoke on the owner's property but not on the complainant's property, the observed odors were experienced outside a visible plume of smoke. MDCH and DEQ staff expects that odor intensity would be greater within a plume of visible smoke.

MDCH used a real-time $PM_{2.5}$ optical aerosol monitor (TSI SidePak model: AM510) to measure $PM_{2.5}$ concentrations in the ambient air while sensory observations were being collected. Similar monitors have been used to measure ambient PM concentrations when providing indicators of personal PM exposure (Appendix B). MDCH recorded the minimum and maximum $PM_{2.5}$ concentrations during both odor (level 1-2) and non-odor (level 0) moments (Table C-4). The monitor was set to report measurements every 1 or 5 seconds and observation periods ranged from 1-11 minutes in length. During non-odor detection moments the average (± one standard deviation) minimum $PM_{2.5}$ concentrations was 8 ± 3 $\mu g/m^3$ and average maximum was 27 ± 9 $\mu g/m^3$. During observed odors, the average (± one standard deviation) minimum $PM_{2.5}$ concentrations was 55 ± 38 $\mu g/m^3$ and average maximum was 177 ± 119 $\mu g/m^3$. The average minimum and maximum $PM_{2.5}$ concentration detected during odor events was statistically significantly greater (p-value = 0.001, alpha=0.05) than the corresponding average minimum and maximum $PM_{2.5}$ concentrations detected during moments without odors (Figure C-1).

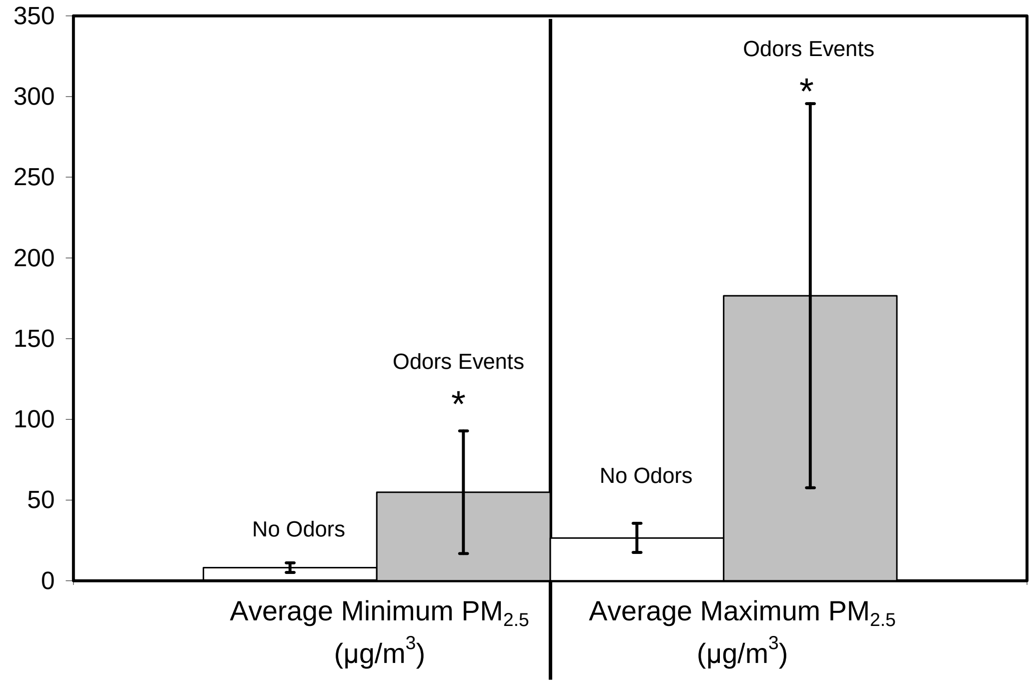

Figure C-1. Comparison of average minimum and maximum $PM_{2.5}$ concentrations during odors and non-odors.

Based on these site visits, MDCH concludes that the OWB in question is capable of creating smoke and noticeable odors. MDCH concludes that timing of the site visits would not represent a reasonable maximum exposure because variable wind direction and speed, time of the year of the site visits, and uncertainty if the site visits represented the owner's typical manner of OWB operation. MDCH concludes that the complainant's video documentation and verbal description of smoke and odor from the OWB are plausible and are in general agreement with published descriptions of OWB operation and emissions (Johnson 2006, NESCAUM 2006). MDCH concludes that even when visible smoke is not present, odors from the OWB operation can be detected. MDCH concludes that during mild odors $PM_{2.5}$ concentrations are significantly higher than $PM_{2.5}$ concentrations measured during times when no odors were observed.

Table C-1. Weather data for 3/13/2008.

Weather Station	Date	Time of Sample	Temperature	Relative Humidity	Wind Direction	Wind Speed
		Hours	**°F**	**%**	**degrees**	**mph**
KJXN	3/13/2008	1856	49	59	260	20
KJXN	3/13/2008	1956	48	56	270	12
KJXN	3/13/2008	2056	50	48	290	11
KLAN	3/13/2008	1853	43	70	260	21
KLAN	3/13/2008	1953	45	66	270	19
KLAN	3/13/2008	2053	46	61	280	14
		Mean	47	60	272	16
		Standard Deviation	3	8	12	4
		Median	47	60	270	17
		Minimum	43	48	260	11
		Maximum	50	70	290	21

Table C-2. Weather data for 3/20/2008.

Weather Station	Date	Time of Sample	Temperature	Relative Humidity	Wind Direction	Wind Speed
		Hours	**°F**	**%**	**degrees**	**mph**
KLAN	3/20/2008	1553	34	55	330	15
KLAN	3/20/2008	1653	36	51	300	12
KLAN	3/20/2008	1753	37	52	290	10
KLAN	3/20/2008	1853	39	48	290	9
KLAN	3/20/2008	1953	41	45	290	13
KJXN	3/20/2008	1556	37	50	320	12
KJXN	3/20/2008	1656	38	50	310	11
KJXN	3/20/2008	1756	41	44	310	15
KJXN	3/20/2008	1856	42	43	310	10
KJXN	3/20/2008	1956	43	41	290	14
		Mean	39	48	304	12
		Standard Deviation	3	4	14	2
		Median	39	49	305	12
		Minimum	34	41	290	9
		Maximum	43	55	330	15

Table C-3. Weather data for 3/24/2008.

Weather Station	Date	Time of Sample	Temperature	Relative Humidity	Wind Direction	Wind Speed
		Hours	**°F**	**%**	**Degrees**	**mph**
KJXN	3/24/2008	1456	29	61	360	0
KJXN	3/24/2008	1556	28	58	360	0
KJXN	3/24/2008	1656	31	47	360	0
KJXN	3/24/2008	1756	32	43	210	3
KLAN	3/24/2008	1453	25	54	320	4
KLAN	3/24/2008	1553	25	50	360	0
KLAN	3/24/2008	1653	28	31	360	0
KLAN	3/24/2008	1753	30	31	270	4
		Mean	29	47	325	1
		Standard Deviation	3	11	57	2
		Median	29	49	360	0
		Minimum	25	31	210	0
		Maximum	32	61	360	4

Table C-4. $PM_{2.5}$ concentration ranges during odor and non-odor moments.

Date	Opacity [1]	Odor Level[2]	Range of $PM_{2.5}$[3] µg/m³
3/13/2008	Clear	0	7-18
3/13/2008	Clear	0	14-39
3/13/2008	Clear	0	10-20
3/20/2008	Clear	0	7-35
3/20/2008	Clear	0	8-27
3/20/2008	Clear	0	6-36
3/20/2008	Clear	0	5-27
3/20/2008	Clear	0	6-23
3/20/2008	Clear	0	7-15
3/20/2008	Clear	0	12-25
3/20/2008	Clear	0	11-15
3/20/2008	Clear	0	10-25
3/24/2008[4]	Clear	0	10-15
3/24/2008[4]	Clear	0	10-23
3/24/2008[4]	Clear	0	6-40
3/24/2008[4]	Clear	0	2-42
3/13/2008	Clear	1	50-368
3/13/2008	Clear	1	140-325
3/13/2008	Clear	1	100-150
3/13/2008	Clear	1	100-150
3/13/2008	Clear	1	95-154
3/13/2008	Clear	1	15-68
3/20/2008	Clear	1	37-108
3/20/2008	Clear	1	28-107
3/20/2008	Clear	1	23-98
3/20/2008	Clear	1	36-179
3/20/2008	Clear	1	23-98
3/20/2008	Clear	1	53-147
3/20/2008	Clear	1	23-68
3/24/2008[4]	Clear	2	45-453

[1] Opacity represents the visual observations at the immediate location of the $PM_{2.5}$ measurements. The word "Clear" means no visible smoke in the air at the point of $PM_{2.5}$ measurements. With visible smoke the DEQ engineer would have provided a percentage estimate of opacity with 100% being an opaque smoke plume.
[2] Odor Level: DEQ number system for odors ranging from 0-5 and described in the text of Appendix C.
[3] Range of $PM_{2.5}$: One second averages of the minimum and maximum concentrations observed over a recorded time period during the site visit, unless otherwise noted.
[4] The $PM_{2.5}$ measurements taken on 3/24/08 were collected as 5 second averages, instead of one second averages.

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Appendix D. Continuous monitoring of $PM_{2.5}$ at the complainant and referent locations.

Background

The three site visits described in Appendix C confirmed the increase in $PM_{2.5}$ concentration during observed mild odor events and smoke releases from the OWB in question. The continuous one-minute average $PM_{2.5}$ data collection was conducted to document relative change in $PM_{2.5}$ over time during the evening when human activity outdoors would be minimal. Two monitoring events were conducted on consecutive evenings. The first monitoring event was at the complainant's property and the second event was at a location not near an OWB (i.e., referent residential development). The TSI DustTrak model 8520 was used to monitor for ambient $PM_{2.5}$ concentrations. The DustTrak was operated according to manufacture instructions.

Meteorological Data

Meteorological data from regional weather stations in Lansing (KLAN) and Jackson (KJXN) Michigan that are part of the Automated Surface Observing Systems (ASOS) program were used in this effort. The ASOS program is a combined effort of the National Weather Service (NWS), the Federal Aviation Administration (FAA), and the Department of Defense (DOD). The purpose of the ASOS system is to serve as the nation's primary surface weather observing network. ASOS is designed to both support weather forecast activities, aviation operations, and the needs of the research community.

$PM_{2.5}$ monitoring at the complainant's property began on March 25, 2008 at approximately 6:00 pm and lasted until March 26, 2008 at 6:40 am. The data collection was conducted outside on the complainant's deck, which placed the DustTrak between 9 to 10 feet above the ground (Figure D-1). The DustTrak was placed inside a protective case and locked. Air was drawn through a metal tube that projected out the top of the case, into a plastic cup intended to catch unwanted moisture, and then through flexible tubing to the DustTrak. The plastic cup was dry at the start and end of the sampling event. No precipitation occurred during the sampling event.

KJXN station, which was approximately 11 miles from the complainant's property, recorded 40 ^oF at the start of the $PM_{2.5}$ data collection with an average (standard deviation) of 42±2 ^oF, a maximum of 46 ^oF, and an end temperature of 38 ^oF (Table D-3). KLAN station, which was approximately 30 miles from the complainant's property, recorded 36 ^oF at the start of the $PM_{2.5}$ data collection with an average (±standard deviation (SD)) of 41±3 ^oF, a maximum of 46 ^oF, and an end temperature of 37 ^oF (Table D-1). Relative humidity ranged from 48-70% (KJXN) and 53-75% (KLAN) with average (±SD) of 59±8% and 63±7%, respectively. Wind speed ranged from 5-22 mph with an average (±SD) of 13±5 mph at KJXN and ranged from 8-23 mph with an average (±SD) of 14±5 mph at KLAN. In general, wind speeds were at the maximum at the start of the data collection and were less over the evening hours. According to both weather stations, wind direction was primarily a southwesterly wind at the beginning of the data collection becoming a more westerly wind as the data collection progressed toward the morning.

The $PM_{2.5}$ monitoring at the referent residential development began on March 26, 2008 at approximately 5:30 pm and lasted until March 27, 2008 at 1:40 am. The referent location was closer to an urban center compared to the complainant's property. The data collection was conducted outside on a deck, which placed the DustTrak between 6 to 7 feet above the ground. The DustTrak was inside a protective case and locked. Air was drawn through a metal tube that projected out the top of the case, into a plastic cup intended to catch unwanted moisture, and then through flexible tubing to the DustTrak. The plastic cup was dry at the start and end of the sampling event. No precipitation occurred during the sampling event.

KJXN station, which was approximately 28 miles from the referent location, recorded 39 ^oF at the start of the $PM_{2.5}$ data collection with an average (±SD) of 43±3 ^oF, a maximum of 46 ^oF, and an end temperature of 37 ^oF (Table D-4). KLAN station, which was approximately 10 miles from the referent location, recorded 39 ^oF at the start of the $PM_{2.5}$ data collection with an average (±SD) of 42±3 ^oF, a maximum of 45 ^oF, and an end temperature of 36 ^oF (Table D-2). Relative humidity ranged from 39-62% (KJXN) and 39-60% (KLAN) with average (±SD) of 49±8% and 47±7%, respectively. Wind speed ranged from 4-13 mph with an average (±SD) of 9±3 mph at KJXN and ranged from 4-16 mph with an average (±SD) of 10±4 mph at KLAN. According to both weather stations, wind direction was primarily from the southwest and west.

$PM_{2.5}$ Results

MDCH collected $PM_{2.5}$ data (Number of samples (N) = 770 1-minute averages) at the complainant's property for 12.8 hours. The referent location data (N = 499 1-minute averages) collection was conducted for 8.3 hours. The mean (±SD) $PM_{2.5}$ concentration at the complainant's property was 31±13 $\mu g/m^3$ with a range of 1-minute averages of 18-151 $\mu g/m^3$. The mean (±SD) $PM_{2.5}$ concentration at the referent property was 1±1 $\mu g/m^3$ with a range of 1-minute averages of 0-11 $\mu g/m^3$. The two $PM_{2.5}$ data collections (complainant versus referent) had non-overlapping concentration ranges, thus representing two significantly different data sets.

Evaluation

MDCH provides interpretation of the $PM_{2.5}$ data in context to the surrounding conditions and opportunity for human exposure in accordance with ATSDR's guidance manual (ATSDR 2005). ATSDR defines a public health hazard as "conditions are such that there is a reasonable possibility that adverse health effects have occurred or are likely to occur in sufficiently [hazardous substance] exposed members of the population."

<u>Surrounding Conditions</u>
MDCH concludes that the location and operation of the OWB in relation to the complainant's property indicate a chronic $PM_{2.5}$ exposure scenario that is variable in concentration, and at times may reach concentrations which could be acutely hazardous for sensitive individuals. The OWB is used as the primary source of heat for the house during cold winter months (7 months per year). The OWB is located in a topographically low area and had a short stack that resulted in ground level smoke. The prevailing winds are from the west and complainant's property is directly east of the OWB. The complainants cannot avoid the exposure based on the location of

their house. The male complainant has been diagnosed as a sensitive individual for wood smoke exposure.

Uncertainties in Data Interpretation

This data set provides a precise measure of variation of $PM_{2.5}$ concentrations over time during a period when the OWB was operating and few other $PM_{2.5}$ sources would be present. The interpretation of this data set in a health context has the following limitations.

MDCH collected this $PM_{2.5}$ dataset as a snap-shot in time during the end of the heating season. Temperatures during this data collection ranged from 36-46 ^{o}F. Colder temperatures would require more heat to be generated by the OWB resulting in more emissions. MDCH did not have control over the operation (type and condition of wood, timing of loading wood into the OWB, frequency of heat demand of house, etc…) of the OWB. Operational conditions can affect the amount and frequency of emissions. MDCH did not test a range of meteorological conditions that could effect the resulting concentration on the complainant's property. For these reasons, MDCH cannot presume that this $PM_{2.5}$ data represents a reasonable maximum exposure. Therefore, the average and peak exposures may be greater than what is reported in this dataset. Johnson (2006), in a study of $PM_{2.5}$ concentrations from an OWB, recorded 1-minute averages exceeding 2000 µg/m^3 and a 1-hour mean of 416 µg/m^3 when downwind 50 to 150 feet. DEQ has conducted a similar investigation and found similarly high concentrations (DEQ 2004). Having a reasonable maximum exposure is useful for public health evaluations because it provides an upper-bound on the risk associated with a hazardous substance.

The data set was not collected to provide $PM_{2.5}$ concentration for which the accuracy could be statistically defined. Reported research has shown the DustTrak 8520 to overestimate $PM_{2.5}$ concentrations relative to gravimetric measurements by 2-3 times (Appendix B).

MDCH recognizes that $PM_{2.5}$ data are only a measure of mass of particles per volume of air, and that it is not known which combination of components (i.e. chemicals and particle sizes) gives PM its toxicity (Appendix E). Larger and smaller fractions of PM, not measured in this study, can also be toxic. Toxicity of the PM can vary based on its source.

No government-based screening values have been developed for the explicit purpose of evaluating the public health risk of $PM_{2.5}$ concentrations within a single residential neighborhood. Nor does the implementation of the Clear Air Act regulate down to the level of individual (i.e., personal) exposure or over small spatial areas like a single neighborhood. Under the Clean Air Act, the US EPA is required to issue National Ambient Air Quality Standards (NAAQS) for six pollutants, one of which is particulate matter. US EPA has established two NAAQS for $PM_{2.5}$ (15 µg/m^3 and 35 µg/m^3). These standards are applied either to metropolitan regions (i.e., a city plus its suburbs), which can cover numerous counties (e.g., Detroit, Michigan could cover up to 10 counties) or rural regions. In rural regions, the smallest geographic area to which the standards are applied in Michigan is a county. The 15 µg/m^3 NAAQS is the concentration to which the arithmetic average of 3-years of data collected as 24-hour averages on a periodic basis (e.g. once every 3 or 6 days is common) is compared. The 3-year average must be below 15 µg/m^3, otherwise the geographic region is considered to be in violation of the Clean Air Act and the state must comply with a US EPA process to reduce the $PM_{2.5}$ ambient air concentrations in that region. The 35 μg/m^3 NAAQS is the concentration to which the 98th percentile (i.e., 98% of the data must be below 35 μg/m^3) of a 3-year data collection of 24-hour averages is compared. The same action is taken if the 98th percentile exceeds 35 μg/m^3. The US EPA stipulates specific $PM_{2.5}$ data collection methods (i.e., Federal Reference Methods (FRM)) that use filters to capture $PM_{2.5}$ and determines the total mass (i.e., gravimetric methods). Gravimetric methods are used as the method to which all other methods are compared. In addition to the fact that the methods under the Clean Air Act for $PM_{2.5}$ are not applied to residential exposures, practical limitation exist to using these methods to assess public health risk. First, the $PM_{2.5}$ data collection requires 3-years, which is much too long. Harm to sensitive (i.e., vulnerable) individuals correlates with short-term exposures (1-h to 1 day). Second, short-term exposures can fluctuate to high levels of $PM_{2.5}$, thus annual averages or the 98th percentile over 3-years does not allow a timely response for public health to be protective of vulnerable populations.

Recent Michigan Urban and Rural $PM_{2.5}$ Concentration Ranges

MDEQ collected regional $PM_{2.5}$ ambient air concentration in accordance with US EPA methods under the Clean Air Act at several urban and a few rural locations. From 2004-2006, the average annual concentrations for $PM_{2.5}$ from urban locations (Grand Rapids, Detroit, Kalamazoo, Lansing, Ypsilanti, Dearborn, Livonia) ranged from 12-17 μg/m^3 (DEQ 2006). Less populated areas such as Sault Ste Marie and Houghton Lake were 7.6 and 8.1 μg/m^3, respectively. The 98th percentile (i.e., 98% of the data were less than these concentrations) of these datasets for the more industrial cities ranged from 30-44 μg/m^3. Sault Ste Marie and Houghton Lake 98th percentiles were 27 and 25 μg/m^3, respectively.

$PM_{2.5}$ Concentration Ranges of Concern

The US EPA NAAQS are useful to public health because they identify two concentrations of $PM_{2.5}$ that the US EPA says are unacceptable to exceed under the given methods. Using these methods under the Clean Air Act, the US EPA seeks to ensure that the average annual exposure to $PM_{2.5}$ is below 15 μg/m^3 and that 98 percent of all $PM_{2.5}$ concentrations are below 35 μg/m^3. This regulatory method limits exposure to spiked concentration above 35 μg/m^3 and that days of spiked concentrations would need to be offset by many days of concentration below 15 μg/m^3, so the annual average is below 15 μg/m^3. The US EPA recognizes that spiked concentrations are a risk to vulnerable populations. MDCH finds that the epidemiologic literature supports the conclusion that vulnerable populations are at risk to concentrations between 12-36 μg/m^3 of $PM_{2.5}$ (Table D-5). MDCH concludes that when ambient air $PM_{2.5}$ concentrations can be within or above 12-36 μg/m^3 that the risk to public health is greater than minimal.

Data Interpretation

Published studies have compared co-collected DustTrak and gravimetric results and found the two methods to be linear and highly correlated (r^2 = 0.82, 0.86, 0.99) to each other (Appendix B). The precision of the DustTrak allows for statistical comparisons between different location and conditions. Beyond making comparisons between two conditions, MDCH is providing a qualitative evaluation of the results with the recognition that the nephelometric methods can overestimate gravimetric concentrations by as much as 2-3 times (Appendix B).

MDCH compared the $PM_{2.5}$ average ambient air concentration between the complainant (31±13 μg/m^3) and referent (1±1 μg/m^3) locations and concluded that the two datasets do not overlap and are significantly different. The average concentration is 31 times greater at the complainant location. The spiked pattern of $PM_{2.5}$ in the complainant's ambient air was similar to the pattern reported Johnson (2006) in a study of an OWB. Johnson (2006) demonstrated that OWBs can generate much higher 1-minute and 1-hour average $PM_{2.5}$ concentrations than found in this investigation. This supports MDCH's conclusion that this $PM_{2.5}$ dataset cannot be assumed to be a maximum reasonable exposure.

Plotting the complainant location $PM_{2.5}$ ambient air concentrations over time demonstrates spiked concentration pattern consistent with the operation of first-generation OWBs (Johnson 2006) (Figure D-2). These results were collected while the OWB was in operation during the evening when few other point sources would be operating. The referent site had minimal variation in $PM_{2.5}$ ambient air concentrations over time (Figure D-3). During either sampling event, $PM_{2.5}$ ambient air concentrations do not appear to change with the variation in temperature or relative humidity over time.

This dataset of $PM_{2.5}$ ambient air concentrations from the complainant's property is a snap-shot in time and does not represent the range of OWB operational conditions or weather related conditions that could affect emission over an entire heating season (approximately 7 months long). For these reasons and those stated previously, the measured $PM_{2.5}$ concentrations cannot be assumed to represent a reasonable maximum exposure and higher concentrations are likely. The measured concentrations, without any adjustments for potential overestimation, overlap with and exceed those concentrations that have been correlated with causing harm to people, especially vulnerable populations. If a reasonable worst case adjustment for overestimation was applied to the dataset resulting in a downward adjust of 3 fold to all data, then 122 of the $PM_{2.5}$ measurements would still be in or above the range of 12-36 μg/m^3 found in the epidemiologic literature that associates with health risk.

Additional factors are considered in assessing the exposure to $PM_{2.5}$ from this OWB. The frequency of exposure with the OWB could be daily during the heating season. Continued use of the OWB could continue for numerous years. Finally, the complainant's attending physicians have provided statements that diagnose health conditions that are similar to the $PM_{2.5}$ epidemiologic literature and those physicians state that further exposure of the complainant to smoke needs to end.

Conclusions

MDCH agrees with the US EPA that $PM_{2.5}$ is a hazardous substance. MDCH concludes from the continuous monitoring $PM_{2.5}$ data collection that the OWB in question significantly elevates the $PM_{2.5}$ ambient air concentration on the complainant's property as compared to ambient air at a referent location. MDCH concludes that the spiked pattern of $PM_{2.5}$ concentrations provides evidence that the $PM_{2.5}$ measured in this investigation was from the OWB in question. MDCH concludes that elevated $PM_{2.5}$ ambient air concentrations provides confirming evidence to the visual observations and the complainant's medical statements about the public health hazard posed by the location and operation of this OWB.

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Table D-1. Meteorological data from KLAN during complainant location $PM_{2.5}$ data collection.

Weather Station	Date	Time of Sample Hours	Temperature °F	Relative Humidity %	Wind Direction degrees	Wind Speed mph
KLAN	3/25/2008	1653	36	69	210	23
KLAN	3/25/2008	1753	37	75	220	21
KLAN	3/25/2008	1853	41	60	230	17
KLAN	3/25/2008	1953	43	61	220	15
KLAN	3/25/2008	2053	45	57	220	18
KLAN	3/25/2008	2153	46	53	230	18
KLAN	3/25/2008	2253	46	57	230	12
KLAN	3/25/2008	2353	45	61	240	9
KLAN	3/26/2008	53	43	61	250	8
KLAN	3/26/2008	153	43	56	260	9
KLAN	3/26/2008	253	41	60	280	9
KLAN	3/26/2008	353	39	65	270	12
KLAN	3/26/2008	453	39	65	280	12
KLAN	3/26/2008	553	39	70	280	12
KLAN	3/26/2008	653	37	75	300	9
		Mean	41	63	248	14
		Standard Deviation	3	7	28	5
		Median	41	61	240	12
		Minimum	36	53	210	8
		Maximum	46	75	300	23

Table D-2. Meteorological data from KLAN during referent location $PM_{2.5}$ data collection.

Weather Station	Date	Time of Sample Hours	Temperature °F	Relative Humidity %	Wind Direction degrees	Wind Speed mph
KLAN	3/26/2008	1553	39	60	240	5
KLAN	3/26/2008	1653	43	52	220	10
KLAN	3/26/2008	1753	43	52	250	13
KLAN	3/26/2008	1853	45	45	270	12
KLAN	3/26/2008	1953	45	39	260	16
KLAN	3/26/2008	2053	45	42	270	14
KLAN	3/26/2008	2153	45	42	250	12
KLAN	3/26/2008	2253	43	42	270	14
KLAN	3/26/2008	2353	41	41	270	9
KLAN	3/27/2008	53	39	48	250	6
KLAN	3/27/2008	153	36	55	220	4
		Mean	42	47	252	10
		Standard Deviation	3	7	19	4
		Median	43	45	250	12
		Minimum	36	39	220	4
		Maximum	45	60	270	16

Table D-3. Meteorological data from KJXN during complainant location $PM_{2.5}$ data collection.

Weather Station	Date	Time of Sample	Temperature	Relative Humidity	Wind Direction	Wind Speed
		Hours	^{o}F	%	degrees	mph
KJXN	3/25/2008	1656	40	53	220	18
KJXN	3/25/2008	1756	41	48	210	22
KJXN	3/25/2008	1856	42	50	220	15
KJXN	3/25/2008	1956	44	53	220	17
KJXN	3/25/2008	2056	45	53	230	19
KJXN	3/25/2008	2156	46	53	240	14
KJXN	3/25/2008	2256	45	57	230	11
KJXN	3/25/2008	2356	44	67	220	9
KJXN	3/26/2008	56	44	70	260	5
KJXN	3/26/2008	156	42	70	250	6
KJXN	3/26/2008	256	42	57	270	10
KJXN	3/26/2008	356	41	57	280	9
KJXN	3/26/2008	456	41	60	300	13
KJXN	3/26/2008	556	39	64	290	10
KJXN	3/26/2008	656	38	70	300	11
		Mean	42	59	249	13
		Standard Deviation	2	8	32	5
		Median	42	57	240	11
		Minimum	38	48	210	5
		Maximum	46	70	300	22

Table D-4. Meteorological data from KJXN during referent location $PM_{2.5}$ data collection.

Weather Station	Date	Time of Sample	Temperature	Relative Humidity	Wind Direction	Wind Speed
		Hours	**^oF**	**%**	**degrees**	**mph**
KJXN	3/26/2008	1556	39	62	240	7
KJXN	3/26/2008	1656	41	60	250	9
KJXN	3/26/2008	1756	44	53	270	12
KJXN	3/26/2008	1856	45	47	260	11
KJXN	3/26/2008	1956	46	43	280	11
KJXN	3/26/2008	2056	45	43	270	12
KJXN	3/26/2008	2156	46	40	260	13
KJXN	3/26/2008	2256	44	39	260	11
KJXN	3/26/2008	2356	42	44	260	5
KJXN	3/27/2008	56	39	50	250	4
KJXN	3/27/2008	156	37	54	250	5
		Mean	43	49	259	9
		Standard Deviation	3	8	11	3
		Median	44	47	260	11
		Minimum	37	39	240	4
		Maximum	46	62	280	13

Table D-5. 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 µg/m^3 , 36.2 µg/m^3 standard deviation: 21.8 µg/m^3, 25.5 µg/m^3 range: 7.2 – 197 µg/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 µg/m^3 range: 1.3 – 22.6 µg/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 µg/m^3 standard deviation: 21.8 µg/m^3 1-hour maximum: 90.1 standard deviation: 79.8 µg/m^3 8-hour maximum: 46.2 standard deviation: 33.4 µg/m^3	Delfino et al. 2008

Table 5. Con't.

Reported Study Findings	**$PM_{2.5}$ Concentration Summary**	**Citation**
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 µg/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 µg/m^3 standard deviation: 3.0 µg/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 µg/m^3 standard deviation: 10.6, 11.9, 9.8 µg/m^3 maximum: 108, 94, 82 µg/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 µg/m^3	Gauderman et al. 2004.
In three California counties, daily respiratory mortality significantly increased by 2.1-7.6% per 10 µg/m^3 increase in $PM_{2.5}$ on the same day or previous day.	mean (24-hr), minimum-maximum: Contra Costa Co.: 14 µg/m^3, 1-77 µg/m^3 Los Angeles Co.: 21 µg/m^3, 4-85 µg/m^3 Orange Co.: 21 µg/m^3, 4-114 µg/m^3	Ostro et al. 2006
In U.S. population over 65 years old, long-term exposure to a 10 µg/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 (25^{th} -75^{th} percentiles): central US: 10.7 µg/m^3 (9.8-12.2 µg/m^3) eastern US: 14.0 µg/m^3 (12.3-15.3 µg/m^3)	Zeger et al. 2008

Table D-6. Individual $PM_{2.5}$ ambient air results from complainant's property.

Number	Date	Time hours	$PM_{2.5}$ mg/m^3
1	3/25/2008	17:52:33	0.021
2	3/25/2008	17:53:33	0.021
3	3/25/2008	17:54:33	0.021
4	3/25/2008	17:55:33	0.021
5	3/25/2008	17:56:33	0.021
6	3/25/2008	17:57:33	0.021
7	3/25/2008	17:58:33	0.021
8	3/25/2008	17:59:33	0.021
9	3/25/2008	18:00:33	0.021
10	3/25/2008	18:01:33	0.021
11	3/25/2008	18:02:33	0.021
12	3/25/2008	18:03:33	0.021
13	3/25/2008	18:04:33	0.021
14	3/25/2008	18:05:33	0.022
15	3/25/2008	18:06:33	0.021
16	3/25/2008	18:07:33	0.021
17	3/25/2008	18:08:33	0.021
18	3/25/2008	18:09:33	0.021
19	3/25/2008	18:10:33	0.021
20	3/25/2008	18:11:33	0.021
21	3/25/2008	18:12:33	0.021
22	3/25/2008	18:13:33	0.021
23	3/25/2008	18:14:33	0.021
24	3/25/2008	18:15:33	0.021
25	3/25/2008	18:16:33	0.021
26	3/25/2008	18:17:33	0.021
27	3/25/2008	18:18:33	0.021
28	3/25/2008	18:19:33	0.021
29	3/25/2008	18:20:33	0.022
30	3/25/2008	18:21:33	0.022
31	3/25/2008	18:22:33	0.022
32	3/25/2008	18:23:33	0.022
33	3/25/2008	18:24:33	0.022
34	3/25/2008	18:25:33	0.021
35	3/25/2008	18:26:33	0.021
36	3/25/2008	18:27:33	0.022
37	3/25/2008	18:28:33	0.021
38	3/25/2008	18:29:33	0.022
39	3/25/2008	18:30:33	0.022
40	3/25/2008	18:31:33	0.022
41	3/25/2008	18:32:33	0.022
42	3/25/2008	18:33:33	0.022
43	3/25/2008	18:34:33	0.021
44	3/25/2008	18:35:33	0.021
45	3/25/2008	18:36:33	0.021

Table D-6. Con't

Number	Date	Time hours	$PM_{2.5}$ mg/m^3
46	3/25/2008	18:37:33	0.021
47	3/25/2008	18:38:33	0.021
48	3/25/2008	18:39:33	0.021
49	3/25/2008	18:40:33	0.022
50	3/25/2008	18:41:33	0.021
51	3/25/2008	18:42:33	0.021
52	3/25/2008	18:43:33	0.021
53	3/25/2008	18:44:33	0.022
54	3/25/2008	18:45:33	0.021
55	3/25/2008	18:46:33	0.021
56	3/25/2008	18:47:33	0.021
57	3/25/2008	18:48:33	0.021
58	3/25/2008	18:49:33	0.021
59	3/25/2008	18:50:33	0.021
60	3/25/2008	18:51:33	0.022
61	3/25/2008	18:52:33	0.022
62	3/25/2008	18:53:33	0.021
63	3/25/2008	18:54:33	0.021
64	3/25/2008	18:55:33	0.022
65	3/25/2008	18:56:33	0.022
66	3/25/2008	18:57:33	0.022
67	3/25/2008	18:58:33	0.022
68	3/25/2008	18:59:33	0.022
69	3/25/2008	19:00:33	0.022
70	3/25/2008	19:01:33	0.022
71	3/25/2008	19:02:33	0.022
72	3/25/2008	19:03:33	0.022
73	3/25/2008	19:04:33	0.023
74	3/25/2008	19:05:33	0.022
75	3/25/2008	19:06:33	0.022
76	3/25/2008	19:07:33	0.023
77	3/25/2008	19:08:33	0.023
78	3/25/2008	19:09:33	0.023
79	3/25/2008	19:10:33	0.022
80	3/25/2008	19:11:33	0.023
81	3/25/2008	19:12:33	0.023
82	3/25/2008	19:13:33	0.023
83	3/25/2008	19:14:33	0.023
84	3/25/2008	19:15:33	0.023
85	3/25/2008	19:16:33	0.023
86	3/25/2008	19:17:33	0.023
87	3/25/2008	19:18:33	0.023
88	3/25/2008	19:19:33	0.024
89	3/25/2008	19:20:33	0.024
90	3/25/2008	19:21:33	0.024

Table D-6. Con't

Number	Date	Time hours	$PM_{2.5}$ mg/m^3
91	3/25/2008	19:22:33	0.024
92	3/25/2008	19:23:33	0.024
93	3/25/2008	19:24:33	0.024
94	3/25/2008	19:25:33	0.024
95	3/25/2008	19:26:33	0.025
96	3/25/2008	19:27:33	0.025
97	3/25/2008	19:28:33	0.025
98	3/25/2008	19:29:33	0.025
99	3/25/2008	19:30:33	0.025
100	3/25/2008	19:31:33	0.025
101	3/25/2008	19:32:33	0.025
102	3/25/2008	19:33:33	0.025
103	3/25/2008	19:34:33	0.025
104	3/25/2008	19:35:33	0.025
105	3/25/2008	19:36:33	0.025
106	3/25/2008	19:37:33	0.025
107	3/25/2008	19:38:33	0.025
108	3/25/2008	19:39:33	0.025
109	3/25/2008	19:40:33	0.025
110	3/25/2008	19:41:33	0.025
111	3/25/2008	19:42:33	0.025
112	3/25/2008	19:43:33	0.025
113	3/25/2008	19:44:33	0.024
114	3/25/2008	19:45:33	0.025
115	3/25/2008	19:46:33	0.025
116	3/25/2008	19:47:33	0.025
117	3/25/2008	19:48:33	0.024
118	3/25/2008	19:49:33	0.024
119	3/25/2008	19:50:33	0.025
120	3/25/2008	19:51:33	0.025
121	3/25/2008	19:52:33	0.025
122	3/25/2008	19:53:33	0.025
123	3/25/2008	19:54:33	0.024
124	3/25/2008	19:55:33	0.025
125	3/25/2008	19:56:33	0.025
126	3/25/2008	19:57:33	0.025
127	3/25/2008	19:58:33	0.025
128	3/25/2008	19:59:33	0.025
129	3/25/2008	20:00:33	0.025
130	3/25/2008	20:01:33	0.025
131	3/25/2008	20:02:33	0.025
132	3/25/2008	20:03:33	0.025
133	3/25/2008	20:04:33	0.025
134	3/25/2008	20:05:33	0.025
135	3/25/2008	20:06:33	0.025

Table D-6. Con't

Number	Date	Time hours	$PM_{2.5}$ mg/m^3
136	3/25/2008	20:07:33	0.027
137	3/25/2008	20:08:33	0.026
138	3/25/2008	20:09:33	0.026
139	3/25/2008	20:10:33	0.028
140	3/25/2008	20:11:33	0.030
141	3/25/2008	20:12:33	0.033
142	3/25/2008	20:13:33	0.038
143	3/25/2008	20:14:33	0.034
144	3/25/2008	20:15:33	0.035
145	3/25/2008	20:16:33	0.033
146	3/25/2008	20:17:33	0.026
147	3/25/2008	20:18:33	0.026
148	3/25/2008	20:19:33	0.026
149	3/25/2008	20:20:33	0.026
150	3/25/2008	20:21:33	0.027
151	3/25/2008	20:22:33	0.031
152	3/25/2008	20:23:33	0.033
153	3/25/2008	20:24:33	0.029
154	3/25/2008	20:25:33	0.030
155	3/25/2008	20:26:33	0.032
156	3/25/2008	20:27:33	0.028
157	3/25/2008	20:28:33	0.033
158	3/25/2008	20:29:33	0.030
159	3/25/2008	20:30:33	0.028
160	3/25/2008	20:31:33	0.028
161	3/25/2008	20:32:33	0.027
162	3/25/2008	20:33:33	0.029
163	3/25/2008	20:34:33	0.045
164	3/25/2008	20:35:33	0.045
165	3/25/2008	20:36:33	0.037
166	3/25/2008	20:37:33	0.031
167	3/25/2008	20:38:33	0.029
168	3/25/2008	20:39:33	0.030
169	3/25/2008	20:40:33	0.029
170	3/25/2008	20:41:33	0.033
171	3/25/2008	20:42:33	0.032
172	3/25/2008	20:43:33	0.030
173	3/25/2008	20:44:33	0.030
174	3/25/2008	20:45:33	0.029
175	3/25/2008	20:46:33	0.030
176	3/25/2008	20:47:33	0.031
177	3/25/2008	20:48:33	0.032
178	3/25/2008	20:49:33	0.031
179	3/25/2008	20:50:33	0.034
180	3/25/2008	20:51:33	0.041

Table D-6. Con't

Number	Date	Time hours	$PM_{2.5}$ mg/m^3
181	3/25/2008	20:52:33	0.035
182	3/25/2008	20:53:33	0.032
183	3/25/2008	20:54:33	0.031
184	3/25/2008	20:55:33	0.030
185	3/25/2008	20:56:33	0.030
186	3/25/2008	20:57:33	0.030
187	3/25/2008	20:58:33	0.030
188	3/25/2008	20:59:33	0.033
189	3/25/2008	21:00:33	0.037
190	3/25/2008	21:01:33	0.034
191	3/25/2008	21:02:33	0.034
192	3/25/2008	21:03:33	0.033
193	3/25/2008	21:04:33	0.032
194	3/25/2008	21:05:33	0.032
195	3/25/2008	21:06:33	0.033
196	3/25/2008	21:07:33	0.032
197	3/25/2008	21:08:33	0.031
198	3/25/2008	21:09:33	0.030
199	3/25/2008	21:10:33	0.031
200	3/25/2008	21:11:33	0.034
201	3/25/2008	21:12:33	0.031
202	3/25/2008	21:13:33	0.030
203	3/25/2008	21:14:33	0.033
204	3/25/2008	21:15:33	0.034
205	3/25/2008	21:16:33	0.035
206	3/25/2008	21:17:33	0.031
207	3/25/2008	21:18:33	0.033
208	3/25/2008	21:19:33	0.039
209	3/25/2008	21:20:33	0.038
210	3/25/2008	21:21:33	0.080
211	3/25/2008	21:22:33	0.068
212	3/25/2008	21:23:33	0.062
213	3/25/2008	21:24:33	0.055
214	3/25/2008	21:25:33	0.068
215	3/25/2008	21:26:33	0.096
216	3/25/2008	21:27:33	0.098
217	3/25/2008	21:28:33	0.063
218	3/25/2008	21:29:33	0.048
219	3/25/2008	21:30:33	0.060
220	3/25/2008	21:31:33	0.055
221	3/25/2008	21:32:33	0.050
222	3/25/2008	21:33:33	0.039
223	3/25/2008	21:34:33	0.034
224	3/25/2008	21:35:33	0.031
225	3/25/2008	21:36:33	0.032

Table D-6. Con't

Number	Date	Time hours	$PM_{2.5}$ mg/m^3
226	3/25/2008	21:37:33	0.031
227	3/25/2008	21:38:33	0.031
228	3/25/2008	21:39:33	0.031
229	3/25/2008	21:40:33	0.030
230	3/25/2008	21:41:33	0.030
231	3/25/2008	21:42:33	0.030
232	3/25/2008	21:43:33	0.030
233	3/25/2008	21:44:33	0.030
234	3/25/2008	21:45:33	0.030
235	3/25/2008	21:46:33	0.031
236	3/25/2008	21:47:33	0.032
237	3/25/2008	21:48:33	0.032
238	3/25/2008	21:49:33	0.030
239	3/25/2008	21:50:33	0.032
240	3/25/2008	21:51:33	0.030
241	3/25/2008	21:52:33	0.030
242	3/25/2008	21:53:33	0.029
243	3/25/2008	21:54:33	0.035
244	3/25/2008	21:55:33	0.030
245	3/25/2008	21:56:33	0.029
246	3/25/2008	21:57:33	0.029
247	3/25/2008	21:58:33	0.033
248	3/25/2008	21:59:33	0.034
249	3/25/2008	22:00:33	0.031
250	3/25/2008	22:01:33	0.030
251	3/25/2008	22:02:33	0.029
252	3/25/2008	22:03:33	0.031
253	3/25/2008	22:04:33	0.039
254	3/25/2008	22:05:33	0.034
255	3/25/2008	22:06:33	0.034
256	3/25/2008	22:07:33	0.047
257	3/25/2008	22:08:33	0.035
258	3/25/2008	22:09:33	0.028
259	3/25/2008	22:10:33	0.030
260	3/25/2008	22:11:33	0.028
261	3/25/2008	22:12:33	0.037
262	3/25/2008	22:13:33	0.028
263	3/25/2008	22:14:33	0.044
264	3/25/2008	22:15:33	0.030
265	3/25/2008	22:16:33	0.028
266	3/25/2008	22:17:33	0.032
267	3/25/2008	22:18:33	0.028
268	3/25/2008	22:19:33	0.027
269	3/25/2008	22:20:33	0.027
270	3/25/2008	22:21:33	0.025

Table D-6. Con't

Number	Date	Time hours	$PM_{2.5}$ mg/m^3
271	3/25/2008	22:22:33	0.025
272	3/25/2008	22:23:33	0.025
273	3/25/2008	22:24:33	0.025
274	3/25/2008	22:25:33	0.025
275	3/25/2008	22:26:33	0.024
276	3/25/2008	22:27:33	0.024
277	3/25/2008	22:28:33	0.027
278	3/25/2008	22:29:33	0.025
279	3/25/2008	22:30:33	0.024
280	3/25/2008	22:31:33	0.024
281	3/25/2008	22:32:33	0.024
282	3/25/2008	22:33:33	0.024
283	3/25/2008	22:34:33	0.026
284	3/25/2008	22:35:33	0.024
285	3/25/2008	22:36:33	0.024
286	3/25/2008	22:37:33	0.026
287	3/25/2008	22:38:33	0.026
288	3/25/2008	22:39:33	0.033
289	3/25/2008	22:40:33	0.033
290	3/25/2008	22:41:33	0.048
291	3/25/2008	22:42:33	0.054
292	3/25/2008	22:43:33	0.080
293	3/25/2008	22:44:33	0.151
294	3/25/2008	22:45:33	0.094
295	3/25/2008	22:46:33	0.065
296	3/25/2008	22:47:33	0.054
297	3/25/2008	22:48:33	0.054
298	3/25/2008	22:49:33	0.044
299	3/25/2008	22:50:33	0.040
300	3/25/2008	22:51:33	0.064
301	3/25/2008	22:52:33	0.087
302	3/25/2008	22:53:33	0.085
303	3/25/2008	22:54:33	0.049
304	3/25/2008	22:55:33	0.032
305	3/25/2008	22:56:33	0.027
306	3/25/2008	22:57:33	0.022
307	3/25/2008	22:58:33	0.021
308	3/25/2008	22:59:33	0.021
309	3/25/2008	23:00:33	0.020
310	3/25/2008	23:01:33	0.021
311	3/25/2008	23:02:33	0.021
312	3/25/2008	23:03:33	0.021
313	3/25/2008	23:04:33	0.021
314	3/25/2008	23:05:33	0.021
315	3/25/2008	23:06:33	0.020

Table D-6. Con't

Number	Date	Time hours	$PM_{2.5}$ mg/m^3
316	3/25/2008	23:07:33	0.020
317	3/25/2008	23:08:33	0.020
318	3/25/2008	23:09:33	0.020
319	3/25/2008	23:10:33	0.020
320	3/25/2008	23:11:33	0.020
321	3/25/2008	23:12:33	0.020
322	3/25/2008	23:13:33	0.020
323	3/25/2008	23:14:33	0.020
324	3/25/2008	23:15:33	0.020
325	3/25/2008	23:16:33	0.020
326	3/25/2008	23:17:33	0.020
327	3/25/2008	23:18:33	0.020
328	3/25/2008	23:19:33	0.020
329	3/25/2008	23:20:33	0.020
330	3/25/2008	23:21:33	0.020
331	3/25/2008	23:22:33	0.020
332	3/25/2008	23:23:33	0.020
333	3/25/2008	23:24:33	0.020
334	3/25/2008	23:25:33	0.020
335	3/25/2008	23:26:33	0.020
336	3/25/2008	23:27:33	0.021
337	3/25/2008	23:28:33	0.021
338	3/25/2008	23:29:33	0.021
339	3/25/2008	23:30:33	0.019
340	3/25/2008	23:31:33	0.020
341	3/25/2008	23:32:33	0.020
342	3/25/2008	23:33:33	0.021
343	3/25/2008	23:34:33	0.020
344	3/25/2008	23:35:33	0.020
345	3/25/2008	23:36:33	0.019
346	3/25/2008	23:37:33	0.020
347	3/25/2008	23:38:33	0.023
348	3/25/2008	23:39:33	0.021
349	3/25/2008	23:40:33	0.021
350	3/25/2008	23:41:33	0.021
351	3/25/2008	23:42:33	0.020
352	3/25/2008	23:43:33	0.021
353	3/25/2008	23:44:33	0.020
354	3/25/2008	23:45:33	0.021
355	3/25/2008	23:46:33	0.020
356	3/25/2008	23:47:33	0.020
357	3/25/2008	23:48:33	0.019
358	3/25/2008	23:49:33	0.019
359	3/25/2008	23:50:33	0.021
360	3/25/2008	23:51:33	0.023

Table D-6. Con't

Number	Date	Time hours	$PM_{2.5}$ mg/m^3
361	3/25/2008	23:52:33	0.022
362	3/25/2008	23:53:33	0.019
363	3/25/2008	23:54:33	0.019
364	3/25/2008	23:55:33	0.022
365	3/25/2008	23:56:33	0.022
366	3/25/2008	23:57:33	0.021
367	3/25/2008	23:58:33	0.020
368	3/25/2008	23:59:33	0.023
369	3/25/2008	0:00:33	0.045
370	3/25/2008	0:01:33	0.037
371	3/25/2008	0:02:33	0.034
372	3/25/2008	0:03:33	0.034
373	3/25/2008	0:04:33	0.029
374	3/25/2008	0:05:33	0.026
375	3/25/2008	0:06:33	0.027
376	3/25/2008	0:07:33	0.049
377	3/25/2008	0:08:33	0.035
378	3/25/2008	0:09:33	0.041
379	3/25/2008	0:10:33	0.035
380	3/25/2008	0:11:33	0.030
381	3/25/2008	0:12:33	0.021
382	3/25/2008	0:13:33	0.021
383	3/25/2008	0:14:33	0.019
384	3/25/2008	0:15:33	0.018
385	3/25/2008	0:16:33	0.018
386	3/25/2008	0:17:33	0.019
387	3/25/2008	0:18:33	0.019
388	3/25/2008	0:19:33	0.019
389	3/25/2008	0:20:33	0.019
390	3/25/2008	0:21:33	0.019
391	3/25/2008	0:22:33	0.019
392	3/25/2008	0:23:33	0.019
393	3/25/2008	0:24:33	0.019
394	3/25/2008	0:25:33	0.019
395	3/25/2008	0:26:33	0.019
396	3/25/2008	0:27:33	0.019
397	3/25/2008	0:28:33	0.019
398	3/25/2008	0:29:33	0.018
399	3/25/2008	0:30:33	0.018
400	3/25/2008	0:31:33	0.018
401	3/25/2008	0:32:33	0.018
402	3/25/2008	0:33:33	0.018
403	3/25/2008	0:34:33	0.019
404	3/25/2008	0:35:33	0.019
405	3/25/2008	0:36:33	0.019

Table D-6. Con't

Number	Date	Time hours	$PM_{2.5}$ mg/m^3
406	3/25/2008	0:37:33	0.019
407	3/25/2008	0:38:33	0.018
408	3/25/2008	0:39:33	0.019
409	3/25/2008	0:40:33	0.018
410	3/25/2008	0:41:33	0.019
411	3/25/2008	0:42:33	0.019
412	3/25/2008	0:43:33	0.019
413	3/25/2008	0:44:33	0.019
414	3/25/2008	0:45:33	0.019
415	3/25/2008	0:46:33	0.019
416	3/25/2008	0:47:33	0.021
417	3/25/2008	0:48:33	0.020
418	3/25/2008	0:49:33	0.019
419	3/25/2008	0:50:33	0.019
420	3/25/2008	0:51:33	0.019
421	3/25/2008	0:52:33	0.019
422	3/25/2008	0:53:33	0.020
423	3/25/2008	0:54:33	0.019
424	3/25/2008	0:55:33	0.020
425	3/25/2008	0:56:33	0.021
426	3/25/2008	0:57:33	0.021
427	3/25/2008	0:58:33	0.020
428	3/25/2008	0:59:33	0.021
429	3/25/2008	1:00:33	0.021
430	3/25/2008	1:01:33	0.021
431	3/25/2008	1:02:33	0.022
432	3/25/2008	1:03:33	0.026
433	3/25/2008	1:04:33	0.026
434	3/25/2008	1:05:33	0.024
435	3/25/2008	1:06:33	0.026
436	3/25/2008	1:07:33	0.031
437	3/25/2008	1:08:33	0.033
438	3/25/2008	1:09:33	0.037
439	3/25/2008	1:10:33	0.045
440	3/25/2008	1:11:33	0.036
441	3/25/2008	1:12:33	0.035
442	3/25/2008	1:13:33	0.033
443	3/25/2008	1:14:33	0.028
444	3/25/2008	1:15:33	0.036
445	3/25/2008	1:16:33	0.027
446	3/25/2008	1:17:33	0.034
447	3/25/2008	1:18:33	0.037
448	3/25/2008	1:19:33	0.031
449	3/25/2008	1:20:33	0.031
450	3/25/2008	1:21:33	0.040

Table D-6. Con't

Number	Date	Time hours	$PM_{2.5}$ mg/m^3
451	3/25/2008	1:22:33	0.053
452	3/25/2008	1:23:33	0.045
453	3/25/2008	1:24:33	0.031
454	3/25/2008	1:25:33	0.023
455	3/25/2008	1:26:33	0.022
456	3/25/2008	1:27:33	0.033
457	3/25/2008	1:28:33	0.068
458	3/25/2008	1:29:33	0.121
459	3/25/2008	1:30:33	0.093
460	3/25/2008	1:31:33	0.083
461	3/25/2008	1:32:33	0.065
462	3/25/2008	1:33:33	0.042
463	3/25/2008	1:34:33	0.043
464	3/25/2008	1:35:33	0.032
465	3/25/2008	1:36:33	0.026
466	3/25/2008	1:37:33	0.027
467	3/25/2008	1:38:33	0.029
468	3/25/2008	1:39:33	0.027
469	3/25/2008	1:40:33	0.025
470	3/25/2008	1:41:33	0.022
471	3/25/2008	1:42:33	0.022
472	3/25/2008	1:43:33	0.023
473	3/25/2008	1:44:33	0.022
474	3/25/2008	1:45:33	0.023
475	3/25/2008	1:46:33	0.022
476	3/25/2008	1:47:33	0.022
477	3/25/2008	1:48:33	0.023
478	3/25/2008	1:49:33	0.023
479	3/25/2008	1:50:33	0.023
480	3/25/2008	1:51:33	0.023
481	3/25/2008	1:52:33	0.022
482	3/25/2008	1:53:33	0.023
483	3/25/2008	1:54:33	0.023
484	3/25/2008	1:55:33	0.023
485	3/25/2008	1:56:33	0.023
486	3/25/2008	1:57:33	0.023
487	3/25/2008	1:58:33	0.024
488	3/25/2008	1:59:33	0.024
489	3/25/2008	2:00:33	0.023
490	3/25/2008	2:01:33	0.023
491	3/25/2008	2:02:33	0.024
492	3/25/2008	2:03:33	0.024
493	3/25/2008	2:04:33	0.024
494	3/25/2008	2:05:33	0.024
495	3/25/2008	2:06:33	0.024

Table D-6. Con't

Number	Date	Time hours	$PM_{2.5}$ mg/m^3
496	3/25/2008	2:07:33	0.024
497	3/25/2008	2:08:33	0.024
498	3/25/2008	2:09:33	0.024
499	3/25/2008	2:10:33	0.024
500	3/25/2008	2:11:33	0.025
501	3/25/2008	2:12:33	0.025
502	3/25/2008	2:13:33	0.025
503	3/25/2008	2:14:33	0.025
504	3/25/2008	2:15:33	0.025
505	3/25/2008	2:16:33	0.025
506	3/25/2008	2:17:33	0.025
507	3/25/2008	2:18:33	0.025
508	3/25/2008	2:19:33	0.025
509	3/25/2008	2:20:33	0.025
510	3/25/2008	2:21:33	0.025
511	3/25/2008	2:22:33	0.025
512	3/25/2008	2:23:33	0.026
513	3/25/2008	2:24:33	0.025
514	3/25/2008	2:25:33	0.027
515	3/25/2008	2:26:33	0.027
516	3/25/2008	2:27:33	0.026
517	3/25/2008	2:28:33	0.027
518	3/25/2008	2:29:33	0.028
519	3/25/2008	2:30:33	0.029
520	3/25/2008	2:31:33	0.039
521	3/25/2008	2:32:33	0.034
522	3/25/2008	2:33:33	0.031
523	3/26/2008	2:34:33	0.029
524	3/26/2008	2:35:33	0.036
525	3/26/2008	2:36:33	0.034
526	3/26/2008	2:37:33	0.031
527	3/26/2008	2:38:33	0.033
528	3/26/2008	2:39:33	0.032
529	3/26/2008	2:40:33	0.035
530	3/26/2008	2:41:33	0.032
531	3/26/2008	2:42:33	0.056
532	3/26/2008	2:43:33	0.064
533	3/26/2008	2:44:33	0.042
534	3/26/2008	2:45:33	0.031
535	3/26/2008	2:46:33	0.038
536	3/26/2008	2:47:33	0.041
537	3/26/2008	2:48:33	0.044
538	3/26/2008	2:49:33	0.044
539	3/26/2008	2:50:33	0.039
540	3/26/2008	2:51:33	0.035

Table D-6. Con't

Number	Date	Time hours	$PM_{2.5}$ mg/m^3
541	3/26/2008	2:52:33	0.038
542	3/26/2008	2:53:33	0.040
543	3/26/2008	2:54:33	0.035
544	3/26/2008	2:55:33	0.035
545	3/26/2008	2:56:33	0.036
546	3/26/2008	2:57:33	0.034
547	3/26/2008	2:58:33	0.033
548	3/26/2008	2:59:33	0.032
549	3/26/2008	3:00:33	0.035
550	3/26/2008	3:01:33	0.033
551	3/26/2008	3:02:33	0.033
552	3/26/2008	3:03:33	0.034
553	3/26/2008	3:04:33	0.032
554	3/26/2008	3:05:33	0.032
555	3/26/2008	3:06:33	0.032
556	3/26/2008	3:07:33	0.032
557	3/26/2008	3:08:33	0.032
558	3/26/2008	3:09:33	0.032
559	3/26/2008	3:10:33	0.032
560	3/26/2008	3:11:33	0.032
561	3/26/2008	3:12:33	0.033
562	3/26/2008	3:13:33	0.036
563	3/26/2008	3:14:33	0.035
564	3/26/2008	3:15:33	0.032
565	3/26/2008	3:16:33	0.032
566	3/26/2008	3:17:33	0.033
567	3/26/2008	3:18:33	0.032
568	3/26/2008	3:19:33	0.032
569	3/26/2008	3:20:33	0.031
570	3/26/2008	3:21:33	0.030
571	3/26/2008	3:22:33	0.031
572	3/26/2008	3:23:33	0.031
573	3/26/2008	3:24:33	0.030
574	3/26/2008	3:25:33	0.030
575	3/26/2008	3:26:33	0.030
576	3/26/2008	3:27:33	0.030
577	3/26/2008	3:28:33	0.029
578	3/26/2008	3:29:33	0.030
579	3/26/2008	3:30:33	0.030
580	3/26/2008	3:31:33	0.030
581	3/26/2008	3:32:33	0.030
582	3/26/2008	3:33:33	0.030
583	3/26/2008	3:34:33	0.035
584	3/26/2008	3:35:33	0.035
585	3/26/2008	3:36:33	0.034

Table D-6. Con't

Number	Date	Time hours	$PM_{2.5}$ mg/m^3
586	3/26/2008	3:37:33	0.036
587	3/26/2008	3:38:33	0.034
588	3/26/2008	3:39:33	0.035
589	3/26/2008	3:40:33	0.034
590	3/26/2008	3:41:33	0.034
591	3/26/2008	3:42:33	0.035
592	3/26/2008	3:43:33	0.033
593	3/26/2008	3:44:33	0.033
594	3/26/2008	3:45:33	0.033
595	3/26/2008	3:46:33	0.032
596	3/26/2008	3:47:33	0.033
597	3/26/2008	3:48:33	0.034
598	3/26/2008	3:49:33	0.039
599	3/26/2008	3:50:33	0.068
600	3/26/2008	3:51:33	0.046
601	3/26/2008	3:52:33	0.035
602	3/26/2008	3:53:33	0.031
603	3/26/2008	3:54:33	0.031
604	3/26/2008	3:55:33	0.030
605	3/26/2008	3:56:33	0.036
606	3/26/2008	3:57:33	0.033
607	3/26/2008	3:58:33	0.037
608	3/26/2008	3:59:33	0.043
609	3/26/2008	4:00:33	0.051
610	3/26/2008	4:01:33	0.078
611	3/26/2008	4:02:33	0.063
612	3/26/2008	4:03:33	0.076
613	3/26/2008	4:04:33	0.066
614	3/26/2008	4:05:33	0.048
615	3/26/2008	4:06:33	0.044
616	3/26/2008	4:07:33	0.035
617	3/26/2008	4:08:33	0.032
618	3/26/2008	4:09:33	0.033
619	3/26/2008	4:10:33	0.033
620	3/26/2008	4:11:33	0.033
621	3/26/2008	4:12:33	0.033
622	3/26/2008	4:13:33	0.032
623	3/26/2008	4:14:33	0.031
624	3/26/2008	4:15:33	0.031
625	3/26/2008	4:16:33	0.031
626	3/26/2008	4:17:33	0.031
627	3/26/2008	4:18:33	0.032
628	3/26/2008	4:19:33	0.033
629	3/26/2008	4:20:33	0.032
630	3/26/2008	4:21:33	0.031

Table D-6. Con't

Number	Date	Time hours	$PM_{2.5}$ mg/m^3
631	3/26/2008	4:22:33	0.032
632	3/26/2008	4:23:33	0.031
633	3/26/2008	4:24:33	0.031
634	3/26/2008	4:25:33	0.031
635	3/26/2008	4:26:33	0.031
636	3/26/2008	4:27:33	0.031
637	3/26/2008	4:28:33	0.030
638	3/26/2008	4:29:33	0.031
639	3/26/2008	4:30:33	0.031
640	3/26/2008	4:31:33	0.032
641	3/26/2008	4:32:33	0.034
642	3/26/2008	4:33:33	0.034
643	3/26/2008	4:34:33	0.034
644	3/26/2008	4:35:33	0.033
645	3/26/2008	4:36:33	0.032
646	3/26/2008	4:37:33	0.032
647	3/26/2008	4:38:33	0.033
648	3/26/2008	4:39:33	0.033
649	3/26/2008	4:40:33	0.033
650	3/26/2008	4:41:33	0.033
651	3/26/2008	4:42:33	0.032
652	3/26/2008	4:43:33	0.032
653	3/26/2008	4:44:33	0.033
654	3/26/2008	4:45:33	0.032
655	3/26/2008	4:46:33	0.032
656	3/26/2008	4:47:33	0.033
657	3/26/2008	4:48:33	0.032
658	3/26/2008	4:49:33	0.035
659	3/26/2008	4:50:33	0.078
660	3/26/2008	4:51:33	0.043
661	3/26/2008	4:52:33	0.042
662	3/26/2008	4:53:33	0.044
663	3/26/2008	4:54:33	0.042
664	3/26/2008	4:55:33	0.047
665	3/26/2008	4:56:33	0.051
666	3/26/2008	4:57:33	0.042
667	3/26/2008	4:58:33	0.035
668	3/26/2008	4:59:33	0.033
669	3/26/2008	5:00:33	0.035
670	3/26/2008	5:01:33	0.036
671	3/26/2008	5:02:33	0.038
672	3/26/2008	5:03:33	0.047
673	3/26/2008	5:04:33	0.064
674	3/26/2008	5:05:33	0.091
675	3/26/2008	5:06:33	0.070

Table D-6. Con't

Number	Date	Time hours	$PM_{2.5}$ mg/m^3
676	3/26/2008	5:07:33	0.050
677	3/26/2008	5:08:33	0.036
678	3/26/2008	5:09:33	0.035
679	3/26/2008	5:10:33	0.034
680	3/26/2008	5:11:33	0.032
681	3/26/2008	5:12:33	0.031
682	3/26/2008	5:13:33	0.032
683	3/26/2008	5:14:33	0.033
684	3/26/2008	5:15:33	0.034
685	3/26/2008	5:16:33	0.034
686	3/26/2008	5:17:33	0.042
687	3/26/2008	5:18:33	0.052
688	3/26/2008	5:19:33	0.045
689	3/26/2008	5:20:33	0.042
690	3/26/2008	5:21:33	0.040
691	3/26/2008	5:22:33	0.039
692	3/26/2008	5:23:33	0.037
693	3/26/2008	5:24:33	0.046
694	3/26/2008	5:25:33	0.050
695	3/26/2008	5:26:33	0.049
696	3/26/2008	5:27:33	0.044
697	3/26/2008	5:28:33	0.036
698	3/26/2008	5:29:33	0.033
699	3/26/2008	5:30:33	0.032
700	3/26/2008	5:31:33	0.032
701	3/26/2008	5:32:33	0.044
702	3/26/2008	5:33:33	0.042
703	3/26/2008	5:34:33	0.039
704	3/26/2008	5:35:33	0.038
705	3/26/2008	5:36:33	0.038
706	3/26/2008	5:37:33	0.033
707	3/26/2008	5:38:33	0.031
708	3/26/2008	5:39:33	0.033
709	3/26/2008	5:40:33	0.030
710	3/26/2008	5:41:33	0.029
711	3/26/2008	5:42:33	0.029
712	3/26/2008	5:43:33	0.029
713	3/26/2008	5:44:33	0.028
714	3/26/2008	5:45:33	0.027
715	3/26/2008	5:46:33	0.027
716	3/26/2008	5:47:33	0.027
717	3/26/2008	5:48:33	0.027
718	3/26/2008	5:49:33	0.027
719	3/26/2008	5:50:33	0.027
720	3/26/2008	5:51:33	0.027

Table D-6. Con't

Number	Date	Time hours	$PM_{2.5}$ mg/m^3
721	3/26/2008	5:52:33	0.027
722	3/26/2008	5:53:33	0.027
723	3/26/2008	5:54:33	0.027
724	3/26/2008	5:55:33	0.028
725	3/26/2008	5:56:33	0.028
726	3/26/2008	5:57:33	0.027
727	3/26/2008	5:58:33	0.028
728	3/26/2008	5:59:33	0.027
729	3/26/2008	6:00:33	0.028
730	3/26/2008	6:01:33	0.028
731	3/26/2008	6:02:33	0.028
732	3/26/2008	6:03:33	0.028
733	3/26/2008	6:04:33	0.028
734	3/26/2008	6:05:33	0.030
735	3/26/2008	6:06:33	0.029
736	3/26/2008	6:07:33	0.028
737	3/26/2008	6:08:33	0.029
738	3/26/2008	6:09:33	0.029
739	3/26/2008	6:10:33	0.028
740	3/26/2008	6:11:33	0.028
741	3/26/2008	6:12:33	0.028
742	3/26/2008	6:13:33	0.028
743	3/26/2008	6:14:33	0.028
744	3/26/2008	6:15:33	0.028
745	3/26/2008	6:16:33	0.028
746	3/26/2008	6:17:33	0.028
747	3/26/2008	6:18:33	0.028
748	3/26/2008	6:19:33	0.028
749	3/26/2008	6:20:33	0.027
750	3/26/2008	6:21:33	0.028
751	3/26/2008	6:22:33	0.031
752	3/26/2008	6:23:33	0.048
753	3/26/2008	6:24:33	0.149
754	3/26/2008	6:25:33	0.054
755	3/26/2008	6:26:33	0.034
756	3/26/2008	6:27:33	0.029
757	3/26/2008	6:28:33	0.028
758	3/26/2008	6:29:33	0.027
759	3/26/2008	6:30:33	0.028
760	3/26/2008	6:31:33	0.028
761	3/26/2008	6:32:33	0.027
762	3/26/2008	6:33:33	0.029
763	3/26/2008	6:34:33	0.028
764	3/26/2008	6:35:33	0.029
765	3/26/2008	6:36:33	0.029

Table D-6. Con't

Number	Date	Time hours	$PM_{2.5}$ mg/m^3
766	3/26/2008	6:37:33	0.035
767	3/26/2008	6:38:33	0.033
768	3/26/2008	6:39:33	0.034
769	3/26/2008	6:40:33	0.035
770	3/26/2008	6:41:33	0.033

Table D-7. Individual $PM_{2.5}$ ambient air results from referent location.

Number	Date	Time hours	$PM_{2.5}$ mg/m^3
1	3/26/2008	17:24:30	0.011
2	3/26/2008	17:25:30	0.007
3	3/26/2008	17:26:30	0.004
4	3/26/2008	17:27:30	0.003
5	3/26/2008	17:28:30	0.002
6	3/26/2008	17:29:30	0.002
7	3/26/2008	17:30:30	0.002
8	3/26/2008	17:31:30	0.001
9	3/26/2008	17:32:30	0.001
10	3/26/2008	17:33:30	0.001
11	3/26/2008	17:34:30	0.001
12	3/26/2008	17:35:30	0.001
13	3/26/2008	17:36:30	0.001
14	3/26/2008	17:37:30	0.001
15	3/26/2008	17:38:30	0.001
16	3/26/2008	17:39:30	0.001
17	3/26/2008	17:40:30	0.001
18	3/26/2008	17:41:30	0.001
19	3/26/2008	17:42:30	0.001
20	3/26/2008	17:43:30	0.001
21	3/26/2008	17:44:30	0.001
22	3/26/2008	17:45:30	0.001
23	3/26/2008	17:46:30	0.001
24	3/26/2008	17:47:30	0.001
25	3/26/2008	17:48:30	0.001
26	3/26/2008	17:49:30	0.001
27	3/26/2008	17:50:30	0.001
28	3/26/2008	17:51:30	0.000
29	3/26/2008	17:52:30	0.000
30	3/26/2008	17:53:30	0.000
31	3/26/2008	17:54:30	0.000
32	3/26/2008	17:55:30	0.000
33	3/26/2008	17:56:30	0.000
34	3/26/2008	17:57:30	0.000
35	3/26/2008	17:58:30	0.000
36	3/26/2008	17:59:30	0.000
37	3/26/2008	18:00:30	0.000
38	3/26/2008	18:01:30	0.000
39	3/26/2008	18:02:30	0.000
40	3/26/2008	18:03:30	0.000
41	3/26/2008	18:04:30	0.000
42	3/26/2008	18:05:30	0.000
43	3/26/2008	18:06:30	0.000
44	3/26/2008	18:07:30	0.000
45	3/26/2008	18:08:30	0.000

Table D-7. Con't

Number	Date	Time hours	$PM_{2.5}$ mg/m^3
46	3/26/2008	18:09:30	0.000
47	3/26/2008	18:10:30	0.000
48	3/26/2008	18:11:30	0.000
49	3/26/2008	18:12:30	0.001
50	3/26/2008	18:13:30	0.000
51	3/26/2008	18:14:30	0.000
52	3/26/2008	18:15:30	0.000
53	3/26/2008	18:16:30	0.000
54	3/26/2008	18:17:30	0.001
55	3/26/2008	18:18:30	0.001
56	3/26/2008	18:19:30	0.001
57	3/26/2008	18:20:30	0.001
58	3/26/2008	18:21:30	0.001
59	3/26/2008	18:22:30	0.001
60	3/26/2008	18:23:30	0.001
61	3/26/2008	18:24:30	0.001
62	3/26/2008	18:25:30	0.001
63	3/26/2008	18:26:30	0.000
64	3/26/2008	18:27:30	0.000
65	3/26/2008	18:28:30	0.000
66	3/26/2008	18:29:30	0.000
67	3/26/2008	18:30:30	0.000
68	3/26/2008	18:31:30	0.000
69	3/26/2008	18:32:30	0.000
70	3/26/2008	18:33:30	0.000
71	3/26/2008	18:34:30	0.000
72	3/26/2008	18:35:30	0.000
73	3/26/2008	18:36:30	0.000
74	3/26/2008	18:37:30	0.000
75	3/26/2008	18:38:30	0.000
76	3/26/2008	18:39:30	0.000
77	3/26/2008	18:40:30	0.000
78	3/26/2008	18:41:30	0.001
79	3/26/2008	18:42:30	0.000
80	3/26/2008	18:43:30	0.001
81	3/26/2008	18:44:30	0.001
82	3/26/2008	18:45:30	0.001
83	3/26/2008	18:46:30	0.001
84	3/26/2008	18:47:30	0.001
85	3/26/2008	18:48:30	0.001
86	3/26/2008	18:49:30	0.001
87	3/26/2008	18:50:30	0.001
88	3/26/2008	18:51:30	0.001
89	3/26/2008	18:52:30	0.001
90	3/26/2008	18:53:30	0.001

Table D-7. Con't

Number	Date	Time hours	$PM_{2.5}$ mg/m^3
91	3/26/2008	18:54:30	0.001
92	3/26/2008	18:55:30	0.001
93	3/26/2008	18:56:30	0.001
94	3/26/2008	18:57:30	0.001
95	3/26/2008	18:58:30	0.001
96	3/26/2008	18:59:30	0.001
97	3/26/2008	19:00:30	0.001
98	3/26/2008	19:01:30	0.001
99	3/26/2008	19:02:30	0.001
100	3/26/2008	19:03:30	0.001
101	3/26/2008	19:04:30	0.001
102	3/26/2008	19:05:30	0.001
103	3/26/2008	19:06:30	0.001
104	3/26/2008	19:07:30	0.000
105	3/26/2008	19:08:30	0.000
106	3/26/2008	19:09:30	0.000
107	3/26/2008	19:10:30	0.000
108	3/26/2008	19:11:30	0.001
109	3/26/2008	19:12:30	0.000
110	3/26/2008	19:13:30	0.001
111	3/26/2008	19:14:30	0.001
112	3/26/2008	19:15:30	0.000
113	3/26/2008	19:16:30	0.000
114	3/26/2008	19:17:30	0.000
115	3/26/2008	19:18:30	0.001
116	3/26/2008	19:19:30	0.000
117	3/26/2008	19:20:30	0.000
118	3/26/2008	19:21:30	0.000
119	3/26/2008	19:22:30	0.000
120	3/26/2008	19:23:30	0.000
121	3/26/2008	19:24:30	0.000
122	3/26/2008	19:25:30	0.000
123	3/26/2008	19:26:30	0.000
124	3/26/2008	19:27:30	0.000
125	3/26/2008	19:28:30	0.000
126	3/26/2008	19:29:30	0.000
127	3/26/2008	19:30:30	0.000
128	3/26/2008	19:31:30	0.000
129	3/26/2008	19:32:30	0.000
130	3/26/2008	19:33:30	0.001
131	3/26/2008	19:34:30	0.001
132	3/26/2008	19:35:30	0.001
133	3/26/2008	19:36:30	0.001
134	3/26/2008	19:37:30	0.001
135	3/26/2008	19:38:30	0.001

Table D-7. Con't

Number	Date	Time hours	$PM_{2.5}$ mg/m^3
136	3/26/2008	19:39:30	0.001
137	3/26/2008	19:40:30	0.001
138	3/26/2008	19:41:30	0.001
139	3/26/2008	19:42:30	0.001
140	3/26/2008	19:43:30	0.001
141	3/26/2008	19:44:30	0.001
142	3/26/2008	19:45:30	0.001
143	3/26/2008	19:46:30	0.001
144	3/26/2008	19:47:30	0.001
145	3/26/2008	19:48:30	0.001
146	3/26/2008	19:49:30	0.001
147	3/26/2008	19:50:30	0.001
148	3/26/2008	19:51:30	0.001
149	3/26/2008	19:52:30	0.001
150	3/26/2008	19:53:30	0.001
151	3/26/2008	19:54:30	0.001
152	3/26/2008	19:55:30	0.001
153	3/26/2008	19:56:30	0.001
154	3/26/2008	19:57:30	0.001
155	3/26/2008	19:58:30	0.001
156	3/26/2008	19:59:30	0.001
157	3/26/2008	20:00:30	0.001
158	3/26/2008	20:01:30	0.001
159	3/26/2008	20:02:30	0.001
160	3/26/2008	20:03:30	0.001
161	3/26/2008	20:04:30	0.001
162	3/26/2008	20:05:30	0.001
163	3/26/2008	20:06:30	0.001
164	3/26/2008	20:07:30	0.010
165	3/26/2008	20:08:30	0.007
166	3/26/2008	20:09:30	0.005
167	3/26/2008	20:10:30	0.004
168	3/26/2008	20:11:30	0.003
169	3/26/2008	20:12:30	0.002
170	3/26/2008	20:13:30	0.002
171	3/26/2008	20:14:30	0.002
172	3/26/2008	20:15:30	0.002
173	3/26/2008	20:16:30	0.002
174	3/26/2008	20:17:30	0.001
175	3/26/2008	20:18:30	0.001
176	3/26/2008	20:19:30	0.001
177	3/26/2008	20:20:30	0.001
178	3/26/2008	20:21:30	0.001
179	3/26/2008	20:22:30	0.001
180	3/26/2008	20:23:30	0.001

Table D-7. Con't

Number	Date	Time hours	$PM_{2.5}$ mg/m^3
181	3/26/2008	20:24:30	0.001
182	3/26/2008	20:25:30	0.001
183	3/26/2008	20:26:30	0.001
184	3/26/2008	20:27:30	0.001
185	3/26/2008	20:28:30	0.001
186	3/26/2008	20:29:30	0.001
187	3/26/2008	20:30:30	0.001
188	3/26/2008	20:31:30	0.001
189	3/26/2008	20:32:30	0.001
190	3/26/2008	20:33:30	0.001
191	3/26/2008	20:34:30	0.001
192	3/26/2008	20:35:30	0.001
193	3/26/2008	20:36:30	0.001
194	3/26/2008	20:37:30	0.001
195	3/26/2008	20:38:30	0.001
196	3/26/2008	20:39:30	0.001
197	3/26/2008	20:40:30	0.001
198	3/26/2008	20:41:30	0.001
199	3/26/2008	20:42:30	0.001
200	3/26/2008	20:43:30	0.001
201	3/26/2008	20:44:30	0.001
202	3/26/2008	20:45:30	0.001
203	3/26/2008	20:46:30	0.001
204	3/26/2008	20:47:30	0.001
205	3/26/2008	20:48:30	0.001
206	3/26/2008	20:49:30	0.001
207	3/26/2008	20:50:30	0.001
208	3/26/2008	20:51:30	0.001
209	3/26/2008	20:52:30	0.001
210	3/26/2008	20:53:30	0.001
211	3/26/2008	20:54:30	0.001
212	3/26/2008	20:55:30	0.001
213	3/26/2008	20:56:30	0.001
214	3/26/2008	20:57:30	0.001
215	3/26/2008	20:58:30	0.001
216	3/26/2008	20:59:30	0.001
217	3/26/2008	21:00:30	0.001
218	3/26/2008	21:01:30	0.001
219	3/26/2008	21:02:30	0.001
220	3/26/2008	21:03:30	0.001
221	3/26/2008	21:04:30	0.001
222	3/26/2008	21:05:30	0.001
223	3/26/2008	21:06:30	0.001
224	3/26/2008	21:07:30	0.001
225	3/26/2008	21:08:30	0.001

Table D-7. Con't

Number	Date	Time hours	$PM_{2.5}$ mg/m^3
226	3/26/2008	21:09:30	0.001
227	3/26/2008	21:10:30	0.000
228	3/26/2008	21:11:30	0.000
229	3/26/2008	21:12:30	0.000
230	3/26/2008	21:13:30	0.001
231	3/26/2008	21:14:30	0.001
232	3/26/2008	21:15:30	0.001
233	3/26/2008	21:16:30	0.001
234	3/26/2008	21:17:30	0.000
235	3/26/2008	21:18:30	0.001
236	3/26/2008	21:19:30	0.001
237	3/26/2008	21:20:30	0.001
238	3/26/2008	21:21:30	0.001
239	3/26/2008	21:22:30	0.001
240	3/26/2008	21:23:30	0.001
241	3/26/2008	21:24:30	0.001
242	3/26/2008	21:25:30	0.001
243	3/26/2008	21:26:30	0.001
244	3/26/2008	21:27:30	0.001
245	3/26/2008	21:28:30	0.001
246	3/26/2008	21:29:30	0.001
247	3/26/2008	21:30:30	0.000
248	3/26/2008	21:31:30	0.000
249	3/26/2008	21:32:30	0.001
250	3/26/2008	21:33:30	0.001
251	3/26/2008	21:34:30	0.001
252	3/26/2008	21:35:30	0.001
253	3/26/2008	21:36:30	0.001
254	3/26/2008	21:37:30	0.001
255	3/26/2008	21:38:30	0.000
256	3/26/2008	21:39:30	0.001
257	3/26/2008	21:40:30	0.001
258	3/26/2008	21:41:30	0.001
259	3/26/2008	21:42:30	0.001
260	3/26/2008	21:43:30	0.001
261	3/26/2008	21:44:30	0.001
262	3/26/2008	21:45:30	0.001
263	3/26/2008	21:46:30	0.001
264	3/26/2008	21:47:30	0.001
265	3/26/2008	21:48:30	0.000
266	3/26/2008	21:49:30	0.001
267	3/26/2008	21:50:30	0.001
268	3/26/2008	21:51:30	0.001
269	3/26/2008	21:52:30	0.000
270	3/26/2008	21:53:30	0.000

Table D-7. Con't

Number	Date	Time hours	$PM_{2.5}$ mg/m^3
271	3/26/2008	21:54:30	0.000
272	3/26/2008	21:55:30	0.000
273	3/26/2008	21:56:30	0.000
274	3/26/2008	21:57:30	0.000
275	3/26/2008	21:58:30	0.000
276	3/26/2008	21:59:30	0.000
277	3/26/2008	22:00:30	0.000
278	3/26/2008	22:01:30	0.000
279	3/26/2008	22:02:30	0.000
280	3/26/2008	22:03:30	0.000
281	3/26/2008	22:04:30	0.000
282	3/26/2008	22:05:30	0.000
283	3/26/2008	22:06:30	0.000
284	3/26/2008	22:07:30	0.000
285	3/26/2008	22:08:30	0.000
286	3/26/2008	22:09:30	0.000
287	3/26/2008	22:10:30	0.000
288	3/26/2008	22:11:30	0.000
289	3/26/2008	22:12:30	0.000
290	3/26/2008	22:13:30	0.000
291	3/26/2008	22:14:30	0.000
292	3/26/2008	22:15:30	0.000
293	3/26/2008	22:16:30	0.000
294	3/26/2008	22:17:30	0.000
295	3/26/2008	22:18:30	0.000
296	3/26/2008	22:19:30	0.000
297	3/26/2008	22:20:30	0.000
298	3/26/2008	22:21:30	0.000
299	3/26/2008	22:22:30	0.000
300	3/26/2008	22:23:30	0.000
301	3/26/2008	22:24:30	0.000
302	3/26/2008	22:25:30	0.000
303	3/26/2008	22:26:30	0.000
304	3/26/2008	22:27:30	0.000
305	3/26/2008	22:28:30	0.000
306	3/26/2008	22:29:30	0.000
307	3/26/2008	22:30:30	0.000
308	3/26/2008	22:31:30	0.000
309	3/26/2008	22:32:30	0.000
310	3/26/2008	22:33:30	0.000
311	3/26/2008	22:34:30	0.000
312	3/26/2008	22:35:30	0.000
313	3/26/2008	22:36:30	0.000
314	3/26/2008	22:37:30	0.000
315	3/26/2008	22:38:30	0.000

Table D-7. Con't

Number	Date	Time hours	$PM_{2.5}$ mg/m^3
316	3/26/2008	22:39:30	0.000
317	3/26/2008	22:40:30	0.000
318	3/26/2008	22:41:30	0.000
319	3/26/2008	22:42:30	0.000
320	3/26/2008	22:43:30	0.000
321	3/26/2008	22:44:30	0.000
322	3/26/2008	22:45:30	0.000
323	3/26/2008	22:46:30	0.000
324	3/26/2008	22:47:30	0.000
325	3/26/2008	22:48:30	0.000
326	3/26/2008	22:49:30	0.000
327	3/26/2008	22:50:30	0.000
328	3/26/2008	22:51:30	0.000
329	3/26/2008	22:52:30	0.000
330	3/26/2008	22:53:30	0.000
331	3/26/2008	22:54:30	0.000
332	3/26/2008	22:55:30	0.000
333	3/26/2008	22:56:30	0.000
334	3/26/2008	22:57:30	0.000
335	3/26/2008	22:58:30	0.000
336	3/26/2008	22:59:30	0.000
337	3/26/2008	23:00:30	0.000
338	3/26/2008	23:01:30	0.000
339	3/26/2008	23:02:30	0.000
340	3/26/2008	23:03:30	0.000
341	3/26/2008	23:04:30	0.000
342	3/26/2008	23:05:30	0.000
343	3/26/2008	23:06:30	0.000
344	3/26/2008	23:07:30	0.000
345	3/26/2008	23:08:30	0.000
346	3/26/2008	23:09:30	0.000
347	3/26/2008	23:10:30	0.000
348	3/26/2008	23:11:30	0.000
349	3/26/2008	23:12:30	0.000
350	3/26/2008	23:13:30	0.000
351	3/26/2008	23:14:30	0.000
352	3/26/2008	23:15:30	0.000
353	3/26/2008	23:16:30	0.000
354	3/26/2008	23:17:30	0.000
355	3/26/2008	23:18:30	0.000
356	3/26/2008	23:19:30	0.000
357	3/26/2008	23:20:30	0.000
358	3/26/2008	23:21:30	0.000
359	3/26/2008	23:22:30	0.000
360	3/26/2008	23:23:30	0.000

Table D-7. Con't

Number	Date	Time hours	$PM_{2.5}$ mg/m^3
361	3/26/2008	23:24:30	0.000
362	3/26/2008	23:25:30	0.000
363	3/26/2008	23:26:30	0.000
364	3/26/2008	23:27:30	0.000
365	3/26/2008	23:28:30	0.000
366	3/26/2008	23:29:30	0.000
367	3/26/2008	23:30:30	0.000
368	3/26/2008	23:31:30	0.000
369	3/26/2008	23:32:30	0.000
370	3/26/2008	23:33:30	0.000
371	3/26/2008	23:34:30	0.000
372	3/26/2008	23:35:30	0.000
373	3/26/2008	23:36:30	0.000
374	3/26/2008	23:37:30	0.000
375	3/26/2008	23:38:30	0.000
376	3/26/2008	23:39:30	0.000
377	3/26/2008	23:40:30	0.000
378	3/26/2008	23:41:30	0.000
379	3/26/2008	23:42:30	0.000
380	3/26/2008	23:43:30	0.000
381	3/26/2008	23:44:30	0.000
382	3/26/2008	23:45:30	0.000
383	3/26/2008	23:46:30	0.000
384	3/26/2008	23:47:30	0.000
385	3/26/2008	23:48:30	0.000
386	3/26/2008	23:49:30	0.000
387	3/26/2008	23:50:30	0.000
388	3/26/2008	23:51:30	0.000
389	3/26/2008	23:52:30	0.000
390	3/26/2008	23:53:30	0.000
391	3/26/2008	23:54:30	0.000
392	3/26/2008	23:55:30	0.000
393	3/26/2008	23:56:30	0.000
394	3/26/2008	23:57:30	0.000
395	3/26/2008	23:58:30	0.000
396	3/26/2008	23:59:30	0.000
397	3/27/2008	0:00:30	0.000
398	3/27/2008	0:01:30	0.000
399	3/27/2008	0:02:30	0.000
400	3/27/2008	0:03:30	0.000
401	3/27/2008	0:04:30	0.000
402	3/27/2008	0:05:30	0.000
403	3/27/2008	0:06:30	0.000
404	3/27/2008	0:07:30	0.000
405	3/27/2008	0:08:30	0.000

Table D-7. Con't

Number	Date	Time hours	$PM_{2.5}$ mg/m^3
406	3/27/2008	0:09:30	0.000
407	3/27/2008	0:10:30	0.000
408	3/27/2008	0:11:30	0.000
409	3/27/2008	0:12:30	0.000
410	3/27/2008	0:13:30	0.000
411	3/27/2008	0:14:30	0.000
412	3/27/2008	0:15:30	0.000
413	3/27/2008	0:16:30	0.000
414	3/27/2008	0:17:30	0.000
415	3/27/2008	0:18:30	0.000
416	3/27/2008	0:19:30	0.000
417	3/27/2008	0:20:30	0.000
418	3/27/2008	0:21:30	0.000
419	3/27/2008	0:22:30	0.000
420	3/27/2008	0:23:30	0.000
421	3/27/2008	0:24:30	0.000
422	3/27/2008	0:25:30	0.000
423	3/27/2008	0:26:30	0.000
424	3/27/2008	0:27:30	0.000
425	3/27/2008	0:28:30	0.000
426	3/27/2008	0:29:30	0.000
427	3/27/2008	0:30:30	0.000
428	3/27/2008	0:31:30	0.000
429	3/27/2008	0:32:30	0.000
430	3/27/2008	0:33:30	0.000
431	3/27/2008	0:34:30	0.000
432	3/27/2008	0:35:30	0.000
433	3/27/2008	0:36:30	0.000
434	3/27/2008	0:37:30	0.000
435	3/27/2008	0:38:30	0.000
436	3/27/2008	0:39:30	0.000
437	3/27/2008	0:40:30	0.000
438	3/27/2008	0:41:30	0.000
439	3/27/2008	0:42:30	0.000
440	3/27/2008	0:43:30	0.000
441	3/27/2008	0:44:30	0.000
442	3/27/2008	0:45:30	0.000
443	3/27/2008	0:46:30	0.000
444	3/27/2008	0:47:30	0.000
445	3/27/2008	0:48:30	0.000
446	3/27/2008	0:49:30	0.000
447	3/27/2008	0:50:30	0.000
448	3/27/2008	0:51:30	0.000
449	3/27/2008	0:52:30	0.000
450	3/27/2008	0:53:30	0.000

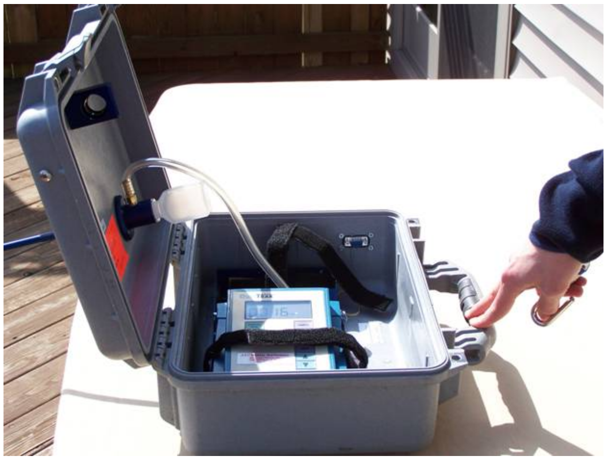
Table D-7. Con't

Number	Date	Time hours	$PM_{2.5}$ mg/m^3
451	3/27/2008	0:54:30	0.000
452	3/27/2008	0:55:30	0.000
453	3/27/2008	0:56:30	0.000
454	3/27/2008	0:57:30	0.000
455	3/27/2008	0:58:30	0.000
456	3/27/2008	0:59:30	0.000
457	3/27/2008	1:00:30	0.000
458	3/27/2008	1:01:30	0.000
459	3/27/2008	1:02:30	0.000
460	3/27/2008	1:03:30	0.000
461	3/27/2008	1:04:30	0.000
462	3/27/2008	1:05:30	0.000
463	3/27/2008	1:06:30	0.000
464	3/27/2008	1:07:30	0.000
465	3/27/2008	1:08:30	0.000
466	3/27/2008	1:09:30	0.000
467	3/27/2008	1:10:30	0.000
468	3/27/2008	1:11:30	0.000
469	3/27/2008	1:12:30	0.000
470	3/27/2008	1:13:30	0.000
471	3/27/2008	1:14:30	0.000
472	3/27/2008	1:15:30	0.000
473	3/27/2008	1:16:30	0.000
474	3/27/2008	1:17:30	0.000
475	3/27/2008	1:18:30	0.000
476	3/27/2008	1:19:30	0.000
477	3/27/2008	1:20:30	0.000
478	3/27/2008	1:21:30	0.000
479	3/27/2008	1:22:30	0.000
480	3/27/2008	1:23:30	0.000
481	3/27/2008	1:24:30	0.000
482	3/27/2008	1:25:30	0.000
483	3/27/2008	1:26:30	0.000
484	3/27/2008	1:27:30	0.000
485	3/27/2008	1:28:30	0.000
486	3/27/2008	1:29:30	0.000
487	3/27/2008	1:30:30	0.000
488	3/27/2008	1:31:30	0.000
489	3/27/2008	1:32:30	0.000
490	3/27/2008	1:33:30	0.000
491	3/27/2008	1:34:30	0.000
492	3/27/2008	1:35:30	0.000
493	3/27/2008	1:36:30	0.000
494	3/27/2008	1:37:30	0.000
495	3/27/2008	1:38:30	0.000

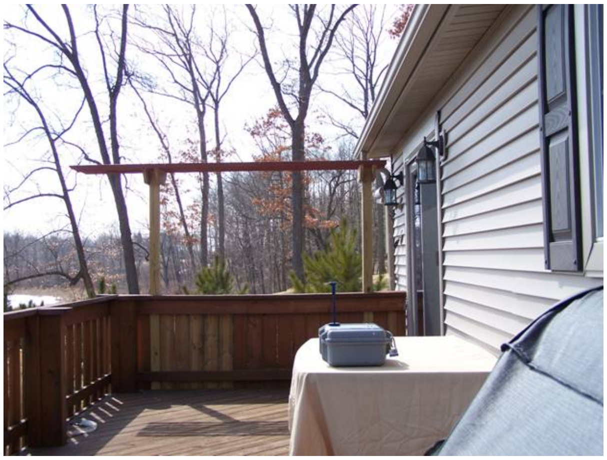
Table D-7. Con't

Number	Date	Time hours	$PM_{2.5}$ mg/m^3
496	3/27/2008	1:39:30	0.000
497	3/27/2008	1:40:30	0.000
498	3/27/2008	1:41:30	0.000
499	3/27/2008	1:42:30	0.000

A.



B.



C.

Figure D-1. Photos of DustTrak placement during complainant property sampling.

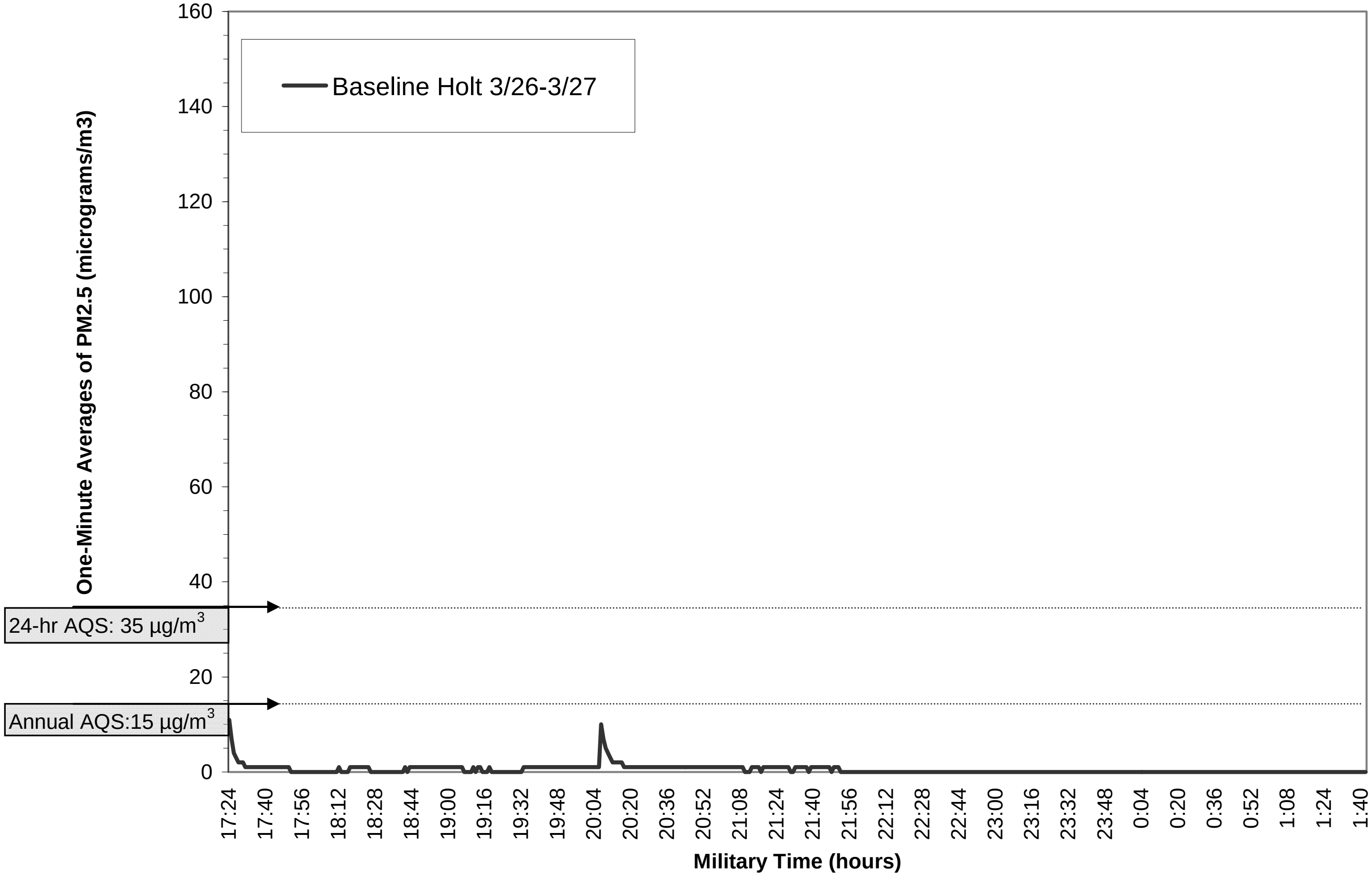


Figure D-2. $PM_{2.5}$ results for the referent location in Holt, Michigan collected on the evening of March 26 & 27, 2008.

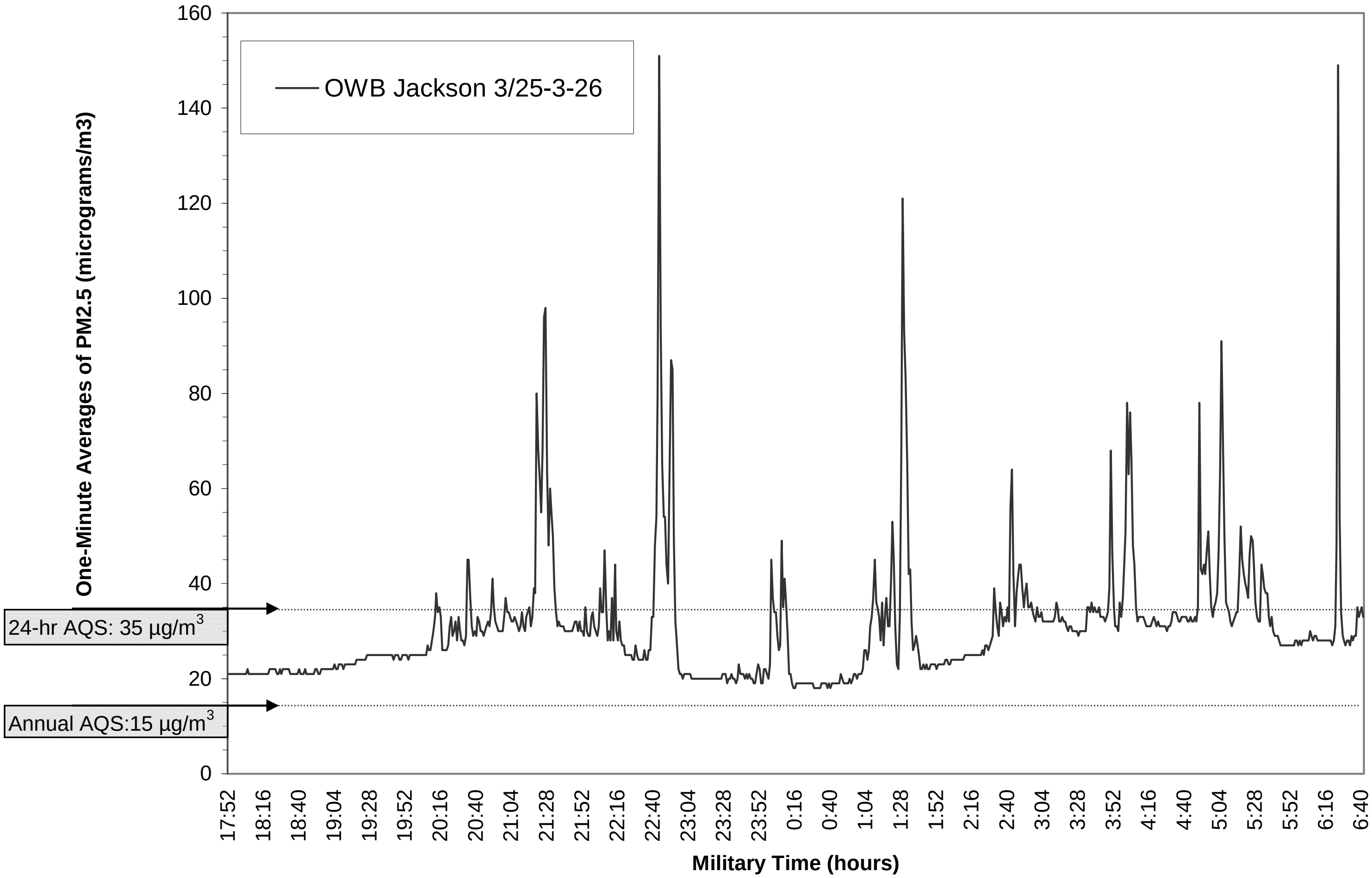


Figure D-3. $PM_{2.5}$ results for the complainant property near Jackson, Michigan collected on the evening of March 25 & 26, 2008.

Appendix E. Toxicology Overview of Wood Smoke and Associated Particulate Matter.

Description of Wood Smoke

Cordwood (i.e., split short chunks of wood) heaters burn wood in an atmosphere of low oxygen and generate incomplete combustion products such as carbon monoxide and numerous organic chemicals. If these vapors are not immediately oxidized, they cool as they vent to the outside and forms particulate matter (PM) that is rich in high molecular weight organic chemicals (US EPA 1993). This PM has a size range measured in micrometers (µm). PM less than 10 µm (PM_{10}) and PM less than 2.5 µm ($PM_{2.5}$) are common size ranges of PM found in wood smoke (Park and Lee 2003, Hellén et al. 2008, Johnson 2006, NESCAUM 2006, Gullett et al. 2004). The smaller the PM the further into the lungs these particles can reach. Thus $PM_{2.5}$ contains the size range that can go furthest into the lungs with the smallest of these particles (less than 0.1 µm) having been shown to pass through the lungs into a person's blood stream (Nemmers et al. 2002).

The gas and particles of wood smoke contain numerous types of organic chemicals (polycyclic aromatic hydrocarbons (PAHs), phenols, aldehydes, alkenes, alkanes, and aromatics) (US EPA 1993, Gullett et al. 2004, Naecher et al. 2007). This includes several chemicals that may increase a person's risk of cancer including benzo(a)pyrene, chrysene, dibenzo(a,h)anthracene, indeno(1,2,3 cd)pyrene, benzo(k)fluoranthene, benzo(a)anthracene, benzo(b)fluoranthene, benzene, and formaldehyde (Brown et al. 2007, Hellén et al. 2008, NESCAUM 2008). Additionally, trace elements can be released during the combustion of wood or other material (US EPA 1993). Amount and types of chemicals in any particular wood smoke will depend on the characteristics of the materials being burned, system used to conduct the combustion, and how the system is operated (Hellén et al. 2008, US EPA 1996, NESCAUM 2008). In residential setting, wood burning can be the dominant source of these chemicals to the atmosphere (e.g. benzene in the air was 70% from wood burning) (Hellén et al. 2008).

Mortality

Daily PM concentrations in ambient air have been associated with death (Ostro et al. 2006, Schwartz 2000, Dockery et al. 1993). Daily deaths increased by 0.67 percent for a 10 $\mu g/m^3$ increase in PM_{10} (Schwartz 2000). This result was based on a study comparing daily deaths in 10 US cities and the daily PM_{10} air concentrations (mean PM_{10} concentrations ranged from 27-41 $\mu g/m^3$). Dockery et al. (1993) found increased mortality rates due to cardiopulmonary disease and lung cancer in cities with higher concentrations of PM. Ostro et al. (2006) reports that short-term (1 day) increases in $PM_{2.5}$ results in cardiovascular and respiratory mortality, with respiratory mortality having a stronger association to $PM_{2.5}$. Kan et al. (2008) reported an increase of 10 $\mu g/m^3$ in PM_{10} concentrations, calculated as two-day averages, was associated with increases in all-cause mortality of 0.25 percent (CI: 0.14-0.37).

Long-term exposure to $PM_{2.5}$ (mean and standard deviation = 17.7 ± 3.7$\mu g/m^3$) significantly increases the relative risk of dying from cardiopulmonary disease (8 percent per 10 $\mu g/m^3$ increase in average $PM_{2.5}$) and lung cancer (12 percent per 10 $\mu g/m^3$ increase in average $PM_{2.5}$) in a study of 319,000 people from 51 US metropolitan areas between 1979-2000 (Pope et al.

2002). Exposure to $PM_{2.5}$ for people that smoke increases their risk in at least an additive manner and may be greater than additive, smokers having some of the highest increased risk of cardiovascular disease mortality (Pope et al. 2004). For adults 65 years and older, Mar et al (2000) documented increased risk of cardiovascular mortality relative to several indicators of PM concentration including $PM_{2.5}$.

Respiratory Effects

Wood smoke has been found to impair the human respiratory system. Wood smoke is shown to be a risk factor for chronic obstructive pulmonary disease (COPD) (Ocozco-Levi et al. 2006). A study of nine children with mild asthma (not using corticosteroids) exposed to wood smoke reported associations between measures of airway inflammation and decreased lung function with measures of increased wood smoke exposure (Allen et al. 2008). Dennis et al. (1996) reported wood smoke to increase the risk by four times (odd ratio 3.9; range of 1.7-9.1) for women contracting obstructed airway disease (OAD). These women were chronically exposed to wood smoke during childhood and the common risk factors for OAD such as cigarette smoking, were not prevalent in these individuals. Sandoval et al. (1993) suggests that the chronic breathing of wood smoke may result in a more severe level of chronic high blood pressure (pulmonary arterial hypertension) than people suffering from smoking-related COPD. They further found that people with pulmonary arterial hypertension and a history of wood smoke exposure were less able to move oxygen into their blood than people with smoking-related COPD.

Short-term exposures (one hour to one day) to increases in PM, including $PM_{2.5}$, has been found to result in significant changes in measurable indicators of airway inflammation (Adamkiewicz et al. 2003, Koenig et al. 2003, Koenig et al. 2005, Jansen et al. 2005, Delfino et al. 2006) and lung obstruction (Delfino et al. 2004, Trenga et al. 2006, Delfino et al. 2008), which are commonly used to diagnose asthma. Increased obstruction and airway inflammation can cause more sensitive individuals (elderly or preexisting respiratory condition) to be admitted to the hospital for treatment (Dominici et al. 2006). Ulirsch et al. (2007) found children under the age of 17 years old and adults 65 years and older were at greater risk of hospitalization due to respiratory disease with increased PM_{10} exposure. Host et al. (2007) reported increased risk (6.2 percent per 10 $\mu g/m^3$ increase in $PM_{2.5\text{-}10}$) of respiratory disease for children under 14 years and increased risk of respiratory infections (2.5 percent per 10 $\mu g/m^3$ increase in $PM_{2.5}$, 4.4 percent per 10 $\mu g/m^3$ increase in $PM_{2.5\text{-}10}$) for all ages. Ostro et al. (2009) reports a 4.1 percent greater risk in child hospitalizations for respiratory effects associated with a 14.6 $\mu g/m^3$ increase in $PM_{2.5}$.

Cardiovascular Effects

Pope et al. (2006) reported that same day ambient air $PM_{2.5}$ concentrations are associated with acute ischemic heart disease (IHD) for people with pre-existing factor for heart disease. IHD is heart disease that is due to blocked or partially blocked arteries. They found a 3.2-4.8 percent increase in ischemic cardiovascular events with every 10 $\mu g/m^3$ increase in $PM_{2.5}$ on the same day as the cardiac event (primarily myocardial infarction or unstable angina). Pope et al. (2006) conclude that people with diseased coronary arteries were the individuals at greatest acute risk from elevated $PM_{2.5}$ exposures, compared to people with relatively healthy arteries. Host et al.

(2007) studied the number of cardiovascular, cardiac, and ischemic heart disease admission in hospitals of five major French cities relative to $PM_{2.5}$ and $PM_{2.5-10}$ ambient air concentrations. Similar to Pope et al., Host et al. reported a 4.5, 2.4, and 1.9 percent increase in excess relative risk of IHD, cardiac diseases, and cardiovascular diseases, respectively, with each 10 µg/m^3 increase in $PM_{2.5}$ among people 65 years and older. Across all ages, 0.9 percent increase in relative risk of cardiovascular diseases with each 10 µg/m^3 increase in $PM_{2.5}$. D'Ippoliti et al. (2003) observed similar findings in a study of 6,531 individuals hospitalized for a first episode of acute myocardial infarction. D'Ippoliti et al. used measures of total suspended solids (TSP), nitrogen dioxide, and carbon monoxide as surrogates for the amount of $PM_{2.5}$ exposure. They found that daily hospital admissions for myocardial infarction events were most strongly correlated with TSP measures on the day of hospital admission or on the immediately previous day. Although TSP is a crude measure for $PM_{2.5}$, they found an association of a 2.8 percent increase in hospital admissions with a 10 µg/m^3 increase in TSP. Peters et al. (2001) used $PM_{2.5}$ measures and found significant increased risk of myocardial infarction with increased exposure (OR: 1.48; 95%CI: 1.09-2.02; for an increase of 25 µg/m^3 during a 2-hour period prior onset). In a study of 22,000 survivors of a myocardial infarction across five European cities, von Klot et al. (2005) found that cardiac re-admissions to the hospital were significantly higher on days with elevated PM_{10} (rate ratio=1.021; 95% confidence interval=1.004-1.039). Zanobetti and Schwartz (2005) found similar significant correlations between increased same day PM_{10} concentrations and increased hospital admissions for myocardial infarction among US citizens 65 years and older covered by Medicare. Sullivan et al. (2005) reported non-significant higher risk for people with preexisting heart disease that experience increases in PM (odds ratio: 1.05, 95% confidence interval = 0.95-1.16).

Mechanisms attempting to explain how PM exposures cause cardiovascular damage have been proposed. PM exposures can cause both an inflammation response and an increase in oxidative stress at a cellular level either in the lungs or at specific tissues within the body. This response may be due to either chemicals associated with PM or small particles causing activation of cellular immune responses (Brook 2007). The inflammation response causes a release of proteins throughout the body that can alter the normal function of the inner lining of blood vessels (i.e., endothelial cells) (Rajagopalan et al. 2005). Change in blood vessel function may alter the stability or build-up of plaques in arteries increasing the chance of free-moving plaques (embolism) and blockage of arteries (O'Neill et al. 2005, Brook 2007, Rajagopalan et al. 2005, Pope et al. 2004).

PM may alter the function of the nervous system that controls the heart (i.e., autonomic nervous system (ANS)). This altered ANS function may be caused by the inflammation response described above or by the particles causing direct irritation to nerves in the lungs that may results in a nerve reflex altering ANS function (Brook 2007, Pope et al. 2004). Abnormal electrocardiograms (ECG) have been observed in relation to increased concentrations of PM. Gold et al. (2000) studied 21 adults between the ages of 53 and 87 years living in Boston, MA and found that a 24-hr average $PM_{2.5}$ concentration (mean=15.5 µg/m^3; range 2.3-45.1µg/m^3) was correlated with a significant decrease in heart rate and the 4-hr average $PM_{2.5}$ concentrations (mean=14.7 µg/m^3; range 0 – 44.9 µg/m^3) was correlated with a significant decrease in heart rate variability. Reduced heart rate variability is a predictor of increased risk of cardiovascular mortality and morbidity. Magari et al. (2001) in a study of 40 workers (19-59 years old) found significantly reduced heart rate variability in relation to short-term increased exposure to $PM_{2.5}$. Pekkanen et al. (2002) conducted an observational study of a sensitive population of 45 adults (over 60 years old, current nonsmokers, diagnosed with stable coronary heart disease) living in Helsinki, Finland ($PM_{2.5}$ range 8.1-39.8 µg/m^3) and found decreased ST-segment depression on ECG during periods of exercise two days after participants experience elevated $PM_{2.5}$ exposures (Odds Ratio (OR): 4.56; 95%CI: 1.73-12.03). ST-segment depression during exercise indicates an increased probability of myocardial ischemia (ACC/AHA guidelines as reported by Pekkanen et al. 2002). Chuang et al. (2008) found similar results in 48 Boston, MA residents (43-75 years old) where the combination of $PM_{2.5}$ and black carbon exposure two days before the ECG correlated with a significant risk of ST-segment depression.

Stroke

Few studies have been conducted looking at relationships between air pollution and stroke. Studies have found significant relationships between elevated concentrations of indicators of PM (i.e, TSP, PM_{10}) and increased risk of ischemic stroke (Wellenius et al. 2005, Hong et al. 2002). Ischemic stroke occurs because of blocked vessels in the brain, preventing essential nutrients such as oxygen.

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